Towards Dose-Efficient Assessment of Trabecular Microstructure using Photon-Counting CT

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DEUTSCHES KREBSFORSCHUNGSZENTRUM
IN DER HELMHOLTZ-GEMEINSCHAFT

Aim

- High-resolution peripheral quantitative CT (HR-pQCT) is a valuable tool in the assessment of trabecular microstructure and bone strength*.
- However, it is restricted to imaging of the extremities.
- Here: comparison of the performance of a clinical CT to HR-pQCT to assess bone density as well as trabecular separation (Tb.Sp)
- In particular: investigation of photon-counting detectors to perform such an assessment at reduced dose levels#.

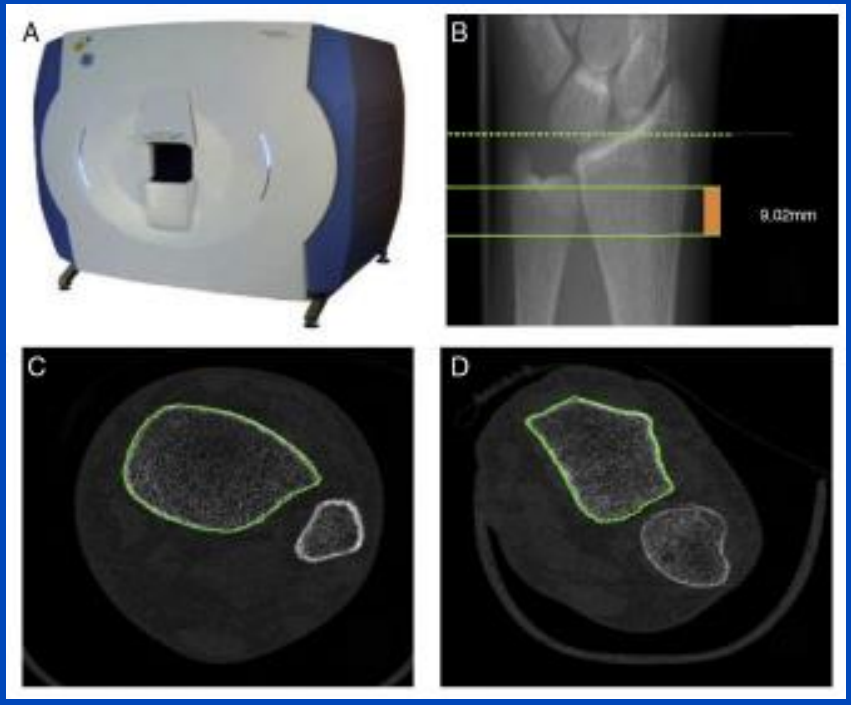


Image from: Fuller et al., DOI: 10.1016/j.rbr.2014.07.010

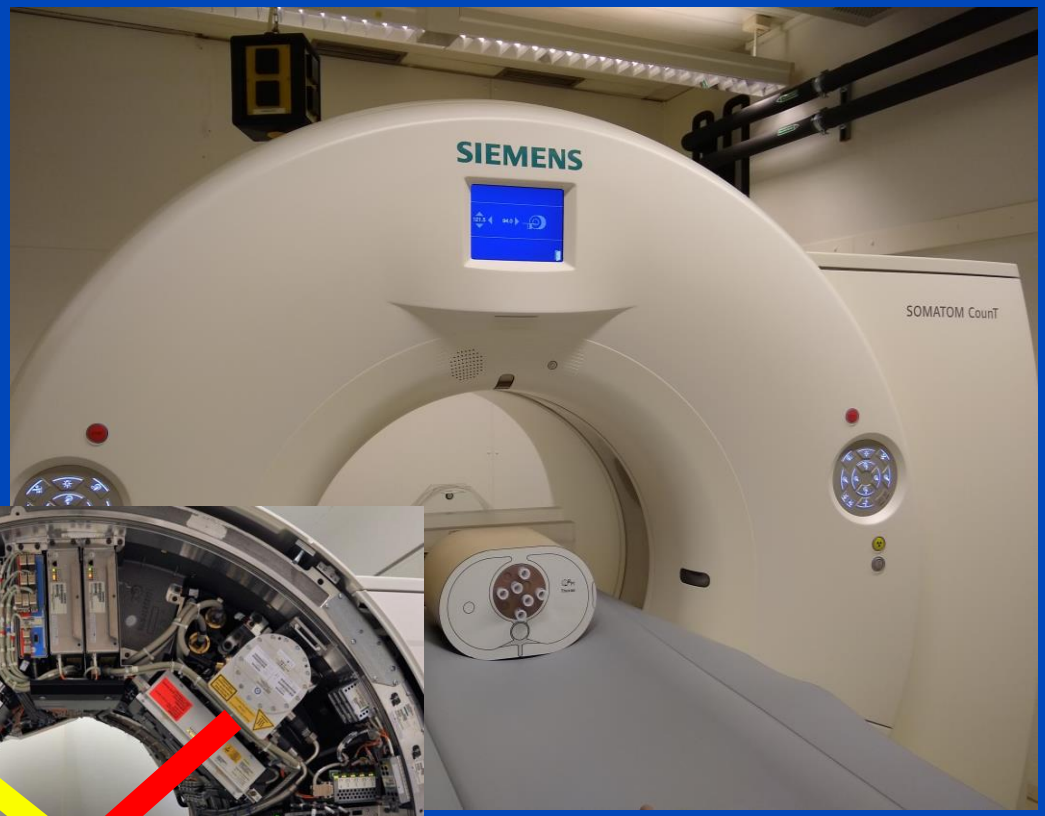
*Graeff, Peña, Glüer et al. Bone 52:568-576, 2013.
#Klein, Kachelrieß, Sawall et al. Invest. Radiol. 55(2):111-119, 2020.

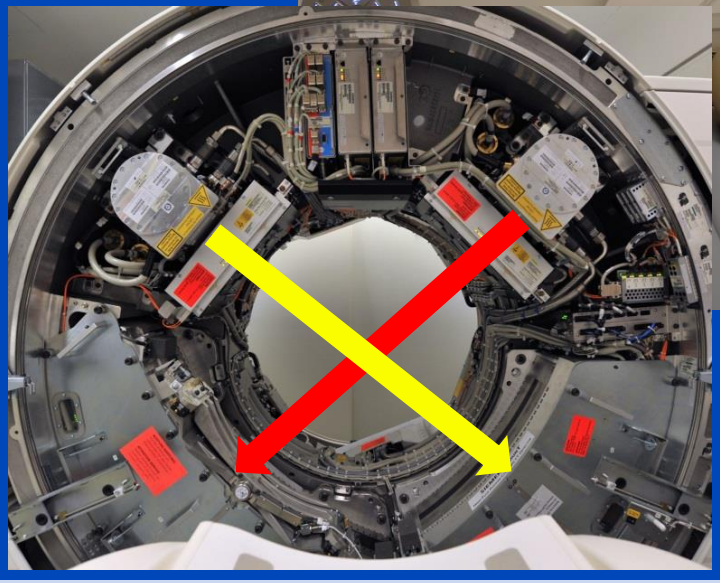
SOMATOM CounT CT @ DKFZ

Gantry of a clinical
dual source CT scanner

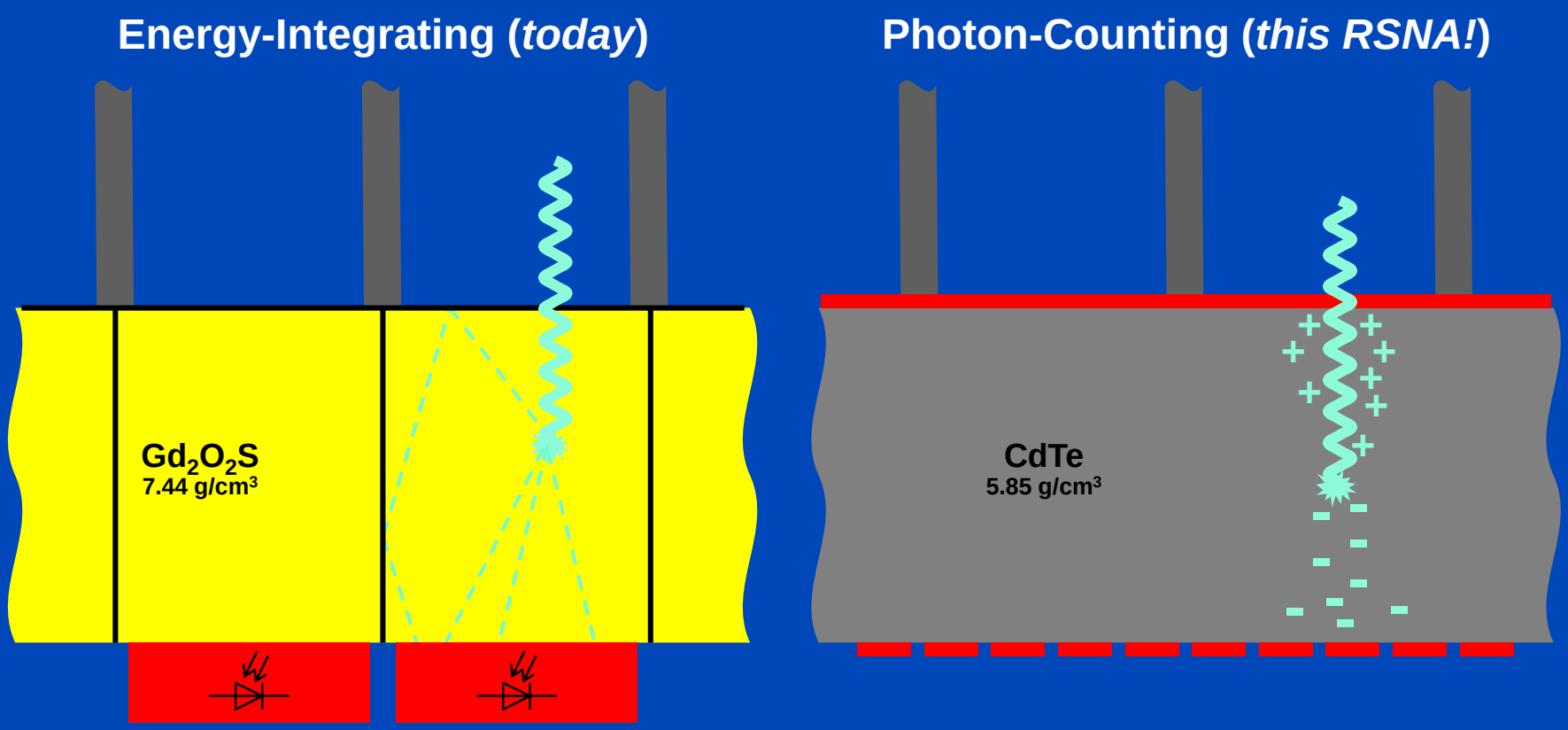
A: Conventional detector
(50 cm FOV)

B: Photon counting detector
(27.5 cm FOV)





Photon-Counting CT



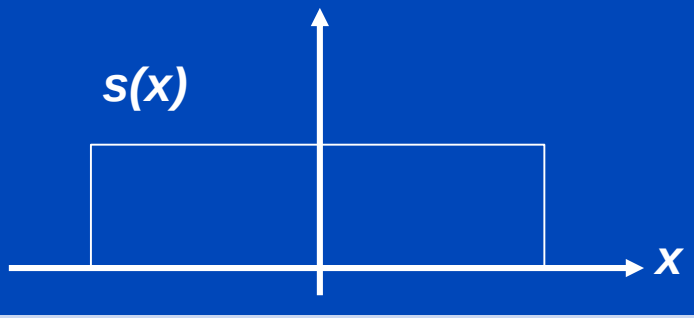
Requirements for CT: up to 10^9 x-ray photon counts per second per mm^2.
Hence, photon counting only achievable for direct converters.

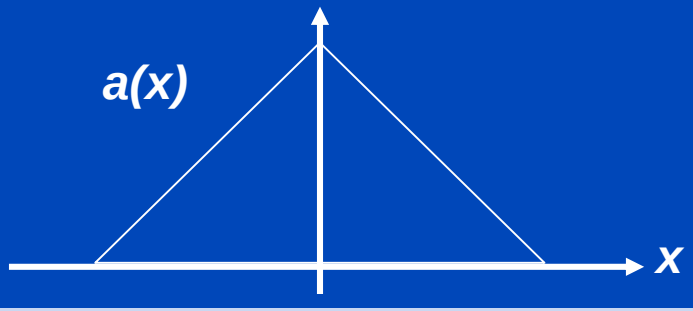
System Model

- Signal / projection to be measured *f*(*x*)
- Presampling function *s*(*x*), normalized to unit area
- Algorithm *a*(*x*), normalized to unit area
- Actual measurement corresponds to *g*(*x*) with

$$g(x) = f(x) * s(x) * a(x) = f(x) * \mathrm{PSF}(x)$$

- Example: Ideal detector + linear interpolation



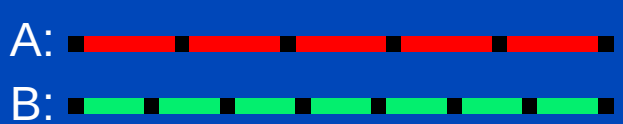


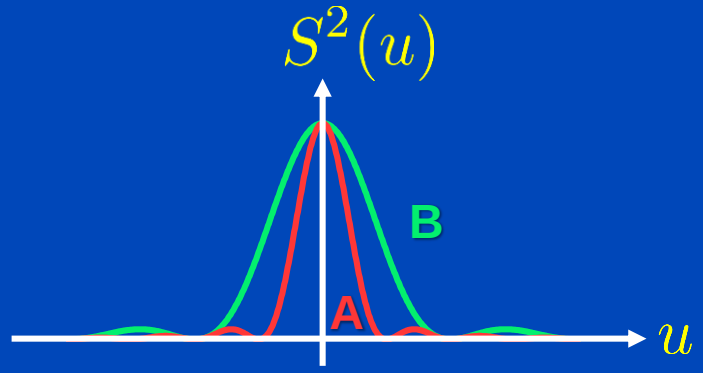
To Bin or not to Bin?
The "Small Pixel Effect"

- We have $\mathrm{PSF}(x) = s(x) * a(x)$ and $\mathrm{MTF}(u) = S(u)A(u)$.
- Using Rayleigh's theorem we find noise is

$$\sigma^2 \propto \int dx\, a^2(x) = \int du\, A^2(u) = \int du\, \frac{\mathrm{MTF}^2(u)}{S^2(u)}$$

- Compare large (A) with small (B) detector pixels:





- We have $S_\mathrm{B}(u) > S_\mathrm{A}(u)$ and thus $\sigma^2_\mathrm{B} < \sigma^2_\mathrm{A}$.
- This "**small pixel effect**" implies that a desired PSF/MTF is often best achieved with smaller detectors.

Phantoms

- We used 6 human vertebrae embedded in epoxy resin.
- One had a defect so we evaluated 5 vertebrae.
- The vertebra were placed in a semi-anthropomorphic phantom mimicking an average patient size.
- Measurements were repeated 3 times.
- A calibration phantom (BDC, QRM, Möhrendorf) was placed below the abdomen phantom and was scanned simultaneously.

Scanned vertebrae at the SOMATOM CounT

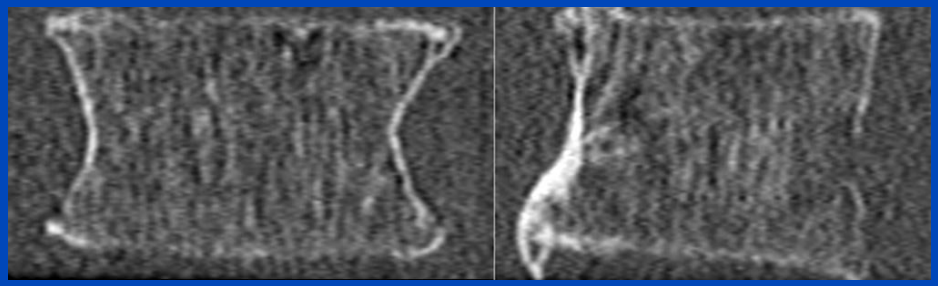
Acquisition and Reconstruction

Parameter	Clinical Reference	UHR_{dm}	UHR_{nm}	HR-pQCT (XtremeCT)
Type	Energy-Integrating	Photon-Counting	Photon-Counting	Energy-Integrating
Tube Voltage	120 kV	120 kV	120 kV	59.4 kV
Tube Current	355 mAs	355 mAs	130 mAs	392 µAs
Trajectory	Spiral	Spiral	Spiral	Circle
$CTDI_{32cm}$	23.8 mGy (100%)	23.8 mGy (100%)	10.5 mGy (44%)	6.6 mGy*
Effective Dose (5 cm scan)[#]	2.15 mSv	2.15 mSv	0.95 mSv	-
Kernel/MTF	B70	B70	B70	Sharp
Slice Thickness	0.600 mm	0.600 mm	0.600 mm	0.082 mm
Slice Increment	0.300 mm	0.300 mm	0.300 mm	0.082 mm
Pixel Size	0.156 mm	0.156 mm	0.156 mm	0.082 mm

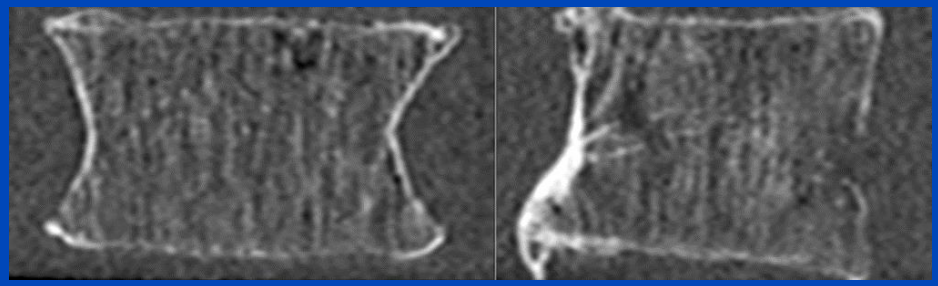
[#]Thorax, k=0.018 mSv/(mGy·cm) *CTDI measured with 10 cm phantom

Reconstruction Results

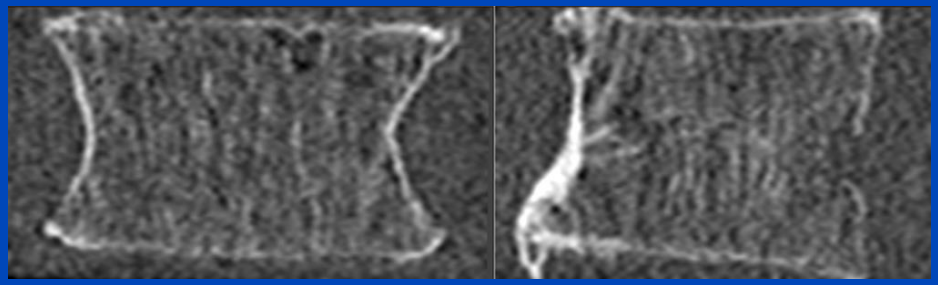
Clinical reference



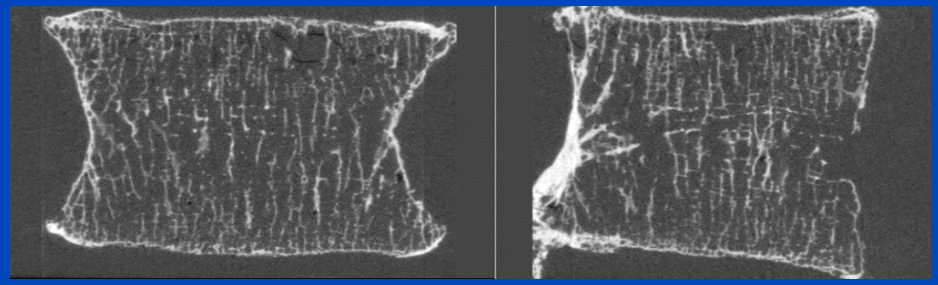
UHR_{dm}



UHR_{nm}



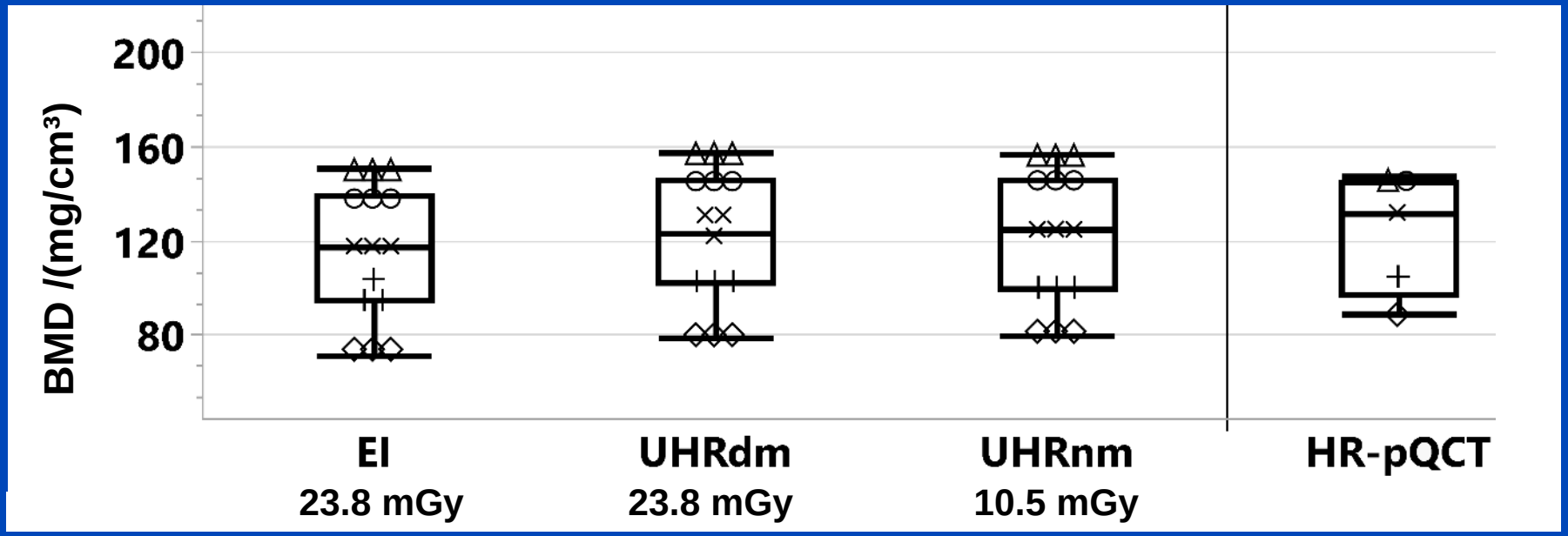
HR-pQCT (XtremeCT)



Data Processing

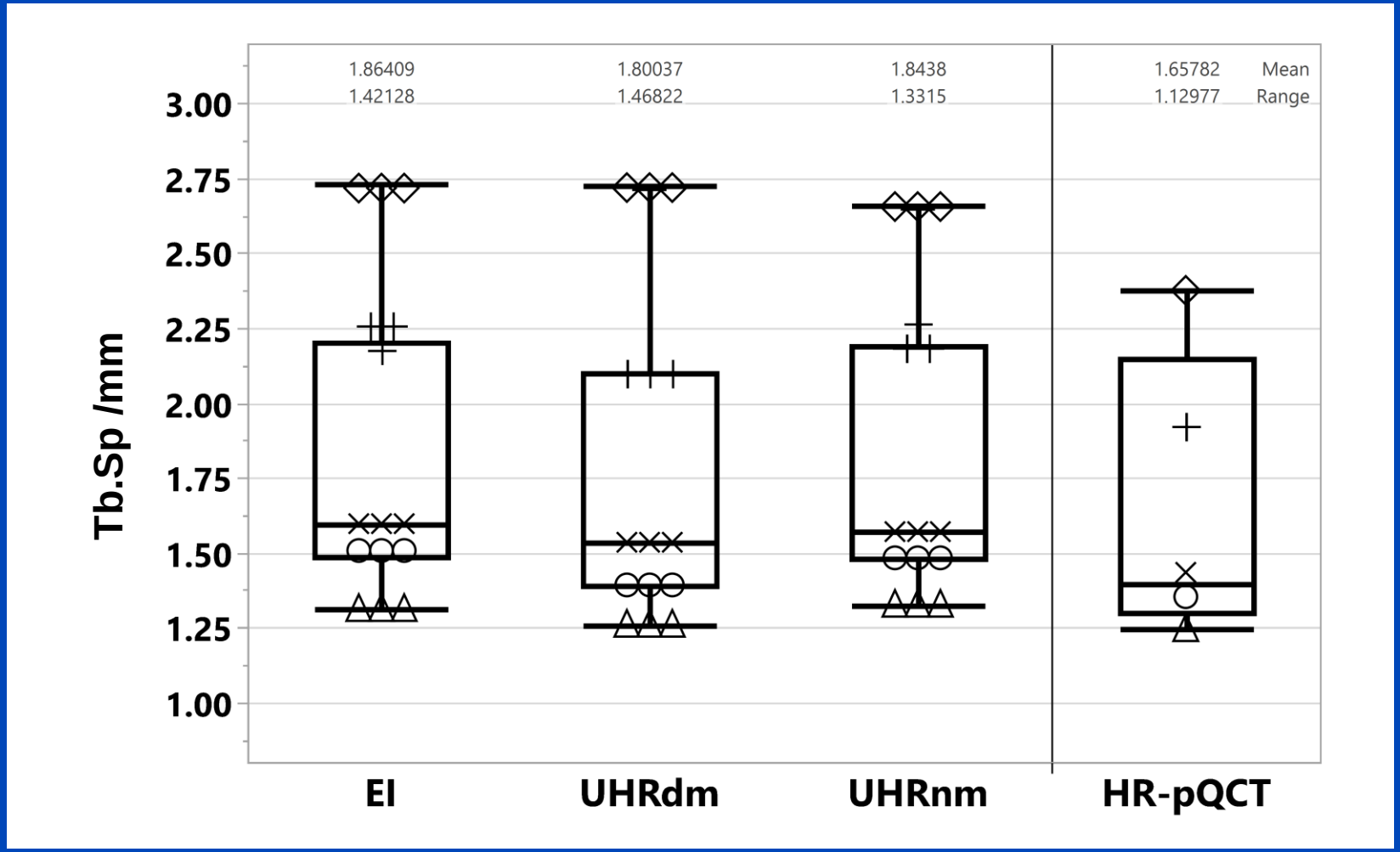
- Vertebra scans were calibrated from CT-values to density units, i.e. mg CaHAP/cm³.
- Bone mineral density (BMD) was measured at the spongiosa and compared between CT protocols.
- Vertebrae images were co-registered between HR-pQCT and the clinical CT protocols to obtain the same volume of interest (mask).
- **Trabecular Separation (Tb.Sp)** from HR-pQCT (XtremeCT, Scanco Medical) was deemed as *gold standard*.

Bone Mineral Density



No statistically significant differences between EI and PC!

Trabecular Separation



Summary & Conclusions

- Photon-counting CT allows for similar noise levels at much lower radiation doses compared to clinical CT.
- BMD derived from conventional HR-pQCT and photon-counting CT showed no significant differences.
- The correlation of Tb.Sp of photon-counting CT with the *gold standard* HR-pQCT showed very good results (RMSE = 0.032 mm).
- Photon-counting CT can achieve this with 56% less radiation dose compared to energy-integrating CT.
- Future research might investigate the influence of ultra-high resolution reconstructions or exploit the intrinsic dual-energy information.

Thank You!

This presentation will soon be available at www.dkfz.de/ct.
Job opportunities through DKFZ's international Fellowship programs (marc.kachelriess@dkfz.de).
Parts of the reconstruction software were provided by RayConStruct® GmbH, Nürnberg, Germany.