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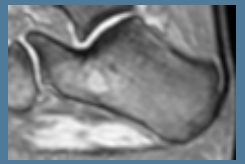
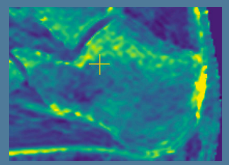
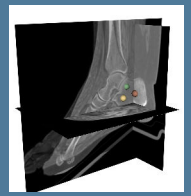
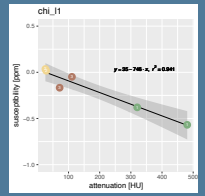
850 Simultaneous R_2^* and Quantitative Susceptibility Mapping of Trabecularized Yellow Bone Marrow: Initial Results in the Calcaneus

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Declaration of Financial Interests or Relationships

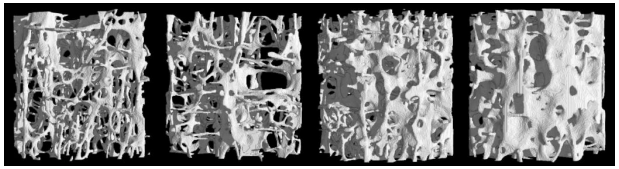
Speaker Name: Maximilian N. Diefenbach

I have the following financial interest or relationship to disclose with regard to the subject matter of this presentation:

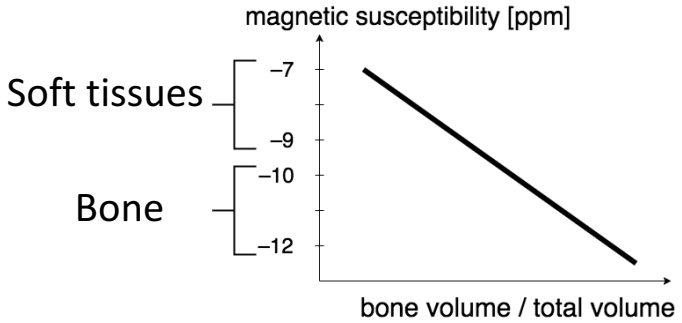
Company Name: : Philips Healthcare

Type of Relationship: Grant Support

Trabecular Bone Imaging



- High clinical significance for predicting fracture risk in patients with osteoporosis [1,2]
- Quantitative susceptibility mapping (QSM) maps differences in dia-/paramagnetic properties of tissues [3]
- Susceptibility differences between bone and soft tissue are several ppm [4,5].



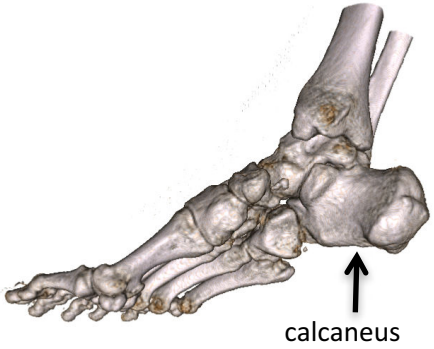
- Previous results indicate the possibility for QSM to detect differences in trabecular bone density [6, 7]

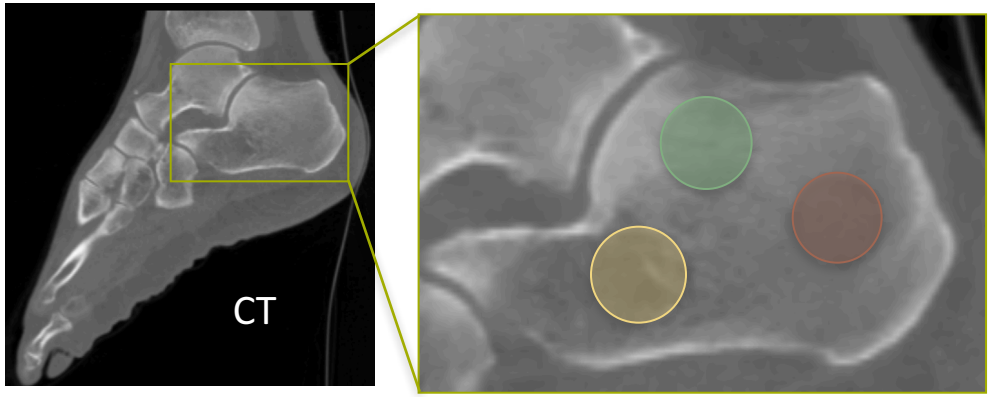
[1] Link, Radiology 2012, 10.1359/jbmr.1998.13.7.1175; [2] Wehrli, NMR Biomed 2006, 10.1002/nbm.1066; [3] Wang, MRM 2014, 10.1002/mrm.25358;
[4] Buch, MRM 2014, 10.1002/mrm.25350; [5] Schenck, Med. Phys. 23 (6), 1996; [6] Dimov, MRM 2017, 10.1002/mrm.26648; [7] Diefenbach, ISMRM 2016 #677

The purpose of this work is to …

investigate whether QSM can reliably measure differences in trabecularized yellow bone marrow at 3 T.

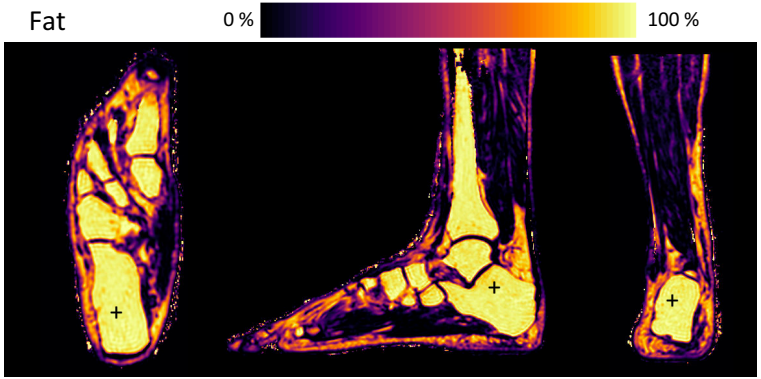
Calcaneus has two features beneficial to test trabecular bone QSM





1. Regions with different trabecular bone density

2. Only fatty yellow bone marrow (no red marrow containing iron!)



[8] Majumdar, Journal of Bone and Mineral Research, Volume 12, Number 1, 1997; [2] Wehrli, NMR Biomed, 2006, 10.1002/nbm.1066

1
MR signal acquisition

2
Magnetic-field mapping

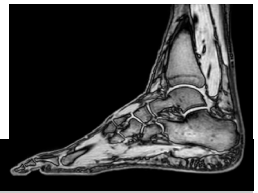
3
Background Field Removal

4
Dipole Inversion

[10] Ruschke, MRM 2016, 10.1002/mrm.26485; [11] Yu, MRM 2008, 10.1002/mrm.21737; [12] Ren, JLR 2008, 10.1194/jlr.D800010-JLR200;
[13] Zhou, NMR Biomed 2013, 10.1002/nbm.3064; [14] Deistung, NMR Biomed 2016, 10.1002/nbm.3569;

Invivo Scan Parameters at 3 T

QSM



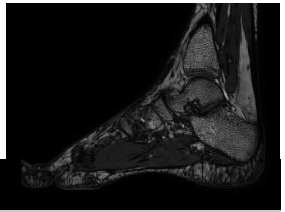
Time-interleaved gradient echo (TIMGRE)

TIMGRE [10]	
Readout	Monopolar
Number of echoes	9 (3 interleaves à 3 echoes)
TE1/delta TE	1.7/0.9 ms
Voxel size	(1.5 x 1.5 x 1.5) mm^3
Flip angle	5°
Scan time	07:30.1 min:s
Bandwidth/pixel	1431.4 Hz

4 subjects + 2 subjects

Hires trabecular bone imaging

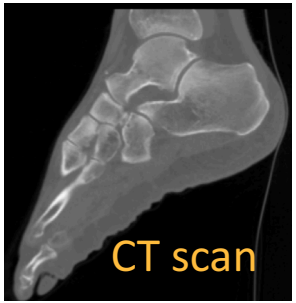
Balanced SSFP with 2 phase cycles



bSSFP	
TE	3.4 ms
Voxel size	(0.3 x 0.3 x 0.45) mm^3
Scan time	07:29.1 min:s
Bandwidth/pixel	233.9 Hz

4 subjects

Apparent trabecular density obtained by ROI histogram-based dual-thresholding method for intra-subject comparison [8]



2 subjects

[10] Ruschke, MRM 2016, 10.1002/mrm.26485; [8] Majumdar, Journal of Bone and Mineral Research, Volume 12, Number 1, 1997

Dipole inversion

Data fidelity term

regularization $R[\chi]$

$$\hat{\chi} = \arg\min_{\chi} \left\| W\left(F^{\dagger} D F \chi - f_L\right) \right\|_2^2 + \lambda \left\| M \nabla \chi \right\|_p$$

Susceptibility

Data weighting

Unit dipole field (k-space)

Fourier transform

Local field

Gradient weighting

Bayesian Interpretation [1]: *a priori* distribution $p(\chi) \sim \exp\left\{-\frac{\lambda}{2} R[\chi]\right\}$

$R[\chi] = \|\nabla \chi\|_2$

Closed form solution, (Tikhonov regularization) [1]

$R[\chi] = \|M \nabla \chi\|_2$

Preconditioned conjugate gradients, (l2-MEDI) [2]

$R[\chi] = \|M \nabla \chi\|_1$

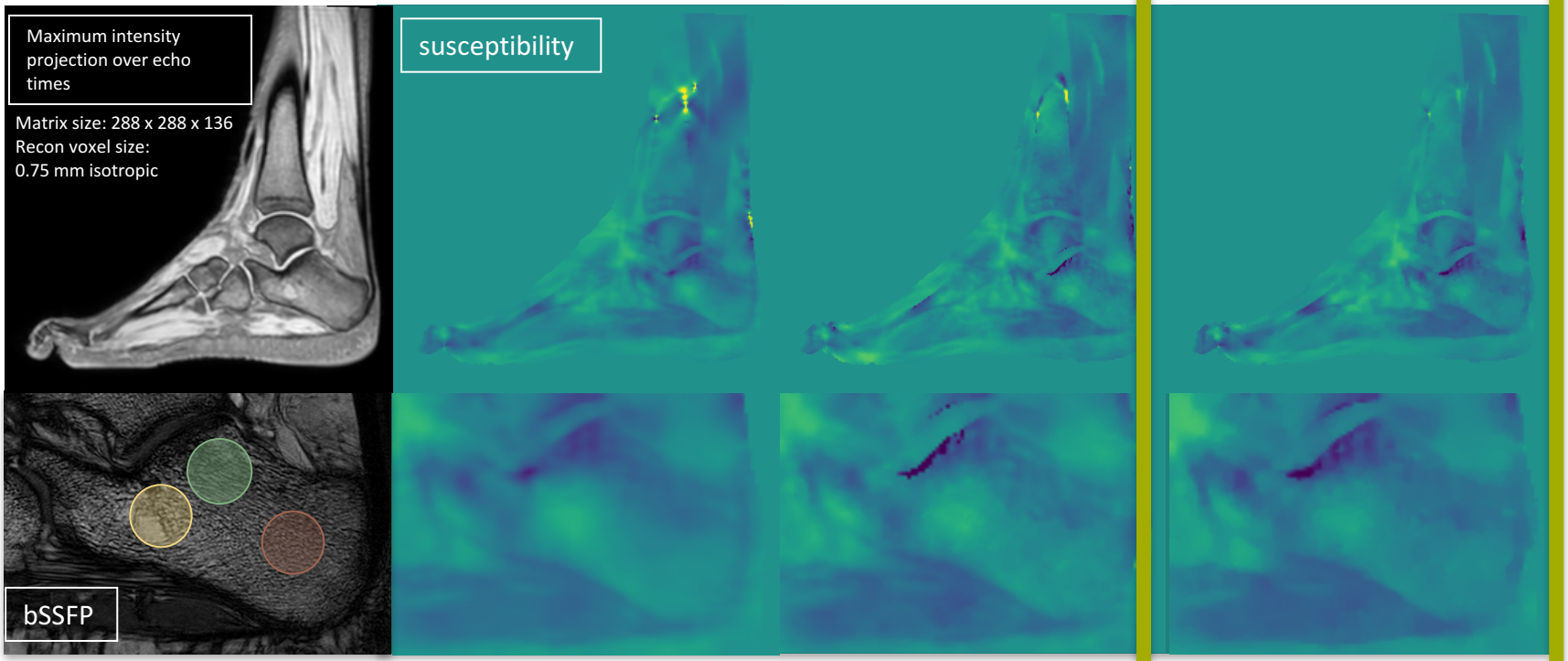
Nesterov's algorithm (NESTA) [3], (l1-MEDI) [2]

[1] Demoment, IEEE Transactions on Acoustics, Speech, and Signal Processing, Vol. 37, No. 12, 1989; [2] Bilgic, MRM 2014, 10.1002/mrm.25029; [3] Becker, SIAM JIS 2011, 10.1137/090756855; [4] Wang, MRM 2014, 10.1002/mrm.25358

Regularizer $R[\chi]$

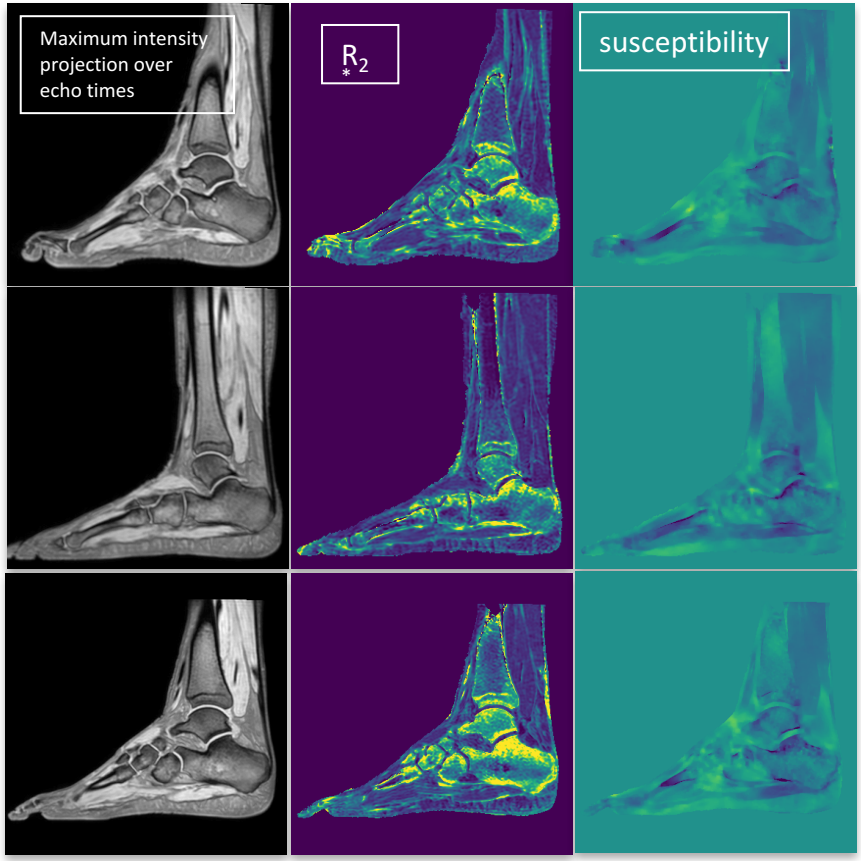
Algorithm

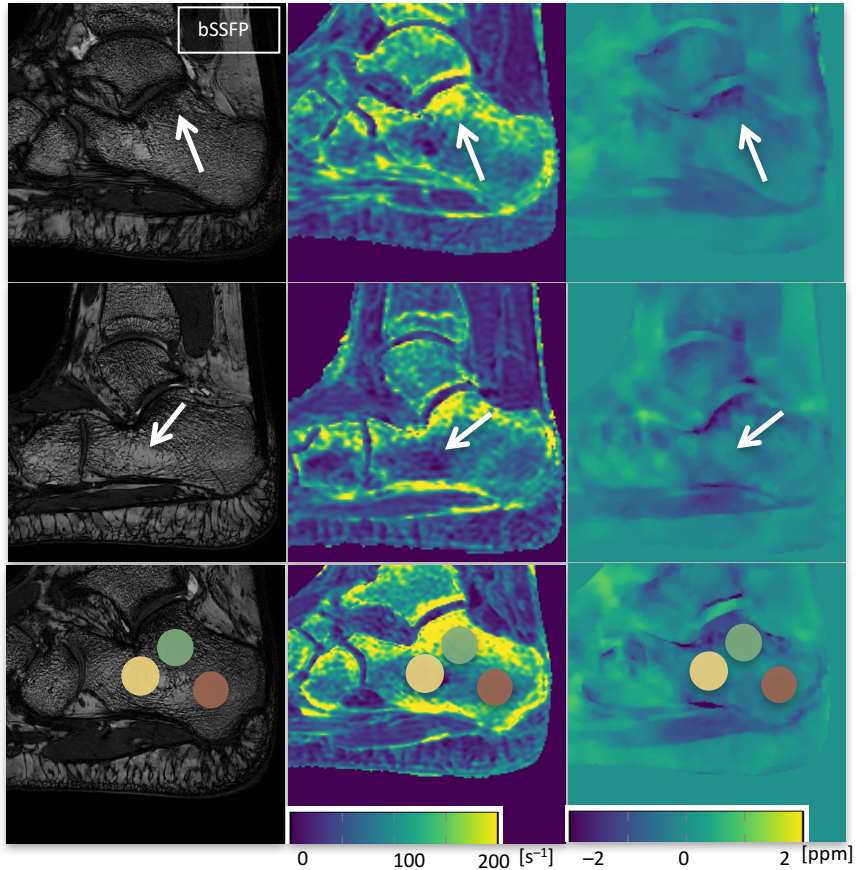
$\|\nabla\chi\|_2$	$\|M\nabla\chi\|_2$	$\|M\nabla\chi\|_1$
Closed form solution	Precond. conjugate gradients	NESTA



Processing time (dipole inversion)	< 2 s	< 40 s	< 150 s

R_2^*, susceptibility maps for three subjects





ROI analysis: TIMGRE: R_2^*, QSM vs. bSSFP: BV/TV

10 % increase in apparent bone volume / total volume (BV/TV)

⇕

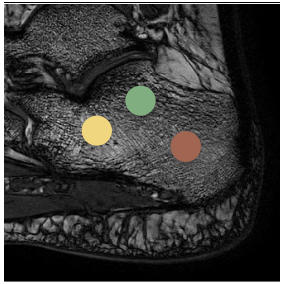
Approximately 0.35 ppm decrease in magnetic susceptibility

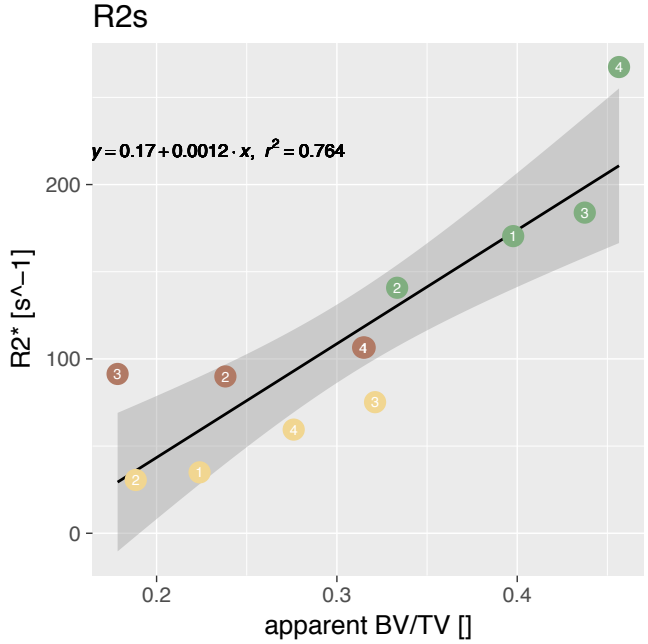
Subject

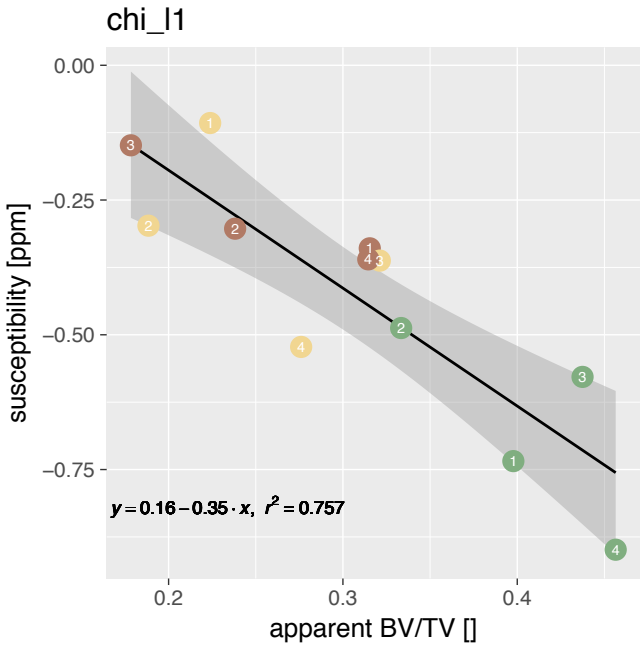
1 – 4 Subtalar

1 – 4 Cavum calcanei

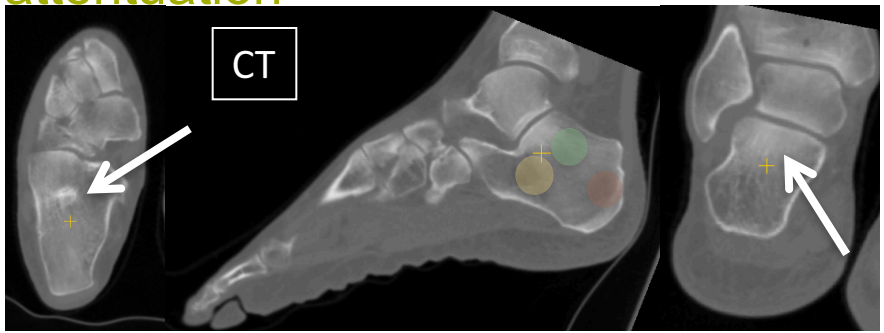
1 – 4 Tuber calcanei

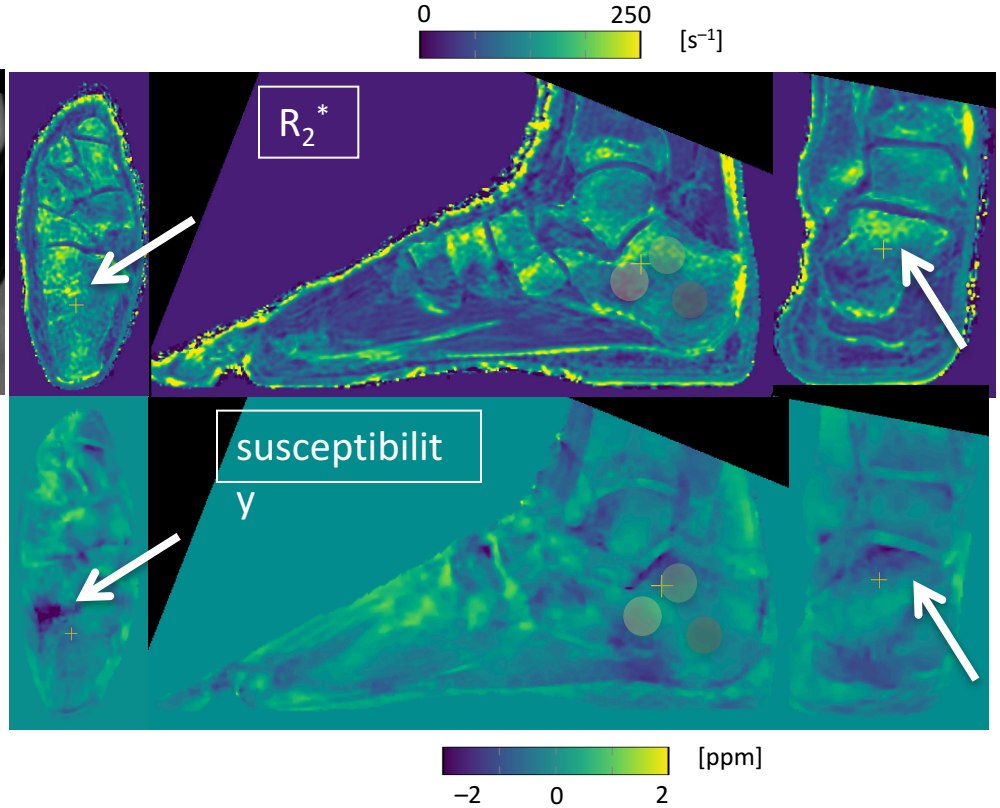




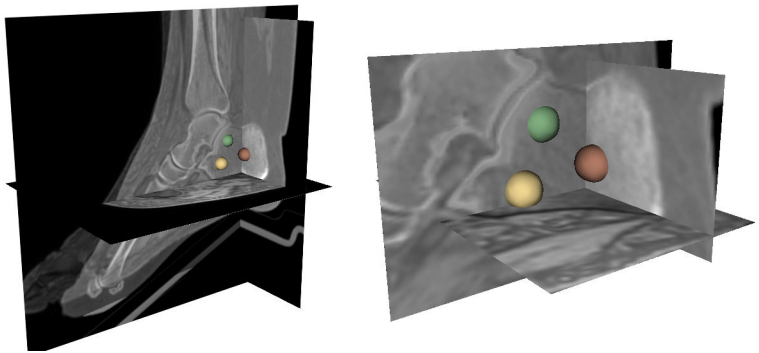


Susceptibility, R2*, CT attentuation





Registration + ROI analysis



ROI Analysis: MR QSM vs. CT attenuation

100 HU increase in attentuation

⇕

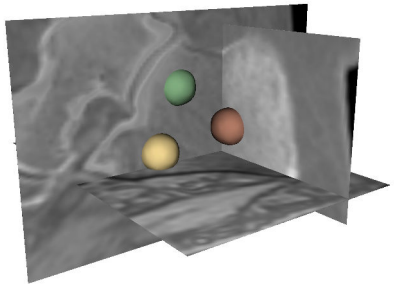
Approximately 0.25 ppm decrease in magnetic susceptibility

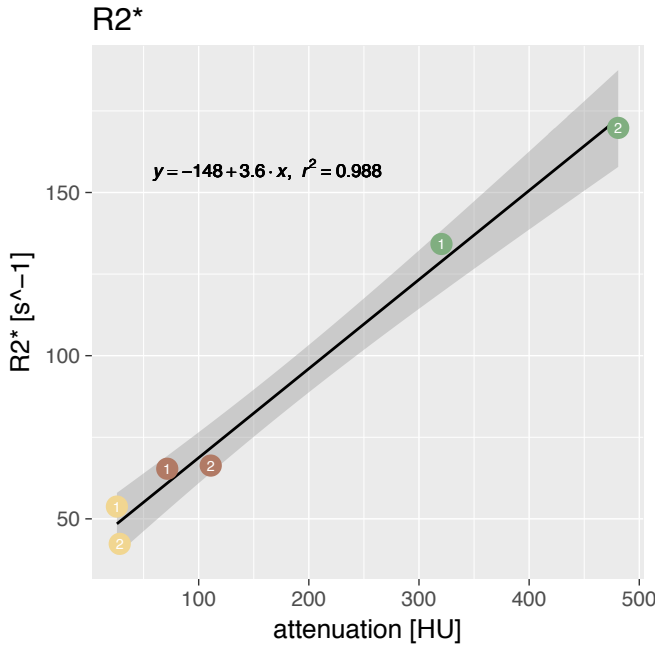
Subject

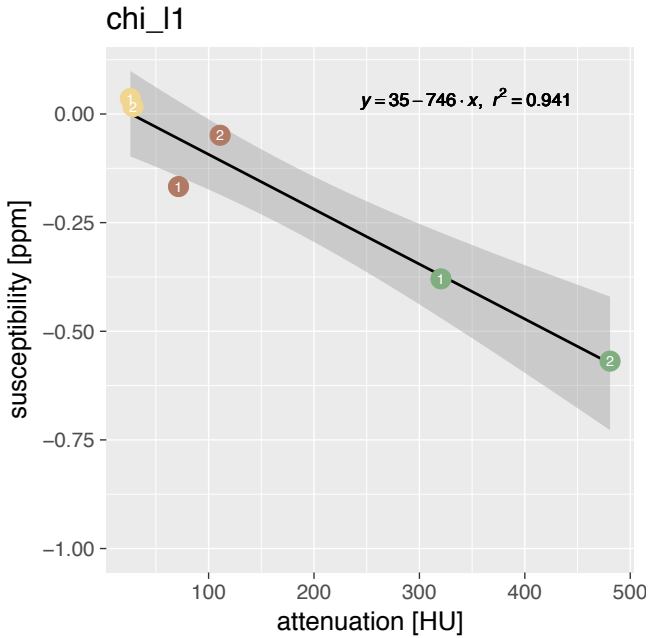
1 2 Subtalar

1 2 Cavum calcanei

1 2 Tubercalcanei



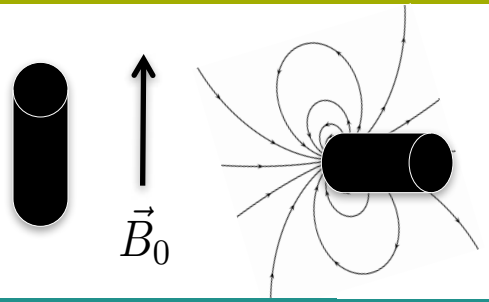


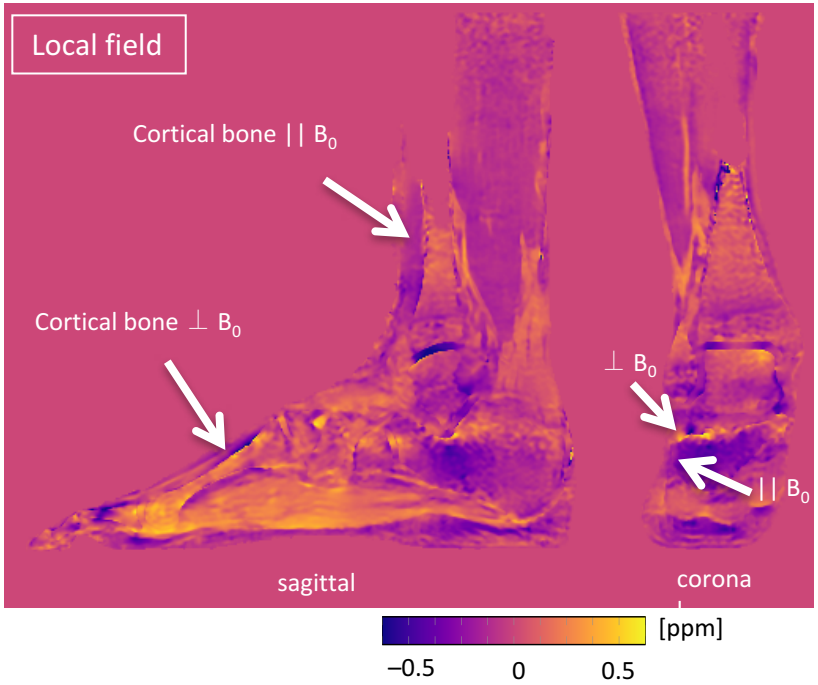


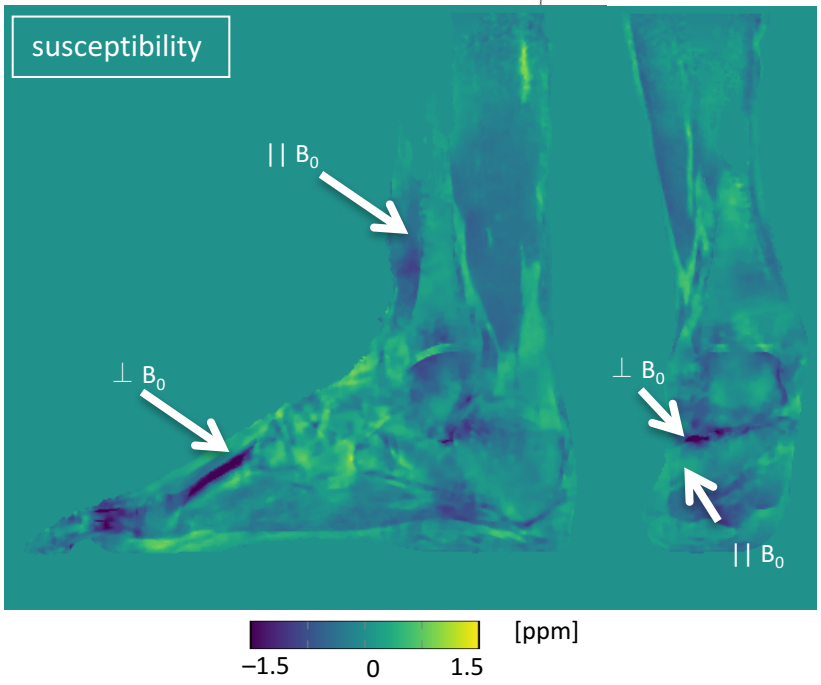
Limitations

Cortical bone ➔ Signal voids (non-UTE sequence)

Geometry aligned with B_0 ➔ invisible to QSM

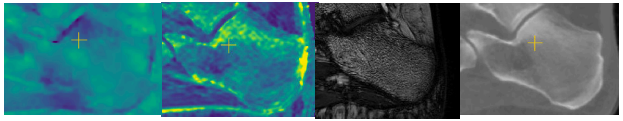




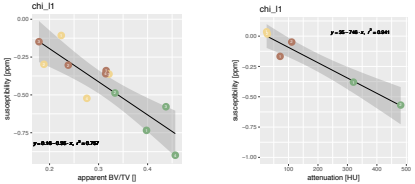


Summary

- Susceptibility maps show trabecular bone densities changes following R_2^* maps, high-resolution magnitude images, and CT



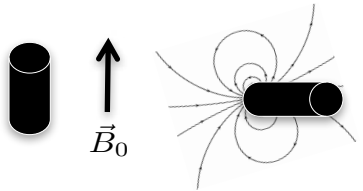
- **QSM is able to detect differences in trabecular bone density at 3 T**



- Anatomical priors in form of **different regularizers** are available

$\|\nabla\chi\|_2$ $\|M\nabla\chi\|_2$ $\|M\nabla\chi\|_1$

- Dependent on geometry w.r.t B_0, **cortical bone invisible** to QSM based on TIMGRE sequence



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