Six-minute, *in vivo* MRI quantification of proximal femur trabecular bone elastic moduli

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BACKGROUND

- Of the 9 million fragility fractures caused by **osteoporosis** each year, **hip fractures are the most devastating**. The mortality rate for a hip fracture ranges from 20 to 24% in the first year following fracture, and hip fractures account for 72% of the total direct annual costs in fracture care in the US.
- Dual-energy X-ray absorptiometry is the clinical standard for diagnosis of osteoporosis, but it has a sensitivity of < 50% and is therefore **a poor predictor of osteoporotic fracture risk**.
- Recent validation has shown that **high-resolution MRI** can visualize and **quantify the 3D trabecular microstructure in the proximal femur**, but implementation in large-scale clinical studies is limited by tradeoffs between resolution, scan time, and signal-to-noise.
- **Parallel imaging and compressed sensing** (**PICS**) are well-established methods for addressing these tradeoffs, but it remains necessary to assess their compatibility for quantifying parameters of trabecular bone.

Objective: **To establish feasibility of a rapid MR imaging protocol for measuring the elastic modulus of proximal femur trabecular bone *in vivo*.**

METHODS

Pulse Sequence: balanced steady-state free precession (bSSFP)
- 400 μm isotropic
- Short TR (6.5 ms) to harness the refocusing (spin-echo-like) property
- TE = TR/2 (3.25 ms) to mitigate T_2^* effects from magnetic susceptibility
- High flip angle (50°) to maximize signal from fatty marrow
- Shinnar-Le Roux pulse to minimize specific absorption ratio

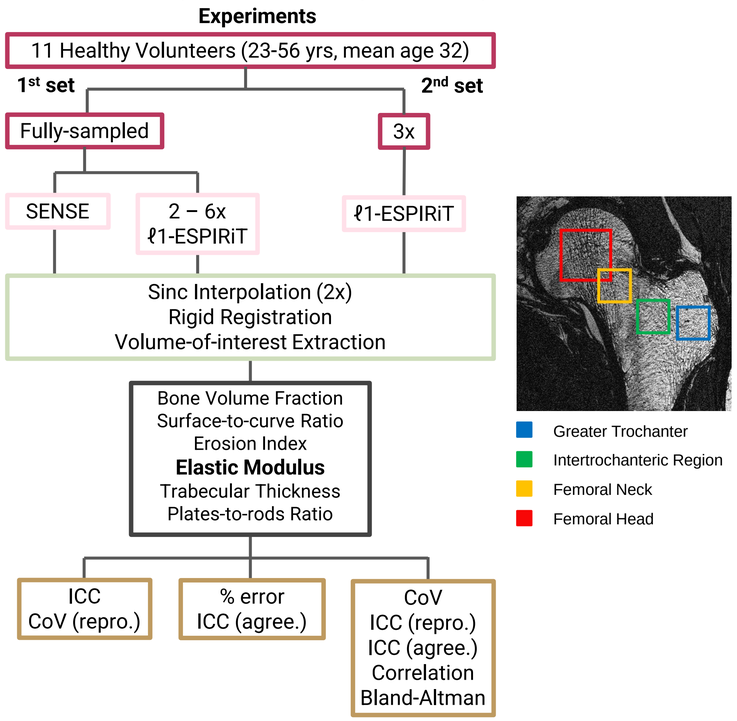
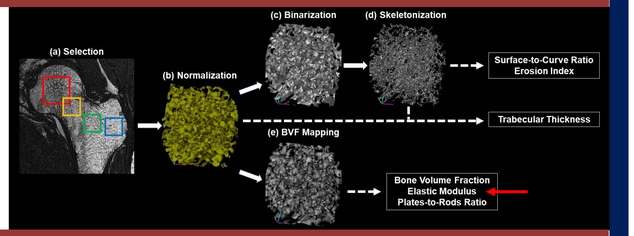


Fig 1. Summary of methods used in the present work. The first set of experiments were comprised of retrospectively undersampling fully-sampled raw data and assessing the theoretical effect of PICS on trabecular quantification. The second set of experiments prospectively accelerated the scan by a factor of 3.

TRABECULAR BONE ANALYSIS

Fig. 2: Isosurface renderings of a VOI for various image processing steps. **(a)** VOI extraction. **(b)** Each VOI is normalized by a local threshold algorithm to remove coil shading. **(e)** A bone volume fraction map is computed, used to calculate the elastic modulus of the VOI.



RESULTS

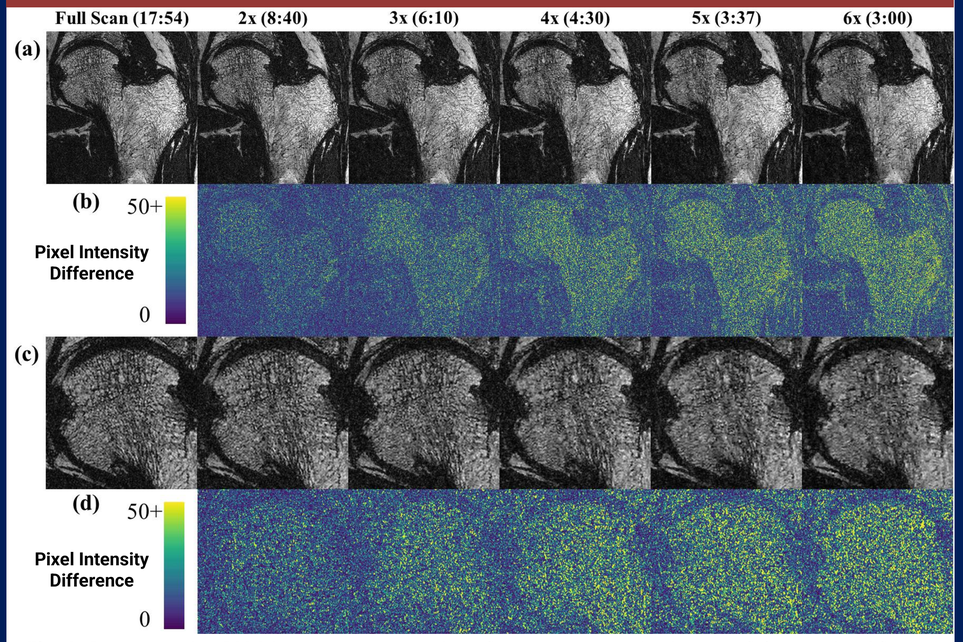


Fig. 3: Retrospective PICS image reconstructions for a representative image of the proximal femur (male, 50 years). Theoretical scan times for each image are listed above each column. **(a)** Images of the proximal femur for accelerations of 2-6x. **(b)** Absolute error maps for each acceleration factor. **(c)** Magnified images and **(d)** absolute error maps around the femoral head.

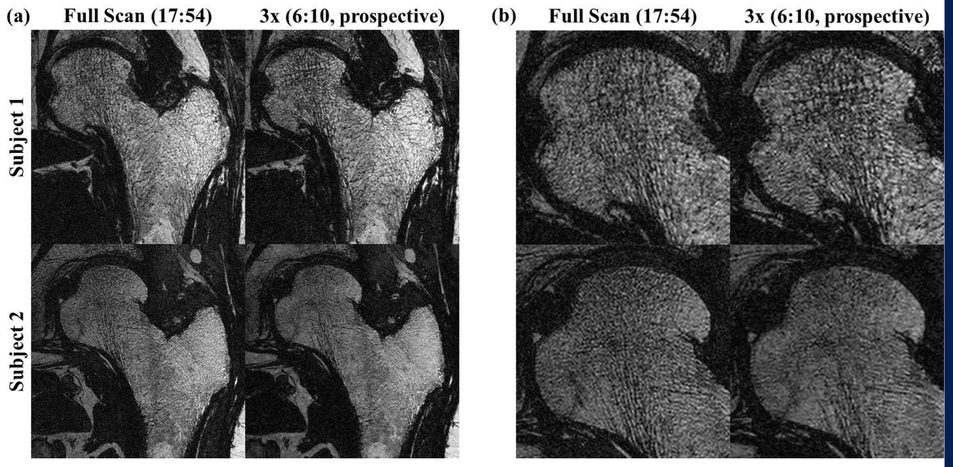


Fig. 4: Proximal femur images from two separate scans: a full scan and 3-fold accelerated scan. **(a)** Images of the proximal femur for two subjects (Subject 1: male, 50 years; Subject 2: female, 56 years). **(b)** Magnified images of the femoral head taken from the same slice as **(a)**.

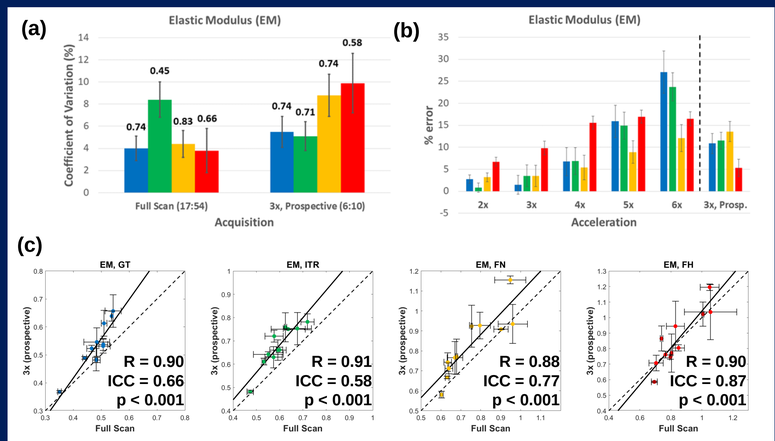


Fig 5. (a) Median coefficient of variation for the elastic modulus in each trabecular region. Corresponding intraclass correlation coefficients (ICCs) are listed above each bar. **(b)** Median percent error values for the elastic modulus in each region. **(c)** Correlation plots to assess agreement between fully-sampled and prospectively 3-fold accelerated scans. Pearson and intraclass correlation coefficients are listed.

DISCUSSION

- Elastic modulus CoVs were generally < 10% and percent error < 10% for a 3x-accelerated sequence.
- Moderately strong correlations and ICCs were found between the prospective 3x scan (6 minute) and the fully-sampled scan (18 minute).
- This study was limited by the use of a generic rigid registration algorithm, which was unable to align the femur trabecular structure such that the same VOI was analyzed in each image.

CONCLUSION

- A fast clinical protocol which images the proximal femur and performs quantification of the elastic modulus is feasible.
- **The use of an SNR-efficient bSSFP and a parallel imaging and compressed sensing technique reduced the total scan time to about six minutes**.
- Future work will use the accelerated method to acquire data from larger cohorts and investigate the sensitivity of trabecular microstructural measurements to various disease states and treatments which induce bone remodeling.
- Future work will also investigate the use of machine learning to further increase reliability of quantification and decrease scan time.

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