Bone marrow fat fraction mapping in the proximal femur *in vivo* using IDEAL gradient echo imaging

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Introduction:
Osteoporosis is a systemic skeletal disease characterized by low bone mass and micro architectural deterioration of bone tissue, with a consequent increase in bone fragility. Using MR spectroscopy at the lumbar spine it has been recently found that osteoporosis may be associated with increased fatty (yellow) marrow content [1]. Therefore, mapping bone marrow composition might be able to provide additional information regarding localized risk of fracture. In particular, the proximal femur is a site of high fracture occurrence. The proximal femur contains regions of both yellow (fatty) and red marrow. Yellow marrow is predominantly found in the greater and lesser trochanter and the femoral head. Yellow marrow is composed of adipocytes [2] and has the typical spectral signature of triglycerides (Fig. 1a). Red marrow is instead encountered in the neck and the head. Red marrow is composed of both water and lipids [2] and therefore its spectrum contains both water and fat peaks (Fig. 1b). Goal of the present work is to map the spatial distribution and quantify the amount of fat in the proximal femur in order to separate red and yellow marrow. IDEAL gradient echo imaging [3] is employed in order to decompose the water and fat signals in the proximal femur marrow of six subjects.

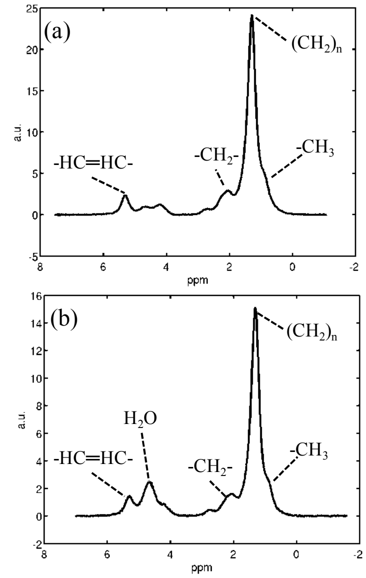

Fig. 1: Example of acquired single-voxel PRESS MR spectra from one subject in the trochanteric region (a) and the neck region (b).

Materials and Methods:
A 3D Fast Gradient Recalled Echo (FGRE) pulse sequence with three asymmetric echoes (IDEAL) was used on a 3T GE MR750 system. The following imaging parameters were used: TR=6.6ms, TE=2.2ms, flip angle=12º, bandwidth=±62.5kHz, FOV=12cm, matrix=128^2 and the total scan time was 6 min 38 sec. Images of the proximal femur from six healthy subjects were acquired with an 8 channel phased array coil. Water-fat separation was performed using an investigational version of IDEAL that takes into account the multiple peaks of the fat spectrum [4]. Fat fraction maps were created removing noise bias effects as in [5]. Three ROIs were defined in the femoral head, greater trochanter and neck for all subjects. The mean and standard deviation of the fat fraction was computed in these ROIs.

Results and Discussion:
Fig. 2 shows representative IDEAL results from one slice in one subject. The dark areas in the fraction map (Fig. 2c) stem from the lower fat fraction values in the red marrow than in the surrounding yellow marrow. Representative ROIs for the femoral head (red), the neck (green) and the trochanter (blue) are also shown in Fig. 2a. The fat fraction results from the multiple subjects are summarized in Table 1. For all subjects, the trochanteric region featured the highest fat fraction (fat fraction of 96% in average) and the femoral neck had the lowest fat fraction (in average 83%). The femoral head had a fat fraction value in between the values of the greater trochanter and the neck (mean fat fraction of 92%). The trend of the measured fat fraction is qualitatively consistent with the representative single-voxel spectroscopy results acquired in the trochanteric and neck regions of one subject (Fig. 1). The greater trochanter contains primarily yellow marrow and therefore its water component is very small (Fig. 1a). The neck contains both yellow and red marrow and therefore its water component is significant (Fig. 1b).

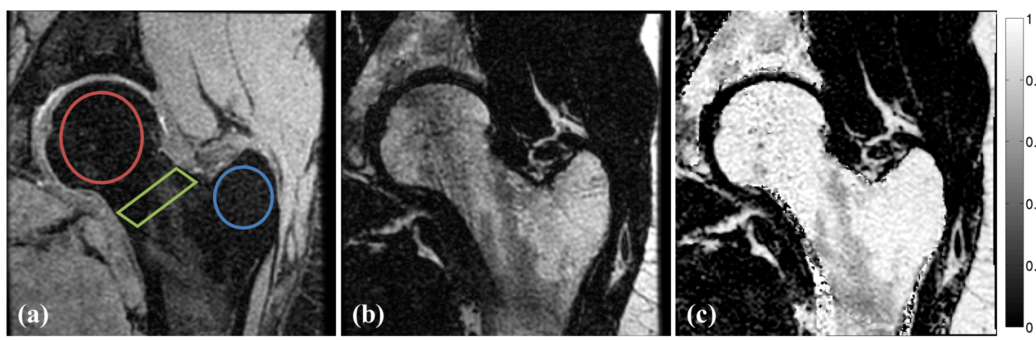

Fig. 2: IDEAL water-fat separation results: (a) water image, (b) fat image, and (c) fat fraction map (fat fraction normalized between 0 and 1).

The present analysis has some limitations related primarily to the confounding factors in fat quantification measurements using IDEAL. Specifically, further work taking into account corrections for T_2* decay and T_1 bias would be required in order to compare the IDEAL fat fraction measurements with spectroscopic measurements of fat content. However, the presented results are the first to our knowledge for mapping the spatial distribution of fat fraction in the proximal femur. Spectroscopy-based fat measurements have been performed earlier in the femur [6]. However, IDEAL fat fraction mapping has the important advantage of higher spatial resolution for separating red and yellow marrow regions over spectroscopic techniques.

Subject	Troch.	Neck	Head	Total
1	94	77	92	90
2	94	82	89	94
3	100	88	96	96
4	96	76	93	91
5	93	77	88	87
6	97	89	95	94

Table 1: IDEAL-based mean fat fraction values (in %) for each of the three ROIs (trochanter, neck and head) of the six subjects scanned.

Conclusion:
IDEAL gradient echo imaging enables the mapping of bone marrow composition in the proximal femur. *In vivo* results in six subjects show a lower fat fraction for the neck region than the trochanteric and head regions, as it is expected due to the presence of red marrow in the neck.

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References:[1] Yeung et al, J Magn Reson Imag 22:279-285, 2005, [2] Schick et al, Eur J Radiol 67: 275-284, 2008, [3] Reeder et al, Magn Reson Med 54: 636-644, 2005, [4] Yu et al, Magn Reson Med 60:1122-1134, 2008, [5] Liu et al, Magn Reson Med 58: 354-364, 2007, [6] Griffith et al, JMRI 29: 1432-1442, 2009.