Assessment of Bone Marrow Oxygenation Based on T2* and T2 Changes Following Oxygen Inhalation

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Background

Osteoporosis affects 1 in 4 women and 1 in 8 men over 50 years and its burden on healthcare resources is enormous. Despite the risk factors and biological processes leading to bone loss have been well studied, little is known about the mechanisms that initiate bone loss in the first place. Osteocytes, marrow adipocytes and haematopoetic cell lines share a common precursor in the marrow mesenchymal stem cell (MSC) which can variably differentiate along osteoblastic, adipocytic or haematopoietic cell lines. The level of oxygenation within bone marrow may affect the pattern of MSC differentiation. On the other hand, a shift in the pattern of MSC differentiation might be observed indirectly by a change in the demand for oxygen in the bone marrow. Therefore, development of an MR-based technique to study marrow oxygenation non-invasively might be helpful to further our understanding on marrow physiology and bone formation.

Introduction

MR relaxometry (T_2* and T_2) techniques have been shown to be useful in osteoporosis studies (1). Patients with osteoporosis have prolonged marrow T_2* due to reduced magnetic field inhomogeneities in less dense trabecular bone (2). Accumulation of fatty marrow in osteoporotic bone is believed to increase the marrow T_2 of subjects with reduced bone mineral density (BMD) (2,3). Deoxyhemoglobin is paramagnetic and breathing carbogen or pure oxygen lowers deoxyhemoglobin concentration and increases both T_2* and T_2 of water in blood and in the tissue surrounding blood vessels (4,5). Our aim in this study was to verify whether oxygen inhalation has a measurable effect on bone marrow T_2* and T_2 relaxation times.

Material and Methods

Seven healthy volunteers (4 males and 3 females; mean age 35 years) were examined in the supine position on a 3.0T scanner (Achieva, Philips Healthcare, Best, The Netherlands) using a standard spine coil. Air or 100% oxygen was delivered via a tight-seal full-face mask (Mirage NV, ResMed, Sydney, Australia) at a rate of 15 L/minute. A 10 mm thick axial image was acquired from each vertebral body L3, L4 and L5 for relaxation measurements before (T_2* air and T_2 air) and after 5 minutes of oxygen inhalation (T_2* oxygen and T_2 oxygen). A multi-echo fast field echo sequence (TR/TE/δTE 93/1.9/1.5 ms; 12 echoes; in-plane pixel size 1.5×1.2 mm) was used to measure T_2*. For T_2 measurement, a multi-echo spin-echo sequence was employed (TR/TE 990/n×20 ms; n = 1-12; in-plane pixel size 1.5×1.2 mm). A pixel-by-pixel T_2* map (Fig. 1) and T_2 map (Fig. 2) were obtained. For a given vertebral body, the same region of interest was drawn on the maps to obtain mean T_2* air, T_2* oxygen, T_2 air and T_2 oxygen. Paired t test was used to evaluate differences T_2* air vs. T_2* oxygen and T_2 air vs. T_2 oxygen with differences considered significant at $P < 0.05$.

Results

Twenty-one pairs of T_2* and T_2 values before and after breathing oxygen were obtained from the 3 vertebral bodies of all 7 subjects. Table below summarizes the results after breathing air and pure oxygen for 5 minutes. On average, T_2* increased by 11.7% compared to 7.9% for T_2. Pair t-test showed that there were significant differences in T_2* ($p = 0.002$) and T_2 ($p < 0.0001$) values when breathing air or oxygen.

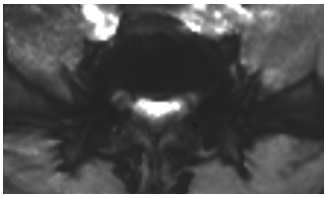

Fig.1 – T_2 map of L3.*

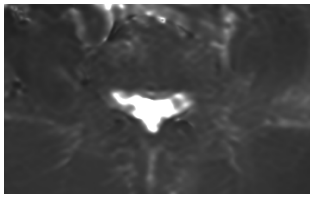

Fig. 2 – T_2 map of L3.

	T_2* air	T_2* oxygen	T_2 air	T_2 oxygen
Range (ms)	1.15 – 3.07	1.21 – 3.79	28.63 – 52.15	30.10 – 55.11
Mean ± SD (ms)	1.80 ± 0.58	2.01 ± 0.76	39.52 ± 6.26	42.66 ± 6.83

Conclusion

T2* changes after breathing carbogen or oxygen have been used to study tumor vascular architecture (4). Our results were the first to report that similar effects can be observed in the human bone marrow. Oxygen-rich blood transported into the marrow cavity reduced the amount of deoxyhemoglobin in the marrow vasculature and surrounding tissues thereby prolonging marrow T_2* and T_2. Apart from susceptibility differences at the marrow-bone boundaries influencing T_2* decay, iron-rich red bone marrow might also play a role. T_2* change (11.7%) was higher than T_2 change (7.9%) after oxygen inhalation probably due to higher oxygen demand (and blood supply) in the red marrow compared to fatty marrow. Further studies involving subjects with different BMD are necessary to confirm our initial results.

References

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