The resolution of Oxygen in EPR Images

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Introduction: Tissue oxygenation maps identifying normoxic and hypoxic areas are useful to understand tumor biology. Recent advances in EPR imaging have realized mapping of the tissue oxygenation in three dimensions. Co-registration of oxygen maps with images from other modalities facilitates examination of oxygen levels in sub-volumes or specific organs. However, understanding the contrasts of oxygen levels in different parts of the body requires knowledge of its resolution both in space and magnitude. The intrinsic resolution of pO_2 is governed by the fundamentals of the imaging technique such as the gradient magnitude, relaxation times and oxygen sensitivity. Instrumental parameters including S/N ratio and field homogeneity and image reconstruction artifacts may also add to loss of resolution. Therefore it is necessary to define parameters to specify the resolution of oxygen levels, and present their estimates with digitally enhanced higher resolution images. The definition and determination of these resolution parameters of pO_2 images are yet to be standardized.

Methods: An SCC tumor was grown in the femoral muscle of the right hind leg of a C3H Hen MTV mouse. Three dimensional EPR image of both hind legs of the animal was acquired on a 300 MHz FT-EPR spectrometer using triarylmethyl probe (Oxo63). EPR image of a matrix size of 100^3 covering field of view (FOV) of 42 mm along each dimension was obtained by single point imaging (SPI) method. The same animal was transferred to a Bruker 7T MR imager for MR image acquisition. MR images of 2 mm thick slices of 256 pixels covering FOV of 32 mm in each dimension were obtained for co-registration purpose. The same resonator was used without displacing the an imal in between measurements, except of optimizing the Q of the resonator appropriately.

Results: The aim of this study was to learn the resolution aspects pO_2 images from a developing technology such as EPRI in comparison with a well developed high resolution MR images. Initially, both EPR spin density and line width images were computed according to SPI method and pO_2 values were determined. From this 3D matrix data (of 100^3 voxels), 2 mm slices of 256×256 pixels of FOV=32 mm were computed for co-registration with MR image. The data transformation was done by interpolation of pixels and/or averaging of planes as necessary using MATLAB. Fiducials of about 1 mm diameter were used to aid co-registration of MR slices with computed EPRI slices. A slice of MR image having well defined features was selected to identify anatomical distinctions. Oxygen distribution was mapped by co-registration of the corresponding slice from EPRI for comparison of these two digitally matched images but with different intrinsic resolutions. The spatial and magnitude resolutions of pO_2 were determined considering applied gradient field magnitudes, spin density levels and estimated uncertainties of line width by least squares fit procedure. The effect of digital resolution on a typical EPR image is shown in Fig.1. Fig.2 depicts the different resolutions of MRI, EPRI and Oxygen images and a unique way of indicating the actual resolution of oxygen as an extra bandwidth (here 5 mm of Hg) on the gray scale, on the right hand side of Fig. 2d. The related aspects of intrinsic resolution, blurring, probe characteristics etc. will be discussed, especially in the light of co-registering anatomy and functionality from different modalities at very different resolutions.

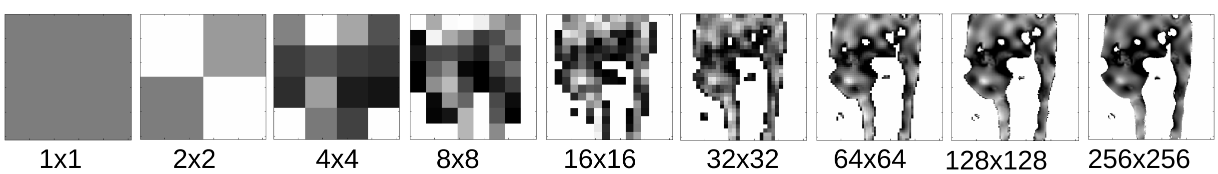

Fig.1 An image at different resolutions. The object size appears to be artificially larger at low resolution.

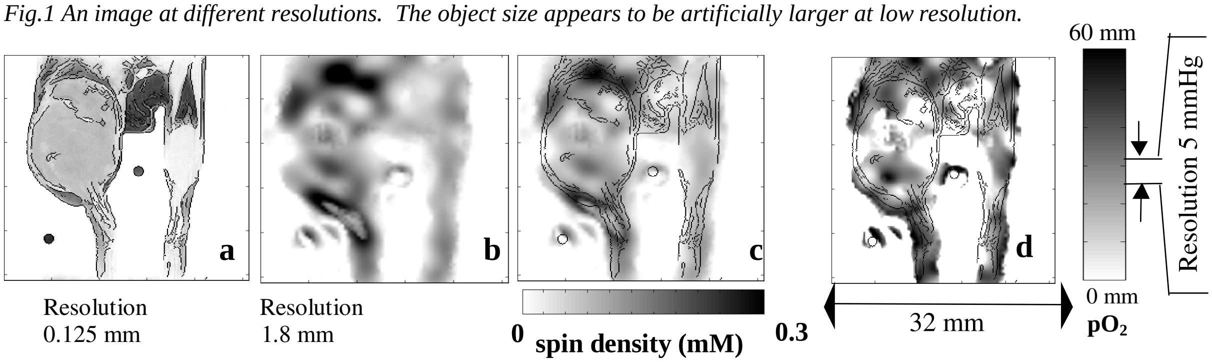

Fig. 2. (a) MRI at resolution 0.125 mm. Edges of objects identified from the intensity gradients are shown by solid lines. (b) EPRI at resolution 1.8 mm but digitally enhanced to a matrix size of 256×256 to match with MRI. (c) Combined EPR image and edges from MRI. High resolution MRI lends support to low resolution EPRI to delineate anatomic details. Data are from a slice of 3D image (d) pO_2 map overlaid on MRI with gray scale *plus* an extra uncertainty band indicated.