10.4 Project: Comparison of fat quantification using 2 point Dixon MRI and MRI Spectroscopy in the gluteus maximus

Introduction and Aim

Muscle atrophy is defined as a decrease in muscle mass secondary to lack of use or neurogenic dysfunction. In the pelvic muscles, fat accumulation is a common indicator of atrophy and can be exacerbated with ageing, childbirth and menopause. Fat fraction measurement in the external anal sphincter (EAS) muscle may provide a more accurate measure of atrophy than a visual assessment of T_2-weighted images and offer an improved criterion for surgical intervention. MR Spectroscopy (MRS) has previously been shown to be accurate for fat quantification in supraspinatus muscle [44]. However, the problem with MRS is the long scan time which makes it difficult for seriously ill patients to keep still. Also the size of the voxel is too large to be placed in small muscles e.g. anal sphincter in the pelvic floor, where the measurement can be contaminated by extra voxel fat. An alternative 3D volumetric interpolated breath-hold sequence (VIBE) is a recently developed fat supressed 3D FLASH sequence which permits dynamic and high resolution imaging under breath hold [45]. It implements an MRI Dixon technique to produce separate fat and water images which can be used for quantifying the percentage of fat [46]. The aim of this study was to validate the use of the MRI Dixon technique to quantify fat in the pelvic muscle by using the adjacent gluteus maximus muscle as a surrogate for the smaller EAS muscle. This provided a larger target for spectroscopy and allowed a comparison with a fat fraction measured with a 2-point Dixon technique. I presented the results of this project at the European Medical Physics and Engineering Conference 2011 (EMPEC) in Dublin and to the Head of MR physics at UCLH (abstract and presentation slides in appendix A1).

The 2 Point Dixon Technique

The VIBE sequence acquires in-phase images (where fat and water magnetizations are in phase) and out-of-phase images (where fat and water magnetizations are out of phase) from consecutive echoes [47, 48]. The signal from each voxel is the vector sum of the fat and water magnetisation within that voxel. In in-phase images, the signal from water and fat are additive whereas in out of phase images, the signal is the difference between the fat and water signal. The two point Dixon method incorporated into the VIBE sequence can be used to produce separate water and fat images (shown in figure 10.4) by addition and subtraction of the in phase and out of phase images respectively [49].

$$W = \frac{1}{2}(I_0 + I_1) \qquad (10.1)$$

$$F = \frac{1}{2}(I_0 - I_1) \qquad (10.2)$$

where W and F are the water and fat images respectively and I_0 and I_1 are the in phase and out of phase images respectively.

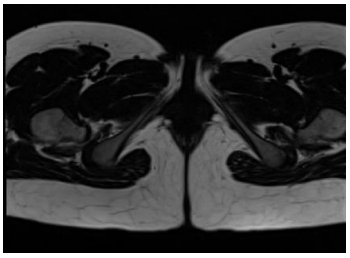
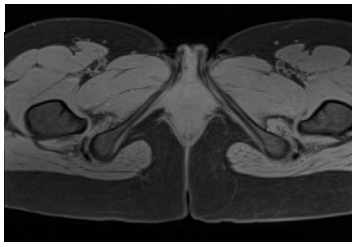
a)  b) 

Figure 10.4 a) Fat image and b) Water Image

Method

Ethical permission for carrying out this project was sought from the ethics committee at the National Hospital for Neurology and Neurosurgery at Queens Square. Written consent was obtained from all participants who were healthy and had not given birth. 10 healthy female volunteers (aged 23-35 years) were scanned on a Siemens 1.5 T system using the phased array coil. Transverse and coronal T_2-weighted FSE images were acquired in the pelvic region. Fat and water images were acquired using a VIBE 3D gradient echo sequence ($TE_{in\ phase}$ /$TE_{out\ of\ phase}$: 4.76/7.14 ms, TR: 11.1 ms, flip angle 10˚, 320 x 270 matrix, 1.143 pixels/mm, slice thickness 3.3 mm). Spectra were acquired using a PRESS sequence with a 10mm cubic voxel placed in the T_2-weighted image (TE_1/TE_2 = 30/50 ms, TR =5000ms). Spectroscopy and VIBE data were analysed offline in jMRUI and MATLAB respectively.

VIBE analysis

The spectroscopy voxel was localised as a 10 mm x10 mm ROI on the VIBE images in MATLAB. Since the ROI extended into three slices, a mean fat fraction was calculated for the three successive slices which contained the voxel. The fat fraction for each slice is computed using the following equation [49]:

$$Fat\ Fraction = \frac{Signal_{fat}}{Signal_{water} + Signal_{fat}} \qquad (10.3)$$

where $signal_{fat}$ is the total signal intensity in the voxel in the fat image and $signal_{water}$ is the total signal intensity in the voxel in the water image.

a) b)

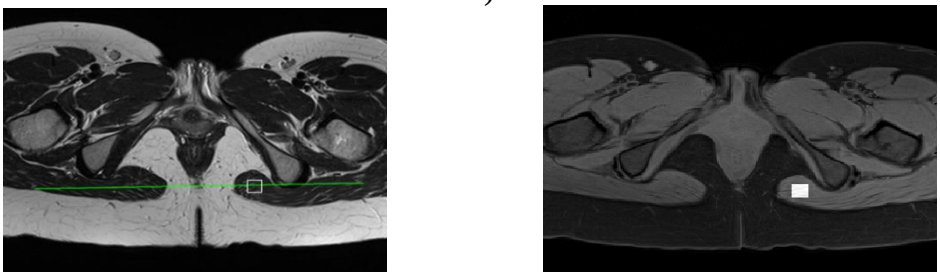


Figure 10.5 a) Voxel position planned on the T_2 image on the console. b) The voxel placed in the water image

Spectroscopy Analysis

The preprocessing was carried out as described in the Spectroscopy Postprocessing section in Chapter 9.2. The water peak was centred at the reference frequency (4.76 ppm) and the AMARES algorithm was used to extract fat and water components using prior knowledge of the location and shape of the components in the spectra (figure 10.6(a)) [48]. The water peaks were fitted with 7 Lorentzian functions whilst the fat was fitted with 2 Lorentzian functions. Soft constraints were applied to keep the frequency of the water components to within 4-6 ppm.

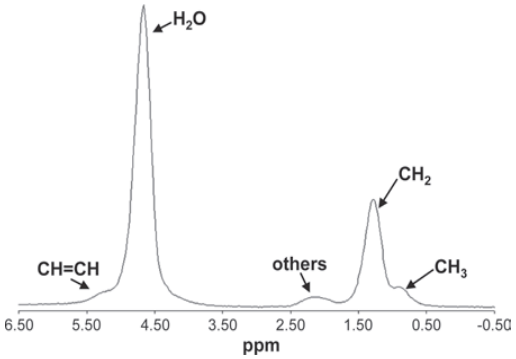


Figure 10.6 Diagram showing the water (4.7ppm) and fat (CH_2) peaks in fatty tissue. The fat fraction is calculated from the ratio of the amplitudes of fat peaks and the summed amplitudes of fat and water.

The peak amplitudes were summed to produce composite water and fat values at TE 30 ms and TE 50ms. Additional spectra were also acquired at TE 35, 40 and 45 ms to allow corrections for T_2 effects to be made [50]. T_1 effects were assumed negligible because of the long TR used [49]. The fat fraction was calculated from the total amplitudes of water and fat using the following formula [48]:

$$Fat\ fraction = \frac{A_{fat}}{A_{fat} + A_{water}} \qquad (10.4)$$

where A_{fat} is the total amplitude of all the fat peaks and A_{water} is the amplitude of all the water component.

Results

The mean fat fractions calculated for the 10 subjects using spectroscopy and 2D Dixon were 14.2% and 14.4% respectively. Linear regression analysis showed good correlation between the two methods (R^2 =0.86). A paired t test showed no significant difference between fat% for MRS and VIBE-Dixon (p=0.81).

The Bland-Altman plot is often used to compare two measurements techniques in medicine where the differences between the two techniques are plotted against the averages of the two techniques [51]. Horizontal lines are drawn at the mean difference, and at the limits of agreement (defined as the mean difference ± 1.96 times the standard deviation of the differences). In this case, all data points lie within these limits of agreement that suggests good agreement between the two methods.

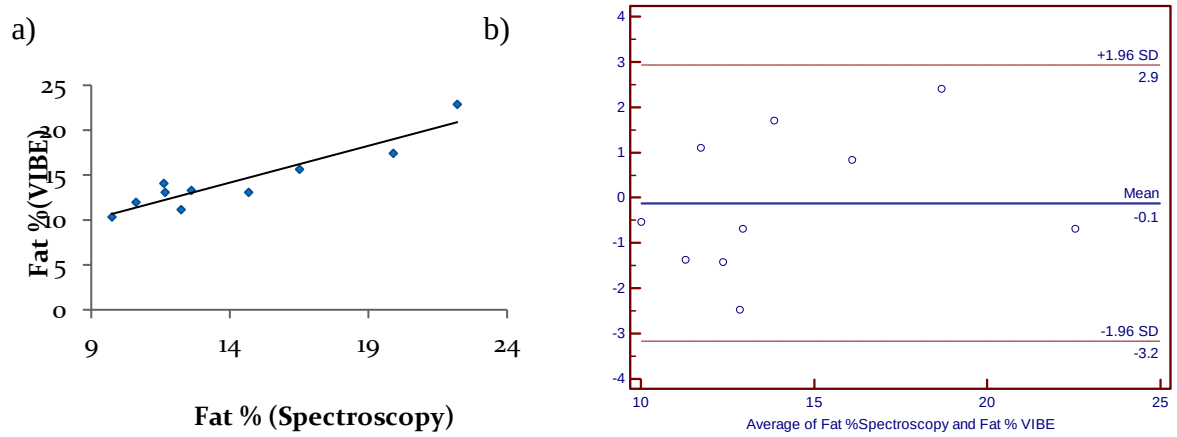


Figure 10.7 a) Plot of fat% calculated using VIBE-Dixon vs. fat% calculated using spectroscopy
b) The Bland Altman plot showing good agreement between fat percentages calculated using VIBE and spectroscopy

Conclusions

The results show that the Dixon technique may be a possible alternative and a promising objective measure of fatty atrophy of the anal sphincter muscles. It is useful for fat quantification in smaller muscles where spectroscopy is difficult to carry out. In addition, it also allows assessment of the spatial distribution of fat content and has a shorter scan time compared to MRS. The PRESS sequence is sensitive to J Coupling. This phenomenon (also known as spin-spin coupling) occurs due to the interaction between the atomic nuclei of neighbouring chemical groups which leads to an acceleration of signal decay and a reduction of the apparent T_2 of fat. This can lead to errors when applying simple T_2 correction techniques if T_2 decay is not mono-exponential. Hence additional spectra were acquired at three additional echo times (35, 40, 45 ms) and examining the multi echo data, which indicated that the T_2 decay curve can be described by a monoexponential decay function [50]. The two point Dixon technique ignores the effects of B_0 inhomogeneity which means that there will be an additional phase accumulation between water and fat [2, 47]. Hence, the added and subtracted images will not be purely water and fat images i.e. they will

contain a mixture of water and fat. This can cause errors in evaluation of fat in regions where T_2^* decay is significant e.g. liver with a high iron content [49, 52]. A more advanced three Point Dixon method can correct for this problem by using three measurements with phase shifts $0, \pi$ and $-\pi$ between the water and fat resonances [53]. The additional information provided by the third measurement is used to calculate an image of the field inhomogeneity and produce pure fat and water images.