# Three and four point Dixon comparison at 3T: *in vitro* and *in vivo*

**J. Noble[1,2], S. Keevil[1,3], J. Totman[4], and G. Charles-Edwards[1,3]**
[1]King's College London, London, United Kingdom, [2]King's College Hospital, London, United Kingdom, [3]Guy's and St Thomas' Hospital, London, [4]Imaging Sciences, King's College London

**Introduction:** The aim of this work was to assess Dixon-based MRI techniques for fat quantification in the calf muscle at 3T. It has been reported in the literature that a strong correlation (r=0.96) exists between 3-point Dixon (3PD) and known concentrations of fat and water in a phantom study at 1.5T [1] and strong correlation ($r^2$=0.985) between 3PD and MRS in a phantom study at 3.0T [2]. In this study, 3PD and 4-point Dixon (4PD) MRI methods were compared at 3T in phantoms with known compositions of fat and water and compared to fat-water ratios from localised MRS in the calf muscle from eight healthy volunteers.

**Methods:** All MR data were acquired on a Philips 3.0T Achieva system, using an 8-channel knee coil.

***In vitro:*** Eight 50 ml test phantoms were produced consisting of 0, 10, 20, 30, 40, 50, 60 and 100% sunflower oil-water percentage, based on the method by Bernard *et al* [2]; 15 mmol of an anionic surfactant sodium dodecyl sulphate was added to 0.5 litres of deionised water and 2.5 g of gelatin dissolved in the solution using a magnetic stirrer hotplate and heated to 50°C. The solution was poured into eight 50 ml plastic tubes along with the corresponding amount of sunflower oil, homogenised and placed on a roller overnight to set. All eight phantoms were placed within the knee coil to enable images of each phantom to be made within a single axial image acquisition. 3PD and 4PD sequences with TE = 2.3 ms, 35° flip angle, 1.4x1.4 mm in-plane resolution, 5 mm slice thickness, was acquired with different ΔTEs, as shown in Table 1. A ΔTE of 1.22 ms gives rise to a 180° phase difference between water and the predominant fat peak in muscle. For 3PD, Pineda *et al* [3] reported that the theoretical maximum effective number of signals averaged (NSA) for magnitude and phase estimation was achieved with phase differences of 180° and 120° respectively. Glover [4] also earlier reported that the maximum NSA is achieved with a 120° phase difference between fat and water producing a uniform spacing of the phase encoding around the full 360° [4]. 120° phase difference is achieved with ΔTE=0.82 ms. If this reasoning is extended to 4PD, the maximum NSA would occur for a phase difference of 90°, i.e. with a ΔTE of 0.61 ms [4]. Both the optimal phase differences for magnitude and phase estimation were investigated, together with a ΔTE of 1 ms as an intermediate value. The known fat content of the phantoms was corrected to take into account the position of the various lipid peaks in the sunflower oil spectrum, adding the magnitude of the lipid peaks around 4.7 ppm to the water signal, since Dixon techniques assume a single chemical shift difference between the fat and water.

| | 3 point Dixon | | | 4 Point Dixon | | |
|---|---|---|---|---|---|---|
| TR (ms) | 6.2 | 6.2 | 6.5 | 6.2 | 7.1 | 7.7 |
| ΔTE (ms) | 0.82 | 1.0 | 1.22 | 0.61 | 1.0 | 1.22 |

Table 1: 3 and 4PD *in vitro* sequence parameters

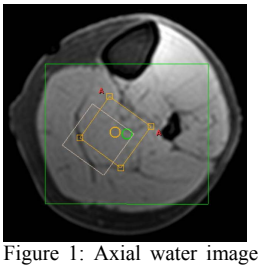

Figure 1: Axial water image of calf muscles acquired using 3PD showing the different MRS voxel positions for fat (orange) and water (white), arising from their chemical shift. The green box is the shim box.

***In vivo:*** Dixon images were acquired with the same imaging parameters as *in vitro* but with an in-plane voxel size of 2x2 mm and a single ΔTE of 1.0 ms. Acquisition time for the 3 and 4 point techniques were 1:03 and 1:37 respectively. Localised MRS data were acquired using a PRESS sequence with a TE/TR of 35/2000 ms, voxel size 40x40x5 mm, 16 step phase cycles and 16 signal averages. MRS data were processed using the AMARES algorithm [5] in jMRUI [6]. Fitted fat and water peaks were corrected for T2 effects using T2 values for water (31.3 ms), extramyocellular fat (77.6 ms) and intramyocellular fat (89.4 ms) from the literature [7]. Different regions of interest (ROI) were drawn on the fat and water Dixon images, to match the corresponding MRS voxel locations for fat and water, as shown in Figure 1. From these ROIs, the mean signal intensities from the fat and water images were measured to create a Dixon-based fat-water ratio. These were compared to MRS-based fat-water ratios, and Bland-Altman agreement plots [8] were calculated.

**Results:** Figure 2 shows a combined graph of the percentage fat determined by each of the Dixon methods investigated against the MRS-measured or known percentage fat values. All of the techniques produce similar results *in vitro*, with the 3PD with ΔTE 0.82 agreeing least with the expected result shown by the black line in Figure 2. The 4PD with ΔTE=0.61 ms had the lowest $r^2$ value of 0.942, whereas the highest $r^2$ value of 0.981 was from the 4PD technique with ΔTE=1.22 ms. Figures 3 and 4 show plots of percentage fat determined by 3 and 4PD against MRS respectively *in vivo*. It can be seen that 4PD has a stronger correlation ($r^2$=0.905) with MRS than 3PD ($r^2$=0.74). Furthermore, due to the steeper slope of Figure 4, differentiation between neighbouring fat percentages is increased for 4 point Dixon compared to 3 point Dixon. Bland-Altman plots in Figure 5 highlight the small difference between the fat content determined 4PD and 3PD compared to MRS.

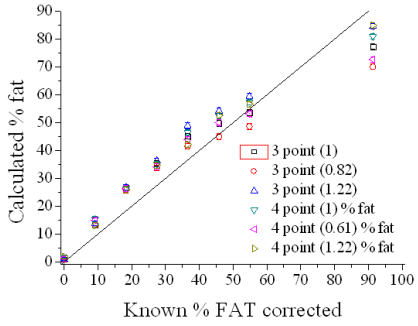


Figure 2: Calculated vs. known % fat determined by each Dixon technique investigated. TE in ( ).

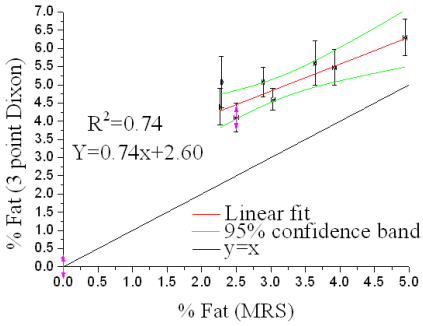


Figure 3: *In vivo* results of % fat determined by 3PD and MRS

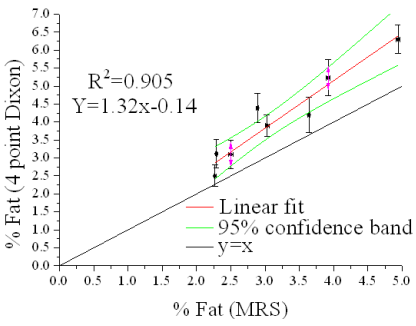


Figure 4: *In vivo* results of % fat determined by 4PD and MRS

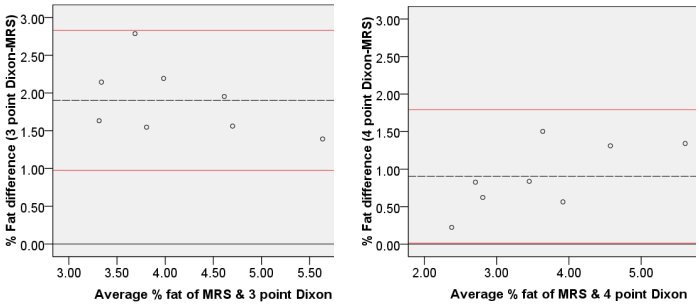


Figure 5: Bland-Altman plots of 3 and 4PD Vs. MRS. 95% confidence band = 2x standard deviation (red line), mean (black dashed line)

**Discussion:** *In vitro* both 3 and 4PD techniques correlated well with the fat content of the phantoms, with the highest correlation for the 4PD technique with ΔTE=1.22 ms. Figure 2 further suggests that the 4PD based techniques with ΔTE=1 and 1.22 ms are the best techniques compared to the ideal line of y=x shown in the figure. *In vivo*, results from the 4PD produced a higher correlation with spectroscopy. 4PD also had a stronger agreement with MRS according to Bland-Altman plots in Figure 5. The 4PD technique with a 1 or 1.22 ms ΔTE appears to be the more reliable technique for *in vivo* intra muscular fat quantification.

**References:** [1] Kovanlikaya et al Acad. radiol. 2005 12:636-639 [2] Bernard et al JMR 2008 27:192-197. [3] Pineda et al MRM 2005 54:625-635 [4] Glover JMRI 1991 1:521-530. [5] Vanhamme et al JMR 1997 129: 35-43 [6] Naressi et al MAGMA, 2001 12(2-3):141-52 [7] Krssak et al MAGMA, 2004 16:155-159 [8] Bland & Altman Lancet 1986 1(8476)307-10.