MRI estimation of donor liver graft steatosis prior to orthotopic liver transplantation: Feasibility and evaluation of possible RF heating effects

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Introduction

Many factors influence orthotopic liver transplantation outcome including donor liver steatosis, known to correlate with an overall worse outcome and increased risk of early graft failure (primary non-function) [1]. There is typically insufficient time to quantify hepatic steatosis histologically or biochemically by donor graft biopsy before transplantation and most centres rely on subjective visual assessment by the surgical teams [1]. Several groups [2] have demonstrated that a rapid, non-invasive quantitative estimate of intracellular hepatic fat can be made in less than 2 minutes using MRI which samples much larger volumes than biopsy. Such a method, if safe and practical, would be ideally suited to the rapid assessment of donor liver steatosis. Potential risks to the graft include mechanical handling damage, loss of sterility, and any heating effects resulting from radio frequency (RF) power deposition. This work assesses the feasibility of MRI estimation of donor liver graft steatosis immediately prior to orthotopic transplantation and evaluates the risk of any heating related adverse effects.

Methods

A 2 kg fresh whole porcine liver was used to simulate an ex-vivo human liver graft. A fibre optic temperature recording device with a sensitivity of 0.1°C (Luxtron 710, Santa Clara, CA) was employed and four fibre optic probes inserted into the porcine liver to different depths within the tissue – the acquisition electronics were positioned outside the scanner room. Measurements from the 4 probes were recorded at 1 Hz before, during and after the MR acquisitions. Temperature changes were evaluated for each probe by comparing the mean of 20 readings prior to acquisition with the mean of 20 readings immediately after the end of the sequence.

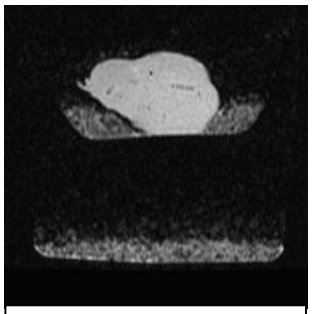

Figure 1: Image of the porcine liver in sterile wrappings and bowl within the thermally insulated box packed in ice (only the melted water is MRI visible).

Three acquisitions were acquired sequentially using a protocol designed for liver fat assessment with only minimal delay between each to allow for the acquisition of temperature data as above. The liver was then left for a period of 15 minutes to restore thermal equilibrium. Subsequently an RF intensive magnetisation transfer sequence and then a multiphase SSFSE sequence were acquired in addition to provide a comparison with the standard liver protocol sequences. These acquisitions were repeated in two settings, firstly the porcine liver was double wrapped in sterile plastic bags, placed in a non-metallic bowl and surrounded by crushed melting ice within a thermal insulated plastic camping ice box identical to those used in our institution for transport of the donor graft. Secondly, the graft was studied wrapped in sterile plastic bags but studied at room temperature and outside the insulated box. In each case the liver was allowed to reach thermal equilibrium prior to the MR examinations. Using an estimated specific heat capacity of 3.6 kJ $kg^{-1}K^{-1}$ for liver tissue [3], assuming no heat loss, equal and homogeneous deposition of RF power in the liver and ice the worst-case expected temperature increase was estimated for each acquisition based on the highest peak SAR (as calculated by the MR system) of the components of the fat measurement protocol (table 2).

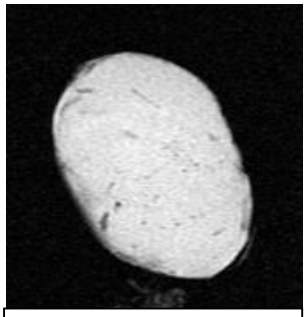

Figure 2 : Coronal 70° In phase image of the porcine liver at room temperature without protective box.

MR protocol: Examinations were performed on a 1.5T whole body MRI (Excite, GEHT, Milwaukee) using the body R.F. coil. In and out of phase gradient echo scans were acquired in the coronal plane using 20 second acquisitions (matrix 256 x 128, 8 sections, section thickness 10mm, gap 1.5mm, TR/TE/NEX = 180/2.2 (out of phase), 4.4 (in phase)/1, flip angles 20° and 70°). A T2* map of the liver for correcting the I/O phase images[4] was obtained using a location-matched, multi-slice, multi-echo gradient sequence (TR = 120 ms, 16 equally spaced echoes, TE1 = 2.2 ms, TE2 = 4.4 ms). The r.f. exposure for this protocol occurs over 100 seconds of scan time.

Table 1: Estimated SAR of sequences

Acquisition Sequence	*Estimated SAR (W/kg)*	*Peak SAR (W/kg)*
MFGRE	0.01	0.02
20° in/out of phase	0.07	0.14
70° in/out of phase	0.23	0.46
rtSSFSE (10 mins)	1.53	3.05
MT (20 MT pulses–10 mins)	1.75	3.51

Results

The porcine liver fat fraction estimation was obtained from the data with a small standard deviation: 7.9% ± 0.5%. The SAR based estimated maximum temperature increase for the liver protocol acquisition was 0.02°C and experimentally no significant increase in temperature was observed at any probe location at either ambient temperature. Using the SSFSE sequence the estimated rise was 0.5°C and only the probe nearest the liver surface recorded a rise in temperature of 0.3°C. The estimate increase for the RF intense MT sequence was 0.6°C and a rise was recorded on at all four probe locations with a maximum of 0.4°C.

Conclusions

This work demonstrates that it is possible to quantify donor liver graft steatosis in a couple of minutes using an MRI examination that can be performed with a donor liver graft undisturbed in its sterile wrappings and transport container. Whilst the assumption of homogeneous RF deposition is unlikely to hold in all cases no potentially harmful heating effects were expected or observed using this simple gradient echo acquisition protocol. Based on these findings Ethical Committee approval has subsequently been obtained to use this protocol for a study of liver fat estimation in human donor liver grafts prior to their transplantation.

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References

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Table 2: Predicted and observed temperature rises (in °C) recorded by the 4 probes

Sequence	*Setting*	*Calculated (°C) temp. rise*	*Probe 1*	*Probe 2*	*Probe 3*	*Probe 4*
1 (mfgre+20+70)	Ice box	0.02	0.0	-0.1	-0.1	0.0
2 (rtssfse-10mins)	Ice box	0.5	-0.1	0.0	0.0	0.0
1 (mfgre+20+70)	Room temp.	0.02	0.1	-0.1	-0.1	0.0
2 (rtssfse-10mins)	Room temp.	0.5	0.3	0.0	0.0	0.0
3 (mt sequence)	Room temp.	0.6	0.4	0.2	0.3	0.4

Figure 3: Plots of temperature changes recorded in the 4 probes over time for: (*left*) sequence 1, the fat quantification sequence with the porcine liver in the icebox. (*right*) sequence 3, the magnetisation transfer sequence with the liver at room temperature unprotected by ice. In both cases the distance between the gridlines is 1°C.