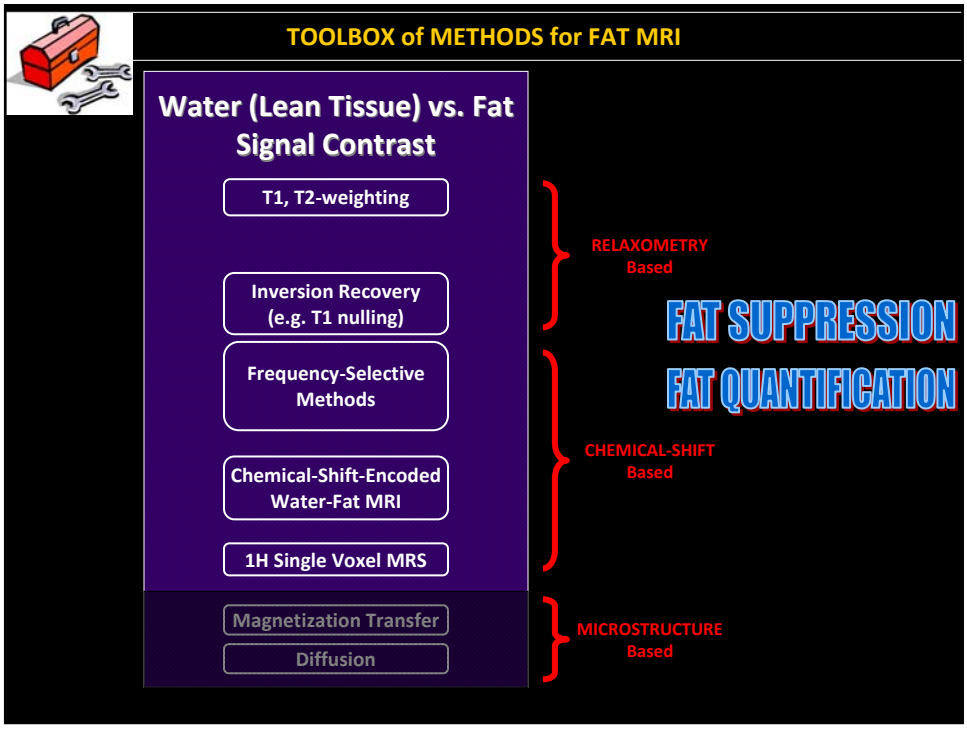
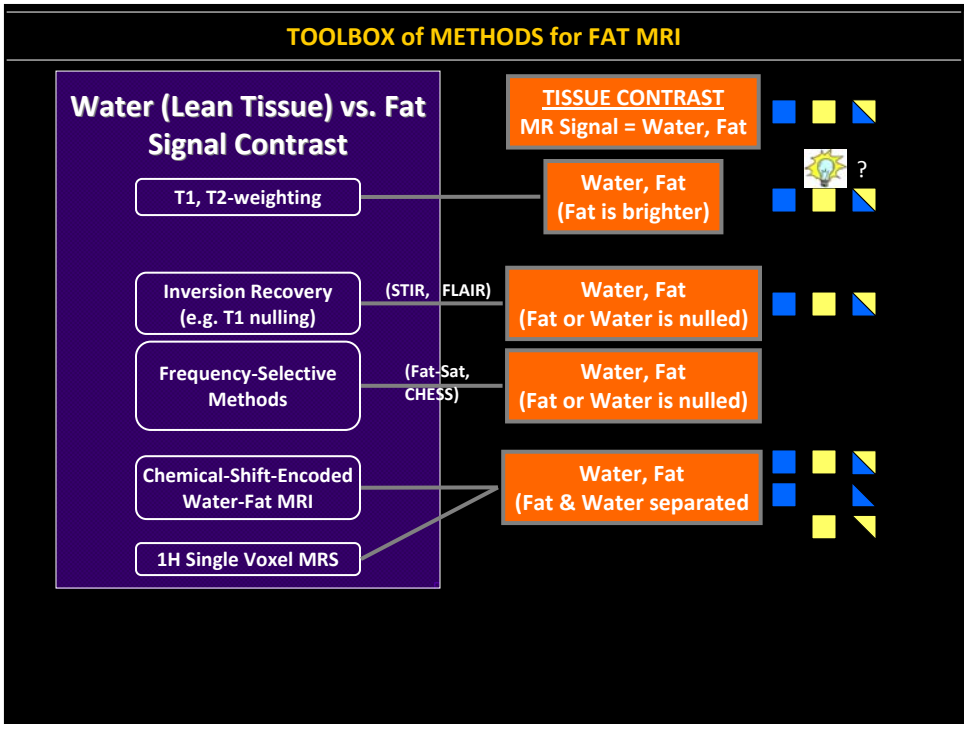
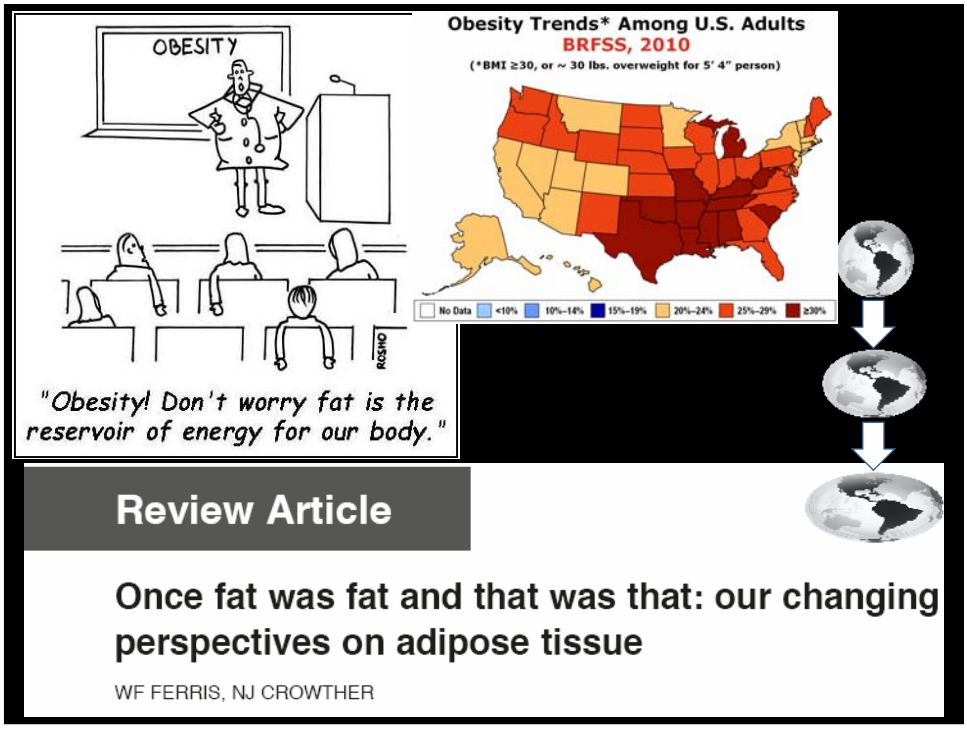
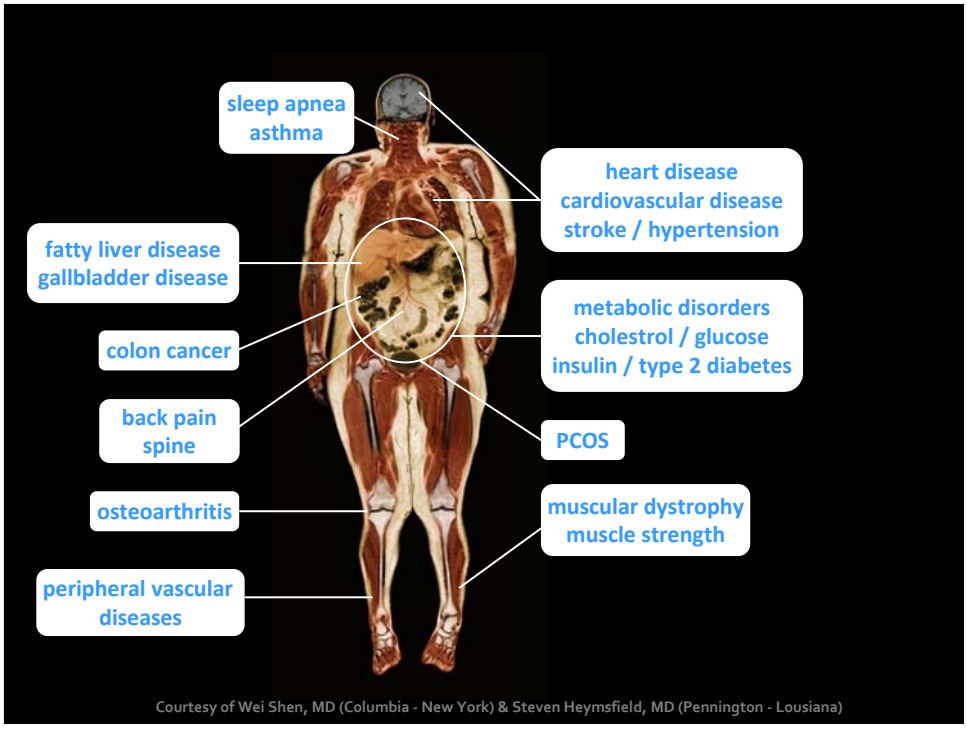

TOOLBOX of METHODS for FAT MRI
Water (Lean Tissue) vs. Fat Signal Contrast
T1, T2-weighting
Inversion Recovery (e.g. T1 nulling)
Frequency-Selective Methods
Chemical-Shift-Encoded Water-Fat MRI
1H Single Voxel MRS
Magnetization Transfer
Diffusion
RELAXOMETRY Based
CHEMICAL-SHIFT Based
MICROSTRUCTURE Based
FAT SUPPRESSION
FAT QUANTIFICATION


TOOLBOX of METHODS for FAT MRI
Water (Lean Tissue) vs. Fat Signal Contrast
T1, T2-weighting
Inversion Recovery (e.g. T1 nulling)
(STIR, FLAIR)
Frequency-Selective Methods
(Fat-Sat, CHESS)
Chemical-Shift-Encoded Water-Fat MRI
1H Single Voxel MRS
TISSUE CONTRAST
MR Signal = Water, Fat
Water, Fat (Fat is brighter)
?
Water, Fat (Fat or Water is nulled)
Water, Fat (Fat or Water is nulled)
Water, Fat (Fat & Water separated)

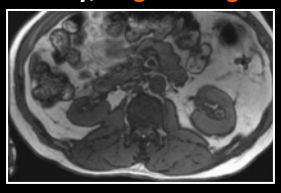

OBESITY
"Obesity! Don't worry fat is the reservoir of energy for our body."
Obesity Trends* Among U.S. Adults
BRFSS, 2010
(*BMI ≥30, or ~ 30 lbs. overweight for 5' 4" person)
No Data
<10%
10%–14%
15%–19%
20%–24%
25%–29%
≥30%
Review Article
Once fat was fat and that was that: our changing perspectives on adipose tissue
WF FERRIS, NJ CROWTHER

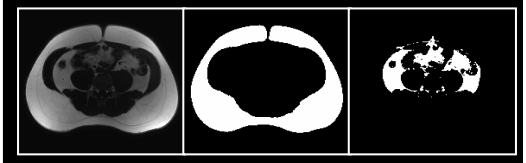

sleep apnea
asthma
heart disease
cardiovascular disease
stroke / hypertension
fatty liver disease
gallbladder disease
metabolic disorders
cholestrol / glucose
insulin / type 2 diabetes
colon cancer
back pain
spine
PCOS
osteoarthritis
muscular dystrophy
muscle strength
peripheral vascular
diseases
Courtesy of Wei Shen, MD (Columbia - New York) & Steven Heymsfield, MD (Pennington - Lousiana)

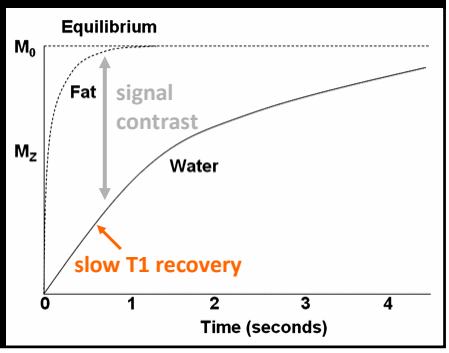
MRI of Fat by T1-WEIGHTING

	T1 Relaxation Time (msec)*
Kidney	
Cortex	1,142 ± 154
Medulla	1,545 ± 142
Liver	809 ± 71
Spleen	1,328 ± 31
Pancreas	725 ± 71
Paravertebral muscle	898 ± 33
Bone marrow (L4 vertebra)	586 ± 73
Subcutaneous fat	382 ± 13
Uterus	
Myometrium	1,514 ± 156
Endometrium	1,453 ± 123
Cervix	1,616 ± 61
Prostate	1,597 ± 42

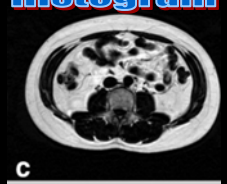
Fat has shortest T1, fast recovery, brightest signal.

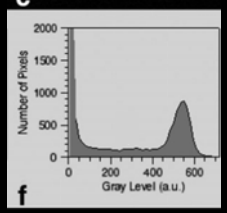






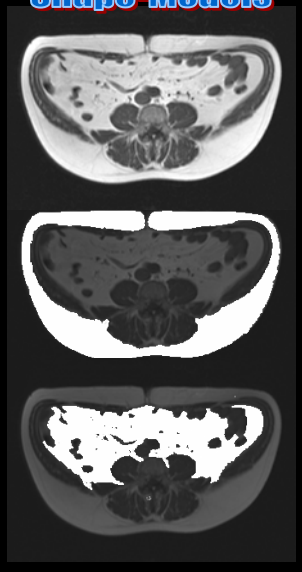
Histogram



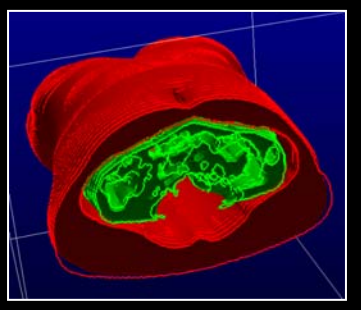


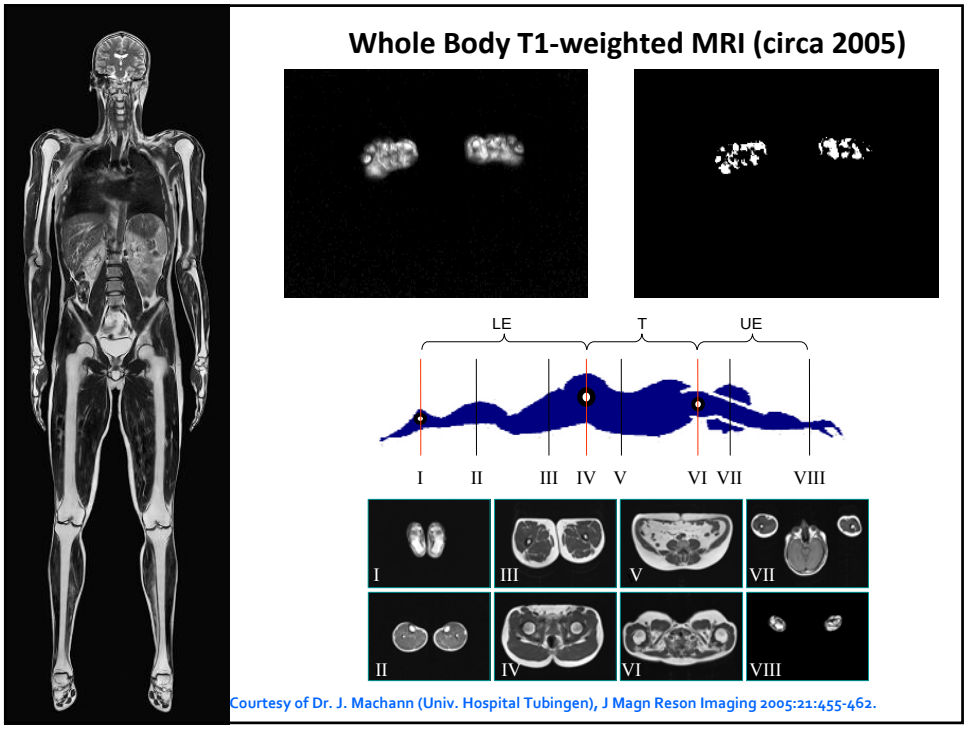
Peng Q, et al. *JMRI* 2005

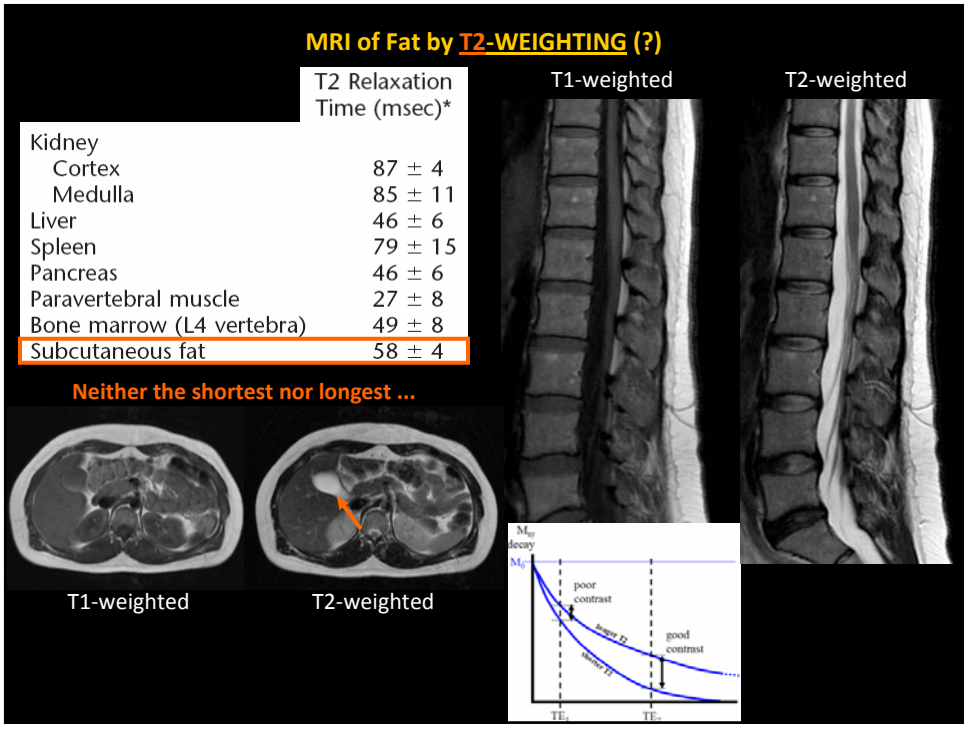
Shape-Models



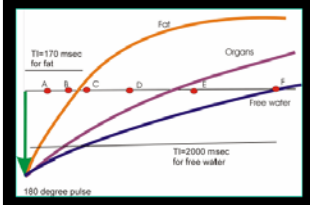
Würslin C, et al. *JMRI* 2010
Jürgen Machann, PhD
(Tübingen, Germany)

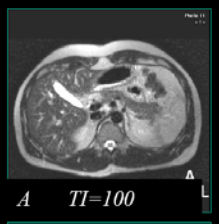


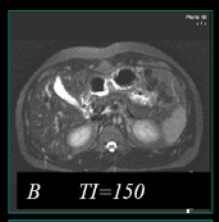

Whole Body T1-weighted MRI (circa 2005)
LE
T
UE
I
II
III
IV
V
VI
VII
VIII
Courtesy of Dr. J. Machann (Univ. Hospital Tubingen), J Magn Reson Imaging 2005:21:455-462.

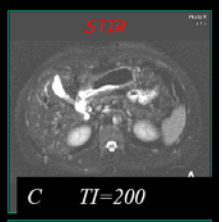

MRI of Fat by T2-WEIGHTING (?)
T2 Relaxation Time (msec)*
Kidney
Cortex 87 ± 4
Medulla 85 ± 11
Liver 46 ± 6
Spleen 79 ± 15
Pancreas 46 ± 6
Paravertebral muscle 27 ± 8
Bone marrow (L4 vertebra) 49 ± 8
Subcutaneous fat 58 ± 4
Neither the shortest nor longest ...
T1-weighted
T2-weighted
T1-weighted
T2-weighted
poor contrast
good contrast

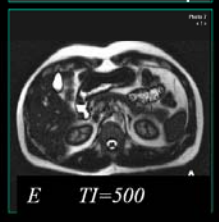
Fat suppression methods – Inversion recovery

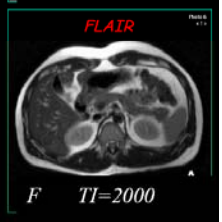












Relaxation time dependent
Not lipid-specific

TI = ln2 x T1 tissue
STIR → @1.5T 130-170 msec

Not affected by field inhomogeneities
Both T1 and T2 contribute to the signal

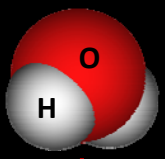
Overall lower SNR

Not suitable after contrast → contrast-enhanced tissues will be suppressed

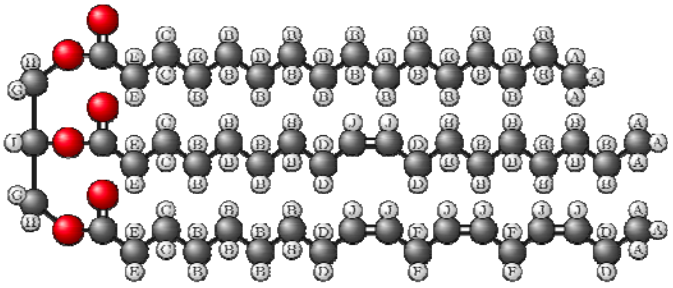
Delfaut et al
Fat Suppression in MR Imaging: Techniques and Pitfalls. RadioGraphics. 1999; 19:373-382

Slide courtesy of Shahid Hussain, MD PhD (Nebraska)

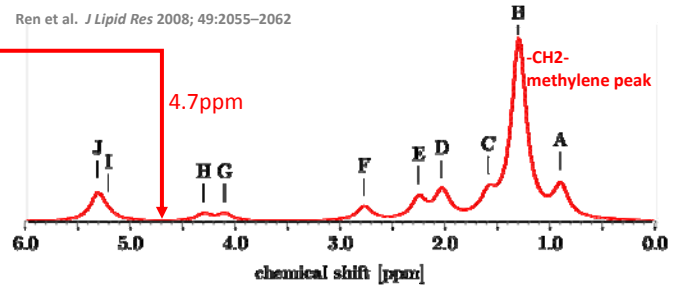
WATER versus FAT (Chemical-Shift)



symmetrical



Ren et al. *J Lipid Res* 2008; 49:2055–2062



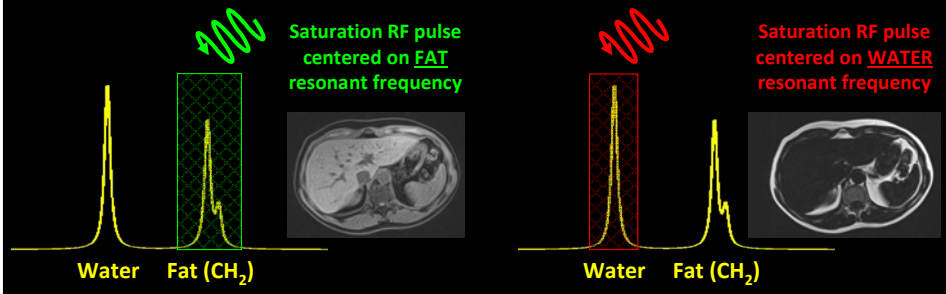
B only:
single-peak model

A thru J:
multi-peak model

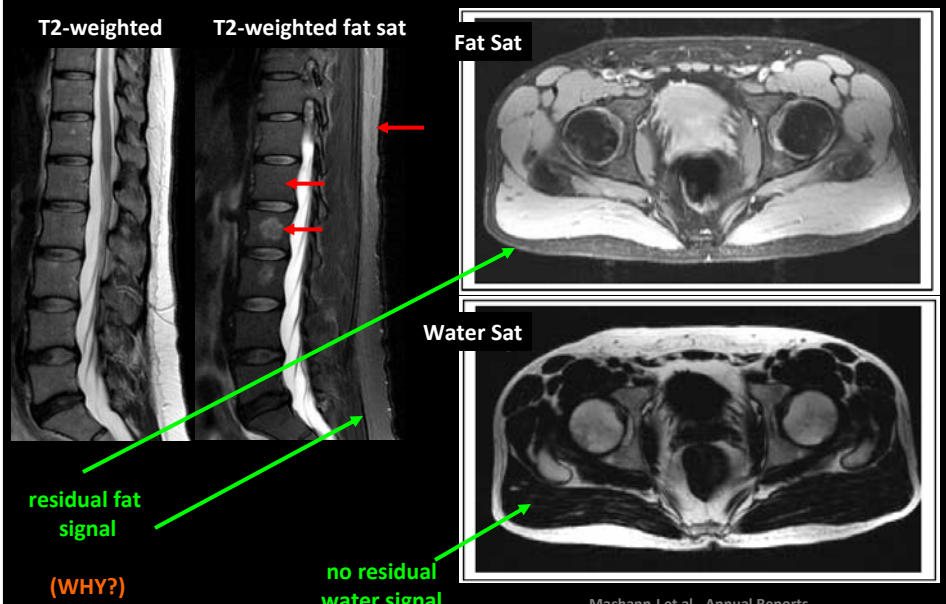
Courtesy of Johan Berglund, PhD (Uppsala University, Sweden)

Selective Water-Fat Excitation / Suppression

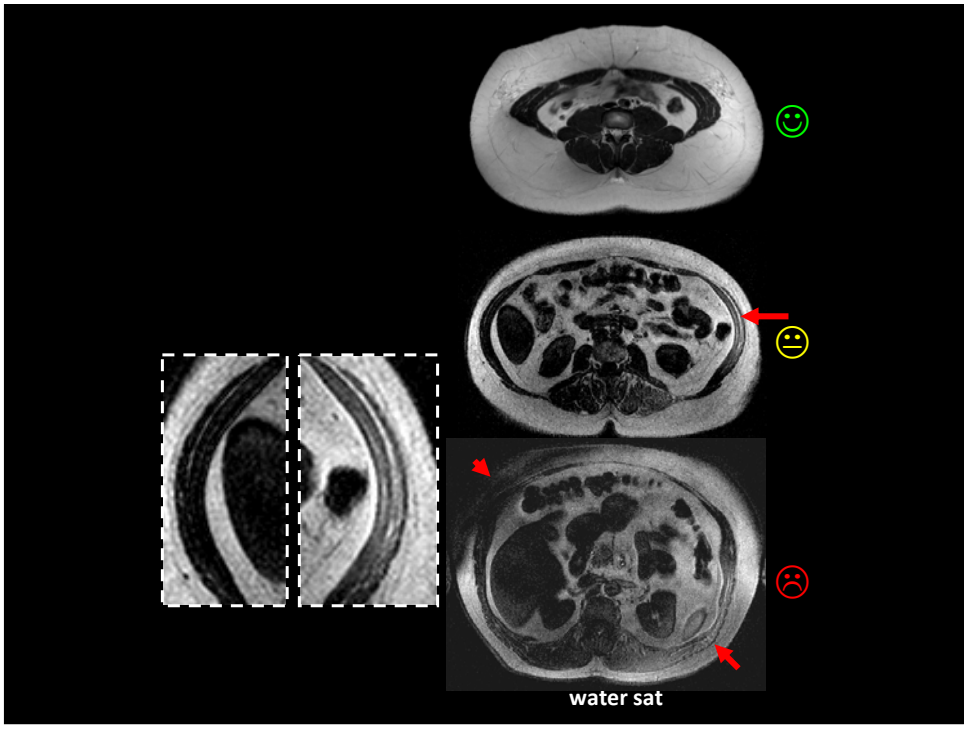
- Develop pulse sequences to …
  … SUPPRESS fat / excite water → mainly water signal remain
  … SUPPRESS water / excite fat → mainly fat signal remain

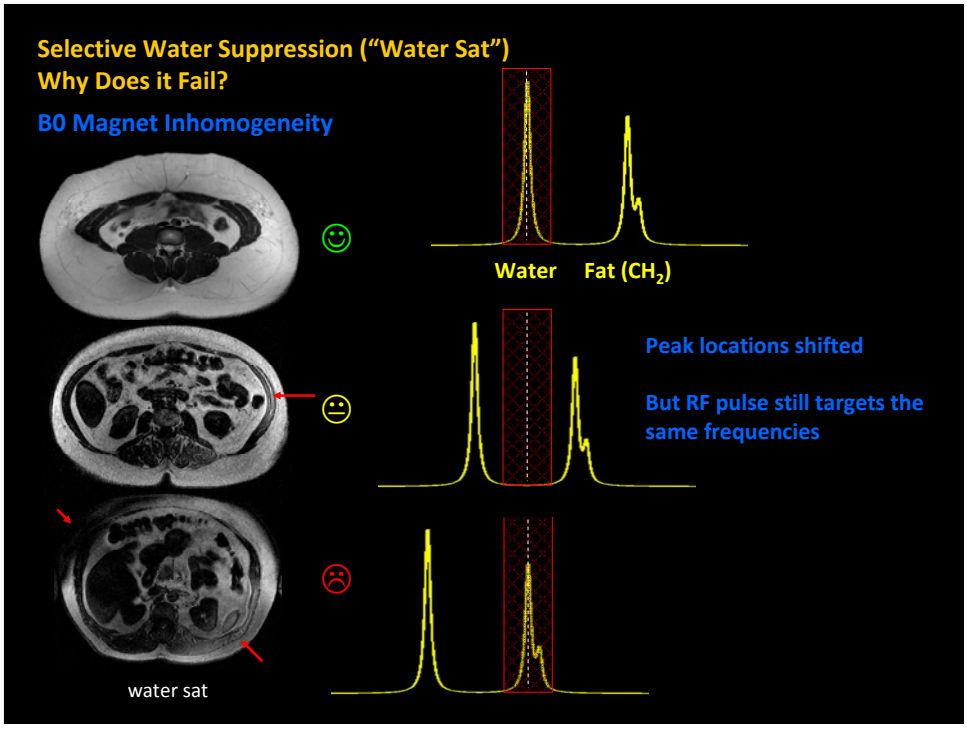


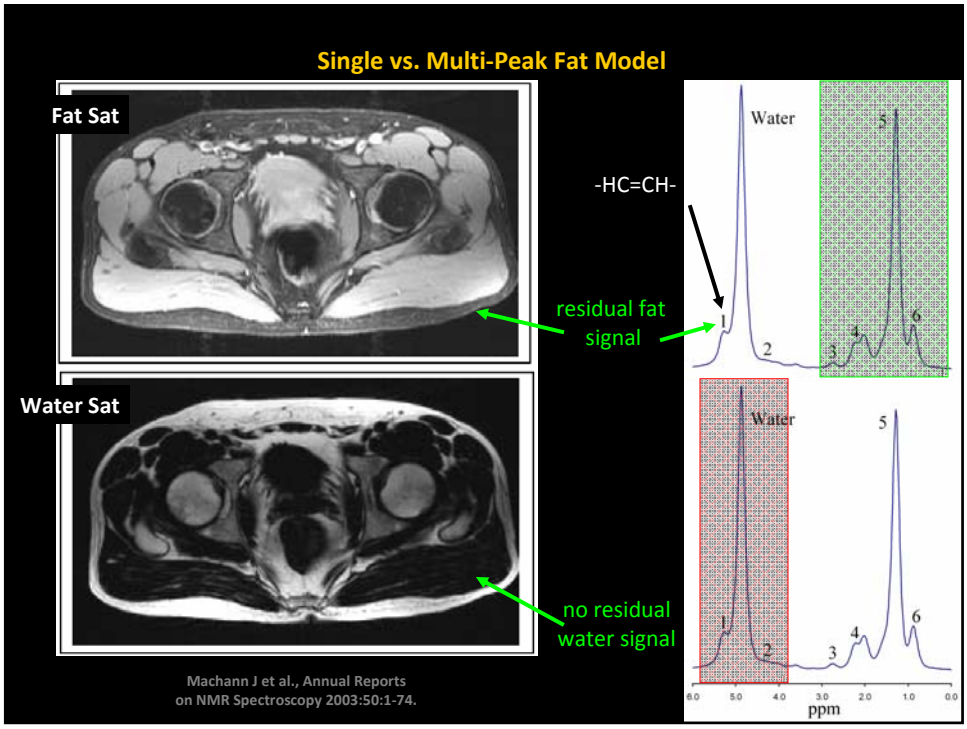
Selective Water-Fat Excitation / Suppression

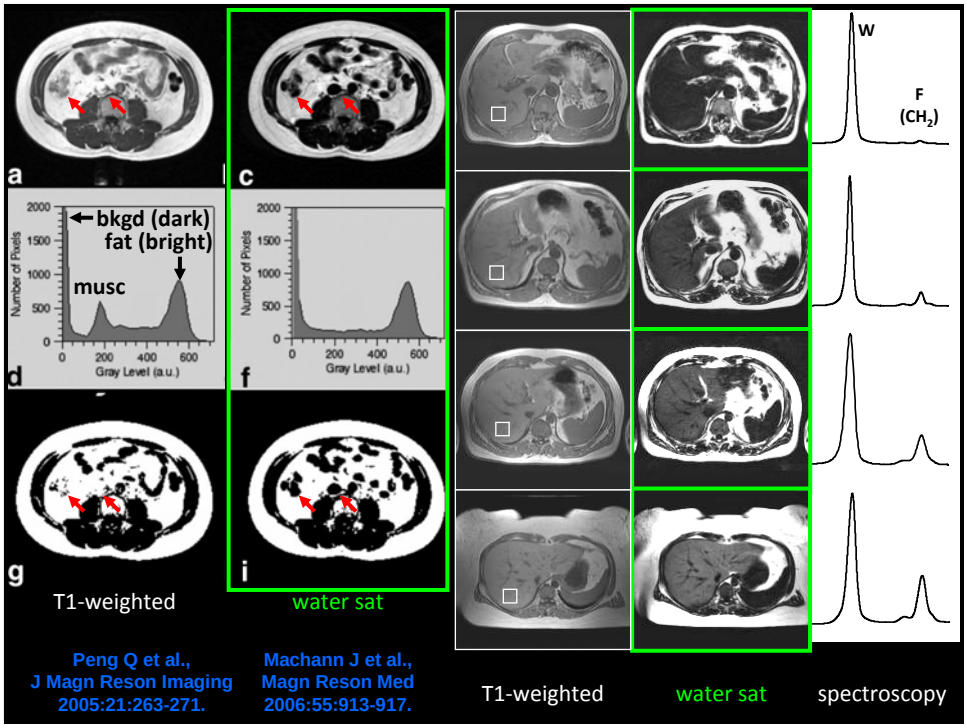


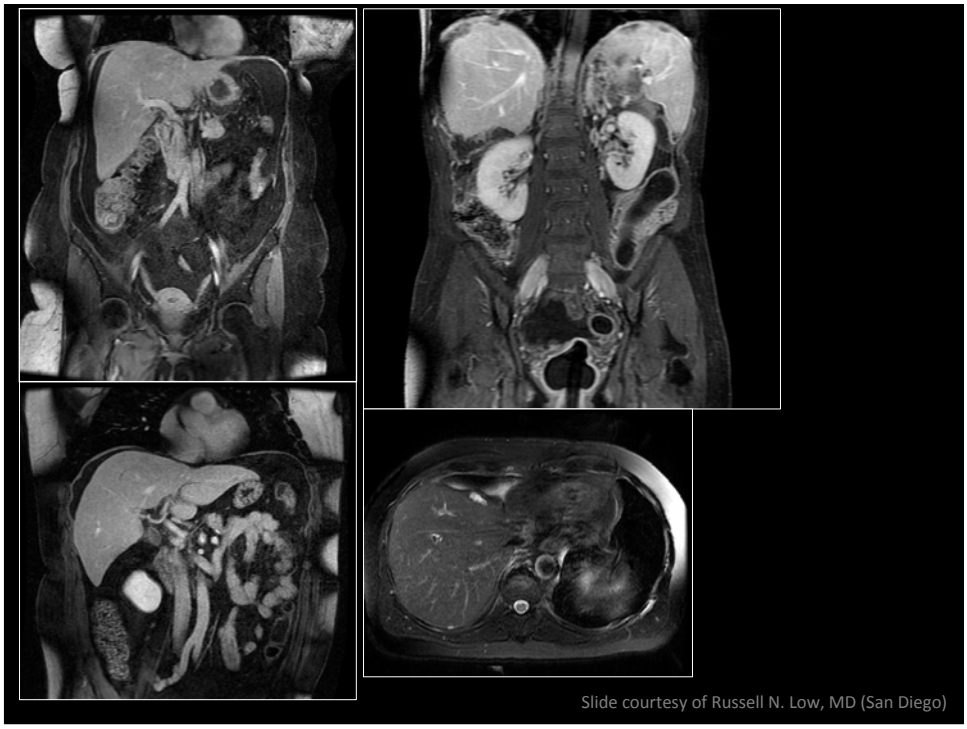
Machann J et al., Annual Reports on NMR Spectroscopy 2003:50:1-74.

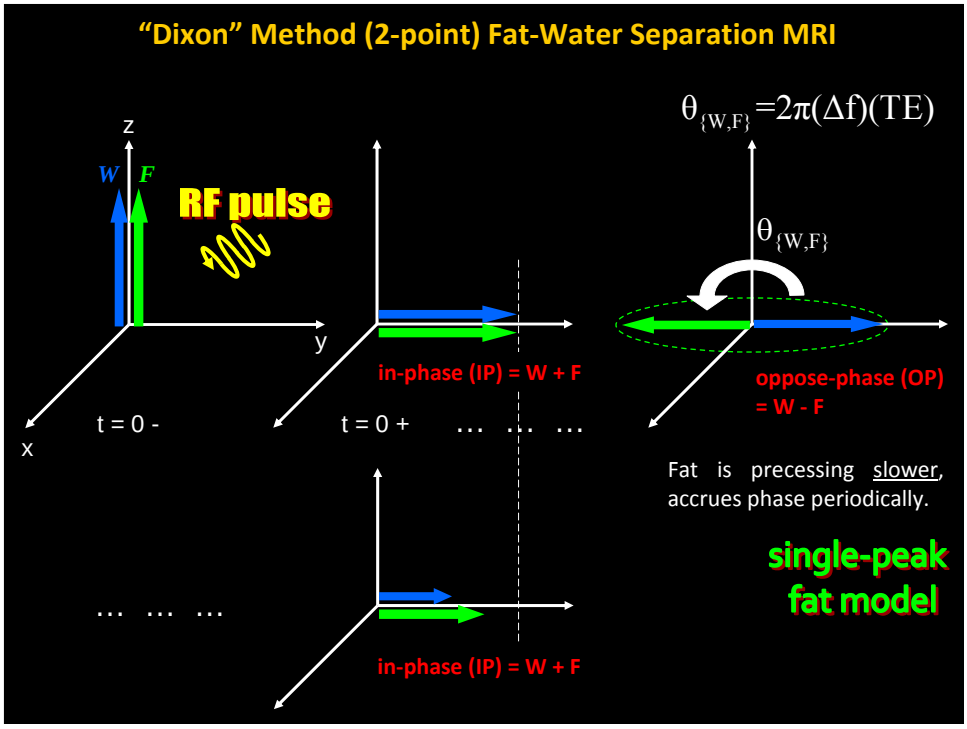

water sat


Selective Water Suppression ("Water Sat")
Why Does it Fail?
B0 Magnet Inhomogeneity
Water
Fat (CH_2)
Peak locations shifted
But RF pulse still targets the same frequencies
water sat


Single vs. Multi-Peak Fat Model
Fat Sat
Water Sat
-HC=CH-
residual fat signal
no residual water signal
Water
ppm
Machann J et al., Annual Reports on NMR Spectroscopy 2003:50:1-74.


bkgd (dark)
fat (bright)
musc
Number of Pixels
Gray Level (a.u.)
W
F (CH2)
T1-weighted
water sat
Peng Q et al., J Magn Reson Imaging 2005:21:263-271.
Machann J et al., Magn Reson Med 2006:55:913-917.
T1-weighted
water sat
spectroscopy

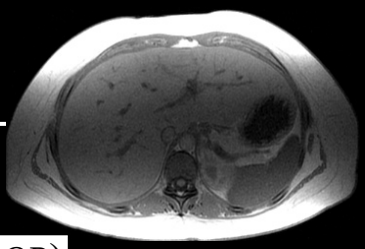

Slide courtesy of Russell N. Low, MD (San Diego)


"Dixon" Method (2-point) Fat-Water Separation MRI
$\theta_{\{W,F\}}=2\pi(\Delta f)(TE)$
z
W
F
RF pulse
y
x
t = 0 -
t = 0 +
in-phase (IP) = W + F
$\theta_{\{W,F\}}$
oppose-phase (OP) = W - F
Fat is precessing slower, accrues phase periodically.
single-peak fat model
in-phase (IP) = W + F

"Dixon" Method (2-point) Fat-Water MRI

Opposed-Phase (OP) = W-F

In-Phase (IP) = W+F



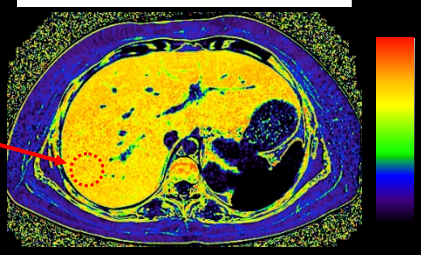
OP = |W-F| = |F-W|

$$\eta = \frac{F}{W+F} = \frac{(IP-OP)}{2\ IP}$$

50% *50%* ambiguity

34% fat-signal fraction !

e.g. 34% of the liver signal originates from fat



0% *100%*

Courtesy of Dr. S. Reeder, U. Wisconsin Madison.

"Dixon" Method Evolution

1990 - 1991
3 and 4-pt. methods

2003 – present
6-pt. methods

1984
2-pt. methods

Mid-1990s, early-2000
Extensive clinical use
Subtle variations

towards robustness and fat-signal fraction accuracy

SINGLE (CH_2) fat peak model
MAGNITUDE-based

MULTLI-peak fat model
COMPLEX-base

Extensive use in liver

- **General Electric**
  - **Lava-Flex (2 pt.) – commercial**
  - **IDEAL-Quant, IDEAL-IQ (3-6 pt.) – commercial + research**
- **Philips**
  - **mDixon (2 pt.) – commercial, (3-6 pt.) – commercial + research**
- **Siemens**
  - **Dixon (2-3 pt.) – research**

"NOT SO SIMPLE" SPECTROSCOPIC IMAGING

W. Thomas Dixon, Ph.D.

Simple Proton Spectroscopic Imaging[1]

Radiology 1984; 153:189-194 (2 echo water-fat MRI)

$$S_{TE_n} = [W + F \cdot e^{i2\pi(TE_n)(\Delta f)}]$$

improving quantitative accuracy

complex unknown

complex unknown

real unknown

water fat

measured MRI signal

$$s(t) = (W + F\sum a_k e^{i2\pi t f_k})e^{i2\pi t\psi}e^{-t/T_2^*}$$

fat chemical shift term

Σ multiple fat peaks
$-CH_2-$
$-HC=CH-$
$-CH_3$

B_0 fieldmap non-uniformity term

signal relaxation

Generalized "Dixon" Method

Fat
Water

iterative algorithm

TE1 TE2 TE3 . . . TE4,5,6

Water

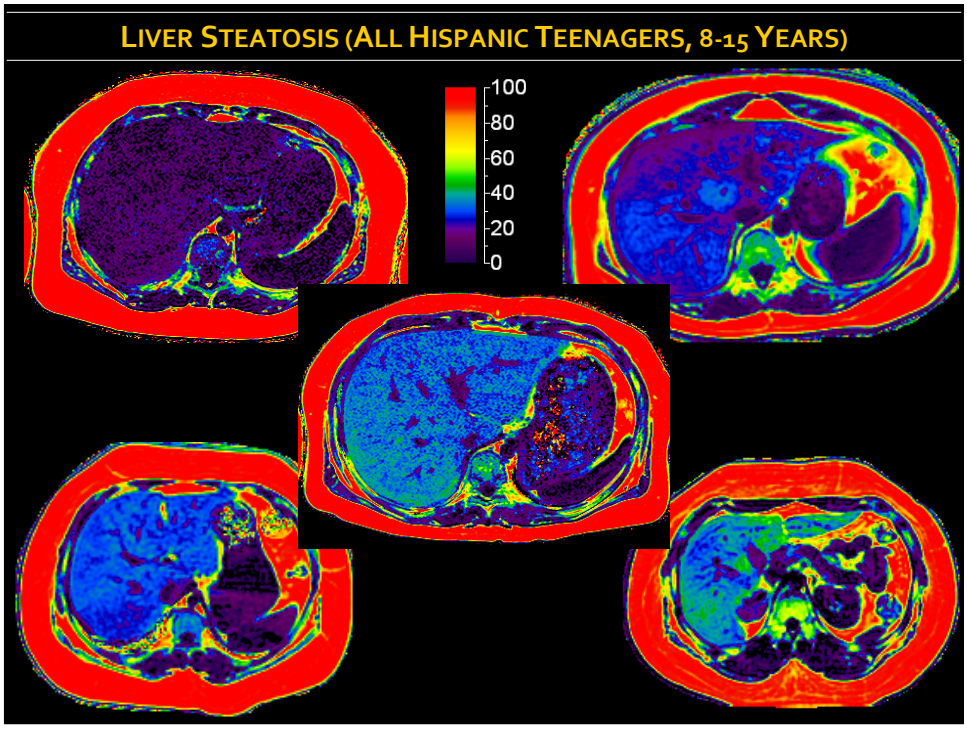
Fat

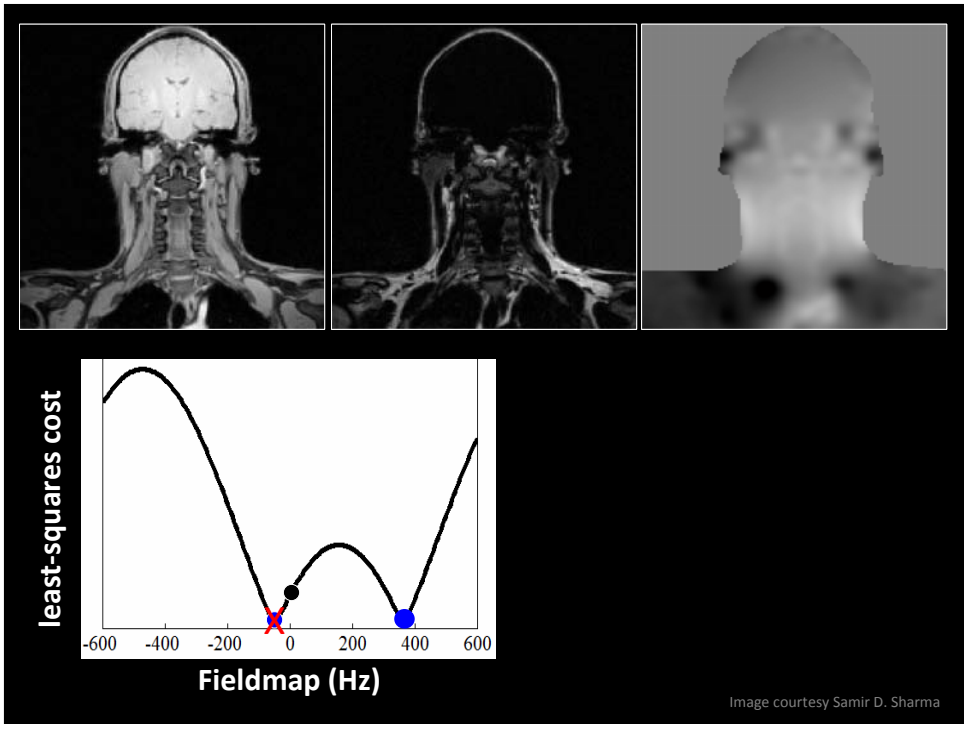
Fat Fraction (%) 0-100%

T2* map (ms)

B_0 Inhomogeneity Field Map (Hz)

QUANTITATIVE !!!


LIVER STEATOSIS (ALL HISPANIC TEENAGERS, 8-15 YEARS)
100
80
60
40
20
0


least-squares cost
-600
-400
-200
0
200
400
600
Fieldmap (Hz)
Image courtesy Samir D. Sharma