Human Body Composition and Energy Expenditure

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PUH 690 "Energetics: Scientific Foundations of Obesity and Other Health Aspects"

Overview

- I. Body composition (fat, lean, bone)
- II. Fat distribution
  - Subcutaneous adipose tissue
  - Visceral adipose tissue
  - Ectopic fat (liver, muscle)
  - Brown adipose tissue
- III. Energy Expenditure

Part I: Body composition

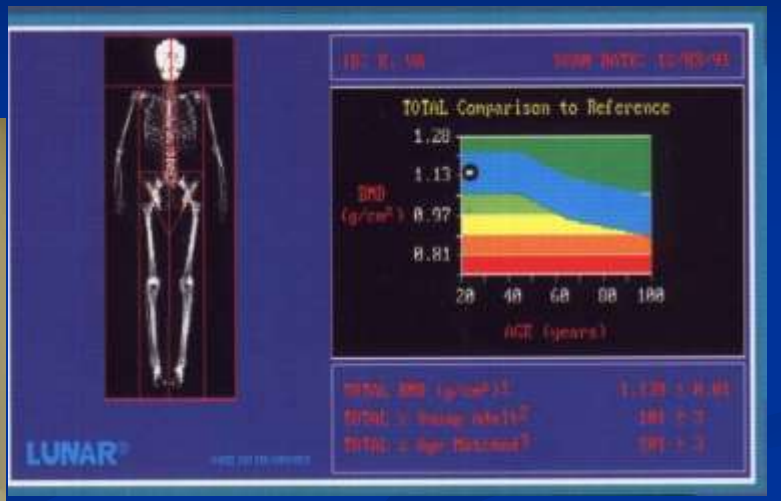
- Dual-energy X-ray absorptiometry (DXA)
- Air-displacement plethysmography
  - BodPod
  - PeaPod
- Stable isotope dilution

Dual-energy X-ray absorptiometry

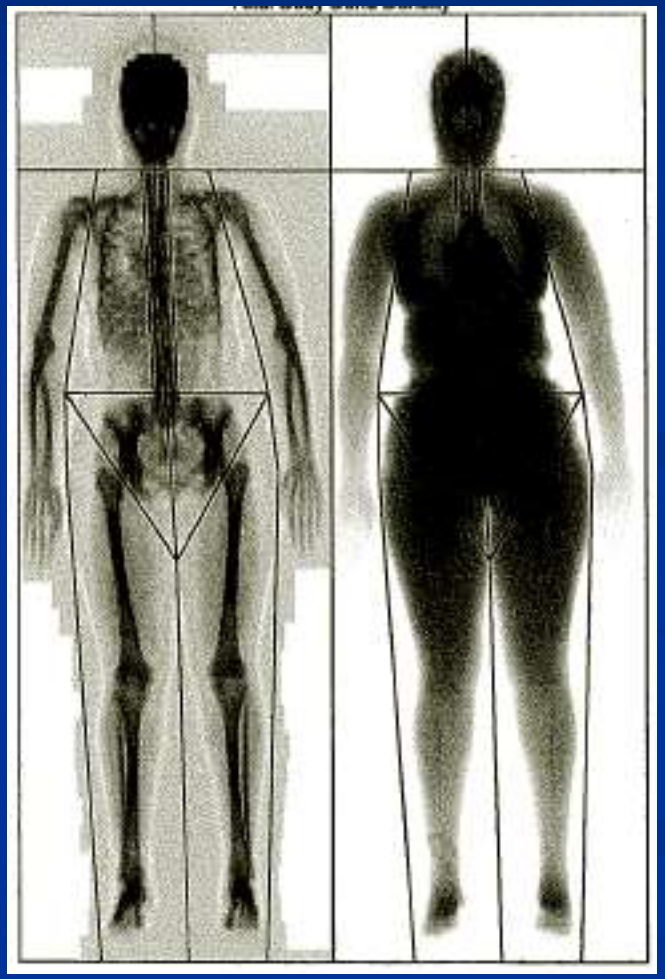
- Differential attenuation of two X-ray beams of differing strength
- Bone > lean mass > fat mass
- "R" values = X-ray attenuation
- Extrapolated R value when bone obscures soft tissue

DXA

Total & regional fat mass, lean mass, bone mineral content and density



DXA analysis image



Sample output

University Of Alabama At Birmingham

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Birmingham, Al 35294

Patient:	4385, 4385		**Patient ID:**	4385	
Birth Date:	1/30/1990 23.5 years		**Referring Physician:**		
Height / Weight:	63.6 in. 146.0 lbs.		**Measured:**	8/27/2013 12:30:06 PM	(13.60)
Sex / Ethnic:	Female White		**Analyzed:**	8/27/2013 12:31:24 PM	(13.60)

BODY COMPOSITION

Region	Tissue[1] (%Fat)	Region (%Fat)	Tissue[1] (g)	Fat[1] (g)	Lean[1] (g)	BMC (g)	Total Mass (kg)
Left Arm	42.9	41.3	3,221	1,382	1,838	127	3.3
Left Leg	41.7	40.4	12,523	5,220	7,304	409	12.9
Left Trunk	33.2	32.4	14,318	4,753	9,565	333	14.7
Left Total	36.8	35.5	31,959	11,753	20,206	1,120	33.1
Right Arm	41.3	39.8	3,412	1,410	2,001	136	3.5
Right Leg	42.9	41.5	11,950	5,127	6,823	403	12.4
Right Trunk	33.2	32.5	15,104	5,016	10,087	350	15.5
Right Total	37.0	35.8	32,244	11,933	20,312	1,128	33.4
Arms	42.1	40.5	6,632	2,793	3,840	263	6.9
Legs	42.3	40.9	24,474	10,347	14,127	812	25.3
Trunk	33.2	32.5	29,422	9,769	19,653	683	30.1
Android	32.9	32.5	4,164	1,369	2,796	46	4.2
Gynoid	41.3	40.6	11,743	4,849	6,893	208	12.0
Total	36.9	35.6	64,203	23,686	40,517	2,248	66.5

FAT MASS RATIOS

Trunk/ Total	Legs/ Total	(Arms+Legs)/ Trunk
0.41	0.44	1.35

Body density with Bod Pod

- Body volume by air displacement
- Body density by volume and mass
- Body volume corrected for tidal volume

Air-displacement plethysmography

Body density via "Bod Pod"

Bod Pod

Bod Pod

Body density with Bod Pod

- > mass/volume = > density
- > density = > lean:fat
- %fat = $(4.95/D_b - 4.5) \times 100$ (Siri, 1956)

Pea Pod for infant body composition

Stable Isotope Dilution

Total body water via deuterium ingestion

TBW with deuterium dilution

- Baseline urine sample
- Oral dose of D_2O
- Deuterium: 1 P + 1 N (H has 1 P)
- 3-4 hour equilibration period
- Second urine sample
- Deuterium enrichment (delta) by IRMS
- TBW=(dose*C1*C2)/deltaT180-deltaT0/1000
- 36.13kg=9.998g*5651619*0.945/1482-3.9/1000

Multi-compartment modeling

- % Fat = (equation)
  - Total body water (isotope dilution)
  - Total body bone mineral content (DXA)
  - Body density (Bod Pod)
- Multiple direct measures
- Fewest assumptions

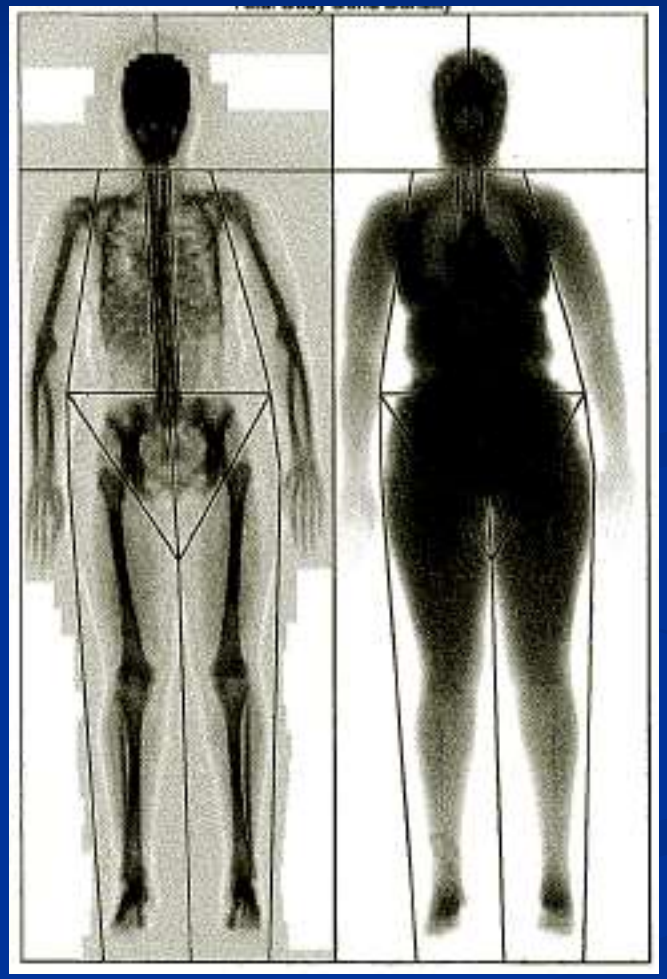
4-compartment model
Baumgartner et al.

- Fat mass (kg) =
- 2.05 * weight (kg) * ((1.34/D_b) – (0.35 * (TBW/weight) + (0.71624 * (bone/weight)) – 1)

Part II: Fat Distribution

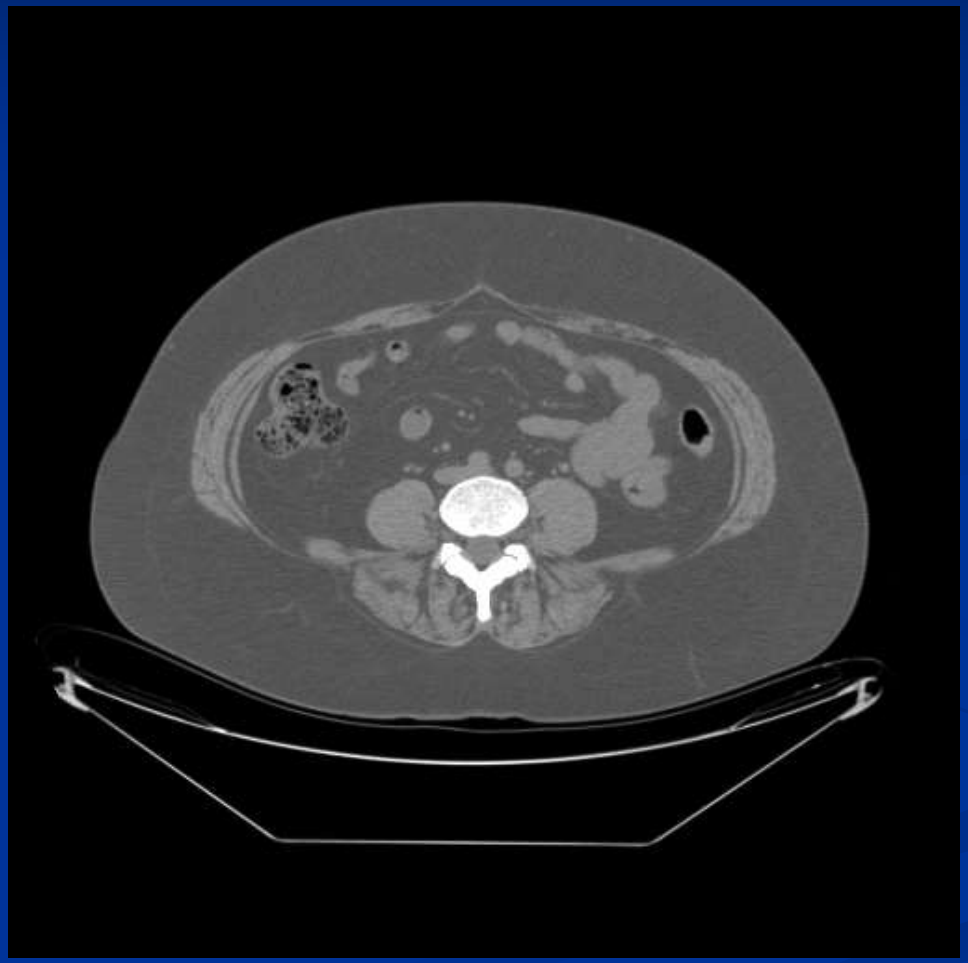
- Subcutaneous adipose tissue:
  - DXA (dual-energy X-ray absorptiometry)
  - CT (computed tomography)
  - MRI (magnetic resonance imaging)
- Visceral adipose tissue: CT, MRI
- BAT: PET (Positron Emission Tomography)
- Ectopic fat
  - Intramuscular fat: CT, MRI, MRS (spectroscopy)
  - Liver fat: CT, MRS, MRI

Regional body composition with DXA



Fat Distribution by CT scan

CT Scan Image



Computed tomography scanning

- Single slice X-ray; 5 mm, 2 sec
- Attenuation of beam in Houndsfield units
- Denser tissue = greater attenuation
- Bone > Lean mass > fat mass

Computed tomography scanning

- Adipose tissue = -190 to -30 HU
- Muscle = 0 – 80 HU
- Low-density muscle = 0 - 20 HU
  - Indicates lipid infiltration
- High-density muscle = 21-80 HU

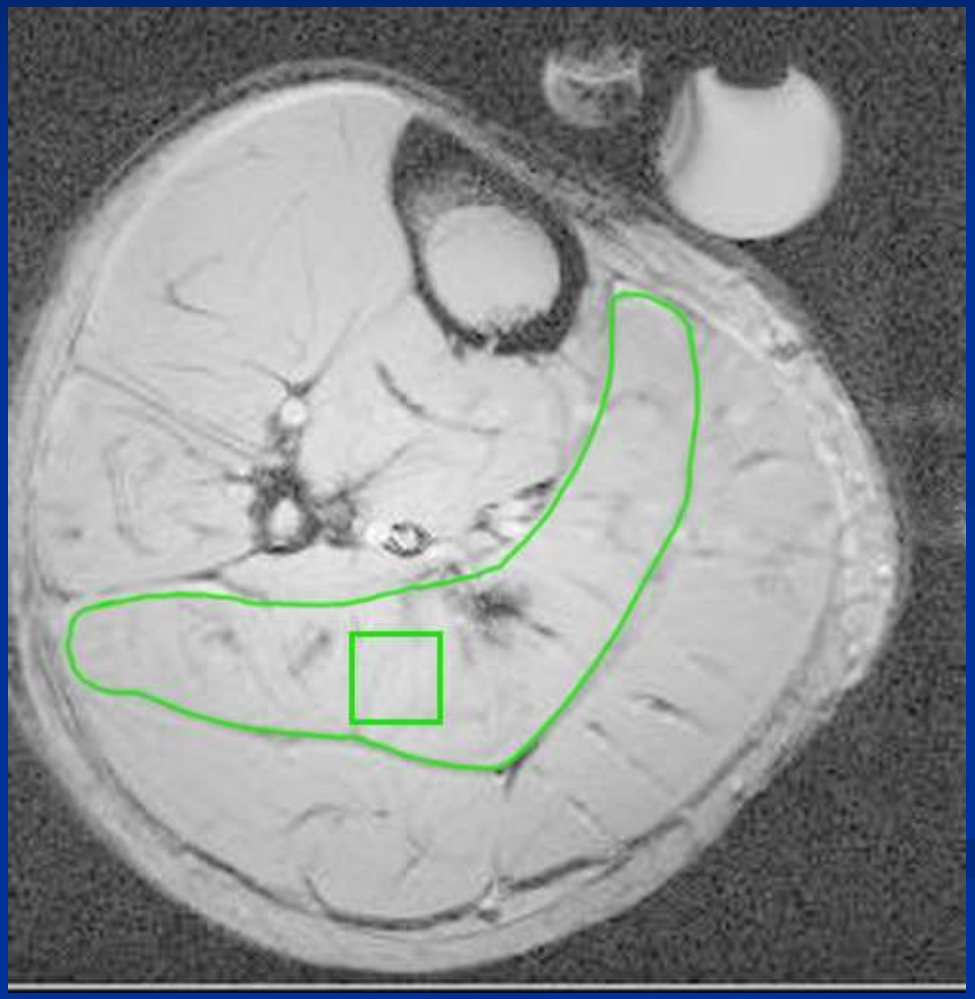
Skeletal Muscle Fat

- Magnetic resonance spectroscopy (MRS)
  - ^{1}H methylene proton resonance
  - Intramyocellular (IMCL)
  - Extramyocellular (EMCL)
- Magnetic resonance imaging (MRI)
  - Visualize fat depots
- Computed tomography (CT)
  - Attenuation value; lower density = more fat
- Biopsy
  - Oil red O staining; microscopy

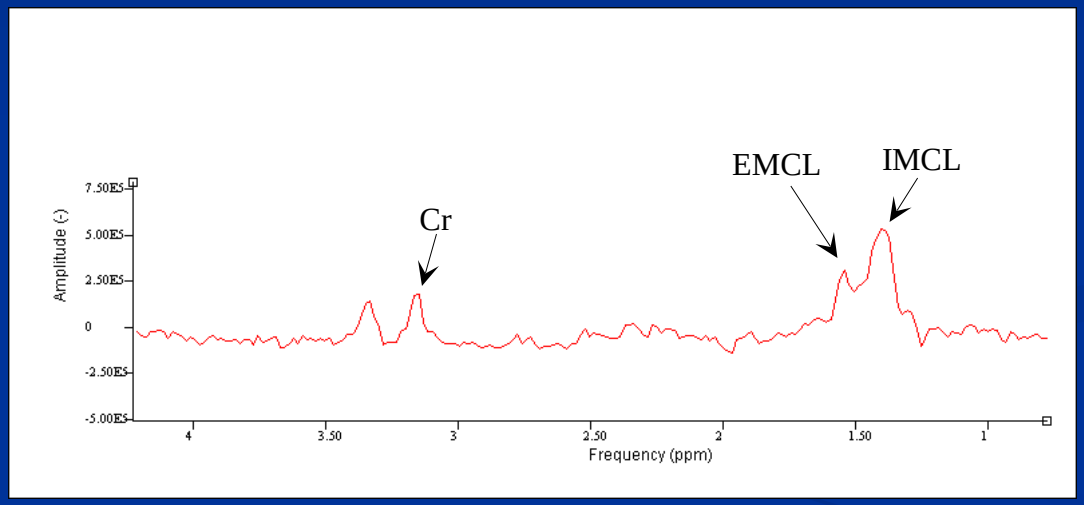
Magnetic Resonance Spectroscopy for IMCL

MRS Measurement

- ^{1}H-MRS of right soleus on a 4.1T magnet
- IMCL – 6x6 voxel average
- Extramocellular lipid (EMCL) – total soleus voxel average
- Normalized to an oil phantom

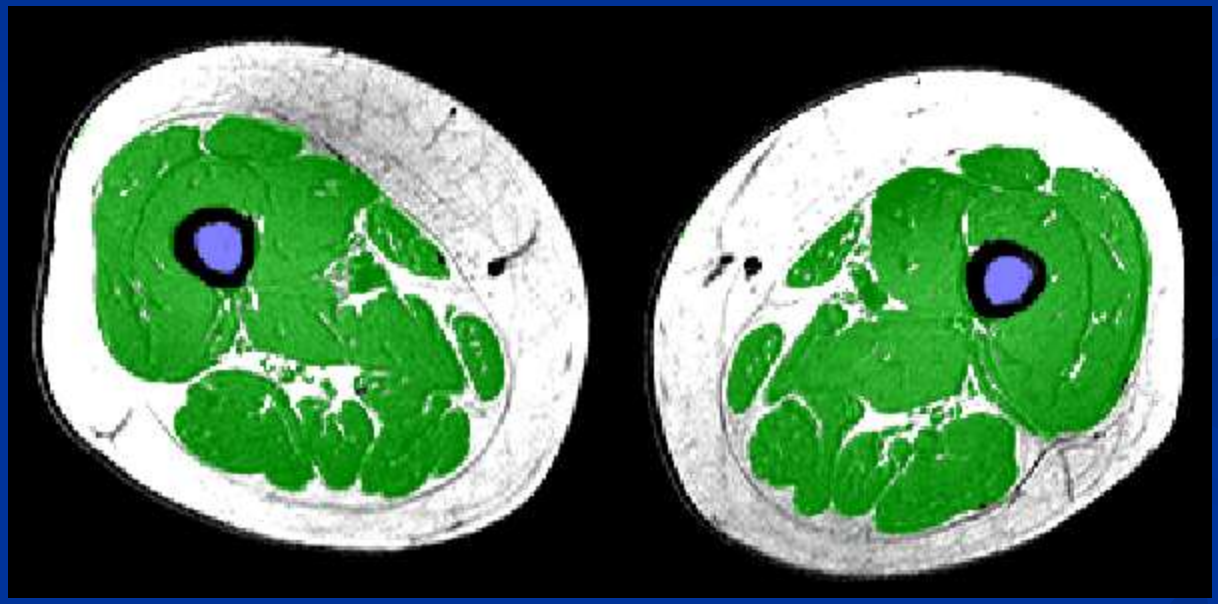


MRS



Water-suppressed 1H spectra collected with a 9.5 cm surface coil
EMCL=extramyocellular lipid; IMCL=intramyocellular lipid;
Cr=creatine.

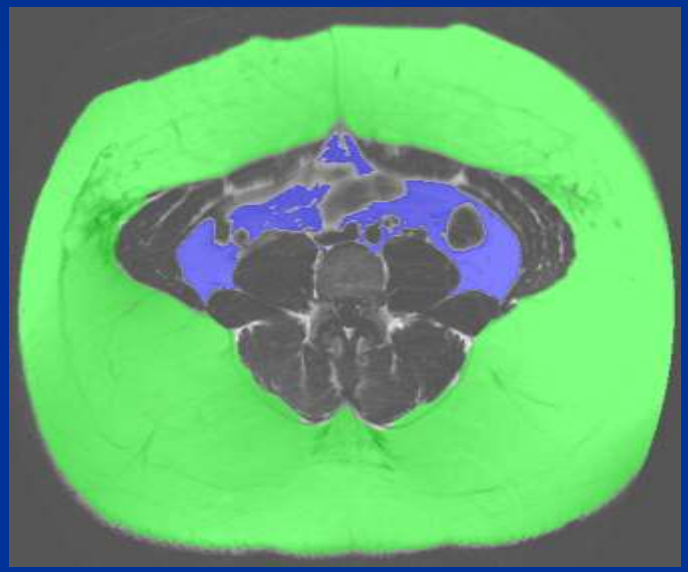
Magnetic Resonance Imaging: Intra-muscular adipose tissue "IMAT"

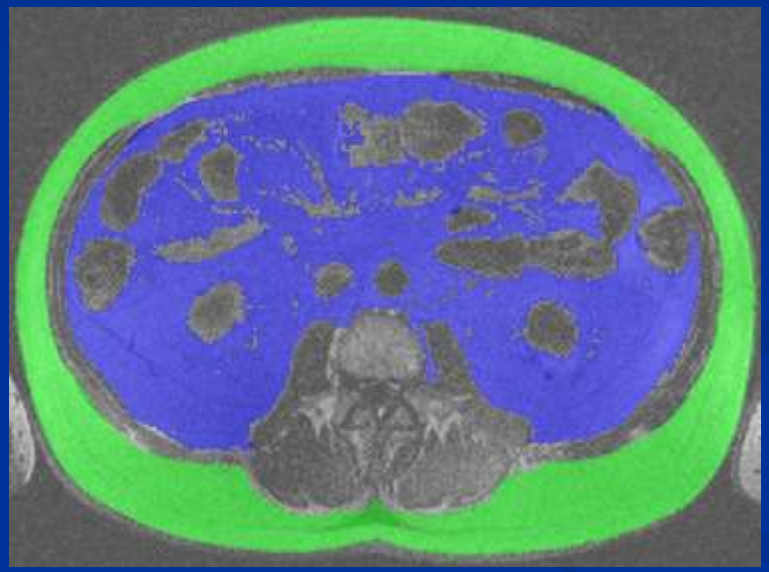


Mid-Thigh

Courtesy Amy Goss

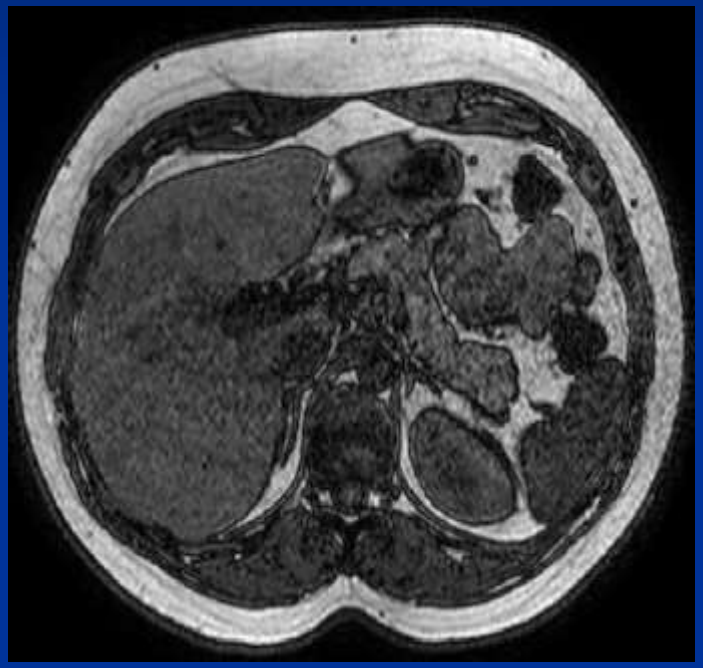
MRI for abdominal fat

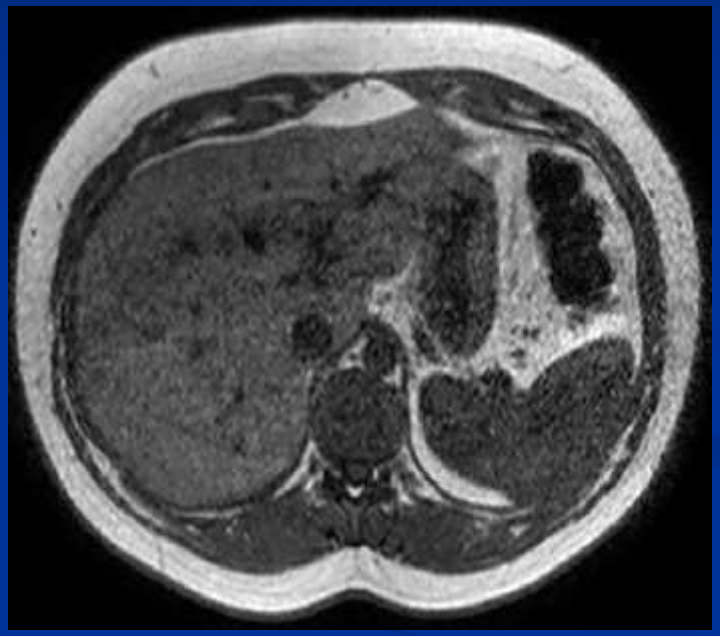




Courtesy Amy Goss

MRI for liver fat



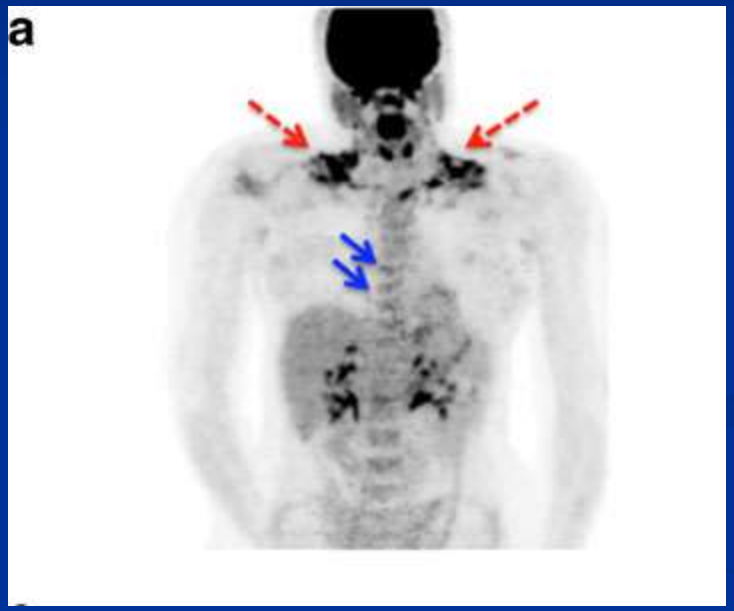


Attenuation of 5 ROI is used as an index of liver fat

Courtesy Amy Goss

PET

PET scanning for BAT



Cold-induced BAT activity using ^{18}F-fluorodeoxyglucose
Lee, P et al. 2012 *Osteoporosis Int.*

Part III: Energy Expenditure

- Indirect calorimetry
  - Resting: Vmax ENCORE 29N Systems metabolic monitor (SensorMedics)
  - 24-h whole room
- Doubly-labelled water
  - Deuterium
  - Oxygen-18

Indirect calorimetry

- Oxygen consumption
- Carbon dioxide production
- 30-min canopy method
  - Resting energy expenditure
- 24-hour room method
  - Total (24-h), resting, and sleeping EE
  - Total includes PA and TEF

Resting Energy Expenditure
Indirect Calorimetry

Sample report

Time Sec HH:MM	REE/Day Kcal/day	VO2 L/min	VCO2 L/min	RQ	VE(BTPS) L/min	FIO2 %	FEO2 %	FICO2 %	FECO2 %
00:01:00	1187	0.168	0.148	0.88	31.2	20.87	20.22	0.07	0.66
00:02:00	1223	0.174	0.150	0.86	30.5	20.91	20.22	0.08	0.68
00:03:00	1119	0.160	0.134	0.84	31.6	20.94	20.33	0.08	0.60
00:04:00	917	0.131	0.110	0.84	25.6	20.94	20.33	0.08	0.61
00:05:00	1037	0.146	0.129	0.88	25.6	20.86	20.16	0.07	0.70
00:06:00	1005	0.143	0.121	0.84	25.4	20.87	20.19	0.07	0.66
00:07:00	802	0.111	0.107	0.96	22.6	20.78	20.17	0.07	0.66
00:08:00	1068	0.153	0.124	0.81	23.9	20.85	20.09	0.07	0.71
00:09:00	988	0.142	0.115	0.82	24.2	20.84	20.15	0.07	0.66
00:10:00	1230	0.176	0.145	0.82	24.2	20.84	19.97	0.07	0.81
00:11:00	1061	0.149	0.134	0.90	24.1	20.83	20.08	0.07	0.76
00:12:00	996	0.140	0.128	0.92	24.2	20.80	20.09	0.07	0.73
00:13:00	859	0.121	0.110	0.92	24.4	20.80	20.19	0.07	0.63
00:14:00	1052	0.149	0.131	0.88	24.4	20.79	20.06	0.07	0.74
00:15:00	936	0.132	0.119	0.90	24.4	20.78	20.12	0.07	0.67
00:16:00	940	0.133	0.117	0.88	24.3	20.77	20.11	0.07	0.66
00:17:00	966	0.136	0.123	0.91	24.4	20.77	20.09	0.07	0.70
00:18:00	833	0.117	0.105	0.89	23.1	20.78	20.16	0.07	0.64
00:19:00	983	0.138	0.124	0.89	23.1	20.77	20.05	0.07	0.74
00:20:00	946	0.134	0.118	0.88	23.1	20.78	20.08	0.07	0.70
00:21:00	918	0.129	0.115	0.89	23.4	20.76	20.09	0.07	0.68
00:22:00	948	0.134	0.118	0.88	23.1	20.76	20.06	0.07	0.70
00:23:00	979	0.138	0.122	0.88	23.2	20.77	20.05	0.07	0.72
00:24:00	972	0.136	0.124	0.91	23.1	20.78	20.06	0.07	0.74
00:25:00	919	0.129	0.116	0.90	22.9	20.78	20.09	0.07	0.70
00:26:00	1063	0.151	0.131	0.87	23.2	20.78	19.99	0.07	0.77
00:27:00	1030	0.144	0.135	0.94	23.0	20.77	20.01	0.07	0.80
00:28:00	885	0.124	0.114	0.91	23.0	20.77	20.12	0.07	0.68
00:29:00	965	0.138	0.115	0.83	23.3	20.78	20.08	0.07	0.68
00:30:00	984	0.141	0.116	0.82	23.1	20.77	20.04	0.07	0.69
00:31:00	1006	0.144	0.118	0.82	23.4	20.77	20.04	0.07	0.69

Measured REE: 990 kcal/day
Respiratory Quotient: 0.87

Mean VO2: 0.140 L/min
Mean VCO2: 0.123 L/min

Calculation of energy expenditure

- REE = [VO2 (3.94) + VCO2 (1.11)] 1440 min/day
- De Weir 1949. New methods for calculating metabolic rate with special reference to protein metabolism. *J. Physiol. Lond.* 109:1-9.

24-h Energy Expenditure
Room Calorimetry

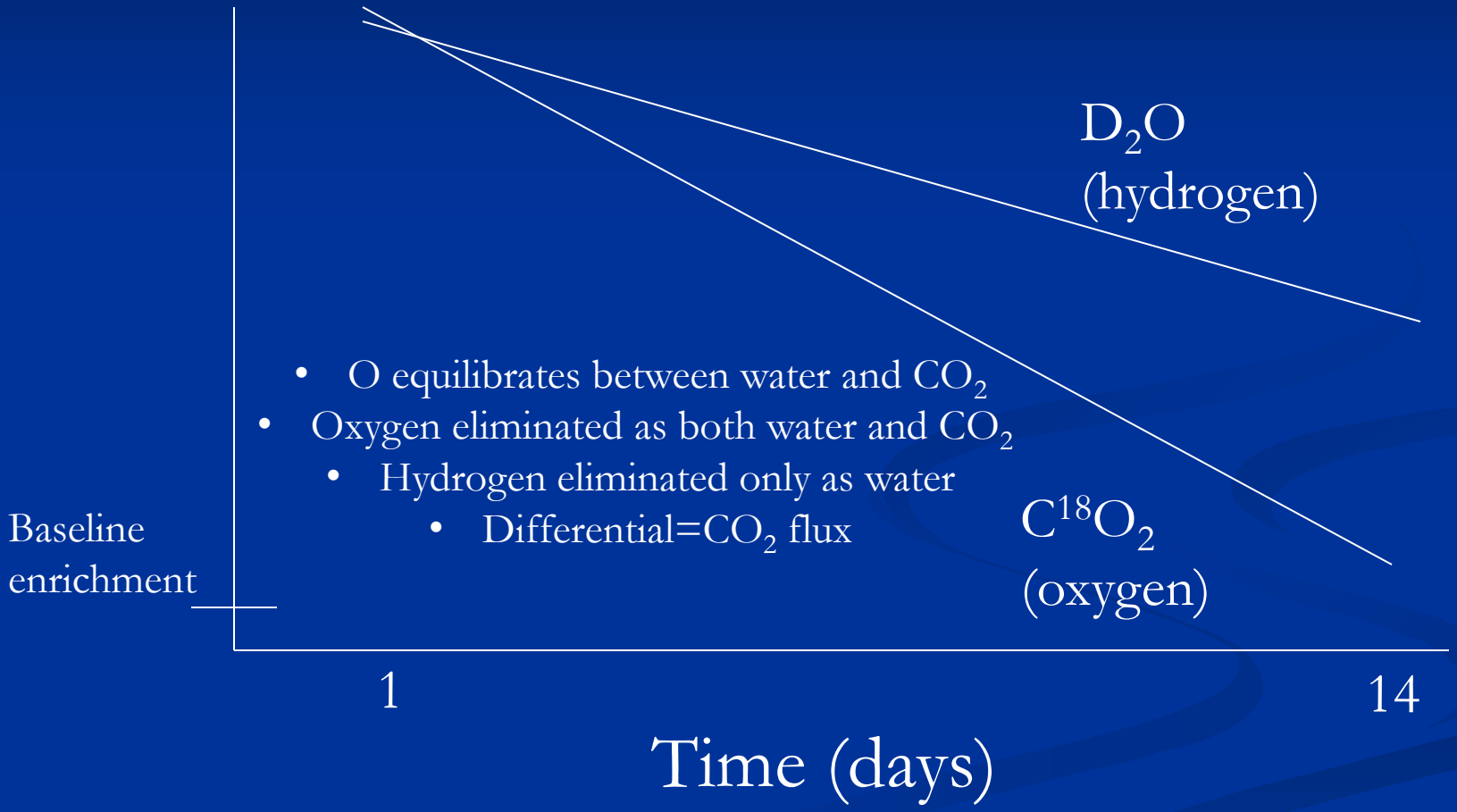
Free-living Total & Activity-related Energy Expenditure

Deuterium, ^{18}O labeled water

Doubly-Labeled Water

- Baseline urine collection
- Oral dose of D_2O^{18}
- Day 1 urine collection
- Day 14 urine collecton
- Deuterium and ^{18}O enrichment by IRMS

Isotopic enrichment in urine



Calculation of energy expenditure

- TEE from standard indirect calorimetry equations
  - $rCO_2 = 0.4554 (k_0 \times V_0 - k_h \times V_h)$
  - TEE (kcal/d) = $3.9\ rCO_2/RQ + 1.11\ rCO_2$
- AEE = (0.9 * TEE) – REE (from indirect cal.)

k and V reflect turnover rate and pool size;
RQ = 0.85 or FQ
Wolfe text ch. 12

Questions?