



Valutazione ambulatoriale della Composizione corporea e del fabbisogno energetico: dalla teoria alla pratica

Andrea P Rossi
Clinica Geriatrica



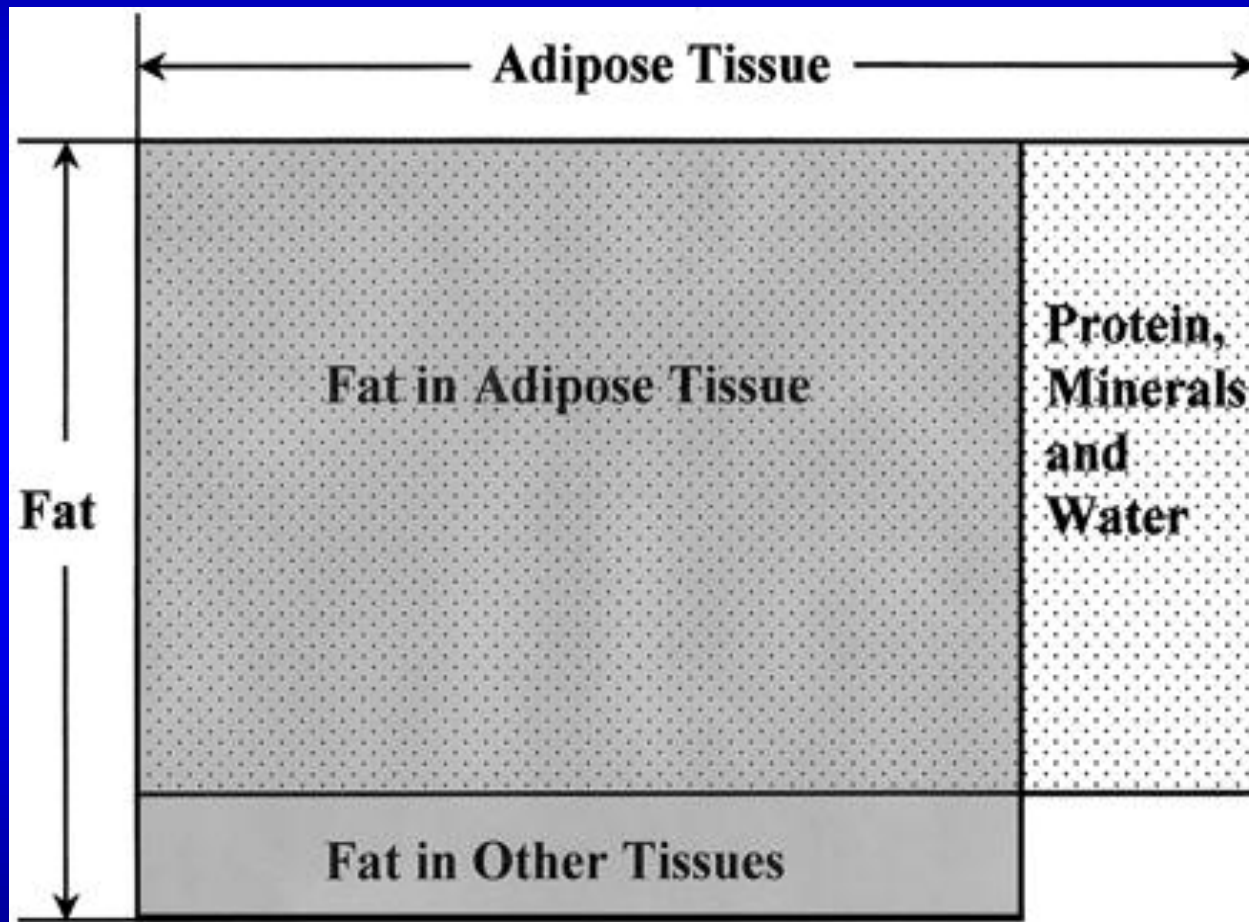
Università di Verona

Vicenza, 03 Novembre, 2017

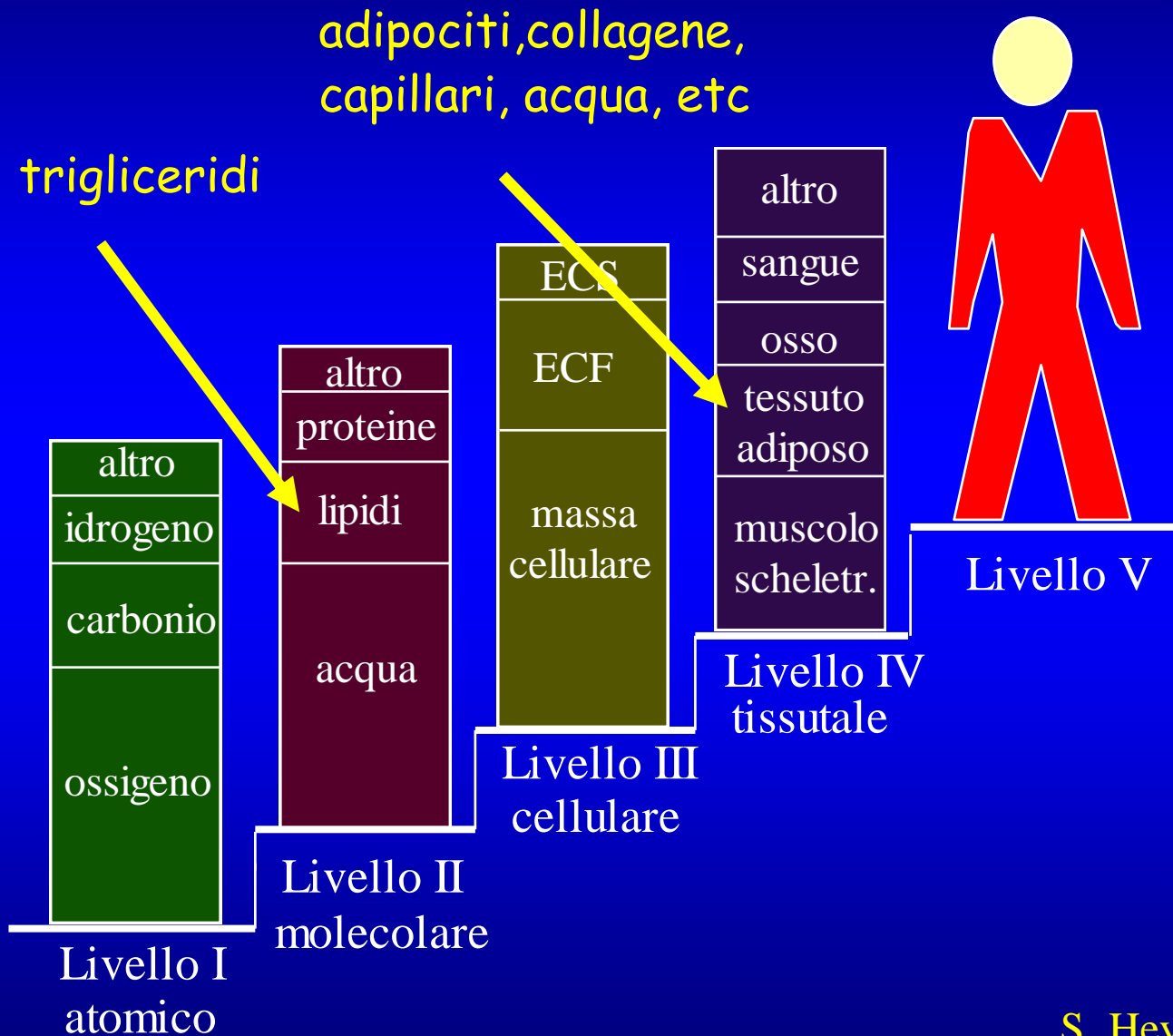
OBJECTIVES:

- methods for quantifying **fat** in vivo
- methods for quantifying **Adipose Tissue** in vivo
- methods for **muscle mass and muscle quality** evaluation in vivo
- methods for quantifying **fat in organs**

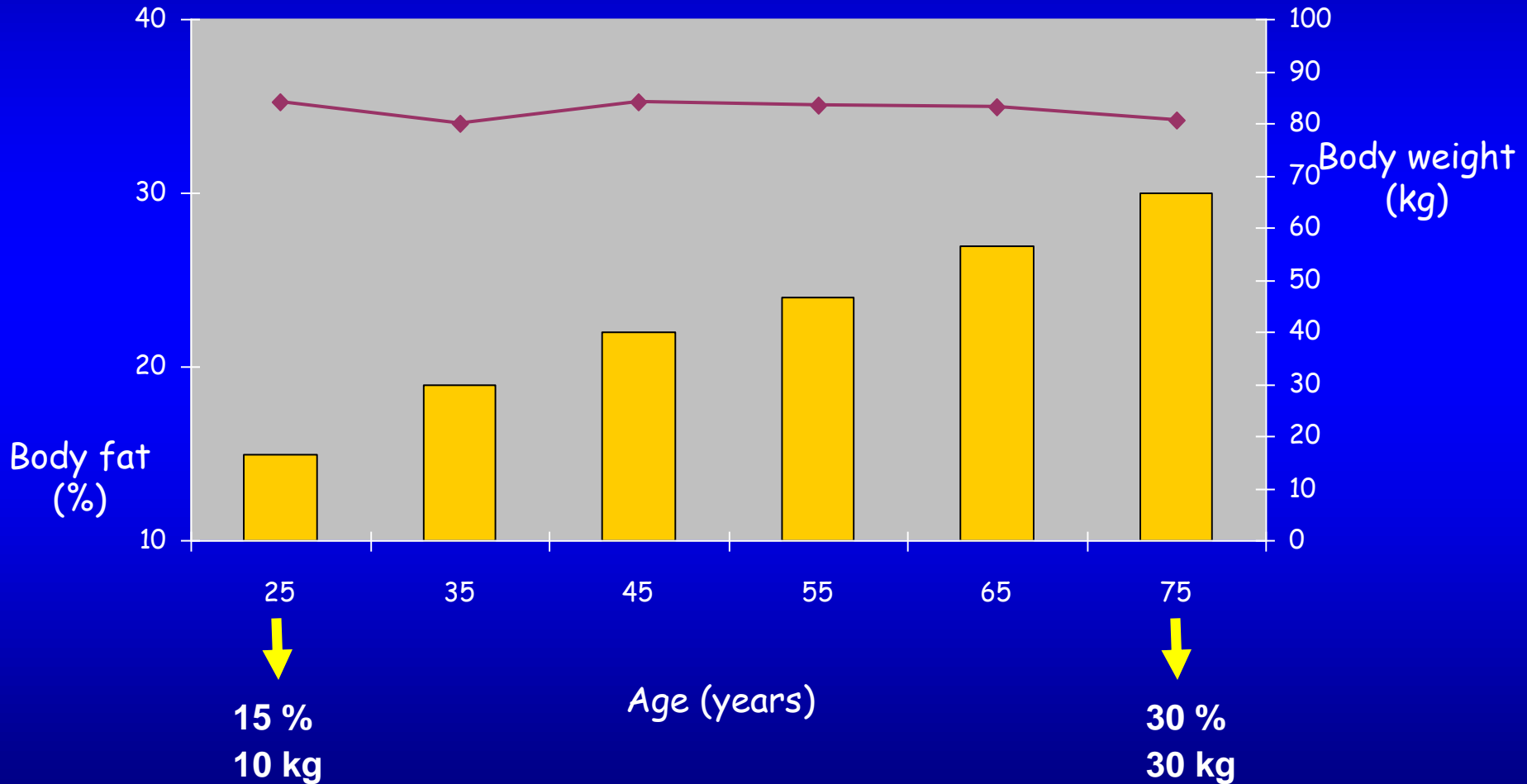
Relation between chemical fat (or lipid) and adipose tissue



The five body composition levels



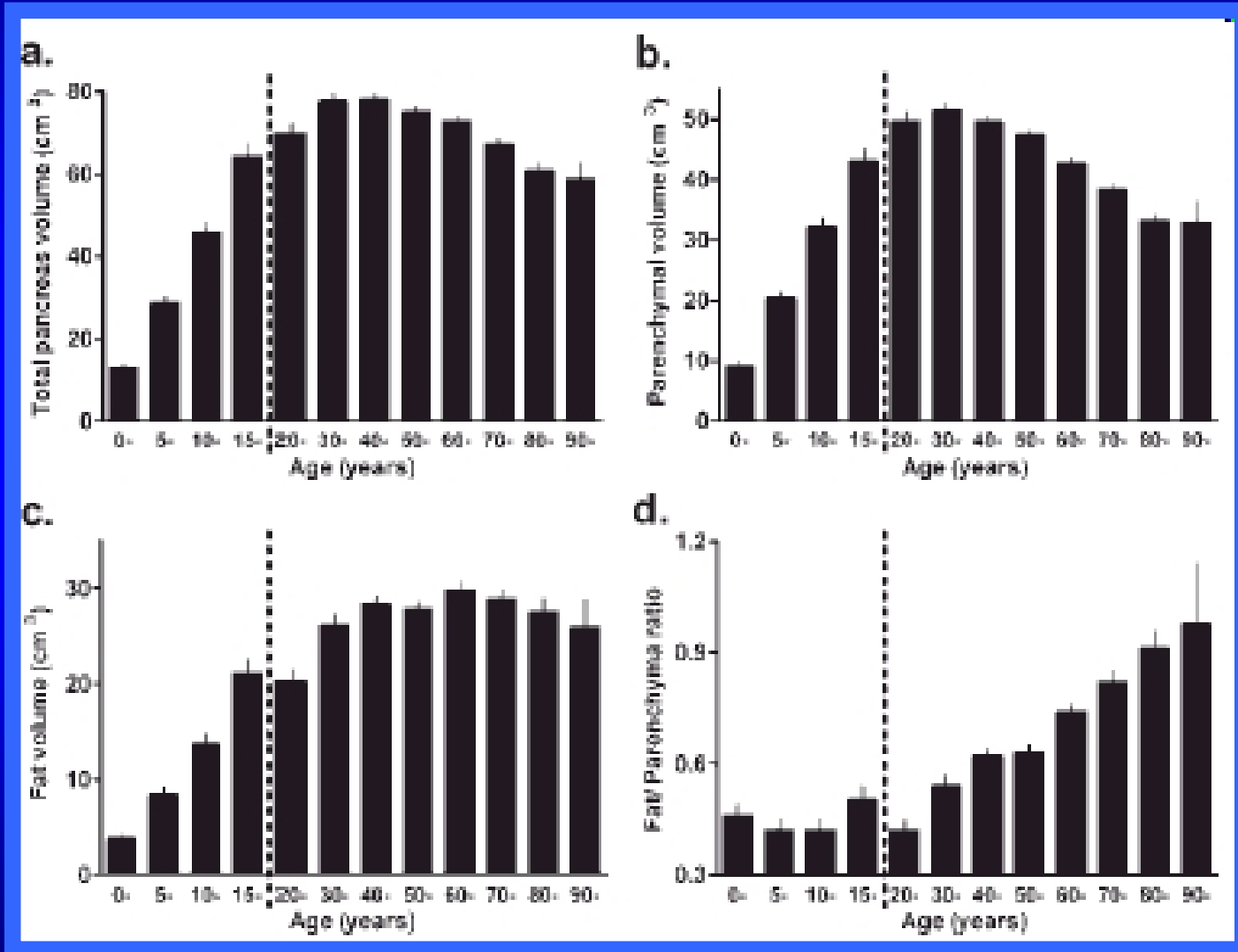
Age related increase in body fat for normal males at constant body mass index (BMI)



Prentice AM & Jebb SA, 2001 (mod)

Total, parenchymal, and pancreatic fat volumes with age calculated from CT images.

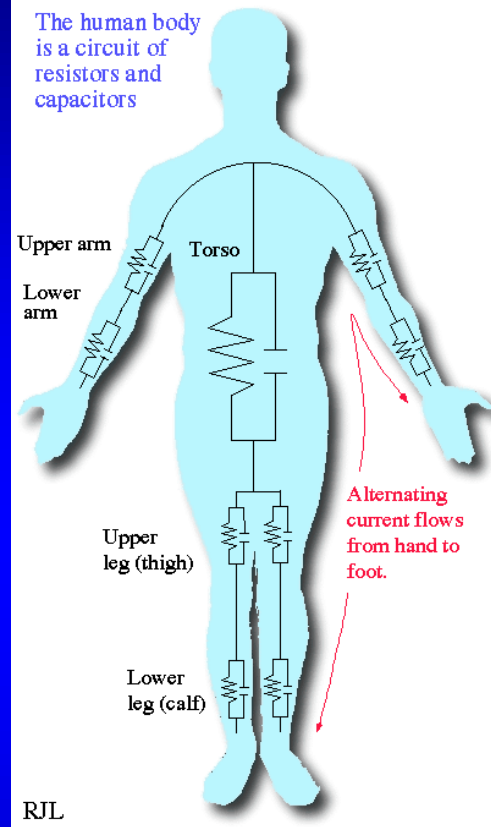
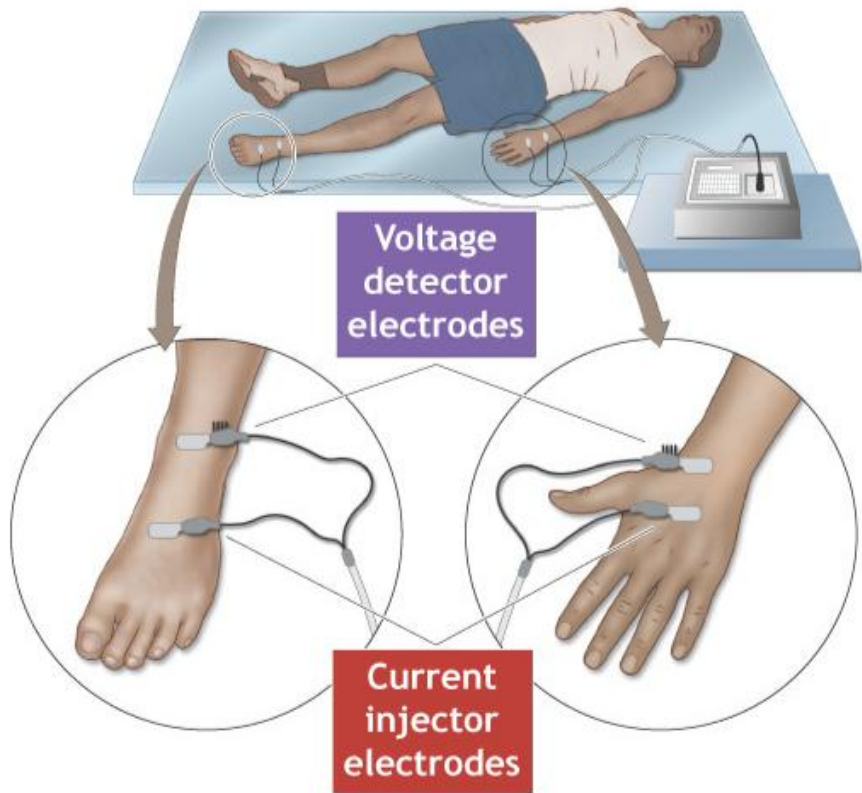
a: Total pancreas volume. **b:** Parenchymal volume. **c:** Fat volume. **d:** Fat/parenchyma ratio (F/P).



Most widely used current methods for quantifying fat in vivo

- Bilancia idrostatica
- Bioimpedenza
- Air-displacement plethysmography system
- DXA

Bioelectrical impedance assessment (BIA)



- Sviluppato negli anni 60
- Una corrente a basso voltaggio (50 kHz 800 μ A max) viene fatta passare attraverso il corpo del paziente

BIOIMPEDENZIOMETRIA: modello bicompartimentale

Consente di stimare l' Acqua Corporea Totale

Corrente



Organismo
vivente

Fluidi extra-cellulari

=

Conduttori

Membrane cellulari

=

Condensatori

Attraversandoli la
corrente incontra una:

Resistenza

La forza con cui si oppongono al
passaggio della corrente:

Reattanza

Resistenza è maggiore nel tessuto grasso (14-22% acqua)
Conduttanza è maggiore nel tessuto magro (73% acqua) che quindi offrirà minore
resistenza

Vantaggi della BIA

- non è richiede molta esperienza ed abilità
- strumentazione è portatile
- investimento e spese di manutenzione relativamente basse
- misurazione sul paziente è indolore e rapida

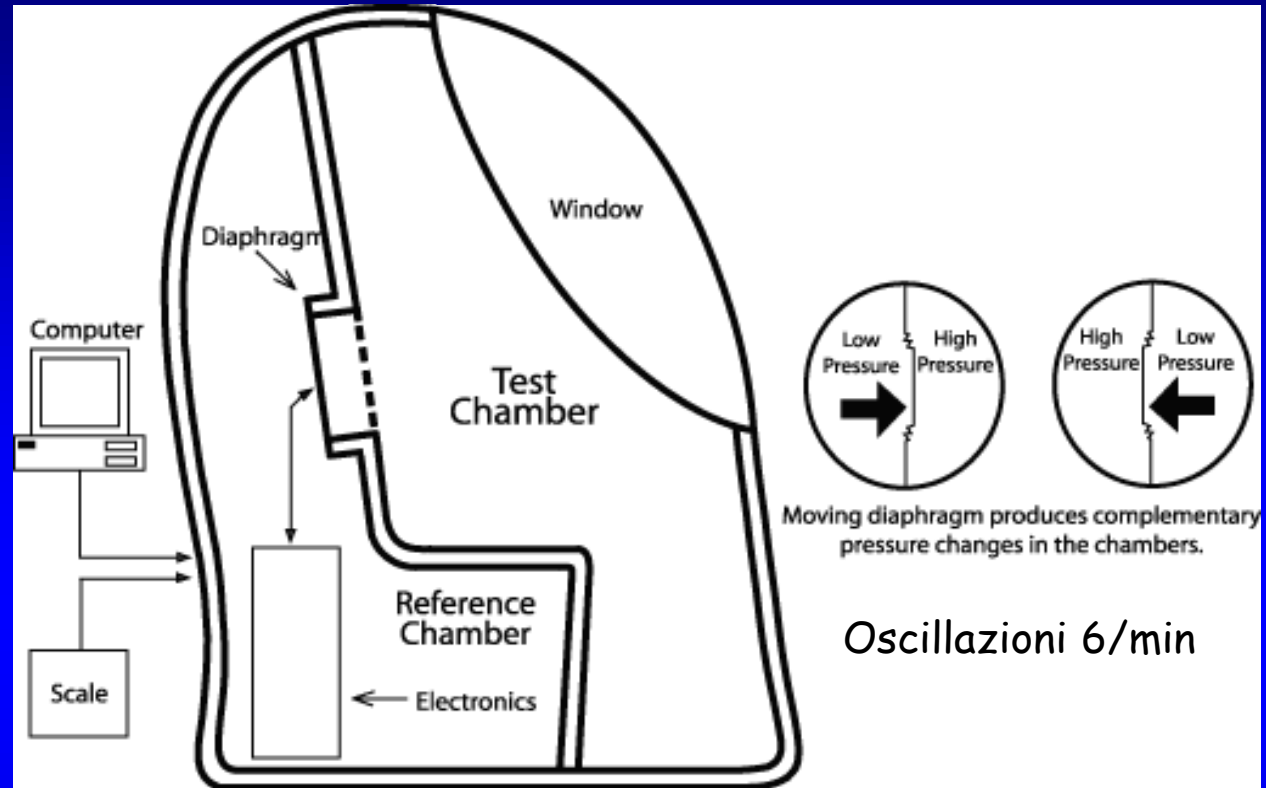
Svantaggi della BIA

- altamente influenzata dallo stato di idratazione del soggetto
- richiede preparazione adeguata
- influenzata da temperatura ambientale
- è formula dipendente

Equazione di Janssen: $MM = [(Ht^2/R \times 0.401) + (\text{sex} + 3.825) + (\text{age} \times -0.071)] + 5.102$

MM = massa muscolare scheletrica, Ht= altezza, R= resistenza

Air-Displacement Plethysmography (BOD POD)



Principio fisico: legge dei gas di Boyle e Mariotte

A temperatura costante il volume (V) occupato da una determinata massa è inversamente proporzionale alla pressione cui quella massa è sottoposta

Calcola il volume, quindi il PS; per ottenere la massa adiposa si usa la Formula di SIRI: Massa adiposa% = (4950/densità-4,5)100

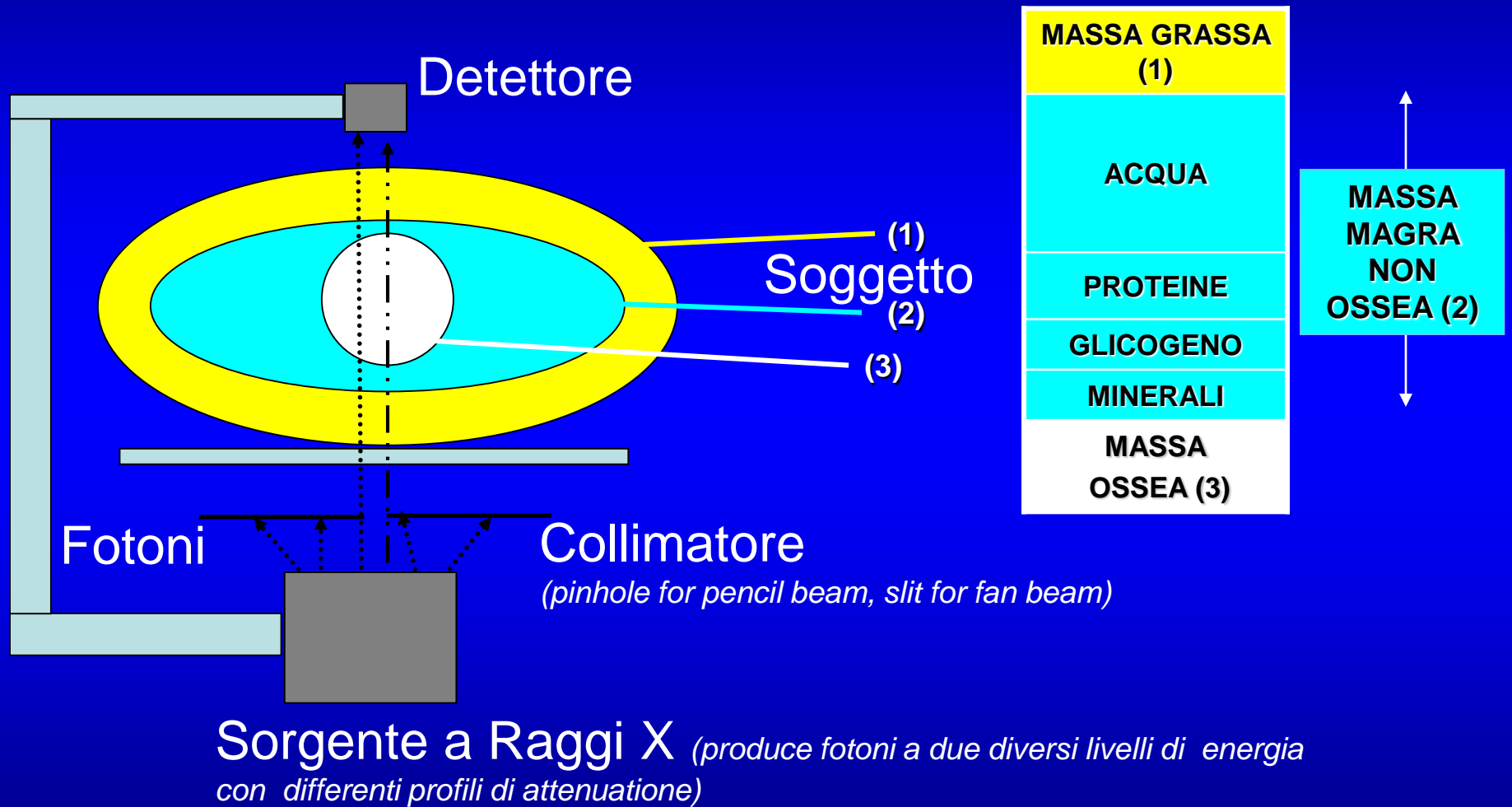
Dove: densità FM = 900 kg/m³; densità FFM= 1100 kg/m³

Air-Displacement Plethysmography (BOD POD)

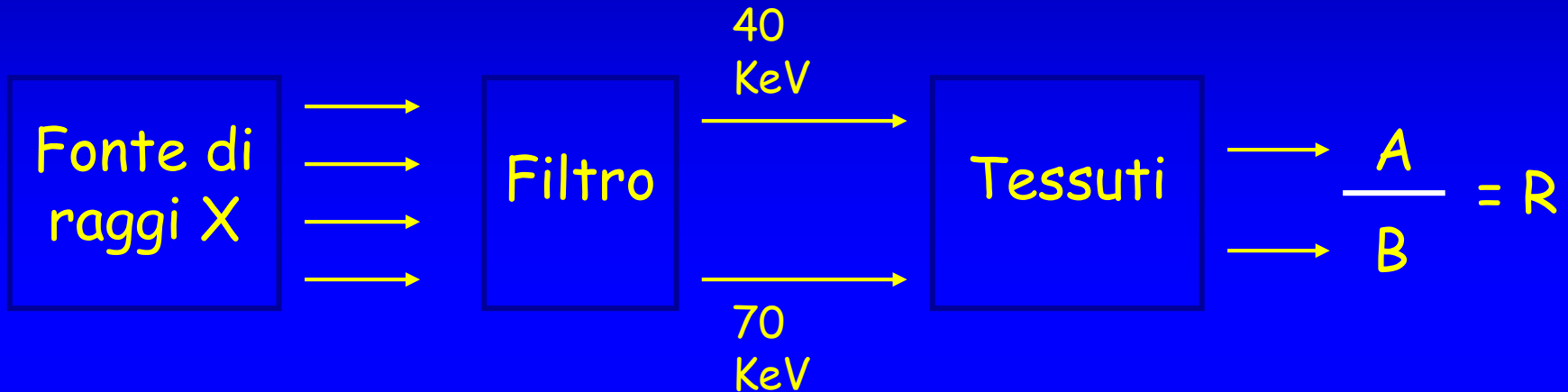
Vantaggi e svantaggi

- Range di errore è dell' 2% simile alla bilancia idrostatica
- Richiede 5 minuti
- Può ospitare soggetti fino ai 400 kg
- Scarsa trasportabilità ed estremamente costosa

Dual Energy X-ray Absorbiometry

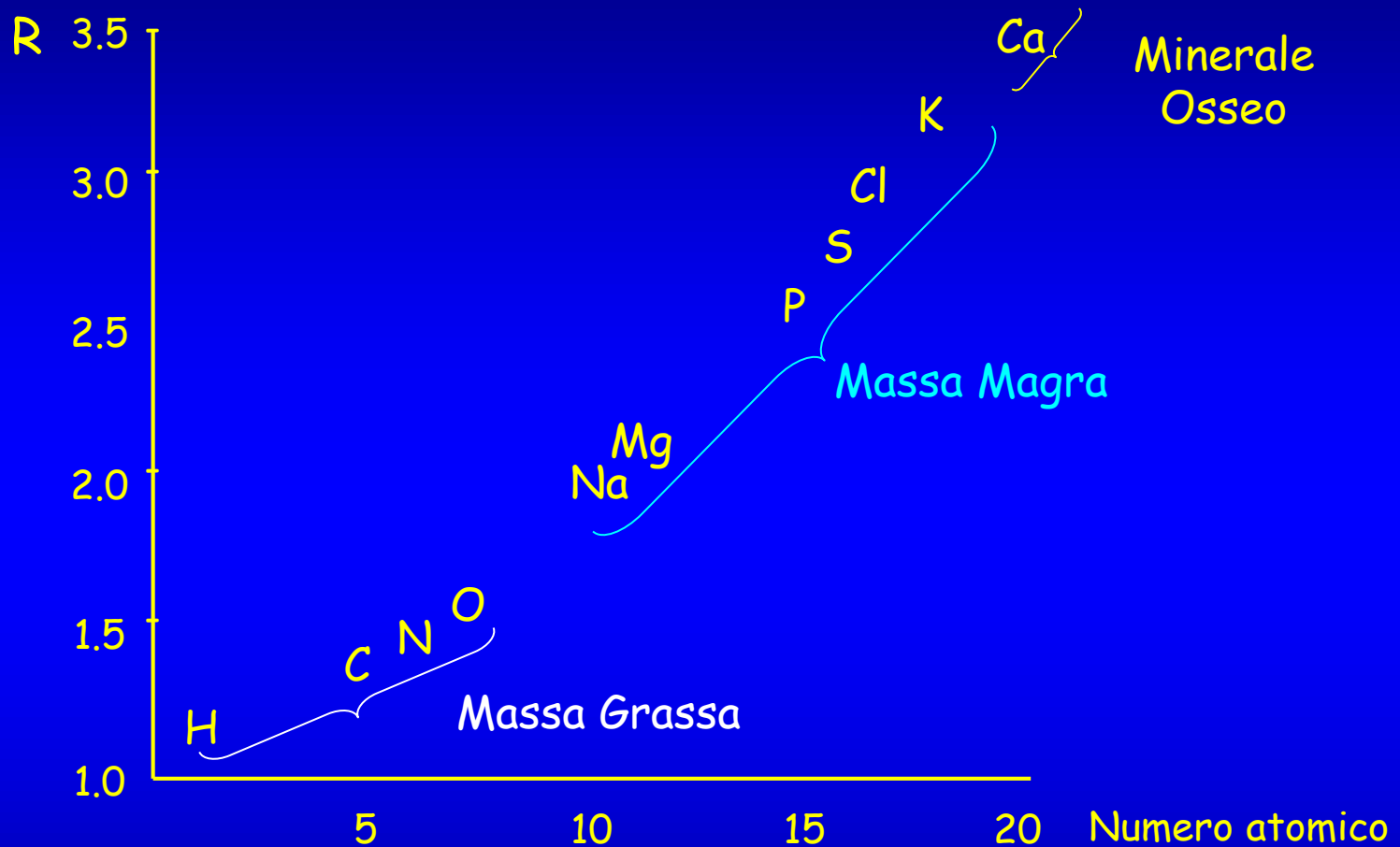


Dual-energy X-ray Absorptiometry (DXA)



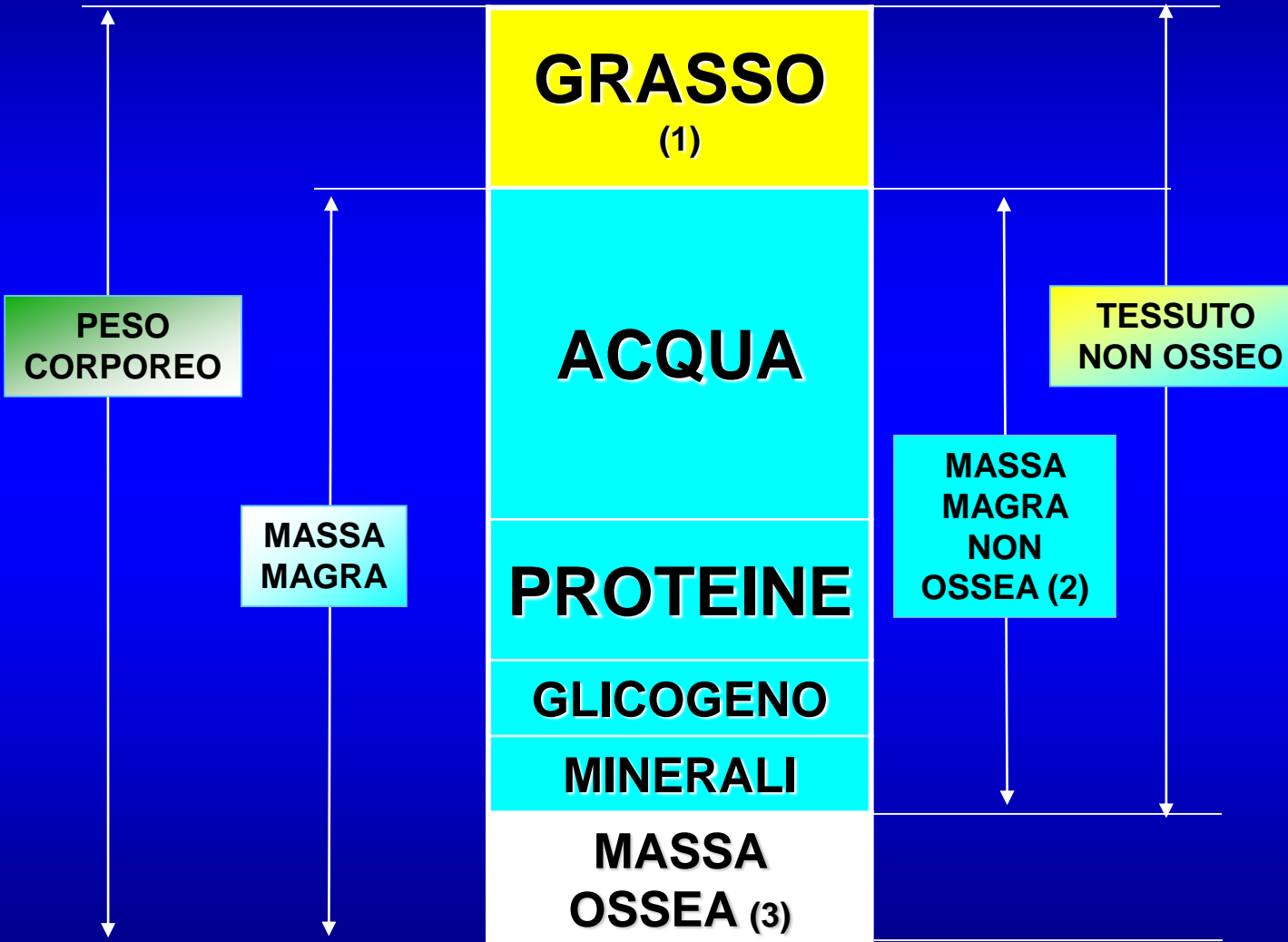
dove R rapporto fra il valore di attenuazione subito dal raggio a più bassa energia (A) e quello subito dal raggio a energia più elevata (B). Tale rapporto risulta tanto più elevato quanto più alto è il numero atomico della sostanza attraversata.

Dual-energy X-ray Absorpiometry (DXA)

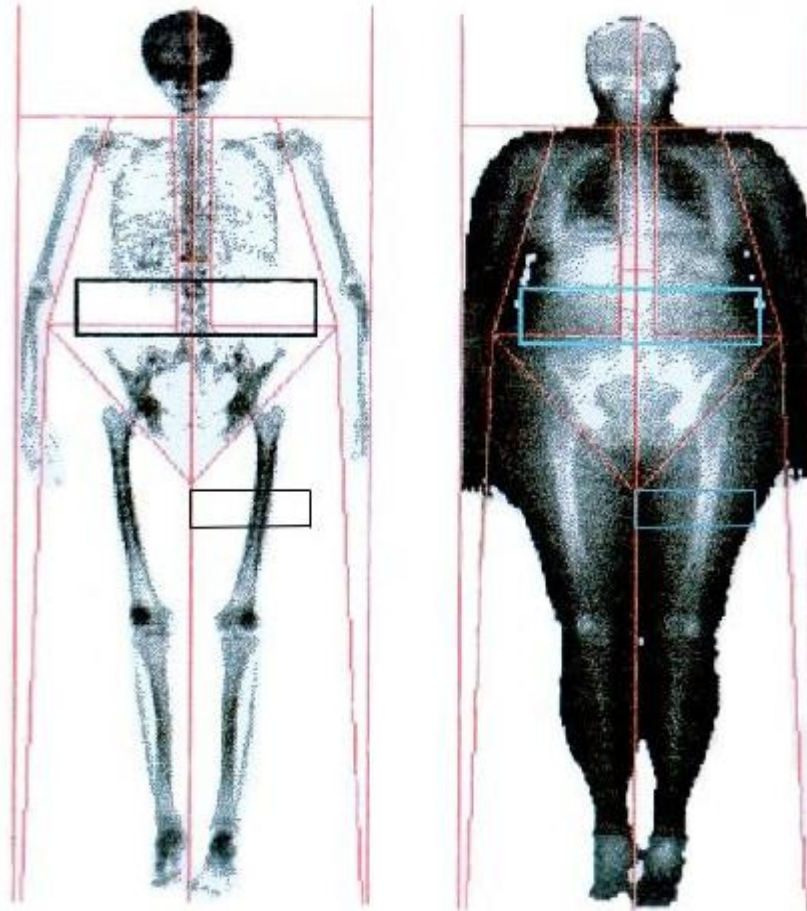


I trigliceridi (= massa grassa), essendo costituiti da H, C e O, hanno il minimo valore di R; i liquidi intra ed extra-cellulari (=massa magra), contenenti Na, K e Cl, hanno valori di R intermedi. L'osso minerale e i cristalli di idrossiapatite hanno i valori più elevati di R

Modello a tre compartimenti, massa magra non ossea (2), massa grassa (1), massa ossea (3)



Total body. Donna, kg 104, BMI 34

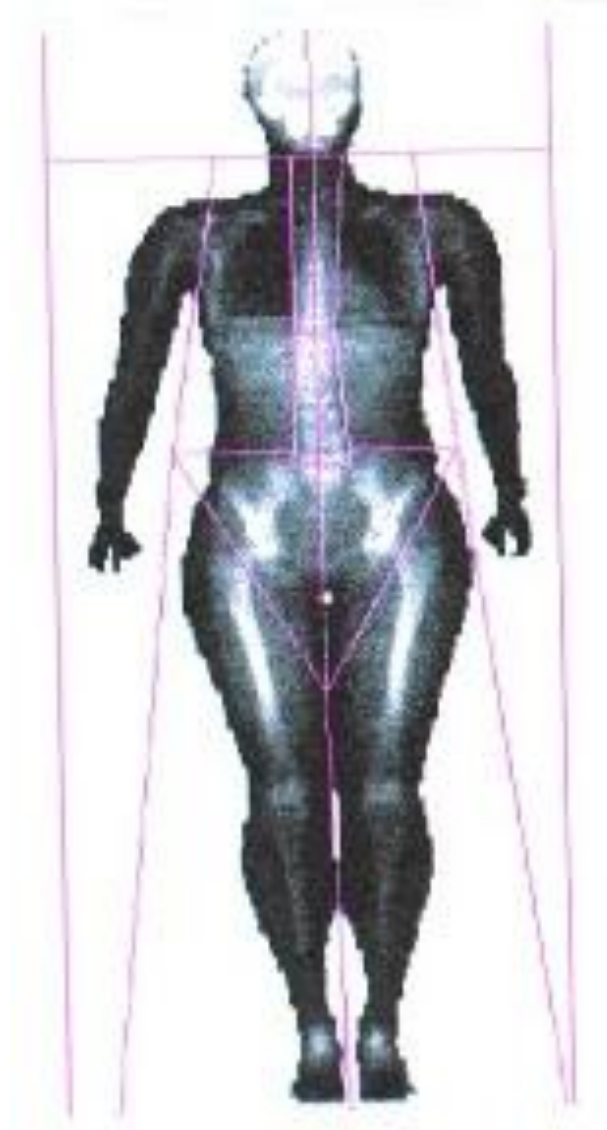


Brownbill RA and Ilich JZ, 2004

Total body.

Donna , 59 kg

BMI 22,6



Brownbill RA and Ilich JZ, 2004

BMI = 31.7



BMI = 31.7



Vantaggi e Svantaggi della DEXA

- **Vantaggi**

bassa dose radiante (una scansione equivalente a dose radiante 4 volte minore rispetto ad una normale radiografia)

può consentire la valutazione di sotto-regioni

rapido: tempo previsto per singola scansione total body

- Pencil beam DXA (20-25 min)
- Fan beam DXA (< 8 min)

estremamente diffusa e la più utilizzata nei grandi trials

non invasiva

tecnica molto precisa, riproducibile

- **Svantaggi**

costo (macchinario ed operatori)

non trasportabilità

esposizione radiante (paragonabile ad una giornata di sole)

limiti di peso e dimensioni

Weight and dimensions limits of different DXA models

Manufacturer/ Densitometer	Weight Limit Kg (lb)	Table Dimensions cm
GE Lunar iDXA	182 Kg	287 × 132
GE Lunar Prodigy	136 (300)	197.5 × 60
GE Lunar DPX-MD	136 (300)	196.8 × 57.6
Hologic QDR series	136 (300)	195.6 × 65- 67
Hologic Discovery Series	204 Kg	195 × 65
Norland XR-46	114 (250)	193 × 64
Norland XR-36	114 (250)	193 × 64

Confronto Dexa Hologic QDR 2000 e 4500

TABLE 1. TOTAL BODY COMPOSITION RESULTS USING PENCIL-BEAM AND FAN-BEAM HOLOGIC DXA INSTRUMENTS

<i>Scan mode</i>	<i>BMD</i> (g/cm ²)	<i>BMC</i> (g)	<i>Fat</i> (kg)	<i>Lean</i> (kg)	<i>%fat</i>	<i>Wt_{DXA}</i> (kg)
Pencil-beam*						
mean	0.942	1549.5	13.9	32.4	26.4	47.9
SD	0.191	838.5	11.0	14.7	9.4	24.7
min.	0.619	384.8	1.8	10.4	8.9	16.0
max.	1.284	3425.6	48.0	67.6	46.9	119.0
Fan-Beam*						
mean [†]	0.949	1556.9	13.1 ^b	33.5 ^c	25.5 ^a	48.2 ^c
SD	0.173	781.0	9.5	15.8	7.1	24.8
min.	0.678	407.4	2.5	10.9	11.7	16.3
max.	1.263	3149.4	41.8	75.1	41.1	120.0

n = 47 (21 males, 26 females); body weight = 48.4 ± 24.8 kg; range = 16.3–120.0 kg.

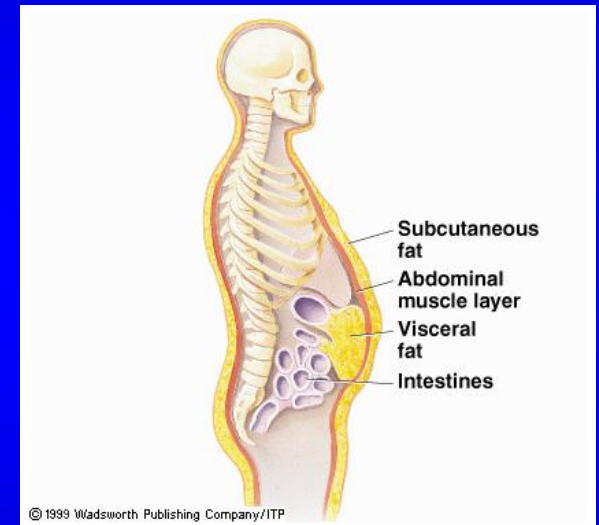
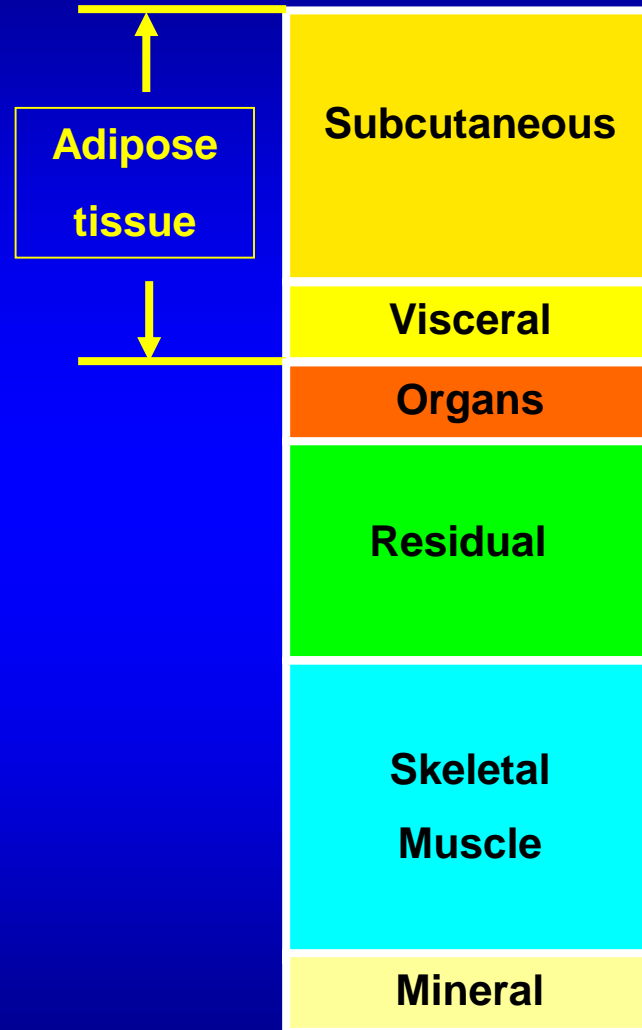
* Pencil-beam = Hologic QDR-2000W, enhanced whole-body V5.71 analysis; fan-beam = Hologic QDR-4500A, whole-body V8.21a analysis.

[†] Paired *t*-test results for pencil-beam vs. fan-beam: (^a*p* < 0.02, ^b*p* < 0.0001, ^c*p* < 0.00001).

Most used current methods for quantifying Adipose Tissue in vivo

- Computed Tomography
- Magnetic Resonance

Tissue organ level of body composition



Classificazione del tessuto adiposo viscerale

Visceral adipose tissue (VAT)

• Tessuto adiposo intratoracico

Intrapericardico

Extrapericardico

• Tessuto adiposo intraaddominopelvico

Intraperitoneale (e.g., omentale e mesenterico)

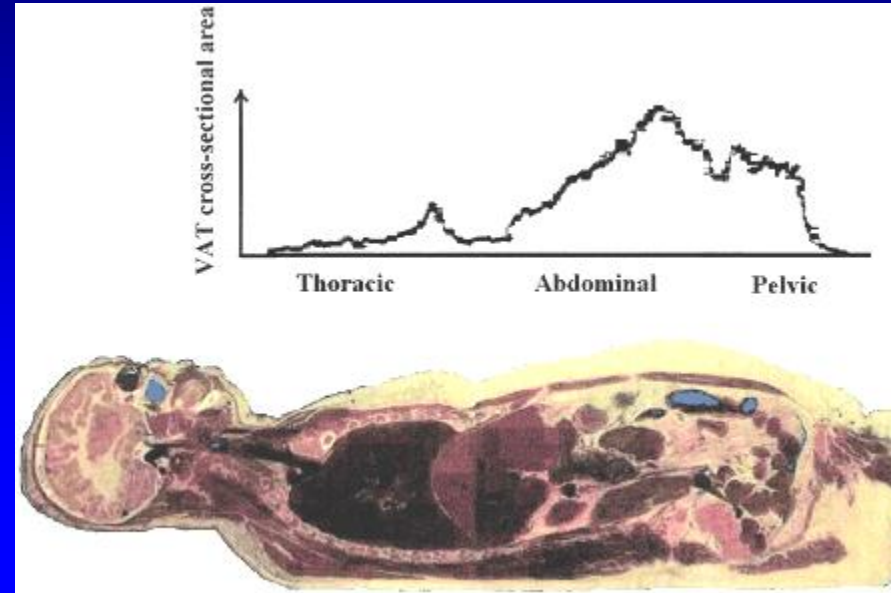
Extraperitoneale

Intraaddominale

Preperitoneale

Retroperitoneale (e.g., perirenale, pararenale, periaortico, e peripancreatico)

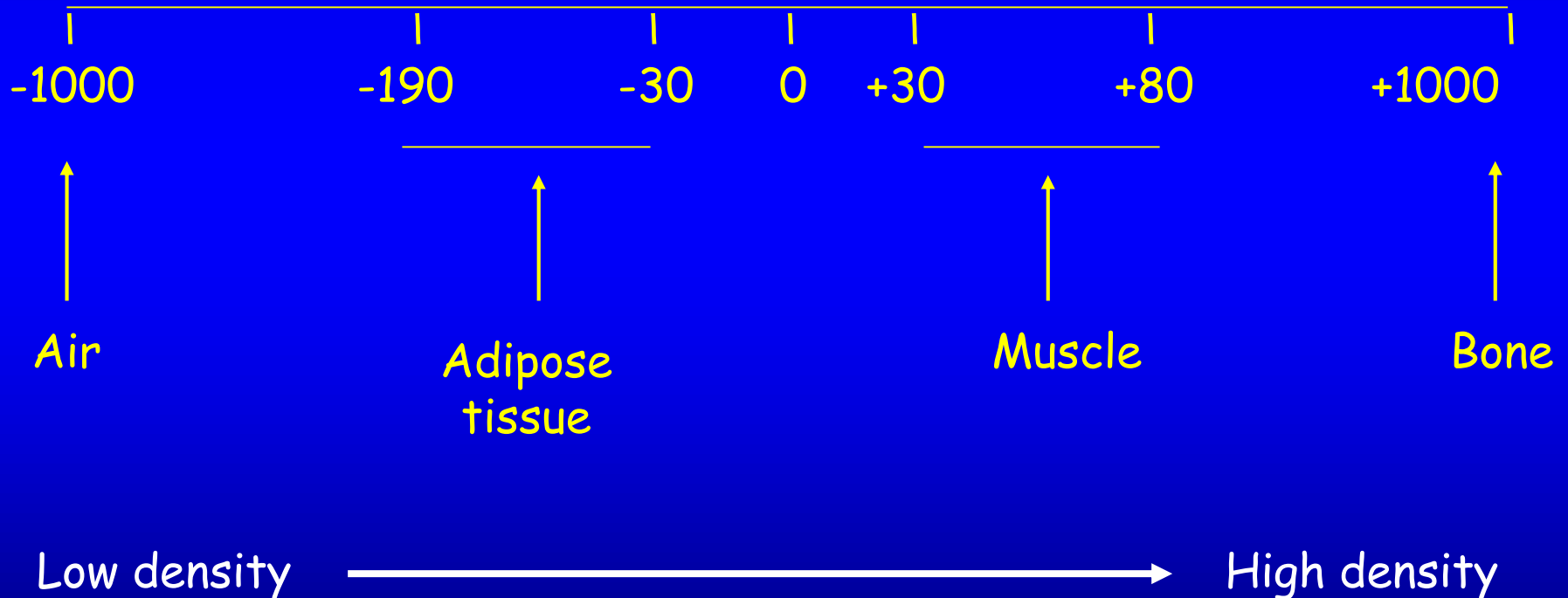
Intrapelvico (e.g., parametricale, retropubico, paravescicale, retrouterino, pararettale, retrorettale)



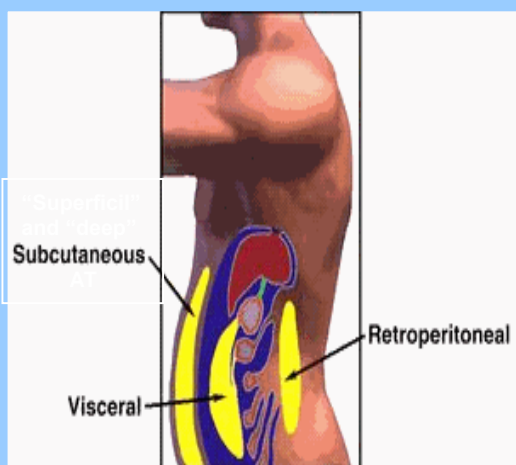
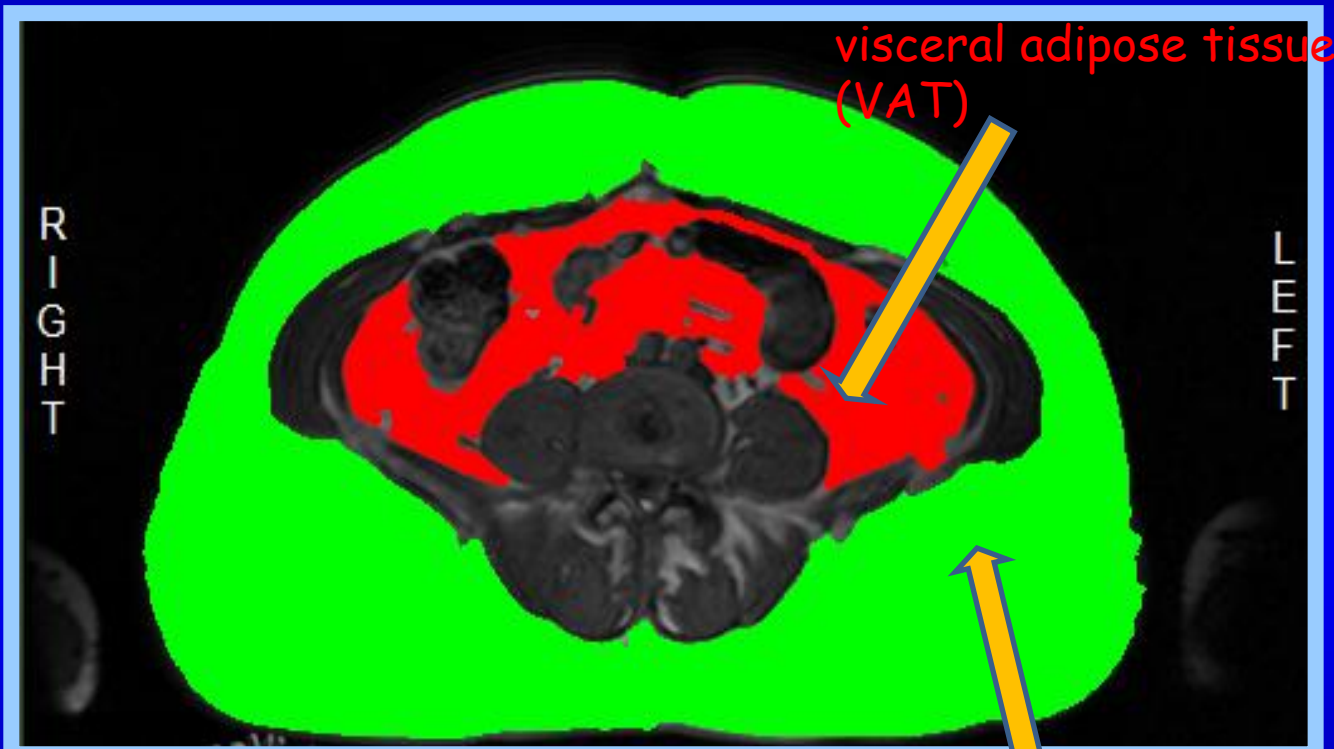
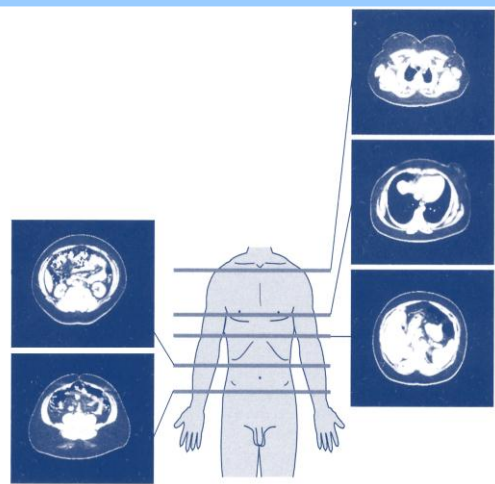
CT scan

CT can differentiate tissues based on their attenuation characteristics, which depend on their density.

X-ray attenuation is quantified as Hounsfield Units (HU).



Abdominal Magnetic Resonance Imaging (MRI) L4-5

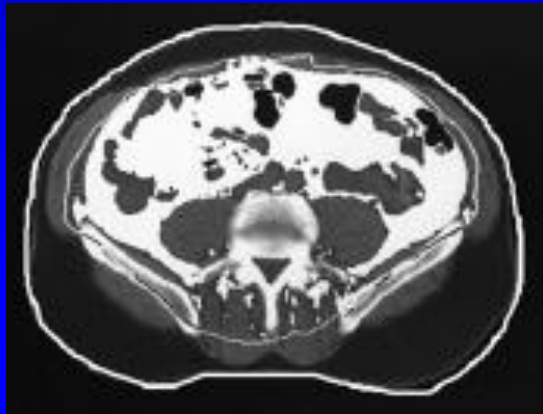


visceral adipose tissue (VAT)

subcutaneous adipose tissue (SCAT)

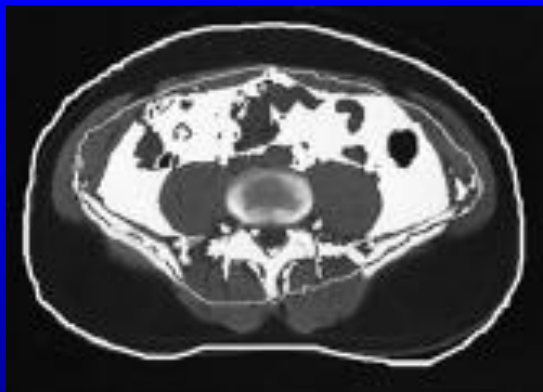
Adiposità Viscerale vs Sottocutanea

scansioni TAC matchati per BMI e adiposità corporea totale



**Obesità
Viscerale**

**Fat mass: 19.8 kg
VFA: 155 cm²**



**Obesità
Sottocutanea (sc)**

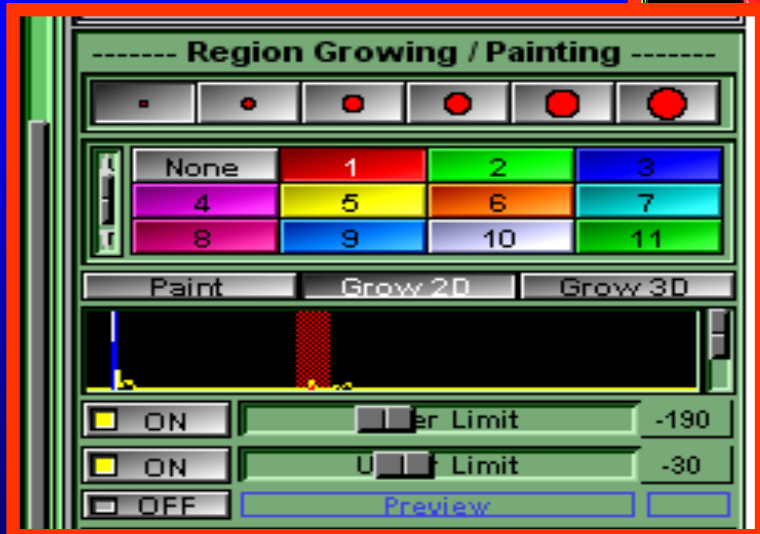
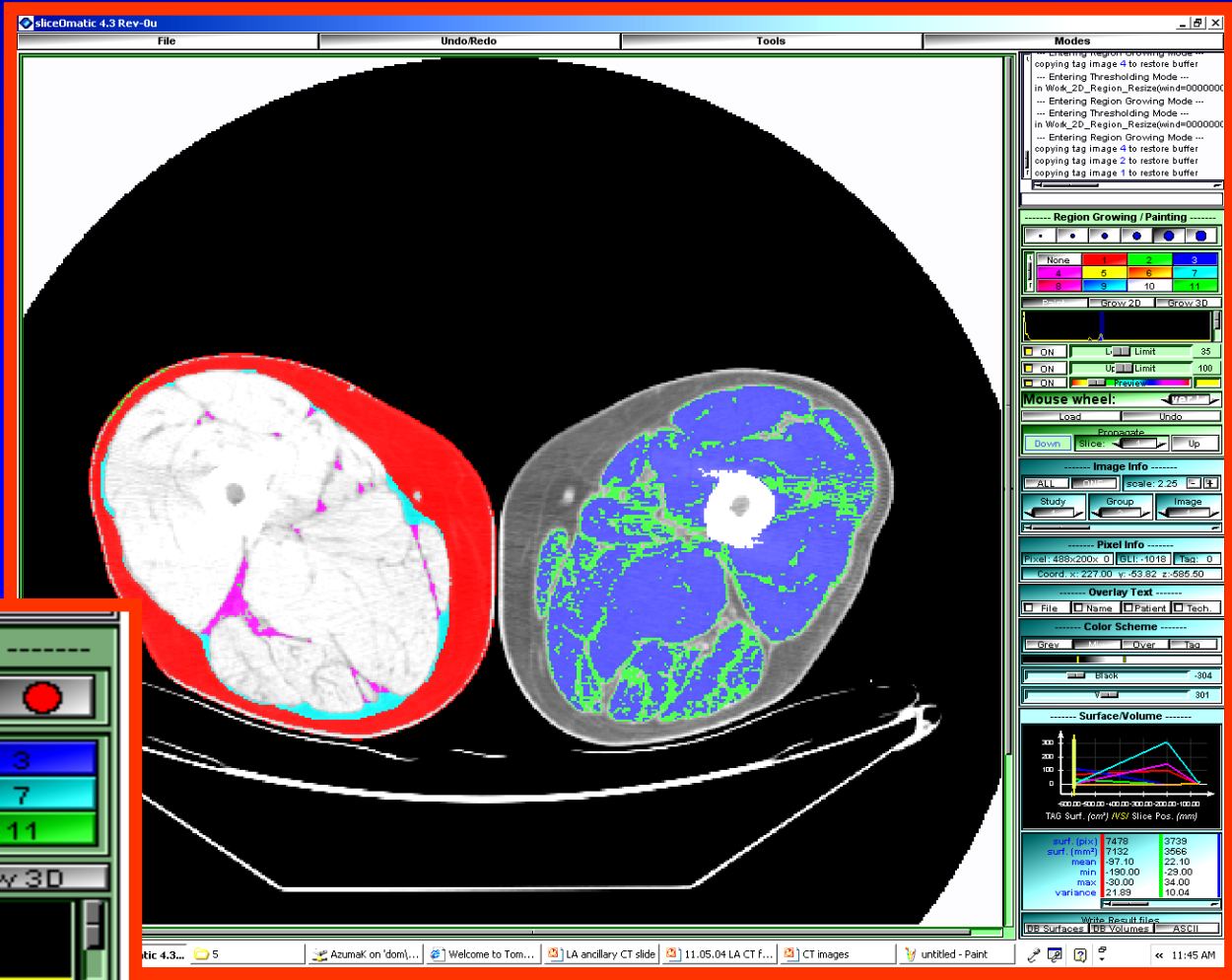
**Fat mass: 19.8 kg
VFA: 96 cm²**

**White = VFA
Black = sc fat**

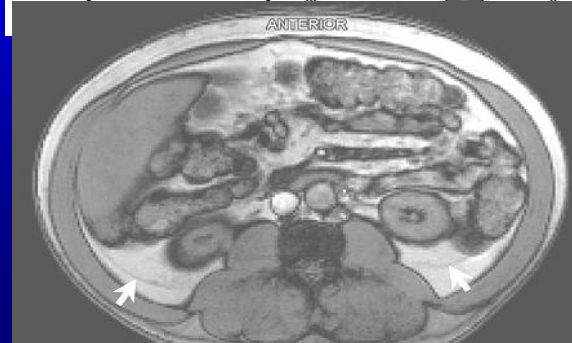
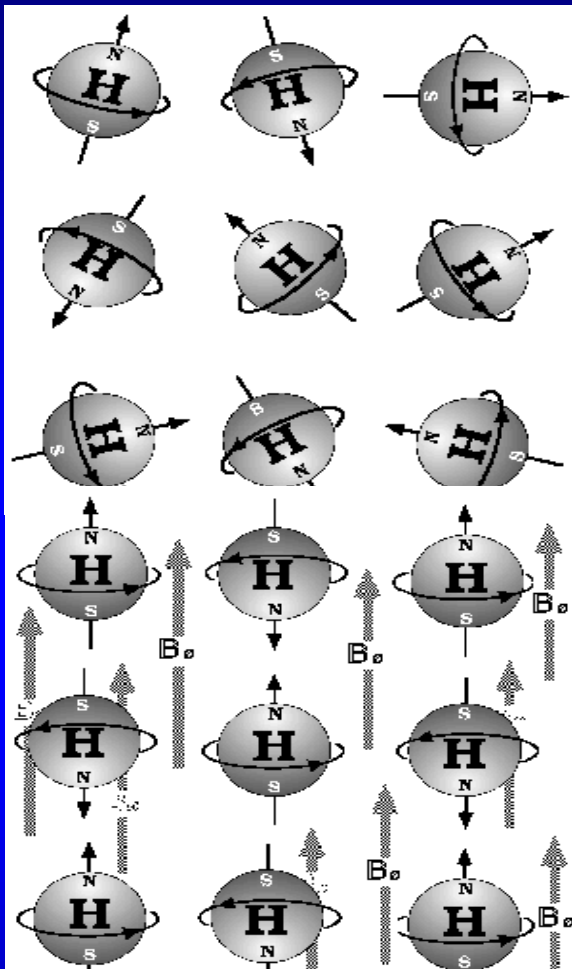
Analisi TAC con programma Sliceomatic con modalità Region Growing a livello della Coscia



Hounsfield units:
>200 HU for bone
-30 to -190 HU for AT
0 to 100 HU for muscle



MRI



Gli atomi e le molecole del corpo umano sono sottoposte ad un campo magnetico di lieve intensità determinato dal campo gravitazionale terrestre.

Un campo magnetico debole determina un **allineamento casuale** dei nuclei che dipende dal loro intrinseco movimento rotatorio.

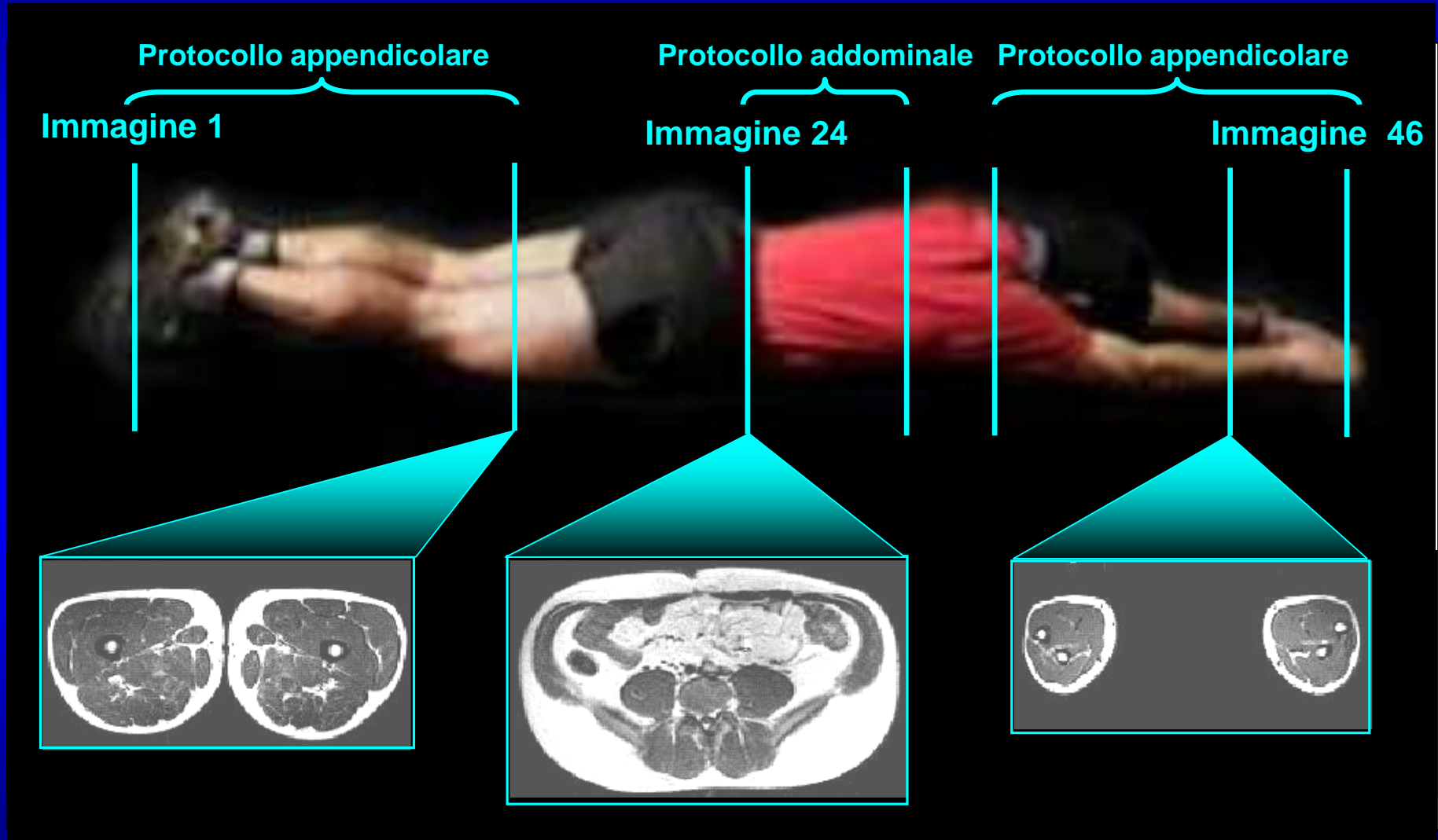
Quando il corpo viene posizionato in un campo magnetico ad alta intensità, alcuni nuclei (ad esempio protoni ^1H , ^{13}C , ^{31}P , ^{23}Na) **si allineano** secondo l'orientamento del campo, altre in senso opposto.

Il campo magnetico viene quindi sottoposto ad onde radio (RF) che determinano una variazione del livello di energia dei nuclei.

Dopo sospensione dell'impulso RF si determina **variazione del livello di energia** dei vari nuclei **che viene quindi rilasciata**. Il tempo impiegato per **riprendere la originale posizione** (**tempo di rilassamento: T1**) è diverso per i vari nuclei. T1 per i protoni della **massa adiposa è più breve** di quello dell'acqua. Il tempo dall'impulso RF è poi aggiustato per il tempo necessario per la rilevazione del segnale (**spin-echo sequenza**).

Il computer MRI ricombina i dati acquisiti determinando l'immagine 3 D

Magnetic Resonance Imaging (MRI) Misurazione del tessuto adiposo Totale e Distrettuale



MRI Validation Studies

Reference	Subject (N)	IV	Correlation (SEE, %)			
			Subcut. AT	Visceral AT	Total AT	SM
Comparison with CT						
Seidell et al., 1990	Human (7)	Mid-abdomen	0.79 (4.9)	0.79 (12.8)	0.99 (4.4)	—
Sobel et al., 1991	Human (11)	Umbilicus	0.98 (8)	0.93 (20)	—	—
Ross et al., 1991	Rat (21)	Whole body	0.98 (12)	0.98 (13.6)	0.99 (8.7)	—
Comparison with Cadavers						
Engstrom et al., 1991	Human (3)	Thigh muscle CSA	—	—	—	0.99

NOTE: MRI, magnetic resonance imaging; SEE, standard error of estimate; IV, independent variable; AT, adipose tissue; SM, skeletal muscle; CT, computerized axial tomography; CSA, cross-sectional area.

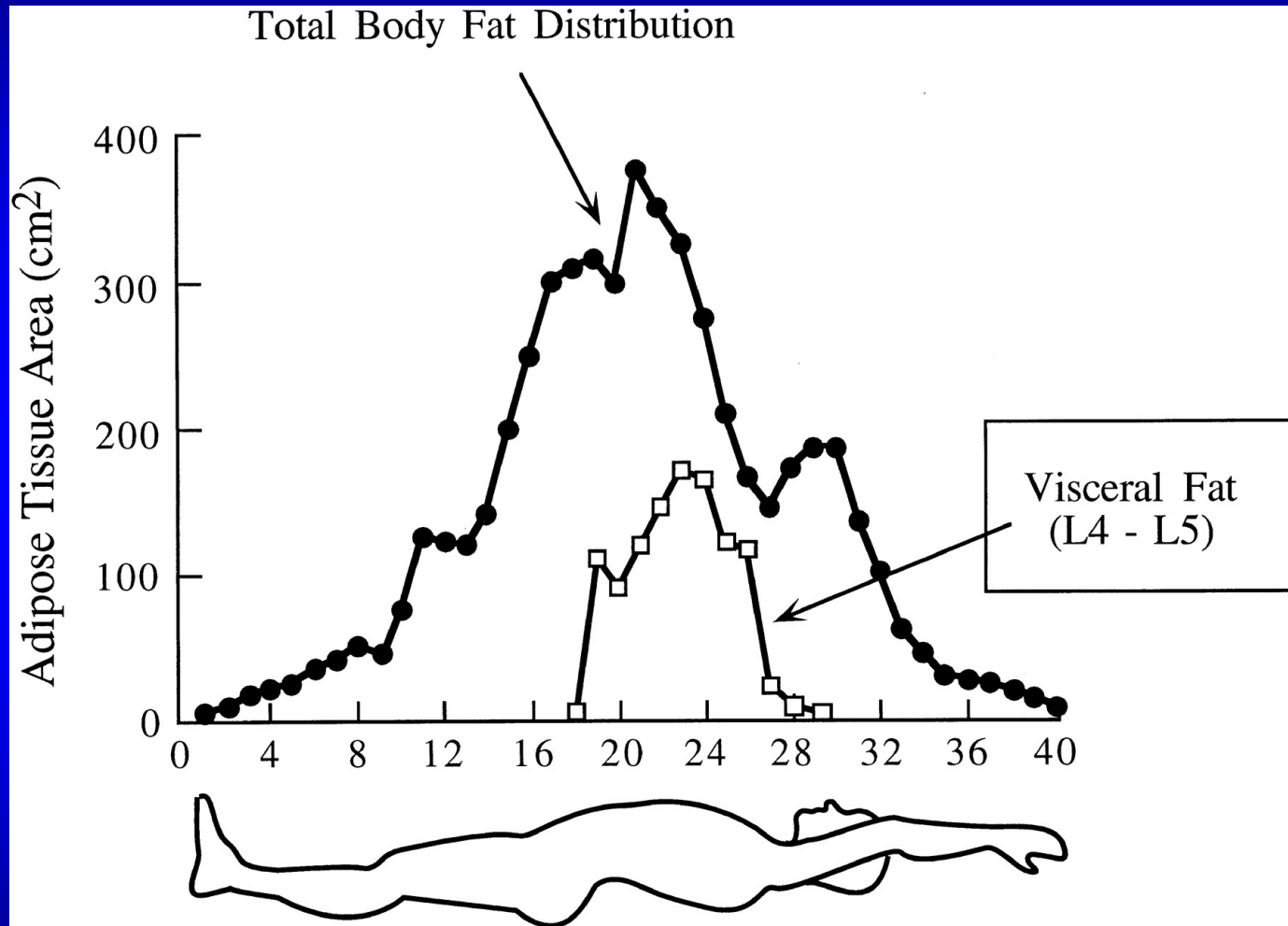
MRI Reliability Studies

Reference	Subject (N)	T	MRI Sequence	Anatomical Position	Coefficient of Variation (%)			
					Subcut. AT	Visceral AT	Total AT	LT
Staten et al., 1989	Human	0.5	SE	Mid-abdomen	5.0	10.0	3.0	—
Seidell et al., 1990	Human	1.5	IR	Umbilicus	10.1	10.6	5.4	—
Garard et al., 1991	Human	1.5	SE	6 in	—	—	—	—
Ross et al., 1991	Rat	1.5	SE	W b	—	—	—	—
Ross et al., 1993	Human	1.5	SE	L W b	—	—	—	—
Sohlström et al., 1993	Human	0.02	SR	W body	—	—	—	—
Ross et al., 1994	Human	1.5	SE	Proximal thigh	—	—	—	1.2
Abate et al., 1994	Cadaver	0.35	SE	Abdomen	2.2	6.0	—	—
Ross et al., 1995a	Human	1.5	SE	L4-L5	—	—	—	1.0

CV's for MRI are about two to three time greater than those reported for studies using CT.

NOTE: MRI, magnetic resonance imaging; T, strength of magnet in Teslas; AT, adipose tissue; LT, lean tissue; SE, spin-echo; IR, inverse recovery; SR, saturation recovery; L4-L5, lumbar vertebrae 4–5.* Reported as nonsubcutaneous adipose tissue.

Distribuzione del tessuto adiposo totale e viscerale in un adulto, maschio non obeso con MRI



Ellis, K. J. *Physiol. Rev.* 80: 649-680 2000

Risonanza Magnetica Nucleare (MRI)

Vantaggi

non utilizza raggi X

qualità di immagine molto alta

relativamente rapida (approx 30 min per total body)

utilizzabile per studi clinici longitudinali

Svantaggi

minore precisione

possibilità di artefatti

apparecchiatura estremamente costosa

alcune esclusioni (e.g. pacemakers)

Main quantitative features of available body composition methods used to evaluate adiposity-related components

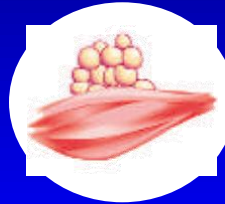
	UWW	ADP	DXA	MRI	CT	ANTH	BIA
Accurate?	●●●	●●●	●●●	●●●●	●●●●	●	●●
Reproducible?	●●	●●	●●●●	●●●	●●●	●	●●●●
Cost to purchase?	●●	●●●	●●●	●●●●	●●●●	●	●
Cost to operate?	●●	●●	●●	●●●	●●●	●	●
Technician training?	●●	●●	●●	●●●	●●●	●●	●
Radiation exposure?	●	●	●●	●	●●●●	●	●
Requires subject participation?	●●●	●●	●	●	●	●	●
Trasportable?	●	●●	●●	●	●	●●●●	●●●●
Regional estimates?	N	N	Y	Y	Y	Y	Y
Appropriate for:							
Very obese adults?	Y	N	N	N	N	Y	Y
Children?	Y	Y	Y	Y	N	Y	Y
Elderly?	Y	Y	Y	Y	Y	Y	Y

Ectopic fat deposition consequences

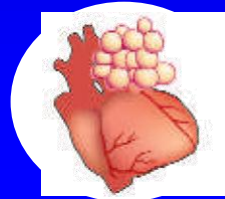
Lipid overflow ectopic fat



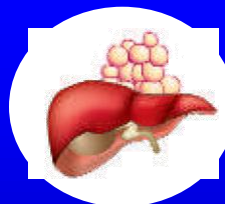
Altered FFA
metabolism
Altered release
of adipokines



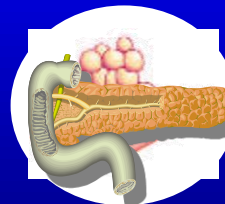
↑ Muscle fat
(↑ Intracellular lipid)



↑ Epicardial fat



↑ Liver fat and
altered function



↑ Pancreas fat and
altered function

↓ Cardiac function
↓ Insulin sensitivity
Dyslipidemia
↓ β -cell function
Atherosclerosis
NASH

FFA = free fatty acids

NASH = nonalcoholic steatohepatitis

Adapted from Després J-P, Lemieux I. *Nature*. 2006;444:881-7.
Molavi B et al. *Curr Opin Cardiol*. 2006;21:479-85.

Most widely used current methods for muscle quality evaluation in vivo

intermuscular fat (extramyocellular lipid)

- CT
- MRI

intramyocellular fat

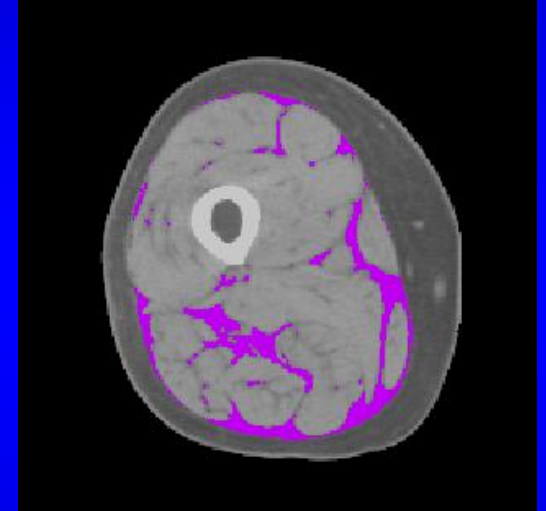
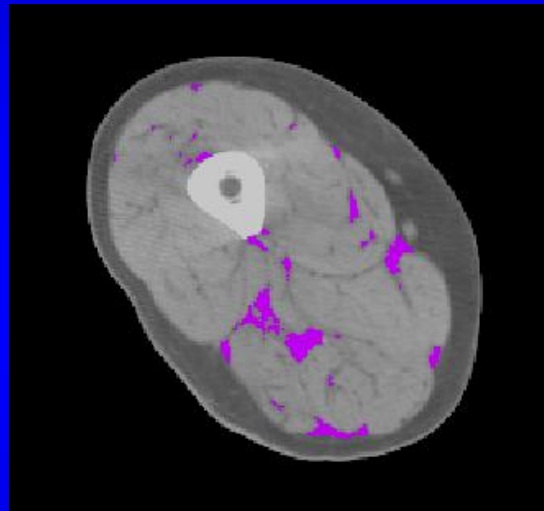
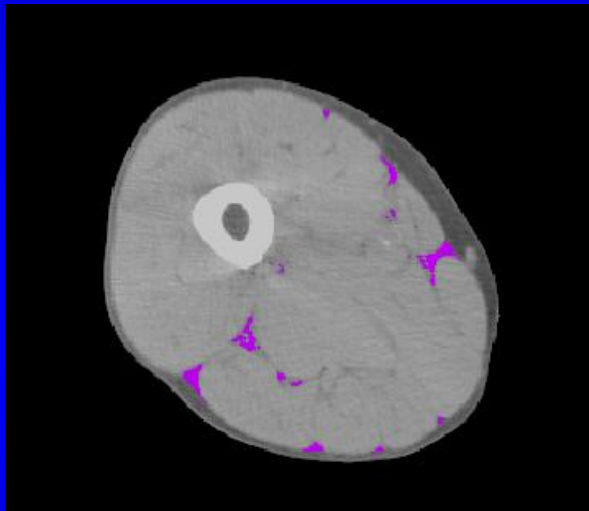
- CT muscle attenuation
- MRS Magnetic resonance spectroscopy

Intermuscular Fat

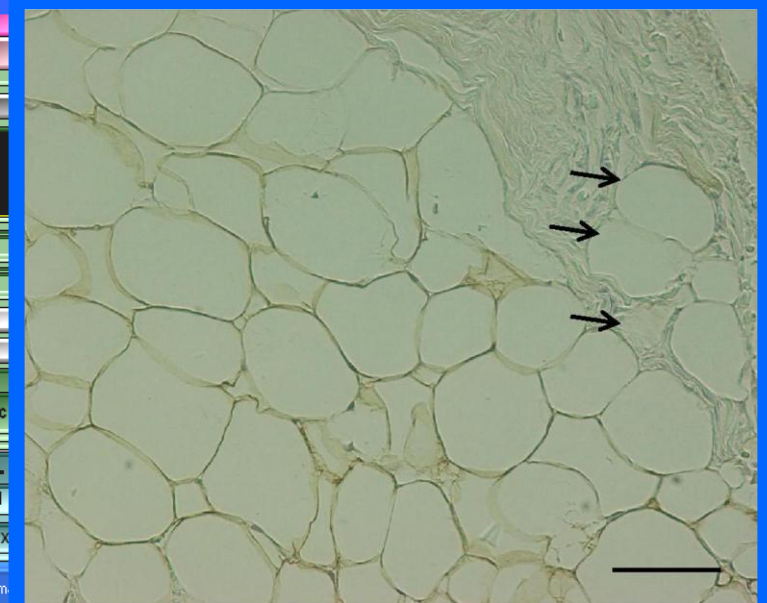
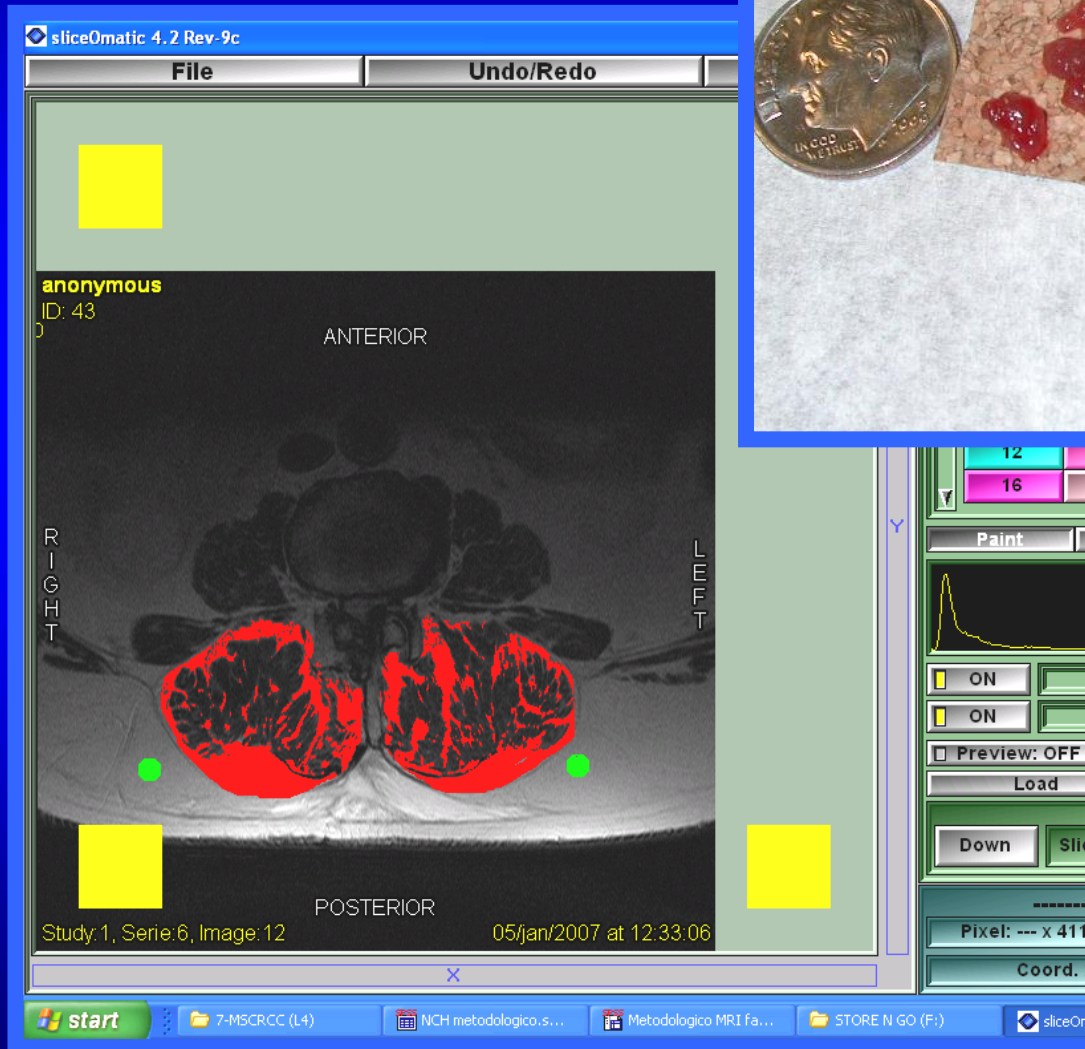
Less

More

Most

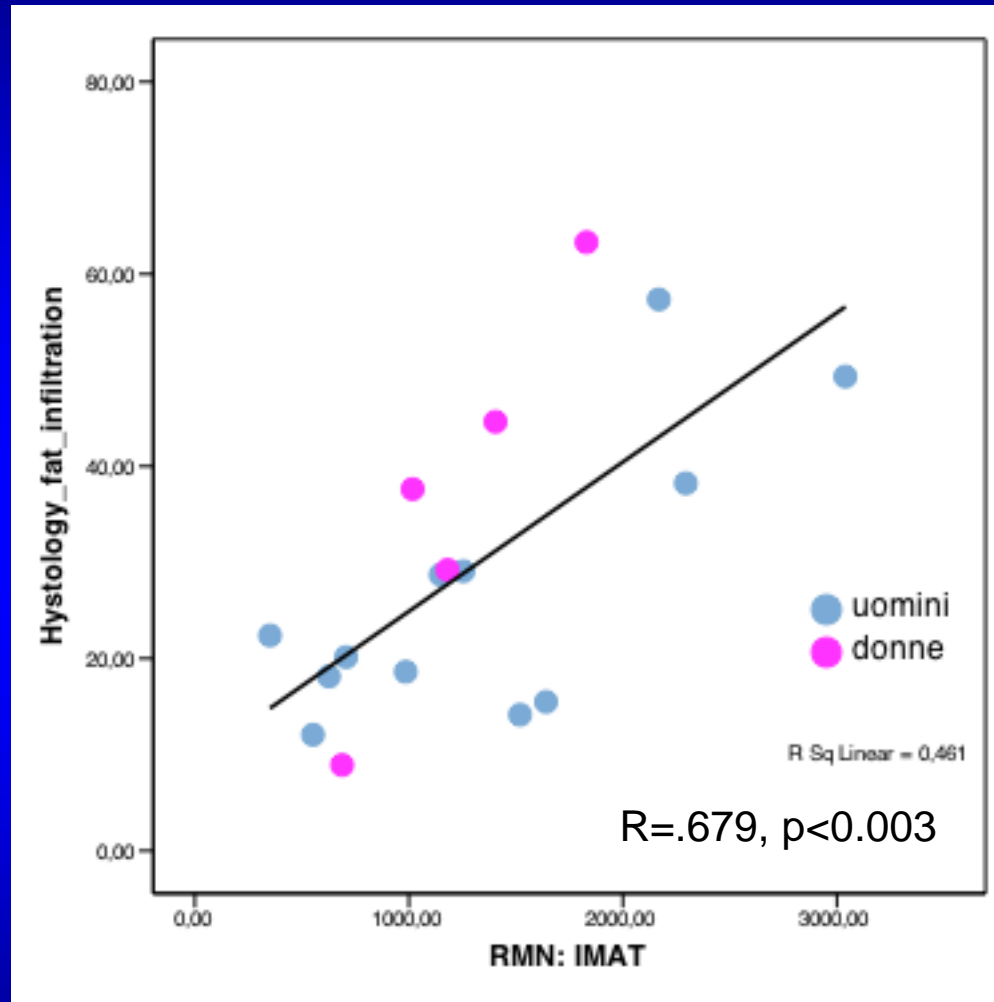


Quantification of Intermuscular Adipose Tissue in the Erector Spinae Muscle by MRI: Agreement With Histological Evaluation



Correlation between IMAT evaluated with MRI and % Histological fat infiltration

N=17
M=12, F=5



TAC

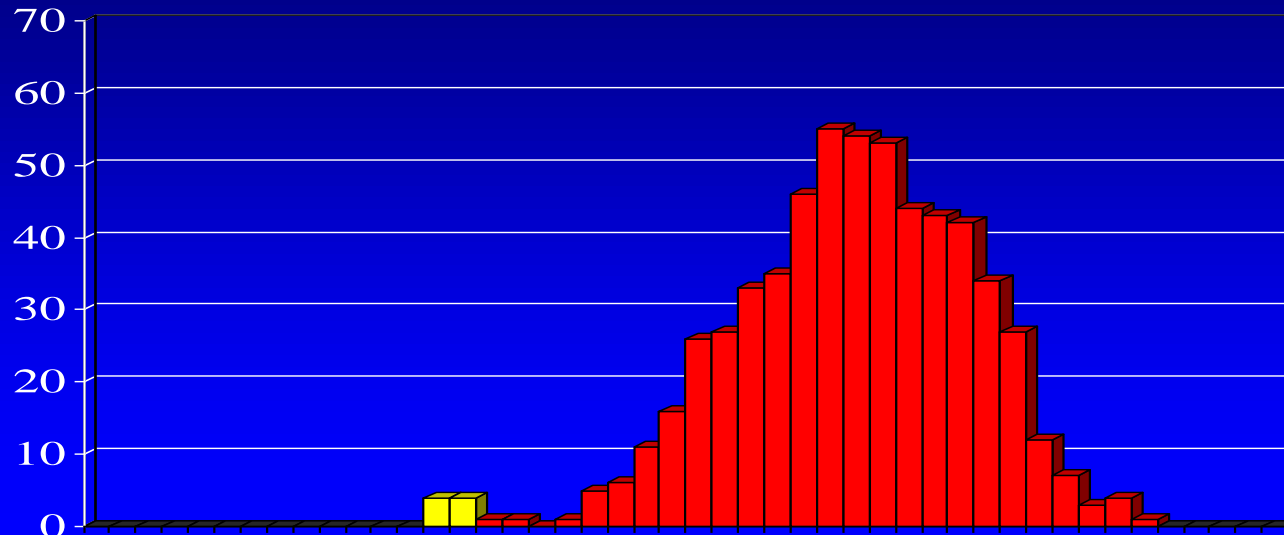
In tale metodica l'attenuazione subita dai raggi X è quantificata in Unità di Hounsfield (HU).



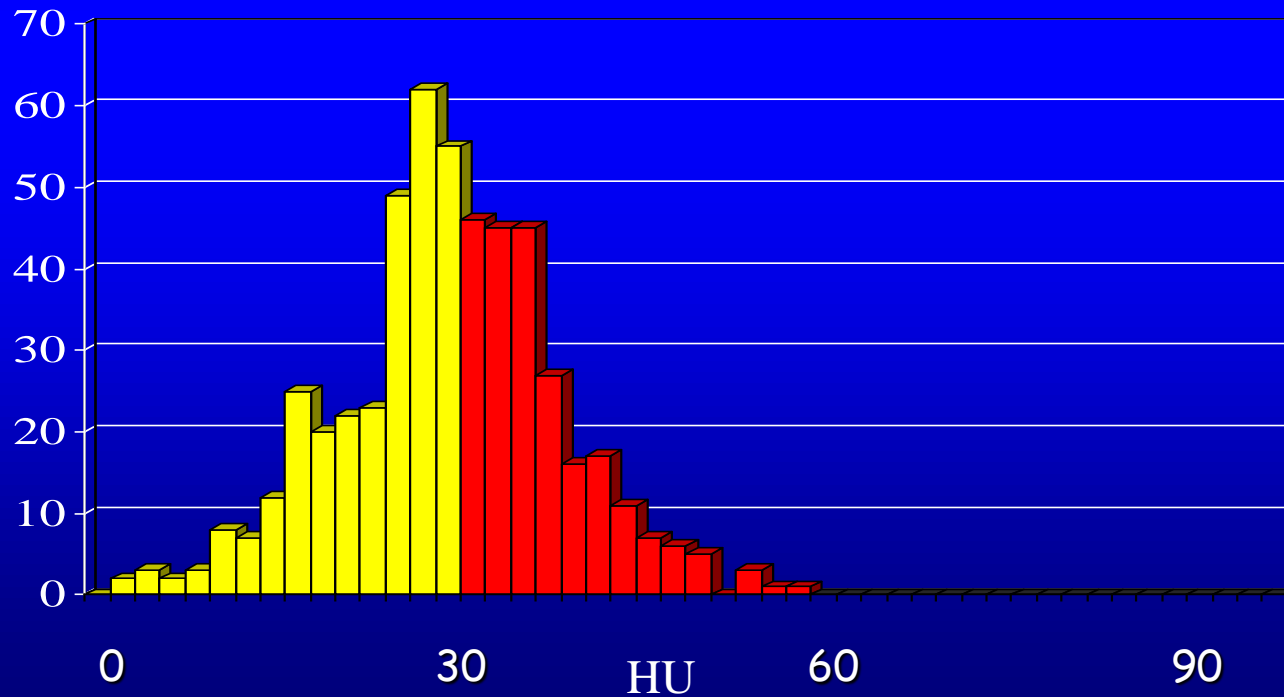
Muscle density - average value of muscle = lean, fat, collagen, blood vessels- lower density means more fat

Myosteatorsis - muscle density and/or intramuscular fat

Skeletal muscle attenuation in lean and obese subjects



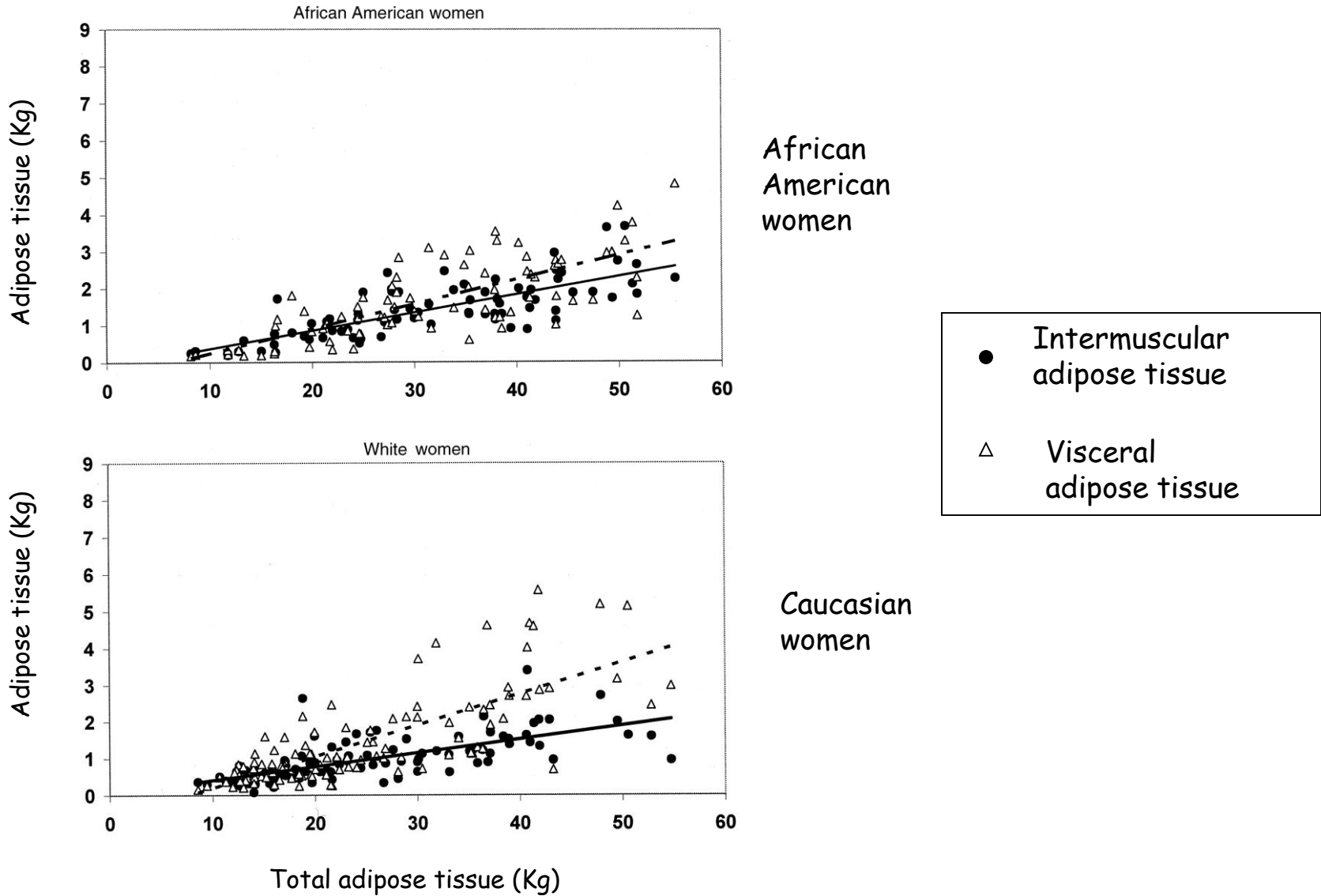
Lean



Obese

Kelley 2001

Tessuto adiposo intermuscolare e viscerale in relazione alla massa adiposa totale in donne di razza diversa



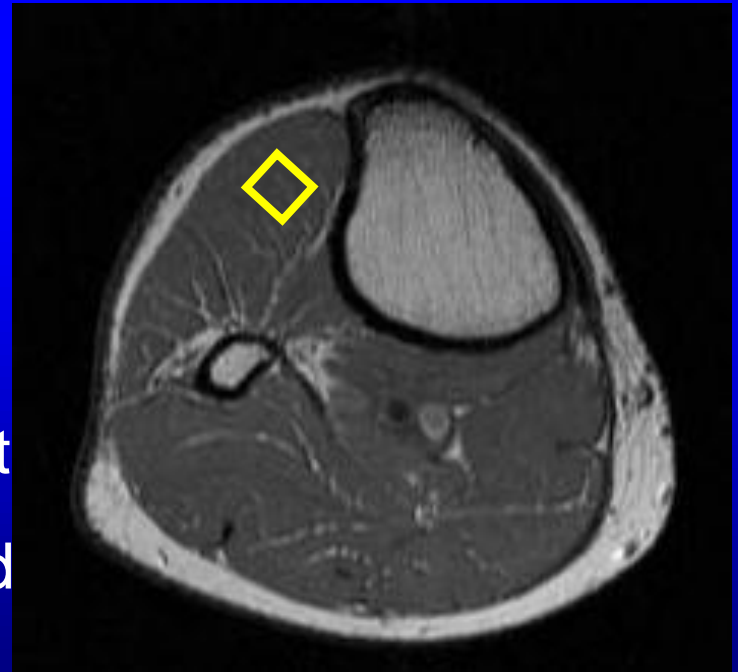
NMR spectroscopy measurements of intramyocellular lipid: ROI Placement

MR images with good separation
of fat / muscle tissue

Place ROI in fat-free muscle
tissue

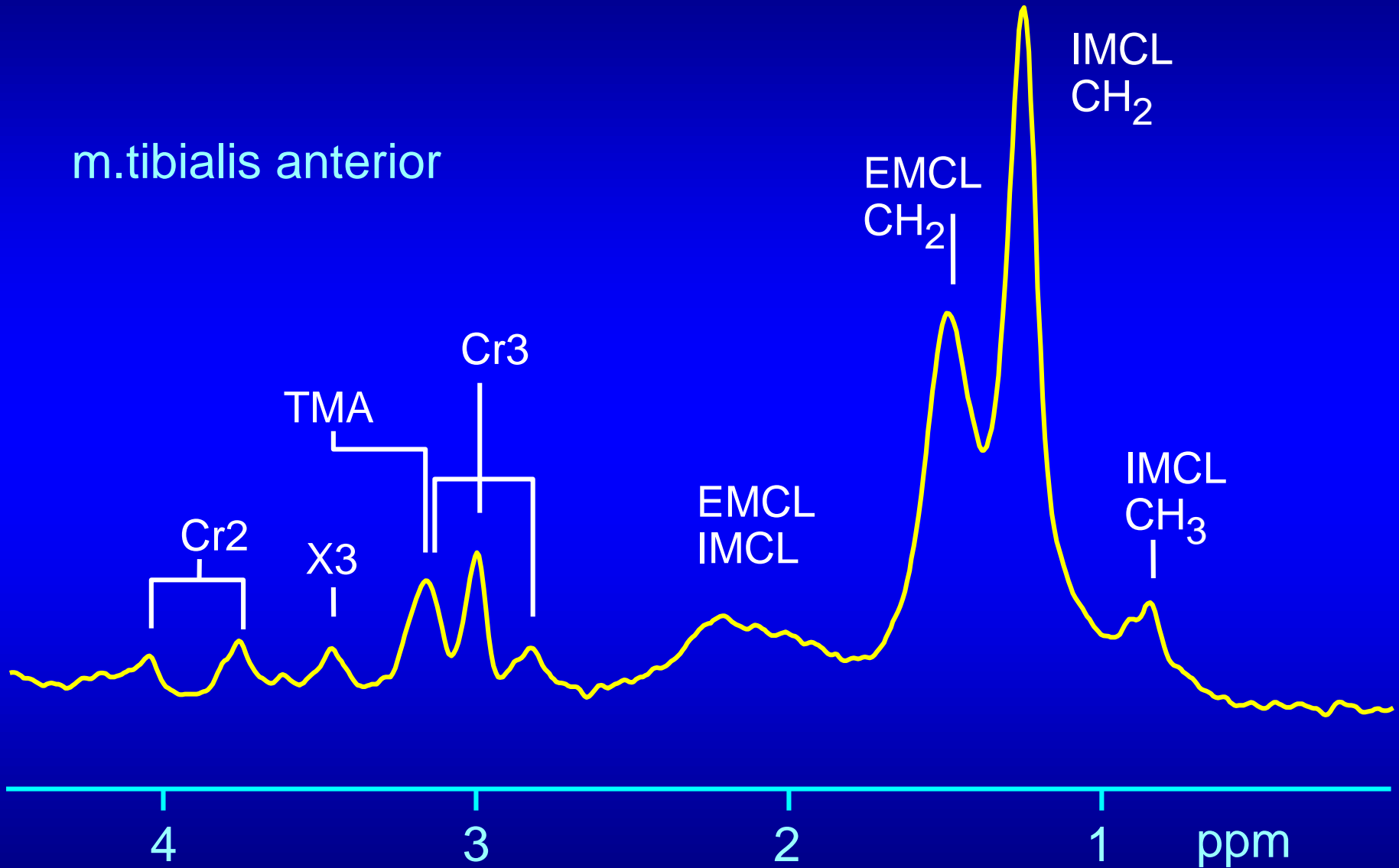
Stay away from subcutaneous fat

Reproduce ROI placement based
on anatomic landmarks



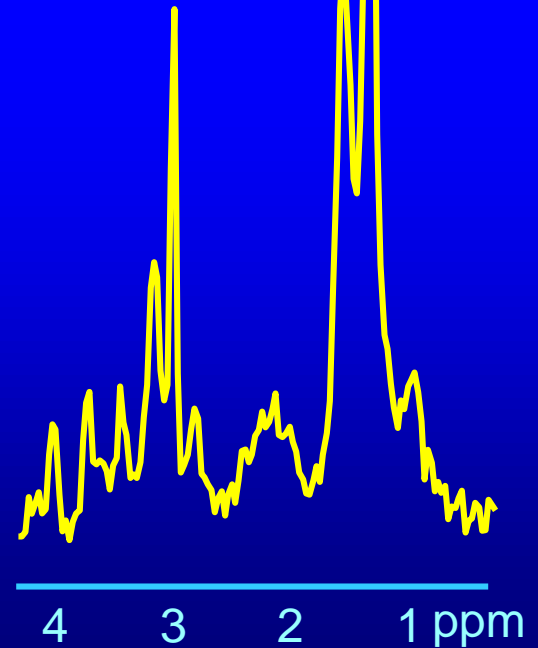
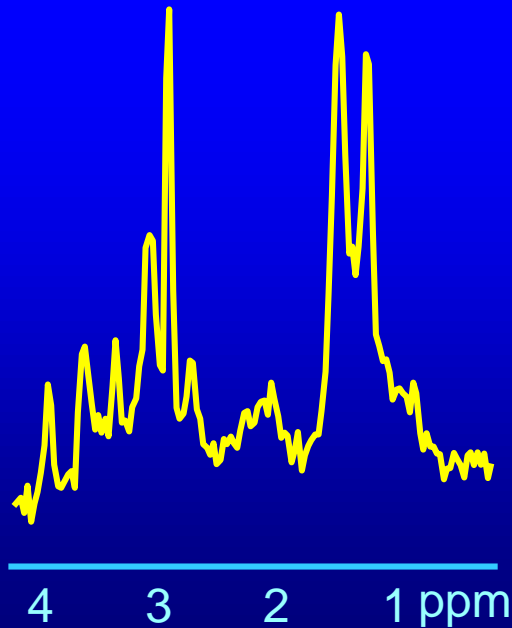
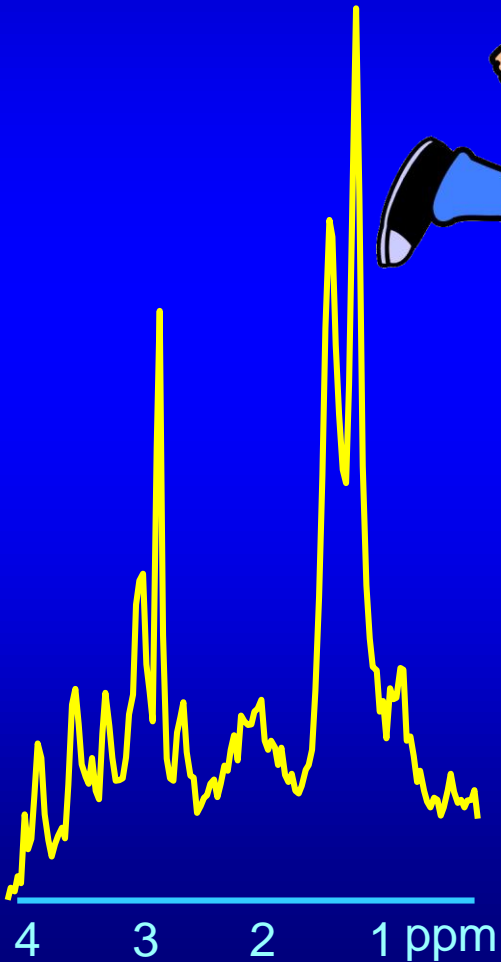
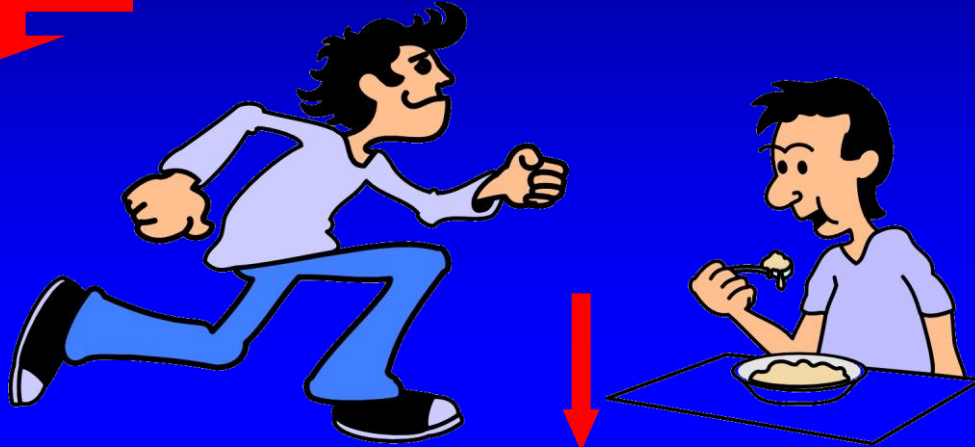
Intramyocellular lipid by proton NMR

m.tibialis anterior



Depletion and replenishment of intramyocellular lipids

IMCL



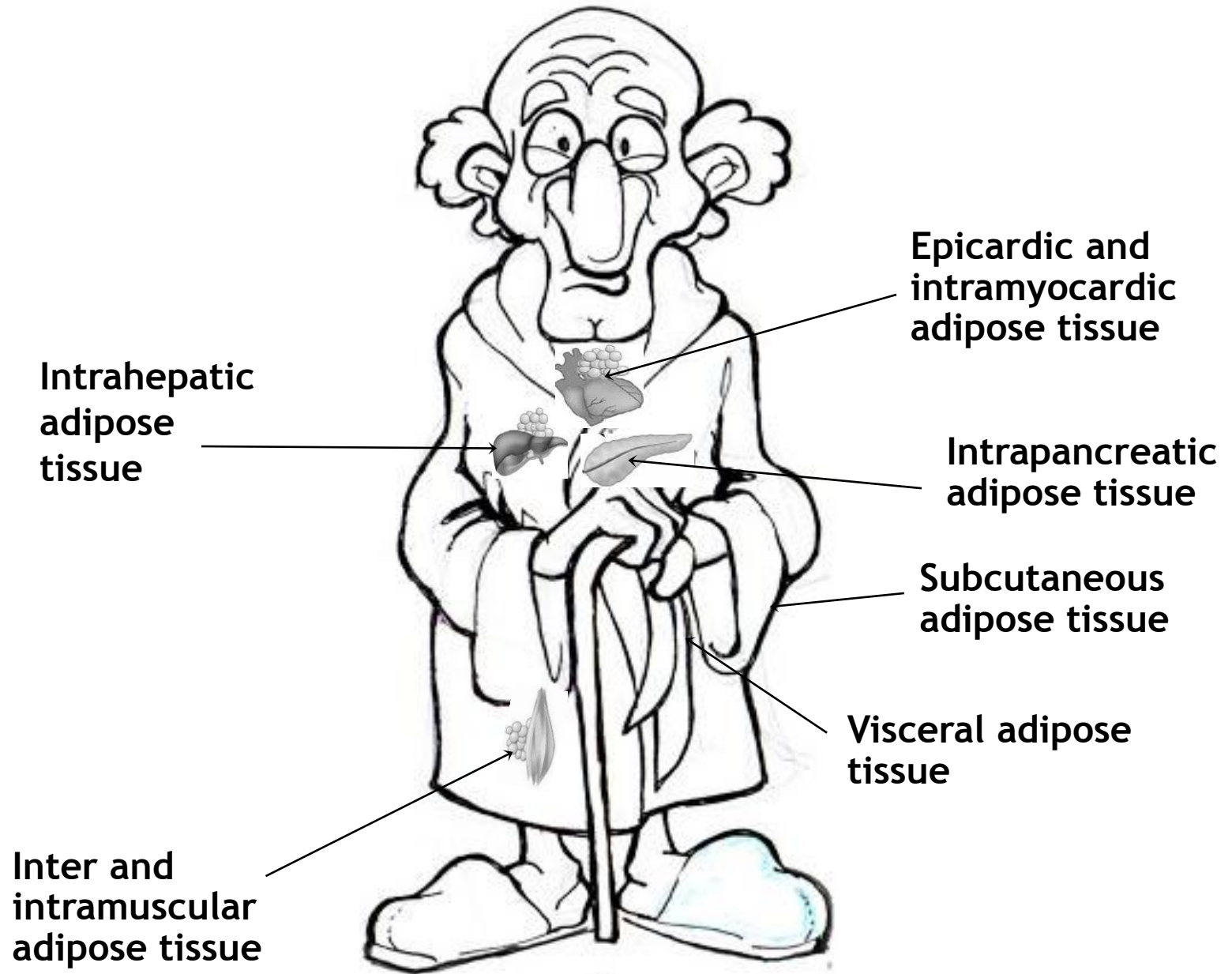
Muscle-associated Triglyceride Measured by CT and Magnetic Resonance Spectroscopy

	H-MRS	CT
distinzione IMCL vs EMCL	sì	no
CV soleo CH 2 within subjects	IMCL 7.25% EMCL 18.8%	1.9%
CV tibiale CH 2 within subjects	IMCL 10.26% EMCL 28.5%	4.0%
Problemi tecnici	elevati	medi

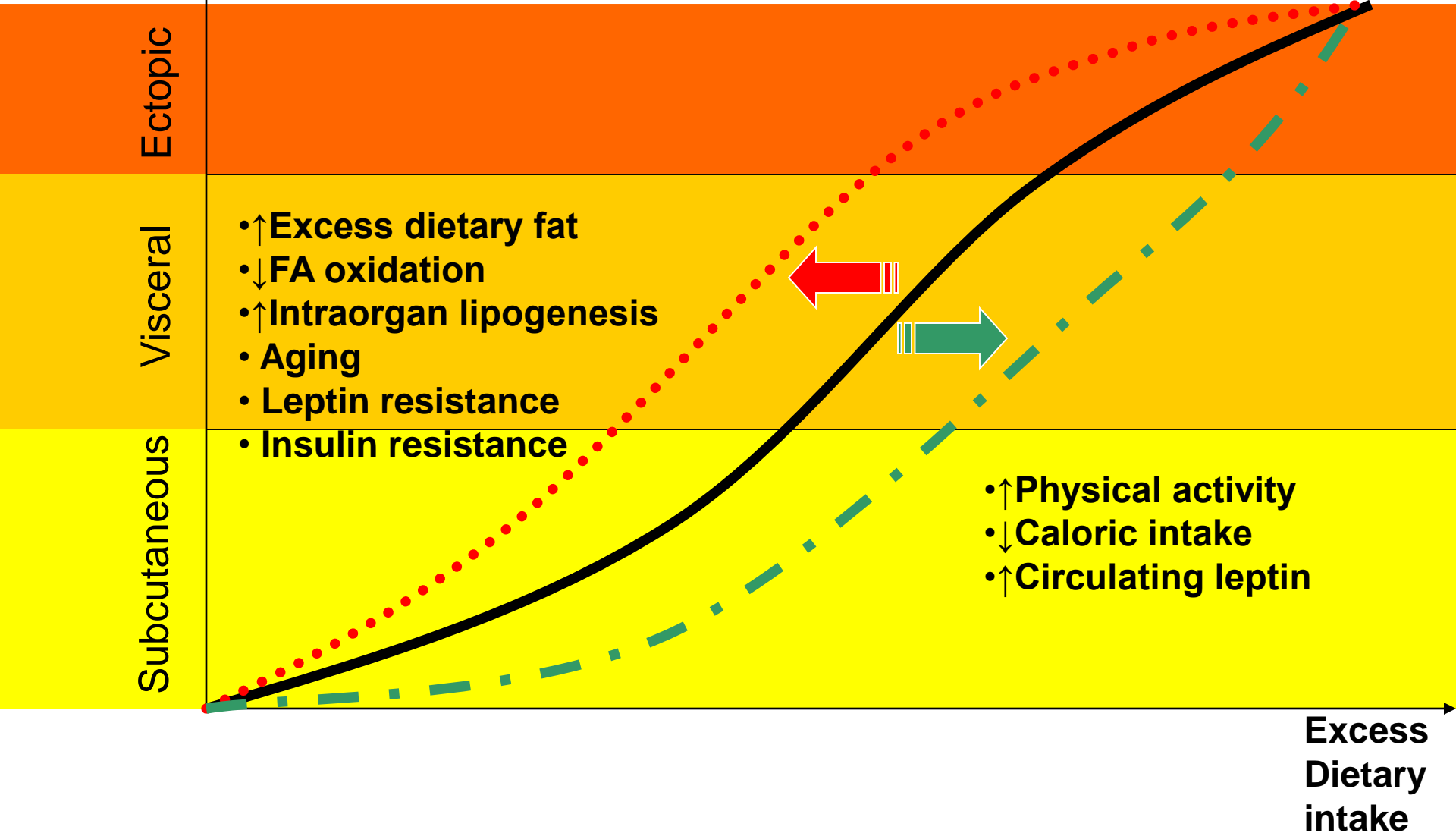
Most widely used current methods for quantifying fat in organs

- Liver ectopic fat deposition
- Pancreas ectopic fat deposition
- Epicardic fat evaluation

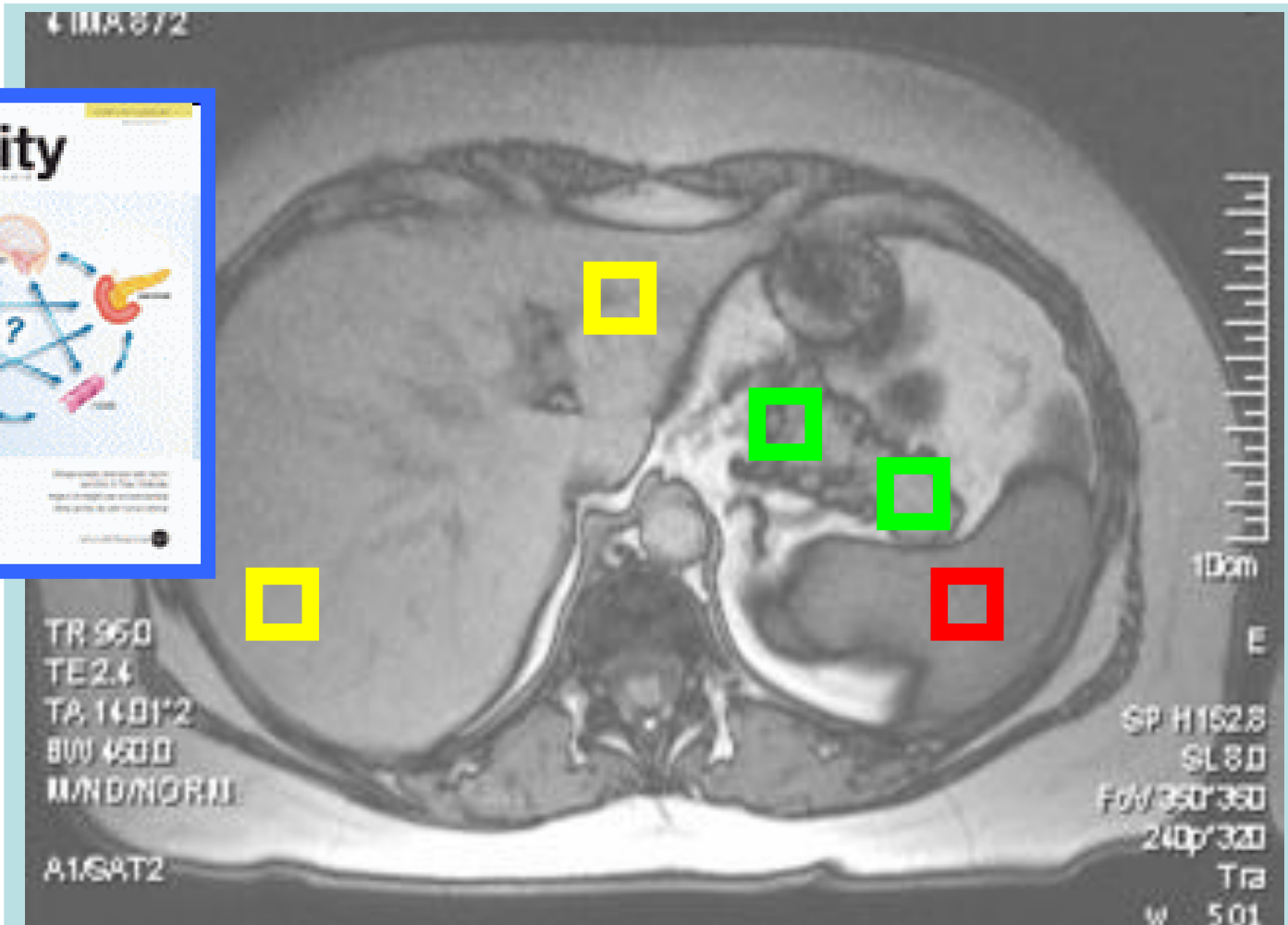
Figure 1: Ectopic fat deposition in the elderly



Adipose Tissue



LIVER and PANCREAS FAT DEPOSITION EVALUATION with in and out of phase CHEMICAL-SHIFT technique



Liver fatty replacement measured with Chemical Shift MRI

BMI = 24

4 IMA 30 / 2

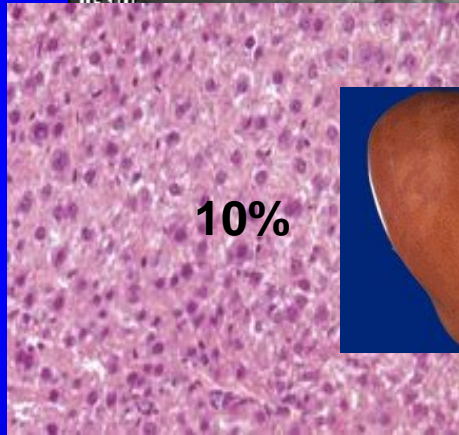
R

MF 100

10cm

E

Policlinico G. B. Rossi Verona
Symphony
MR 2014
HFS
+LPH
Policlinico G. B. Rossi Verona
↓



Policlinico G. B. Rossi Verona
↓

R

MF 100

TR 950
TE 2.4
TA 14.01'2
BW 460.0
M/MO/NORM

A1/SAT2

*10312 / 70

SP H152.8

SL 8.0

Fov 350*350

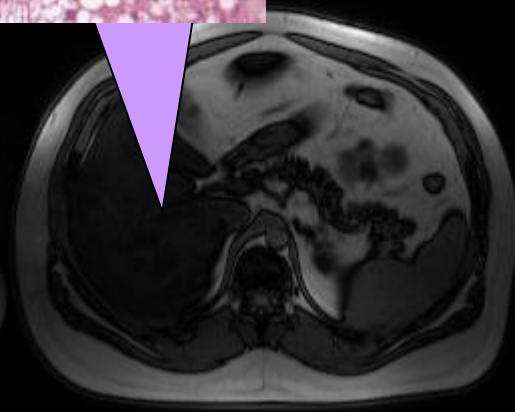
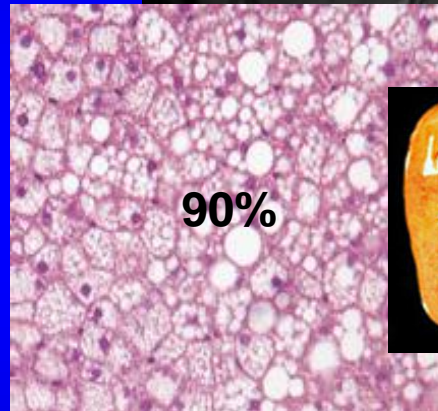
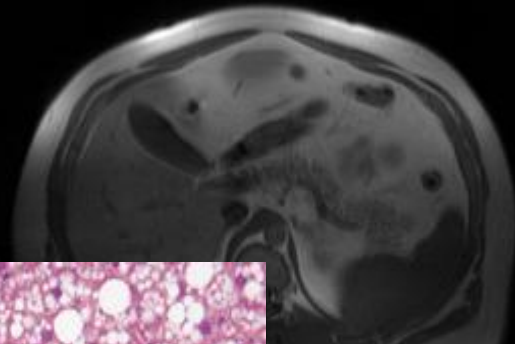
240p*300

Tra

w 501

c 210

BMI = 31



Pancreatic fatty replacement measured with Chemical Shift MRI

BMI = 24

4 IMA 30 / 2

R

MF 100

10%

Policlinico G. B. Rossi Verona
Symphony
MR 2004A
HFS
+LPH
Policlinico G. B. Rossi Verona
↓

10cm

E
SP H152.8
SL 8.0
Fov 350*350
240p*320
Tra

Policlinico G. B. Rossi Verona
Symphony
MR 2004A
HFS
+LPH
Policlinico G. B. Rossi Verona
↓

R

MF 100

TR 950
TE 2.4
TA 14.01*2
BOV 450.0
M/MO/NORM

A1/SAT2

*103d2 / 70

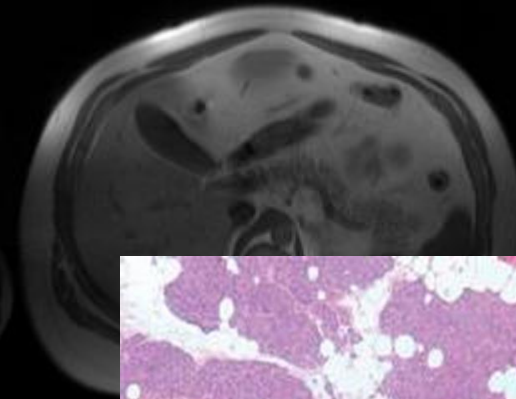
10cm

E
SP H152.8
SL 8.0
Fov 350*350
240p*320
Tra

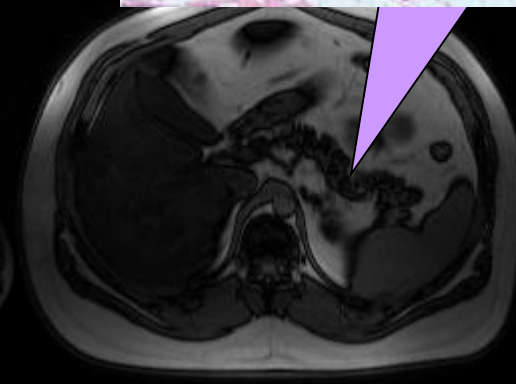
w 501

c 210

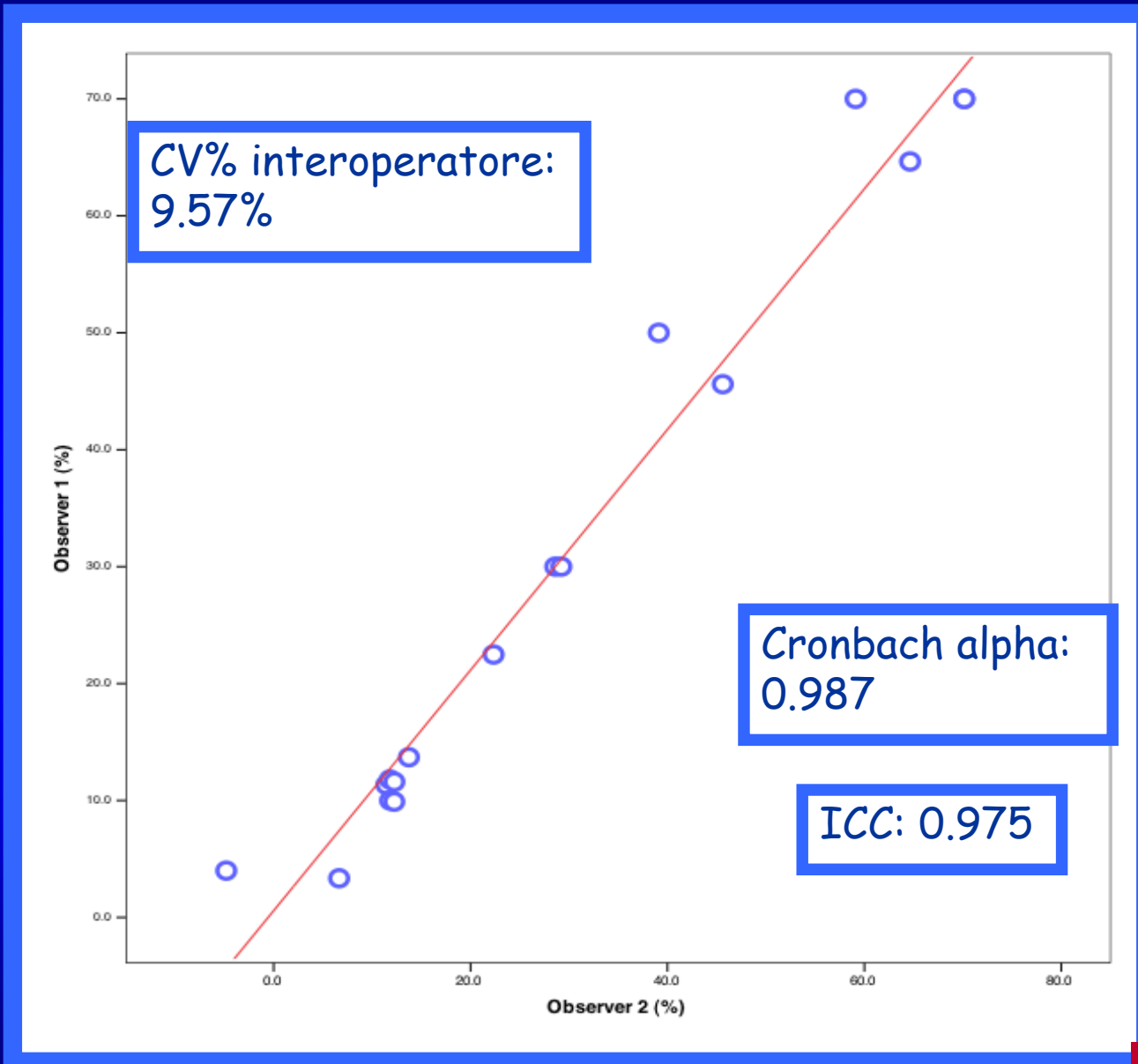
BMI = 31



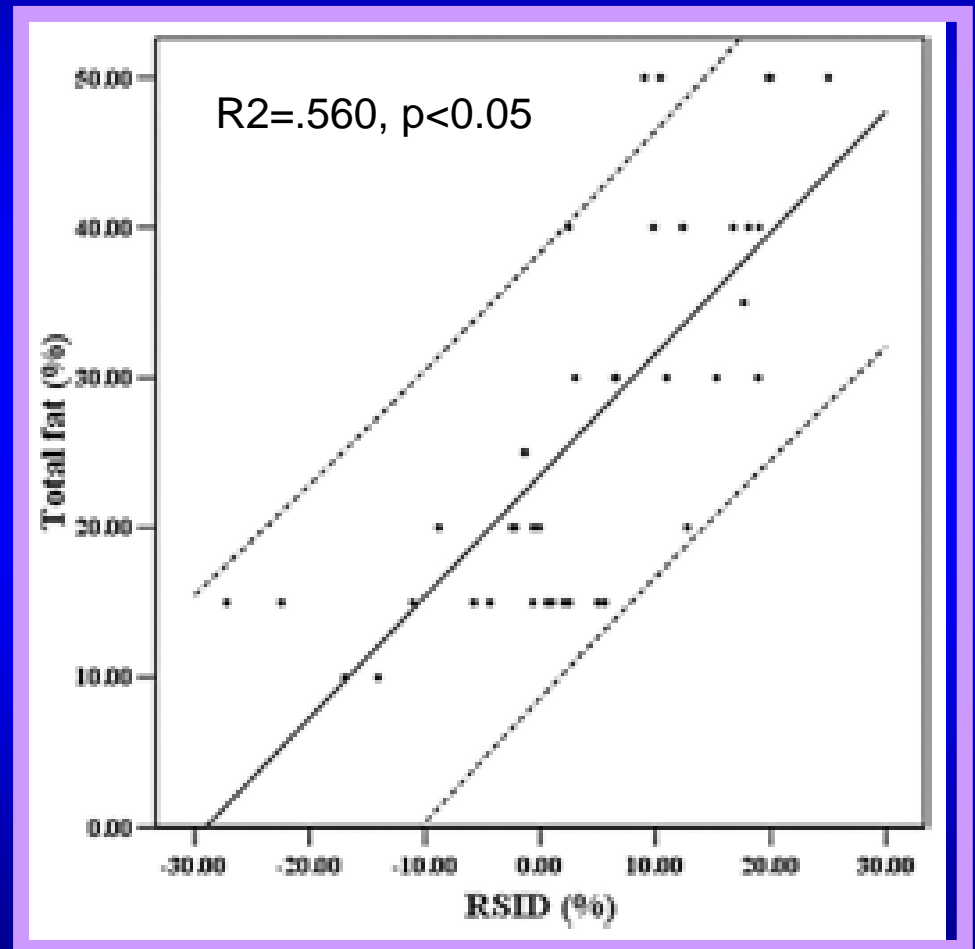
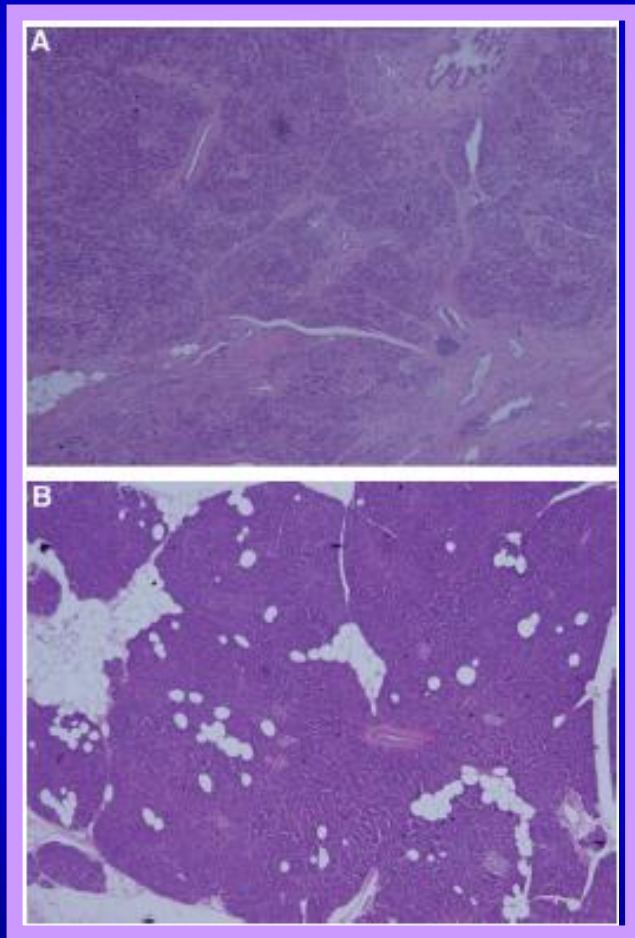
80%



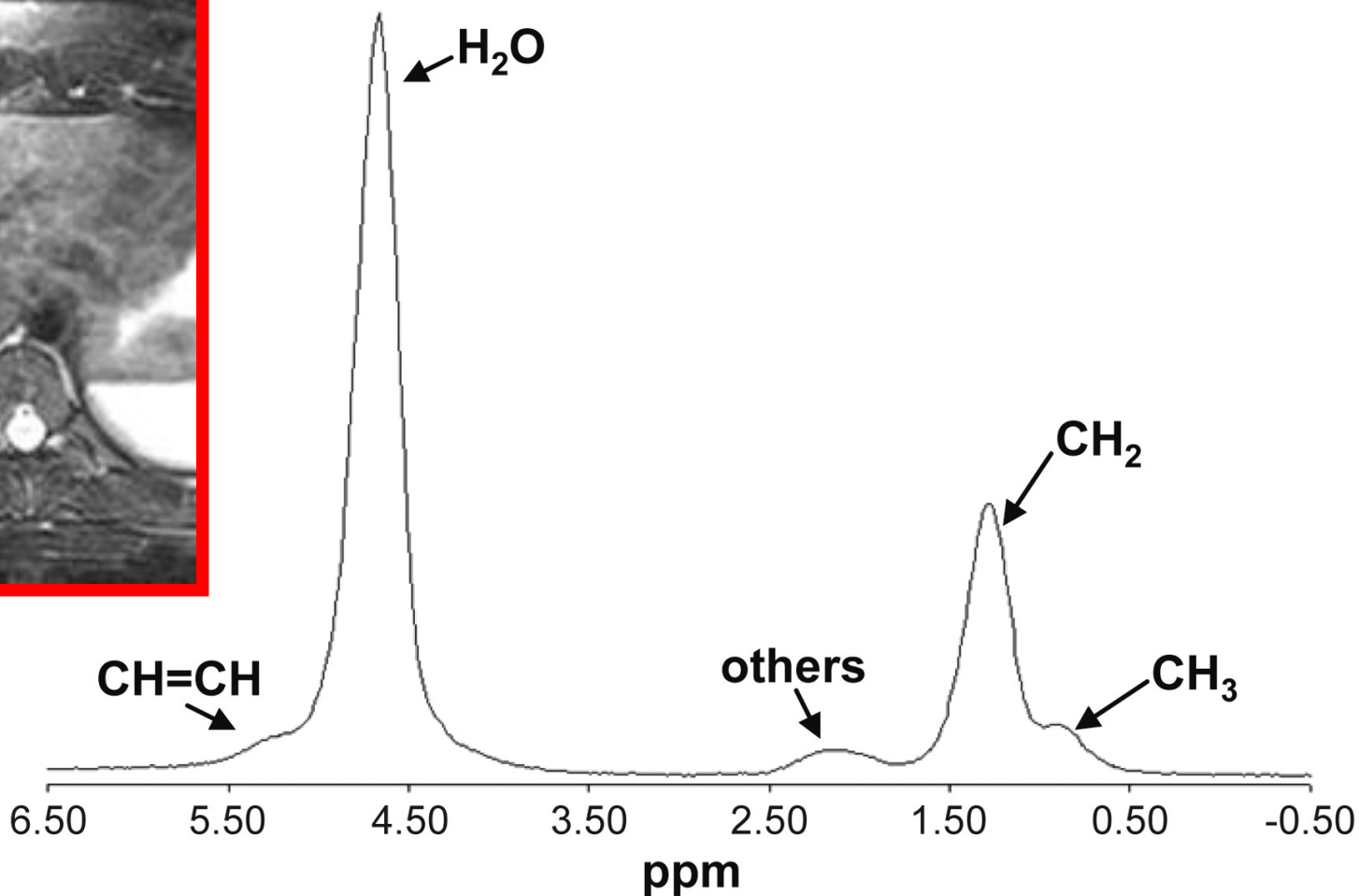
Riproducibilità della quantificazione del contenuto lipidico del pancreas con tecnica chemical shift



Quantification of Pancreas Lipid content by Chemical-Shift technique MRI and by Histological Evaluation



MR imaging spectrum of a fatty human liver



Magnetic Resonance Spectroscopy

• Advantages

MR spectroscopy accounts for the multiple spectral components of fatty acids

Is the most direct method of fat quantification.

• Disadvantages

In vivo abdominopelvic MR spectroscopy requires a skilled operator to correctly perform the examination, process the data, and interpret the results.

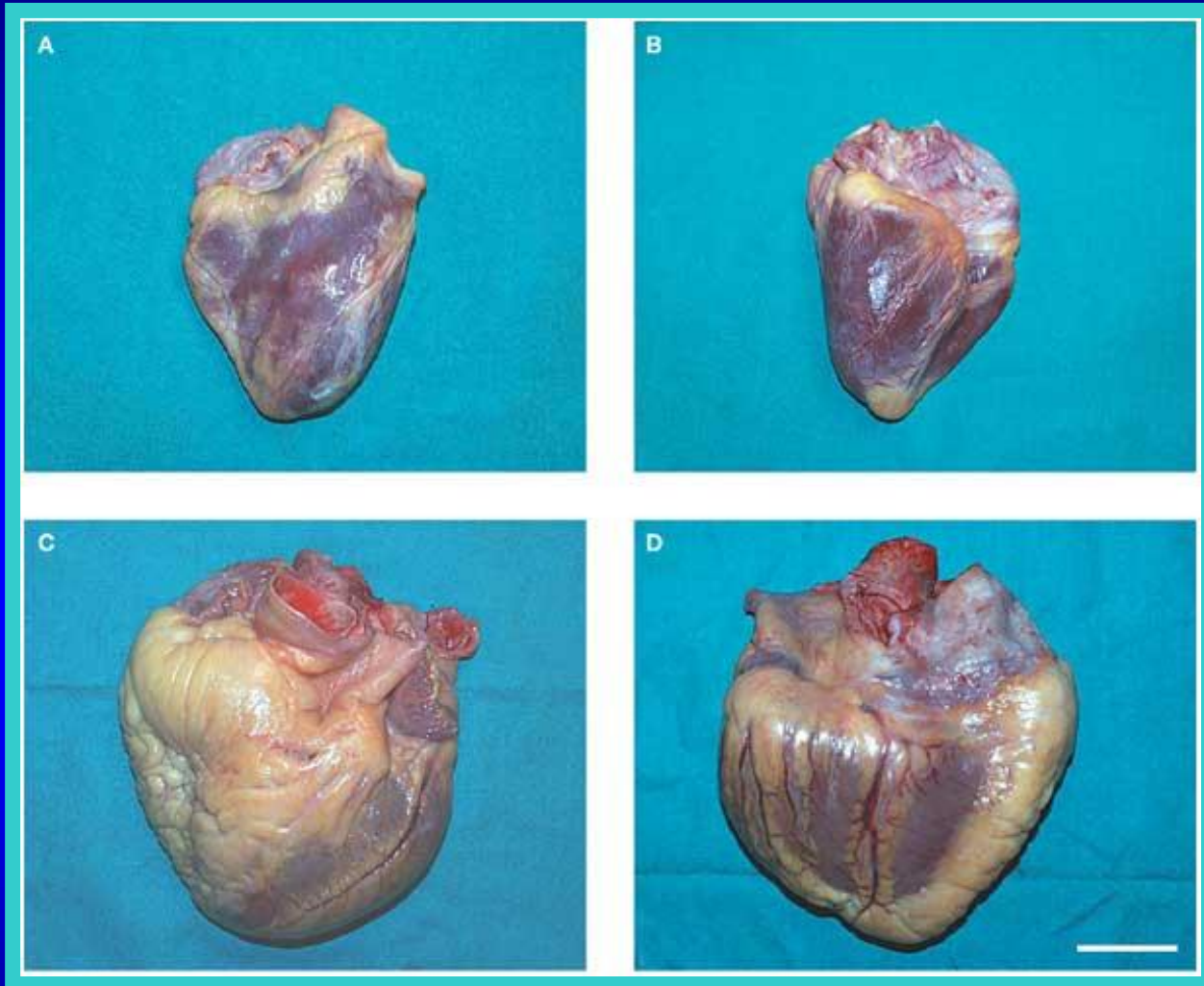
The major disadvantage of MR spectroscopic fat quantification is the complexity of data analysis. The software provided by imager manufacturers generally requires a large amount of user input; is prone to bias; and may not permit accurate, reproducible quantification of all fat signal components.

Standard MR spectroscopic pulse sequences have relatively long minimum echo times (about 20 and 30 msec for STEAM and PRESS, respectively), which may introduce T2 weighting between the signals of individual peaks and, unless T2 relaxation effects are taken into account, may lead to quantification errors.

Shimming the MR spectroscopy voxel tends to be time consuming and may lengthen overall examination time considerably.

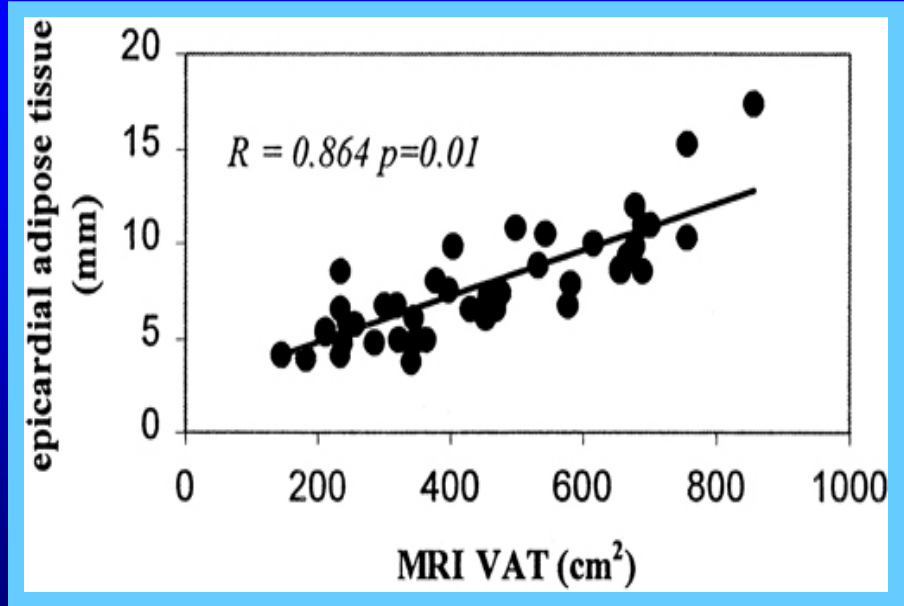
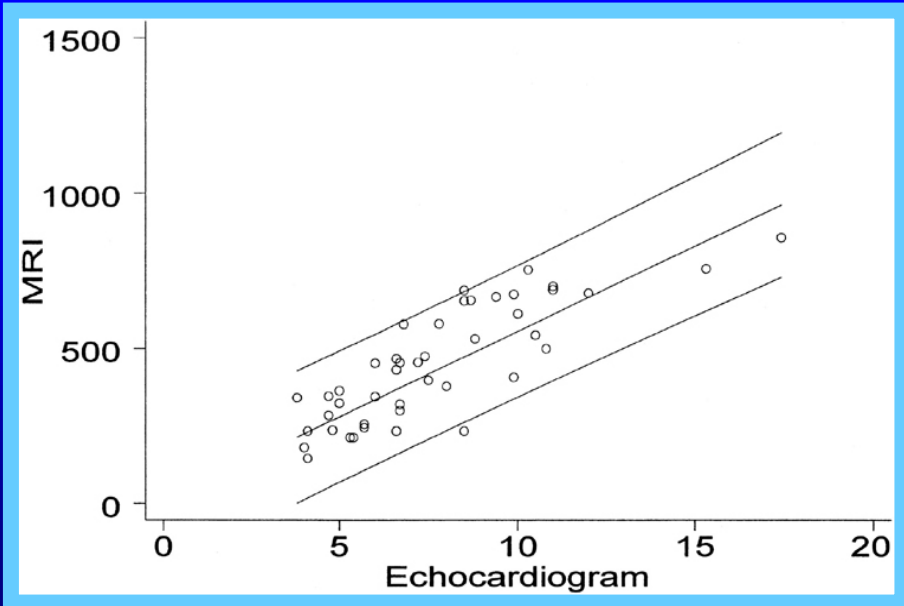
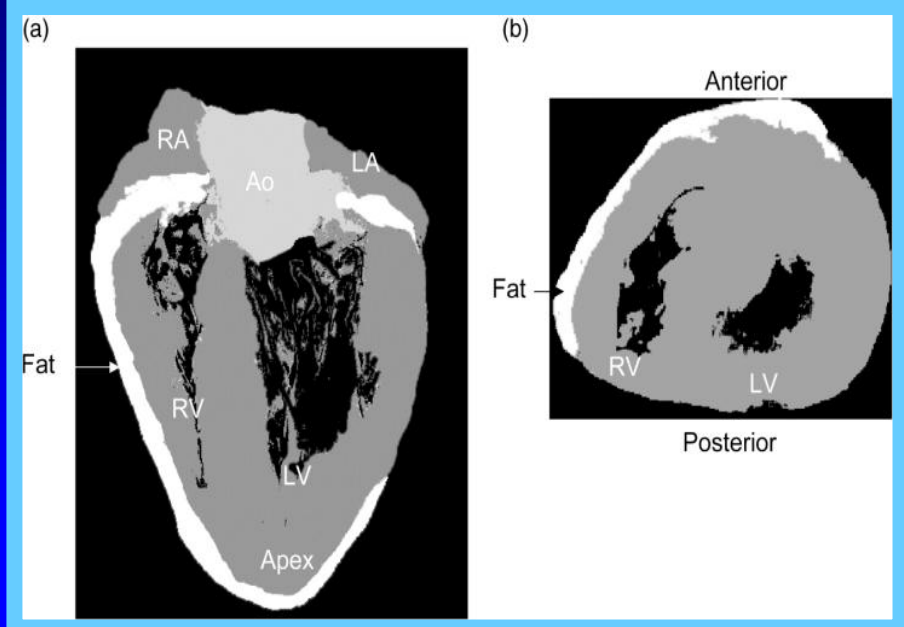
...”We do not recommend the use of MR spectroscopy for the detection of liver fat in routine clinical practice. Magnetic field shimming is time consuming and may add considerably to examination time. In most clinical situations, chemical shift imaging provides adequate detection, especially if advanced techniques are used in a fraction of the time” ...

Macroscopic appearance of epicardial fat



Iacobellis G *et al.* (2005) Epicardial adipose tissue: anatomic, biomolecular and clinical relationships with the heart
Nat Clin Pract Cardiovasc Med 2: 536–543 doi:10.1038/ncpcardio0319

EPICARDIAL FAT: Echocardiography and Magnetic Resonance



Most widely used current methods for anthropometry

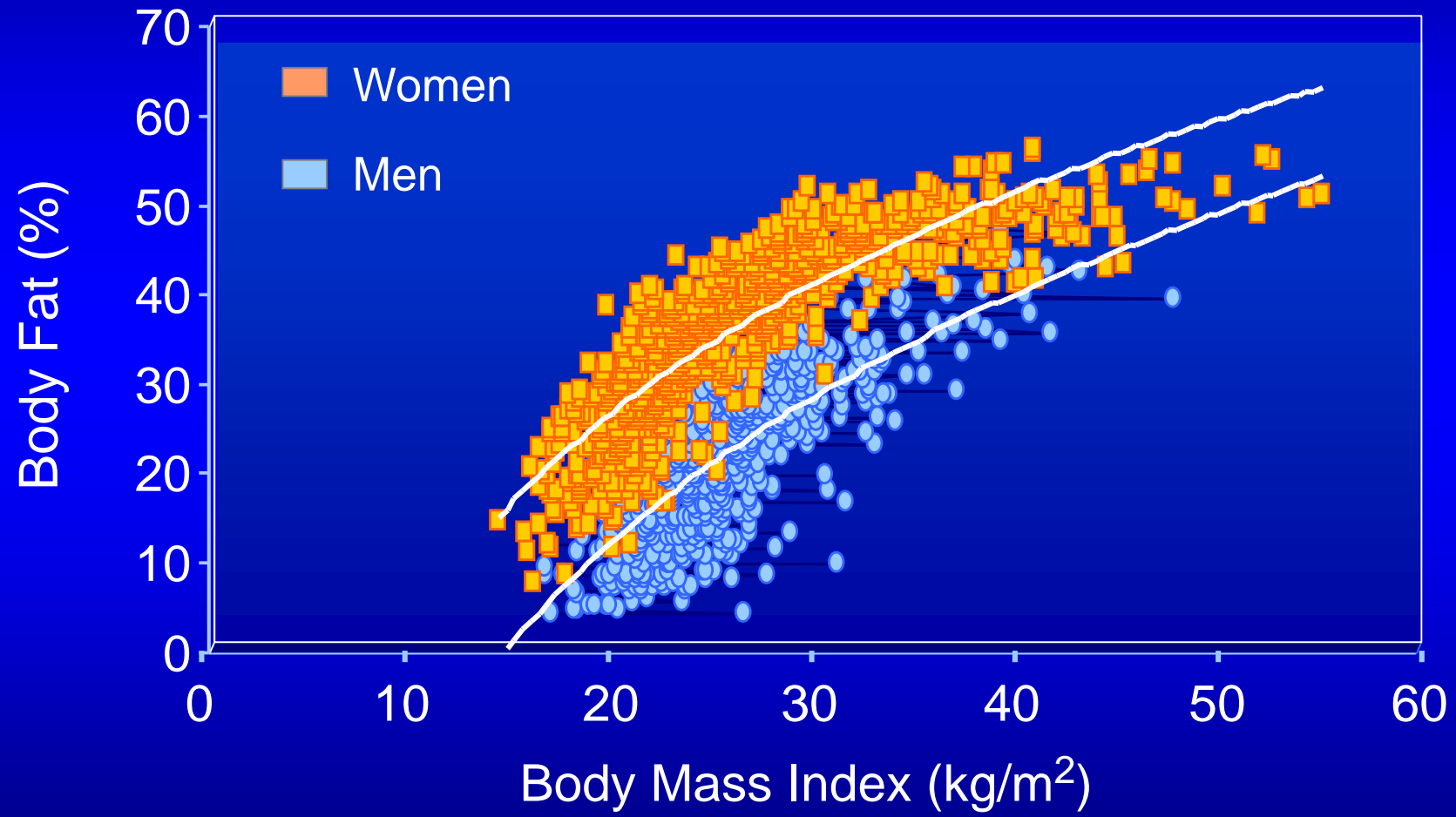
- BMI
- Waist Circumference
- Waist to hip ratio

Classificazione degli stati ponderali

WHO, 1998

	BMI
sottopeso	< 18.5
normopeso	18.5-24.9
sovrapeso	25-29.9
obesità	>= 30
grande obesità	>=40

Relationship Between BMI and Percent Body Fat in Men and Women



Adapted from: Gallagher et al. *Am J Clin Nutr* 2000;72:694.

opposite effects of age-related body composition changes on BMI

BMI = weight/ height squared

where with age



the ratio between fat and lean body mass is higher

height is reduced



Increased true adiposity



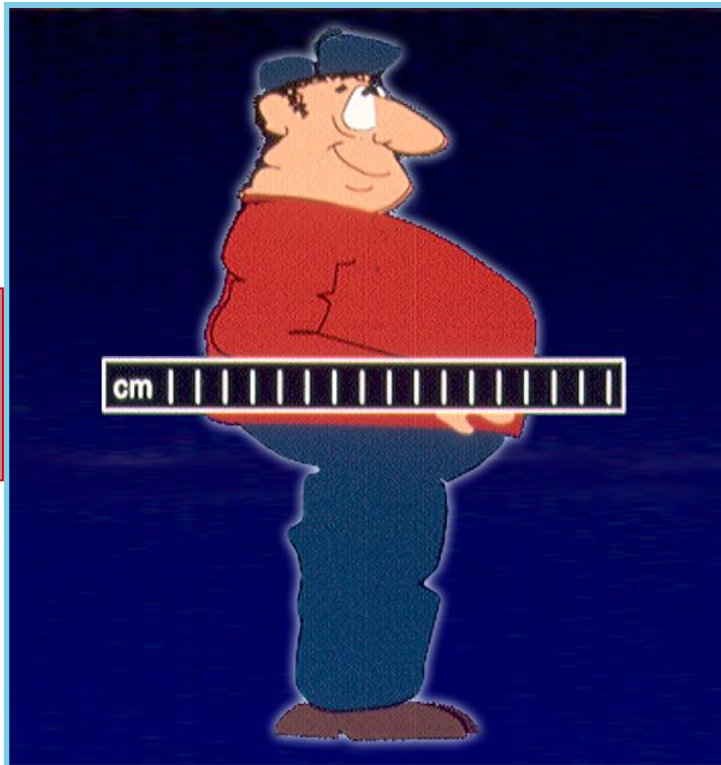
from 20-80 years BMI increased 1.5 for men and 2.5 in women, independently of body weight changes

J Sorkin and R Andres, BLSA, 1999

Waist circumference is a surrogate marker of visceral fat

Women

>88 cm-increased risk



Men

>102 cm-increased risk

Circonferenza della vita e livello di rischio cardiovascolare

Han et al, 1995

	Uomini (cm)	Donne (cm)
Normalità	< 94	< 80
Rischio moderato	95 — 102	80 — 88
Rischio elevato	> 102	> 88

WHR e rischio di malattia cardiovascolare

	donna	uomo
Rischio aumentato	$>0,8$	>1

Comparazione tra misurazione della circonferenza della vita in 4 siti differenti

Measurement sites	Comment
Immediately below the lowest rib (WC1) At the narrowest waist (WC2)	ASM site¹
Midpoint between the lowest rib and the iliac crest (WC3)	WHO site²
Immediately above the iliac crest (WC4)	NIH and NHANES III site³

¹Recommended in the Anthropometric Standardization Reference Manual (ASM).

²Recommended in the World Health Organization (WHO) guidelines.

³Recommended in the National Institutes of Health (NIH) guidelines and applied in the third National Health and Nutrition Examination Survey (NHANES III).

Fonti di errore

Il punto di repere

- difficoltà nella sua individuazione
- possibilità di "suo spostamento"
(esempio ombelico se addome pendulo o panniculite)

Influenza di Muscolo e Osso

- riduzione di Hip per riduzione muscolo
- problemi valutazione di Waist per riduzione spazio
ultima costa -cresta iliaca

Significativa correlazione adiposità totale, waist e hip

Come si misura il diametro sagittale

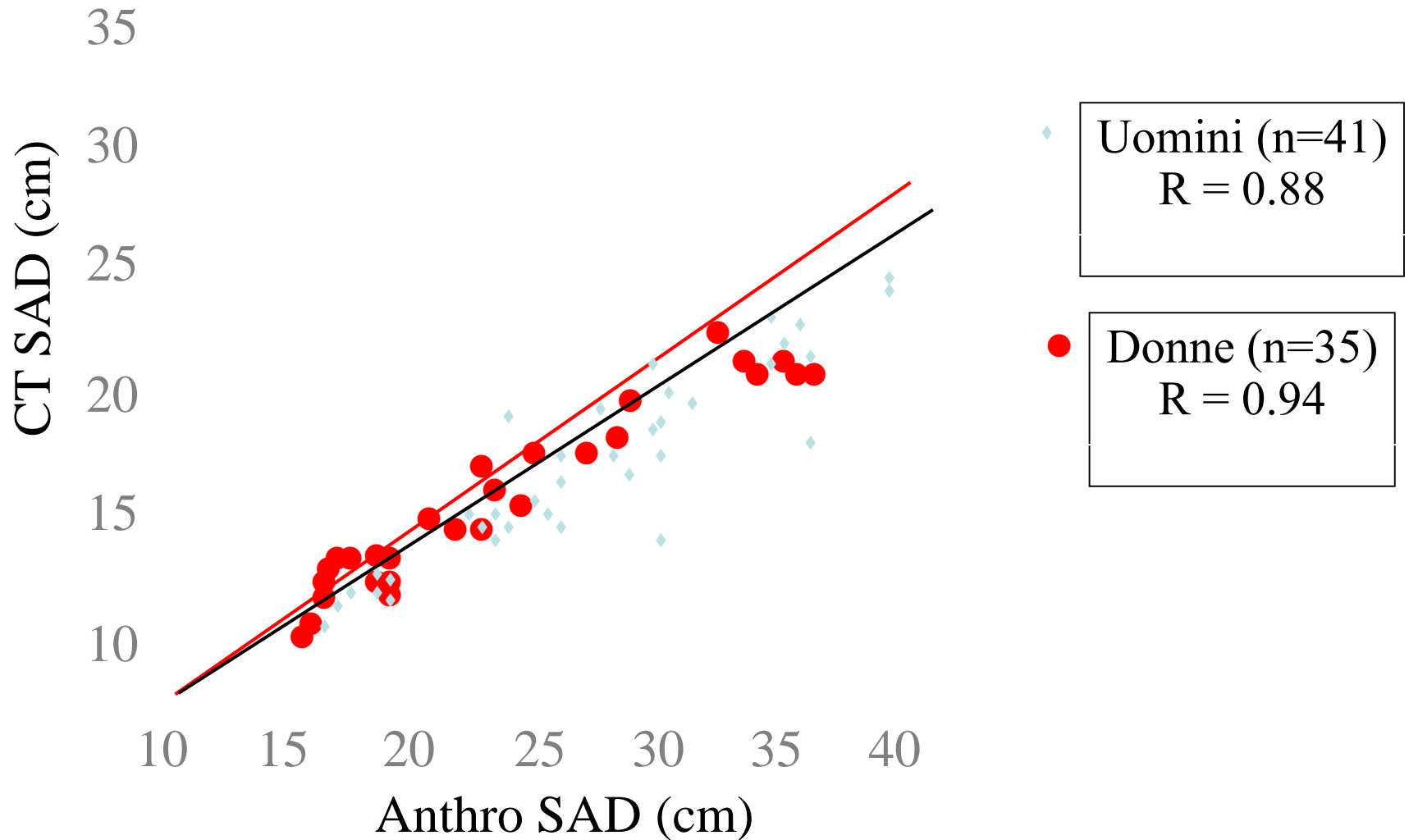
- Il soggetto deve essere sdraiato su un piano rigido
- lo strumento di misura deve possedere stabilità, robustezza e precisione
- La misurazione viene effettuata fra il processo xifoideo e l'ombelico, mentre il soggetto respira dolcemente

Errore tecnico < 1%

**Con strumentazione
inadeguata > 2%**



Correlazione tra SAD misurato con CT e SAD misurato antropometricamente



Clasey et al., 1999 (mod.)

Nella pratica clinica

Non Massa adiposa

Non Tessuto Adiposo

Non Infiltrazione Lipidica del Muscolo

ma **Surrogati**

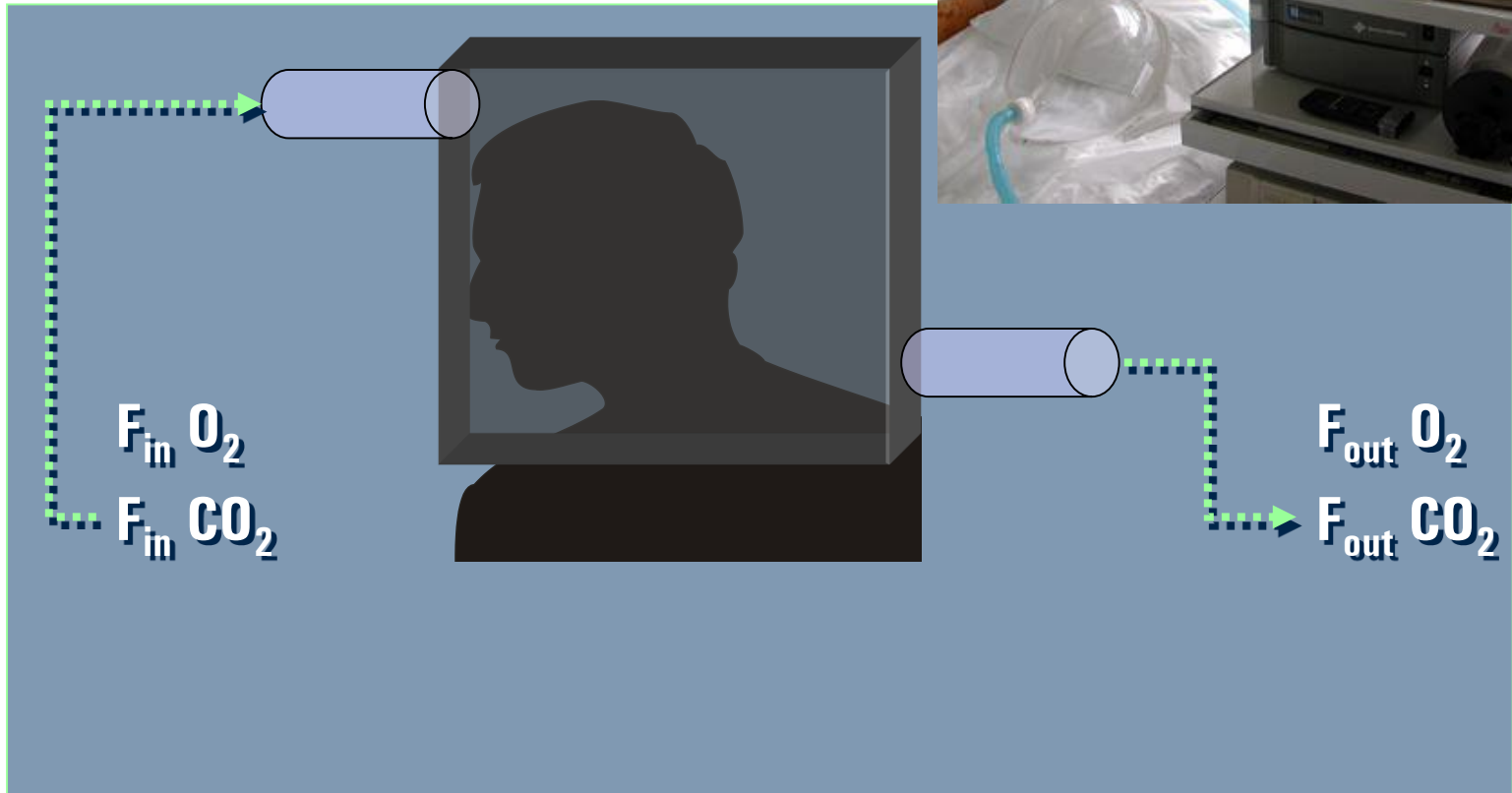
Valutazione del dispendio energetico

- ***equazione di Harris e Benedict***
- ***calorimetria indiretta***

Calorimetria indiretta

- **Misura la PRODUZIONE di calore da parte dell'organismo indirettamente attraverso l'analisi dei gas respiratori (CO₂ prodotta e O₂ consumato).**
- **Spesa energetica totale:**
 - metabolismo basale: 60-80%**
 - effetto termico del cibo: 10-15%**
 - effetto termico dell'attività fisica: 15-20%**

Calorimetria indiretta



$$VO_2 = V (F_{in} O_2 - F_{out} O_2)$$

$$VCO_2 = V (F_{out} CO_2 - F_{in} CO_2)$$

Predizione del fabbisogno energetico

metabolismo basale kcal/die

Equazione di Harris-Benedict

uomo: $66 + (13.7 \times \text{peso}) + (5 \times \text{altezza}) - (6.8 \times \text{età})$

esempio 40 anni, 70 kg, 175 = 1630
a 75 anni = 1392

donna: $655 + (9.6 \times \text{peso}) + (1.9 \times \text{altezza}) - (4.7 \times \text{età})$

esempio 40 anni, 60 kg, 165 = 1350
a 80 anni = 1160

REE (formule) + AF + SF = TEE

Fattori di correzione per l'attività (AF)

- *Riposo assoluto* 1.00
- *Allettato sveglio* 1.20
- *Deambulante* 1.30

Fattori di correzione per lo stress (SF)

- *Malnutrizione* 0.85-1.00
- *Chirurgia elettiva* 1.10
- *Chirurgia maggiore o complicata* 1.20-1.80
- *Sepsi* 1.20-1.40
- *Politrauma (\pm corticosteroidi)* 1.40-1.60
- *Risposta infiammatoria sistemica* 1.50
- *Ustioni* 1.50-1.90