Body composition
A tool for nutritional assessment

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Outline

- What is body composition?
- What is nutritional assessment?
- Why use body composition?
- Body composition by DXA and impedance
- Clinical body composition - perspectives

What is body composition?

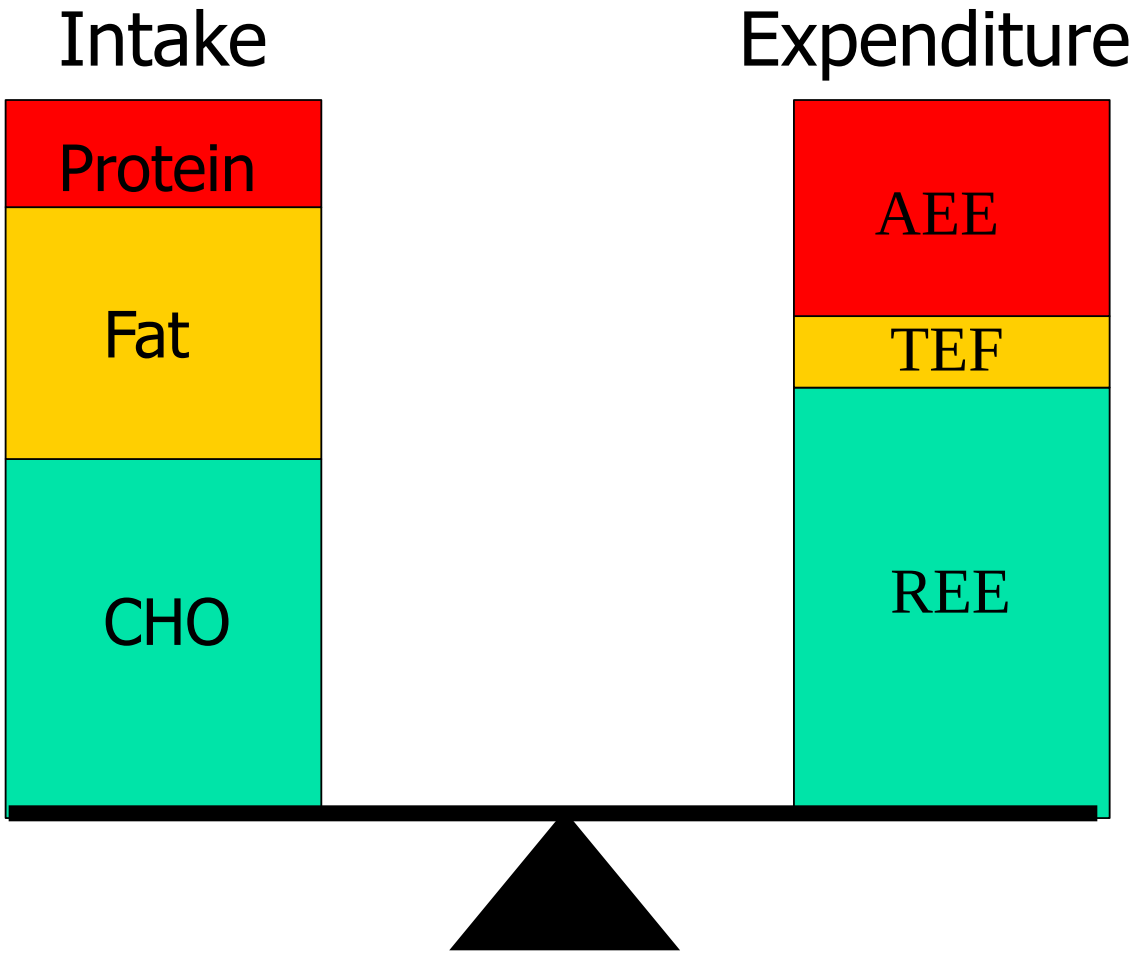
”The study of human body composition can be defined as a branch of human biology which mainly focuses on the *in vivo* quantification of body components, the quantitative relationships between components, and component alterations related to various influencing factors.”

Wang, Pierson & Heymsfield 1992

Why use body composition?

- Quantification of body energy stores
- Precise estimation of long-term energy balance
- Analysis of fat depots and skeletal muscle

Energy balance – the fundamental base of nutritional status

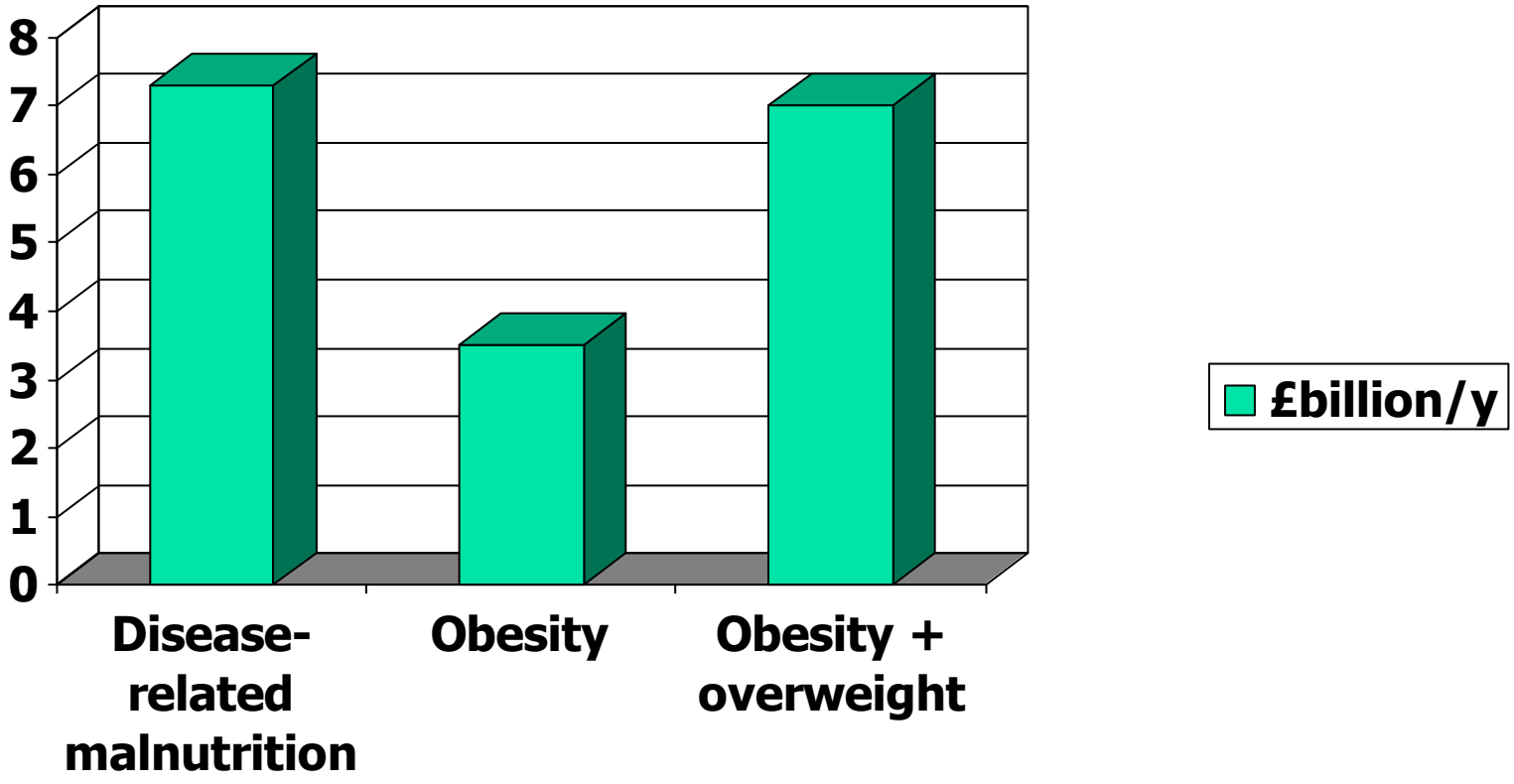


Energy balance – so what?

- Positive = weight gain
  - Overweight, obesity and its consequences
- Negative = weight loss
  - Disease-related malnutrition and its consequences

Yes, but we all know that overweight and obesity is the great problem of our time, or…

Annual cost of DRM, obesity and overweight in UK



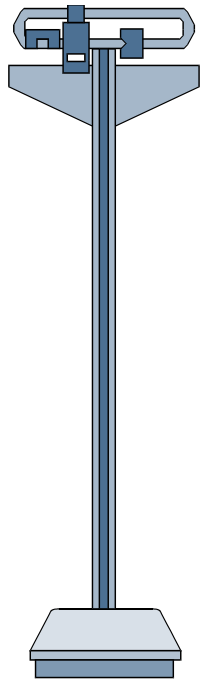
House of Commons Health Committe 2004, cited by Elia (2007)

Changes in fat and fat-free mass = Energy balance

- Fat and fat-free mass have very different energy densities:
- Fat: 39.4 MJ/kg
- Fat-free mass: 3.7 MJ/kg
- By e.g. DXA this can be measured with a precision of 1-2%
- This is 3-10 times better than resource demanding reference methods used for estimation of energy balance components

Elia et al Proc Nutr Soc 2003;62:529-537

Why not use a scale? Of course:



- It is inexpensive
- It has good precision (about 1%)
- But we can´t tell what is fat or fat-free mass

What kind of differences are we talking about?

- Weight change:

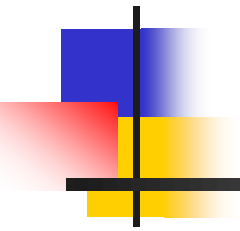
- 5 %/3m (BW 70 kg): 1.2 MJ/d (280 kcal)
- 1 kg/month: 1 MJ/d (240 kcal)
- 1 kg/week: 4 MJ/d (960 kcal)

(Assumption: mixed tissue change, 30 MJ/kg [Elia])

Analyzing fat depots

- Mammals have 4 distinct, highly organized fat depots
- Subcutaneous fat – low inflammatory
- Visceral (or mesenteric) fat – high infl
- Ectopic fat (liver, muscle) – very high infl
- Brown fat - heat generation, low infl

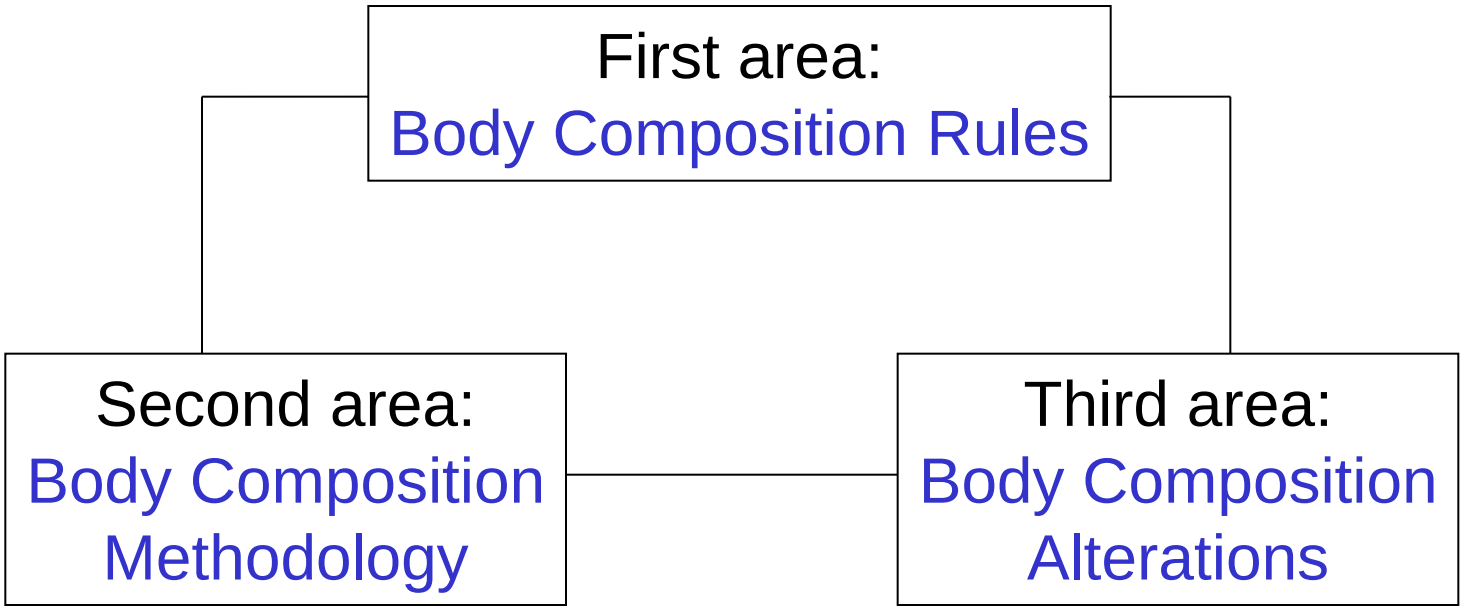
Roth et al Am J Clin Nutr 2011



Body composition rules

The conceptual framework

Body composition – research areas



Wang ZM 1997

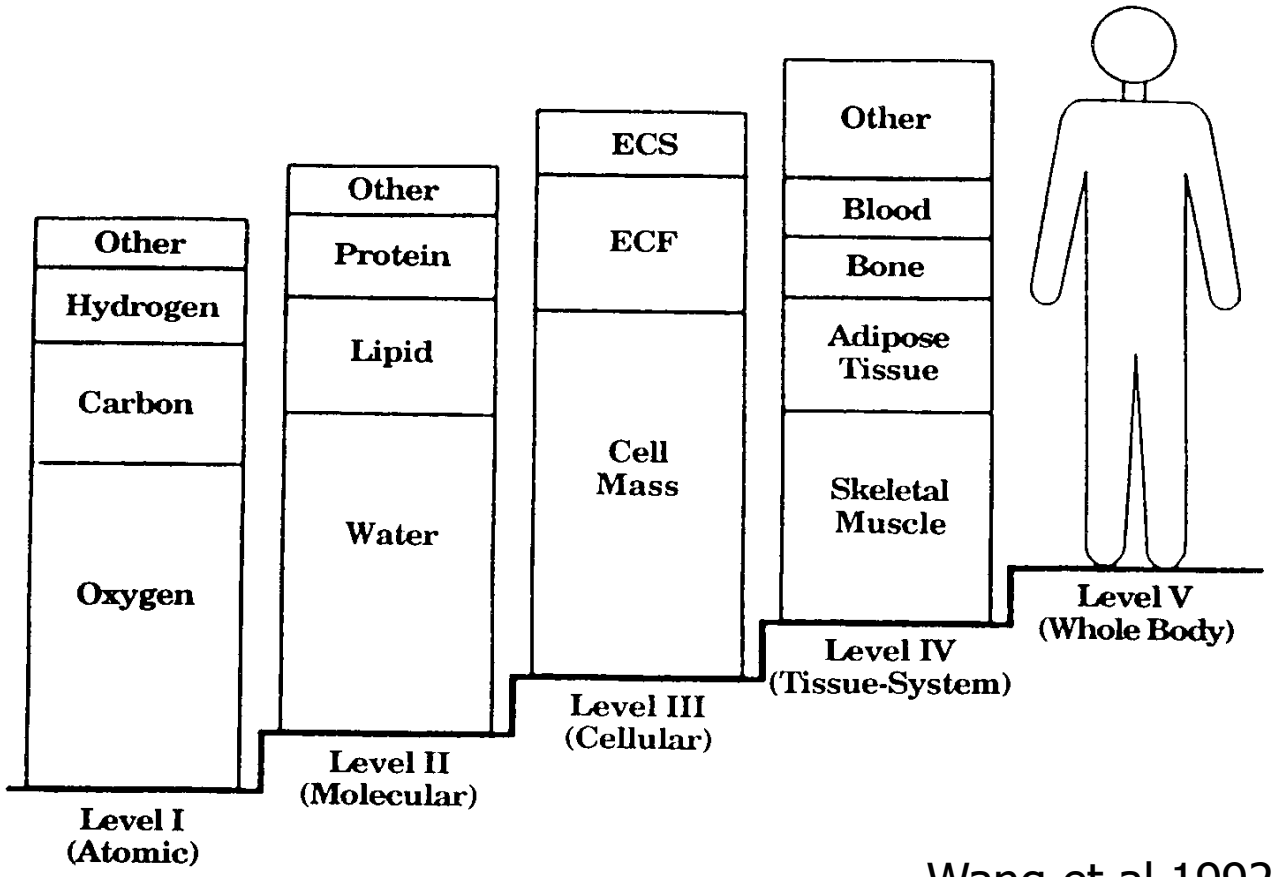
Body composition rules

- The ≈ 40 major components of the human body can be organized into five separate but interconnected body composition levels:

I. Atomic II. Molecular III. Cellular IV.Tissue-System V. Whole body

Wang et al 1992

The five-level model



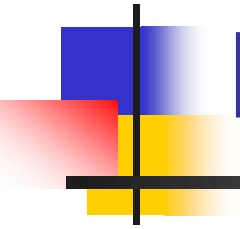
Wang et al 1992

Body mass (weight) is the sum of components at the five levels:

- Atomic: BW = O + C + H + N + Ca + P + S + K + Na + Cl + Mg
- Molecular: BW = lipids + water + protein + bone mineral + soft tissue mineral + glycogen
- Cellular: BW = cell mass + extracellular fluid + extracellular solids
- Tissue/system: BW = adipose tissue + skeletal muscle + skeleton + viscera + blood + others
- Whole body: BW = head + neck + trunk + lower extremities + upper extremities

Body composition rules

- Each level and its multiple components are distinct, but biochemical and physiological connections exist such that the five levels are consistent and function as an entity.
- In a steady-state of body composition, relatively constant relationships are maintained between components at the same or different levels.
- This provides a matrix for creating explicit body composition equations, and development of multi-compartment methods.



Body composition methodology

Quantifying unknown components

Classification of methodology

Body composition methods

- In vitro methods
- In vivo methods

Classification of methodology

- The fundamental concepts of *in vivo* body composition methods can be summarized as:

$$\mathbf{C = \mathit{f}\,(Q)}$$

- where **C** = unknown component, **Q** is a measurable quantity, and ***f*** is the mathematical function relating Q with C.

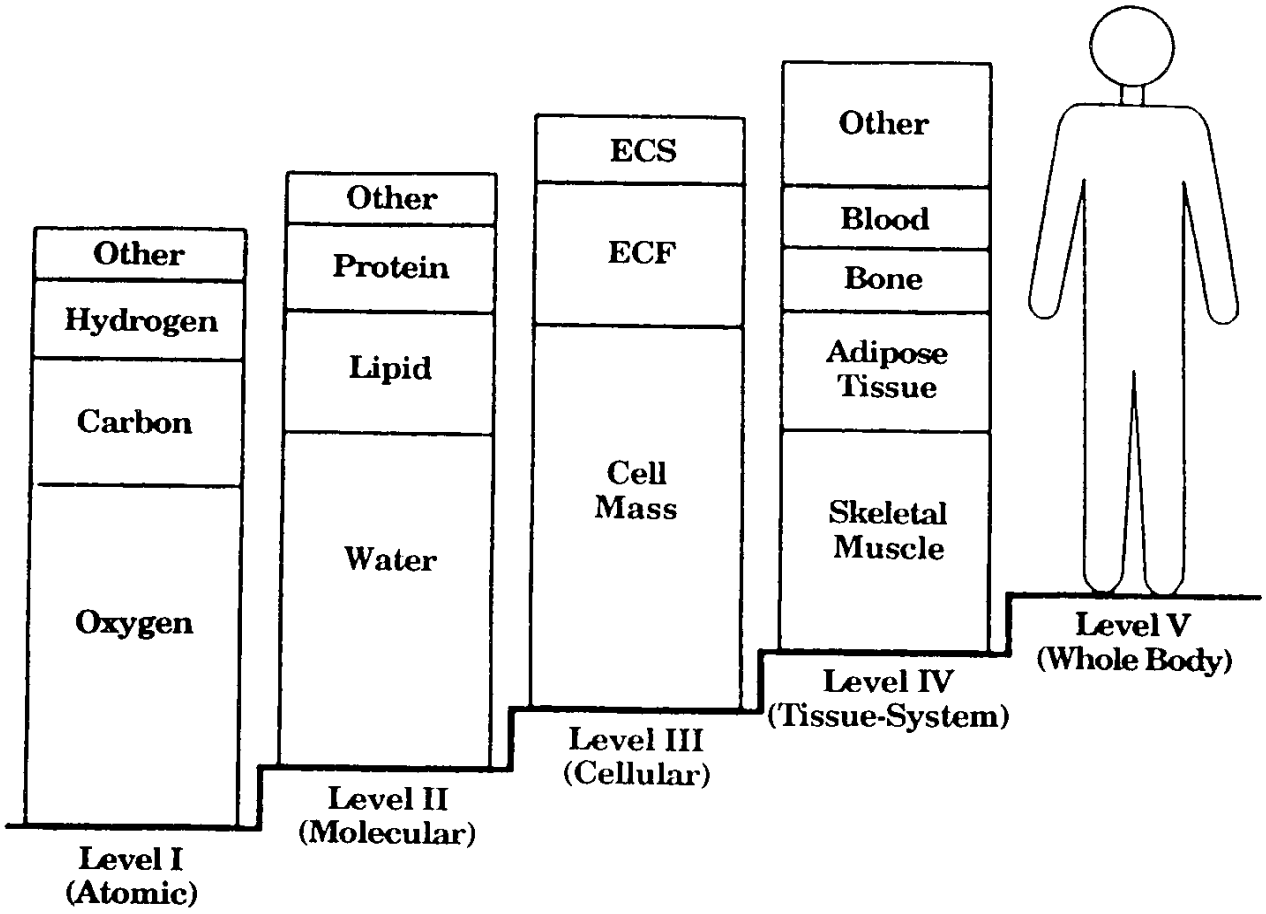
Methodology: **C = *f*(Q)**

- Primarily, the measurable quantity Q represents a **property** (e.g. density, electrical impedance, and so on) from which a **component** of the body can be derived.
- Other components can then be derived, in which Q is either another measured property or a known component, or both.
- The measurement of a property (or properties) is thus the basis of all methods

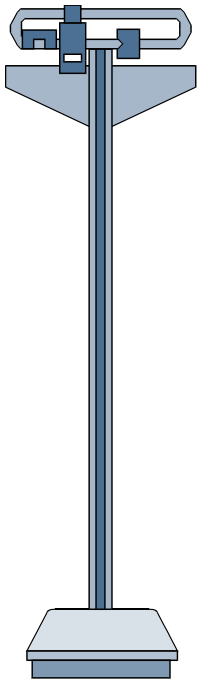
Body composition methods

From theory to practice

The five-level model



Body height and weight



- Body weight (kg)
- Body height (m)
- Body mass index $BMI = BW/BH^2$

- Very good precision (≈ 1 %) (outstanding value for money), but unable to quantify lower level components

Obesity definition: WHO

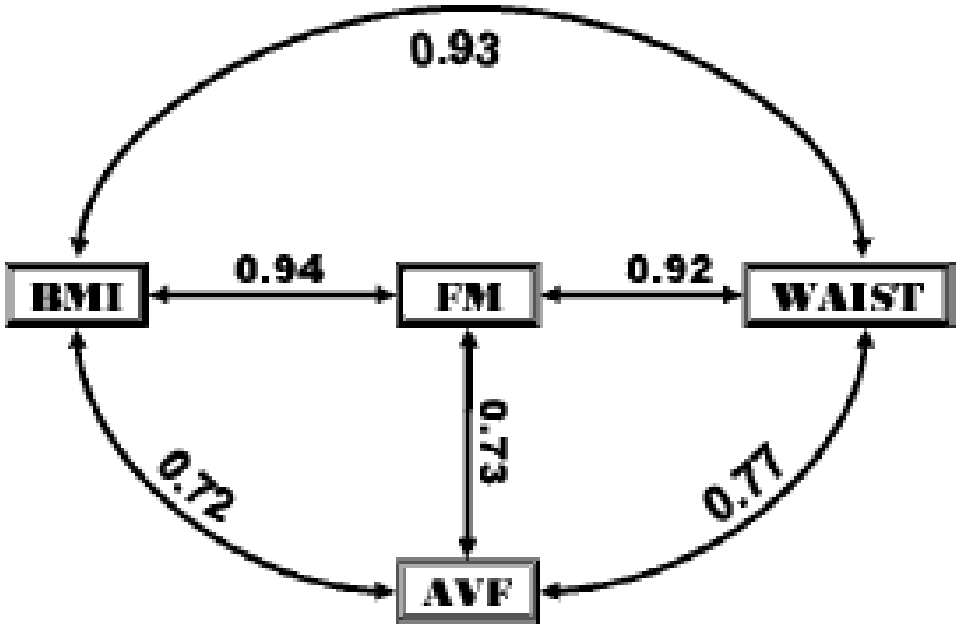
- Obesity is defined as abnormal or excessive fat accumulation that presents a risk to health.
- A crude population measure of obesity is the body mass index (BMI).
- A person with a BMI of 30 or more is generally considered obese.

Obesity: Body weight vs. Body fat

- We define obesity as excess fat and we measure it as excess weight (height-adjusted)
- Does it matter?

On the one hand…

”…most of the variance in obesity-related anthropometrics is captured by BMI.”



Bouchard Int J Obes 2007

And on the other…

- ”BMI…is only a surrogate measure of body fatness”
- ” …a wide range of conditions in which surrogate anthropometric measures (especially BMI) provide misleading information about body fat content”.
- ”…initiate a gradual evolution beyond BMI towards standards based on actual measurements of body fat mass.”

Prentice & Jebb Obes Rev 2001

Conditions with BMI limitations

- infancy and childhood
- ageing
- racial differences
- athletes
- military and civil forces personnel
- weight loss with and without exercise
- physical training
- special clinical circumstances

Prentice & Jebb Obes Rev 2001

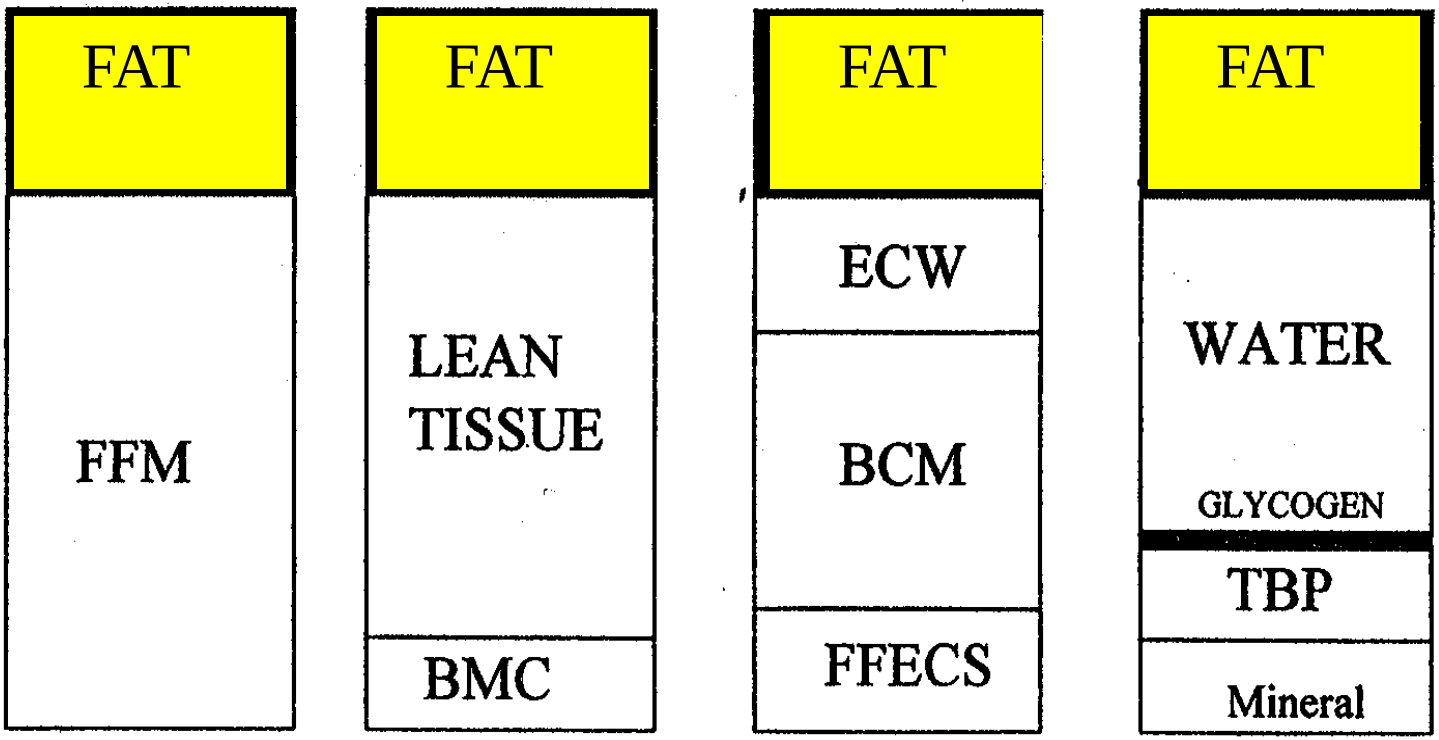
How measure body fat?

- **Body composition methods:**
- Accuracy and precision
- Limitations in body size/weight
- Feasibility and cost
- Ability to provide measures of body fat distribution

Method	Capability Total fat	Capability Fat distrib.	Applicability large scale
CT	Moderate	Very high	Low
MRI	High	Very high	Low
DXA	Very high	High	Moderate
Densitometry	Very high	Very low	Low
Dilution	High	Very low	Moderate
BIA	Moderate	Very low	High
BMI	Moderate	Very low	Very high
WC,WHR,SAD	Low	High	Very high
Skinfolds	Moderate	Moderate	High

Snijder et al Int J Epidemiol 2006

Body composition models



2- Compartment Model
BIA, TBK, TBN, TBW

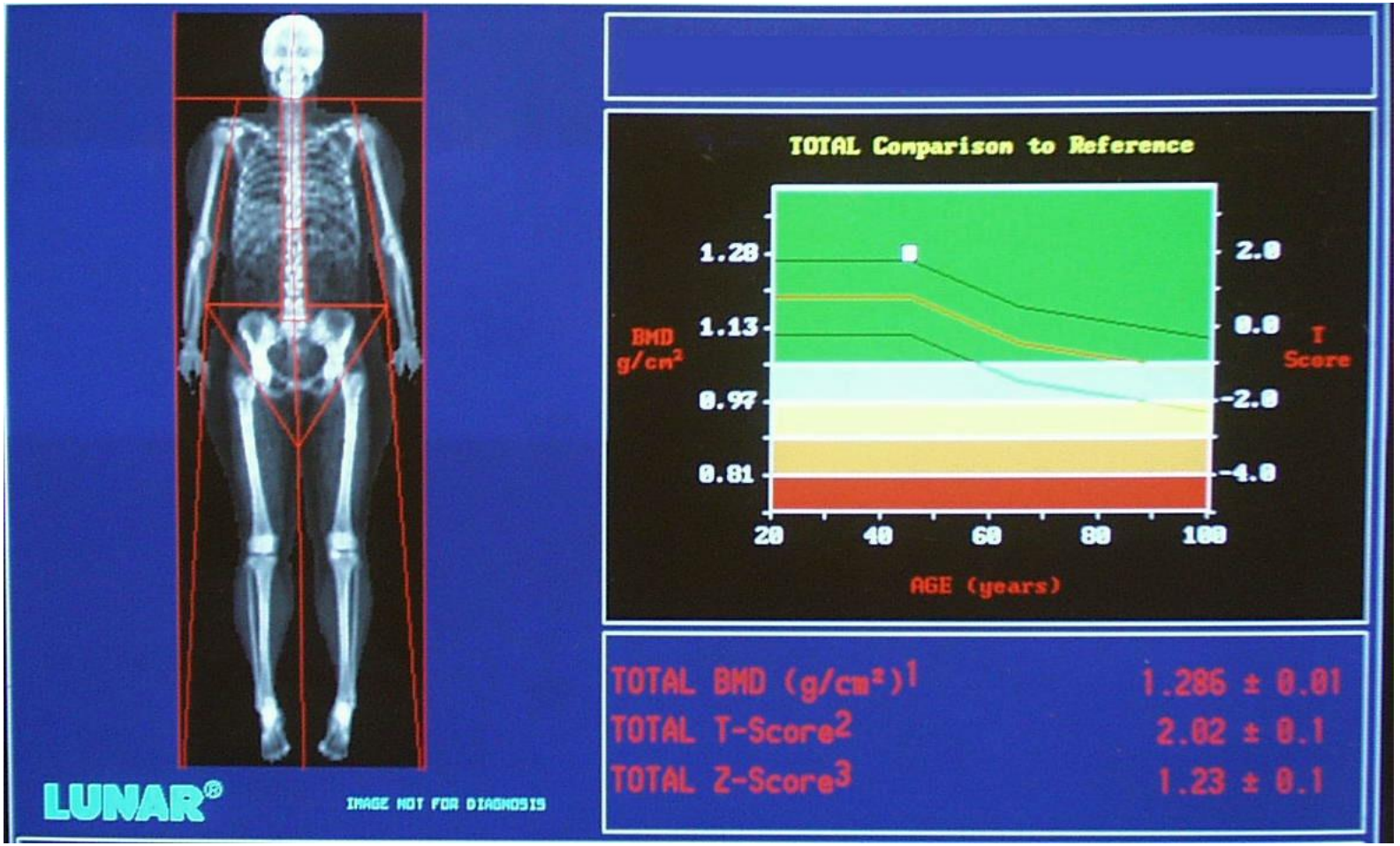
3-Compartment Model
DEXA

4-Compartment Model

Multicompart-ment Chemical Model

DXA
Dual-energy X-ray Absorptiometry

DXA
Dual-energy X-ray Absorptiometry



Which method should I use?

The answer is (perhaps annoying) a number of questions:

- What do you want to measure?
- In what context?
- What is your budget?
- What is an acceptable burden on the subject?

– And so on…

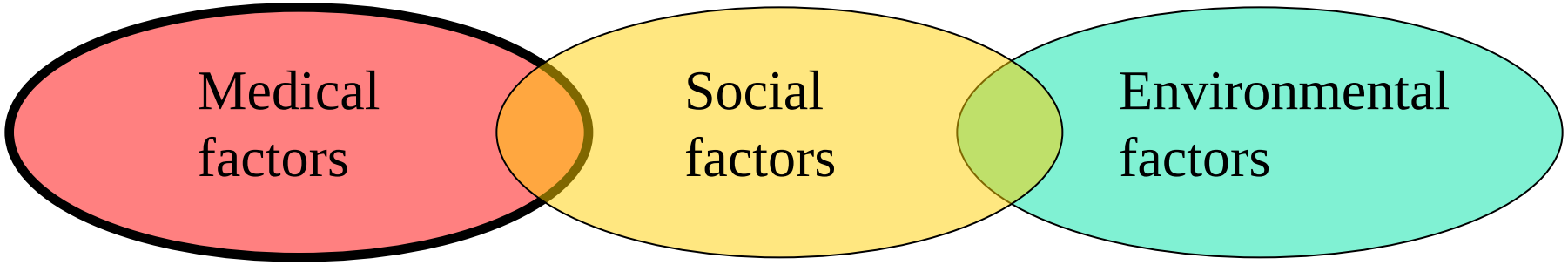
Malnutrition is common, under-recognised and under-treated

Elia et al 2005

"- The number of undernourished hospital patients in Europe is unacceptable."
"- Undernutrition among hospital patients leads to extended hospital stays, prolonged rehabilitation, diminished quality of life and unnecessary costs."

Council of Europe, Resolution ResAP(2003)3

Development of undernutrition



Intake below requirements

↓

Depletion of body stores

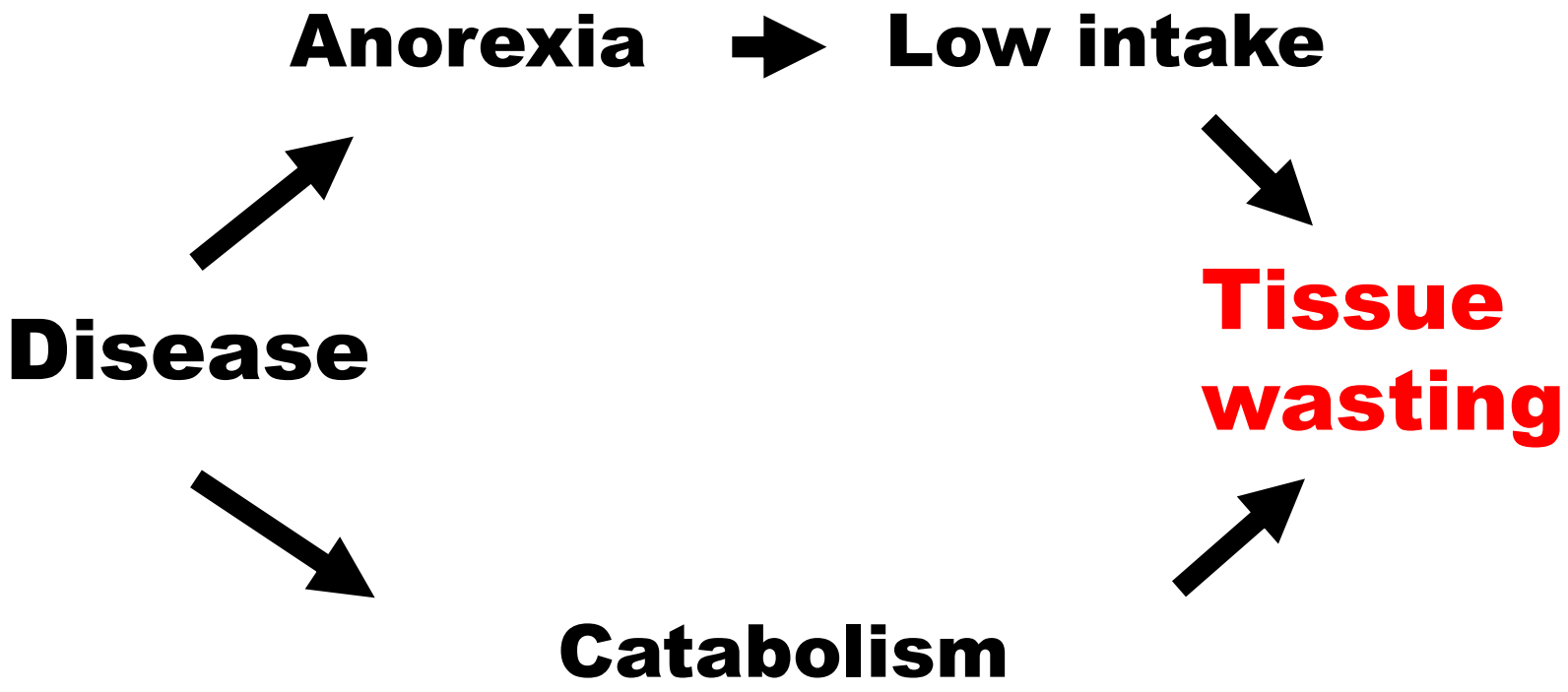
↓

Biochemical changes

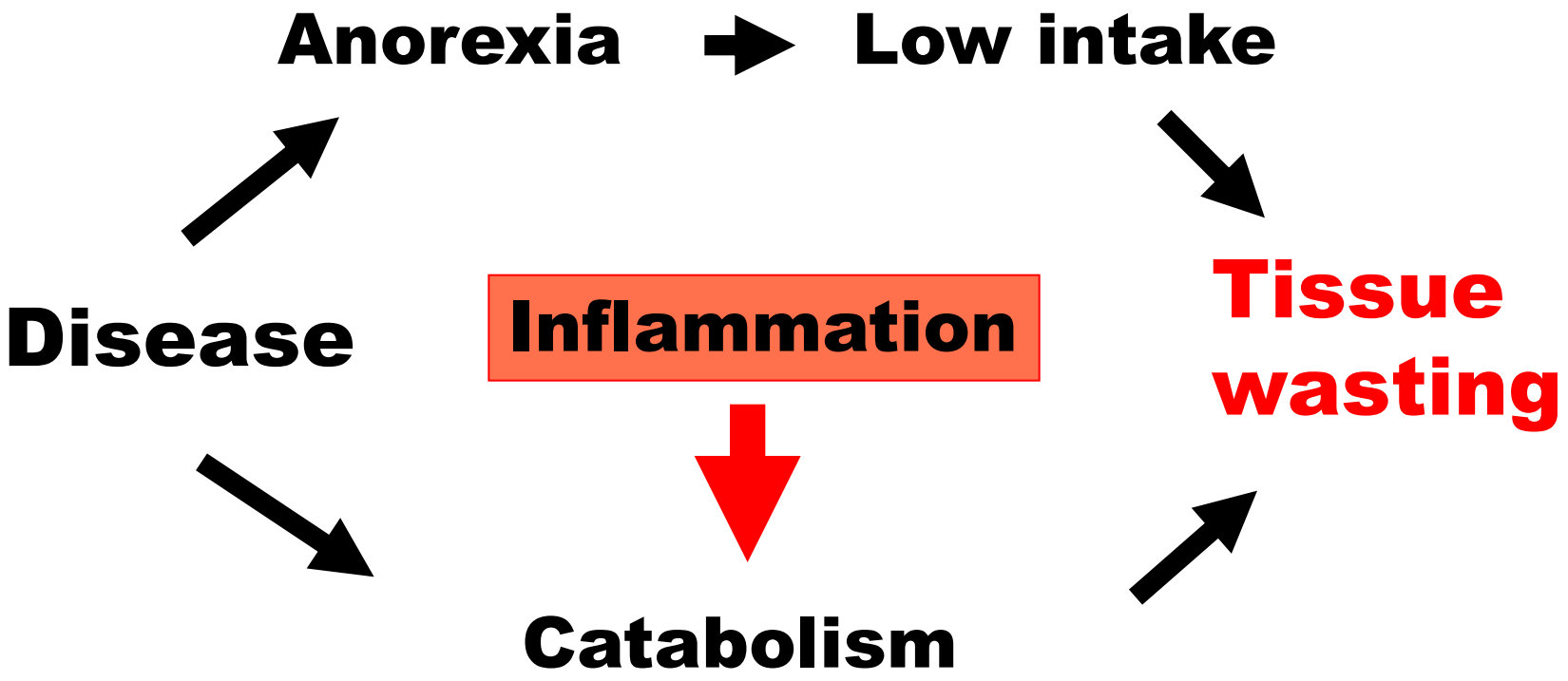
↓

Anatomical and functional changes

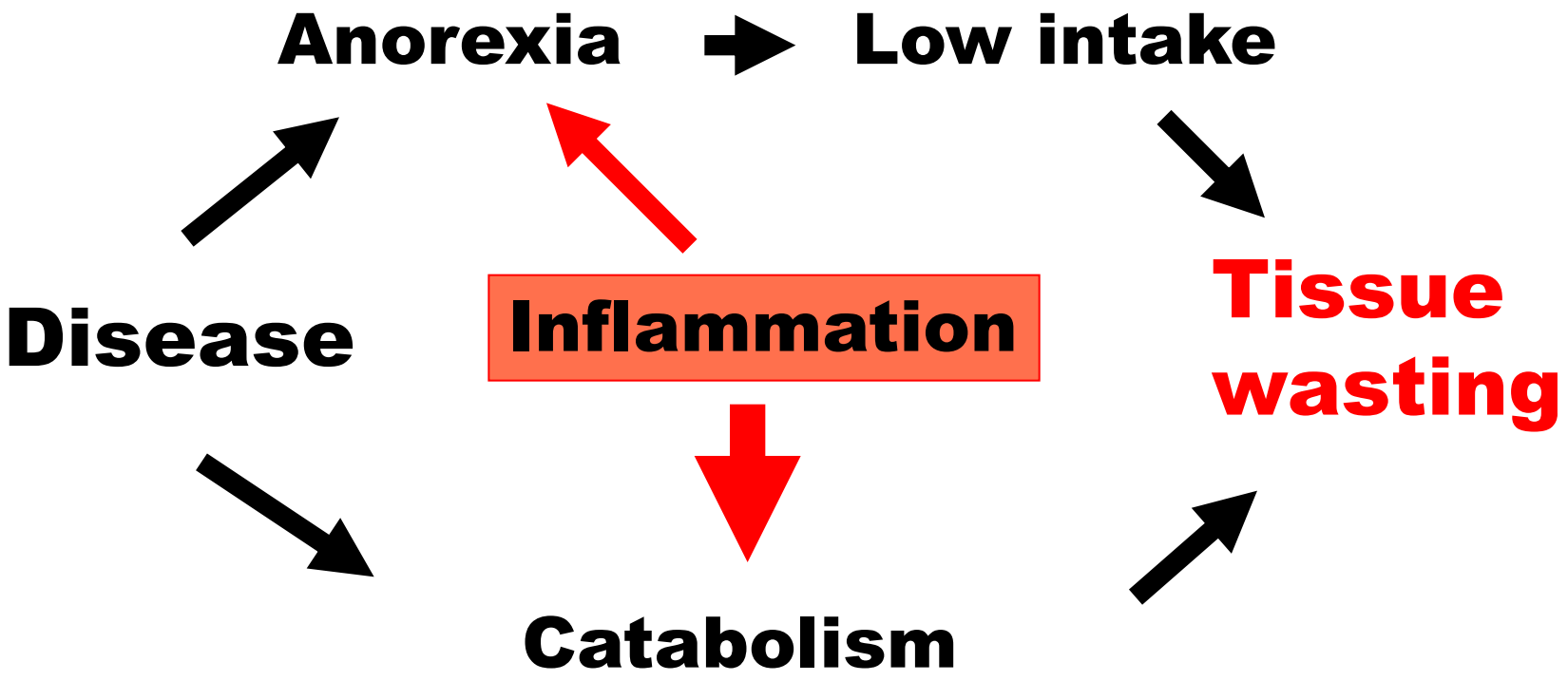
Development of disease-related malnutrition: The two pathways



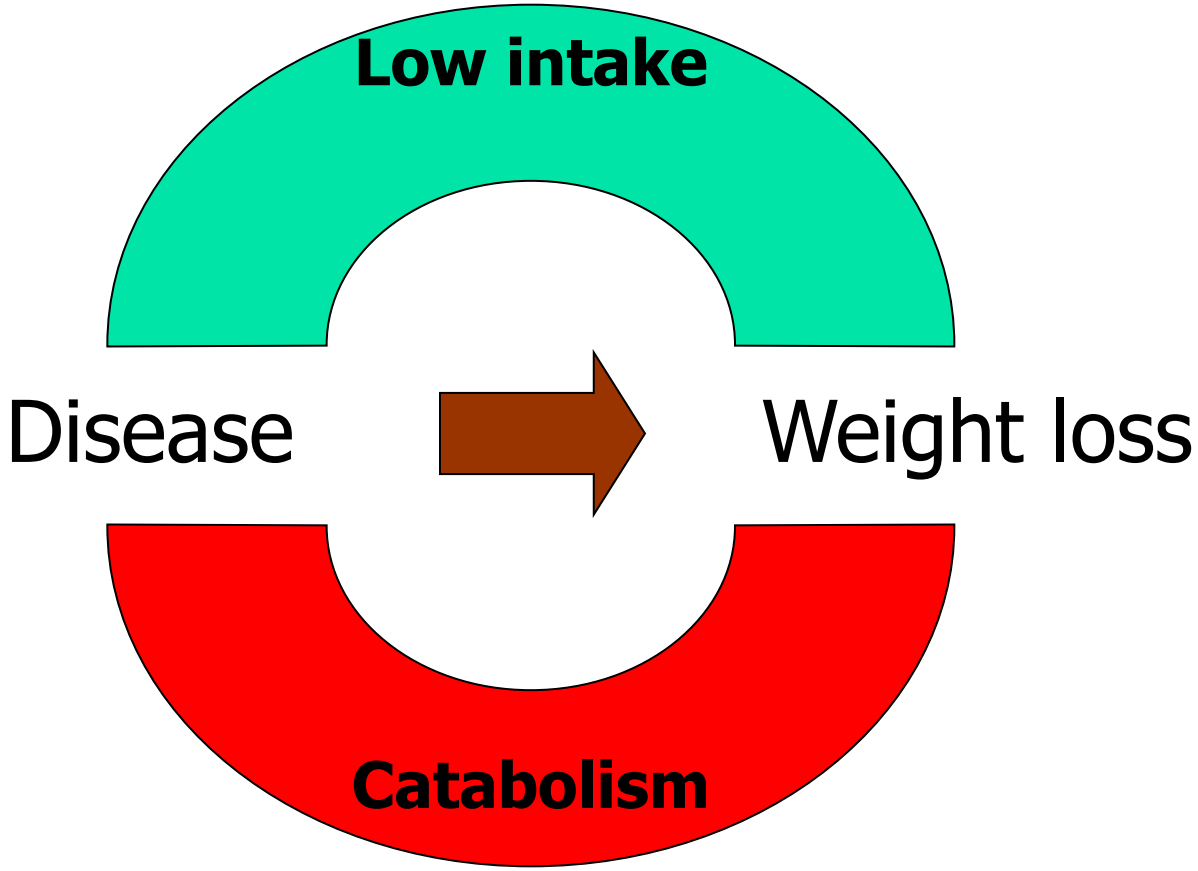
Development of disease-related malnutrition: The two pathways



Development of disease-related malnutrition: The two pathways



The pathways to weight loss

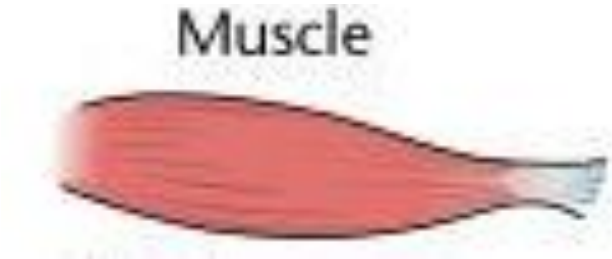


How do the pathways differ?

Low intake =
Negative energy balance

Fat stores depleted more than muscle

Cancer cachexia with systemic inflammation



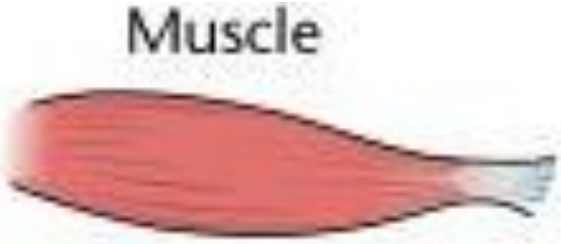
Muscle breakdown and fat depletion

Nutritional support in inflammation: Limited effect – one pathway

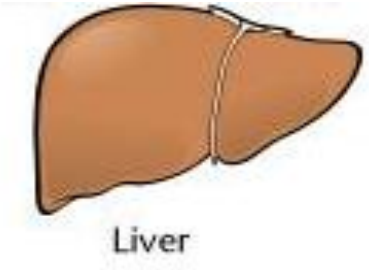
Fat stores repleted

but

Muscle breakdown continues
driven by systemic inflammation



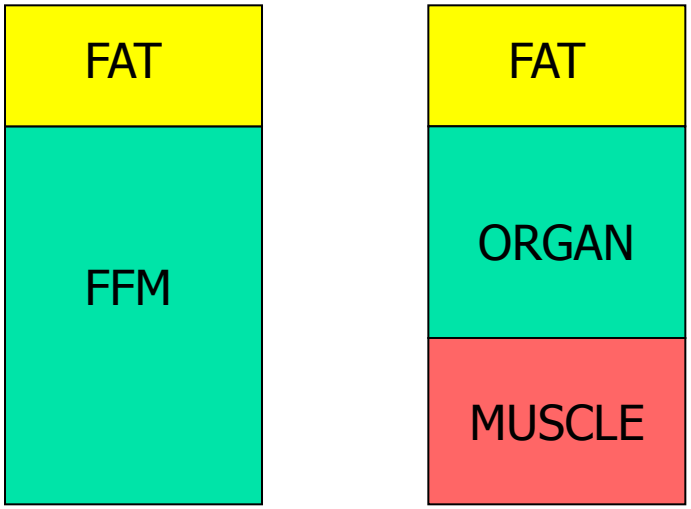
Skeletal muscle loss



Preservation of viscera

Clinical body composition

- All (almost) body composition methods estimate fat and fat-free mass
- In wasting disease, muscle should be separated out from fat-free mass

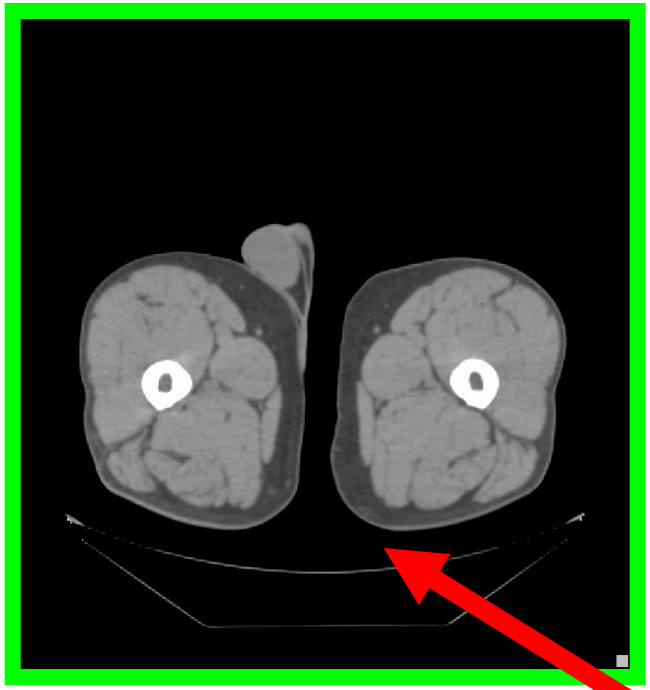


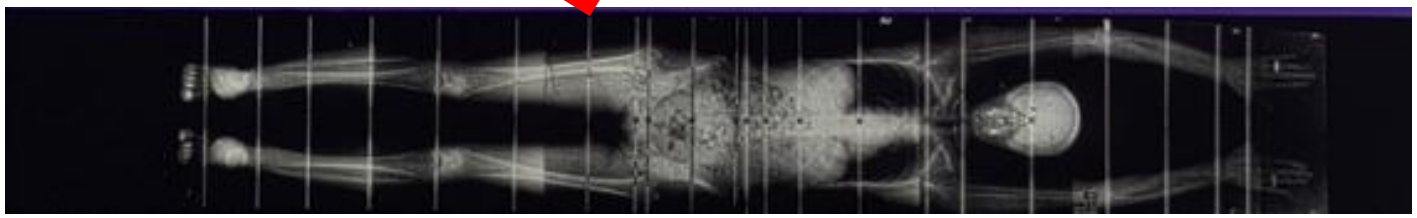
How measure muscle mass?

- CT / MRI
- DXA
- Bioimpedance (?)
- Anthropometry?

- Many functional tests in use

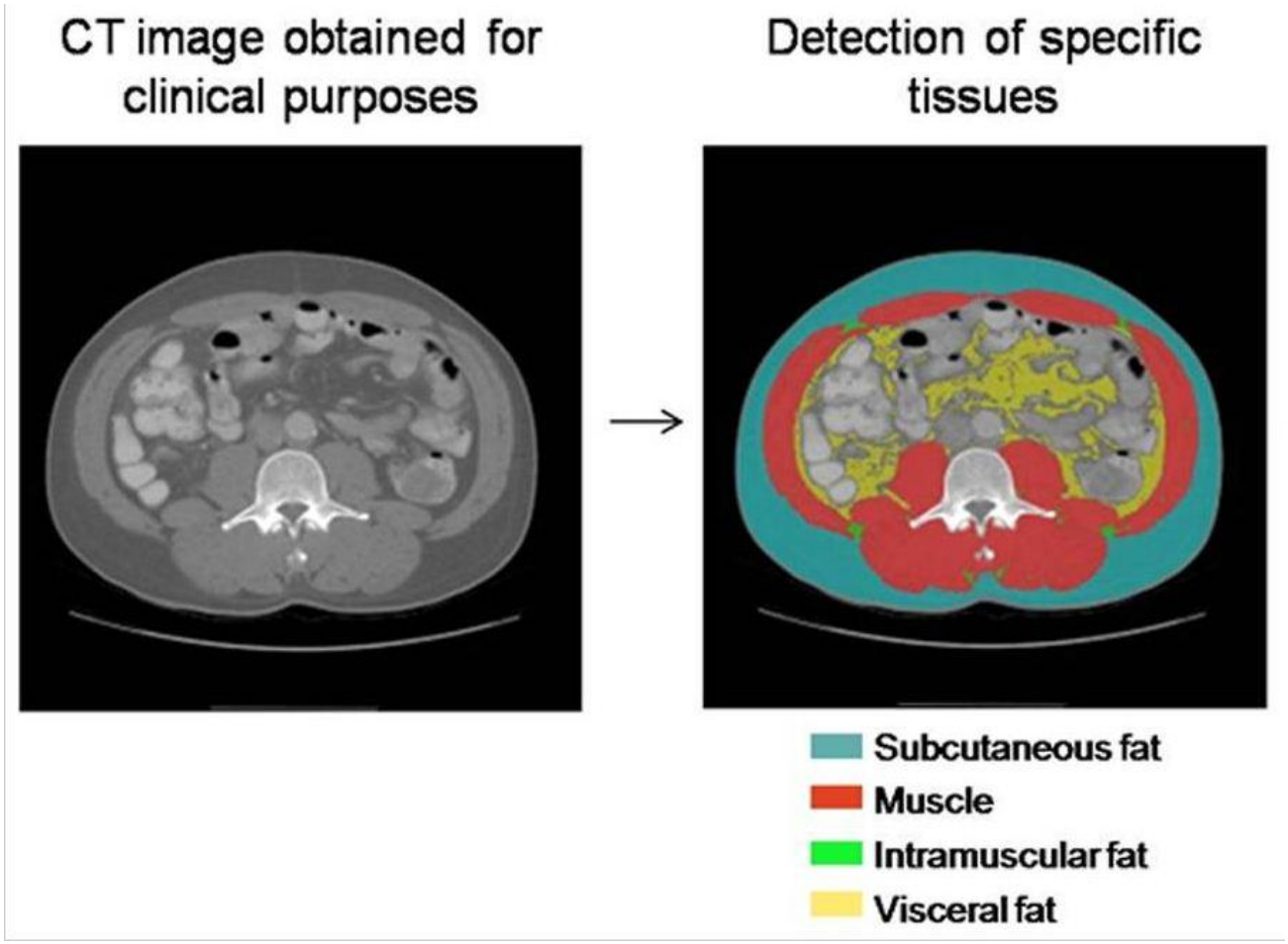
Skeletal muscle mass – reference method CT/MRI





Muscle tissue
volume determination
by whole-body imaging

Muscle by single slice CT/MR



Baracos et al JPEN 2012

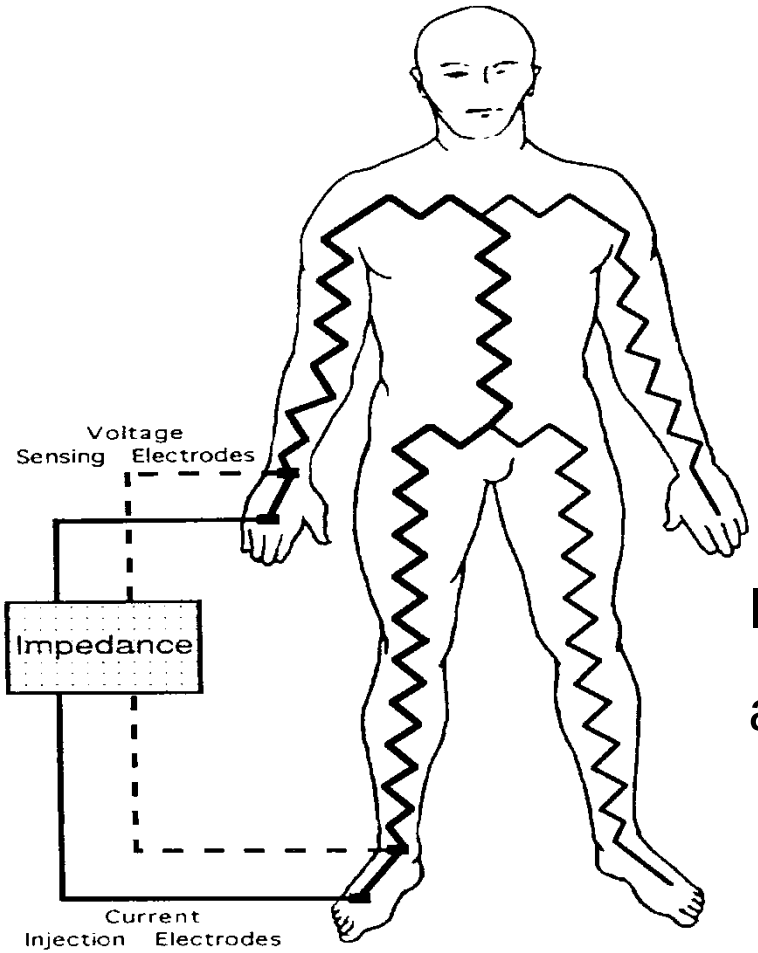
Muscle mass by DXA

Appendicular lean soft tissue (ALST) =
Lean soft tissue (LST) in arms + legs

Skeletal muscle mass (SM, kg):
1.19 x ALST – 1.65
R^2 = 0.96 SEE = 1.46 kg
(Kim et al JAP 97:655, 2004)

Adjusting for height:
SM index = SM / height^2 (kg/m^2)
ALST index = ALST / height^2 (kg/m^2)

Muscle by bioimpedance?



Theoretically sound –

impedance measures mainly arms and legs +

Segmental measurements possible +

In need of further development and validation to become routine -

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VÄSTRA GÖTALANDSREGIONEN
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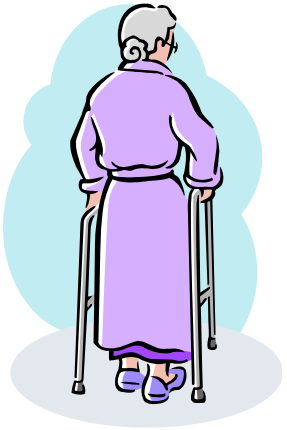
BIS in elderly

- **BIS can accurately estimate body fat and fat-free mass in 75-year old Swedes.**
- **Muscle mass can also be accurately estimated compared to DXA, population-specific equations are required**
- **Our data could be used as reference for elderly patient populations.**

Ref: Tengvall M, Ellegård L, Malmros V, Bosaeus N, Lissner L, Bosaeus I.
Body composition in the elderly: reference values and bioelectrical impedance spectroscopy to predict total body skeletal muscle mass.
Clin Nutr 2009 (28): 52-58



Bioelectric impedance analysis

$R = \rho L/A \longrightarrow R = \rho L^2/V \longrightarrow V=\rho L^2/R$

BIA - Conclusions I

- BIA provides a reliable estimate of total body water under most conditions
- It can be a useful technique for body composition analysis in healthy individuals
- It can be used in medical conditions where major disturbances of water distribution is not prominent

NIH Technology Assessment Conference 1994

BIA - Conclusions II

- BIA values are affected by numerous variables, including:
  - Body position
  - Hydration status
  - Consumption of food and beverages
  - Ambient air and skin temperature
  - Recent physical activity
  - Conductance of the examining table

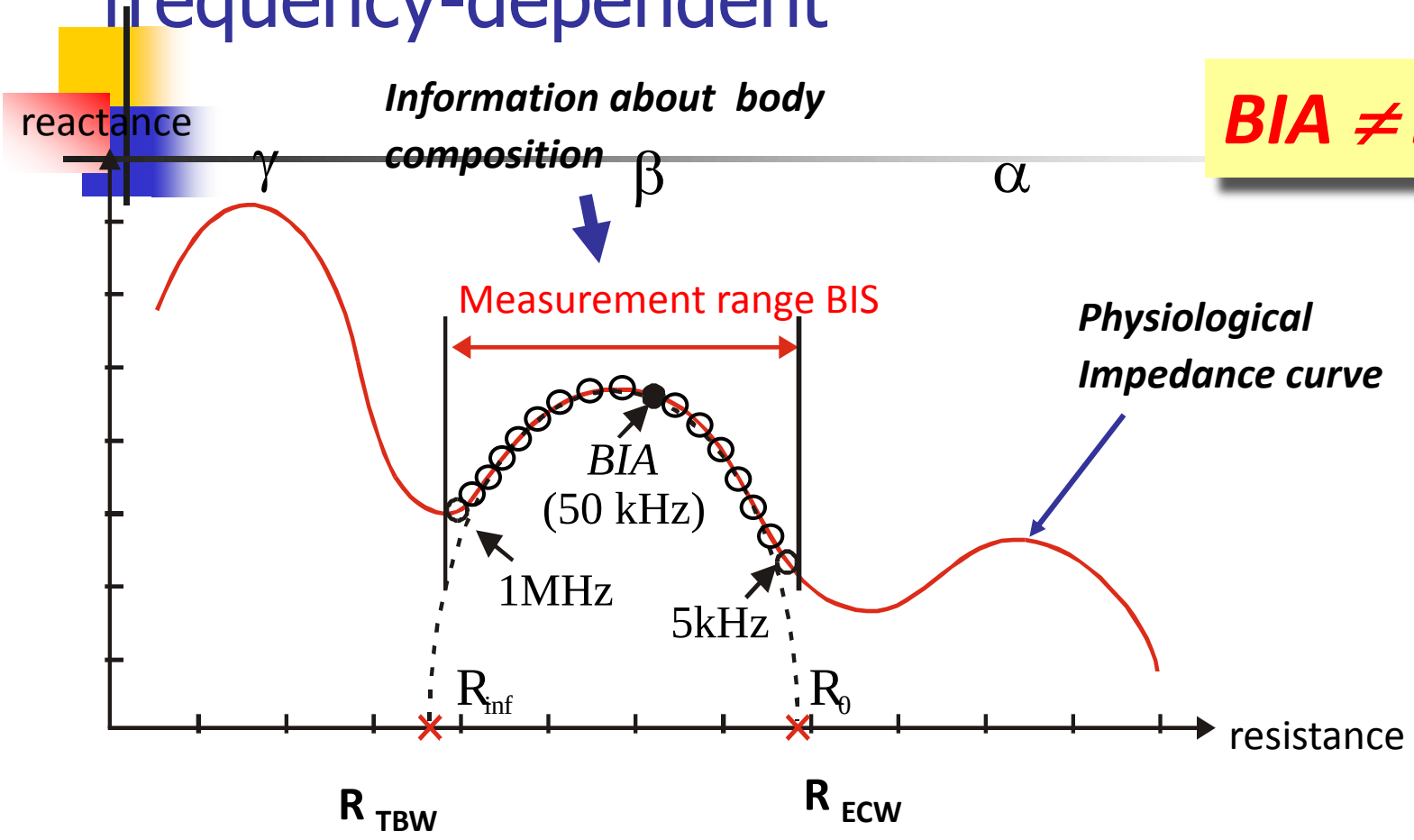
NIH Technology Assessment Conference 1994

BIA - Conclusions III

- Reliable BIA requires standardization
- A specific, well-defined procedure is not practiced.
- Instrument standards and procedural methods should be standardized

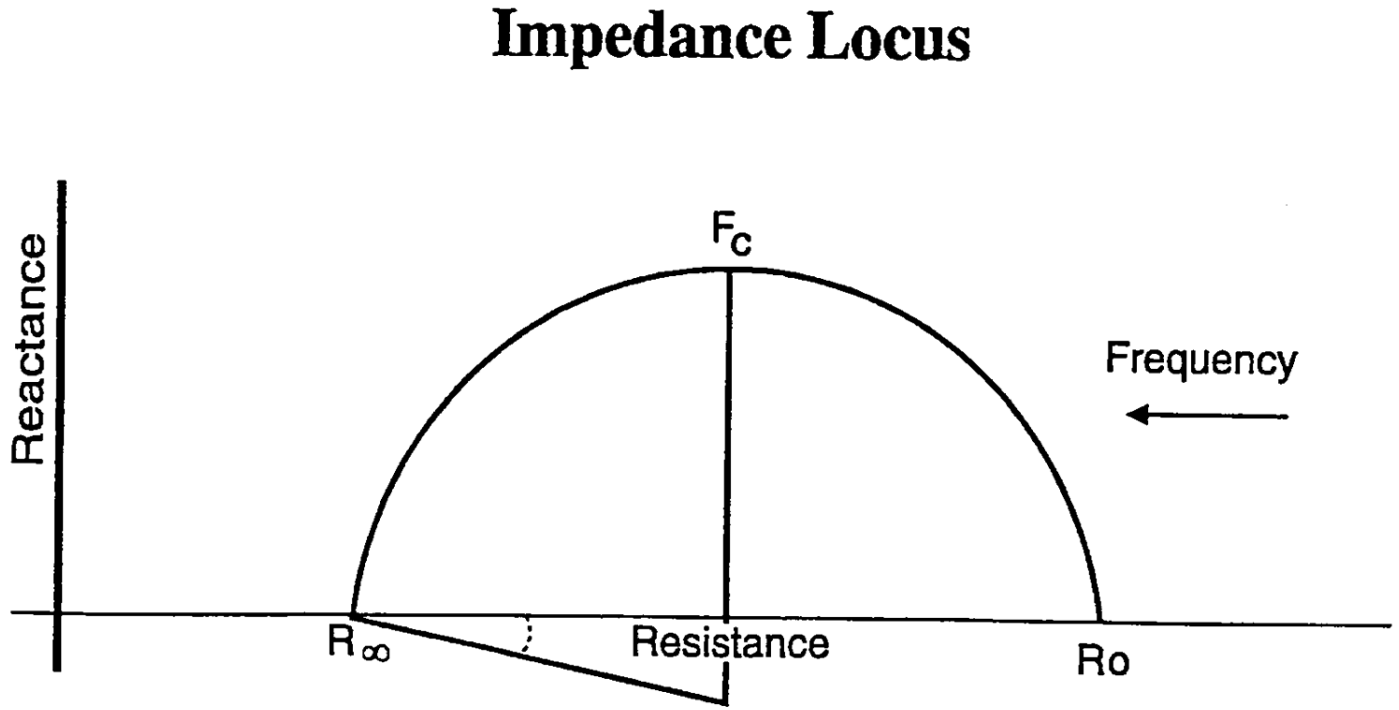
NIH Technology Assessment Conference 1994

Electrical properties of tissues are frequency-dependent

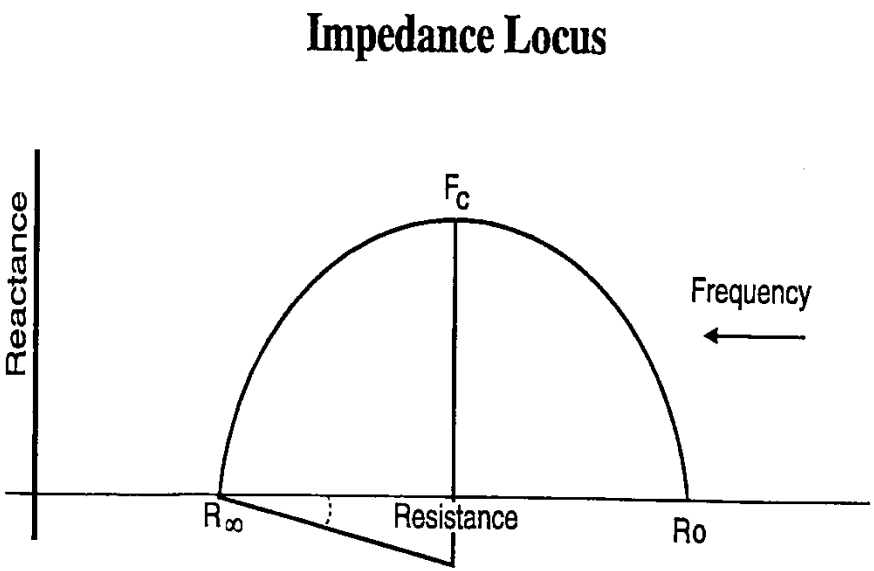


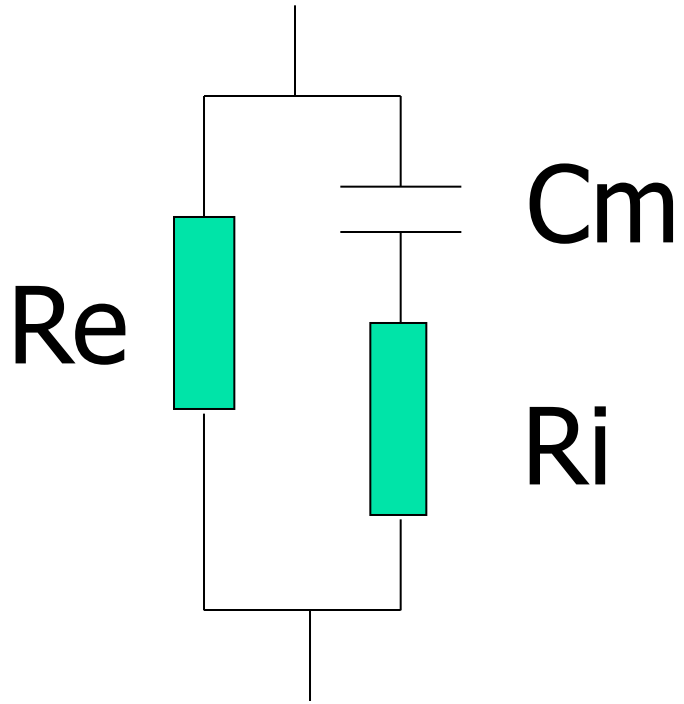
Bioimpedance spectroscopy (BIS) can measure the physiologic impedance curve.

Bioimpedance: Cole modelling



Bioimpedance: Cole modelling





R_0 = Re $1/R\infty = 1/Re + 1/Ri$

BIS volume equations

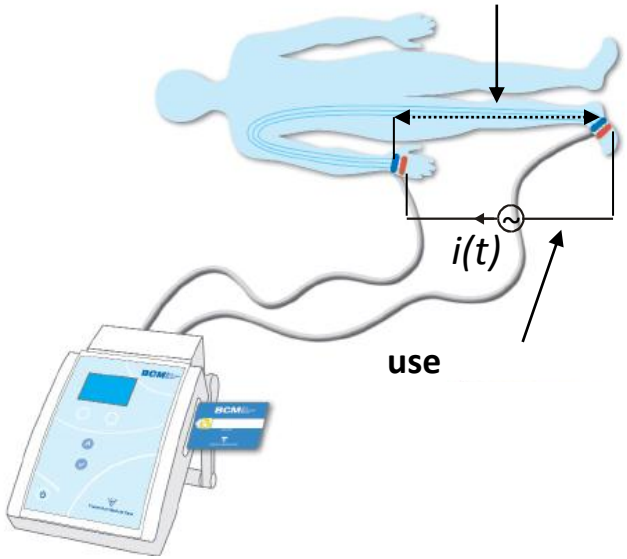
$$ECW_{BIS}(l) = 0.01 \times \left(K_B^2 \times \rho ECW^2 \div D_B\right)^{1/3} \times \left(Ht^2 \times \sqrt{BW} \div R_e\right)^{2/3}$$

$$ICW_{BIS}(l) = ECW_{BIS} \times \{[\rho TBW \times (R_e + R_i) \div (\rho ECW \times R_i)]^{2/3} - 1\}$$

$$TBW_{BIS}(l) = ECW_{BIS} + ICW_{BIS}.$$

Tengvall et al Physiol Meas 2010;31:59-71

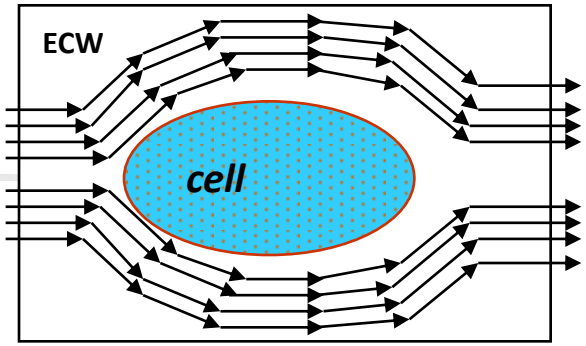
BIS – measurement principle



Bioimpedance spectroscopy

Low frequency

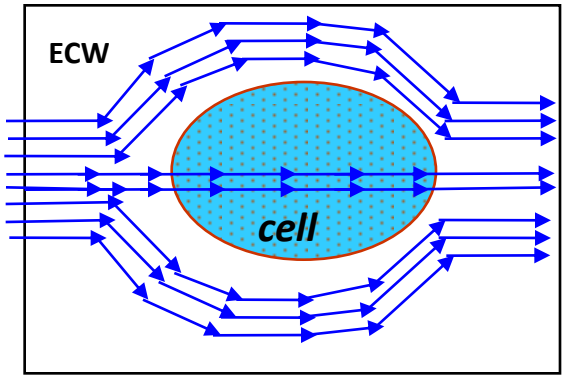
(current does not penetrate the cell)



Middle frequency

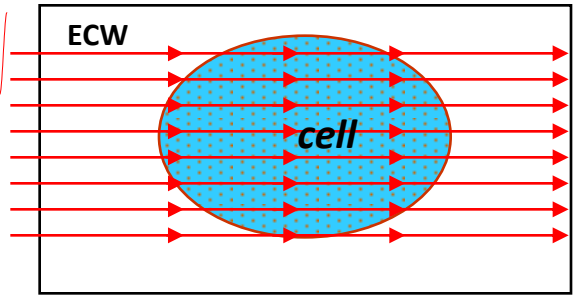
(50 kHz)

(current partially penetrates the cells)



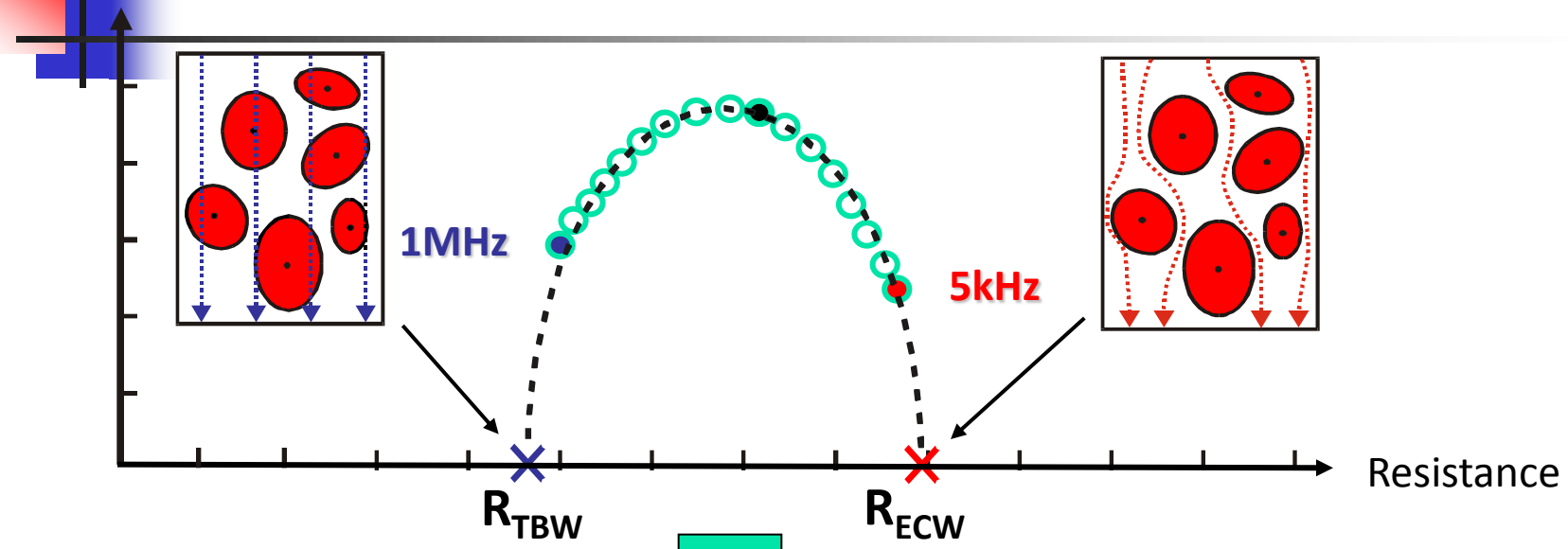
High frequency

(current flows through the cells)



www.bcm-fresenius.com

From impedance to body composition



Weight, height →

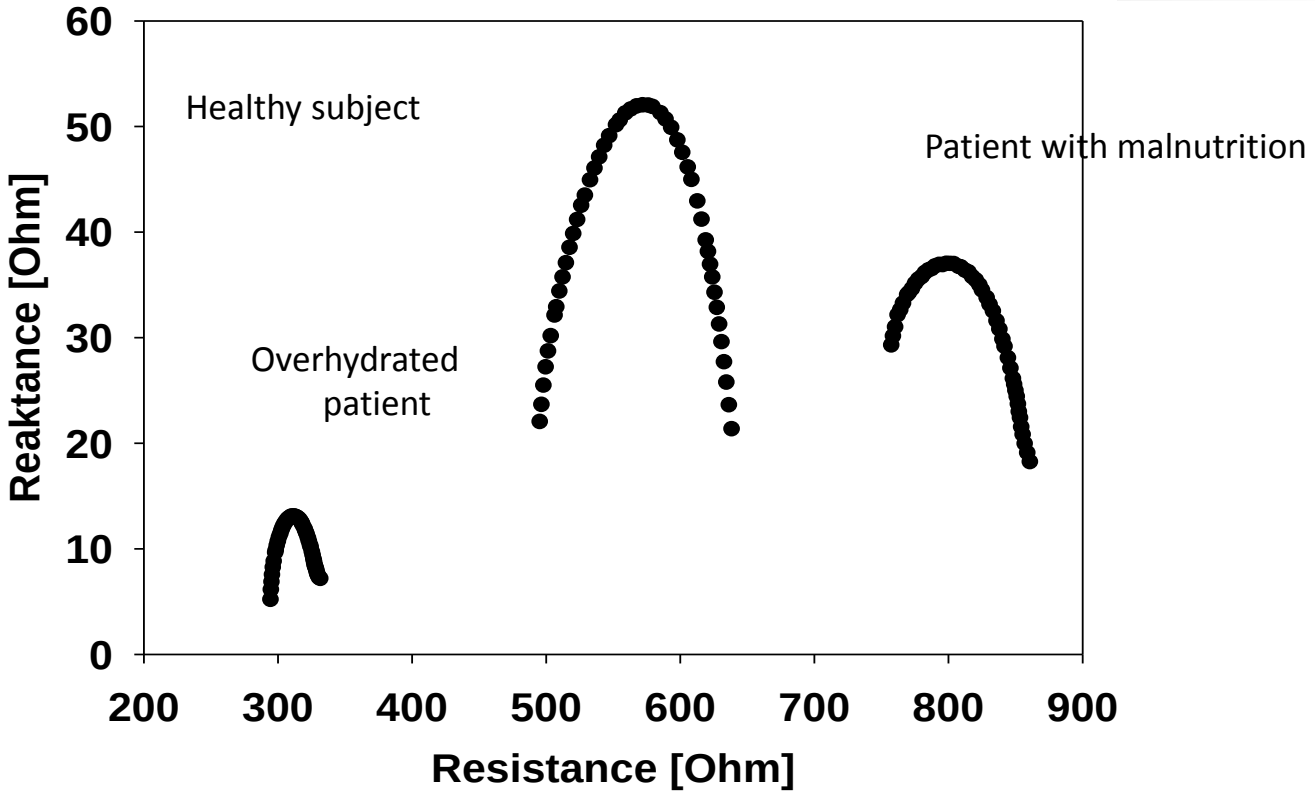
Fluid Model

- ECW, ICW

Body Comp

- Overhydration
- Lean Tissue
- Fat

How does it work in practice?



Bioimpedance: Different methods

- Single frequency BIA: FFM and TBW
  - Difficult separating ICW and ECW, unsuitable in altered hydration states.
- Multi-frequency BIA: FFM, TBW, ICW and ECW from regression equations
- Bioelectrical spectroscopy (BIS): FFM, TBW, ICW and ECW from mathematical modeling of multiple frequencies

And now… the problems:

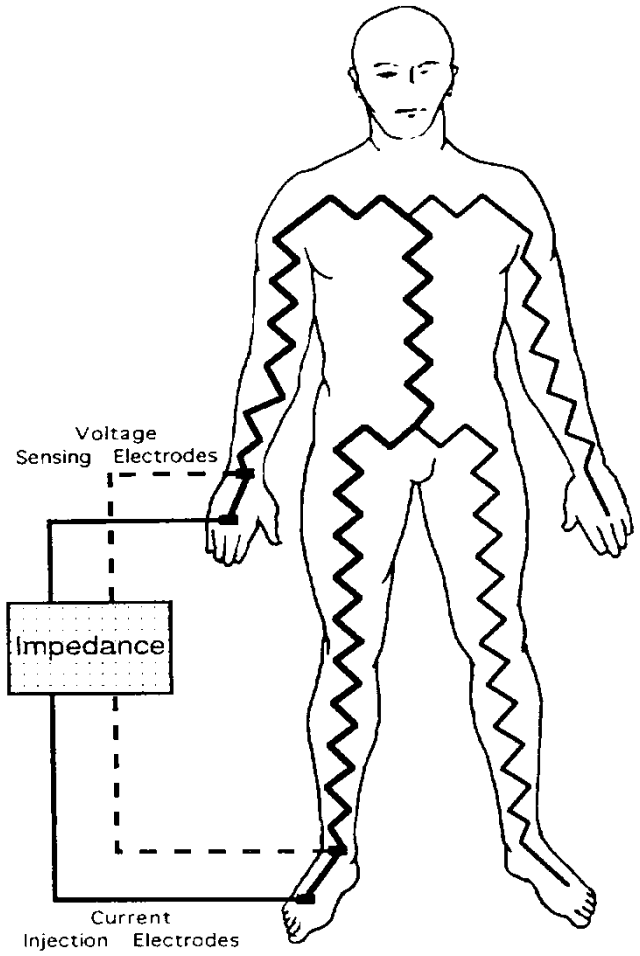
- An increasing number of studies show that BIS can, fairly accurate, measure water compartments in some, but not all patient groups
- However, most studies find a considerable variation in individuals, raising concerns about clinical usefulness

Bioimpedance methods

- Model assumptions – big problem!
- Measurement errors – yes and no
- Validation in study populations – reasonable in some applications
- Feasibility – very good!

Bioimpedance - model assumptions 1

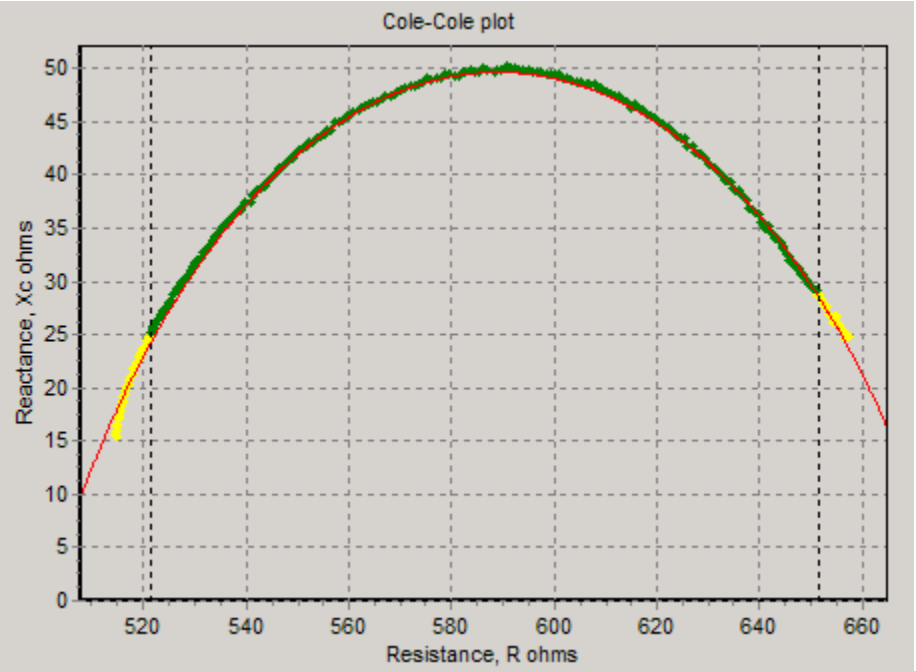
- Five-cylinder body model –far from perfect!
- ”Shape factor” in BIS calculations
- Resistivity constants – constant or variable?
- Body height as proxy for distance between electrodes

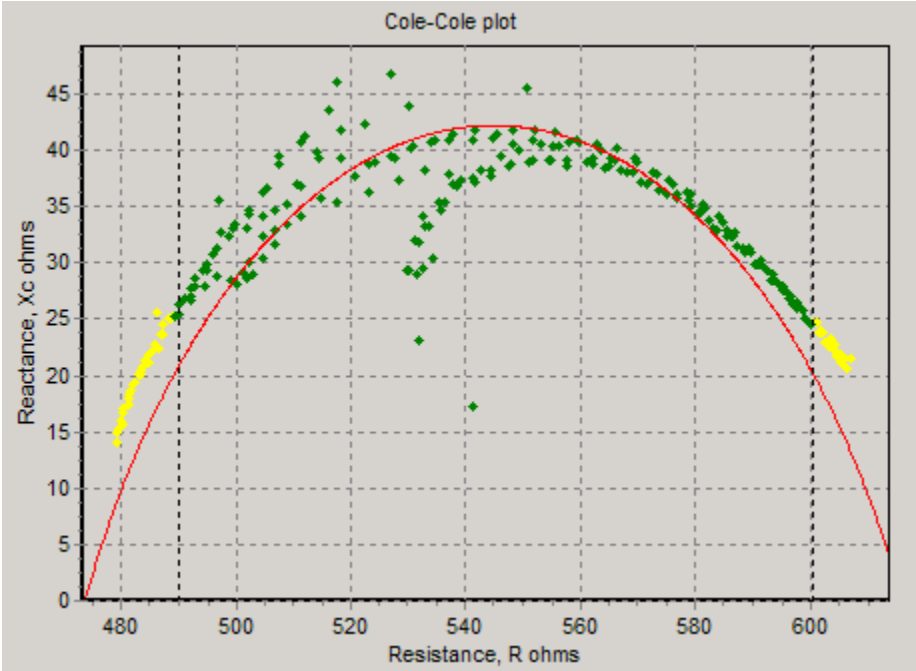


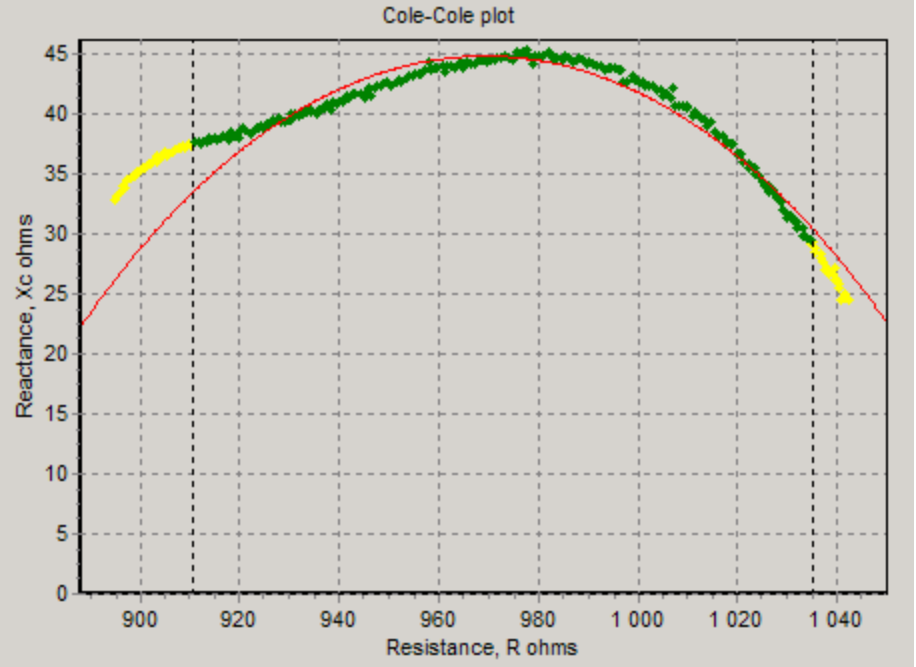
Bioimpedance – measurement errors 2

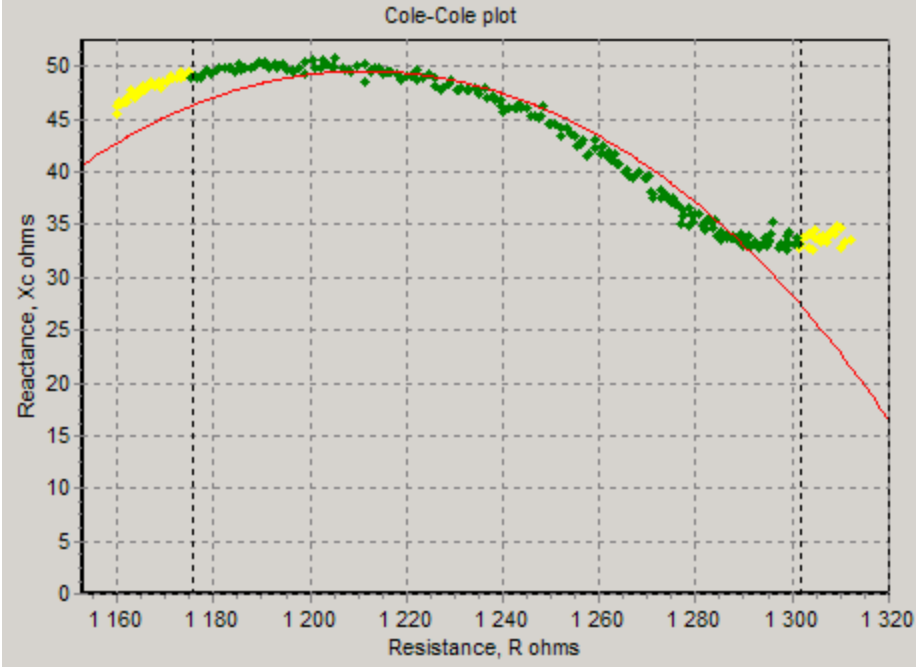
- Electrical measurement quite accurate (~1%)
- Reactance component more dependent on good quality instruments than resistance
- High frequencies more prone to errors – stray capacitance e.g. between electrodes, electrode leads or skin-electrode interface

Some patients are more difficult to measure by BIS…









What does this mean?

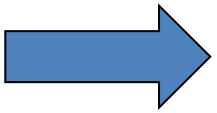
- Generally ”easier” to measure ECW than ICW by BIS in ”problem subjects”
- The Td (time delay) correction method widely used may yield incorrect results in some cases
- To be useful as a tool in clinical practice, these limitations should be recognized

Malnutrition & disease

Step 1: To recognize the problem

Screening:

1. Weight loss
2. Eating problems
3. Underweight



Result:

At risk /not at risk for malnutrition

Malnutrition & disease

Step 2: Assessment

At risk for malnutrition

Assessment of:
Energy stores (fat)
Fat free mass

Diagnosis based
on body composition

Step 3: Diagnosis (2c BC model)

Fat free mass	Fat: -	Fat: ±	Fat: +
+ / ±	Lean	Normal	Overweight/ obese
-	Malnutrition Cachexia	Malnutrition (sarcopenia?)	Malnutrition (sarcopenic obesity?)

Which cut-off values should we use?

- Fat and fat free mass should be related to body size
- Let us do it in the same way as for body weight (that is, BMI)
- Fat-free mass index, FFMI = FFM/height^2
- Fat mass index, FMI = Body fat/height^2
- FFMI + FMI =BMI

Which cut-off values? Males:

Low FFMI	< 16,7
Normal FFMI	16,7 – 19,8
High FFMI	> 19,8
Low FMI	< 1,8
Normal FMI	1,8 – 8,3
High FMI	> 8,3

Kyle et al Nutrition 2003;19:597-604

Which cut-off values? Females:

Low FFMI	< 14,6
Normal FFMI	14,6 – 16,8
High FFMI	> 16,8
Low FMI	< 3,9
Normal FMI	3,9 – 11,8
High FMI	> 11,8

Kyle et al Nutrition 2003;19:597-604

Nutritional Diagnosis Males:

Fat mass index

Fat-free mass index

	< 1,8	**1,8 – 8,3**	**> 8,3**
>= 16,7	Lean	Normal	Obese
< 16,7	Malnutrition (Cachexia)	Malnutrition (Sarcopenia)	Malnutrition (Sarcopenic obesity)

Nutritional Diagnosis Females:

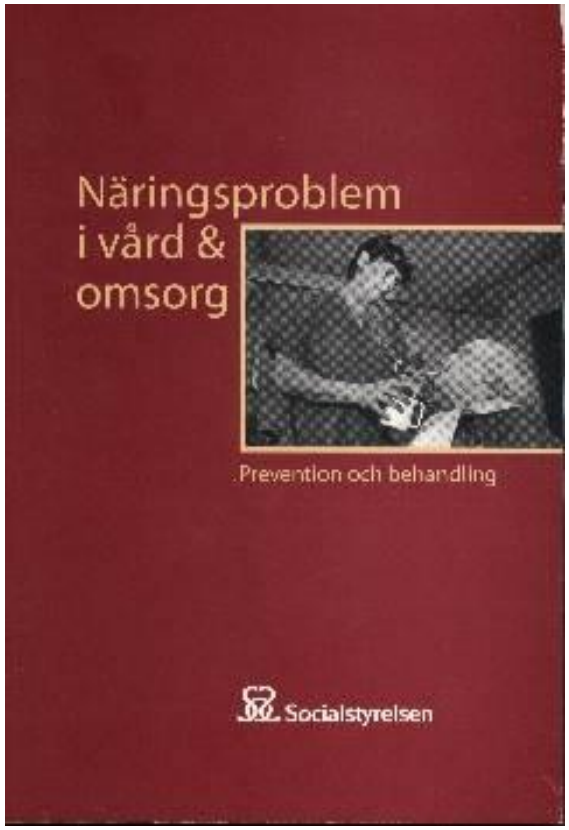
Fat mass index

Fat-free mass index

	< 3,9	3,9 – 11,8	> 11,8
>= 14,6	Lean	Normal	Obese
< 14,6	Malnutrition (Cachexia)	Malnutrition (Sarcopenia)	Malnutrition (Sarcopenic obesity)

Swedish guidelines disease-related malnutrition

2000



2011

Undernutrition – diagnostic criteria

- **Weight loss > 10 %** *and* at least one of the following:
- BMI <19 if <70 y, <21 kg/m^2 if >70 y, or
- Fat free mass index (FFMI) <15 kg/m^2 (women), <17 kg/m^2 (men), or
- Fat mass index (FMI) <4 kg/m^2 (women), <2 kg/m^2 (men), or
- Gait speed <1 m/s, or low hand grip strength (by validated method related to relevant reference population)

SWESPEN & Swedish National Board of Health and Welfare 2011

Summary

- Current nutritional assessment is generally based on body weight (and its change)
- Improved nutritional assessment requires diagnostics based on body composition
- Standard methods using body fat and fat-free mass are still to be implemented
- Future applications will likely also use muscle mass determinations


Thanks for your attention!
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