Does size matter?

Clinical applications of scaling cardiac size and function for body size

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Faculty relationships

- *There are no conflicts of interest to disclose*

From the shrew to the whale…

Heart rate: 1200 bpm

Heart mass: 0.012 g

6 bpm

600000 g

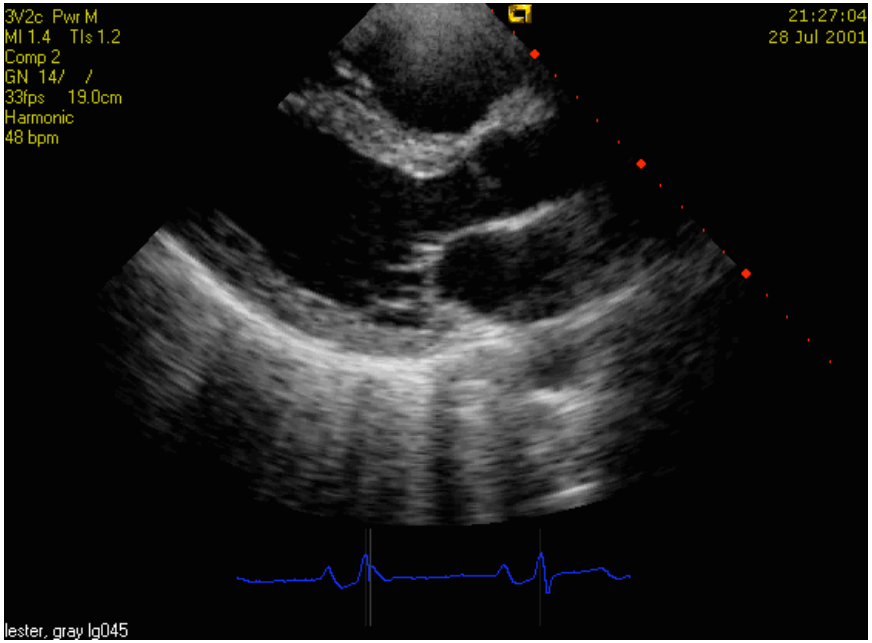
Why scale CV structure and function?

- Measurement accuracy is improving with advances in non-invasive imaging and invasive monitoring
- There are areas of ambiguity between normal and abnormal CV structure and function
- Clinical decision making is affected by these areas of ambiguity
- Proper consideration for patient size may resolve some of these ambiguities
- Improper consideration for patient size adversely affects patient care

Clinical Vignette I

- 23 y/o 200 kg, 100 cm tall male rower evaluated for pre-participation physical
- History notable for “light-headedness” during strenuous exercise
- No syncope, chest pain, palpitations, of family history of SCD
- Exam notable for SEM that does not change with valsalva, S3, and cardiomegaly

Clinical Vignette II



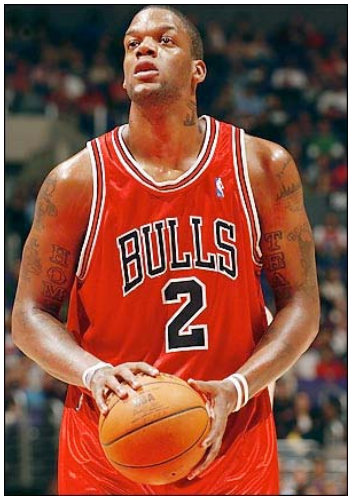
- ECG: 15 mV in aVL, v1+v6 voltage = 42 mV
- Echocardiogram: LV wall thickness 14 mm; LVEDd 53 mm; no obstructive pattern or systolic anterior motion of the mitral valve; E:A and E':E within normal limits

Athlete's Heart vs CMP

- A significant grey area exists between physiological responses to training and primary cardiomyopathy
- Diagnosis means yearly clinical follow-up, exclusion from sport, and potentially ICD implantation
- Though rare, playing field deaths captivate the public imagination

Reggie Lewis dies at 27

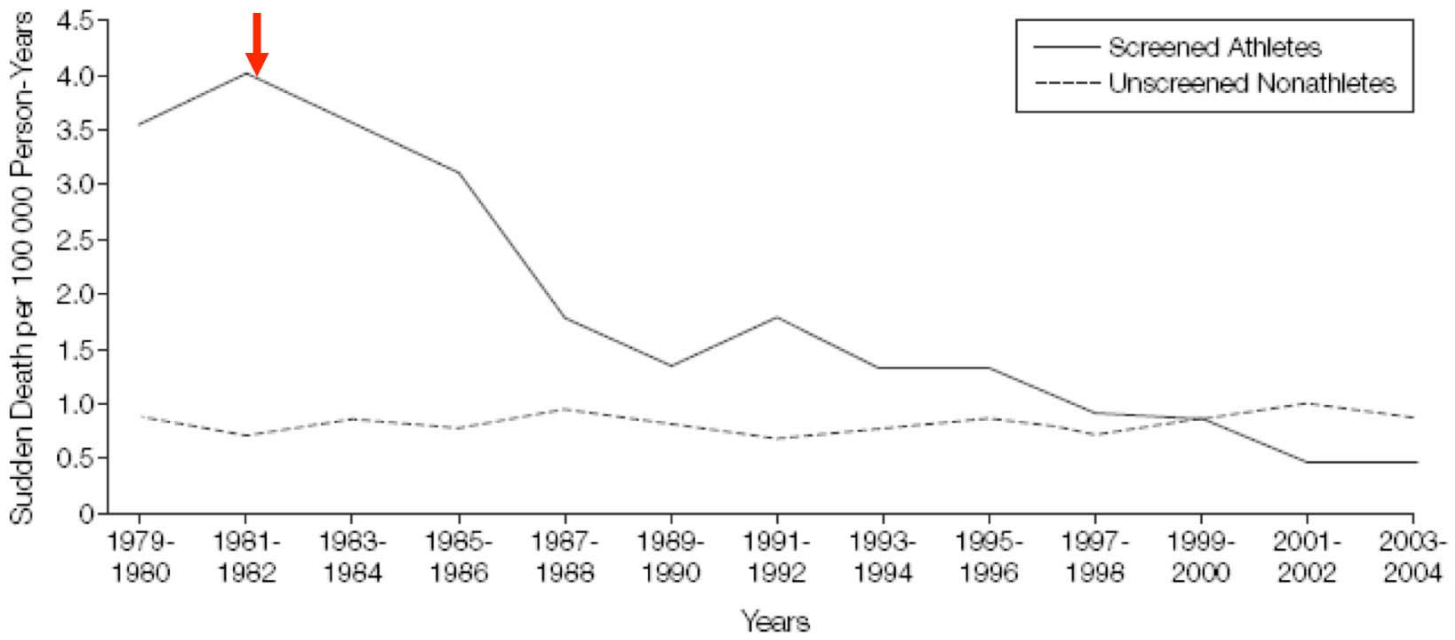
Three months after he collapsed in a 1993 playoff game against the Hornets, Lewis, one of the most beloved players in Boston Celtics history, crumbled to the court again…He never got up. Reggie Lewis, dead at 27.



Bulls: Chicago was forced to trade its most effective offensive player last season, Eddy Curry, after a dispute over a DNA test for his heart ailment threatened to keep him out all season….

Pre-participation screening

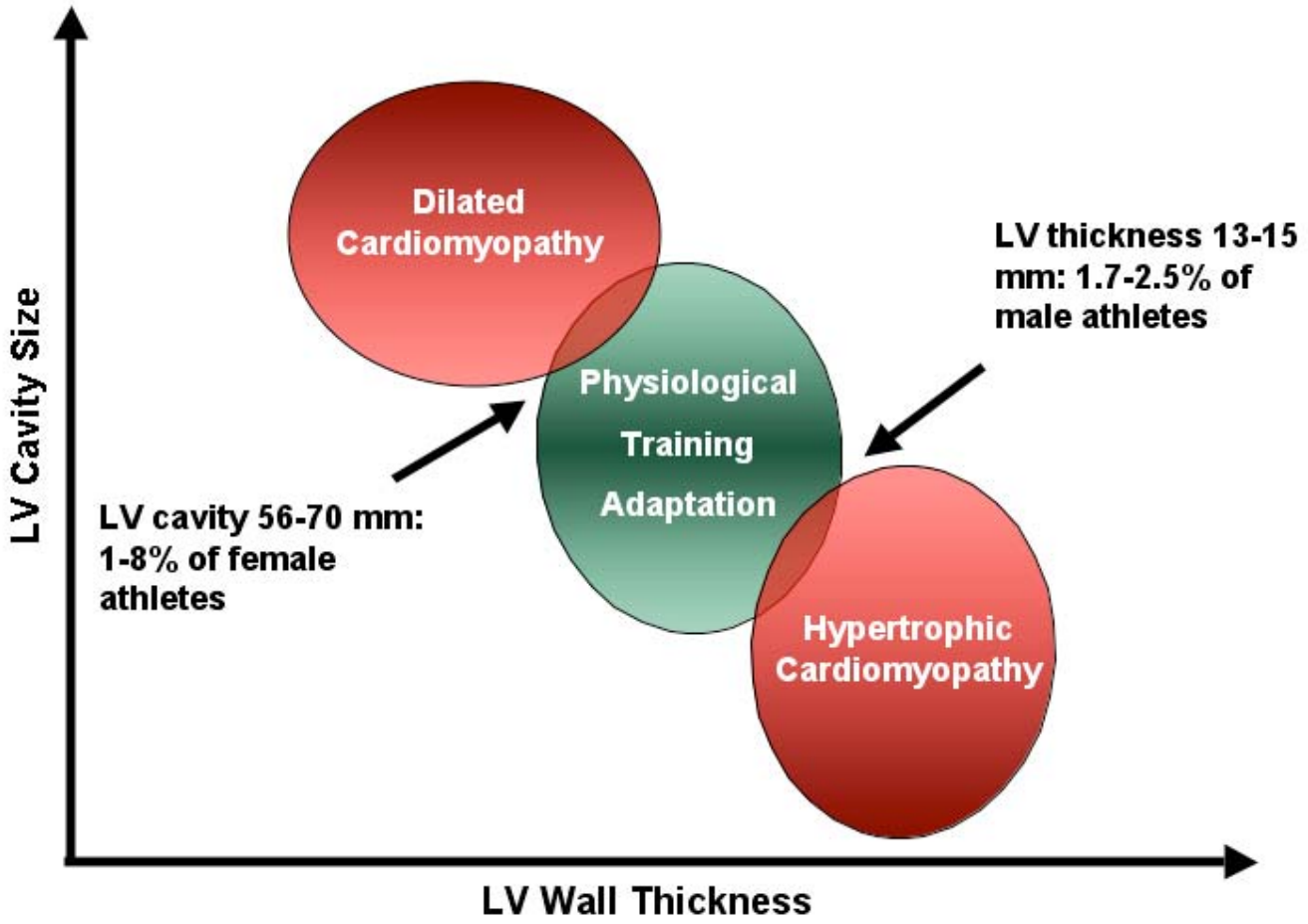
Figure. Annual Incidence Rates of Sudden Cardiovascular Death in Screened Competitive Athletes and Unscreened Nonathletes Aged 12 to 35 Years in the Veneto Region of Italy (1979-2004)



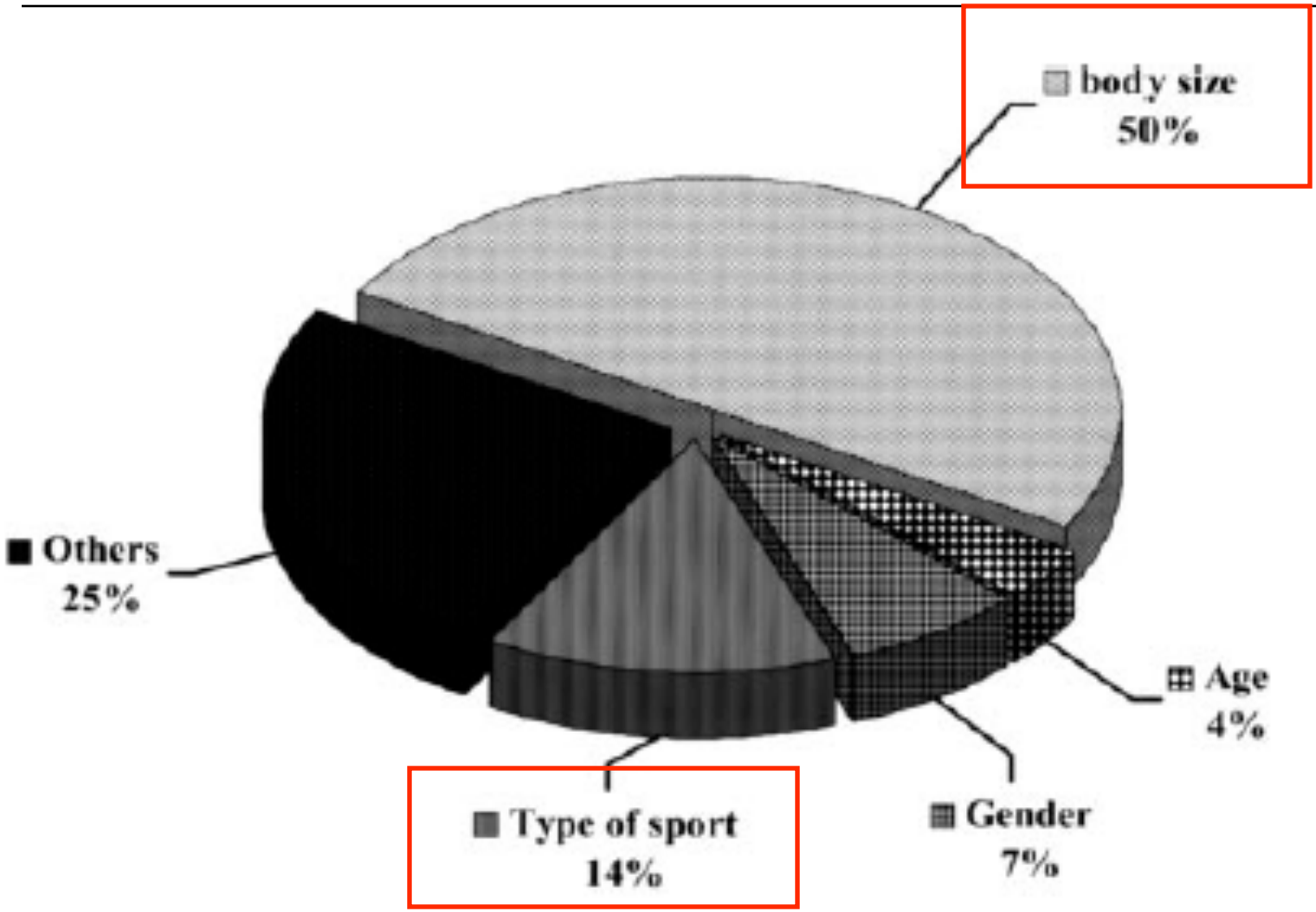
During the study period, the annual incidence of sudden cardiovascular death decreased by 89% in screened athletes (*P* for trend <.001). In contrast, the incidence rate of sudden cardiovascular death did not demonstrate consistent changes over time in unscreened nonathletes.

Corrado, et al. JAMA. 2006 Oct 4;296(13):1593-601

Differential Diagnosis of Athlete's Heart

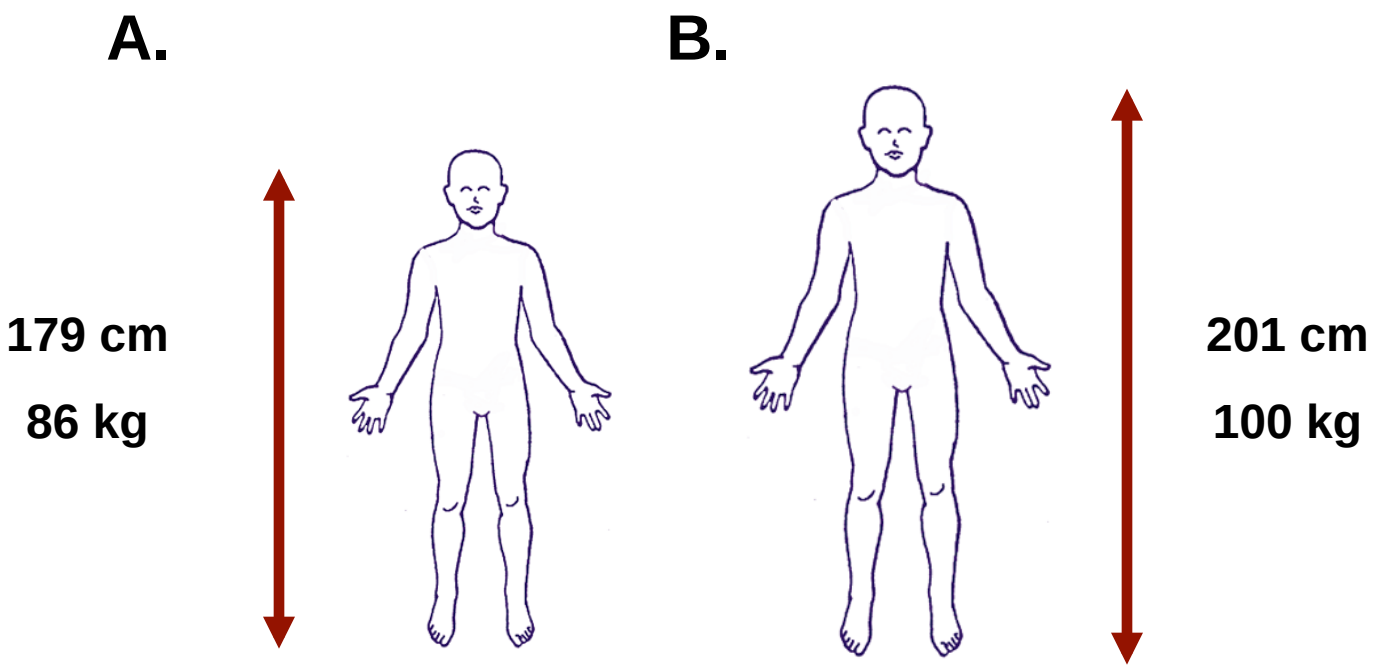


Associations of physiological hypertrophy



*Maron, et al. Circulation. 2006 Oct 10;114(15):*1633-44

Body size as a potential confounder



Relative size of A) average 20-29 year old United States male according to *NHANES* 1999-2002 and B) NBA player for the 2006-2007 competitive season

CDC center for vital statistics 1999-2002

www.nba.com

Scaling - Definitions

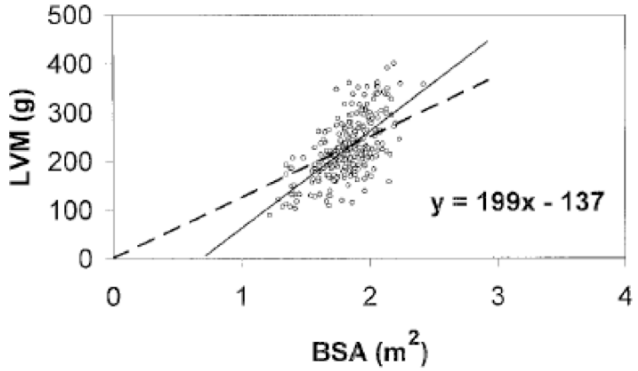
- Ratiometric
  - Division of cardiovascular variable by body size variable
  - $S = x/y$
  - Linear relationship
- Allometric
  - Division of cardiovascular variable by body size variable raised to exponent
  - $S = x/y^b$
  - Exponential relationship

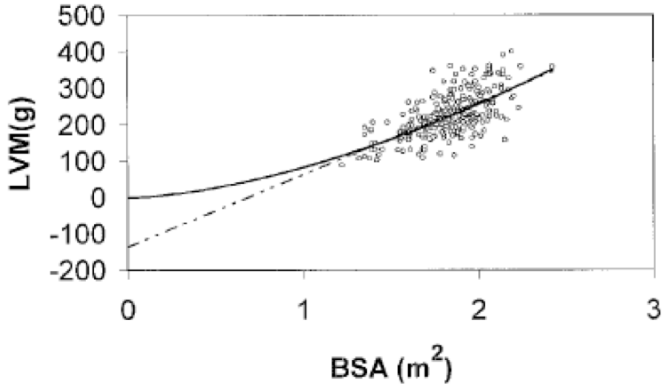
Current Scaling Practice

- LV mass index: LV mass/BSA
- LVEDVI: LVEDV/BSA
- LVESVI: LVESV/BSA
- Stroke volume index: SV/BSA
- Cardiac index: CO/BSA
- VO2 max: VO2/(body mass)

Shortcomings of Current Methods

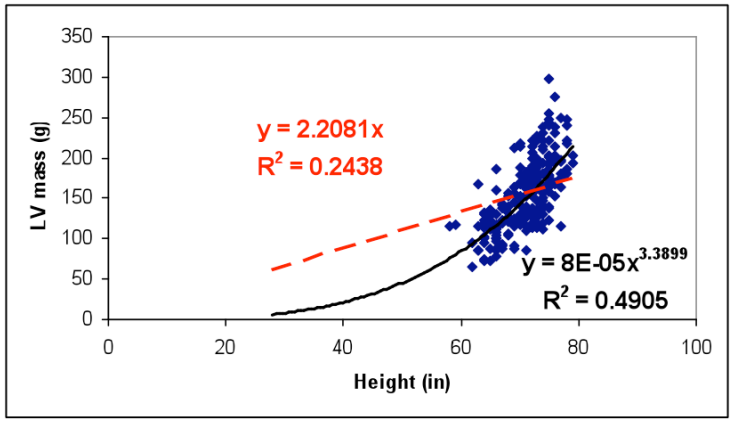
- For a ratiometric scaling approach to be valid, the relationship between body size and the CV variable should be linear
- Theory of similarity: relative geometries define the scaling relationship between body size and cardiovascular variables
- Consider the LV mass index:
  - LV mass is proportional to (major dimension)^3
  - BSA is proportional to (major dimension)^2
  - LV mass should be proportional to BSA$^{3/2}$

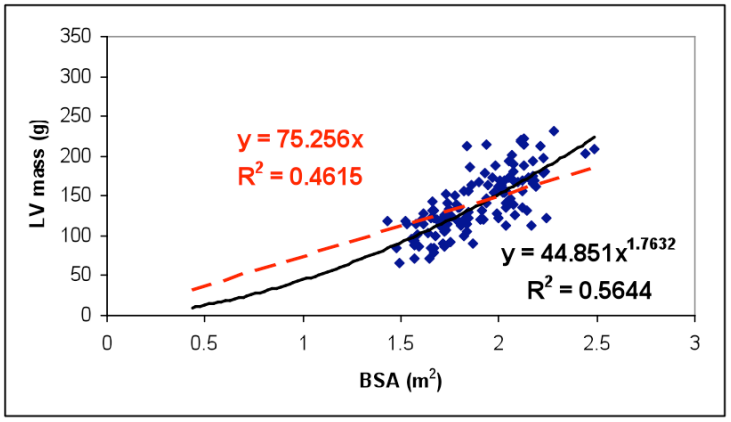


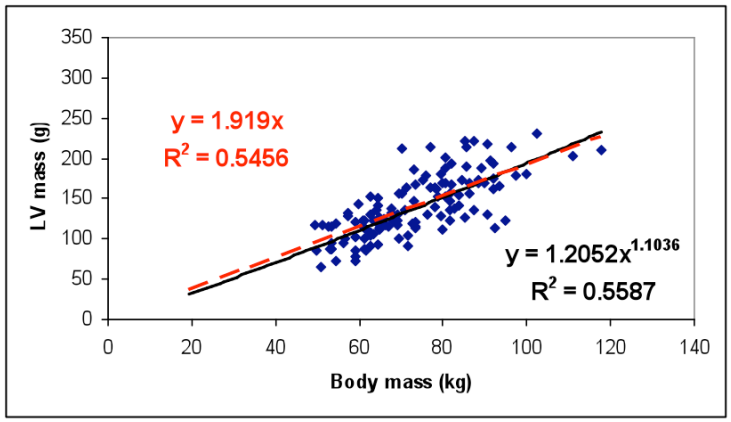


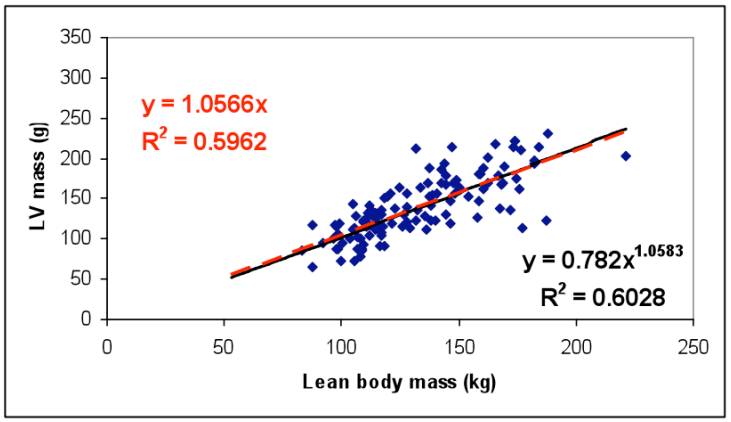
Batterham, et al. Int J Sports Med 1999;20:495-502

Evidence for allometric scaling of CV structure in athletes



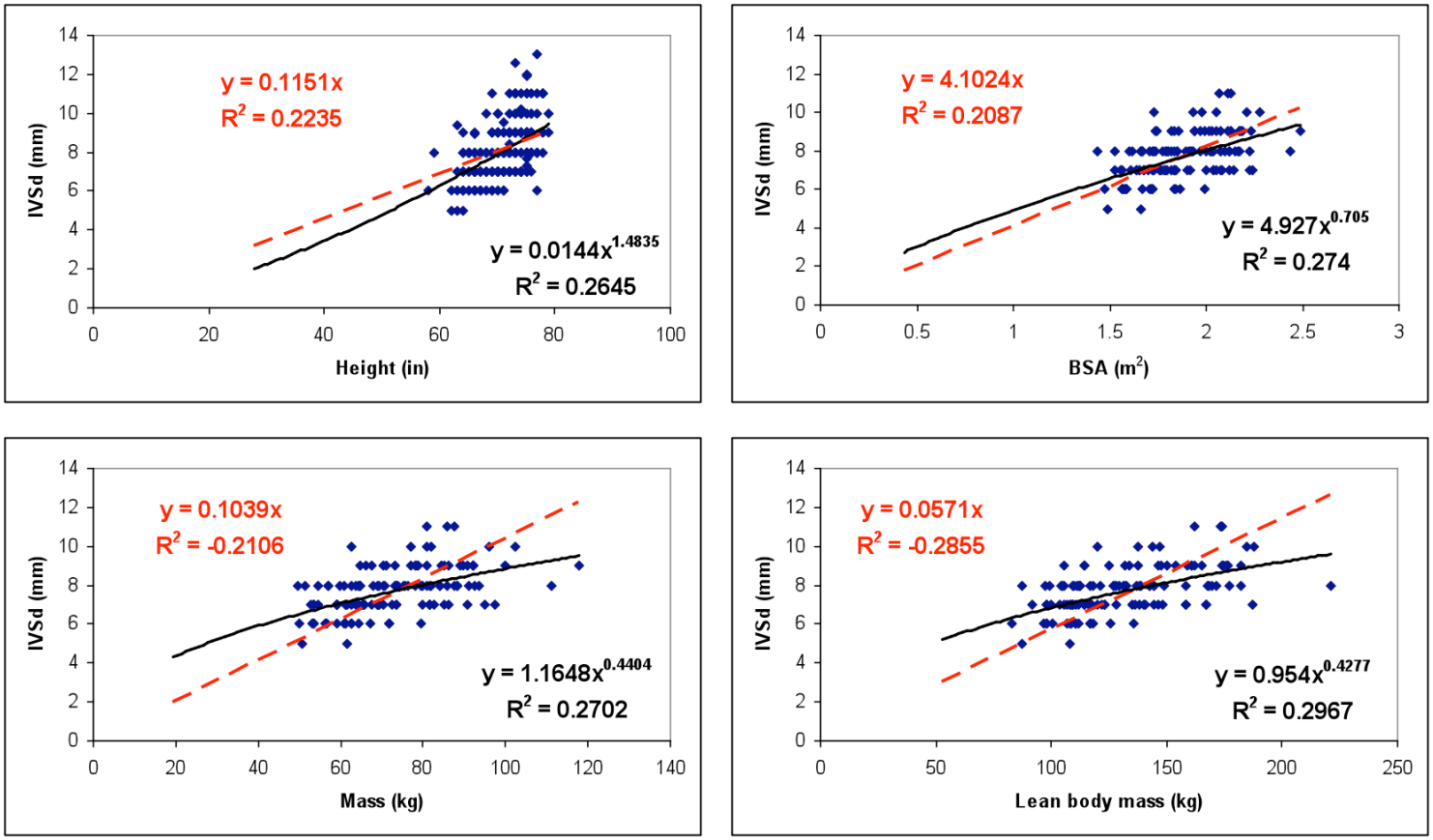






Relationships between body size and LV mass in 250 Stanford athletes

Evidence for allometric scaling of CV structure in athletes



Relationships between body size and septal thickness in 250 Stanford athletes

Recommendations for scaling of cardiovascular structure

- Dimensionally-consistent allometric scaling should be employed
- Scaling to FFM is preferable to scaling to BSA and body mass
- Height may be an acceptable alternative

Evidence for allometric scaling of resting stroke volume

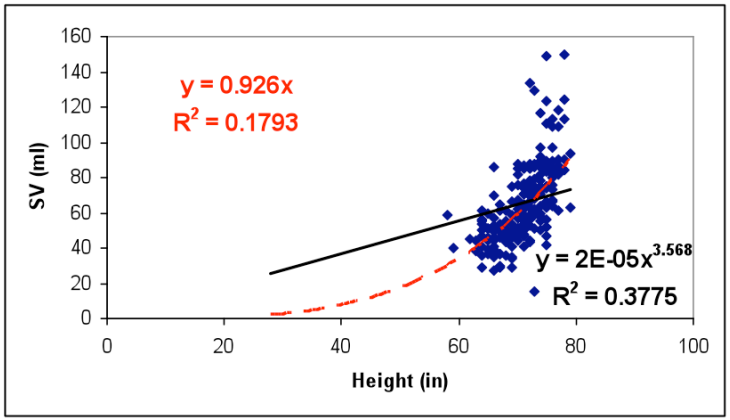
Equation	R^2	$P<$
$SV=5.09 \times weight^{0.62}$	.69	.0001
$SV=40.38 \times BSA^{0.93}$	.69	.0001
$SV=26.47 \times height^{1.78}$	.66	.0001

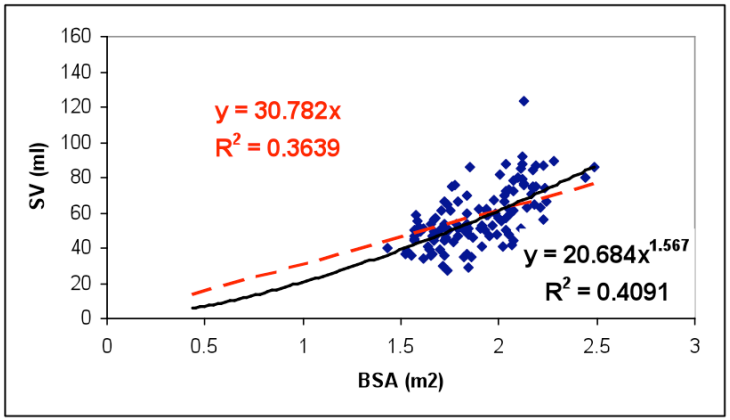
- Subjects: 970 normotensive subjects aged 1-85
- M-mode estimation of SV
- 204 were overweight to obese

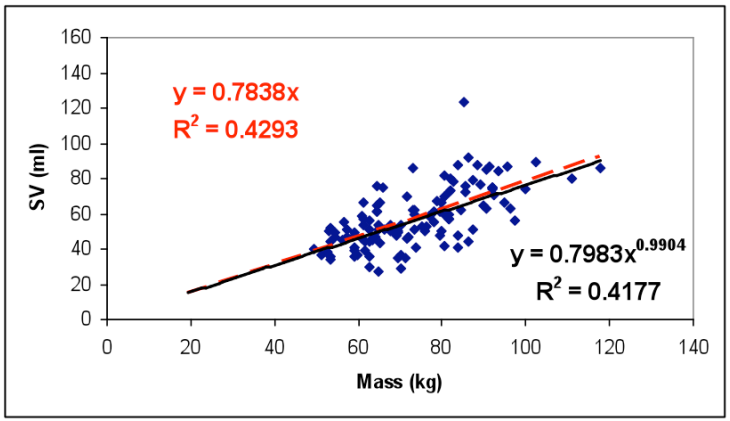
- Stroke volume scaled to BSA with scaling exponent not significantly different from 1 in normal weight subjects
- These scaling equations systematically underestimated SV in overweight or obese subjects by up to 17%

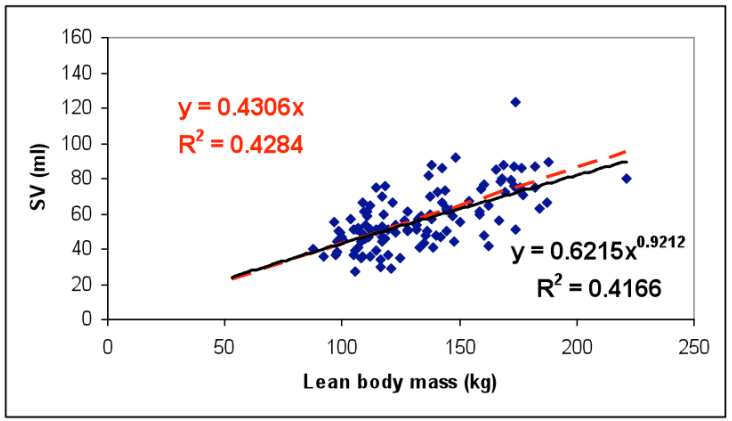
De Simone, et al. Circulation. 1997;95:1837-1843

Evidence for allometric scaling of stroke volume in athletes









Relationships between body size and stroke volume in 250 Stanford athletes

Evidence for allometric scaling of cardiac output

Equation	R^2	$P<$
$CO=820 \times weight^{0.41}$	.42	.0001
$CO=3277 \times BSA^{0.62}$	.42	.0001
$CO=2499 \times height^{1.16}$	.38	.0001

- *Regardless of body composition, the cardiac index underestimated appropriateness of CO for large patients*

De Simone, et al. Circulation. 1997;95:1837-1843

Recommendations for scaling of CV function

- SVI may be valid in normal weight subjects
- CI underestimates adequacy of CO for larger patients and overestimates adequacy of CO for smaller patients
- Dimensionally consistent scaling relationships should instead be applied

Why allometric scaling?

- Metabolic demand defines the need for effective circulatory supply
- Fractal scaling defines self-similar structures that maximize efficiency of oxygen transport
- These scaling properties define mass-specific metabolic rate, the “fourth dimension” of life
- BMR scales with $mass^{0.75}$, MMR scales with $mass^{0.9}$
- HR scales with $mass^{-0.25}$, whereas lifespan scales with $mass^{0.25}$

Back to the case….

- Our patient:
  - LV wall thickness 14 mm
  - Body fat percentage via BIA: 7%.
  - Fat free mass = 100 kg – 7 kg = 93 kg
  - 14 mm/(93 kg)$^{1/3}$ = 3.20 mm/(kg$^{1/3}$)
- Upper limit of normal:
  - LV wall thickness 13 mm
  - Mean body fat percentage from skinfold thicknesses for the 1999-2002 NHANES 26.2%
  - Mean body mass: 89 kg
  - “Upper limit” of scaled LV wall thickness: 3.26 mm/(kg$^{1/3}$).

Thank you

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