Scaling strength in human simulation models

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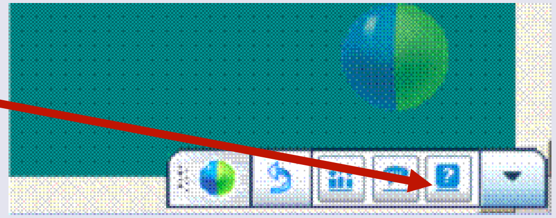

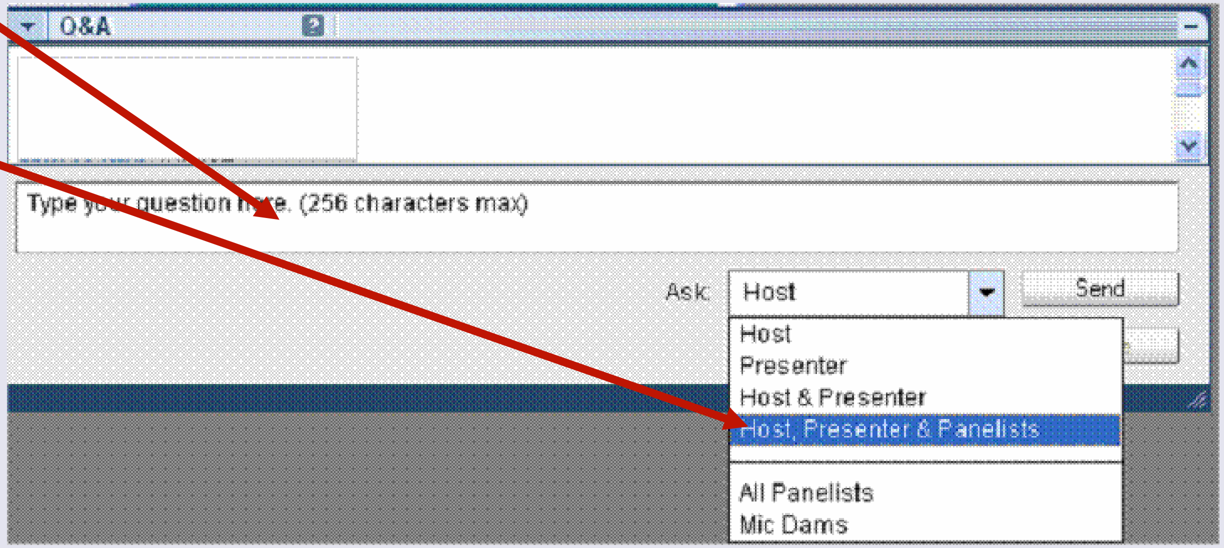

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Online resources

- AnyBody Technology
  www.anybodytech.com
  - Free evalutation licenses
  - Tutorials and documentation
  - Replay of webcasts
  - Further info: Email: anybody@anybodytech.com
- The AnyBody Research Project
  www.anybody.aau.dk
  - Public domain library of body models and applications
    Publications – many for direct download.

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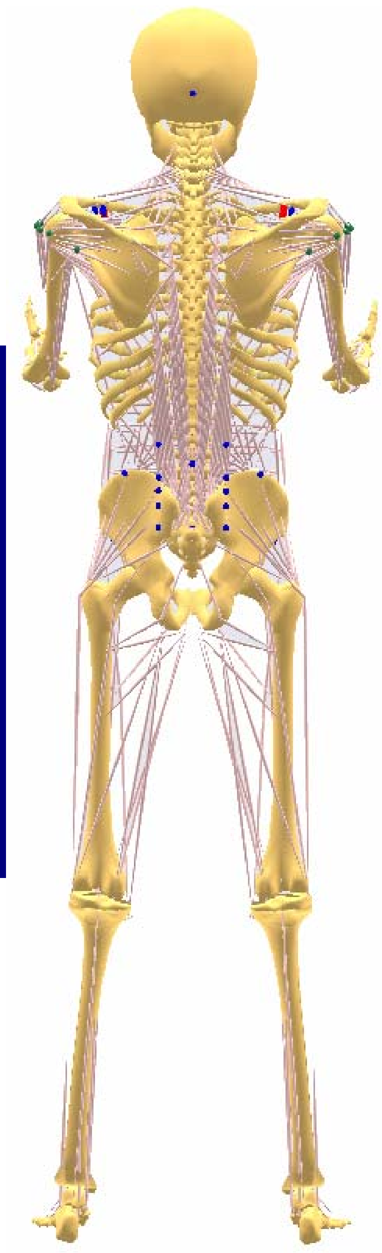
Forthcoming webcasts

- 22 February 2007:
  Kinematic analysis of over-determinate Systems (the mocap interface) by Michael Skipper Andersen

Sign up at www.anybodytech.com

Scaling strength in human simulation models



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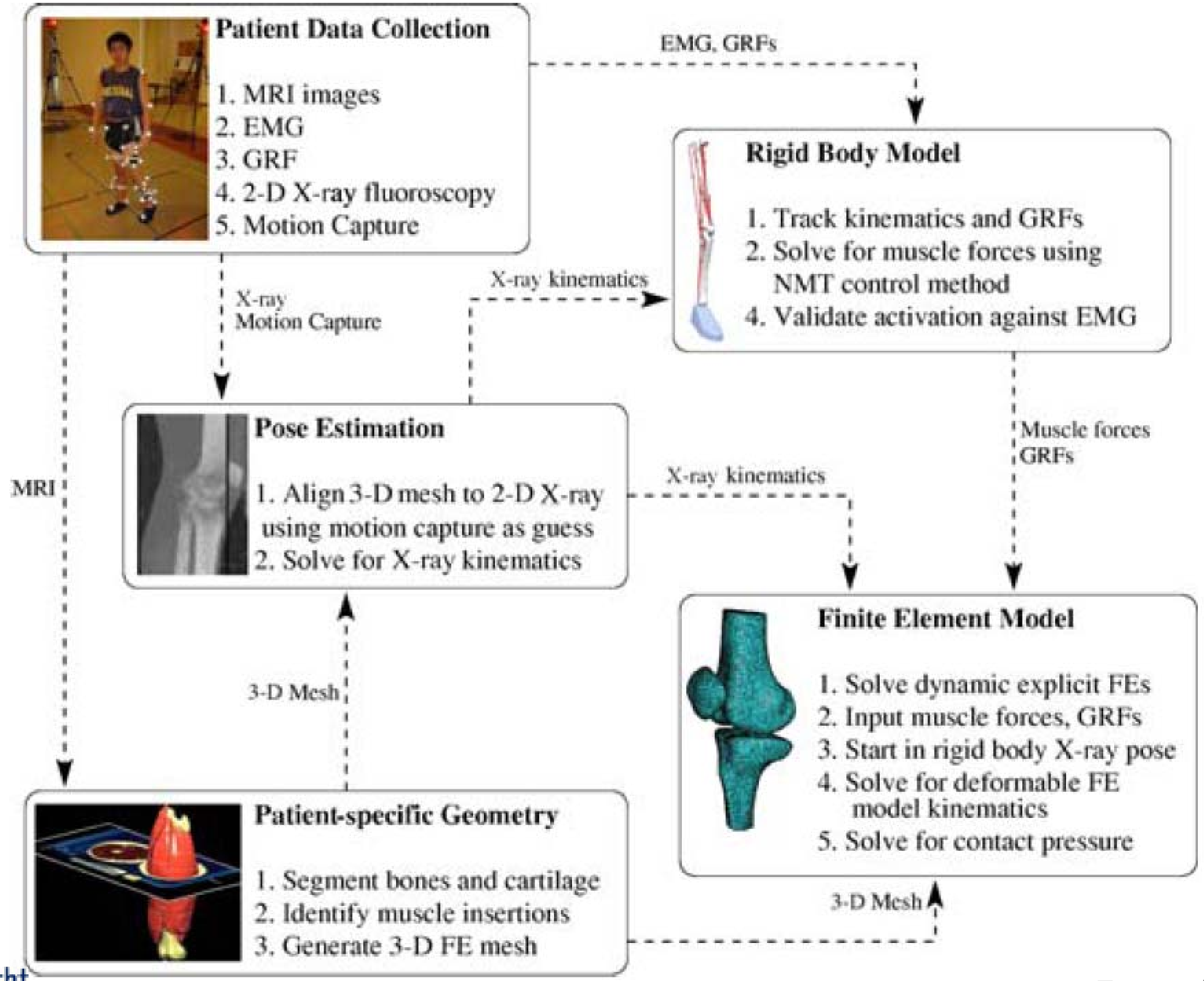
Background

- Muscle function and mobility in chronically ill patients (Diabetes & COPD) and elderly
  - Patients suffer from
    - Reduced muscle mass / quality
    - Limitations in mobility
  - Evaluate relationships with simulation models
  - Subject/population specific models

Option 1; detailed assessment of patient data



Fernandez and Pandy 2006

Option 2; scaling of reference model

- Built reference model from anatomical data
- Implement scaling laws
  - Bone geometry
  - Muscle morphology

www.anybodytech.com

1: Geometric scaling

$$Force \sim M^{2/3}$$

- Simple surface to volume relationship with body mass
- Between species
- Within species?

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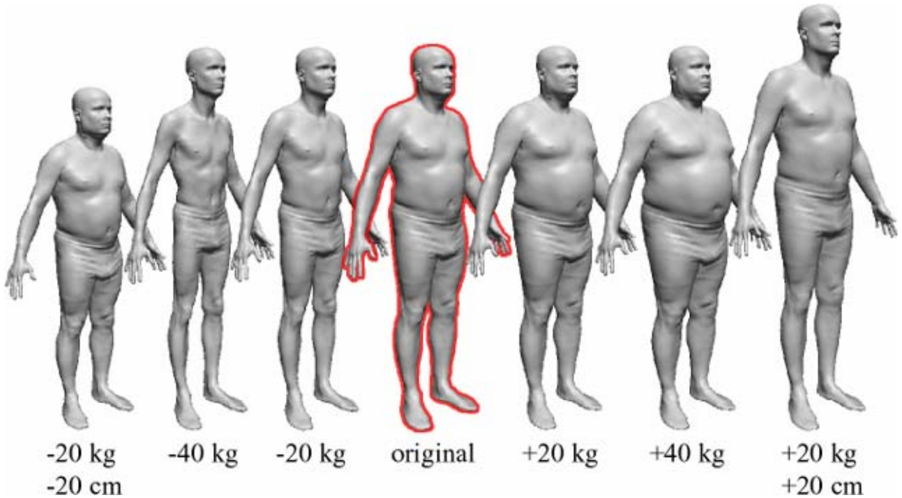
Scaling within species

- Humans vary greatly in shape and size



- Humans vary greatly in the amount of force they can produce

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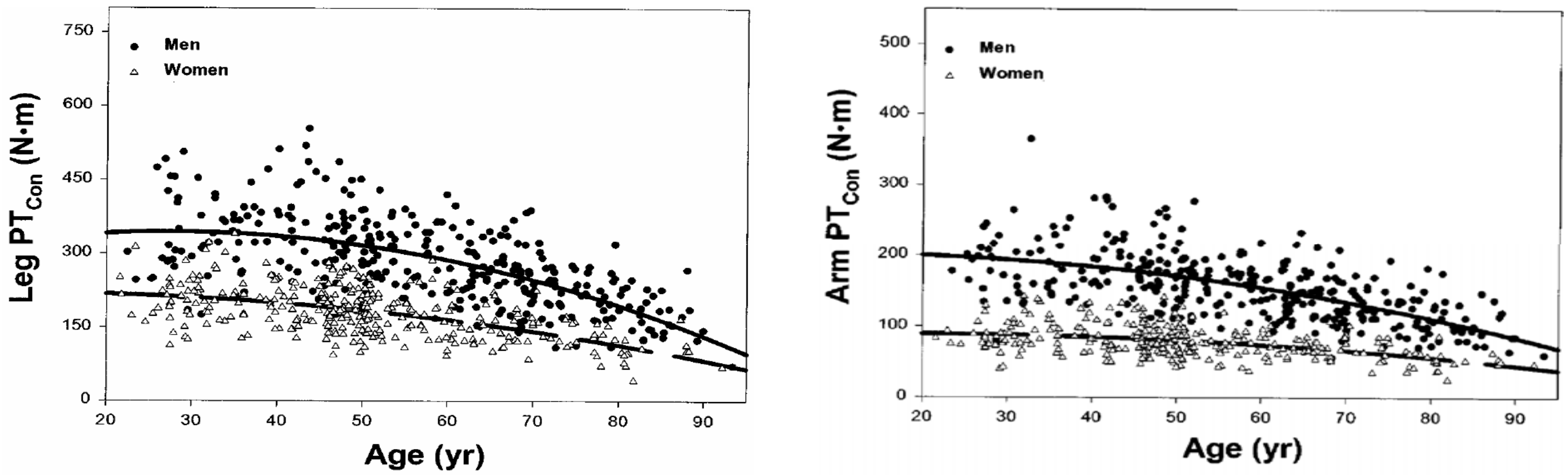
Factors to consider

- Body size
  - Length
  - Mass ($M_{segment} \sim M_{Body}^{(1.1\text{-}1.4)}$)
- Body composition
  - Fat %
- Age
- Gender
- Activity level / Training status

Aim of the study:

- To validate existing strength scaling methods with experimental data on upper leg and arm strength
- Evaluate the influence of gender and age.



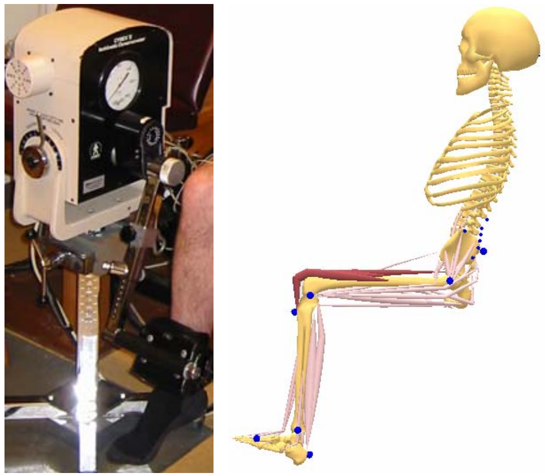
Lynch et al 1999

Experiments

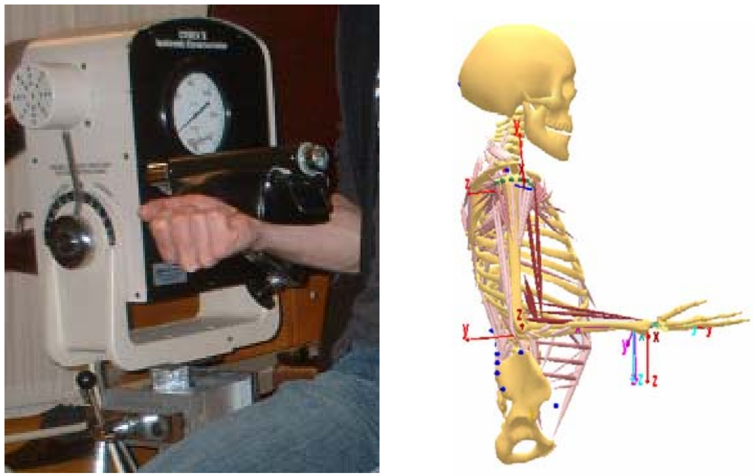
- Heterogeneous population
  - men (N=34)
  - women (N=29)
  - Age (19-84 years)
- Anthropometric measurements
  - Body mass
  - Stature
  - Segment volumes

Strength measurements

- Isometric strength measurements of elbow flexion and knee extension with a CYBEX II apparatus



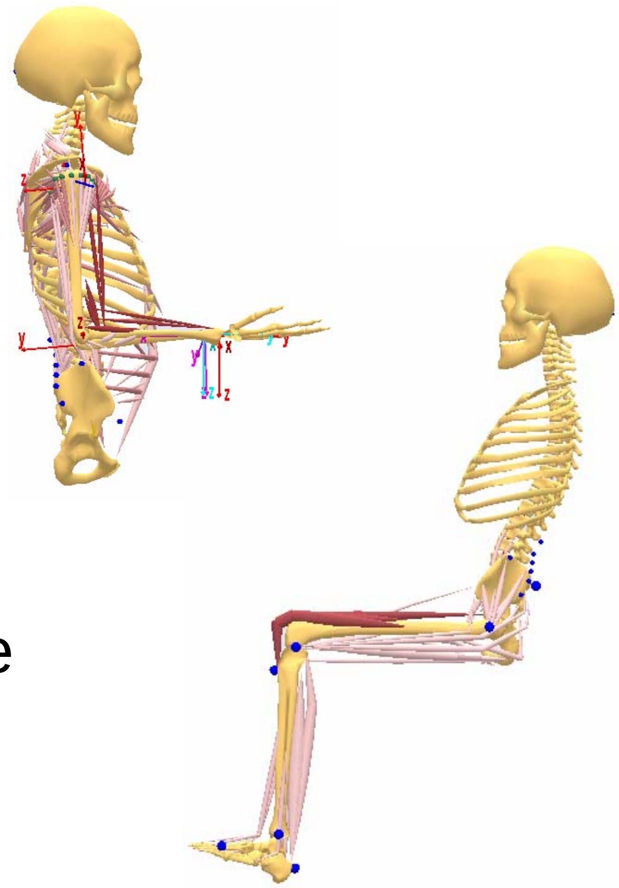
(N=63)



(N=26)

Simulation

- Development of leg and arm model in AnyBody
- AnyMuscleModel
- Simulation;
  - Input:
    - anthropometrics
    - measured torque
  - Output:
    - predicted maximal muscle force
    - required muscle force



- **PSSF**= predicted force / reference force
- **MSSF**=required force / reference force

1. *www.anybodytech.com*

Scaling within AnyBody

- Bone geometry scaling
  - Based on static load considerations
- Muscle strength scaling
  1. Geometric scaling for segment mass
  2. Geometric scaling including segment mass and body composition

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1: Geometric scaling

$$F_{1,predicted} = F_0 K_m^{2/3}$$

$F_{1,predicted}$ = scaled force of the subject in question

F_0 = reference force

K_m = mass ratio: mass of the segment that needs to be scaled divided by the reference segment mass

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2: Segment mass and body composition scaling

$$F_{1,predicted} = F_0 \frac{K_m}{K_L} \frac{R_{muscle,1}}{R_{muscle,0}} = F_0 \frac{K_m}{K_L} \frac{1 - R_{other} - R_{fat,1}}{1 - R_{other} - R_{fat,0}}$$

$F_{1,predicted}$ = scaled force of the subject in question

F_0 = reference force

K_m = mass ratio: mass of the segment that needs to be scaled divided by the reference segment mass

K_L = length ratio: the scaled segment mass divided by the original segment mass

R_{muscle} = % muscle mass

R_{other} = % other tissue = 0.5

R_{fat} = % fat (calculated from BMI, age & gender; Gallagher 2000)

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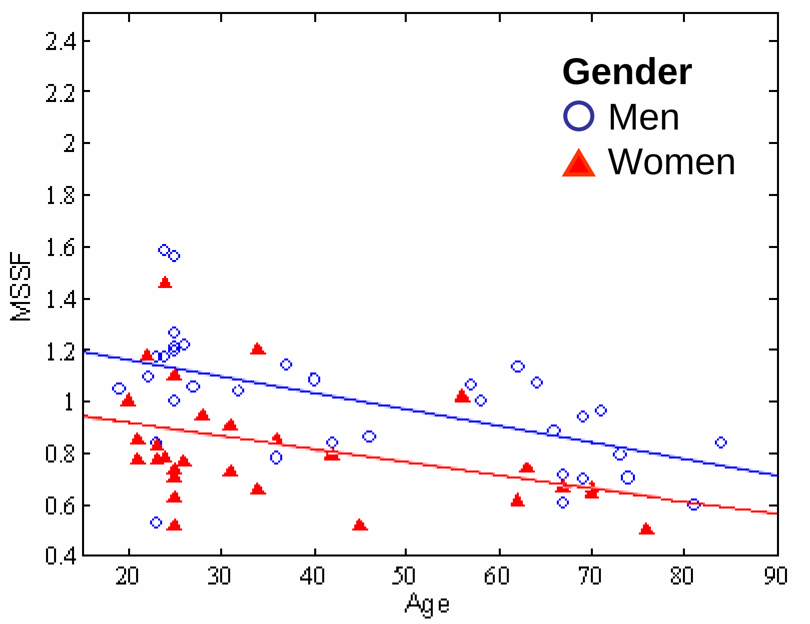
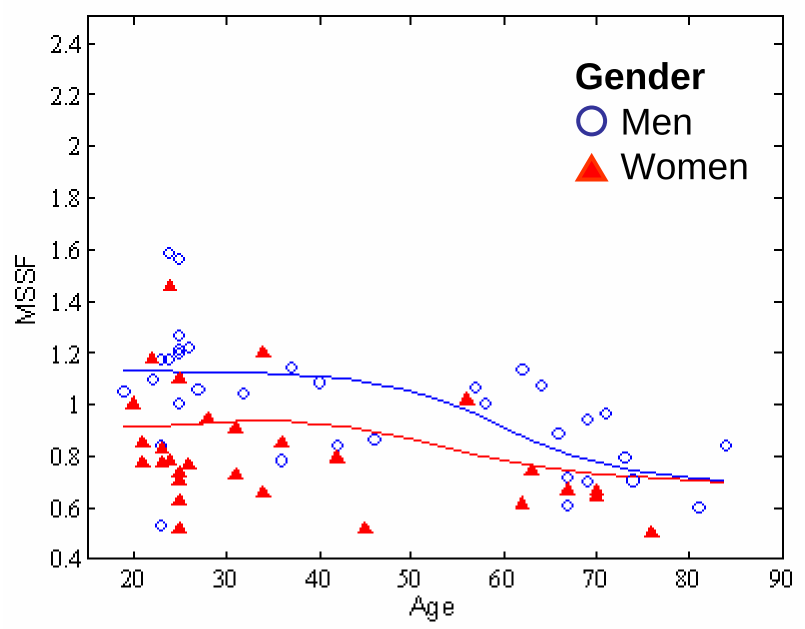
3: Empirical scaling, including age & gender effects

- Multiple linear regression
- Cumulative approximation



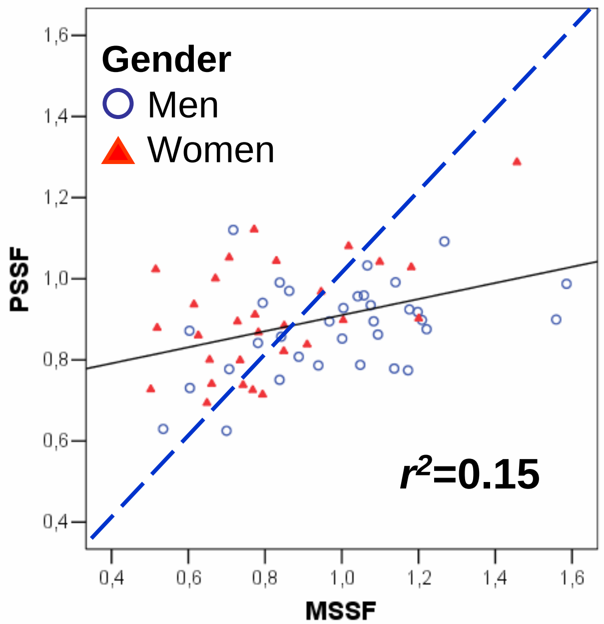


Results; anthropometry

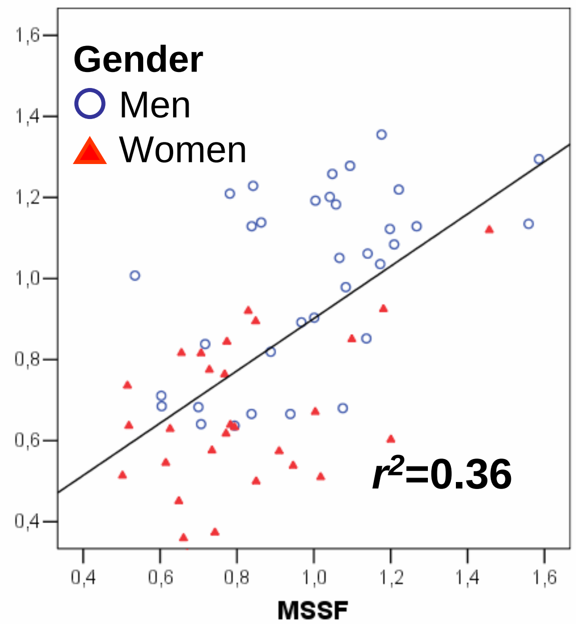
Physical characteristics	**Men** (n = 34)	**Women** (n = 29)
	Range	Range
Age (years)	19.0 - 84.0	20.0 - 76.0
Weight (kg)	56.5 - 94.0	51.0 – 82.0
Height (m)	1.59 - 1.98	1.57 - 1.81
BMI (kg/m2)	19.2 - 34.8	17.6 - 30.5
Mass thigh (kg)	4.24 - 8.15	4.13 - 8.06
Length thigh (m)	0.34 - 0.45	0.30 - 0.41
Mass upper arm (kg)	1.56 - 2.73	1.22 - 2.20
Length upper arm (m)	0.28 - 0.37	0.27 - 0.32

Results leg; theoretical scaling

Geometric



Body composition



- Poor prediction for geometric scaling
  - overestimation at low strength
  - underestimation at high strength
- Improvement when accounting for body composition

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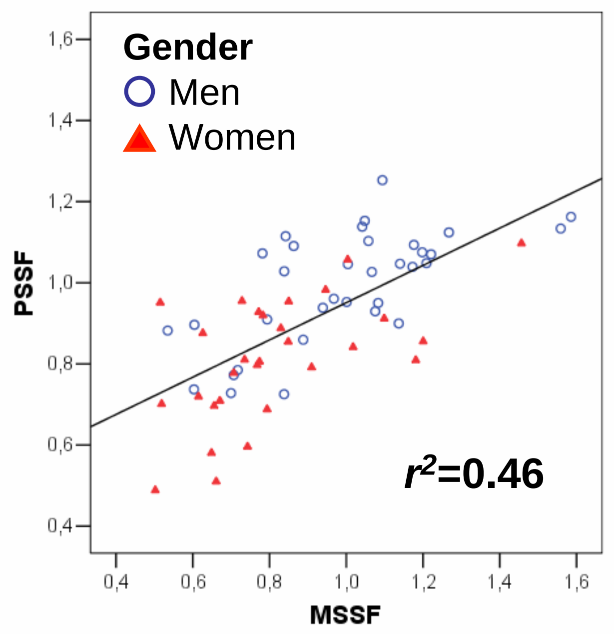
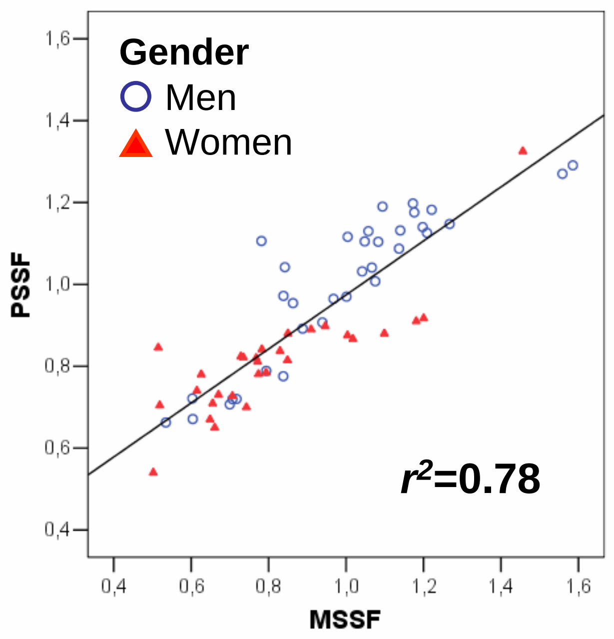
Results leg; empirical scaling

Regression



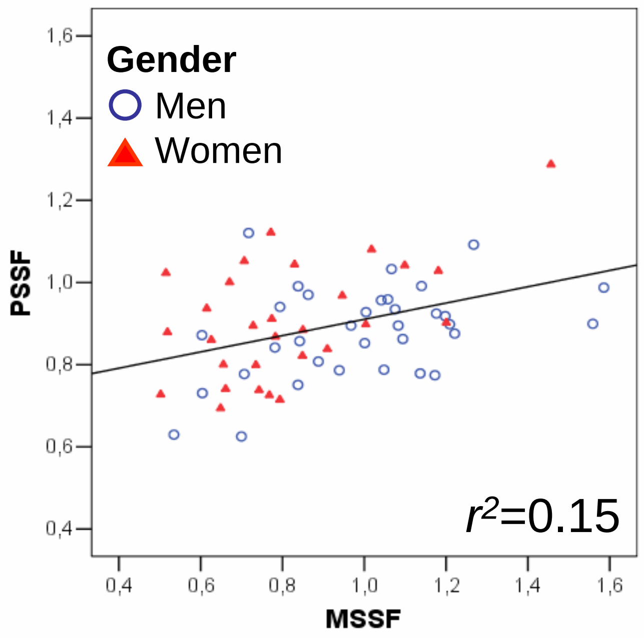
Approximation



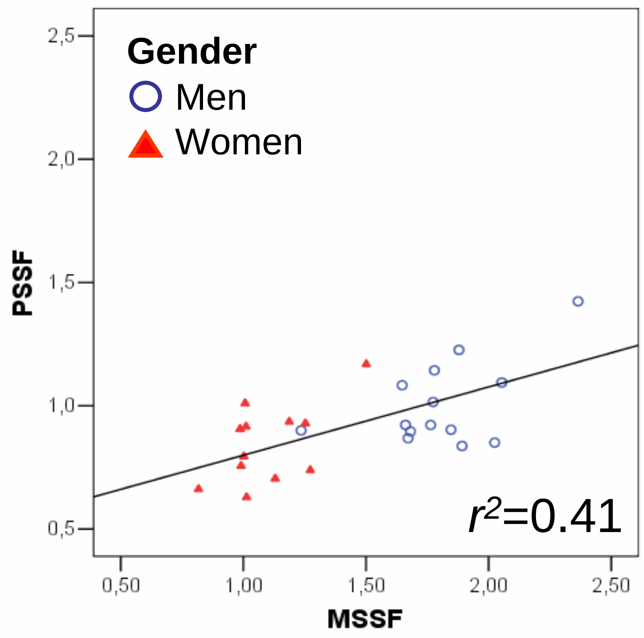
- Reasonable prediction for both methods

Results; leg vs. arm

Leg



Arm



- Arm group was more homogeneous
- Substantial underestimation arm strength

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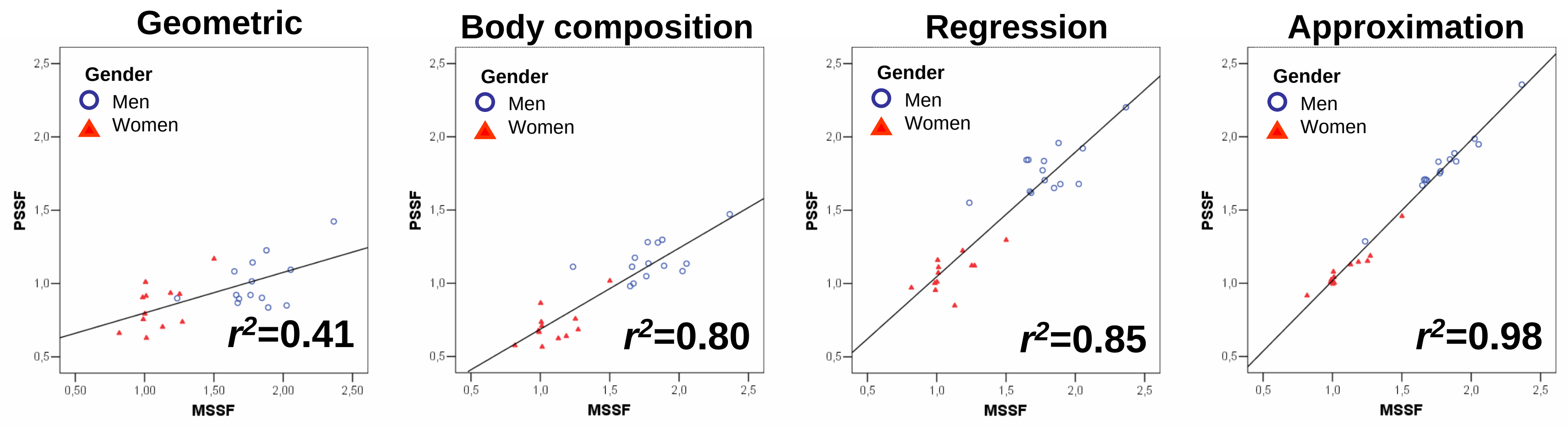
Results; arm



- Empirical scaling is needed to get realistic strength values

Discussion (1)

- Geometric scaling is not sufficient for an adequate model prediction

- Empirical scaling, accounting for age and gender is needed

Discussion (2)

- Resolve the remaining discrepancies between measured and predicted strength
  - Measurement inaccuracies
  - Inadequate bone geometry scaling
  - Inadequate estimation of body composition

Future steps

- Include more empirical data, particularly for the arm

- Apply scaling to model that includes length-force and force–velocity curves

- Derive empirical scaling laws for patient populations and apply them to study muscle function and mobility

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Acknowledgements

- Janneke Annegarn (UM)

- Lex Verdijk (UM)
- Hans Savelberg (UM)
- Mark de Zee (AnyBody)
- John Rasmussen (AnyBody)

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