The webcast will start in a few minutes….

How does human gait respond to muscle impairment in TKA patients?

SIMULATION OF MUSCLE WEAKNESS IN ANYBODY MODELING SYSTEM

Outline

- Introduction by the Host
- Presentation
  - Motivations and goals
  - Model
  - Data analysis
- Final words from the host
- Questions and answers

Marzieh M. Ardestani , PhD
Postdoc Fellow, Rush University
(Presenter)

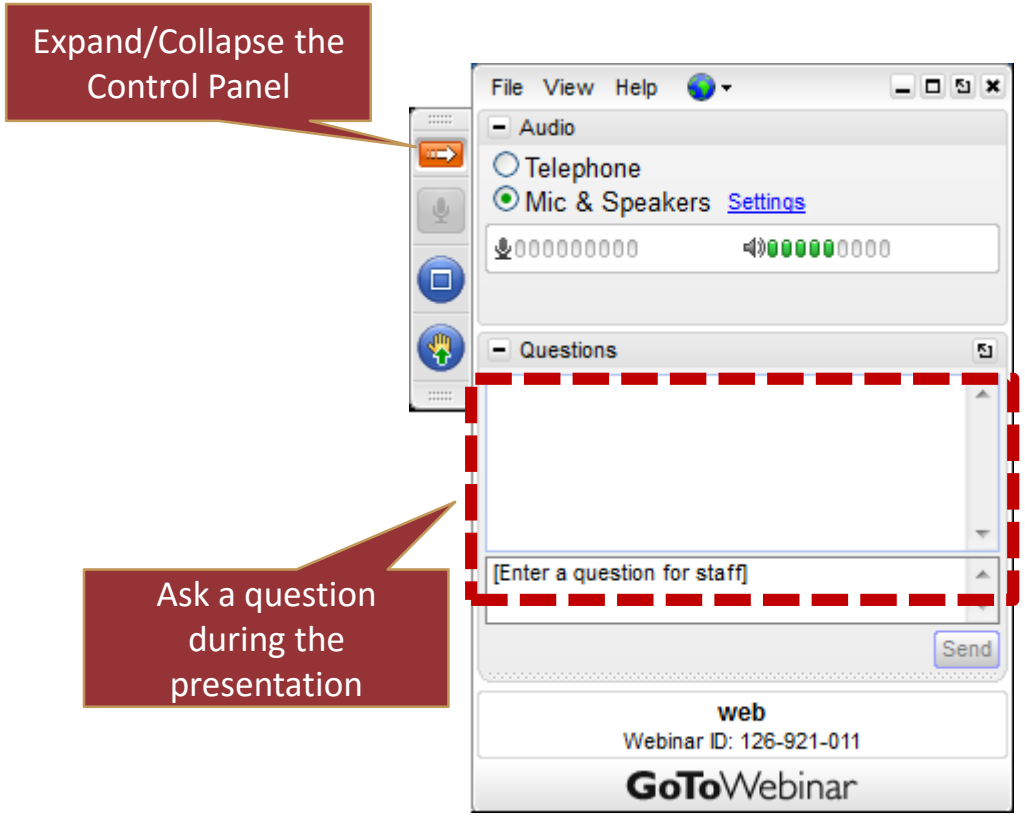
Mohammad S. Shourijeh, PhD
R&D Engineer, AnyBody Tech.
(Host)

Control Panel

The Control Panel appears on the right side of your screen.

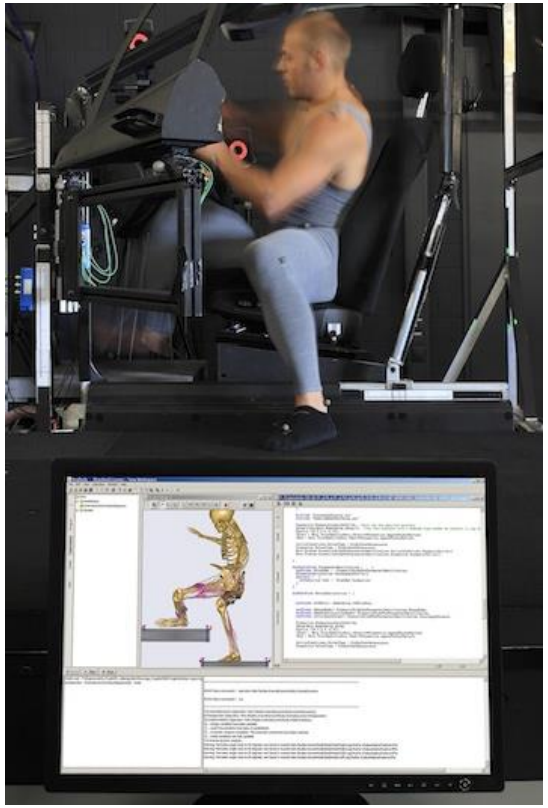
Submit questions and comments via the Questions panel.

Questions will be addressed at the end of the presentation. If your question is not addressed we will do so by email.



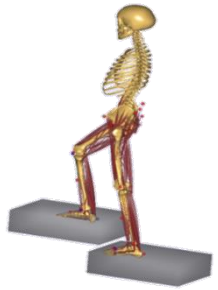
AnyBody Modeling System

- Simulations of Musculoskeletal systems
  - Multibody kinematics and dynamics analysis
- AnyBody Managed Model Repository
- Special simulation features
  - Reaction force prediction
  - Imaging → Patient-specific anatomy
  - Man-machine interaction simulation

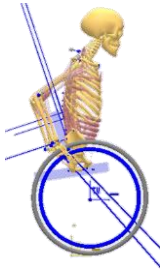


Rasmussen et. al. (2011), ORS Annual Meeting

ANYBODY Applications

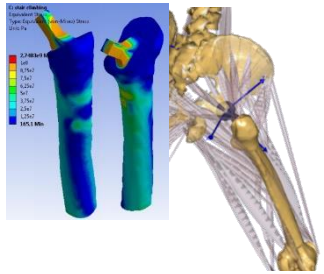


Movement Analysis

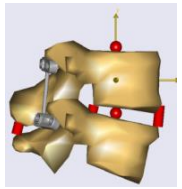


Product Design Optimization

Ergonomic Analysis



Load Cases for Finite Element Analysis



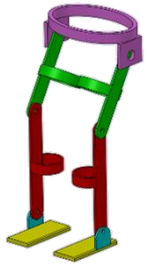
Surgical Planning and Outcome Evaluation

AnyBody Modeling System

Motion and External Forces

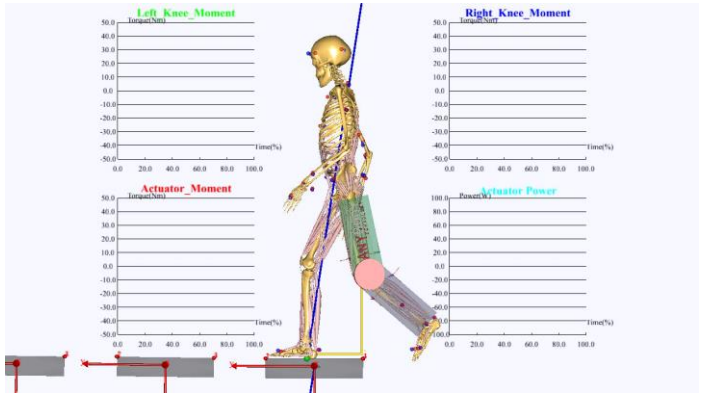
Body model

Environment CAD model



Inverse dynamics

Simulation



Output variables

- Muscle activity, force, metabolics
- Ligament force
- Joint loads
- Human-environement interaction forces

Design Optimization

Post Processing (e.g. FE tools)

How does human gait respond to muscle impairment in TKA patients?

Dr. Marzieh M. Ardestani
Postdoctoral Fellow
Rush University

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How human gait responds to muscle impairment in TKA patients?

Simulation of muscle weakness in AnyBody modeling System

Marzieh M Ardestani
Post-doctoral research fellow
Department of Orthopedic Surgery
Rush University Medical Center

Total knee arthroplasty

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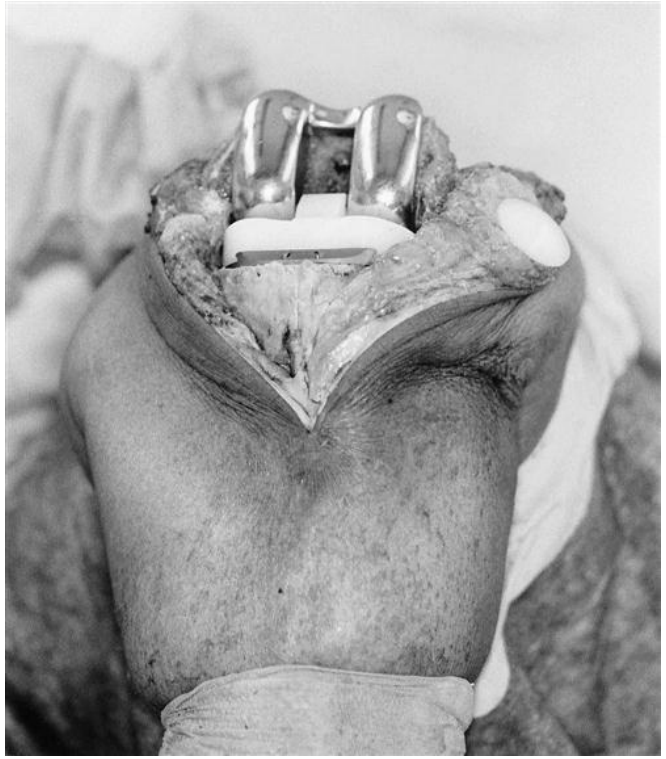
Goals:

- ❑ Pain relief
- ❑ Restoration of normal alignment
- ❑ Restoration of function
  - Mobility
  - Stability

Gait !



Normal gait following TKA

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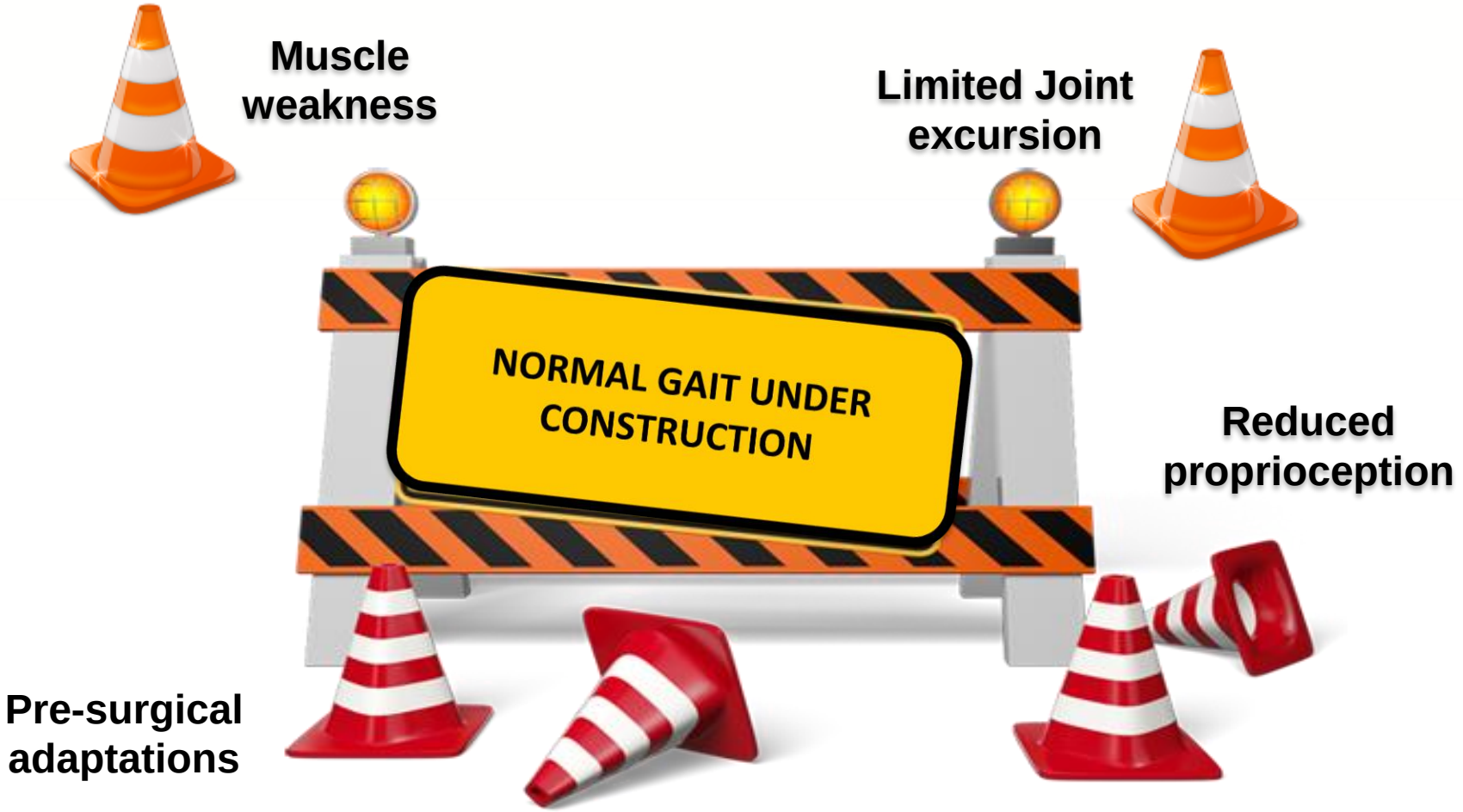

Muscle weakness

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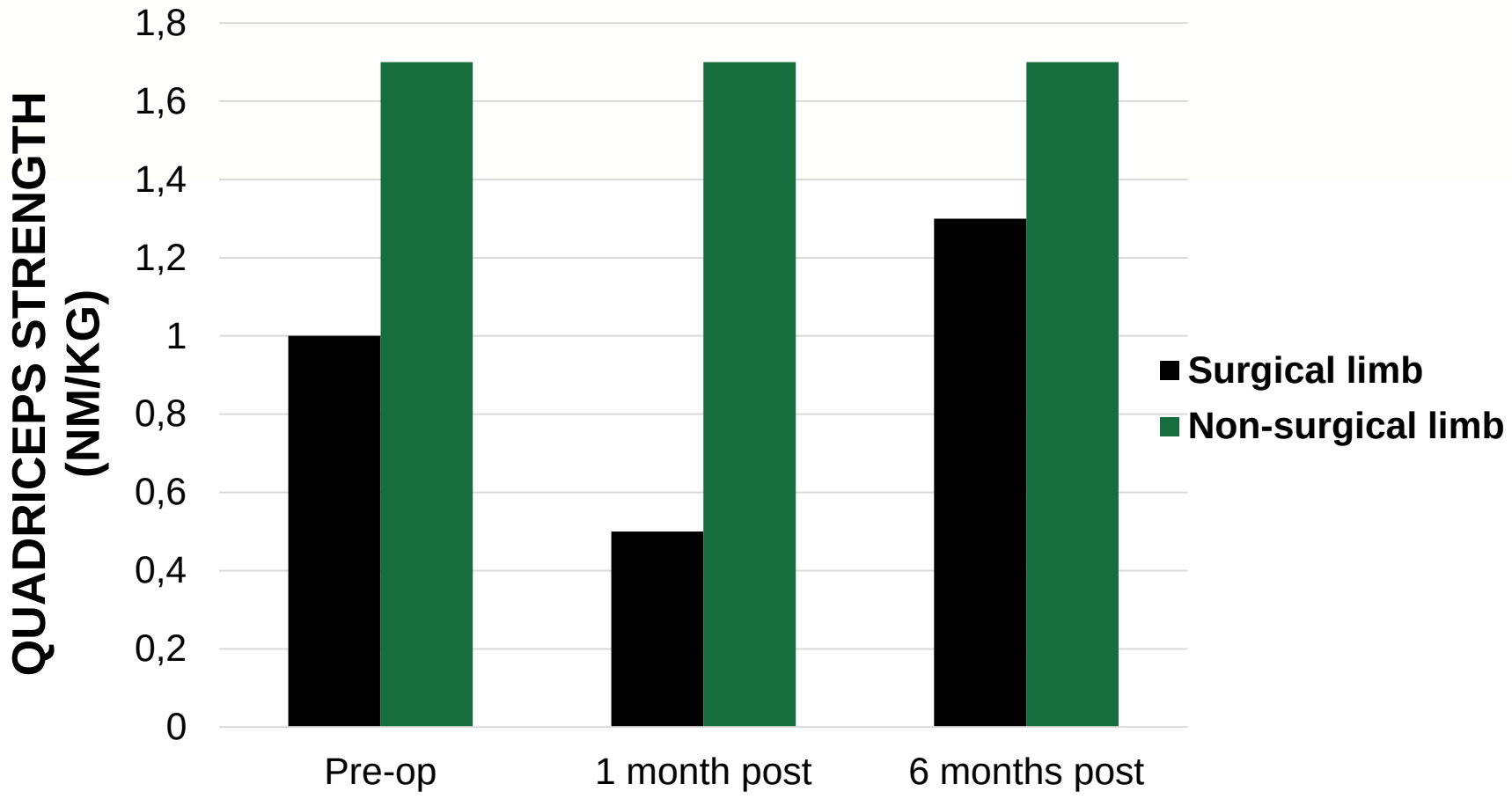

- 50- 60% strength decline in hamstring and quadriceps

(Judd et al., 2012, Stevens-Lapsley et al., 2010)

Muscle weakness

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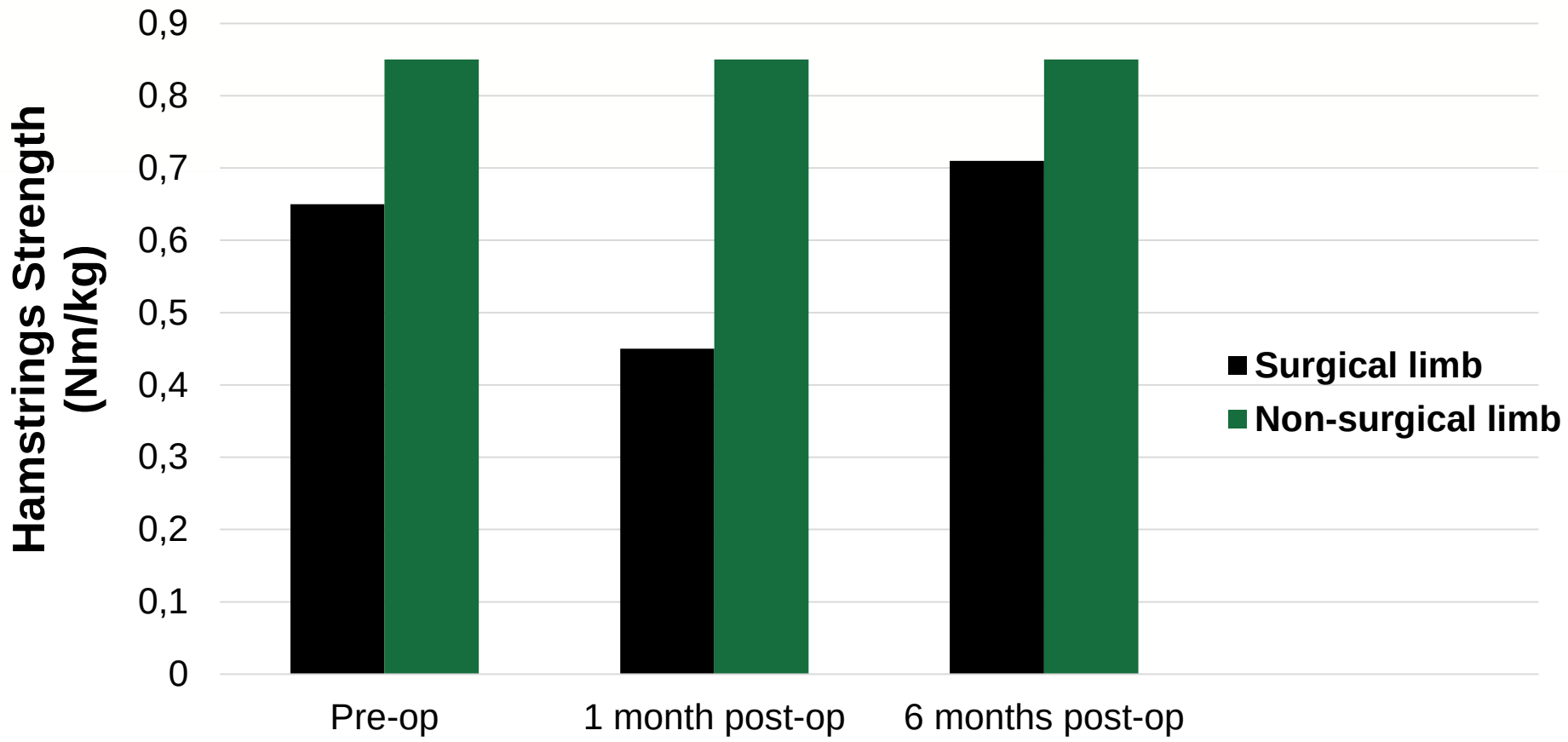

- Muscle weakness may persist up to three years after surgery (Schache et al., 2014).

Muscle weakness affects gait ?

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- How much weakness ?
- A little ?

- A subtle weakness in an individual muscle can be compensated by additional contribution of other muscles

- Too much ?

- Severe muscle impairments(postoperative muscle deficits in TKA patients) will lead to "kinematic" compensations so as to offload the impaired muscles

- Quadriceps avoidance (Andriacchi, 1993)
- knee stiffening strategies (Benedetti et al., 2003)

Research questions

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- How much muscle weakness can be tolerated by TKA patients before demanding any kinematic adaptation?

- How muscle impairment may perturb muscle and joint forces?

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How human gait responds to muscle impairment in total knee arthroplasty patients: Muscular compensations and articular perturbations

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Methodology

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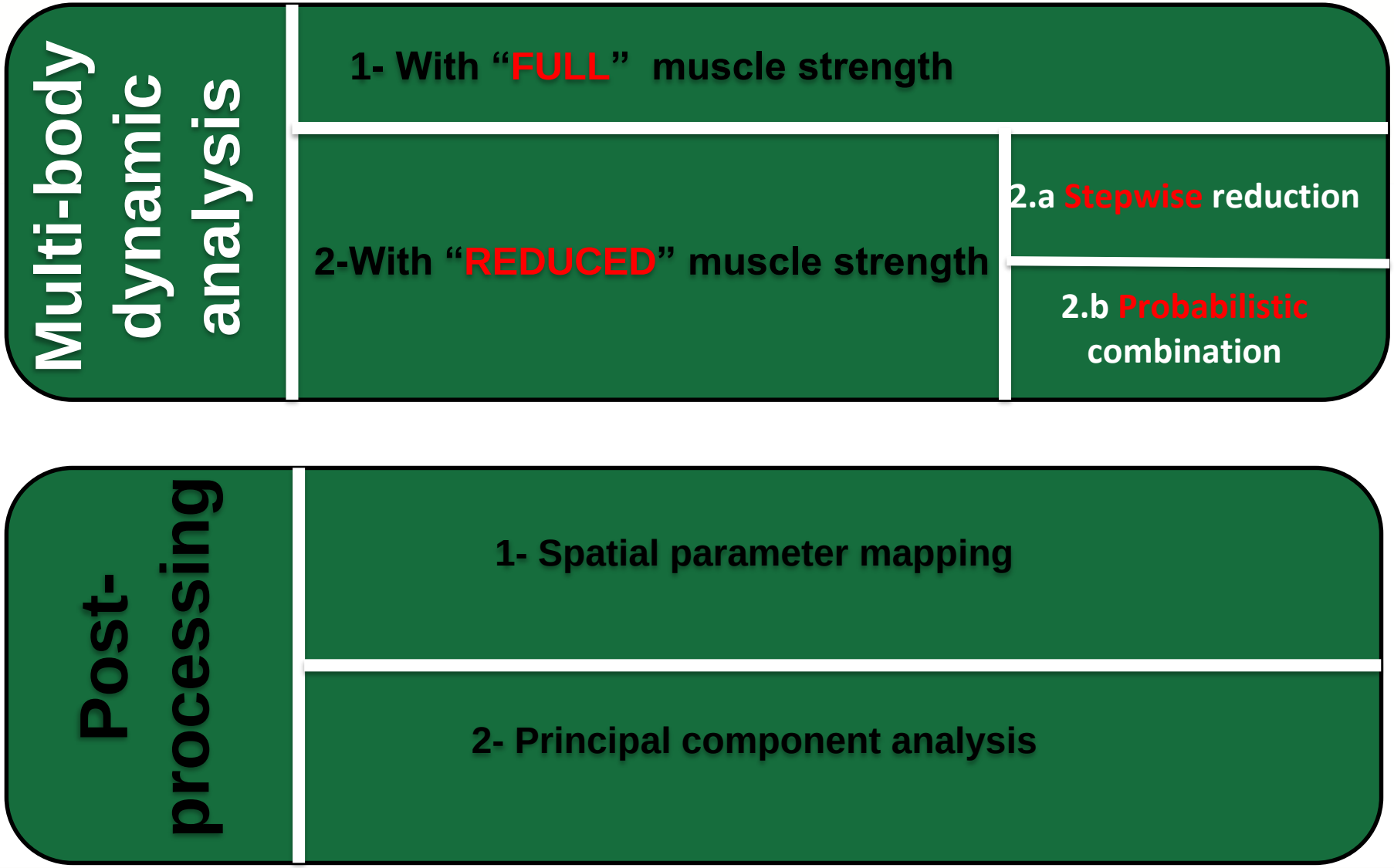
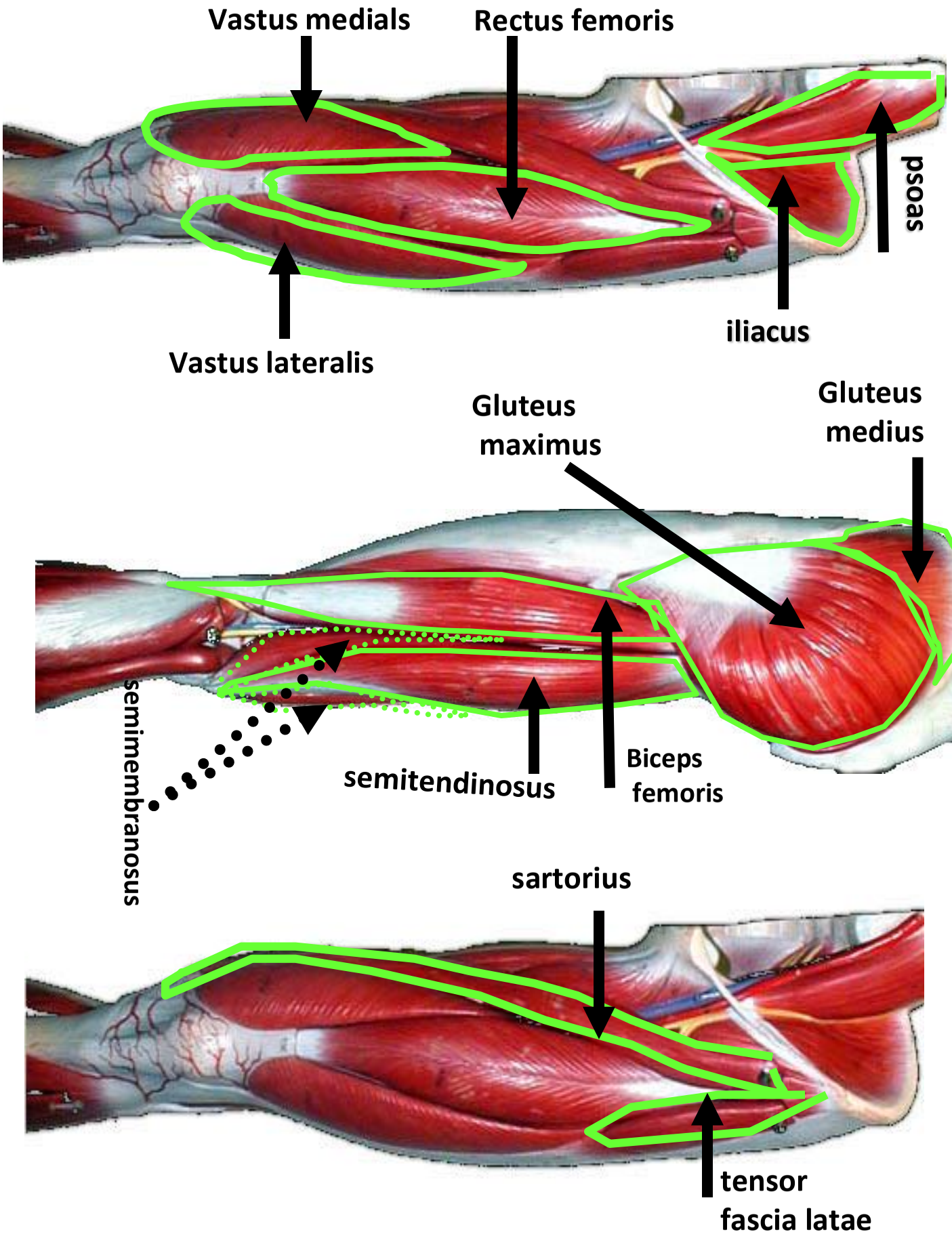
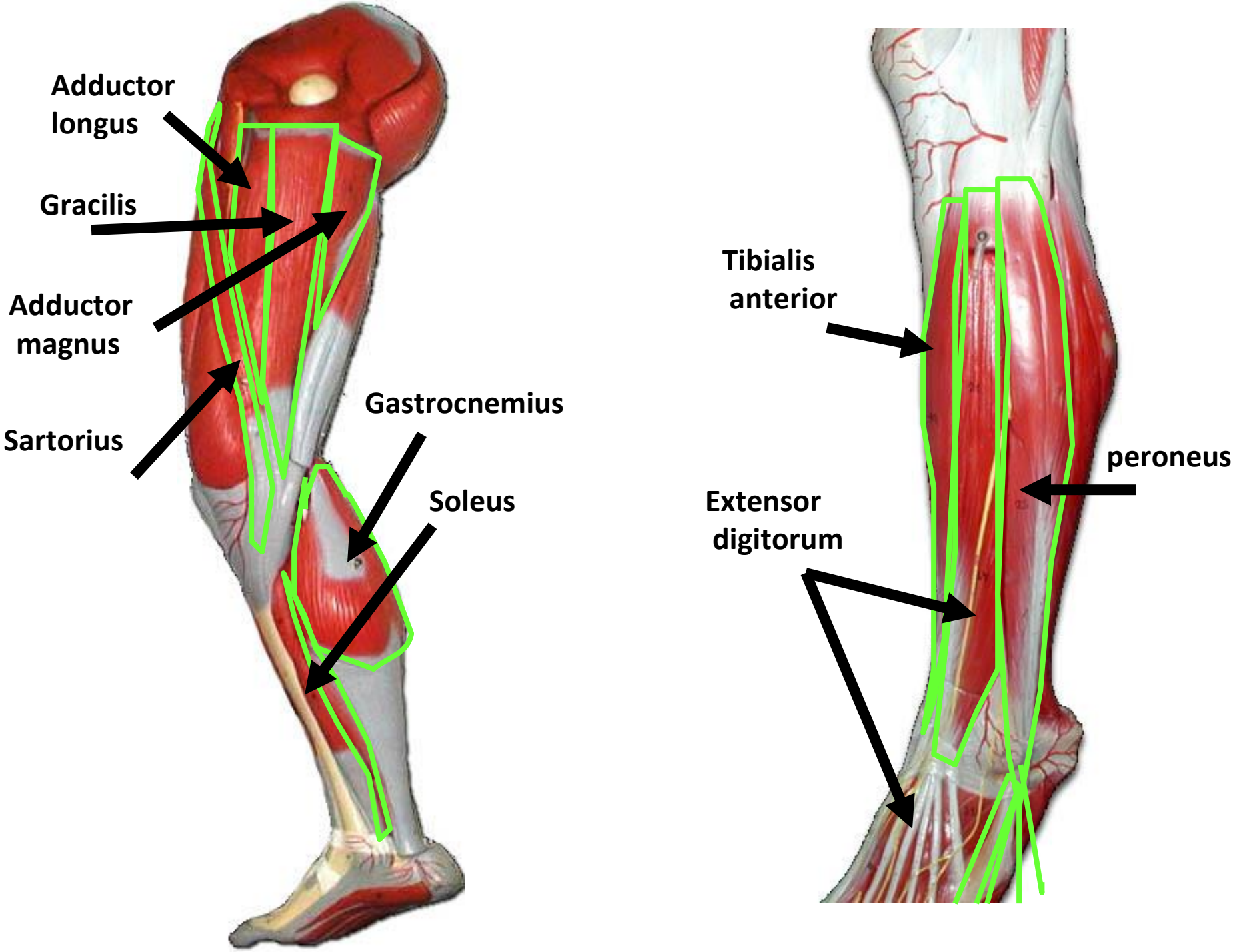



Vastus medials
Rectus femoris
psoas
iliacus
Vastus lateralis
Gluteus maximus
Gluteus medius
semimembranosus
semitendinosus
Biceps femoris
sartorius
tensor fascia latae


Adductor longus
Gracilis
Adductor magnus
Sartorius
Gastrocnemius
Soleus
Tibialis anterior
peroneus
Extensor digitorum

AnyBody modelling system
Musculoskeletal model

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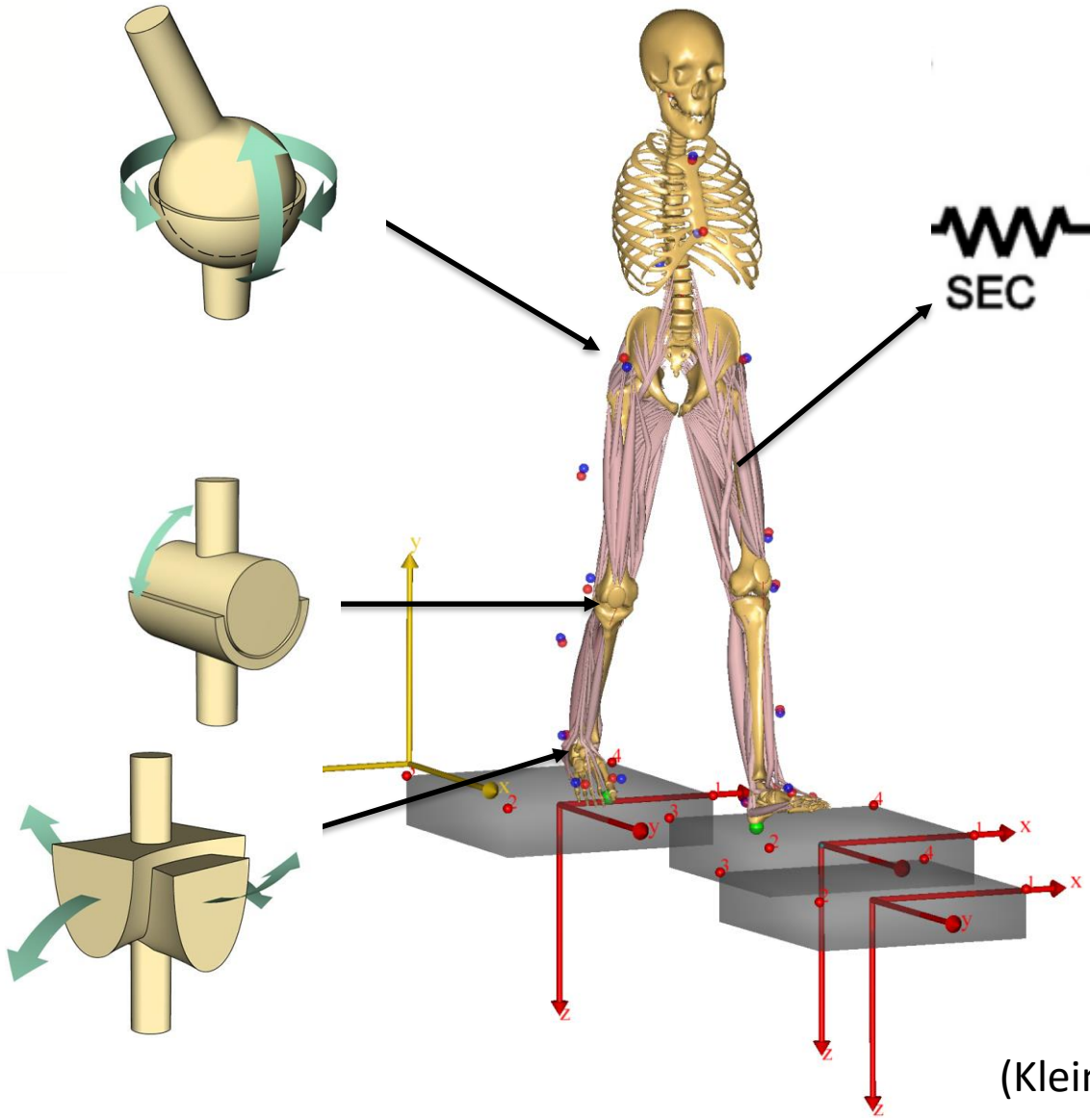


Muscle groups:

Hip flexor
Hip extensor
Hip abductor
Hip adductor
Ankle plantar flexor
Ankle dorsi flexor

(Klein Horsman, 2007)

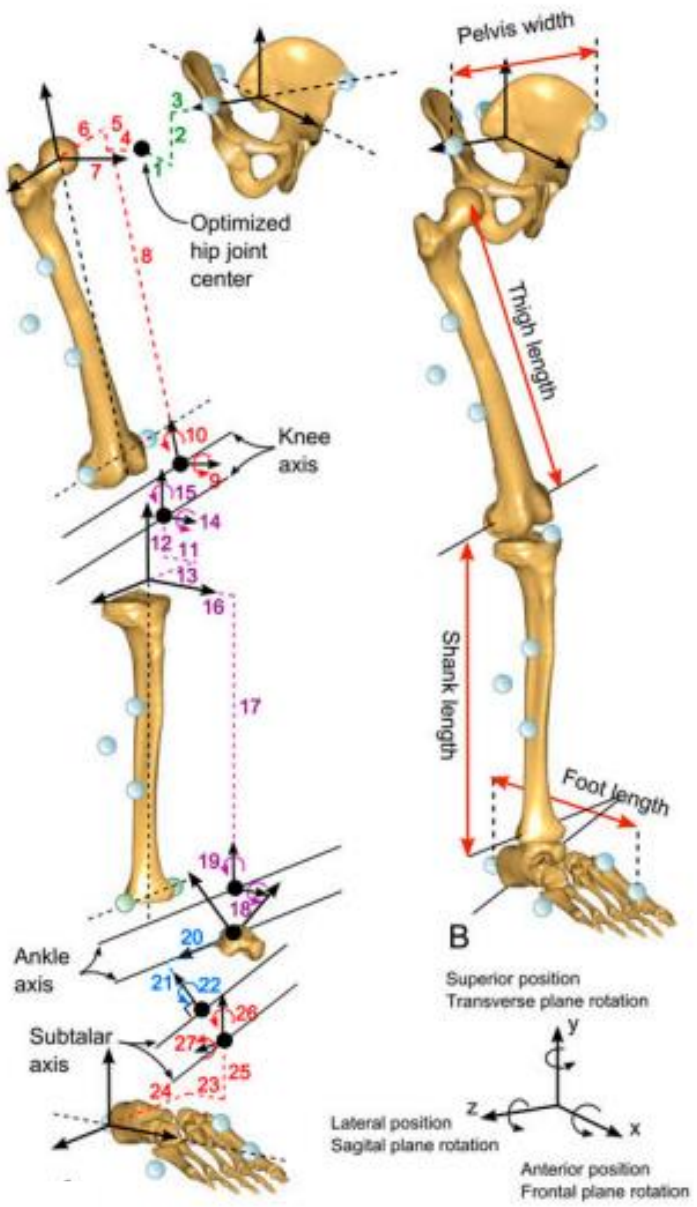
AnyBody modelling system

UNIVERSITY

Scaling:
Length–Mass–Fat law

Motion & Parameter Optimization

Inverse Dynamic Analysis



(Ali et al., 2013; M.E. Lund et al.,2015; Worsley et al., 2011)

AnyBody modelling system
Muscle model

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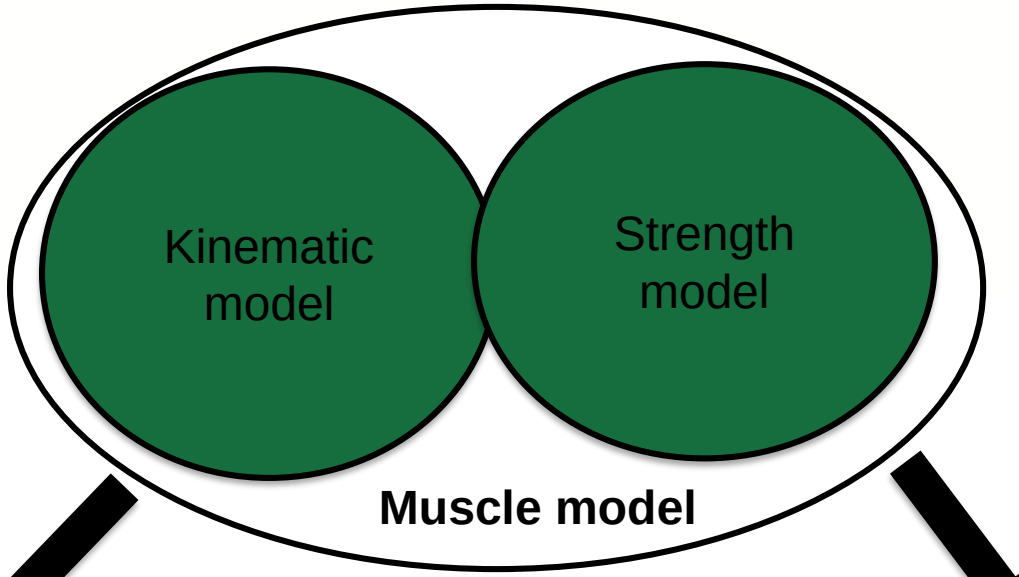

Calculate the length and contraction velocity of the muscle as a function of body posture and muscle path

Determines the muscle's strength as a function of kinematic state of the muscle.

AnyBody modelling system
Muscle model

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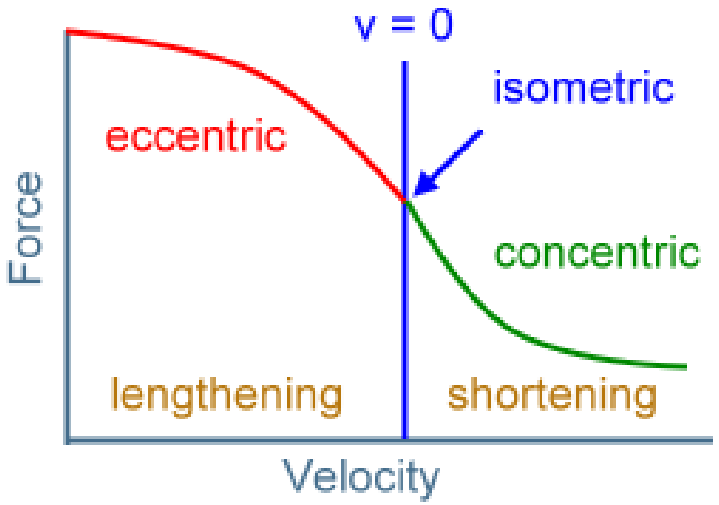
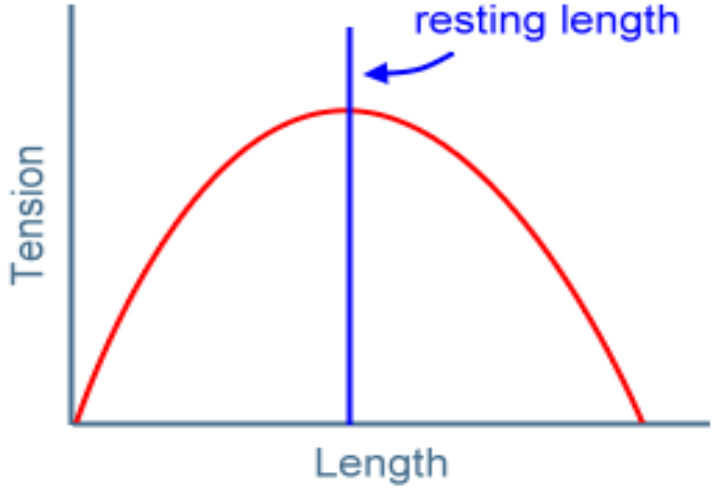
$$Strength = F_0\left(2\frac{L_m}{L_f} - 1\right)\left(1 - \frac{L_m'}{V_0}\right)$$

- ✓ Lf : Neutral fiber length
- ✓ Lm' : Contraction velocity
- ✓ Lm : Current length of the contractile element
- ✓ V0 : Contraction velocity at maximum voluntary contraction
- ✓ F0 : Muscle isometric strength

(Klein Horsman, 2007)



Force-Velocity Curve of a Muscle



Length-Tension Curve of a Single Muscle Fiber

Optimization routine :

(Damsgaard et al., 2006; Rasmussen et al., 2001)

$$Minimize_f \; G\left(f^{(M)} \right) \quad , \quad G(f^{(M)}) = Max(\frac{f_i^{(M)}}{N_i})$$

$$Subject\ to\ :\ C \times f\ =\ d \qquad \text{and} \quad 0 \le f_i^{(M)} \le N_i \quad i = \left\{1, \ldots,\ n^{(M)}\right\}$$

- ✓ G :objective function
- ✓ f(M) : muscle forces
- ✓ f(R) : joint reaction forces
- ✓ Ni : Strength of the muscle
- ✓ C : Coefficient-matrix for the unknown forces
- ✓ D : All known applied loads and inertia forces

Methodology- Multi-body dynamic simulation

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Marker trajectories and GRF

Inverse dynamic routine

Inverse dynamic routine

Stepwise reduction of strength

Inverse dynamic routine

Probabilistic reduction of strength

Joint loadings
muscle forces

Methodology- Post-processing

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- Spatial parameter mapping (SPM)

(Pataky et al, 2011)

- Principal component analysis (PCA)

(Fitzpatrick et al., 2011)

Results- Minimum requirements

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Hip extensor	65% OF BASELINE
Hip abductor	60% OF BASELINE
Hip adductor	46% OF BASELINE
Knee extensor	50% OF BASELINE
Knee flexor	42% OF BASELINE
Ankle plantar flexor	40% OF BASELINE
Ankle dorsi-flexor	25% OF BASELINE

Results- Compensatory mechanisms

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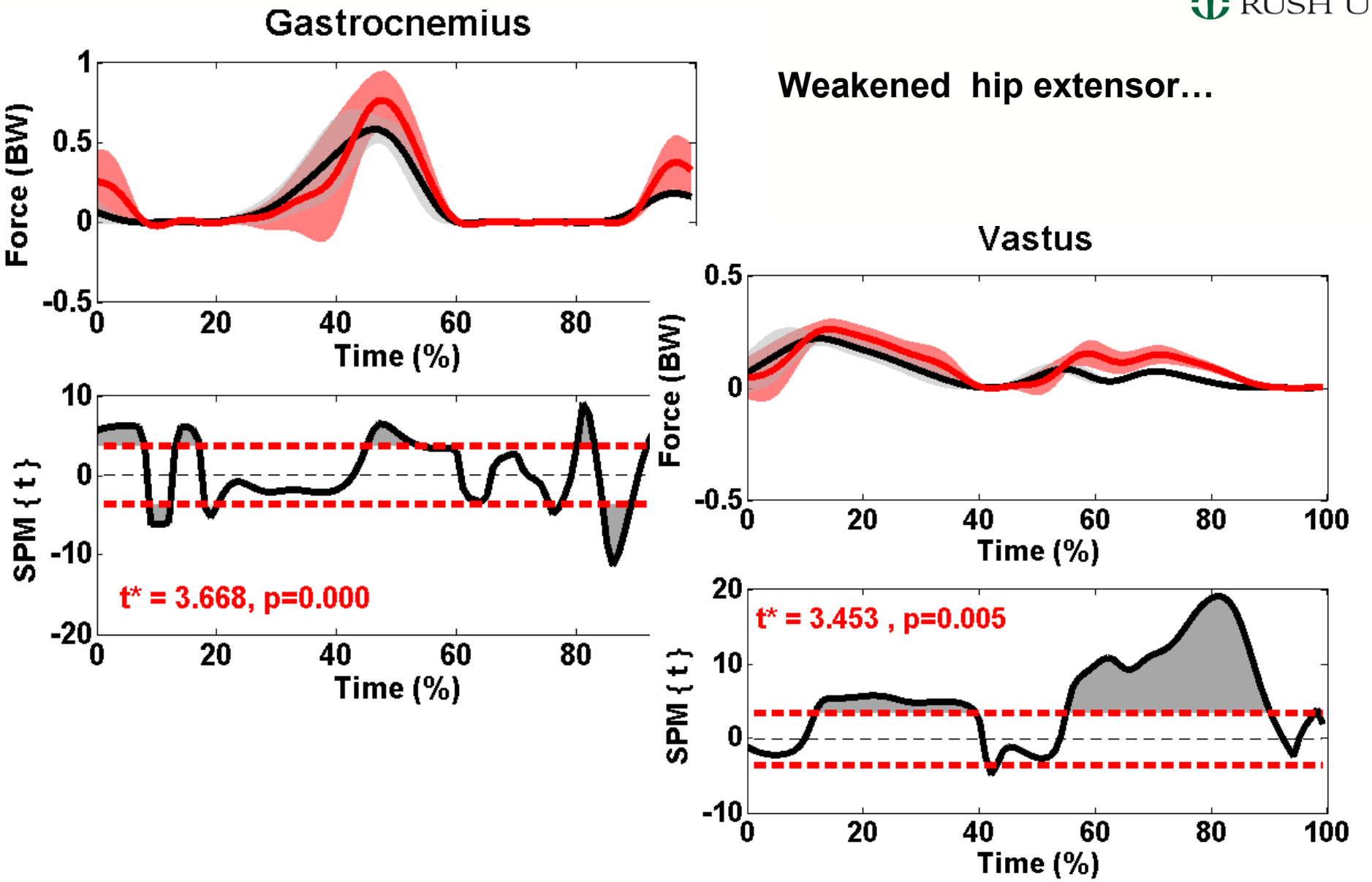

Results- Compensatory mechanisms

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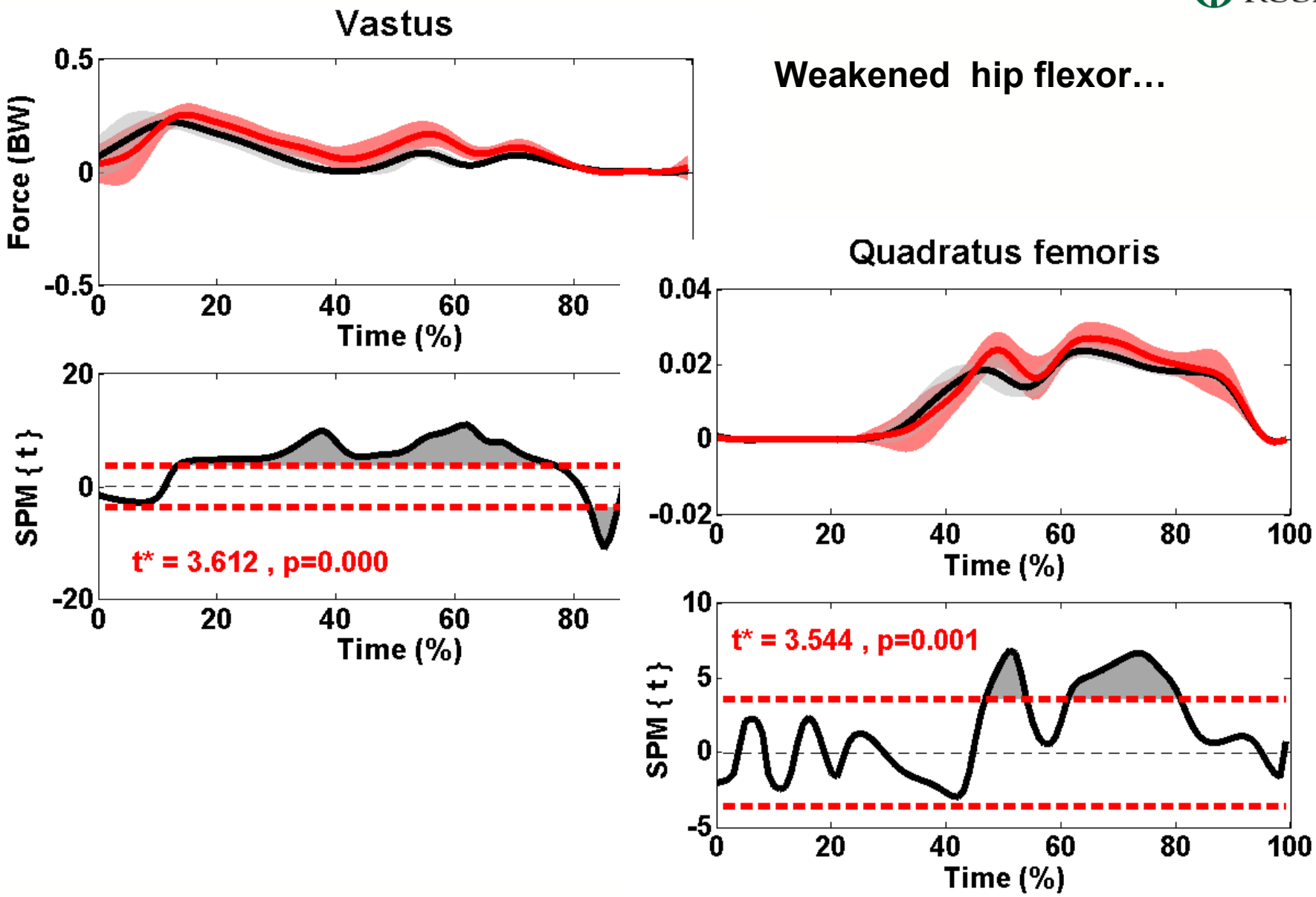

Results- Joint force perturbations

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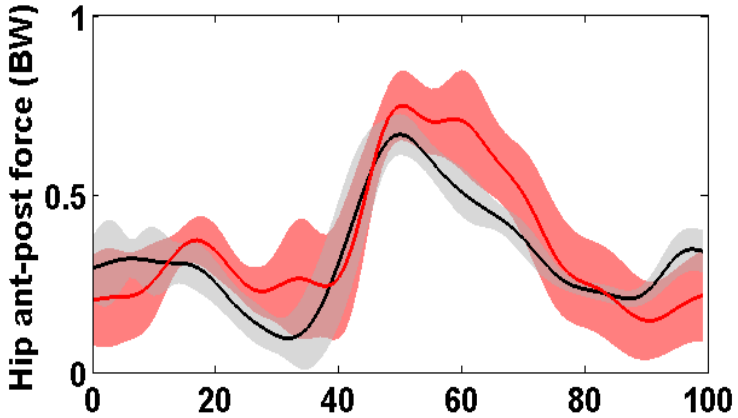

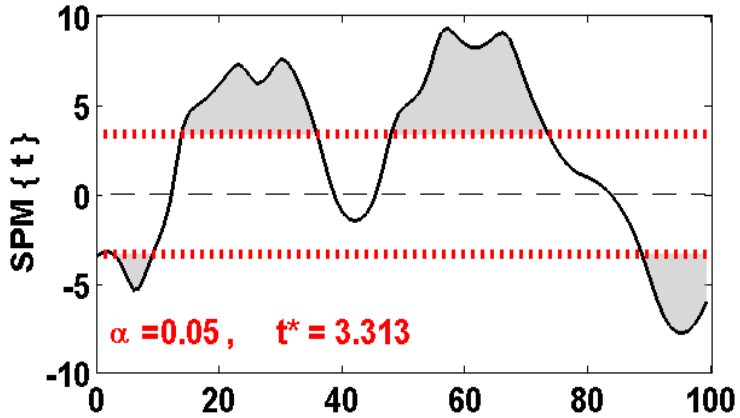

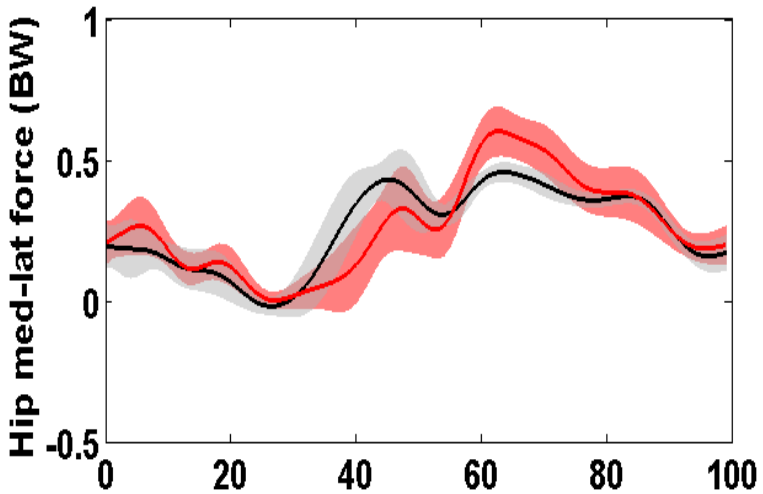

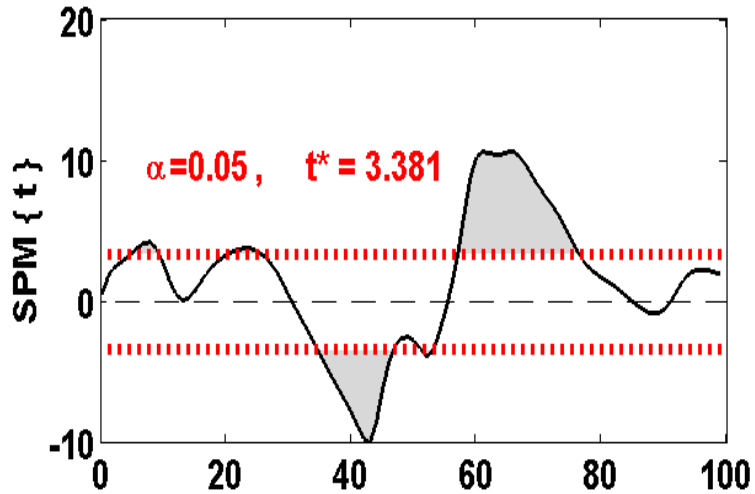

Results- Sensitivity analysis

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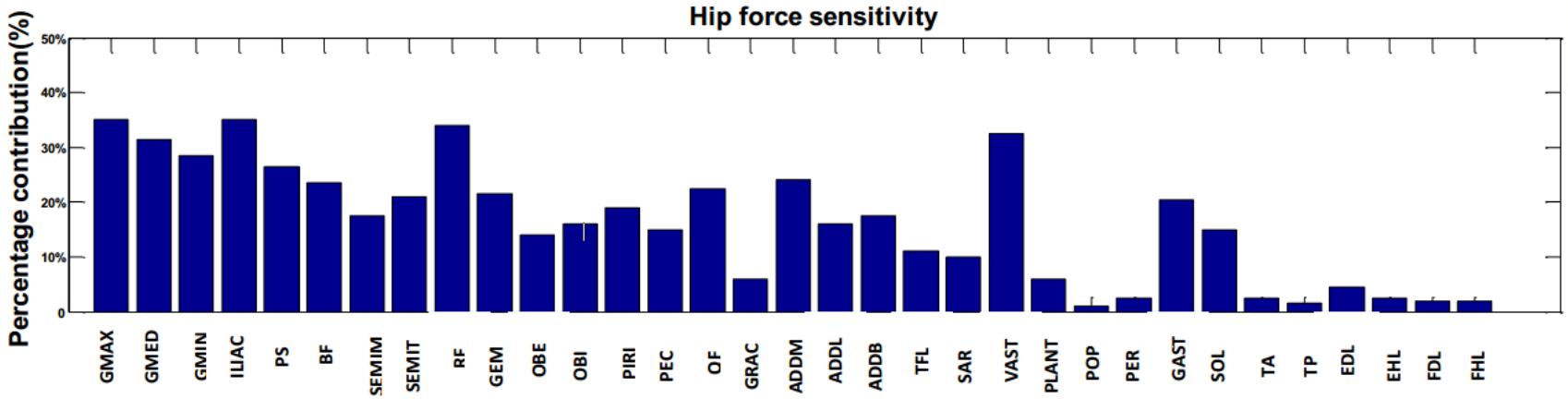
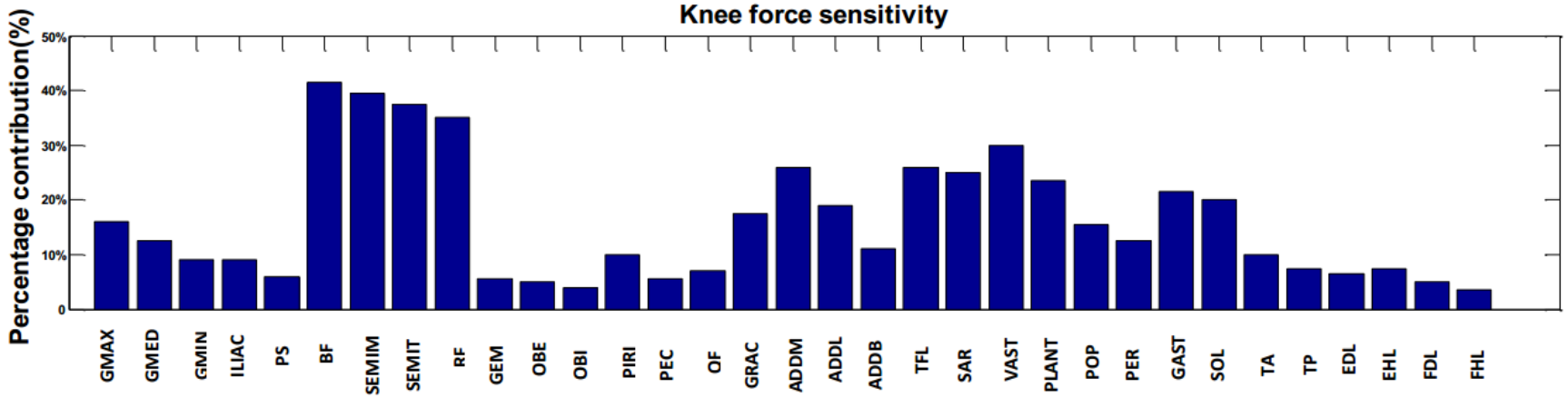
- Sensitivity of every joint force component due to the weakness of individual muscles





Limitations

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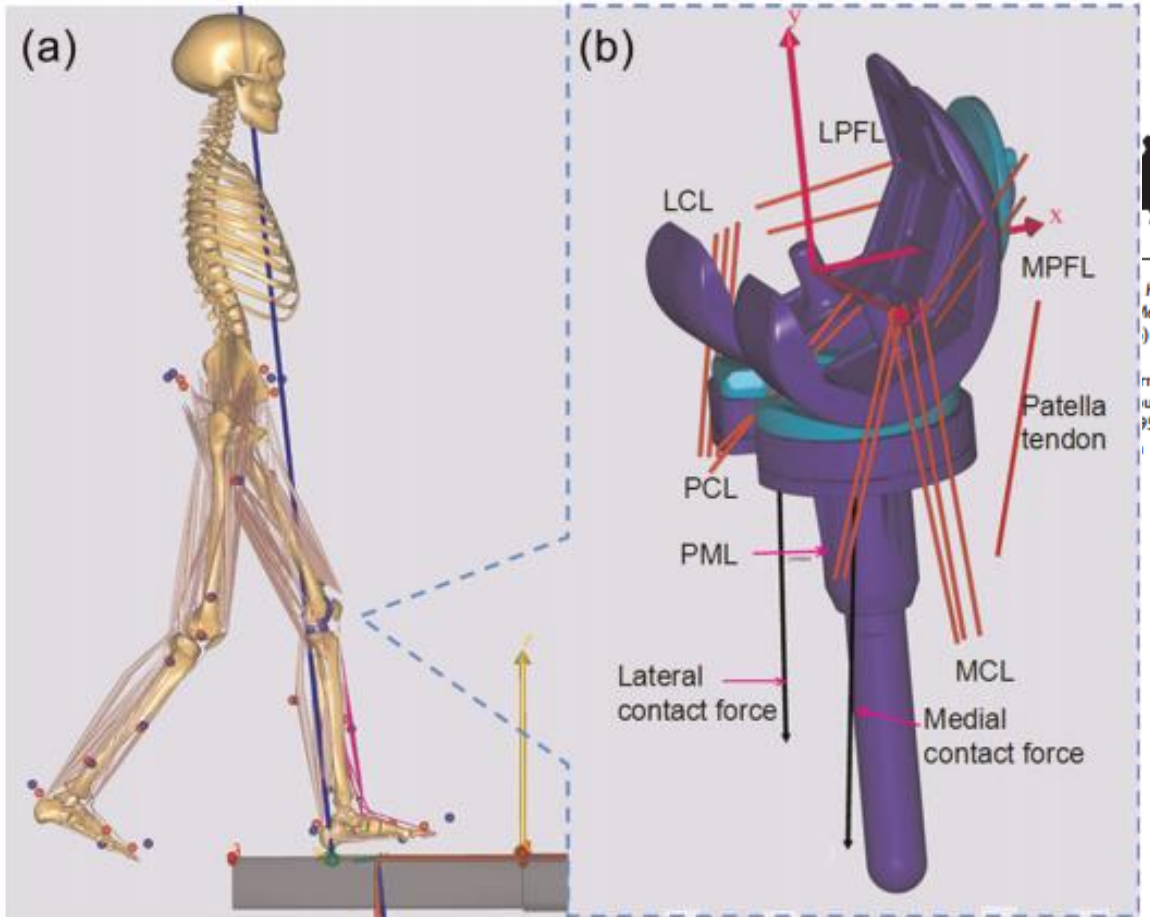

Journal of ENGINEERING IN MEDICINE

(Chen et al., 2014)

A full lower limb musculoskeletal model of TKR in AnyBody combing (a) dynamics musculoskeletal models and (b) knee implants with articular contacts and ligaments.

Summary

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- Probabilistic multi-body dynamic analysis to evaluate the minimum strength requirements of muscles and muscular compensatory mechanisms in TKA patients.

- Simulation of muscle weakness in AnyBody modeling System

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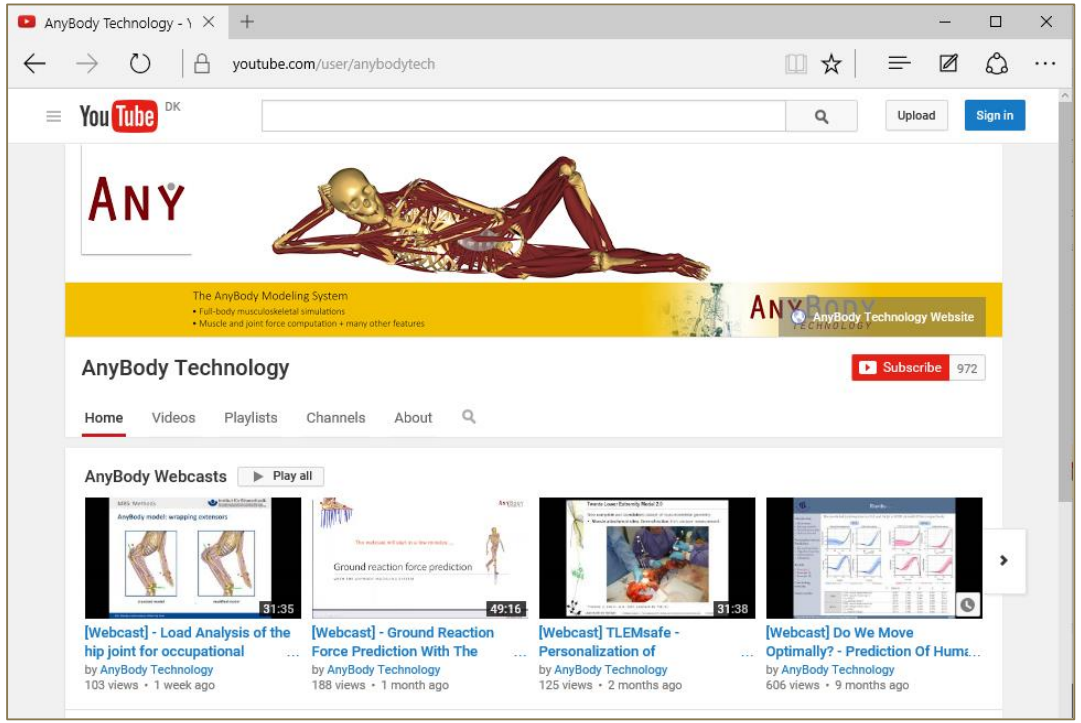
Webcasts

- New round of webcasts will start after summer 2016
- Check our YouTube channel for previous webcasts
  - Search channels for ‘AnyBody Technology’



www.anybodytech.com

- Useful links, events, publication list, ...

www.anyscript.org

- Wiki, Forum

Upcoming Events

- ESB 2016, 22nd Congress of the European Society of Biomechanics, Lyon, France, 10-13 Jul.
  - **Free AnyBody Hands-on training workshop** – Crowne Plaza Lyon-Cité Internationale., 10th Jul 2016, 12:00 – 16:00
  - Come visit us at our booth
- ASB 2016, Annual meeting of the American Society of Biomechanics, Raleigh, USA, 2-5 Aug.
- WeRob 2016, The International Symposium on Wearable Robotics, La Granja, Segovia, Spain, 18-21 October

Time for questions