DEVELOPMENT AND VALIDATION OF MUSCULOSKELETAL MODELS TO PREDICT QUADRICEPS MOMENTS

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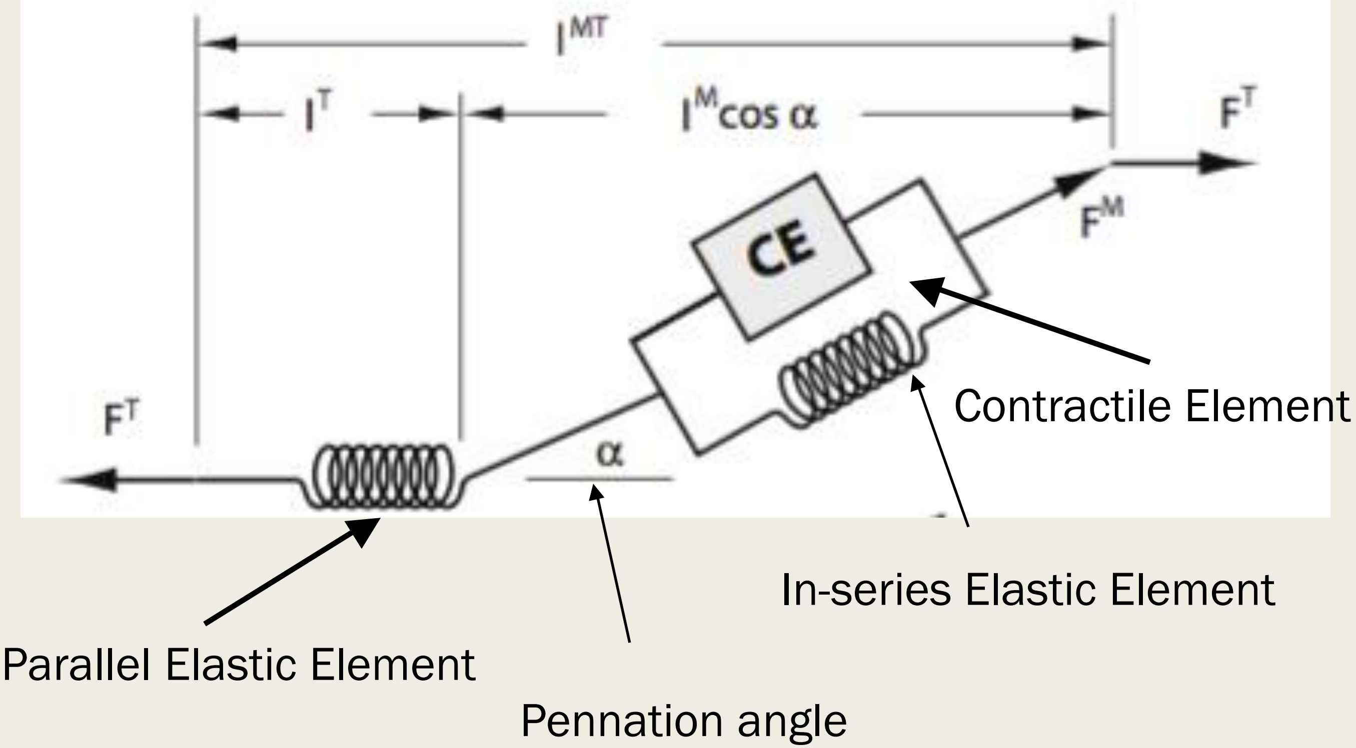
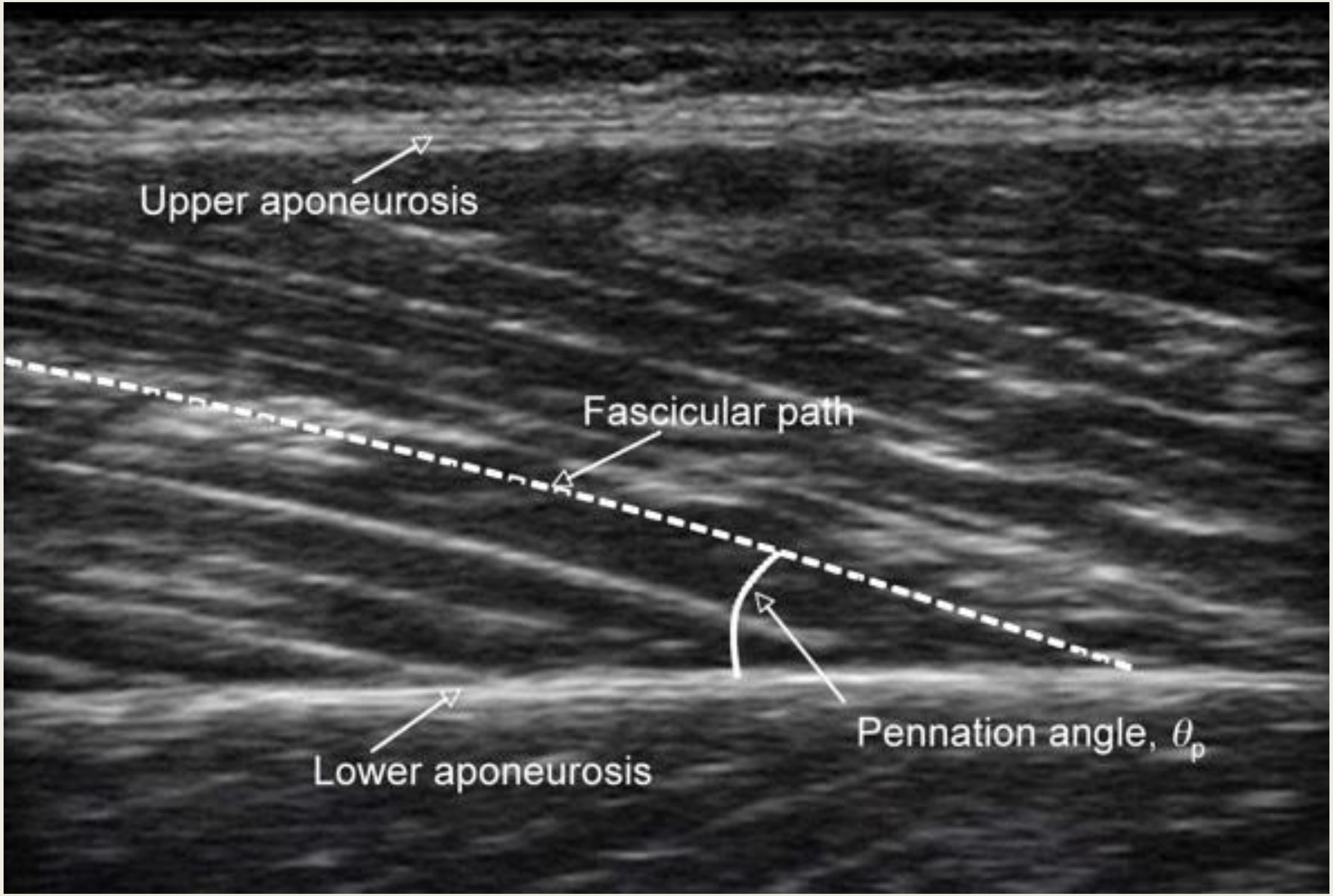
Background

- Lumped-parameter muscle model expressed through a Hill-type model developed by Zajac (1989)

Figure from Arnold et al 2009





https://www.ljmu.ac.uk/~/media/ljmu/faculty_scs/sport_and_exercise_science/research/rises/figures/rises_exercise_metabolism_figure6.jpg?h=399&w=593&la=en

Background

- Maximum Isometric Force
  - (Physiological Cross Sectional Area) x (Specific Tension)

- Optimal Fiber Length (OFL)

- Pennation angle

- Calculated Tendon Slack Length (TSL)

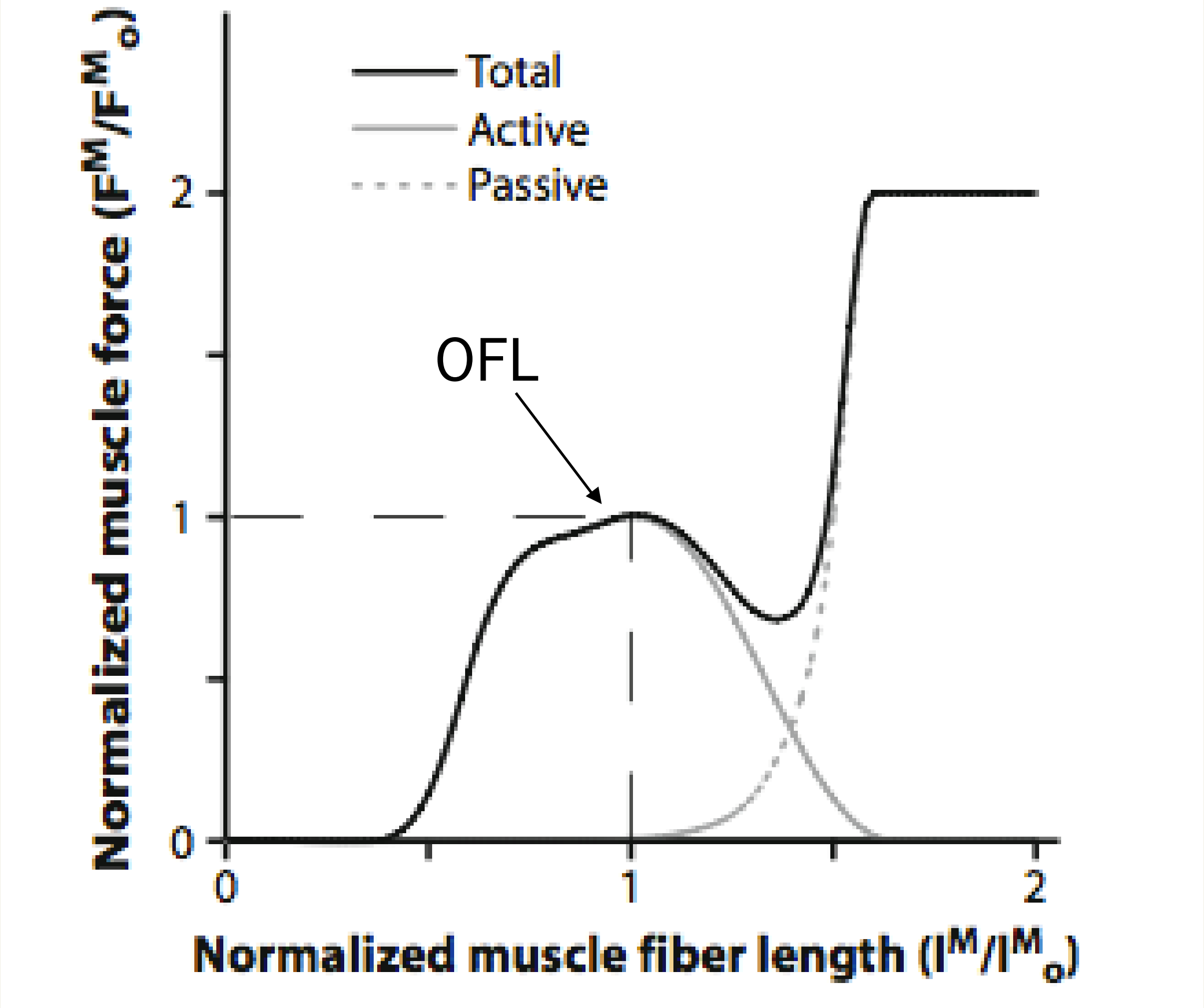
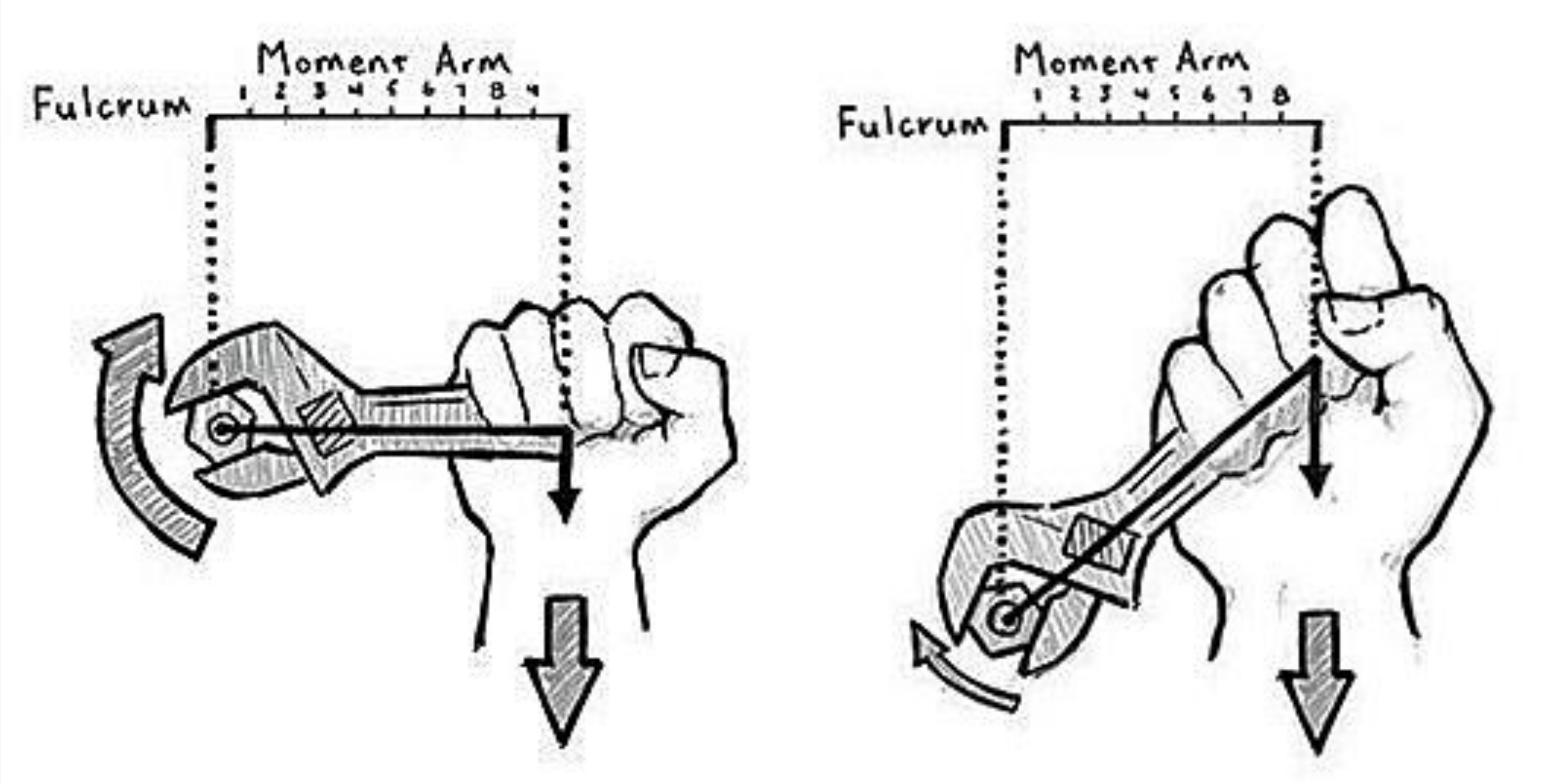


Figure from Arnold et al 2009

Background

- Moment = Force x Moment Arm



http://www.powerliftingtowin.com/wp-content/uploads/2014/02/momentarm-rightangle.jpg

Background

-Arnold et al (2009) updated a model by Delp et al (1990) which utilized this lumped-parameter model to calculate hip, ankle, and knee moments.

- Moment= Force x Moment Arm

Knee flexor moments

Knee extensor moments

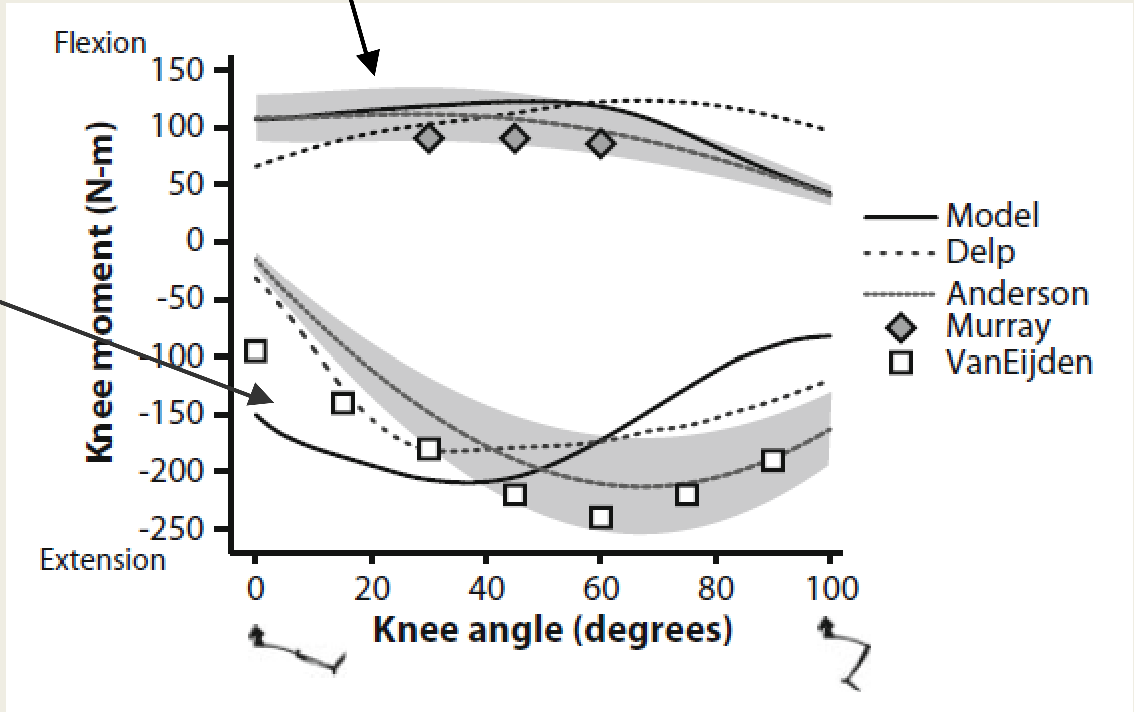


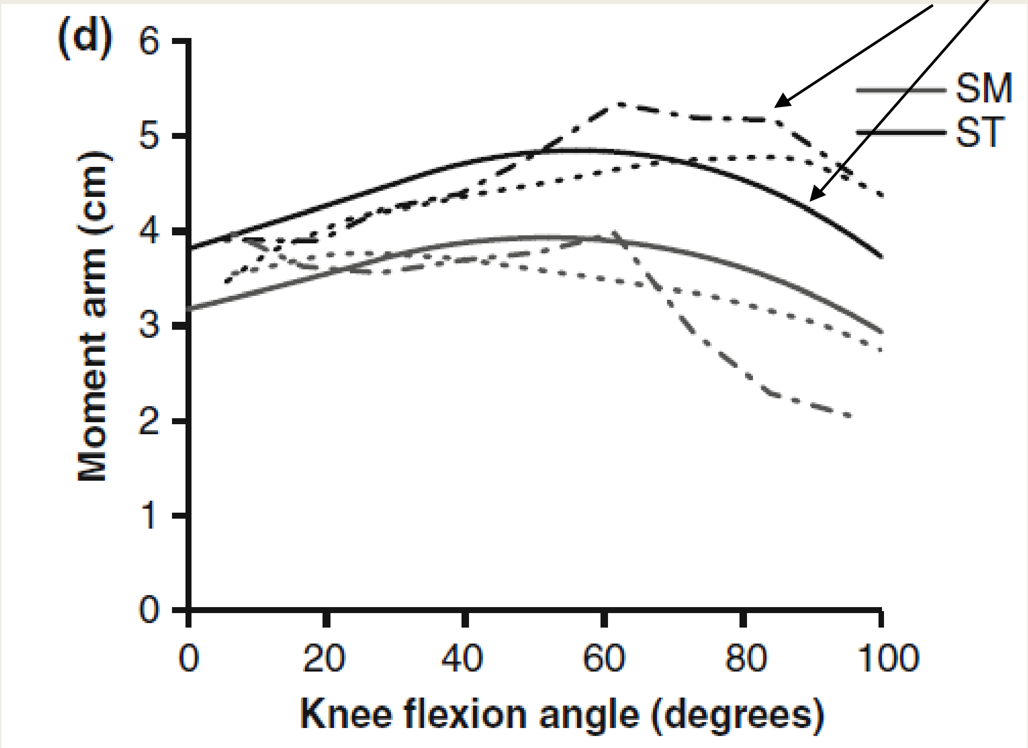
Figure from Arnold et al (2009)

Background

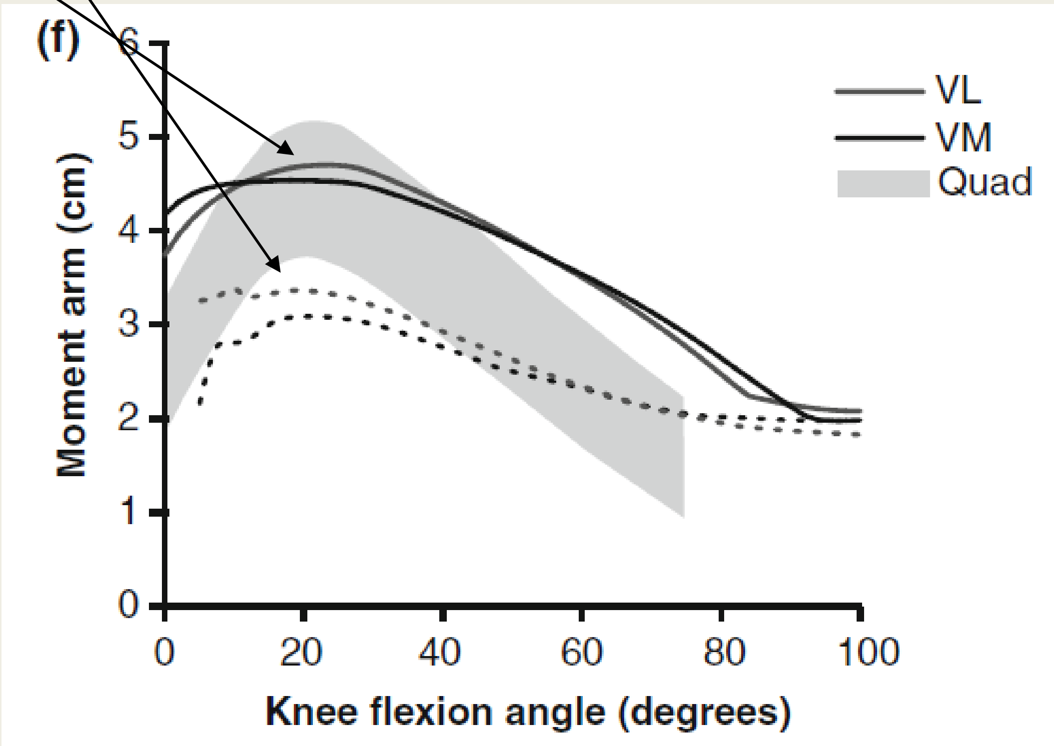
- Arnold et al (2009) poorly predicted knee extensor moment arms

Model Data
Experimental Data

Figures from Arnold et al (2009)



Knee flexor moment arms



Knee extensor moment arms

Purpose

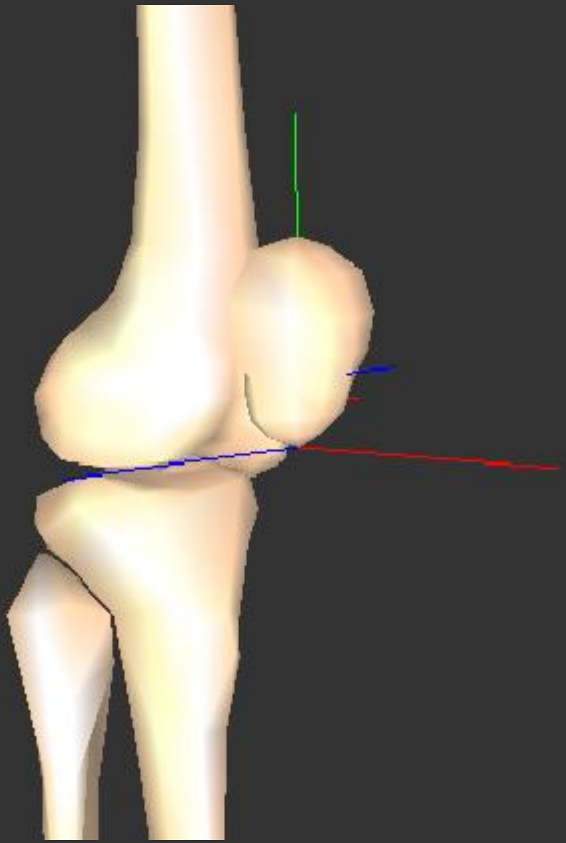
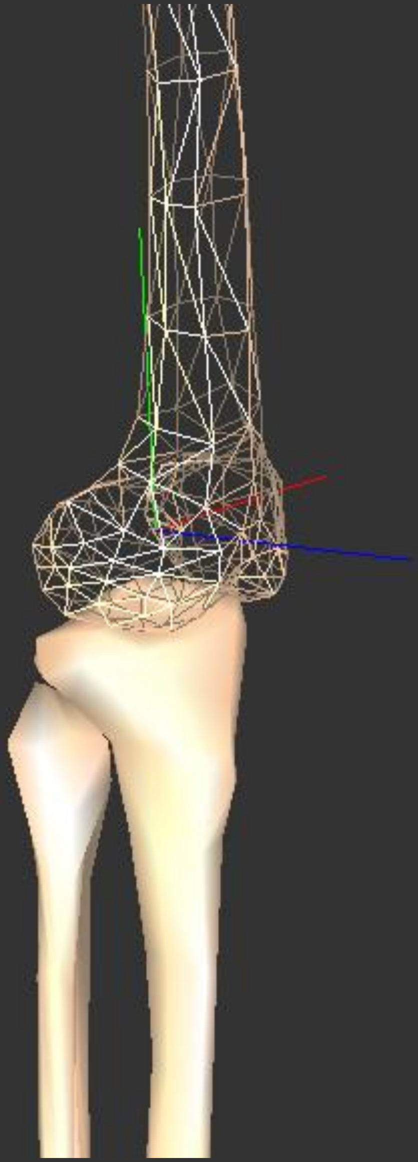
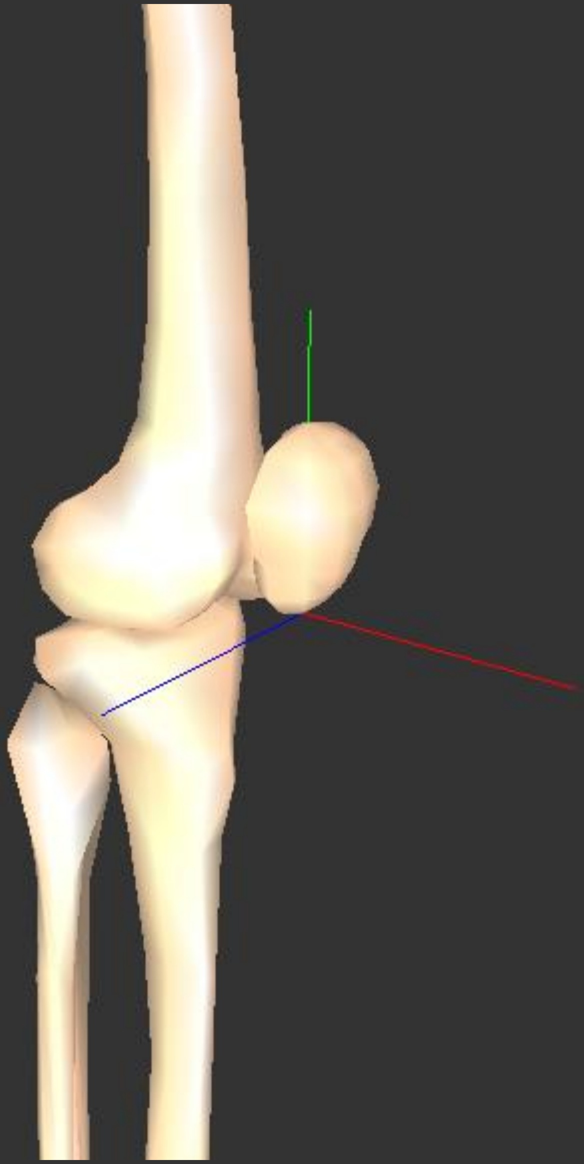
- Better predict knee extensor moments generically and subject-by-subject
  - *Better predict knee extensor moment arms*

Methods

- Implemented *in vivo* kinematics
  - *Li et al (2007)*

- Adjusted muscle attachments
  - *Becker et al (2004)*

- Scaled generic model to participant data

Methods

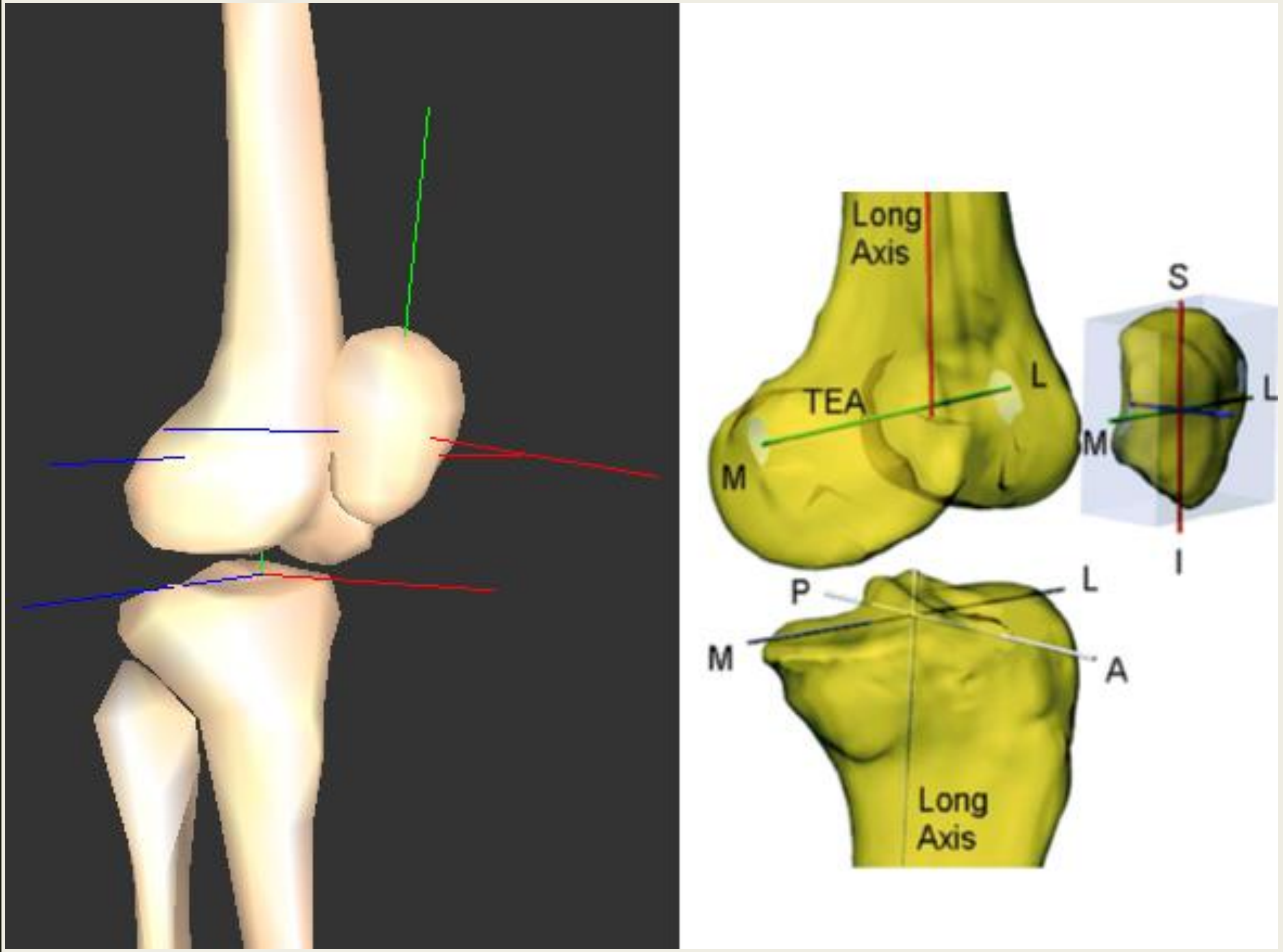
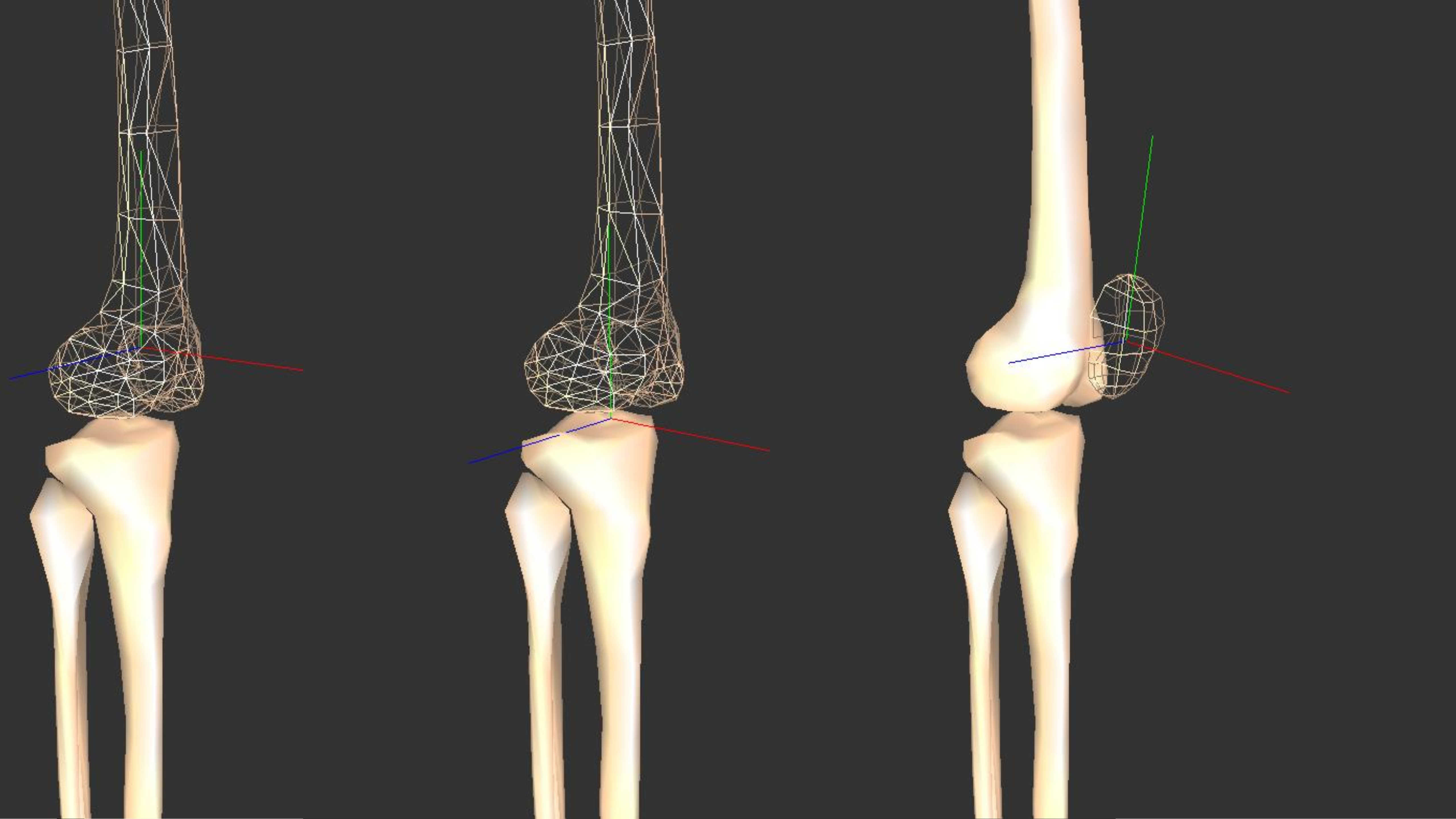
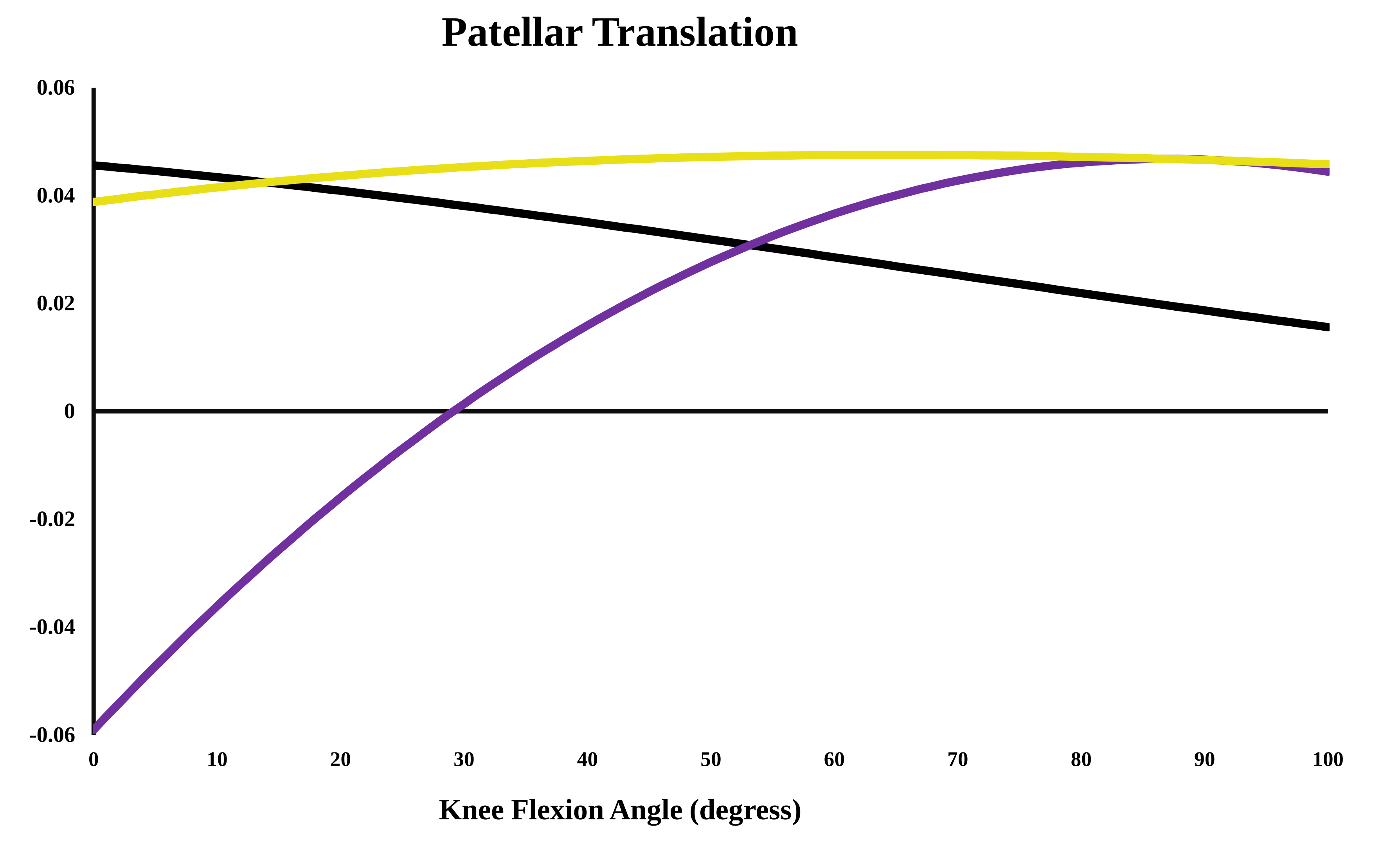


Figure from Li et al (2007)

Incorporated axes which the patella, femur, and tibia moved relative to based on Li et al (2007).



Methods


Patellar Translation
0.06
0.04
0.02
0
-0.02
-0.04
-0.06
0
10
20
30
40
50
60
70
80
90
100
Knee Flexion Angle (degress)

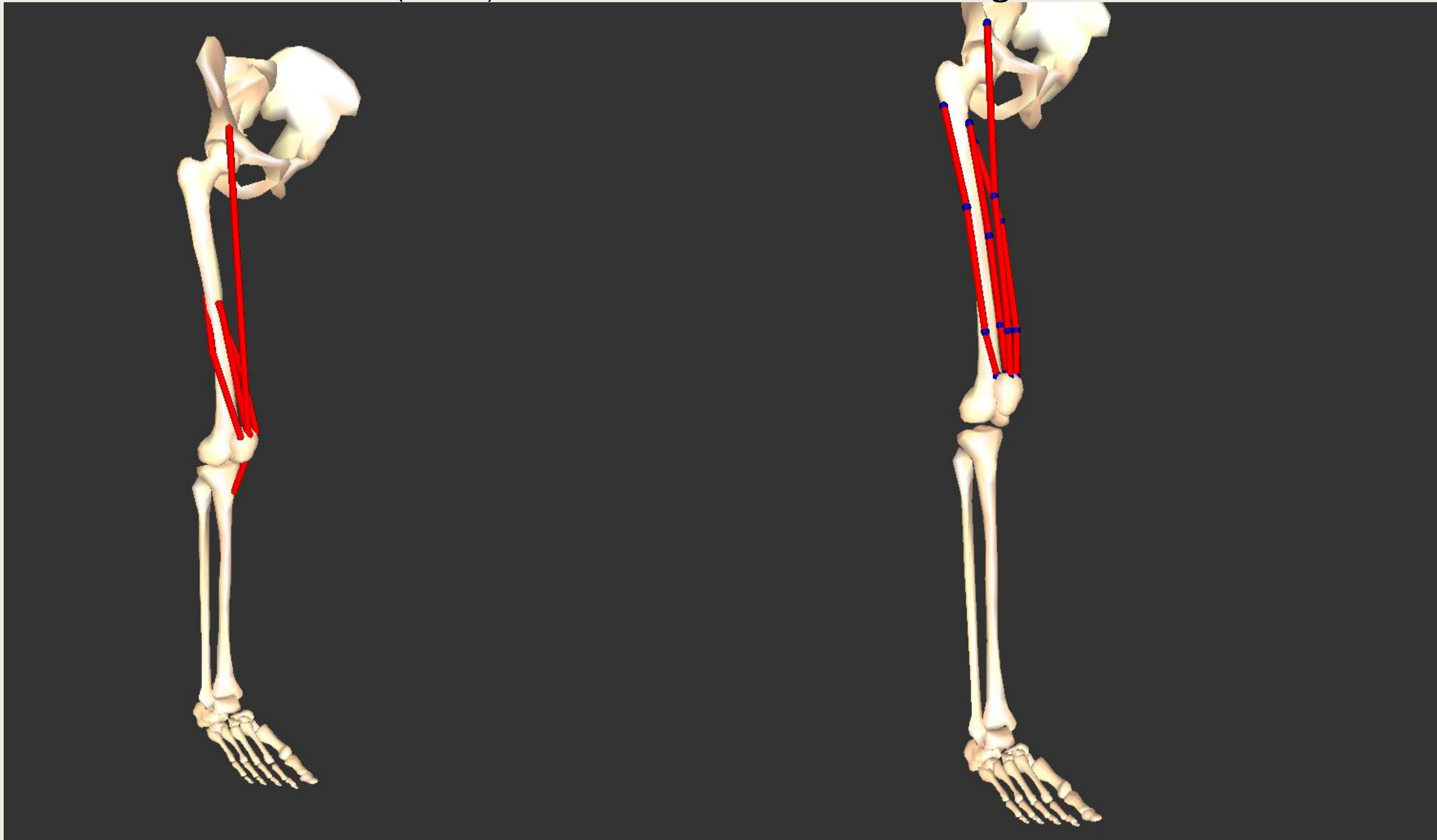
Methods

- Implemented *in vivo* kinematics
  - *Li et al (2007)*
- Adjusted muscle attachments
  - *Becker et al (2004)*
- Scaled generic model to participant data

Methods

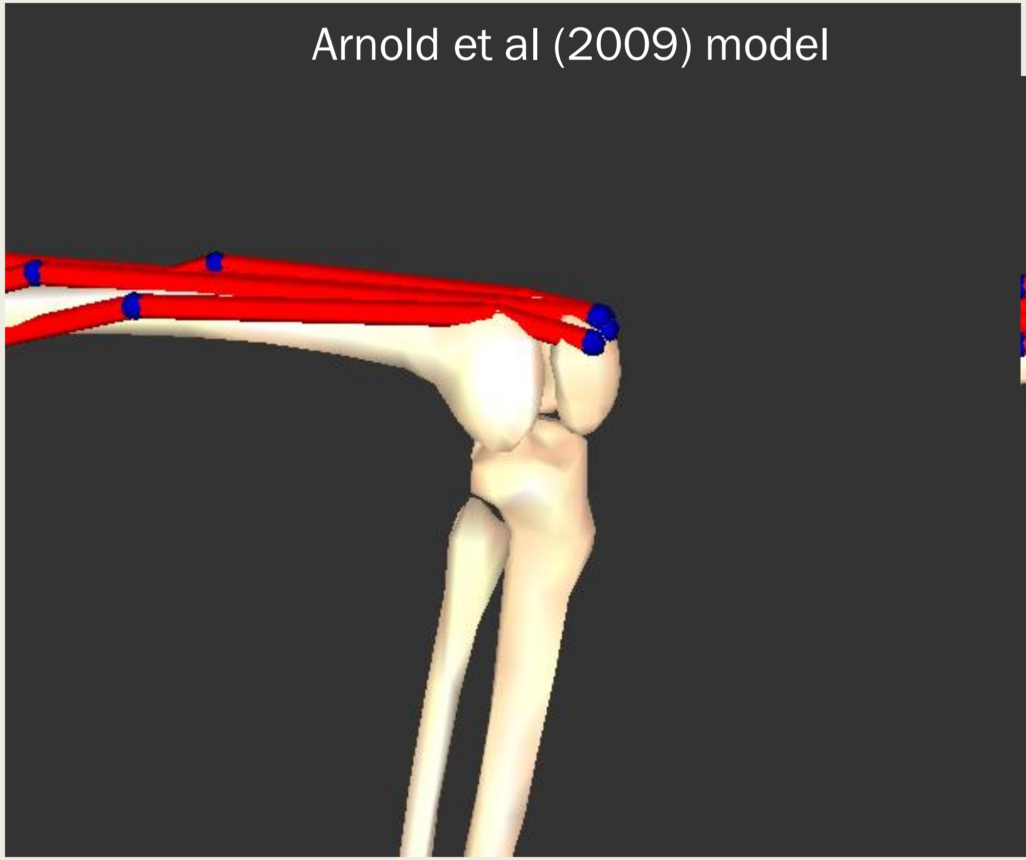
Altered muscles to represent anatomically realistic origins and insertions from Becker et al (2004).

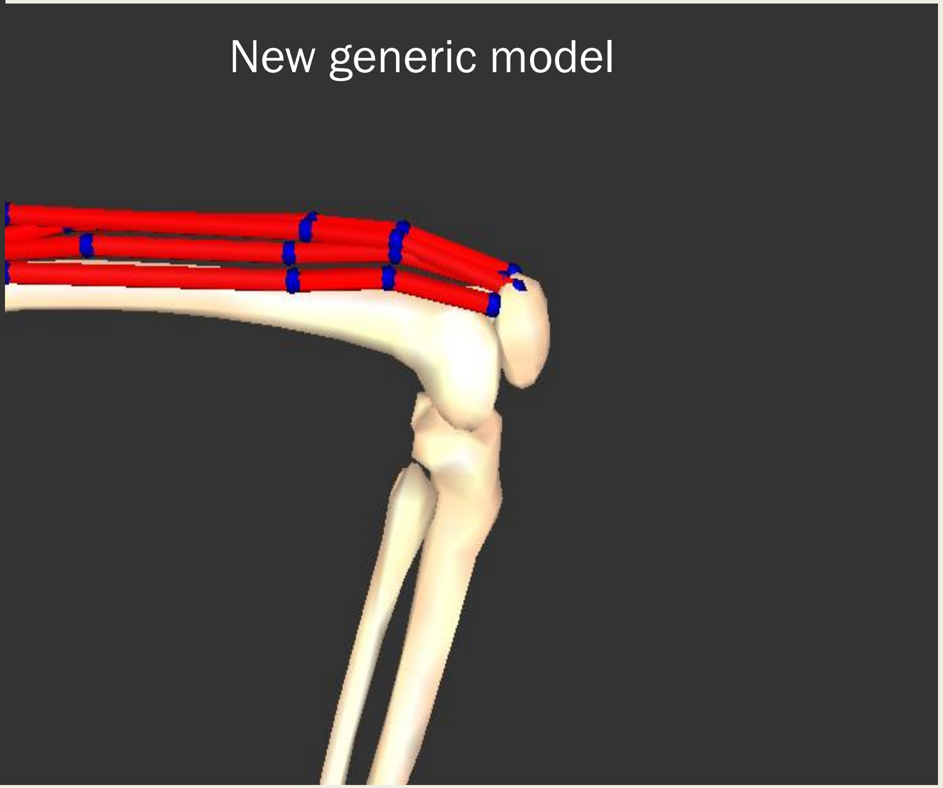
Arnold et al (2009) model   New generic model



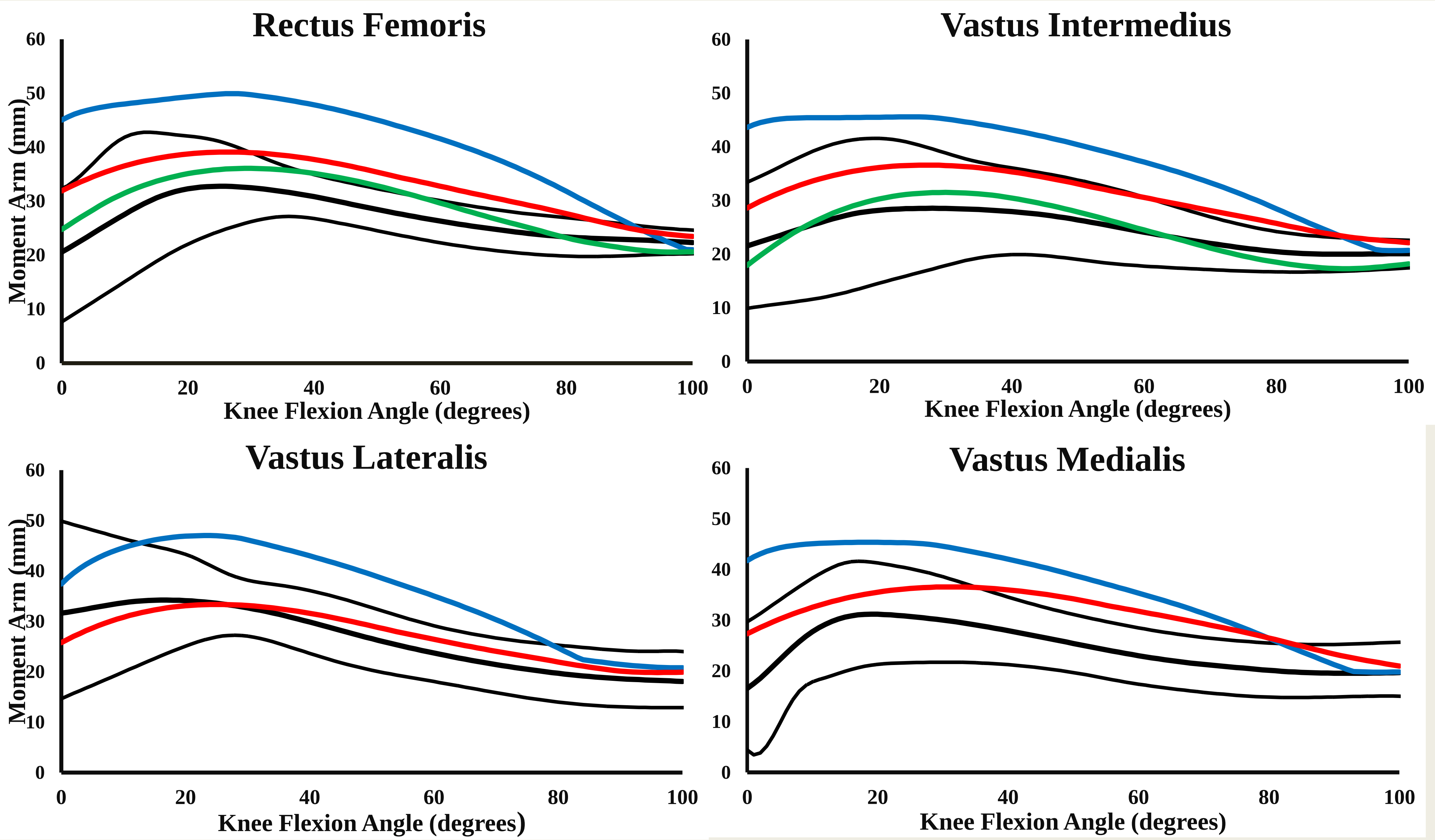
Methods

Altered muscles paths to prevent bone penetration

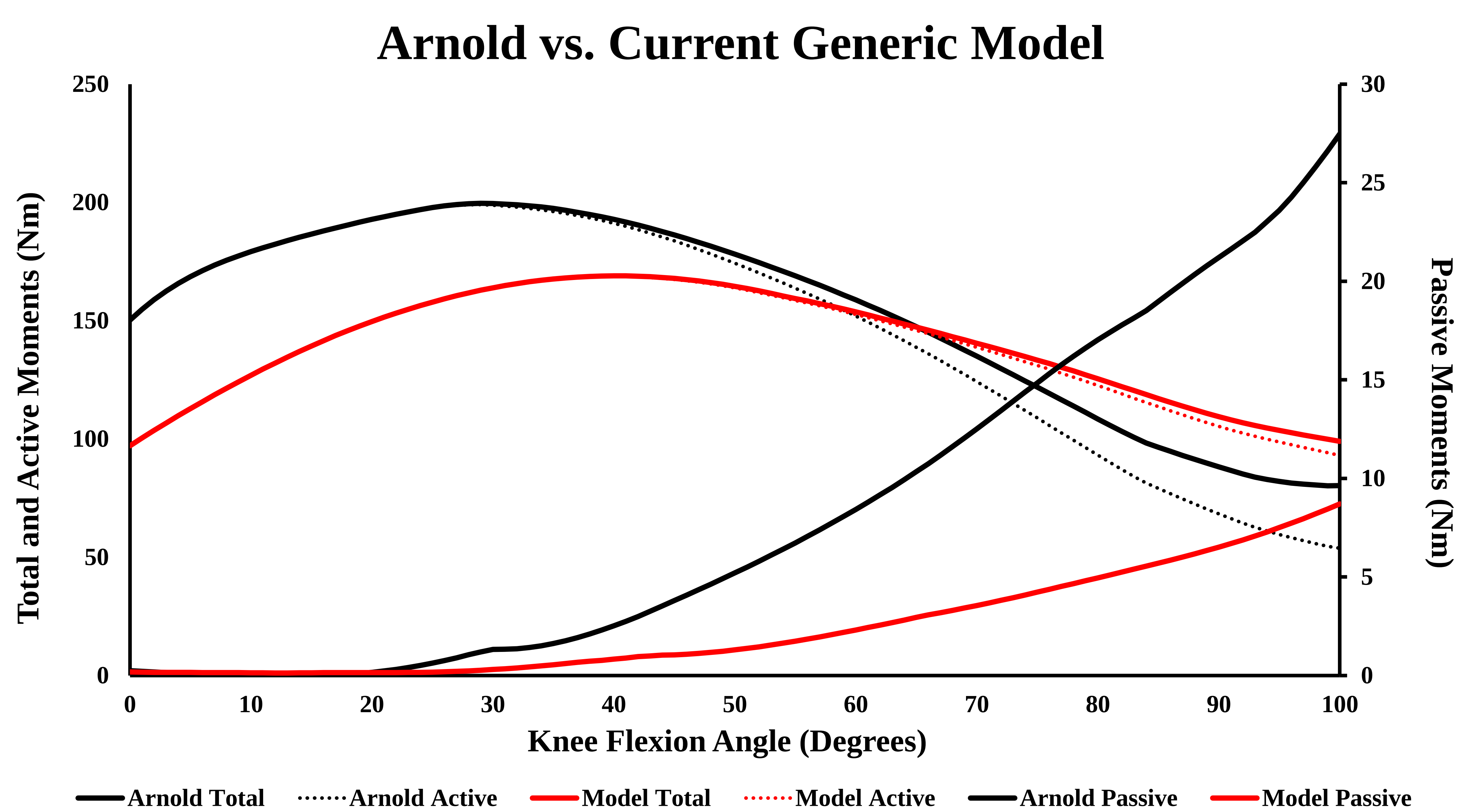




Quadriceps Moment Arms



Buford et al. Blemker et al. Arnold et al. Current Model


Arnold vs. Current Generic Model
Total and Active Moments (Nm)
Passive Moments (Nm)
Knee Flexion Angle (Degrees)
0
50
100
150
200
250
0
5
10
15
20
25
30
0
10
20
30
40
50
60
70
80
90
100
Arnold Total
Arnold Active
Model Total
Model Active
Arnold Passive
Model Passive

Methods

- Implemented *in vivo* kinematics
  - *Li et al (2007)*

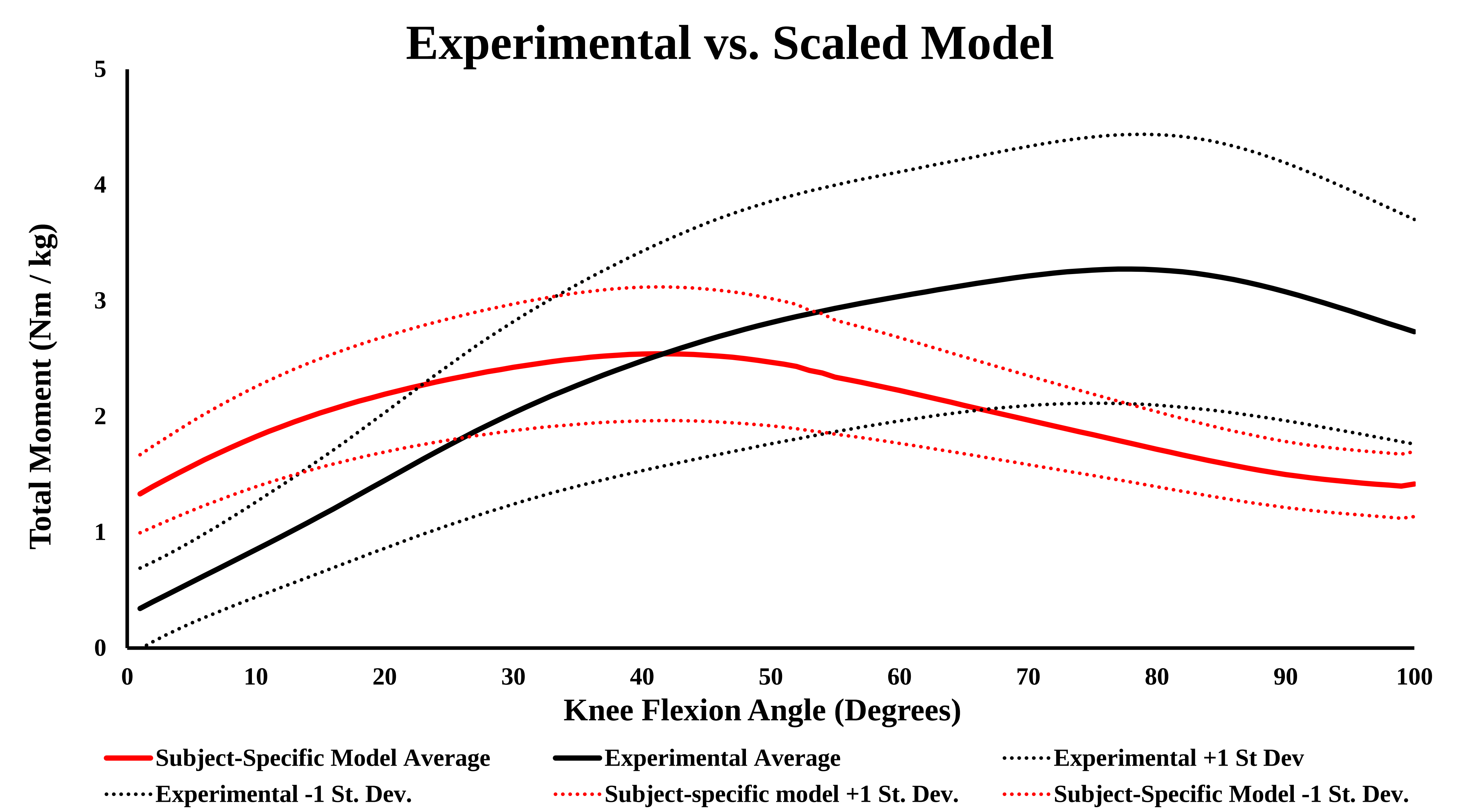
- Adjusted muscle attachments
  - *Becker et al (2004)*

- Scaled generic model with participant data

Methods

- Scaled generic model geometry using bone measurements

- Measured and calculated muscle force producing properties
  - *PCSA, fascicle length, and pennation angle*
  - *Equations from Ward et al (2004), Garner and Pandy (2004)*
  - *Muscle volume, Force$_{max}$, optimal fiber length, pennation angle at optimal fiber length, and tendon slack length*



Experimental vs. Scaled Model
Total Moment (Nm / kg)
0
1
2
3
4
5
0
10
20
30
40
50
60
70
80
90
100
Knee Flexion Angle (Degrees)
Subject-Specific Model Average
Experimental Average
Experimental +1 St Dev
Experimental -1 St. Dev.
Subject-specific model +1 St. Dev.
Subject-Specific Model -1 St. Dev.

Discussion

- Positives
  - *Moment Arm Predictions*
  - *Passive Moment Prediction*

- Negatives
  - *Angle of peak moment*

- Future Work
  - *Force Producing Properties*
    - Titin
    - Passive properties

  - *Fiber behavior modifications*
    - Fibers behave differently within muscle
    - Ultrasound measurement for multiple muscles and locations
    - Large variability between persons

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NSF REU
BME-SIM
EAST CAROLINA UNIVERSITY

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ECUPOL
Performance Optimization Lab

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