Simulation of Human Movement and Gait Pathology: An Introduction to OpenSim for the Clinician

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OpenSim and Surgical Planning
Learning Objectives

Through a series of lectures, demos, and hands-on practice learn to:

- Describe a musculoskeletal model
- Load a model in OpenSim and animate it with gait kinematics
- Plot hamstrings lengths over the gait cycle
- List the capabilities and limitations of computer simulation
1. Introduction to musculoskeletal models and simulation of movement with OpenSim
2. Exploring joint angles, muscle-tendon lengths, & moment arms
3. Clinical Example: Assessment of hamstrings lengths during crouch gait
4. More applications of OpenSim and how to get involved
Agenda

1. Introduction to musculoskeletal models and simulation of movement with OpenSim
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Generation of Movement

Neural Command → Muscle-Tendon Dynamics → Musculoskeletal Geometry → Multibody Dynamics → Observed Movement

- EMGs
- Forces
- Moments
- Angles/Velocities
- Accelerations/Ground Reaction Forces
Generation of Movement

- Neural Command
- EMGs
- Muscle-Tendon Dynamics
- Forces
- Musculoskeletal Geometry
- Moments
- Multibody Dynamics
- Angles
- Velocities
- Accelerations
- Ground Reaction Forces
- Observed Movement
Generation of Movement

Neural Command → Muscle-Tendon Dynamics → Forces → Musculoskeletal Geometry → Moments → Multibody Dynamics → Observed Movement

EMGs

Angles, Velocities, Accelerations, Ground Reaction Forces

activation dynamics
contraction dynamics
Generation of Movement

- Neural Command
- Muscle-Tendon Dynamics
- EMGs
- Forces
- Musculoskeletal Geometry
- Moments
- Multibody Dynamics
- Angular Velocities
- Accelerations
- Ground Reaction Forces
- Observed Movement

muscle moment arm
Generation of Movement

- Neural Command
- Muscle-Tendon Dynamics
  - EMGs
  - Forces
- Musculoskeletal Geometry
  - Moments
- Multibody Dynamics
  - Angles
  - Velocities
  - Accelerations
  - Ground Reaction Forces
- Observed Movement

gravity
Generation of Movement

Neural Command → Muscle-Tendon Dynamics → Musculoskeletal Geometry → Multibody Dynamics → Observed Movement

- EMGs
- Forces
- Moments
- Angles, Velocities, Accelerations, Ground Reaction Forces
Many Factors Contribute to Gait Abnormalities

- Impaired Motor Control
  - Abnormal Muscle-Tendon Dynamics
    - EMGs
  - Abnormal Musculoskeletal Geometry
    - Forces
  - Abnormal Multibody Dynamics
    - Moments
      - Angles
      - Velocities
      - Accelerations
      - Ground Reaction Forces
    - Observed Movement
Limitations of the Current Approach

Impaired Motor Control → Abnormal Muscle-Tendon Dynamics → Abnormal Musculoskeletal Geometry → Abnormal Multibody Dynamics

EMGs → Forces → Moments

Angles, Velocities, Accelerations, Ground Reaction Forces → Observed Movement
Limitations of the Current Approach

Selective Dorsal Rhizotomy

Impaired Motor Control
- Abnormal Muscle-Tendon Dynamics
  - EMGs
  - Abnormal Muscle-Tendon Dynamics
  - Forces
  - Abnormal Musculoskeletal Geometry
  - Moments
  - Abnormal Multibody Dynamics
  - Angles Velocities
  - Accelerations Ground Reaction Forces
  - Observed Movement

Muscle-Tendon Lengthenings, Strengthening Exercises
- Tendon Transfers, Osteotomies
- Orthotics
Potential Contributions of Biomechanical Models

- Impaired Motor Control
  - EMGs
  - Abnormal Muscle-Tendon Dynamics
    - Multibody Dynamics
      - Abnormal Musculoskeletal Geometry
        - Moments
          - Forces
            - Muscle-Tendon Lengthenings
              - Selective Dorsal Rhizotomy
                - Transfers,
                  - Osteotomies
                    - Strengthening Exercises
                      - Forces
                        - Tendon Transfers
                          - Orthotics
                            - Accelerations
                              - Ground Reaction Forces
                                - Observed Movement
                                  - Simulated Movement
How does altered muscle-tendon dynamics affect movement?

- Neural Command
- Altered Muscle-Tendon Dynamics
- EMGs
- Forces
- Musculoskeletal Geometry
- Moments
- Multibody Dynamics
- Angles, Velocities
- Accelerations, Ground Reaction Forces
- Observed Movement

Muscle-Tendon Lengthenings
• 13 body segments

• 86 muscle-tendon actuators
Launch OpenSim
Questions

- Which motions have been simplified or not modeled?
- What muscles are represented with multiple lines of action and why?
- Which knee extensor muscles have wrapping points?
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Neural Command 
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muscle moment arm

force 
moment
Example: Muscle Moment Arms

How much force must a muscle generate to balance the moment produced at the elbow joint by a weight being held at the end of the arm?

\[ W = 10N \]
Example: Muscle Moment Arms

\[
\sum \vec{M}_o = 0 \\
\sum M_o = F^m(ma) - Wd = 0 \\
F^m = \frac{Wd}{(ma)}
\]
Example: Muscle Moment Arms

Elbow muscle moment arm:
Brachialis $\sim$ 2.5 cm

\[
F^m = \frac{Wd}{ma}
\]

\[
F^m = \frac{(10N)(25cm)}{(2.5cm)} = 100N
\]
Muscle Force-Length Property

- Muscle force production diminishes for short and long fibers

![Graph showing the relationship between Force and Muscle-fiber Length with $F_0^M$ indicating the maximum force at a certain length.](image-url)

Muscle Sarcomeres

- Actin
- Myosin
Launch OpenSim
Questions

- How do the muscle fiber length curves change when the hip is flexed? Why?
- What are the peak moment arms of rectus femoris and vastus intermedius?
- What is the knee angle at the peak?
- When do discontinuities occur and why?
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Clinical Goal: Identify causes of excess knee flexion
Treatment of crouch gait is challenging

Reputed Cause:
- hamstrings contracture
  i.e., shortened muscle fibers

Courtesy of Gillette Children’s Specialty Healthcare

Adapted from Gage (2004)
Can analyses of muscle-tendon lengths aid treatment planning?
Can analyses of muscle-tendon lengths aid treatment planning?

3D Gait Kinematics → Musculoskeletal Model → Muscle-Tendon Lengths

 normalized
hamstrings length

% gait cycle

Courtesy of S. Õunpuu
Can analyses of muscle-tendon lengths aid treatment planning?

3D Gait Kinematics → Musculoskeletal Model → Muscle-Tendon Lengths

(normalized hamstrings length vs. % gait cycle)

Courtesy of S. Ōunpuu
Can analyses of muscle-tendon lengths aid treatment planning?

3D Gait Kinematics → Musculoskeletal Model → Muscle-Tendon Lengths

hamstrings contracture

normalized hamstrings length vs. % gait cycle

Gage (2004)

Courtesy of S. Ōunpuu
Can analyses of muscle-tendon lengths aid treatment planning?

3D Gait Kinematics → Musculoskeletal Model → Muscle-Tendon Lengths

unimproved knee extension?

Courtesy of S. Õunpuu
Can analyses of muscle-tendon lengths aid treatment planning?

3D Gait Kinematics → Musculoskeletal Model → Muscle-Tendon Lengths

PRE: not short

normalized hamstrings length

% gait cycle

worsened anterior tilt?

Courtesy of S. Ōunpuu
Launch OpenSim
Questions

- When does heel strike occur? When does toe off occur?
- How does the range of motion for crouch gait compare to unaffected gait?
- What recommendation would you give the surgeon?
- What are limitations of our analysis?
Can analyses of muscle-tendon lengths aid treatment planning?

Arnold et al. (2006) *Gait & Posture*

- Estimates of hamstrings lengths & velocities *alone* do not predict the outcome of multi-level surgery.

- Analyses of hamstrings lengths & velocities may help to identify patients who:
  - walk with short or slow hamstrings
    - *at risk for unimproved knee extension*
  - do not walk with short or slow hamstrings
    - *at risk for unimproved or worsened anterior pelvic tilt*
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What can you do with simulation?

- Visualize complex movement patterns
- Probe forces that are difficult to measure
- Perform “what if” studies
- Identify cause-effect relationships
Visualize human running in detail
What can you do with simulation?

- Visualize complex movement patterns
- Probe forces that are difficult to measure
- Perform “what if” studies
- Identify cause-effect relationships
Probe the function of a muscle
What can you do with simulation?

- Visualize complex movement patterns
- Probe forces that are difficult to measure
- Perform “what if” studies
- Identify cause-effect relationships
Examine other causes of crouch gait
What can you do with simulation?

Visualize complex movement patterns

Probe forces that are difficult to measure

Perform “what if” studies

Identify cause-effect relationships
What happens in a drop landing?
What can you do with OpenSim?

- Visualize complex movement patterns
- Probe forces that are difficult to measure
- Perform “what if” studies
- Identify cause-effect relationships
OpenSim is an application
OpenSim is a repository of models

Running:
Hamner et al, 2010

Lumbar-spine:
Christophy et al, 2011

Shoulder:
Matias et al, in prep.

Lower-extremity:
Arnold et al, 2010
OpenSim is a worldwide community
OpenSim is your resource

http://opensim.stanford.edu
Thank you


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