Simulation #2:
Simulation and Analysis of a Tendon Transfer Surgery

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I. Objectives

Purpose of the Tutorial:
The purpose of this tutorial is to demonstrate how musculoskeletal models can be used to study common orthopaedic surgical techniques and to illustrate how muscle moment arm, optimal muscle fiber length, and tendon slack length influence the variation of muscle force with joint angle. By working through this tutorial, you will:

- become familiar with the wrist joint model and SIMM's Muscle Editor
- simulate a tendon transfer surgery and examine the effects of the surgery on joint moment, muscle force, and muscle moment arm
- investigate the effect of tendon slack length on isometric muscle force

Format of this Tutorial:
Each section of the tutorial asks you to execute a set of computer commands and answer a few questions. The computer commands which you must type to run SIMM and complete the tutorial are printed in **bold**. The questions can be answered based on what you observe from analysis of the musculoskeletal model and on what you already know about the human musculoskeletal system. As you complete each section of the tutorial, feel free to explore SIMM and the wrist model further on your own.

II. A Musculoskeletal Model of the Wrist Joint

In this section of the tutorial you will load a model of the human wrist joint and evaluate its motions. Log on to the computer and start SIMM using the instructions outlined in the last tutorial. In this tutorial, you will use the File Loader, Model Viewer, Plot Maker, and Muscle Editor tools.

Getting Started:

SIMM is available on all of the UNIX machines in the BME computer cluster. Even if you have an account on these machines, you will need to login as a me181 student. To start SIMM follow these instructions:

- Login as "**me181**". The password is "**simm_tut**".
- If SIMM opens automatically, you will need to close it. Do this by pressing escape.

In a winterm window, type "**./simm_me181_wrist**". (In this instruction, simm is preceded by a period and then a slash.) Opening SIMM this way results in the correct muscle, joint, and motion files loading automatically so that you don't need to input them manually for the first part of the tutorial. Click the **left mouse** button on **load model.**

Use the Model Viewer tool to investigate the wrist model. In particular, become familiar with wrist **flexion** and extension and radial (toward the thumb) and ulnar **deviation**. It is important to understand the angle conventions to interpret the plots you will make later in the tutorial.

Questions:

1. Which motion is expressed in positive angles, wrist flexion or wrist extension?
2. Is radial deviation or ulnar deviation expressed as a positive angle ?

Commands for how to manipulate the model are reviewed below, as they will be needed later.

- SIMM allows you to position the model using keyboard commands. To rotate the model about the X-axis of the world reference frame, place the cursor in the model window and press the ***CTRL*** key and the **left mouse** button. The direction and speed of rotation are determined by the position of the cursor in the model window. If the cursor is at the far right edge of the window, the model will rotate quickly in the positive direction about the X-axis. As you move the cursor left, toward the center of the window, the rate of rotation slows down. If the cursor is in the middle of the window, the rotation rate is zero. As you move the cursor further left, toward the left edge of the window, the rotation rate increases, but in the negative direction. Pressing the ***CTRL*** key and the **middle mouse** button, in a similar manner, rotates the entire model about the Y-axis. Pressing the ***CTRL*** key and the **right mouse** button rotates the model about the Z-axis. Experiment with these keyboard commands. To return the model to its original position, click the **left mouse** button on **reset view**.

- Additional keyboard commands allow you to zoom and pan. Move the cursor into the model window and try pressing the following keys:
  - **i** — zooms the model in toward you, making it larger
  - **o** — zooms the model out away from you, making it smaller
  - **l** — pans the model to the left within the model window
  - **r** — pans the model to the right within the model window
  - **u** — pans the model up within the model window
  - **d** — pans the model down within the model window

The speed with which the model moves depends on the current "gear". Use the gear slider to change the speed of the model.

Using SIMM we can categorize and display muscles based on their function.

- Hide all of the muscles in the wrist model by pressing the **left mouse** button on the **muscles>** item in the command menu and select ***all off*** from the pop-up menu.

- Choose ***flexor*** from the **muscles>** pop-up menu, **scroll** to the bottom of the Model Viewer and click the **left mouse** button on ***flexor*** (the title bar above the list). The only muscles displayed should be the wrist flexors. Hide the wrist flexors by clicking on the ***flexor*** title bar again.

Display the ***flexors***, ***extensors***, ***radial*** deviators, and ***ulnar*** deviators one group at a time.

Questions:

3. What are the functions of the ECUpre muscle?
4. What are the functions of the ECRB?

III. Simulation of a Tendon Transfer at the Wrist Joint

Spinal cord injury at the level of the cervical spine causes a loss of hand function. In some patients, the ability to grasp and release objects may be restored through electrical stimulation of paralyzed muscles, called functional electrical stimulation (FES). However, FES is only feasible in those muscles where the connection between the nervous system and the muscle remains intact *within the muscle*. That is, FES is only effective in muscles without lower motor neuron damage. In many cases, the muscles that perform the desired functions (e.g., finger flexion, thumb abduction) have been damaged too greatly to respond to FES. In addition, there is often a loss of balance at the wrist joint, causing the wrist to remain in a flexed and ulnarly deviated position. In these situations, tendon transfers are performed to (i) alter the paths of muscles that do respond to FES to locations where they can enhance hand function and (ii) restore a more functional configuration of the wrist joint so that grasp and release tasks can be accomplished.

In this section of the tutorial, you will transfer the Extensor Carpi Ulnaris (ECU) to the Extensor Carpi Radialis Brevis (ECRB) tendon and evaluate the mechanism by which this transfer restores balance to the wrist. Before simulating the transfer,

- Hide all of the muscles in the wrist model

- In the Model Viewer, select ***transfer*** from the **muscles>** pop-up menu, and **select** the two muscles in this surgery.

The "ECUpre" and ECRB muscle paths should be visible on the model. Show the muscle points on these muscles by clicking the **left mouse** button on **show points** in the Model Viewer.

To simulate this surgery, close the Model Viewer and open the Muscle Editor tool. This tool helps you to edit the path of the muscles as well as the force-generating parameters of the muscles. Each end of a muscle connects to bone. The more proximal connection is called the origin, and the more distal connection is called the insertion point. In the model window, select the insertion point of the ECUpre muscle and the two wrapping points just superior to it:

- hold down the **space bar** and click on the muscle point with the **left mouse** button. The muscle points turn from dark blue to light blue as they are selected.

You may want to zoom in for a better view of the muscle points. In the Muscle Editor window, the names of the muscle points (***ECUpre.5, ECUpre.6, and ECUpre.7***) that you have selected are displayed, along with the distances you have moved them in the x,y, and z directions (these should all read 0.0000 now).

Place the cursor in the model window, hold down the **shift** button and the **left mouse** button, and move the cursor toward the ECRB muscle path. The three muscle points you have selected should move radially, toward the ECRB path. Try to align the ECUpre path with the ECRB path as best you can. Don't forget to rotate the wrist model to align the paths in all three directions. (Do not use the DOF's in the Model Veiwer to do this – you need to use the keyboard commands given above.) For fine tuning, **de-select** muscle points and edit the three points one at a time:

- hold down the **space bar** and click on the muscle point with the **left mouse** button. The muscle point should turn from yellow to blue, and the name of the muscle point should disappear from the Muscle Editor Window.

Once you have the ECUpre muscle path aligned with the ECRB, **select** the three points again.

<u>*Questions:*</u>
5. What was the net move for each of these three points?

To analyze the effects of this surgery, we need a model of the transferred muscle and the muscle in its original position. To return the ECUpre back to its original position, click on the **restore** button in the Muscle Editor with the **left mouse** button. Return to the Model Viewer, select ***final*** from the **muscles>** menu, and click on the ECUpost muscle. A muscle path similar to the transfer you just did should appear on the model. At this point, no muscle points should be selected. Close the Muscle Editor tool and open the Plot Maker tool. Before you make any plots make sure the model is in the neutral configuration (**flexion = 0.0** and **deviation = 0.0**)

The first thing we'll investigate is the effect of the transfer on wrist extensor strength.

- In the Plot Maker window, select ***transfer*** and ***final*** from the **muscles>** menu. Also select the ***extensor*** muscles and select all of the extensors by clicking on the extensor title button.

- **De-select** ECUpost from the ***final*** muscle list.

- Initially, the **active, passive,** and **isometric,** boxes should be chosen in the Plot Maker window. That is, the boxes next to them should be yellow, not gray. For this plot, you also need to select **sum.**

- Edit the **curve name** text box to read **before transfer** (be sure to hit enter after typing)**.**

- Select ***flexion moment*** (not elbow flexion!) as the **y-variable** and ***flexion*** as the **x variable** and click on **make curves** with the **left mouse** button.

A plot window with one curve named "before transfer" should appear, this is the sum of the isometric moments generated by all of the wrist extensors. Again, become familiar with the conventions:

<u>*Questions:*</u>
6. Is the sign of the extension moment positive or negative?

To compare the strength of the extensors after the transfer, **deselect** ECUpre from the ***transfer*** muscle list, and **select** ECUpost from the ***final*** muscle list. Edit the **curve name** text box to read **after transfer**, and click on **make curves** with the **left mouse** button.

<u>*Questions:*</u>
7. What happens to the total isometric strength of the wrist extensors if the ECU muscle is transferred to the ECRB?

Now let's examine the effects of the transfer on the deviation strength of the wrist muscles. Before we proceed, **deselect** all of the wrist extensors. After you're sure none of the muscles are selected,

- choose ***extensor*** from the **muscles>** menu. This should cause the list of extensor muscles to disappear from the bottom of the Plot Maker window.

- choose ***new plot*** in the **plot>** menu, select ***deviation moment*** as the **y-variable,** and ***deviation*** as the **x variable.**

- Select all of the ulnar deviators by choosing ***ulnar*** from the **muscles>** menu and clicking on the ulnar title button.

- **de-select** ECUpost from the ***final*** muscle list.

- Make sure that **sum**, **active, passive,** and **isometric,** boxes are chosen in the Plot Maker window, and click on **make curves** with the **left mouse** button.

<u>*Questions:*</u>
8. Is the sign of the ulnar deviation moment positive or negative?

To compare the strength of the ulnar deviators after the transfer, **deselect** ECUpre from the ***transfer*** muscle list, and **select** ECUpost from the ***final*** muscle list. Edit the **curve name** text box to read **after transfer**, and click on **make curves** with the **left mouse** button.

<u>*Questions:*</u>
9. What happens to the total isometric strength of the ulnar deviators if the ECU muscle is transferred to the ECRB?
10. Re-read the description of the goals of tendon transfers in spinal cord injury. Based on the effect of this transfer on wrist extension and deviation strength, why is the ECU transfer to the ECRB a good candidate for accomplishing goal (ii)?

When you're done with these plots you can **delete** them.

III. Using Musculoskeletal Models to Understand the Effects of Surgical Procedures

We are now going to take a more in depth look at the effects of the tendon transfer on the function of the ECU muscle. Before we make more plots **de-select** all of the ulnar deviators in the Plot Maker. After you're sure none of the muscles are selected, choose ***ulnar*** from the **muscles>** menu. This should cause the list of deviator muscles to disappear from the bottom of the Plot Maker window.

- Choose ***new plot*** in the **plot** menu, select ***flexion moment*** as the **y-variable,** and ***flexion*** as the **x variable.**

- Select ECUpre and ECUpost from the t**ransfer** and **final** muscle lists

- **de-select sum**, and click on **make curves** with the **left mouse** button.

- Click the **left mouse** button on the peak of each curve, the coordinates of those points should appear on the screen. (If you want to **delete** one of the points you have selected on the graph, open the **Plot Viewer** tool, choose the appropriate plot, and click on the **delete points** button with the **left mouse** button).

Questions:
11. What is the peak value of the ECU extension moment before transfer? In what joint angle does it occur?
12. What is the peak value of the ECU extension moment after transfer? In what joint angle does it occur?
13. Describe how the two curves differ from one another.

Investigate the differences in wrist strength further by making plots of ***force*** vs. ***flexion***, and ***flexion moment arm*** vs. ***flexion*** for the ECUpre and ECUpost muscles**.**

Questions:
14. Note the peak values of each curve, the joint angle at which the peaks occur, and describe the general shapes of the curves.

Open the Muscle Editor tool, and click on **parameters** with the **left mouse** button. Select ECUpre and examine the list of muscle parameters used to estimate the force-length curve of this muscle.

Questions:
15. What is its optimal fiber length (**lmo**) of ECUpre?

Click on **parameters** again and choose ECUpost. Now examine the list of muscle parameters for ECUpost.

Questions:
16. What is it's optimal fiber length of ECUpost??
17. Calcuate the ratio of optimal fiber length to peak moment arm for ECUpre and ECUpost.
18. Explain the differences in the isometric moment vs wrist flexion angle for the ECUpre and ECUpost based on the plots of force and moment arm and the ratio of optimal fiber length to peak moment arm.
19. Specifically, what does the difference between the ratios of optimal fiber length to moment arm for the ECU before and after tell you?

When you are done with these plots, **delete** them.

IV. The Effect of Tendon Slack Length on the Isometric Force-Angle Curve.

The previous simulation illustrated how a muscle's moment arm and optimal fiber length influence its isometric strength and the portion of the force-angle curve over which the muscle operates. Another important factor in determining the isometric force vs joint angle relationship is tendon slack length, or the length where the tendon just starts to generate force. Before we start the simulation, **de-select** the ECU pre and post muscles in the Plot Maker, and **select** the ECRB.

- Make three new, separate plots, **force vs. flexion, musculotendon length vs. flexion,** and **fiber length vs. flexion** for the ECRB.

- Open the Muscle Editor, and click on **parameters.** Select the muscle parameters for the ECRB muscle.

<u>Questions:</u>

20. What is the tendon slack length of the muscle (**lts**)?
32. What is the optimal fiber length (**lmo**) of ECRB?

- Edit the *lts* text box to read **0.2105** (remember to hit enter).

- Return to the Plot Maker and select the **force vs. flexion** plot from the **plot** menu and **force** as the **y-variable**.

- Edit the **curve name** text box to read **lts = 0.2105**. Click on **make curves**.

- Select the **musculotendon length vs. flexion** plot from the **plot** menu, and change the **y-variable** appropriately. Edit the **cuve name** text box, and click on **make curves**.

- Add the edited ECRB curve the to **fiber length vs. flexion** plot.

<u>Questions:</u>

21. How did changing the tendon slack length of the ECRB alter the force vs. joint angle curve?
22. How did changing the tendon slack length of the ECRB alter the relationship between musculotendon length and joint angle?
23. How did changing the tendon slack length of the ECRB alter the fiber length vs. flexion curve?
24. At what joint angles do the fiber lengths of the ECRB and the edited ECRB reach **lmo**? Compare these joint angles with the peaks in the **force vs. flexion** plot.
25. Explain the effect of tendon slack length on a muscle’s force-angle relationship based on what you’ve learned about it’s effect on fiber length and musculotendon length.

Feel free to edit **lts** to different values and make more curves to further demonstrate this effect. When you’re done with this simulation, quit the SIMM software (by pressing escape) and logout of the workstation.