

Tutorial 2 - Simulation and Analysis of a Tendon Transfer Surgery

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I. Objectives

Purpose

The purpose of this tutorial is to demonstrate how musculoskeletal models can be used to study 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 respect to changes in joint angle. In this tutorial, you will:

- Become familiar with a wrist model and OpenSim's Property Editor
- Simulate a tendon transfer surgery
- 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

Each section of the tutorial guides you through certain tools within OpenSim's GUI and asks you to answer a few questions. The menu titles and option names you must select and any commands you must type to run OpenSim will appear in **bold face**. The questions can be answered based on information from OpenSim and basic knowledge of the human musculoskeletal system. As you complete each section of the tutorial, feel free to explore OpenSim and the wrist model further on your own. Depending on the amount of exploration you do, this tutorial will take about 1-2 hours to complete.

II. Musculoskeletal Model of the Wrist

In this section, you will load a model of the human wrist [1] and examine its motions.

- Click the **File** menu and select **Open Model**.
- Find the Models folder, which is located under your OpenSim installation directory, e.g., *C:\OpenSim3.2*. (*The actual directory name depends on version used and can be changed during installation*).
- Open the **WristModel** folder, select the file **wrist.osim**, and click **Open**.


Use the Coordinate sliders to investigate the wrist model. In particular, become familiar with wrist **flexion** and extension and radial and ulnar **deviation**. It is important to understand the angle conventions to interpret the plots you will make later in the tutorial.

Note: Radial deviation is defined as wrist motion toward the radius bone, or thumb side.

Questions

1. Which motion is expressed in positive angles: wrist flexion or wrist extension?
2. Which motion is expressed in positive angles: radial deviation or ulnar deviation?

In this OpenSim model, muscles are grouped based on their function.

- In the Navigator, expand the **Forces** and **Muscles** headings. To expand a Navigator heading, click the plus icon  to its left.
- To hide all of the muscles in the model, **right-click** on the **all** muscle group heading, then choose **Display > Hide**.
- To show the *flexors* muscle group, **right-click** on the **flexors** heading, then choose **Display > Show**. Now the only muscles displayed

should be the wrist flexors. To hide the wrist flexors, **right-click** on the **flexors** heading again and select **Display > Hide**.

- Repeat the same steps to display the **extensors**, **radial deviators**, and **ulnar deviators** muscle groups individually.

3. What are the functions of the *Extensor Carpi Ulnaris (ECU)* muscle? Check or circle all that apply.

wrist extension wrist flexion radial deviation ulnar deviation hip extension

4. What are the functions of the *Extensor Carpi Radialis Brevis (ECRB)*? Check or circle all that apply.

wrist extension wrist flexion radial deviation ulnar deviation hip extension

III. Simulation of a Tendon Transfer

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. 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 [2]. 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 *ECU* tendon to the *ECRB* tendon and evaluate the mechanism by which this tendon transfer restores balance to the wrist.

- Display the **transfer** muscle group only by **right-clicking** its heading and selecting **Display > Show Only**. The *ECU_pre-surgery* and the *ECRB* muscle paths should now be visible on the model.

Note: ECU_pre-surgery represents the ECU muscle before the simulated tendon transfer surgery.

- Expand the **transfer** muscle group and identify each muscle by using **Display > Show Only** on each.

To simulate the surgery, you will be using the **Property Editor**. This tool allows you to edit the paths of muscles as well as their force-generating parameters. Each end of a muscle-tendon complex connects to bone. In this model, the most proximal connection is the *origin*, and the most distal connection is the *insertion point*. You will now select the insertion point of the *ECU_pre-surgery* muscle and the two via points proximal to it. All muscle points are graphically represented as red spheres on the muscle path.

- Before editing the model, go to the **File** menu select **Save Model As...** Save the current model as **wrist_TendonSurgery.osim**.
- Once you have done this, **right-click** on the **Wrist Model** name in the OpenSim Navigator window and select "**Rename...**" Rename the model to "Wrist Model - Tendon Surgery."
- To return the model to its default pose, click **Poses > Default** in the Coordinates window.

- To view muscle properties, **click** on the *ECU_pre-surgery* muscle name in the Navigator. The muscle parameters will appear in the window below the Navigator.

Note: If the Properties Window is not open, you can open it by going to Window >> Properties in the main menu bar on top of the OpenSim window.

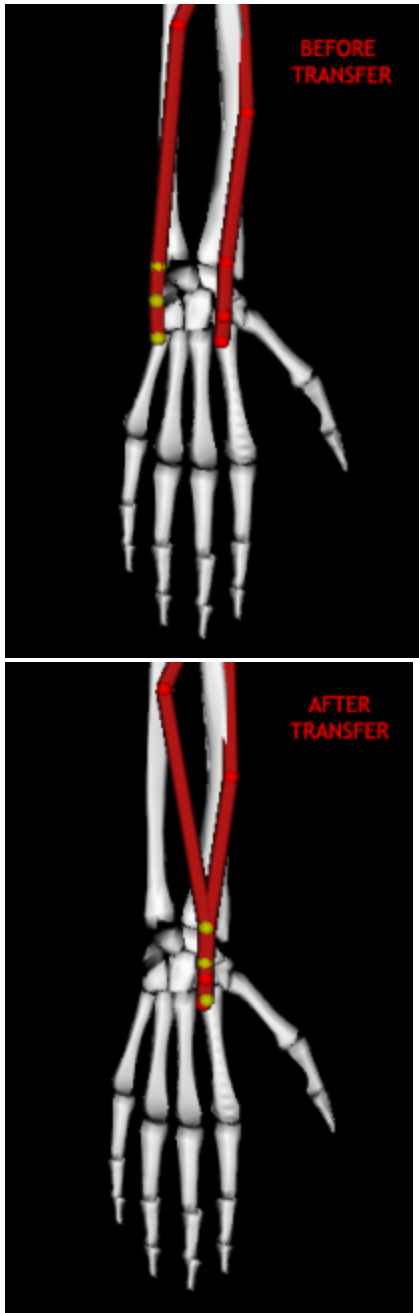
- Zoom in on the wrist joint. Hold down the **ctrl** button and **click** on the insertion muscle point of *ECU_pre-surgery*. Alternatively, muscle points can be selected from the Properties Window by clicking the



next to **GeometryPath** property, and then clicking the check boxes by the appropriate attachment points in the Muscle Editor that appears.

Note: The cursor becomes a crosshair when you press ctrl. Once selected, a muscle point changes to yellow.

- Hold down the **ctrl + shift** buttons simultaneously and **click** on the two muscle points proximal to the insertion point of *ECU_pre-surgery*. All three muscle points should now be yellow and their names (*ECU_pre-surgery-P7*, *ECU_pre-surgery-P6*, *ECU_pre-surgery-P5*) should be displayed at the bottom-left of the GUI.
- To move selected muscle points, **click** and hold the **left mouse** button on one of the selected muscle points, and move the cursor radially toward the *ECRB* muscle path.
Note: You must close the GeometryPath window (opened from the Property Window) before you can move the muscle path with your mouse.
- Align the *ECU_pre-surgery* path with the *ECRB* path, as shown to the right. Rotate the view of wrist model to align the paths in all three directions. For fine-tuning, **de-select** muscle points by using **control-click** to unselect muscle points in the View panel or "**un-checking**" the appropriate checkboxes in the Muscle Editor and edit the location of each point individually.



IV. Biomechanical Effects of Tendon Transfer

To analyze the effects of the surgery, you need a model of the *ECU* muscle both before and after surgery. Although you did a great job moving the muscle points, a muscle with a path similar to the transfer you just completed has already been built into the model.

- To close the current model you just edited, **right-click** on the model in the Navigation window and select **Close**. Alternatively, you can click the **File** menu and select **Close Model**.
- Open the original, unedited wrist.osim model by clicking **File > Open Model**, and opening **wrist.osim**.
- Expand the Forces and Muscles group. Open the *final* muscle group and **double-click** on the muscle titled **ECU_post-surgery**. A muscle path similar to the transfer you completed should appear in the model.

Note: ECU_post-surgery represents the ECU muscle after the simulated tendon transfer surgery.

- Ensure no muscle points are selected and the model is in the neutral (**default**) configuration.

Note: You can return the model to its default configuration by selecting Poses >> Default in the Coordinates window.

Now you will investigate the effect of the transfer on wrist extensor strength by creating plots of the maximum isometric wrist moments before and after the simulated surgery. To see how the surgery will affect wrist extension strength, you will examine maximum wrist extension moments (i.e., the moments generated when all the extensor muscles are maximally excited).

Note: Isometric moments assume zero muscle velocity.

- Open a new plot from the Tools menu, click the **Y-Quantity** button, and select **moment > flexion**.
Note: Do not select elbow_flexion!
- Click the **Muscles** button, and filter the *extensors* group by selecting the **model** option, and then selecting **extensors** from the **group** drop down menu.
- To select all of the muscles in the *extensors* group, click the **select all shown** checkbox.
- To de-select the *ECU_post-surgery* muscle, "un-check" the **ECU_post-surgery** checkbox.
- To plot the sum of all the moments, click the **sum only** checkbox.
Note: Keep the muscle selection window open.
- Click the **X-Quantity** button and select **flexion**.
- Click the **Properties** button and type **Wrist Flexion Moment vs. Flexion Angle** into the textbox under the **Title** tab. Click **OK**.
- Edit the **Curve Name** text to read **Before Transfer**. Then click **Add**.

A curve labeled "Before Transfer" should appear on the plot, which is the sum of the isometric moments generated by all of the *wrist extensors* before the surgery. Do *not* to close this plot, as you will add more curves to compare the strength of the extensors after the transfer.

- In the muscle selection window, **de-select** *ECU_pre-surgery* and **select** *ECU_post-surgery* by clicking the appropriate check boxes.
- Edit the **Curve Name** text box to read **After Transfer**. Then click **Add**.

*Note: To print or save a plot, right-click on the plot and select **Print or Export Image**.*

Questions

5. Is the sign of the extension moment positive or negative?

6. What happens to the maximum moment of the wrist extensors if the *ECU* muscle is transferred to the *ECRB*?

Hint: Remember, one of the goals of the surgery is to increase wrist extension strength.

Now let's examine the effects of the transfer on the deviation strength of the wrist muscles.

- To delete the previous curves, select all the names from the **Curves List** and click **Delete**.
*Note: To select multiple curve names, hold down **ctrl** while selecting.*
- Click **Y-Quantity** and select **moment > deviation**.
- To clear the muscle selection list, click the **deselect all shown** check box.
- Filter the **ulnar deviators** group and click the **select all shown** check box.
- To de-select the *ECU_post-surgery* muscle, "un-check" the **ECU_post-surgery** checkbox.
*Note: Ensure the **sum only** checkbox is still selected and keep the muscle selection window open.*
- Click **X-Quantity** and select **deviation**.
- Edit the plot title to read **Wrist Deviation Moment vs. Deviation Angle**.
- Edit the **Curve Name** text to read **Before Transfer**. Then click **Add**.

Again, a curve labeled "Before Transfer" will appear on the plot, which is the sum of the isometric moments generated by all of the *wrist deviators* before the surgery. Do *not* to close this plot, as you will add more curves to compare the strength of the deviators after the transfer.

- To compare the strength of the ulnar deviators after the transfer, **de-select** *ECU_pre-surgery* and **select** *ECU_post-surgery* by clicking the appropriate check boxes in the muscle selection window.
- Edit the **Curve Name** text box to read **After Transfer**. Then click **Add**.

Questions

7. Is the sign of the ulnar deviation moment positive or negative?
8. What happens to the maximum moment of the ulnar deviators if the ECU muscle is transferred to the ECRB location?
9. One goal of this tendon transfer surgery is to decrease excessive ulnar deviation. Has your simulated surgery achieved this goal?

After answering these questions, close the plotter window.

You are now going to take a more in-depth look at the effects of the tendon transfer on the function of the ECU muscle.

- Open a new plot, and click **Y-Quantity** and select **moment > flexion**.
- Click the **Muscles** button and select **ECU_pre-surgery** and **ECU_post-surgery** from the list.
- Click **X-Quantity** and select **flexion**.
- Edit the plot title to read **Wrist Moment vs. Flexion Angle**, and then click **Add**.
- **Hover** the cursor over a curve on the plot to see a tool tip that gives the coordinates of that particular point on the curve.

Questions

10. What is the peak value of the ECU extension moment before transfer? At what flexion angle does it occur?
Note: Remember, extension moments are negative.
11. What is the peak value of the ECU extension moment after transfer? At what flexion angle does it occur?
12. Does the moment-generating capacity of the ECU vary more with flexion angle before or after the simulated surgery?

Investigate the differences in wrist strength further by creating plots of **tendon force vs. flexion** and **flexion moment arm vs. flexion** for the **ECU_pre-surgery** and **ECU_post-surgery** muscles. *Note: You can open multiple plotter windows simultaneously. When finished, you should have created three plots in three separate plotter windows with two curves each.*

Questions

13. Write down the peak values of each curve (**flexion moment**, **tendon force**, **moment arm**), the joint angle at which the peak occurs, and describe the general shapes of the curves.

OpenSim's Property Editor allows you to examine and edit the muscle parameters used to estimate the force-length curve of this muscle.

- To view the properties of a muscle, **click** on the muscle name in the Navigator. The muscle parameters are visible below the Navigator in the **Properties** window.

Questions

14. What is the optimal fiber length of the ECU_pre-surgery muscle?
15. What is the optimal fiber length of ECU_post-surgery?
16. Calculate the ratio of optimal fiber length to peak moment arm for ECU_pre-surgery and ECU_post-surgery.
17. Explain the differences in the isometric moment vs. wrist flexion angle plots for the ECU_pre-surgery and ECU_post-surgery muscles, based on the plots of force and moment arm and the ratio of optimal fiber length to peak moment arm.
18. Specifically, what does the difference between the ratios of optimal fiber length to moment arm for the ECU before and after the tendon transfer tell you?

After answering these questions, close all of the plotter windows.

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

The previous simulation illustrated how the moment arm and optimal fiber length of a muscle influence its isometric strength and the portion of the force-angle curve over which the muscle operates. Another factor in determining the isometric force vs. joint angle relationship is tendon slack length. Tendon slack length is the length at which the tendon begins to generate force.

- Make three new plots in three separate plotter windows for the *ECRB* muscle: **tendon force vs. flexion, muscle-tendon length vs. flexion, fiber length vs. flexion**.

Note: You can open multiple plotter windows simultaneously. Do not close any of the plots.

- Click on **ECRB** in the Navigator and examine its properties in the **Properties** Window.

Questions

19. What is the tendon slack length of the *ECRB* muscle?

20. What is the optimal fiber length of the *ECRB* muscle?

Now you will examine the effect of changing muscle parameters.

- Edit the **tendon_slack_length** text box to read **0.2105** in the Properties Window..
- To add new curves for the edited *ECRB* muscle, click **Add** in each plotter window.

*Note: It may be helpful to edit each **Curves Name** to read "**ECRB Its = 0.2105 m**" before adding the curves.*

Questions

21. How did changing the tendon slack length of the *ECRB* alter the tendon force vs. flexion angle curve?

22. How did changing the tendon slack length of the *ECRB* alter muscle-tendon length vs. flexion angle curve?

23. How did changing the tendon slack length of the *ECRB* alter the fiber length vs. flexion curve?

24. At what flexion angles do the fiber lengths of the *ECRB* and the edited *ECRB* reach the optimal fiber length? Compare these angles with the peaks of the force vs. flexion plots.

25. Explain the effect of tendon slack length on the force-angle relationship of a muscle based on what you have learned about its effect on fiber length and muscle-tendon length.

Feel free to change the tendon slack length and make more curves to further demonstrate the effects you have seen. For additional information, refer to the references below.

References

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2. Herrmann, A., Delp, S.L. Moment arms and force-generating capacity of the extensor carpi ulnaris after transfer to the extensor carpi radialis brevis. *Journal of Hand Surgery*, vol. 24A, pp. 1083-1090, 1999.
3. Zajac, F.E. Muscle and tendon: properties, models, scaling, and application to biomechanics and motor control. *Critical Reviews Biomedical Engineering*, vol. 17, pp. 359-411, 1989.
4. Delp, S.L. and Zajac, F.E. Force- and moment-generating capacity of lower-limb muscles before and after tendon lengthening. *Clinical Orthopaedics and Related Research*, vol. 284, pp. 247-259, 1992.