



Simulation and Analysis of a Tendon Transfer Surgery

This document and tutorial is a modified version of the online [OpenSim tutorial 2](#) and aims to replicate the findings from the paper by Delp, Ringwelski and Carroll (1994) Transfer of the rectus femoris: effects of transfer site on moment arms about the knee and hip. *J Biomechanics*, 27 (10), 1201-1211.

The tutorial was created by [Hans Kainz](#) for the [ESMAC 2022 seminar](#). Liesel De Block and Lissa Aerts helped creating this tutorial during their internship at the University of Vienna.

I. Objectives

Background

Decreased knee flexion during the swing phase of gait might be caused by over-activity of the rectus femoris muscle in some patients with stroke or cerebral palsy. Limited knee range of motion is often treated by surgically releasing the rectus femoris from the patella and transferring it to one of four sites: semitendinosus, gracilis, sartorius, or the iliotibial tract. The aim of the study by Delp, Ringwelski and Carroll (1994) was to determine if there are differences between these four tendon transfer sites in terms of post-surgical moment arms about the knee and hip joint.

Purpose

The purpose of this tutorial is to demonstrate how musculoskeletal models can be used to study orthopedic surgical techniques and to illustrate how muscle moment arms are affected by a muscle-tendon transfer surgery. In this tutorial, you will:

- Become familiar with the *gait2392_simbody_RF_surgery_tutorial.osim* model and OpenSim's Property Editor
- Simulate a tendon transfer surgery
- Examine the effects of the surgery on knee and hip moments arms
- Use OpenSim to approach an important clinical problem

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 font**. 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 *gait2392_simbody_RF_surgery_tutorial.osim* further on your own.

II. Musculoskeletal Model

In this section you will load a model of the human body and examine its motions. You will then explore four different muscle transfer sites (semitendinosus, gracilis, sartorius, or the iliotibial tract) and its muscle functions.

- Click the **File** menu and select **Open Model**.
- Select the ***gait2392_simbody_RF_surgery_tutorial.osim***, and click **Open**.

Use the Coordinate sliders to investigate the model. In particular, become familiar with knee flexion and extension, hip flexion and extension and hip internal and external rotation. It is important to understand the angle conventions to interpret the plots you will make later in the tutorial.

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

- In the Navigator, expand the **Forces** and **Muscles** headings. Use the buttons to the left of the Navigator (**+** or **-**) to **expand or collapse** the heading.
- To hide all of the muscles in the model, **right-click** on the **all** muscle group heading, then choose **Display > Hide**.
- To show the *knee flexors* group, **right-click** on the **R_knee_bend** heading, then choose **Display > Show**. Now the only muscles displayed should be the knee flexors. To hide the knee flexors, **right-click** on the **R_knee_bend** heading again and select **Display > Hide**. You can see which muscles are in the knee flexors group by **expanding** the list.
- Repeat the same steps to display the *R_knee_ext*, *R_hip_flex*, *R_hip_ext*, *R_hip_inrot* and *R_hip_exrot* muscle groups individually.

*Note: You can go to the **Coordinates** window to change the values of the coordinates.*

Questions

1. Which motion is expressed in the positive angles: knee flexion or knee extension?
2. Which motion is expressed in the positive angles: hip internal or external rotation?
3. What are the functions of the rectus femoris (*rect_fem*) muscle? Check or circle all that apply.
 hip flexion hip extension knee flexion knee extension hip abduction hip adduction
4. What are the functions of the sartorius (*sar*) muscle? Check or circle all that apply.
 hip flexion hip extension knee flexion knee extension hip abduction hip adduction
5. What are the functions of the semitendinosus (*semiten*) muscle? Check or circle all that apply.
 hip flexion hip extension knee flexion knee extension hip abduction hip adduction
6. What are the functions of the gracilis (*grac*) muscle? Check or circle all that apply.
 hip flexion hip extension knee flexion knee extension hip abduction hip adduction

III. Simulation of a tendon transfer

From the paper from Delp, Ringwelski and Carroll (1994):

Excessive knee flexion during the stance phase is one of the most common abnormalities found in people with spastic cerebral palsy (crouch gait). The hamstrings can be lengthened to improve knee extension and reduce excessive knee flexion during the stance phase (Gage et al., 1987; Ray & Ehrlich, 1979; Thometz et al., 1989). However, a common complication of isolated hamstring lengthening is decreased postoperative knee flexion during the swing phase (Baumann et al., 1980), which is often caused by an over-active rectus femoris (Gage et al., 1987; Perry, 1987). The rectus femoris is generally only engaged at the start of the swing phase because it provides a flexion and extension moment around the hip and knee. However, in some patients with spastic cerebral palsy, the rectus femoris has prolonged or continuous activity during the swing phase which restricts knee flexion (Perry, 1987; Sutherland, 1990; Waters, 1979). Transfer of the rectus femoris tendon in conjunction with hamstring lengthening has been proposed to avoid decreased knee flexion after surgery (Perry, 1987).

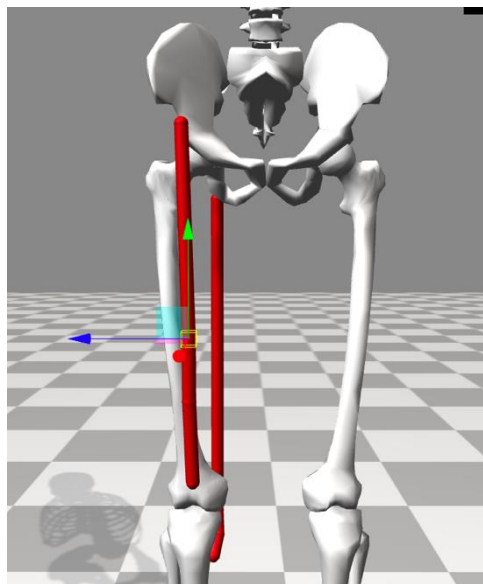
Delp and his colleagues used musculoskeletal modelling and cadaver experiments to assess differences in knee and hip moment arms after different variants of a rectus femoris transfer surgery, (Delp et al., 1994). In this tutorial, we aim to replicate the musculoskeletal modelling part of their study. We will perform virtual surgeries by releasing the rectus femoris from the patella and transferring it to one of four sites: semitendinosus, gracilis, sartorius, or the iliotibial tract. We will then determine if there are any differences between these four tendon transfer sites in terms of post-surgical moment arms about the knee and hip.

In this section of the tutorial, you will transfer the *rectus femoris* tendon to the four tendon transfer sites and evaluate the mechanism by which these tendon transfers affect knee and hip moment arms.

- Display the **Transfer** muscle group only by **right-clicking** its heading and selecting **Display > Show Only**.
- Identify each muscle by using **Display > Show Only** on each. The *rect_fem_r_to_GRA*, *rect_fem_r_to_SAR*, *rect_fem_r_to_ST*, *rect_fem_r_to_IT*, *grac_r*, *sar_r*, *semiten_r* and *tfl_r* muscles paths should now be visible on the model.
Note: rect_fem_r_to_GRA, rect_fem_r_to_SAR, rect_fem_r_to_ST, rect_fem_r_to_IT all represent the *rectus femoris* muscle before the simulated tendon transfer surgeries. Hence, all these muscles are identical.

To simulate the surgery, you will edit the paths of the muscles (*rect_fem_r(to_GRA, to_SAR, to_ST, to_IT)*) in the visualizer window. Each end of a muscle-tendon complex connects to a bone. In this model, the most proximal connection is the *origin*, and the most distal connection is the *insertion point*. You will first select the insertion point of the rectus femoris (*rect_fem_r_to_ST*) muscle and move its location to the first tendon transfer site: semitendinosus (*semiten_r*). Then you will perform a similar operation for the other transfer sites: gracilis (*grac_r*), sartorius (*sar_r*), and iliotibial tract (*tfl_r*). All muscle via points are graphically represented as small red spheres on the muscle path, and coincide with the “kinks” in the muscle path.

- Before editing the model, go to the **File** menu and select **Save Model As...** . Save the current model as **RectusFemoris_TendonSurgery.osim**.
- Once you have done this, **right-click** on the **3DGaitModel2392TendonTransferRectusFemoris** name in the OpenSim Navigator Window and select "**Rename...**" . Rename the model to "RectusFemoris_Model_TendonSurgery".
- To return the model to its default pose, click **Poses > Default** in the Coordinates Window.
- To view muscle properties, **click** on **rect_fem_r** 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.
- Before starting the simulated surgery, make sure you can see the muscles from the **Transfer** muscle groups. Then, zoom in on the knee joint. Visualize only the matching muscles (for example: *rect_fem_r_to_ST* and *semiten_r*). **Click** the insertion muscle point of the *rect_fem_r_to_ST* and move it to the insertion of the *semiten_r* muscle. *Note: Once selected, a yellow box will appear around the muscle points. Its name (MovingPathPoint: *rect_fem_r-P1*, *rect_fem_r-P2_0*, and *rect_fem_r-P3*) should be displayed at the bottom-left of the GUI.*
- To move the selected muscle points, use the red, blue, and green arrows that appear on muscle selection to adjust the muscle point's location along a single axis.



- Your goal is to align the *rect_fem_r_to_ST* path with the *semiten_r* path.
- Repeat this process for the three remaining transfer sites: gracilis, sartorius, and iliotibial tract (*grac_r*, *sar_r*, *tfl_r*).
Note: We use the TFL muscle to approximate the location of the iliotibial tract.

IV. Biomechanical Effects of Tendon Transfer

To analyze the effects of the surgery, you need a model of the Rectus Femoris muscle both before and after surgery. Although you did a great job moving the muscle points, a muscle path like the transfer you just completed has already been added to 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 *gait2392_simbody_RF_surgery_tutorial.osim* model by clicking **File > Open Model**, and opening ***gait2392_simbody_RF_surgery_tutorial.osim***.
- Expand the Forces and Muscles group. Open the **RF_post-surgery** group, by **right-clicking** its heading and selecting **Display > Show Only**. The muscle paths similar to the transfer you completed should appear in the model. *Note: RF_toSTsurgery, RF_toGRAsurgery, RF_toSARsurgery and RF_toITsurgery represent the rectus femoris muscle after the simulated tendon transfer surgery to the semitendinosus, gracilis, sartorius muscle and iliotibial tract, respectively.*
- 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** tab.*

Now you will investigate the effect of the transfer on knee flexion moment arm by creating plots of the (peak) knee flexion moment arms after transfer to semitendinosus, gracilis, sartorius, and iliotibial tract. To see how the surgeries affected knee flexion moment arms, you will examine peak knee flexion moment arms (i.e., the maximal perpendicular distance to the joint centre).

- Open a new plot from the Tools menu. Click the **Properties** button and type **knee flexion moment arm vs knee flexion angle** into the Textbox under the **Title** tab. Click **OK**. Click the **Y-quantity** button, and select **moment arm > knee_angle_r**.
- Filter the muscles list by model and *R_knee_ext* or *R_hip_flex* group. Select the following muscle: *rect_fem_r*.
- Click the **X-Quantity** button and select ***knee_angle_r***.
- Edit the **Curve Name** text to read **Before Surgery**.
- Then click **Add**.

A curve labeled "Before Transfer" should appear on the plot, which is the knee flexion moment arm of the rectus femoris before the tendon transfer.

Now you will add four curves to compare the knee flexion moment arm between the transfer to the four different sites.

- In the muscle selection window, **deselect** *rect_fem_r* and **select** the **RF_post_surgery** group (*RF_toGRAsurgery, RF_toSTsurgery, RF_toSARsurgery* and *RF_toITsurgery*). Then click **Add**.

Now let's examine the effects of the four transfers on the knee flexion moment arms of the rectus femoris muscle.

Questions

7. *In these plots, given how the model defines the knee flexion degree of freedom, is knee extension angle denoted by positive or negative values?*
8. *What happens to the maximum knee flexion moment arm of the rectus femoris muscle if this muscle is transferred to the gracilis site?*
9. *Which muscle site has the highest knee flexion moment arm: the gracilis site, the sartorius site, the semitendinosus site or the iliotibial tract?*
10. *One goal of this tendon transfer surgery is to increase knee flexion. Have all the simulated surgeries achieved this goal?*
11. *Are our results in agreement with the findings from by Delp, Ringwelski and Carroll (1994)?*
12. *Do you think our model or analysis include limitations?*

References

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