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Mimics Innovation Suite Training – Part 2

The Hospital for Sick Children

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Notices

This training handout is designed to kick start the hands-on practice of the Mimics Innovation Suite software. As such, this handout is not designed to be a substitute for the Mimics or 3-matic manuals or the training provided by Materialise. This training handout makes use of different MIS modules in different tasks, some which cannot be completed without the relevant module(s).

Note: This familiarization-training does assume the user is familiar with Windows usage and terminology.

I hear and I forget

I see and I remember

I do and I understand

Confucius

Regulatory Information:

The Medical edition of the Mimics Innovation Suite currently consists of the following medical device software components: Mimics Medical version 18.0 and 3-matic Medical version 10.0 (released 2015). Mimics Medical is intended for use as a software interface and image segmentation system for the transfer of imaging information from a medical scanner such as a CT scanner or a Magnetic Resonance Imaging scanner. It is also used as pre-operative software for simulating/evaluating surgical treatment options. 3-matic Medical is intended for use as software for computer-assisted design and manufacturing of medical exo- and endo-prostheses, patient-specific medical and dental/orthodontic accessories and dental restorations.

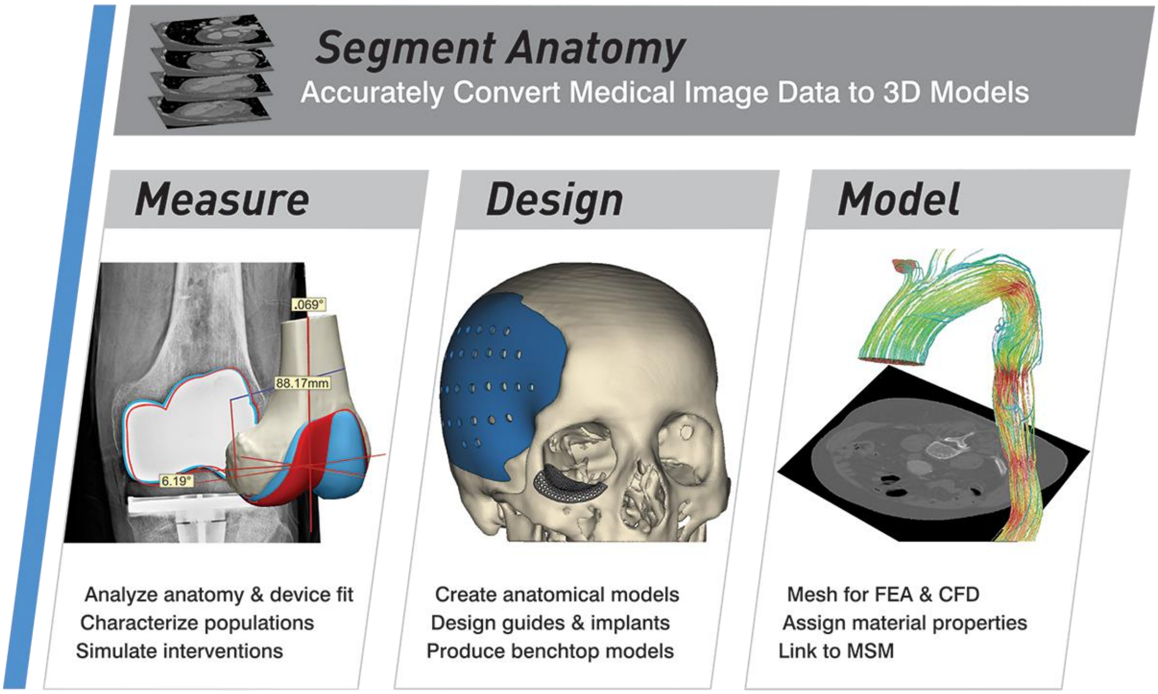
The Research edition of the Mimics Innovation Suite currently consists of the following software components: Mimics Research version 18.0 and 3-matic Research version 10.0 (released 2015). Mimics Research is intended only for research purposes. It is intended as a software interface and image segmentation system for the transfer of imaging information from a variety of imaging sources to an output file. It is also used as software for simulating, measuring and modeling in the field of biomedical research. Mimics Research must not be used, and is not intended to be used, for any medical purpose whatsoever. 3-matic Research is intended for use as a software for computer assisted design and engineering in the field of biomedical research. 3-matic Research must not be used, and is not intended to be used, for the design or manufacturing of medical devices of any kind.

This training guide includes the following exercises: L-10514,L-10515, L-10516, OC001, CV005, OC003, OC005, L-10518, OC013, CV027, L-10522, L-10324-02, OC019, OC016, CV022, OC021, CV015, CV016, OC007, L-10519, OC008

Contents

Mimics® Innovation Suite

The Mimics Innovation Suite is a complete set of tools developed to support biomedical professionals in performing a multitude of engineering operations starting from medical image data.



The Mimics Innovation Suite consists of several complementary products and services:

- ***Mimics® (Medical and Research)***
  - Software for medical image segmentation and 3D model creation
- ***3-matic® (Medical and Research)***
  - Software that combines CAD tools with meshing capabilities for anatomical data
- ***Engineering services***
  - Skilled engineers who help you realize your biomedical engineering projects
- ***3D-printed anatomical model services***
  - Tangible, accurate and realistic models, produced through Additive Manufacturing

"SOFTWARE IS WHAT WE DEVELOP, SOLUTIONS ARE WHAT WE PROVIDE."

Koen Engelborghs, Director Biomedical Engineering, Materialise

Mimics®

Materialise's **I**nteractive **M**edical **I**mage **C**ontrol **S**ystem (MIMICS) is an image-processing package that provides an interface between 2D image data (CT, MRI, Technical scanner, 3D ultrasound, etc.) and 3D engineering applications. Some applications include anatomical measurements & 3D analysis, Finite Element Analysis (FEA), patient-specific implant or device design, Additive Manufacturing (also called rapid prototyping or 3D Printing) and surgical planning or simulation. Mimics is widely used by academic and commercial researchers in the orthopaedic, CMF and cardiovascular industries.

By performing image segmentation in Mimics, users can specify regions and tissues of interest within the image data and use it to calculate accurate 3D surface models.

Additional modules are available for Mimics that provide an interface with different applications. In other words, Mimics can easily be adapted to the individual needs of each user.

Furthermore, the Mimics Innovation Suite includes 3-matic® which is used for 3D analysis, design, and FEA/CFD preprocessing of anatomical models. As such, 3-matic significantly extends the possibilities of Mimics into the field of biomedical engineering.

The software comes in two editions: Research and Medical. Only the Medical edition may be used for treating and diagnosing patients, planning surgeries and interventions, and rehearsing operations. The Research edition is intended for research only and is not approved for clinical use. Usage of the software signifies your acceptance of the above.

3-matic®

3-matic® 10.0 is a unique software that combines CAD tools with pre-processing (meshing) capabilities. More specifically, it works on triangulated (STL) files and as such it is extremely suitable for organic/freeform 3D data, like the anatomical data coming from the segmentation of medical images (from Mimics). We call it Anatomical CAD.

Import your anatomical data in 3-matic Medical to start performing Engineering on Anatomy including, among other actions, thorough 3D measurements and analyses, design an implant or surgical guide, or prepare the mesh for finite element modeling.

Since 3-matic can import CAD data, as well as drive reverse engineering of anatomical data to CAD data, it is perfectly complementary to your CAD package.

The software comes in two editions: Research and Medical. Only the Medical edition of 3-matic may be used for the design or manufacturing of medical devices of any kind. The Research edition is intended for research only. 3-matic Research must not be used, and is not intended to be used, for the design or manufacturing of medical devices of any kind. Usage of the software signifies your acceptance of the above.

Key advantages of the Mimics Innovation Suite:

- The software is intuitive and easy to learn
- Fast segmentation tools (threshold and contour based) and accurate 3D calculation are available so that detailed 3D models can be achieved quickly and easily
- The Mimics Innovation Suite is continuously improved based on market requirements and has one major release per year
- When Mimics is used in combination with 3-matic, users can perform meshing and design operations directly on STL files without the need for anatomical reverse engineering. This option, in turn, allows users to:
    - improve implants by using anatomical data
    - design patient-specific implants or surgical guides
- The software is developed by Materialise, a worldwide leader in innovative software and additive manufacturing technology
- Easy creation of your custom implants
- Heightened understanding of orthopedic structures with the help of analysis color mapping
- Streamlined mesh optimization workflow for creating complex assemblies
- Easily fix and prepare models for 3D Printing

Segmentation

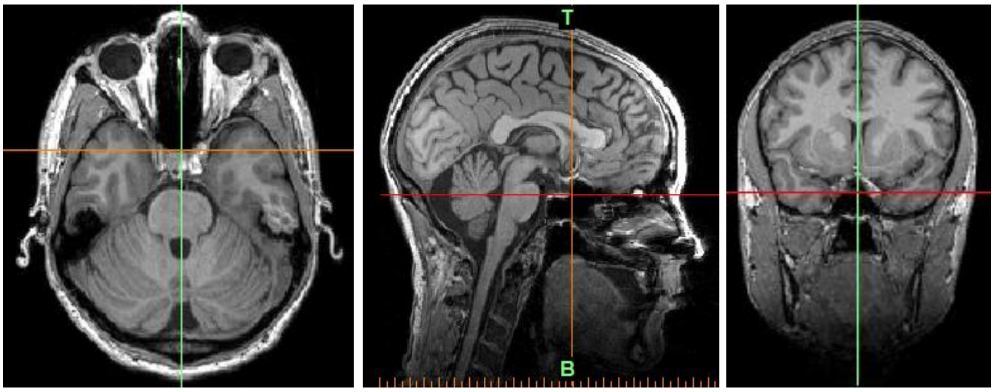
Exercise 1. Segmentation of the Brain using Dynamic Region Growing

For advanced segmentation, Mimics provides several tools according to specific applications. For instance, the Dynamic Region Growing tool, which combines the functionalities of the Region Growing tool and the Thresholding segmentation, can be used to create masks more rapidly and efficiently in cases where the range of gray values remains consistent across the tissue and through the image slices. In the case of vasculature (e.g., arteries), where gray values are consistent, Dynamic Region Growing is an ideal tool to use. Another area where this tool works well is within the brain, as revealed in the following exercise.

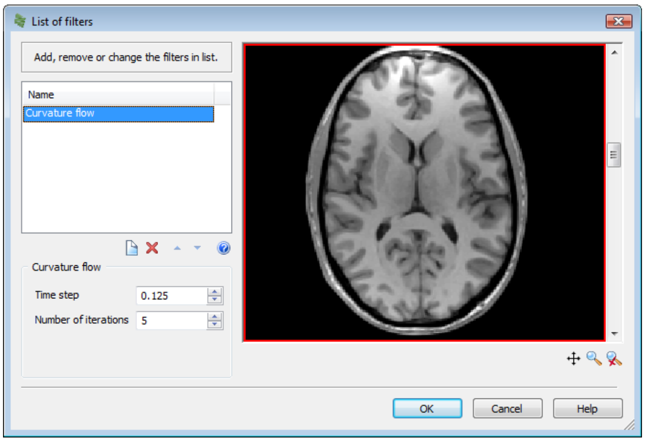
The purpose of this exercise is to look at alternative segmentation tools that make it possible to extract a clean model of the brain. The brain in this case can be extracted rather easily using Dynamic Region Growing with a few seed points. The following tasks rely on Morphological Operations to reduce the noise of connected surrounding tissue around the brain.

Task 1. Filter the Images

1. From the File menu, **Open** the project named “BrainMR.mcs”. This project is a T1-weighted MR of the brain.



2. Apply an image filter to the dataset. First, select the **Apply Filter** tool from the Image menu**.** Then, select the New Filter icon and add Curvature Flow to the list. The Curvature flow filter performs an edge-preserving smoothing effect on the images and helps to reduce some of the artifact seen in the Brain MR. Compare the effects of the different image filters and click *Apply*.



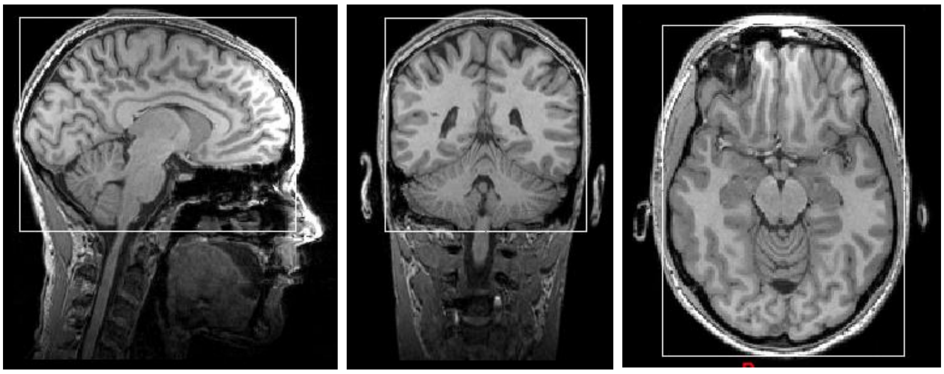
Note: A filter that gives a nice result for this dataset is the Curvature Flow, with a time step of 0.125 and five iterations.

Task 2. Dynamic Region Growing to Mask the Brain

1. Before starting the segmentation process, toggle the **Mask 3D Preview** tool ON. The Mask 3D Preview tool is found in the vertical menu next to the 3D Window and will generate a rendering of the mask's current state during each step of the segmentation process to serve as a guide through the workflow.

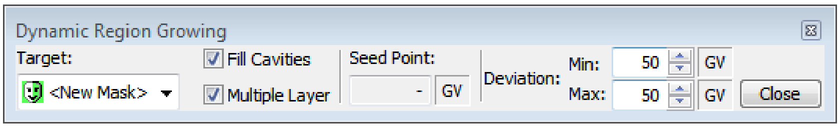
2. Open the **Dynamic Region Growing** tool from the Segment menu. Reposition the white crop box around the brain in each of the three anatomical views.

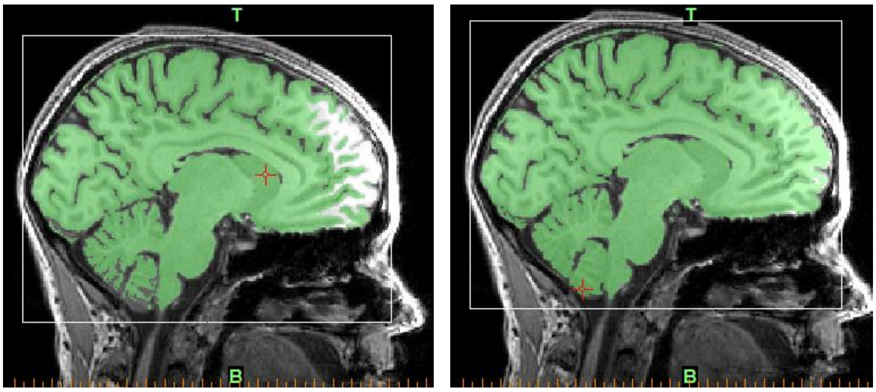
   For example, the crop box should be set just below the cerebellum in the sagittal view. Be careful not to set the crop box too small, as this may result in cropping parts of the brain that should not be removed.



   Within the **Dynamic Region Growing** interface**,** set the Min and Max deviation to 50 GV. The Fill Cavities and Multiple Layer options should also be checked ON. Next, hold down the Control (Ctrl) key on the keyboard and select multiple seed points within the brain. Upon doing so, more pixels within the brain will be selected and added to the new mask. It is important to scroll through the slices to make sure all areas of the brain are selected.

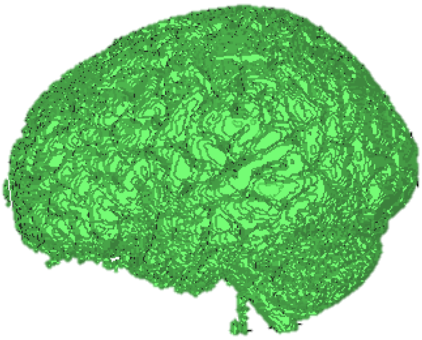
   For example, there is an artifact in the anterior portion of the frontal lobe that is causing the tissue to appear as bright white. Use additional seed points to ensure that these areas are also included in the mask.



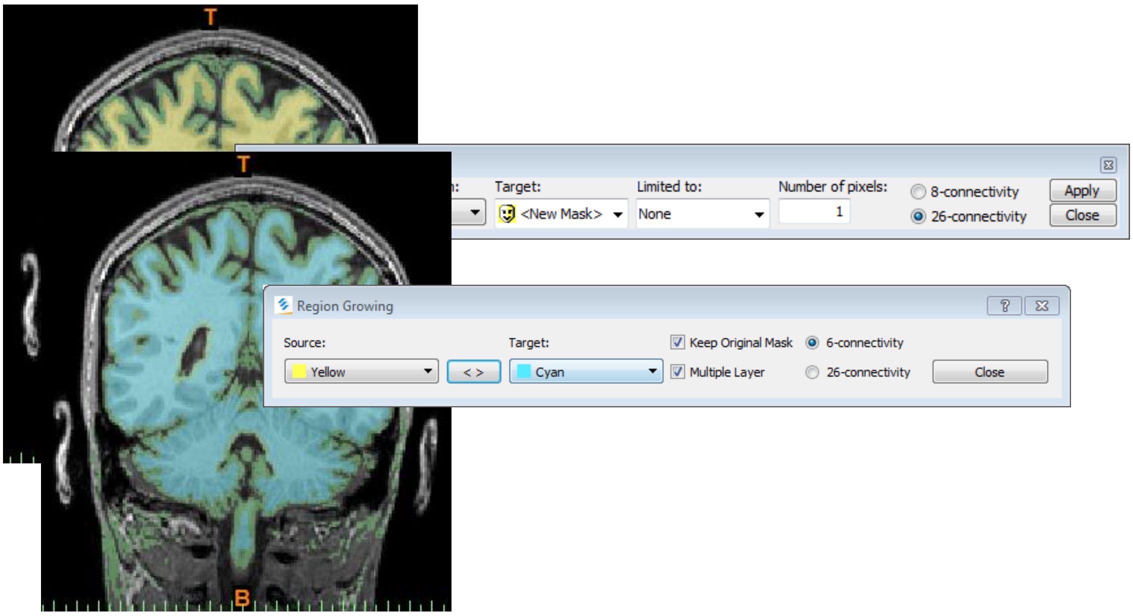


Before & After: Notice how the white artifact has been filled in with additional seed points.

3. As more seed points are added, notice how the Mask 3D Preview continues to update. This will aid in selecting points and giving an indication of how the finished 3D model will look. Don’t worry if some additional tissue (besides the brain) is included. This will be addressed in the coming steps.

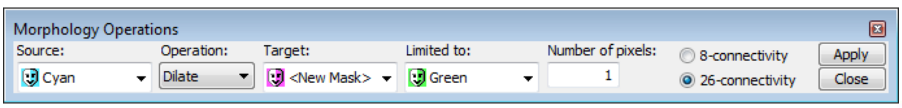


4. It is likely that tissues other than the brain may have also been selected during the Dynamic Region Grow step. From the Segment menu, select the **Morphology Operations** tool. Erode the brain mask (green) by 1 pixel with 26-connectivity selected. Doing so will shrink the boarders of the mask by 1 pixel.



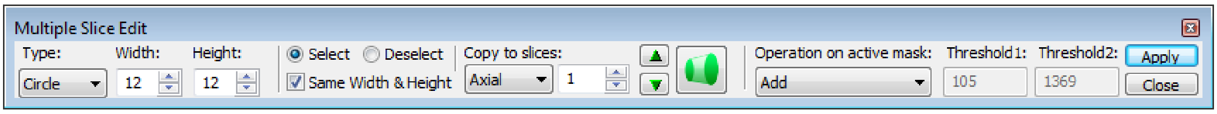
5. Now, use the **Region Growing** tool from the Segment menu to remove any pieces of the mask that have been disconnected from the brain. The result will be a new mask that should remove any areas outside of the brain that were selected during the Dynamic Region Growing process.

6. The mask now has to be dilated back up by 1 pixel to compensate for the erosion in earlier steps. From the Segment menu, select the **Morphology Operations** tool again. This time, Dilate the new brain mask (cyan) by 1 pixel with 26-connectivity. The mask should be Limited to the original green mask that was used to Dynamic Region Grow the brain originally.



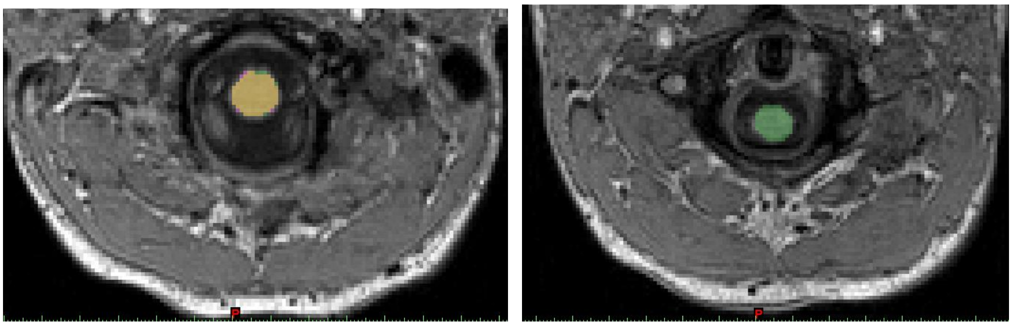
7. The spinal cord is not included in the new fuchsia brain mask because it was cropped out at the beginning of this exercise during the initial Dynamic Region Growing step. The crop box could have been set larger initially, but it is likely that more unwanted pixels would have been added to the mask. Instead, use the **Multiple Slice Edit** tool from the Segment menu to quickly add the spinal cord back into the mask via an interpolation algorithm.

   From the **Multiple Slice Edit** interface, be sure that the Type is set to Circle, the Copy to Slices is set to Axial, and the Operation on active mask is Add. Height and Width will be adjusted during the editing steps.



   From the axial view, scroll down until the last slice where the spinal cord is still masked. This will be the first slice for input into the Multiple Slice Edit operation to ensure there is no gap between the brain and the spinal cord. Using the cursor, fill in the spinal cord fully. Then, scroll downward 3-4 slices and fill in the spinal cord again. Repeat this process until the spinal cord has been marked in about 5 slices total. Change the height and width of the circle cursor as needed to accurately fill in the spinal cord.

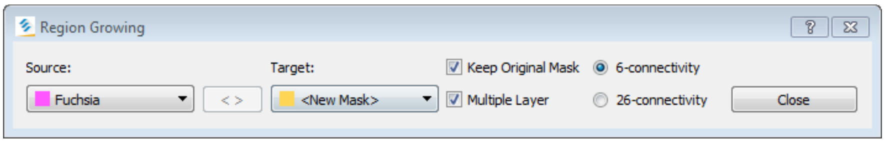
   Below are a few images where the spinal cord has been marked:



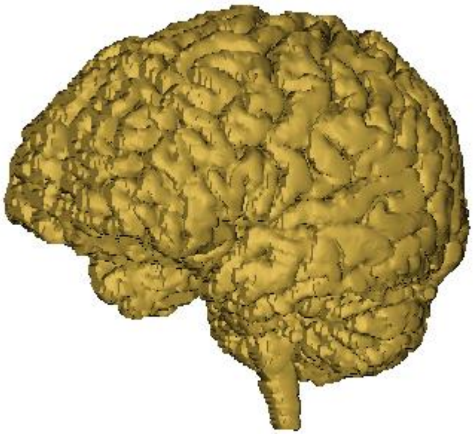
   Once the ~5 slices are marked, select the Interpolate button in the middle of the **Multiple Slice Edit** menu to fill in the mask of the spinal cord on all of the 'in between slices'. Scroll upwards to make sure all slices have been added.

Once added, hit *Apply* to complete the **Multiple Slice Edit** operation.

8.  Lastly, use the **Region Growing** tool from the Segment menu one more time to remove any disconnected or unwanted pixels.

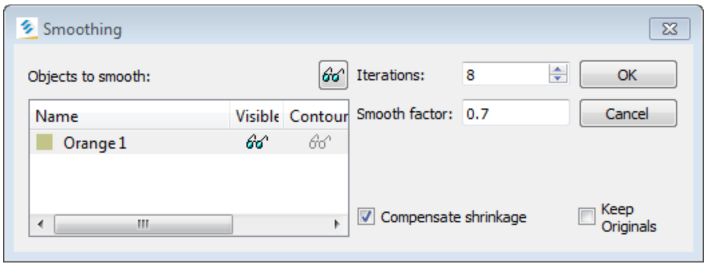


9.  From the Segment menu, choose the **Calculate 3D** tool. Calculate a 3D model of the brain on Optimal quality. The result should look similar to the model below:

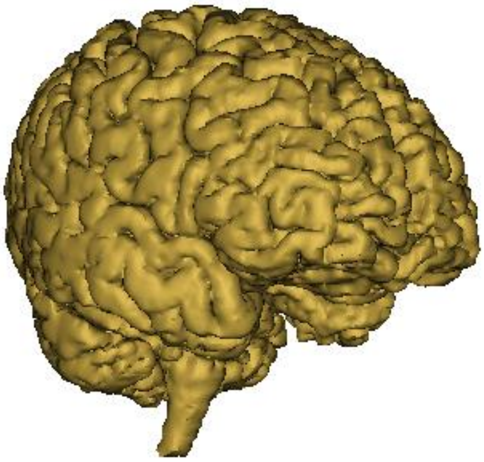


Note: For this first time, the brain is now and STL instead of a mask 3D preview.

10.  The brain model can be further post processed to give a cleaner look. From the 3D Tools menu, select the **Smoothing** tool. Smooth the brain model according to the parameters in the image below. Compensate shrinkage will ensure that total volume is not lost during the smoothing.



11. The final brain model should look like this:



Design

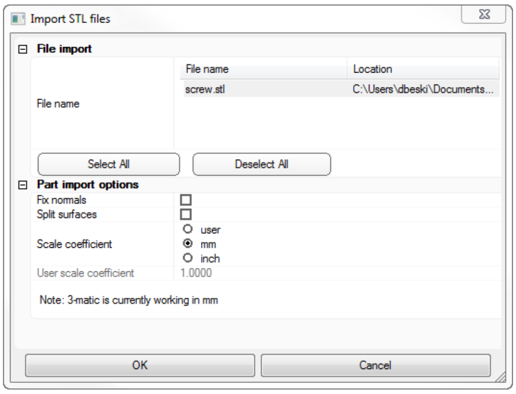
Exercise 1A. Designing a Patient-specific Hand Fracture Plate – Using 3D Tools

The following exercises cover two workflows for designing a patient-specific fracture plate in the hand. The first workflow focuses on designing a plate based on the position of screws in 3D. The second workflow focuses on plate design via sketching. This exercise will help in understanding workflows that are part of a design process. The image below shows the two plates that will be created at the end of this exercise:

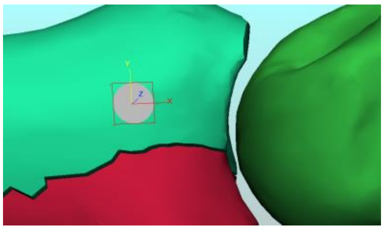
Task 1. Positioning the Screws

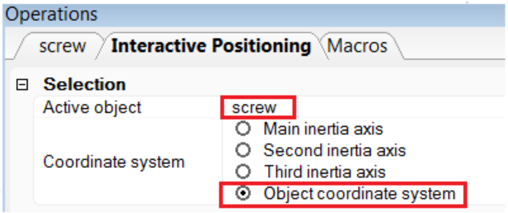
1. From 3-matic, open the “hand.mxp” file from the training folder using **Open Project** in the File menu.

2. Next, import the screw.stl with **Import Part**, which is also located in the File menu.

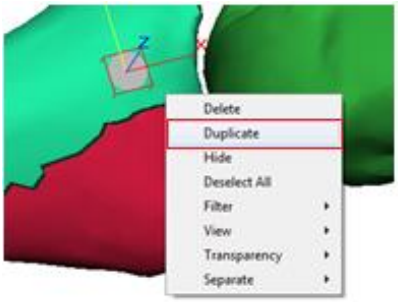


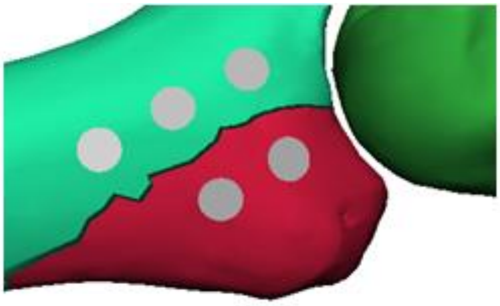
3. From the Align menu, use the **Interactive Positioning** tool to place the screw properly on the bone. The screw should be selected as the Active Object, with the Object Coordinate System option chosen. Hold and drag the left mouse button for a few seconds to see the screw update to the new position.



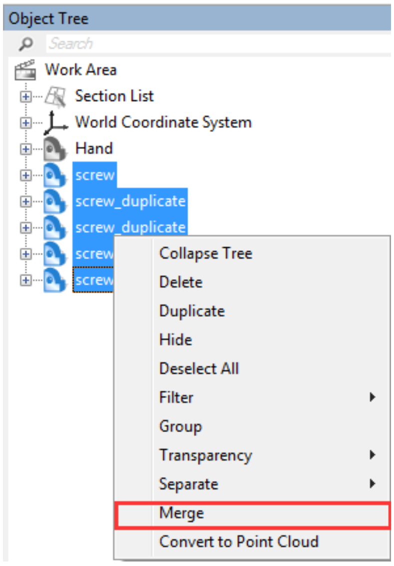


4. The screw should be duplicated a total of four times to match the positions on the image below. Right-click on the screw (either in 3D or in the Object Tree) and select Duplicate. All duplicated screws should be “Interactively Positioned”.

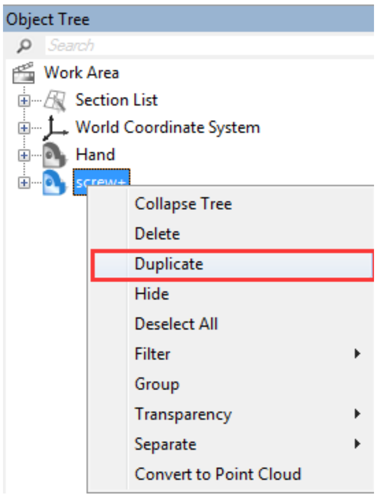




5. Once positioned, **Merge** all five screws together. To merge, select all screws in the Object Tree and right click. Merge will appear as an option.



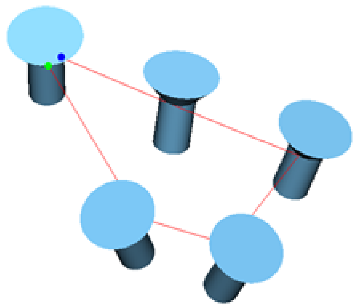
6. Lastly, **Duplicate** the set of screws by selecting the screws and right-clicking *Duplicate*. The duplicate screws will be used in an operation later on in the exercise and, therefore, can be hidden for the moment.

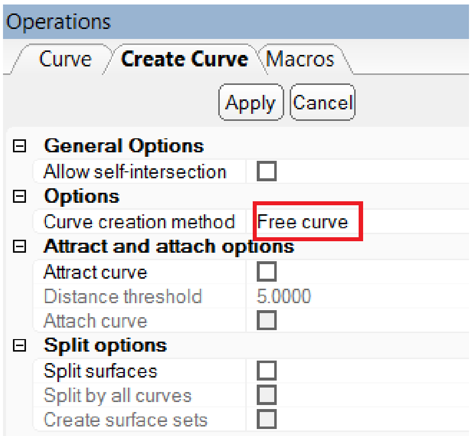


Task 2. Creating the Internal Plate Structure

1. From the Curve menu, select the **Create Curve** operation. Select the Free Curve option as the Curve Creation Method.

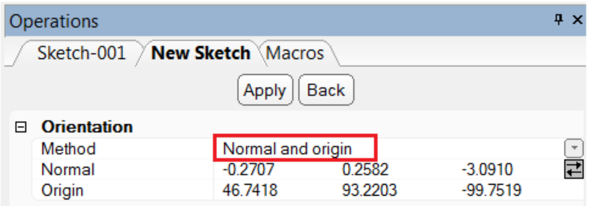
Hide the hand so only the screws are visible. This operation works best when the curve is connected to the sides of the screws. Do NOT close the curve. A sweep operation does not work on a path that is a closed curve.

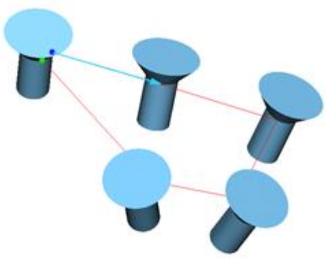


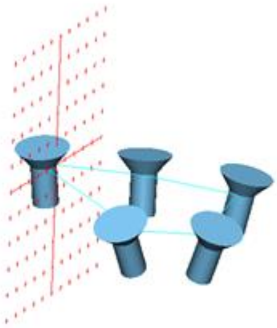


2. Create a **New Sketch** from the Sketch menu. Apply the Normal and Origin methods. Select the first segment of the free curve as the normal direction. The origin will automatically be register as the first point of the curve.

Check the Filter options (F3) if you are unable to select the first curve for the normal direction.

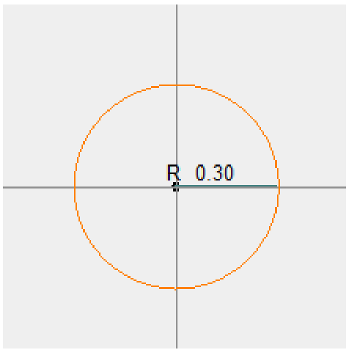




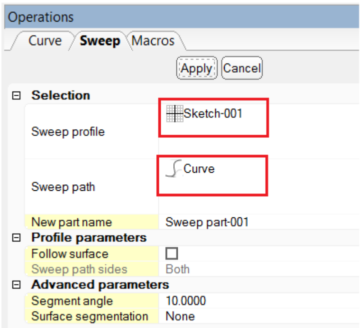


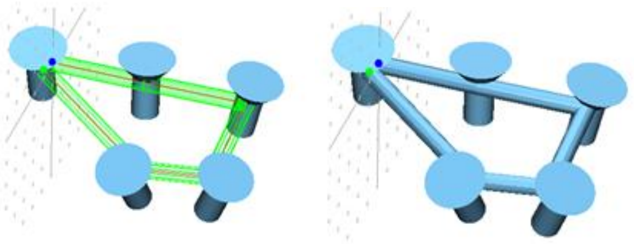
3. Once the sketch is created, open the ‘sketch’ view tab. Create a “Circle” in the origin of the sketch. All of the sketching tools are located in the Sketch menu.

4. After creating the circle, select the **Set Radius** tool and constrain the circle to 0.3 mm.

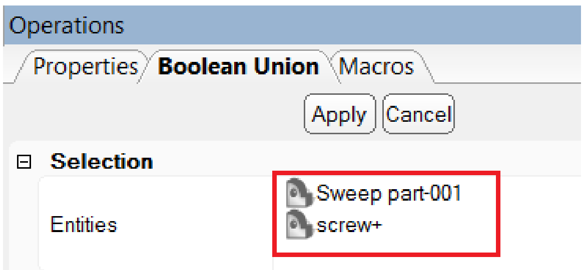


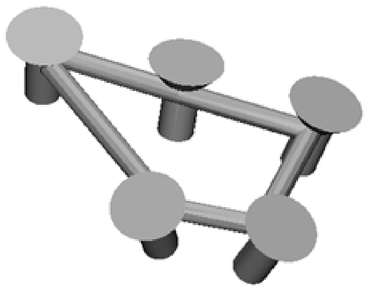
5.  The curve and the sketch will be the inputs for the sweep operation. Go back in the 3D Work Area. From the Design menu, select the **Sweep** tool.





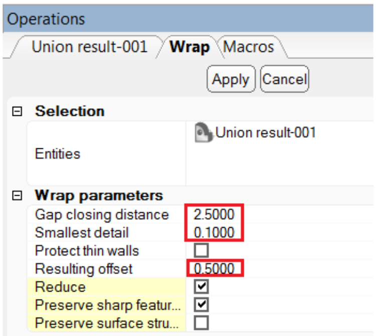
6.  Now, use the **Boolean Union** tool from the Design menu to combine the swept part and the screws together.

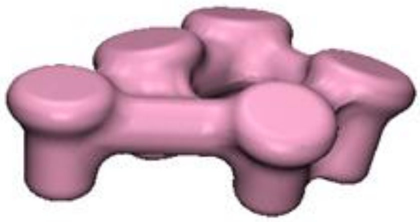


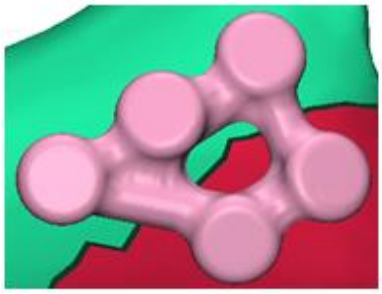


Task 3. Creating the Plate with Thickness

1.  From the Design menu, select the **Wrap** tool. Wrap the Union Result (screws & swept parts) with a Gap Closing Distance of 2.5 mm, a Smallest Detail of 0.1 mm, and a Resulting offset of 0.5 mm. Once wrapped, rename the part to “Hand_Plate”.

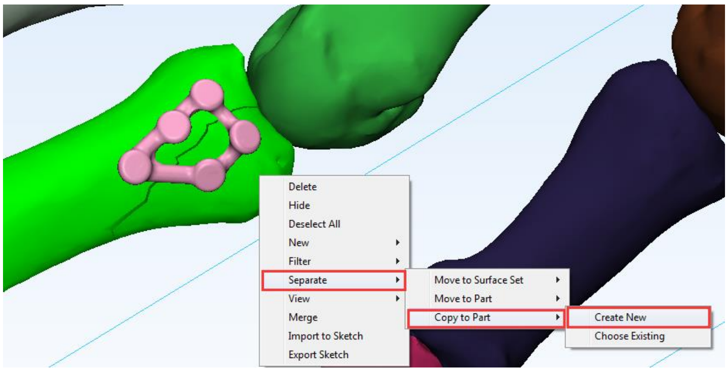




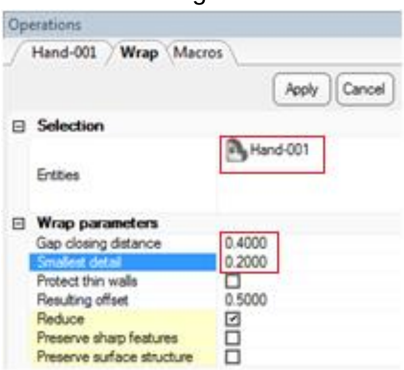


2. Before wrapping the fractured bone, it is necessary to separate this specific bone into its own part. The smaller part is easier to work with and allows for wrapping on a localized level. The new part will be the input of the 'Wrap' operation.

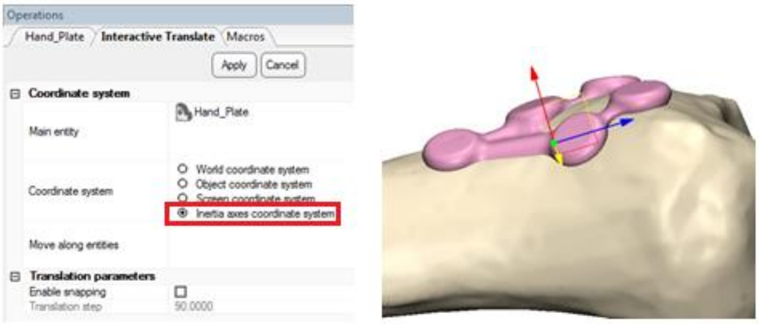
   Show the Hand model from the Object Tree. From the 3D view, select the two surfaces simultaneously by holding the Ctrl key. Next, right-click and chose **Separate → Copy to Part → Create New**.



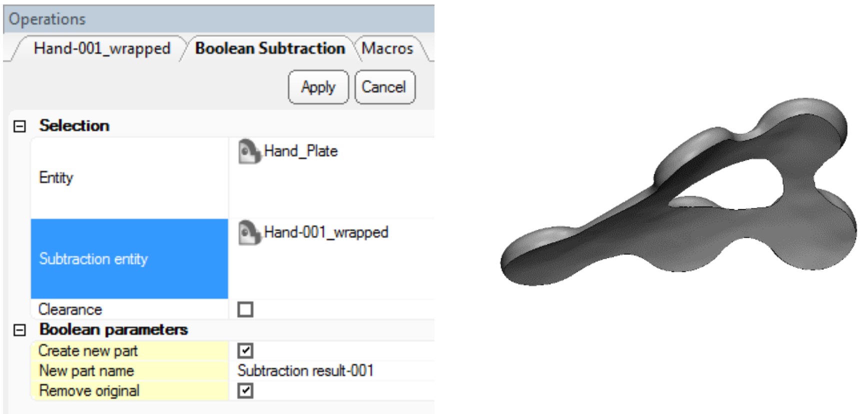
3. From the Design menu, select the **Wrap** tool. This time, set the Gap Closing Distance to 0.4 mm and the Smallest Detail to 0.2 mm. Choose *Apply* and, as a result, a part named "Hand-001_wrapped" will be created. Hide "Hand-001". This time, toggle OFF Preserve sharp features since our goal is to close the fracture for design purposes.



4. Before subtracting the bone from the wrapped plate, it is necessary to translate the plate lower into the bone to make it thinner. From the Align menu, select the **Interactive Translate** tool. Be sure to select the Inertia axes coordinate system.



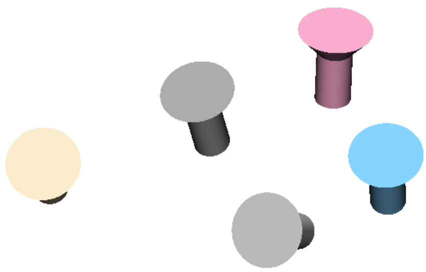
5.  Now, use the **Boolean Subtraction** tool from the Design menu to subtract the wrapped bone part from the hand plate.



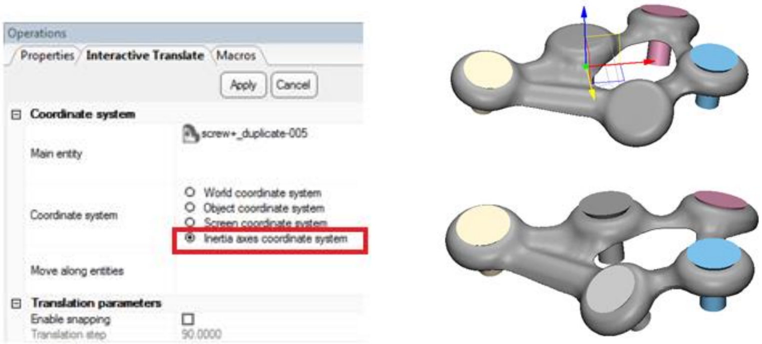
Task 4. Fitting the Screws

The Duplicated Screws (from the beginning of this exercise) will be used to fit the screws to the plate. First hide the other parts and then show the duplicated screws.

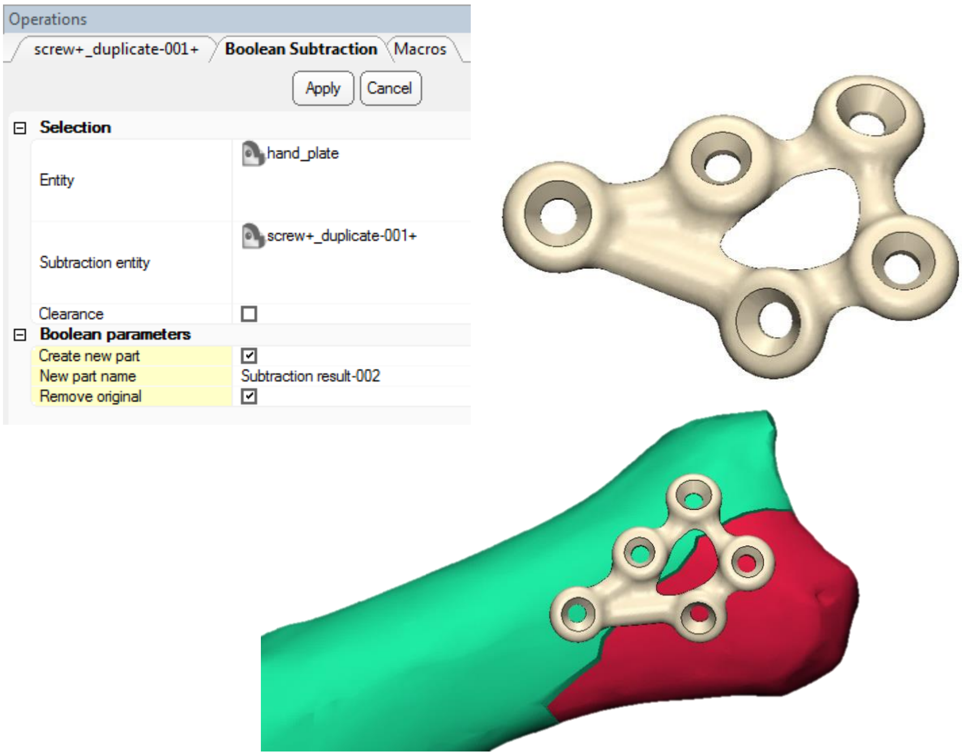
1.  First, the merged screws should be separated into their own parts. In the Surface menu, select the “screws_duplicated” part from the Object Tree and choose the **Shells to Parts** tool. Doing so will create five separate screws in the Object Tree.



2.  Each screw should be moved upwards with respect to its Inertia Coordinate System. From the Align menu, select the **Interactive Translate** operation. Move the screw upwards until the head of it appears. After translating all the screws, **Merge** them back together.



3. Perform a **Boolean Subtraction** via the Design menu to create screw holes in the plate.



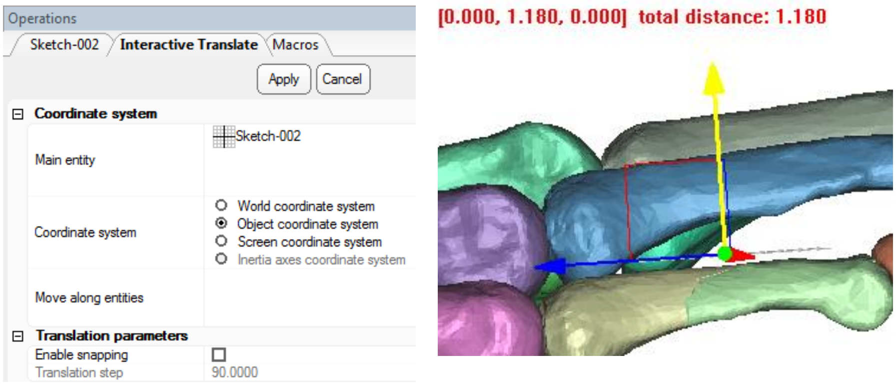
Exercise 1B. Designing a Patient-specific Hand Fracture Plate – Using a Sketch Plane

For this method, a hand plate will be designed for the fracture depicted in the figure below. Sketching is the basis for this plate creation workflow.

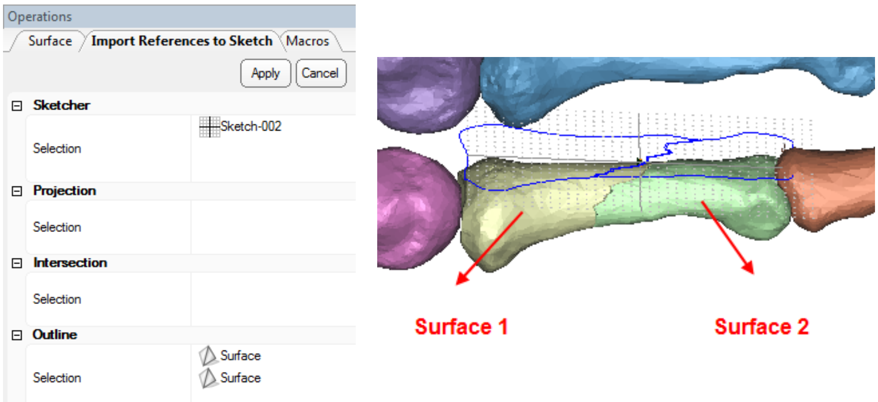
Task 1. Creating a Sketch

1. From the Sketch menu, **Create New Sketch** with the Through 1 point, parallel to a plane Method. Select a point upon the bone to update the coordinates and select the ZX plane from the hand model itself.

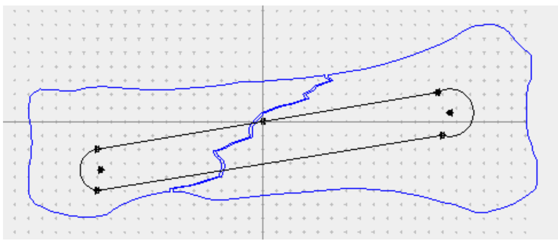
2.  Use the **Interactive Translate** from the Align menu to move the sketch higher in space so there is no intersection with the bone.



3.  In the Sketch menu, choose **Import References**. Import the Outline of the two surfaces that surround the fracture.

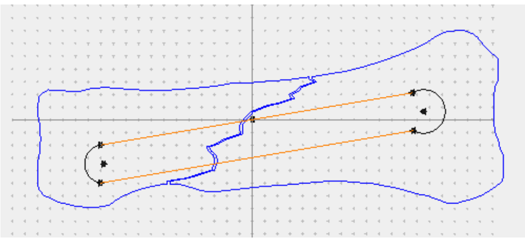


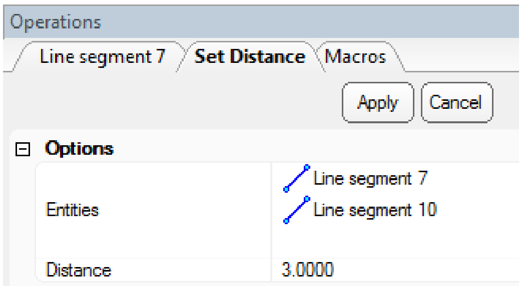
4.   Using the sketching tools in the Sketch menu, start creating the profile for the fracture plate. “Create Line” will allow for straight lines and “Circle Arc” will allow for the ends to be capped.



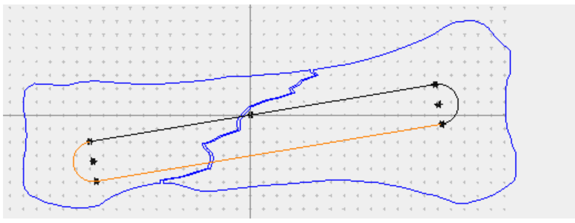
materialise
innovators you can count on

5.  Use the **Add Constraint** tools in the Sketch menu to finalize the profile of the plate. For example, select the two lines and make them parallel. Subsequently, update the Set Distance to 3 mm.





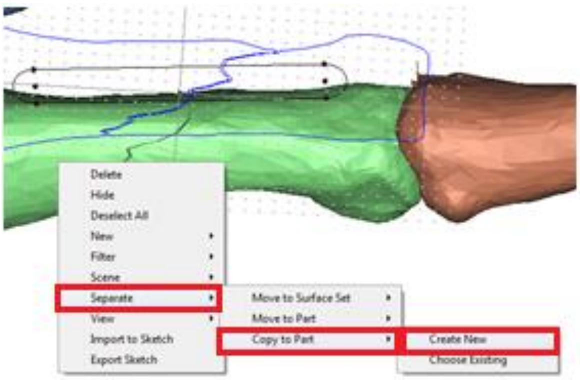
6.  Lastly, select one line and a circle arc to make sure they are “Tangent”. Repeat this for every line.



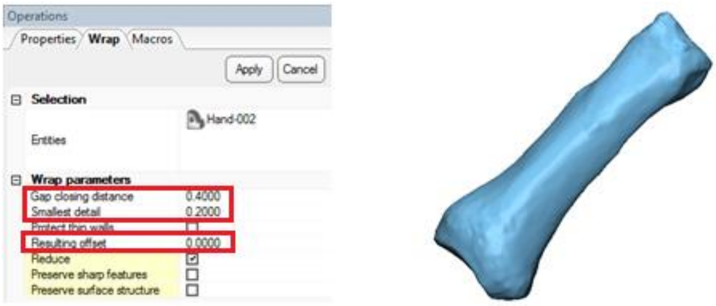
Task 2. Projecting the Sketch

The sketch will now be used to project a curve onto the bone in 3D. Just as with the first plate, it is necessary to create a new part from each half of the fracture and wrap it to ensure that the projection and design is being done on an intact part.

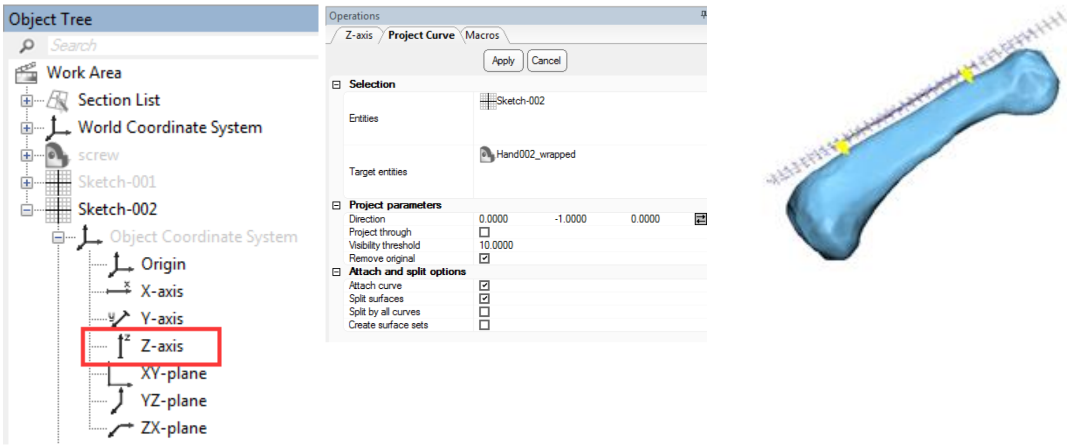
1. Show the Hand model from the Object Tree. From the 3D view, select the two surfaces simultaneously by holding the Ctrl key. Next, right-click and choose **Separate → Copy to Part → Create New**.



2.  Now, **Wrap** the new part via the Design menu. The Gap Closing Distance should be set to 0.4 mm, with the Smallest Detail at 0.2 mm. Select *Apply*. As a result of these commands, a part named “Hand-002_wrapped” will be created.

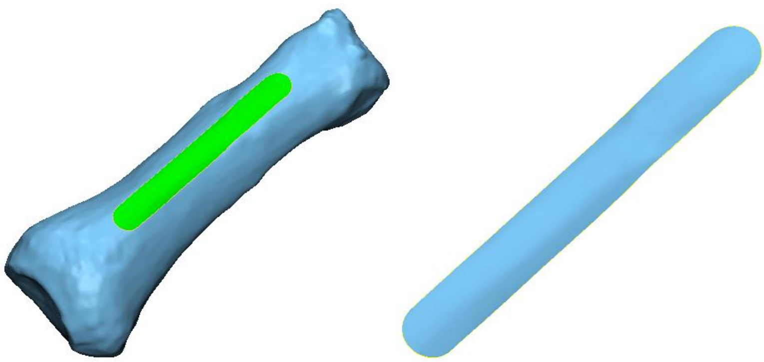


3. From the Curve menu, choose to **Project Curve**. The sketch should project onto the wrapped bone model that was just created. The Direction to project the sketch needs to be its normal direction. This can be selected in the Object Tree by opening the sketch tree and choosing the Z-axis from the Object Coordinate System. Make sure that the projection points downward, in the Z direction (this can be changed with the little arrow on the right of the direction line).

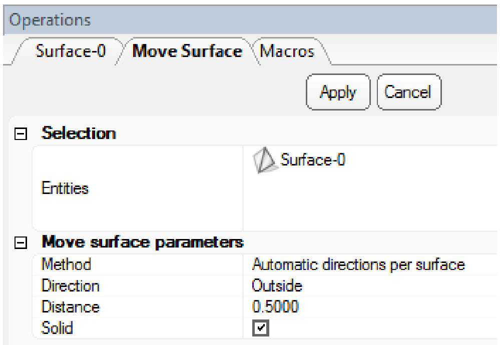


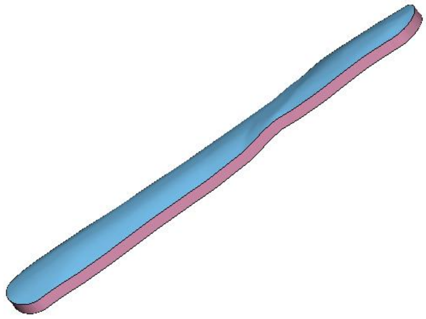
Task 3. Creating the Plate with Thickness

1. Projecting the sketch onto the bone will create a new surface which will serve as the bottom surface for the new hand plate. To select the surface, follow **Separate → Copy to Part → Create New**. Lastly, hide the original wrapped part.



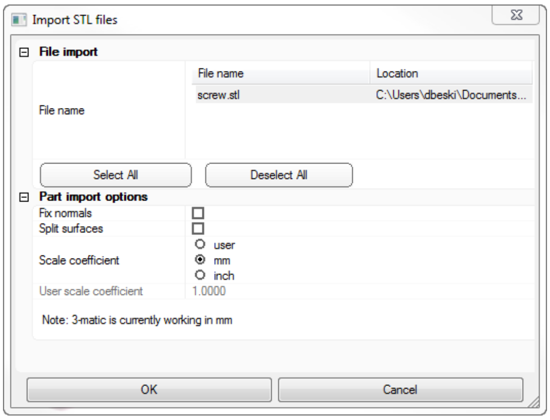
2.  Select the Design menu and chose the **Move Surface** option. The surface should be moved outside, with a thickness of 0.5 mm. Give this part the name “Hand_plate”.



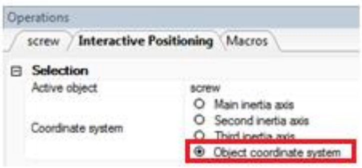


Task 4. Fitting the Screws

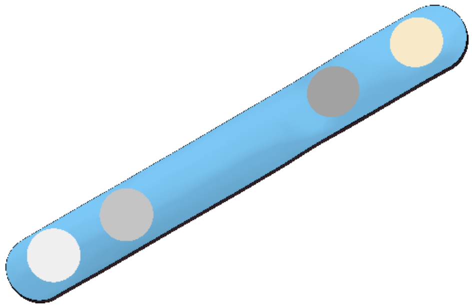
1.  Import the screw.STL again via the **Import Part** option in the File menu.



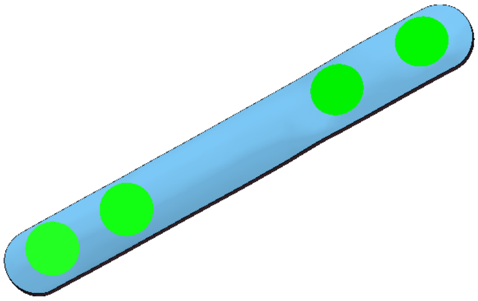
2.  Just as before, use the **Interactive Positioning** tool in the Align menu to position the first screw on the plate. The Object Coordinate System can be used for positioning. Left click and hold (for a few seconds) to update screw position.



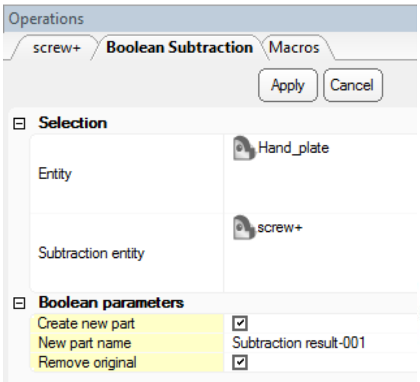
3. **Duplicate** the screw four times and reposition each screw along the newly created plate using **Interactive Positioning** from the Align menu. To duplicate, select the screw (either in 3D or in the Object Tree), right-click and choose *Duplicate*.



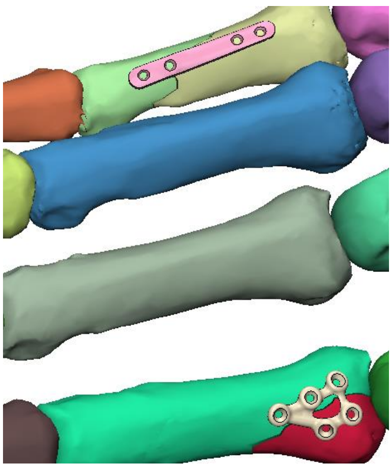
4. After all the screws have been positioned, **Merge** them together. Select all the screws, right-click and choose the **Merge** option.



5. Lastly, use the Design menu to perform a **Boolean Subtraction** between the screws and the plate.



Lastly, compare the two plates.

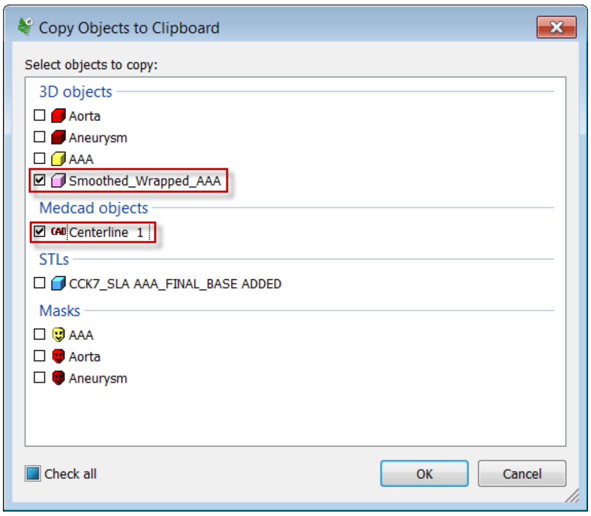


Exercise 2. Designing an Abdominal Aortic Aneurysm Benchtop Model

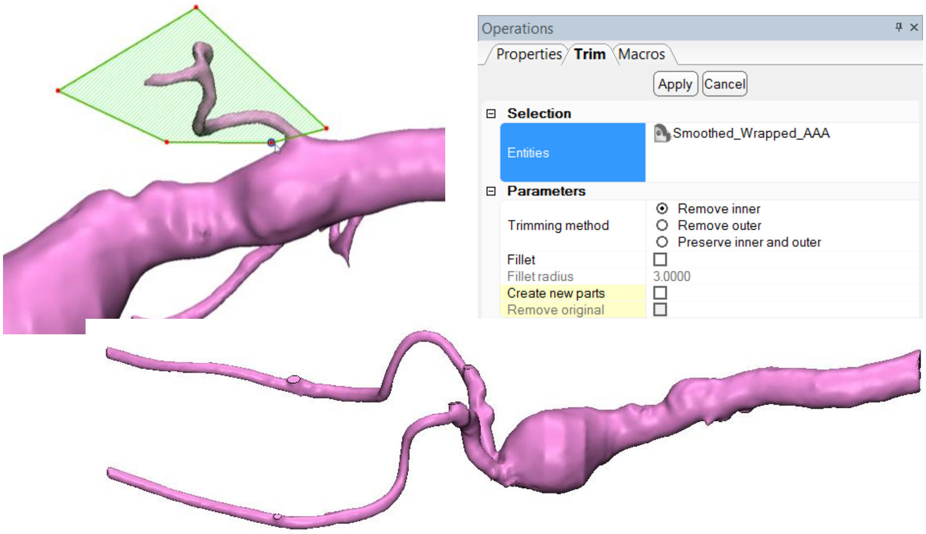
Benchtop models are a useful tool for performing experimental research in device deployment and fluid flow testing, as well as for assisting in verifying the results of a finite element or computational fluid simulation. To ensure meaningful and reliable results, it is important that the benchtop model is made as realistic as possible. In this exercise, we will design a benchtop model of an abdominal aortic aneurysm from patient data to ensure that the model is geometrically realistic. This will be designed in the STL file format so that it can be 3D printed.

Task 1. Preparing the AAA model

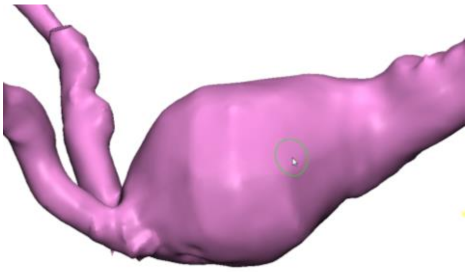
1. Begin by opening the Mimics project, AAA_segmented for design.mcs. Copy the smoothed, wrapped "AAA model" and the Centerline by pressing Ctrl+C in Mimics and check both entities in the pop-up window to copy them to the clipboard. Then, open 3-matic and press Ctrl+V to paste the models.

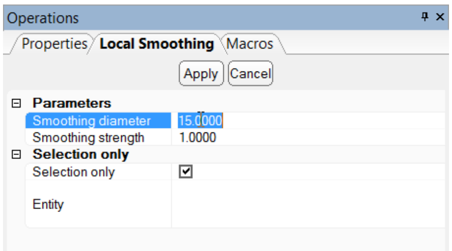


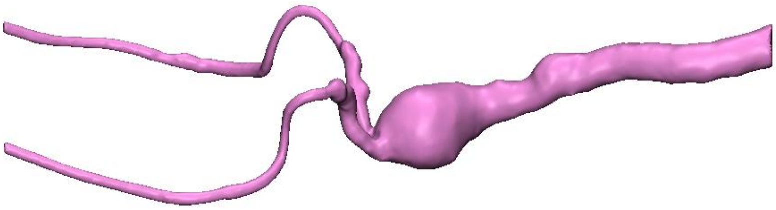
2. Within 3-matic, use the **Trim** tool from the Finish menu to trim off any unwanted features such as the arterial branches from the aorta and main iliac arteries.



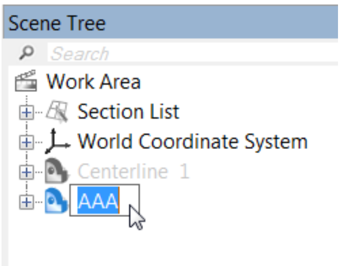
3. Smooth any rough areas on the surface of the model using the **Local Smoothing** tool found under the Finish menu. Adjust the smoothing diameter according to your preference.





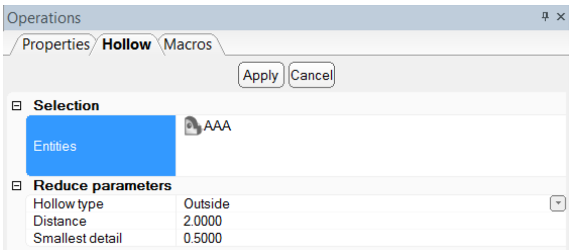


4. When you are satisfied with the model, rename it "AAA" in 3-matic by double-clicking on the name in the Scene Tree.



Currently, we have a model of the blood volume within the aorta. We want to create a model of the aortic wall from this blood volume model.

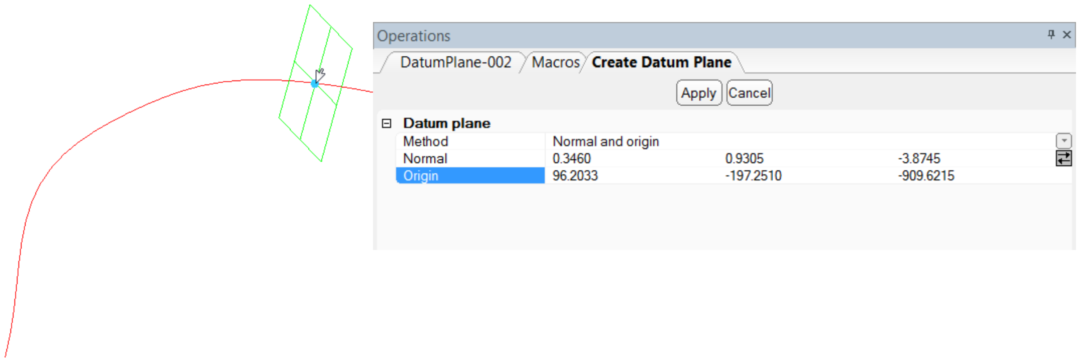
5. To do this, create a shelled structure using the **Hollow** operation found under the Design menu. We will model the vessel wall by creating a hollow on the outside of our model, 2 mm thick.



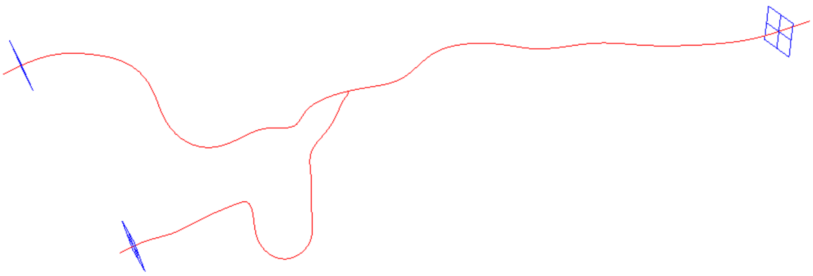
6. **Create Datum Planes** at the inlets and outlets of the geometry. This tool can be found under the Analyze menu. These planes will be used to cut the ends of the model. Because this benchtop model will be used for fluid flow studies, we want to ensure that the cutting planes are perpendicular to the centerline.

   To do this, navigate to Analyze → **Create Datum Plane**. Select the Normal and origin method and choose a normal vector by clicking on the ends of the centerline. To access the centerline, you will have to hide the "AAA" model by right clicking it in the Scene Tree and selecting **Hide**.

Select an Origin point by clicking on the point where the plane preview intersects the centerline and be sure to click *Apply*.



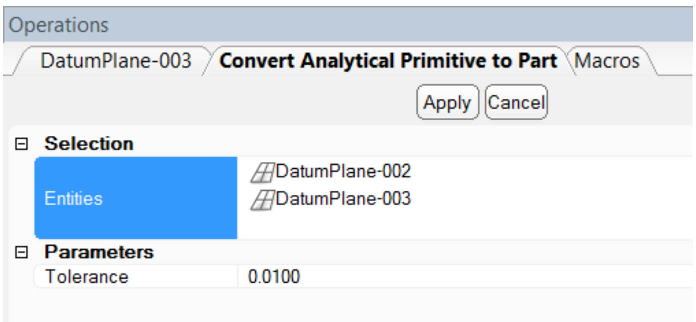
7. Create datum planes for all three outlets.

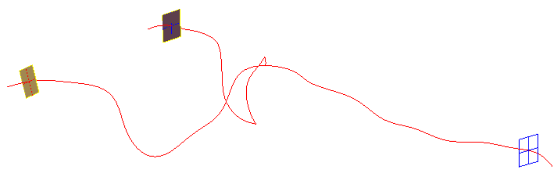


We could cut the model from here with the datum planes, however, the plane will cut anywhere that it intersects the model. Think of a datum plane as an "infinite" plane extending in all directions. Anywhere that this infinite plane intersects the model will be cut during a cutting operation with the datum plane.

We should therefore convert the planes at the femoral artery outlets to parts. When we convert a plane to a part, a boundary is assigned to it so it will only cut up to that boundary.

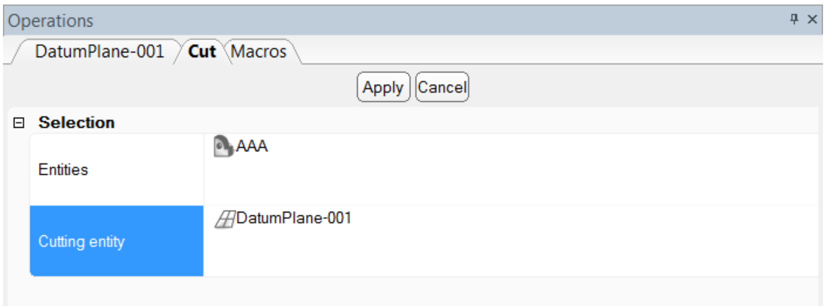
8. Navigate to the Design menu and choose **Convert Analytical Primitive to Part**. Select the planes at the femoral artery outlets as the Entities to convert. Click *Apply*.



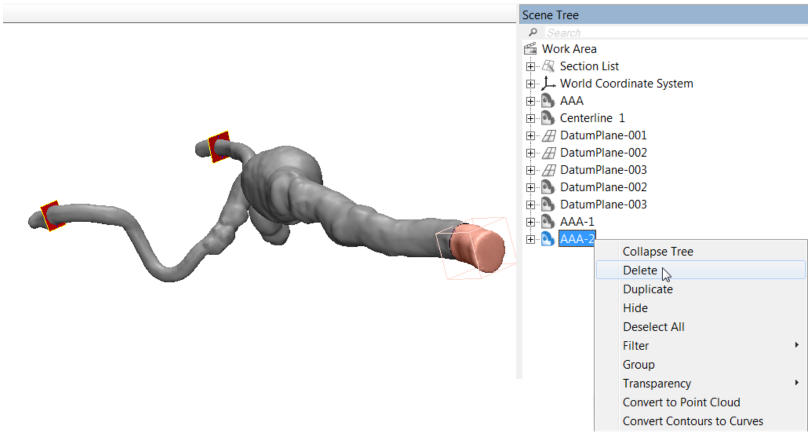


9.  **Cut** each ending using the datum plane and parts you just created by choosing the **Cut** tool from the Design menu. Make the "AAA" model visible again by right-clicking it in the Scene Tree and selecting **Show**.

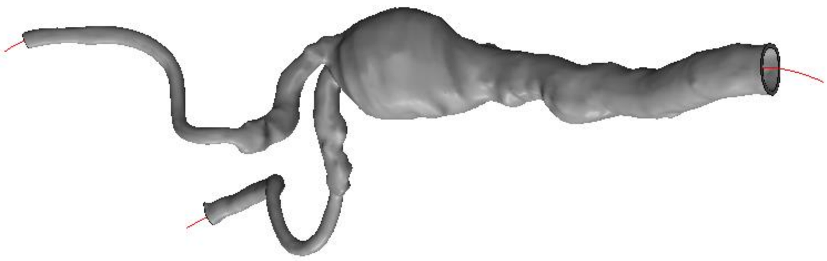
Select your “AAA” model as the Entities you wish to cut, and the datum plane/part as the Cutting entity. Click *Apply*. You will have to do this action separately for each datum plane and parts.



10. After cutting, the model is split into two parts. Right-click on the part corresponding to the cut end in the Scene Tree and select Delete.



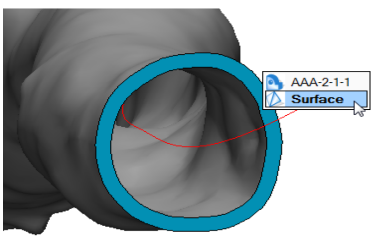
11. Hide the Datum planes and parts by right-clicking them in the Scene tree and selecting Hide.

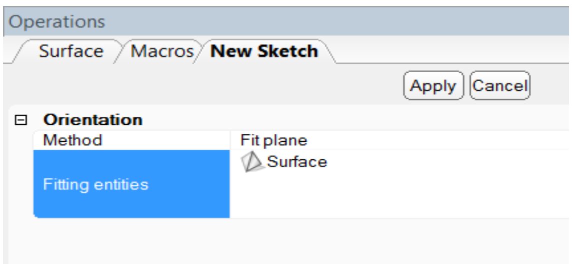


In the next step, we want to design connecting flanges on the inlet/outlets.

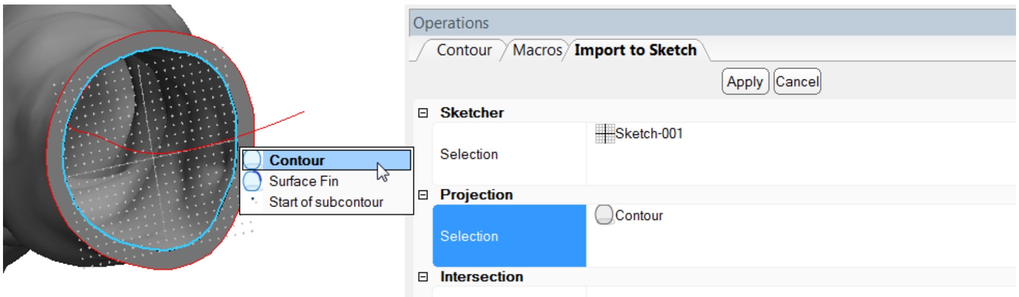
Task 2. Designing the inlet/outlet connections

1. Create a **New Sketch** on the ending of the aorta by navigating into the Sketch menu. Use the Fit Plane method and select the planar surface on the inlet of the upper aorta under Fitting entities.





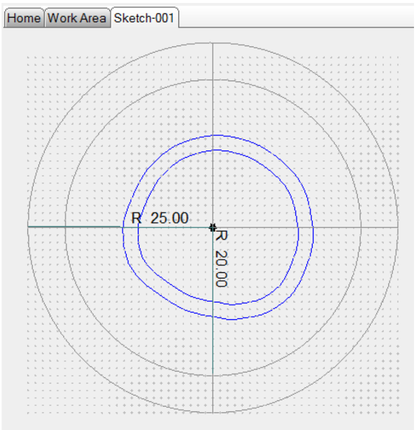
2.  We will now import contour information from our model onto this newly created sketch. Navigate to the Sketch menu and choose **Import → Import References**. Select the new sketch as the Sketcher and the inner and outer perimeter contours of the aorta as a Projection Selection. Click *Apply*.



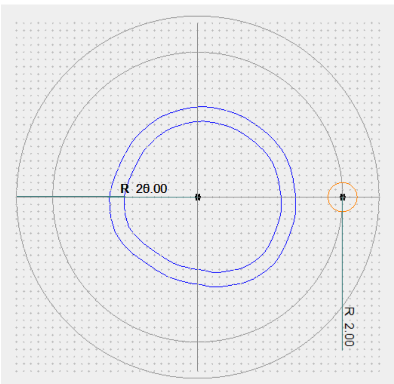
3. Navigate to the Sketch-001 Tab of the work area.
4.  Under the Sketch menu, choose **Add Sketch Entity → Circle**, define a circle on the sketch with the center point of the sketch as the origin of the circle. Constrain the circle (Sketch → **Add Constraint → Set Radius**) to a radius of 25 mm. Be sure to press *Apply*.

Hint: All of the operations under the drop-down menus (Sketch, Design, Analyze, etc.) can also be found under the corresponding colored tabs with picture icons.

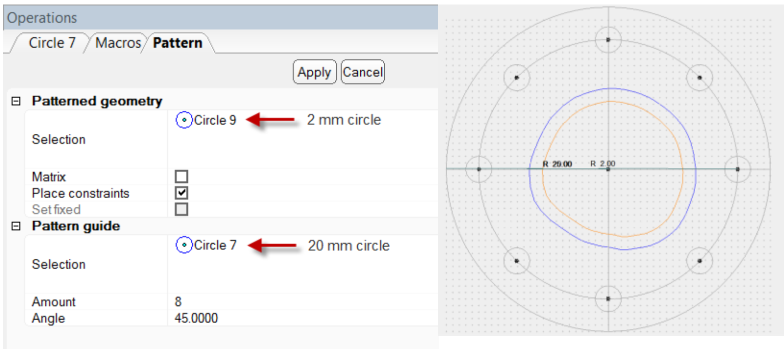
5. Create a second circle with the same origin as the original. Constrain the radius of this circle to 20 mm.



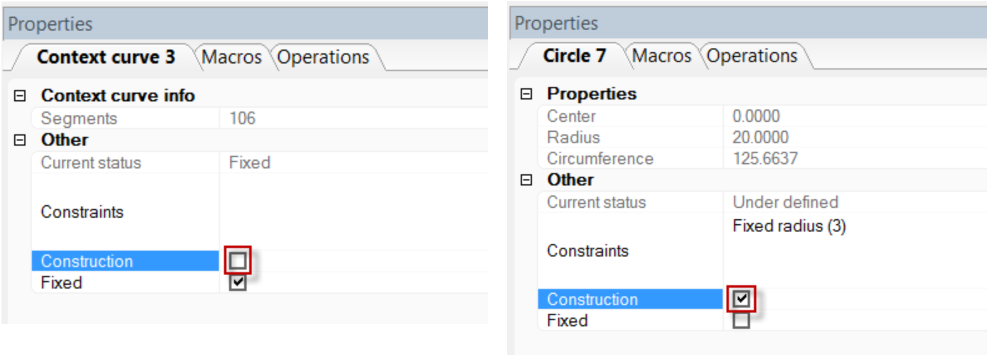
6. Create a third circle with the origin on the circle (with 20 mm diameter) created in step 5. Constrain the radius of this circle to 2 mm.



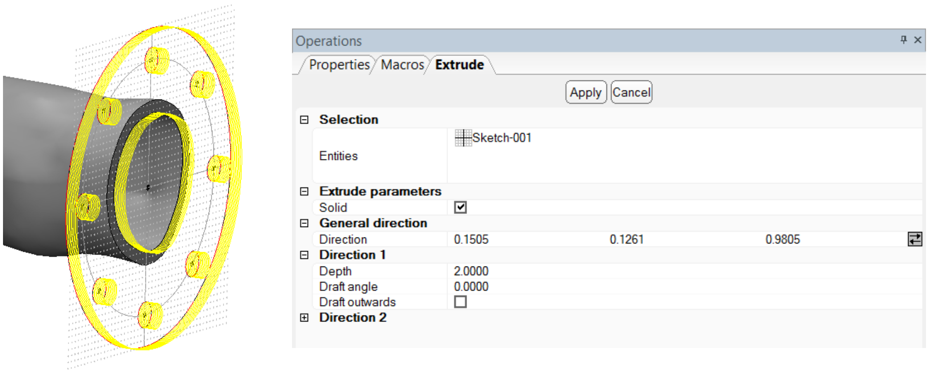
7.  Pattern this 2 mm radius circle using the parameters listed below. You can find the **Pattern** tool under **Tools** in the Sketch menu. Use the parameters below and click *Apply*.



8.  On the sketch, select the inner perimeter of the aorta by navigating to the Sketch menu and choosing **Select → Select Geometry**. Uncheck the Construction option in the Properties window. Alternatively, select the 20 mm circle and check the Construction option box in the Properties window.

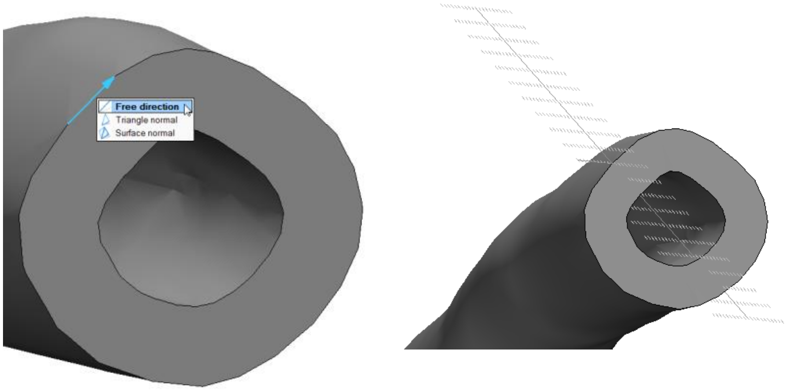


9.  We will now create the flange from the sketch. Go back to the Work Area Tab and navigate to the Design menu and select **Extrude**. Select the sketch as the Entities to extrude and specify a depth of 2 mm. Click *Apply* to perform the operation.

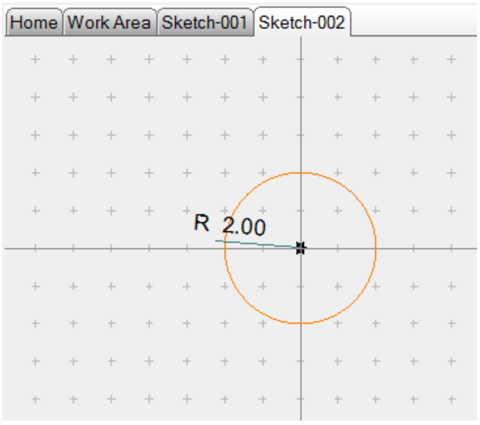


10.  Now, we will create some attachments to connect flexible hosing on both of the femoral artery outlets. To do this, first create a sketching plane normal to the outer contour of one the vessels, as shown below.
Select the **New** option in the Sketch menu, choose the Normal and origin method. Click a vector on the outer contour of the vessel ending and select Free direction as the Normal input.

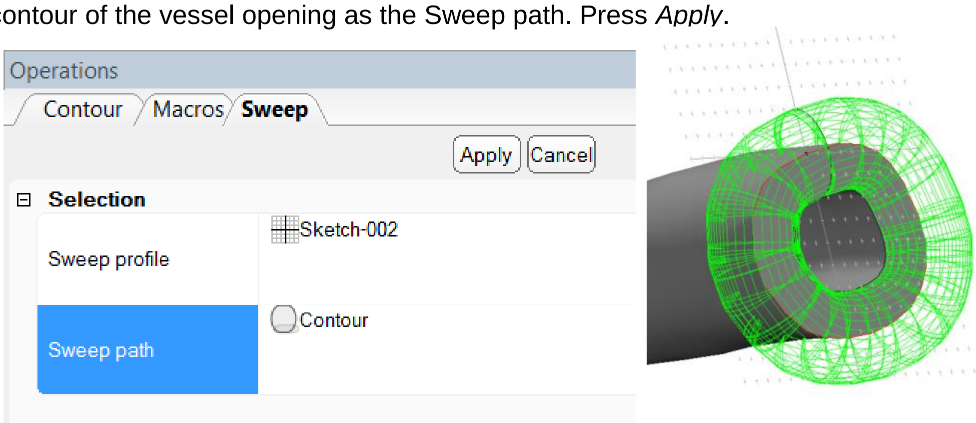
Select the point where the plane preview intersects the vessel contour as the “Origin” input (it may already be selected for you). Click *Apply*.



11. Navigate to the Sketch-002 Tab in your Work Area, and draw a circle on the sketch with the origin falling in the center of the sketch. Constrain the radius to 2 mm.



12. Navigate back to the Work Area Tab. Using the **Sweep** operation from the Design menu, create a toroid around the vessel opening by selecting your sketch as the Sweep profile and the outer contour of the vessel opening as the Sweep path. Press *Apply*.

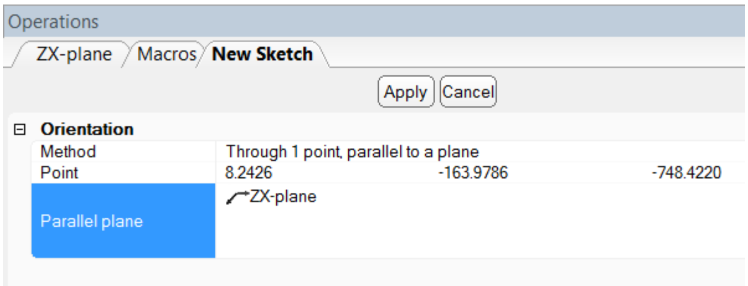


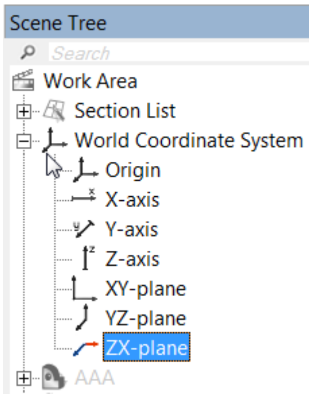
13. Repeat steps 10-13 on the other femoral artery outlet.

We now want to design a base and supports for this model so it can be laid flat on a table.

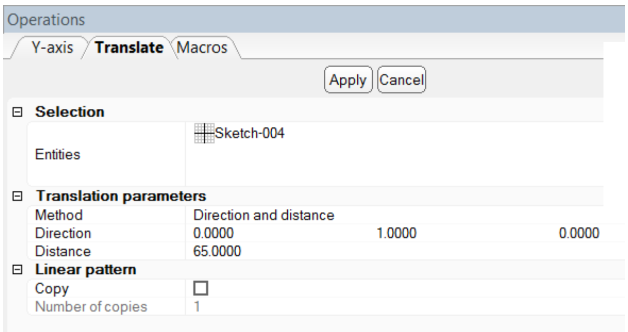
Task 3. Designing the base and supports

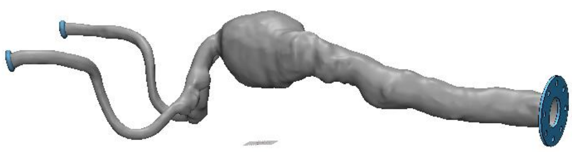
1. Create a **New Sketch** using the Through 1 point, parallel to a plane method. Choose a Point on the posterior side of the aneurysm. Select the ZX-plane of the world coordinate system as the Parallel plane. Click *Apply*.



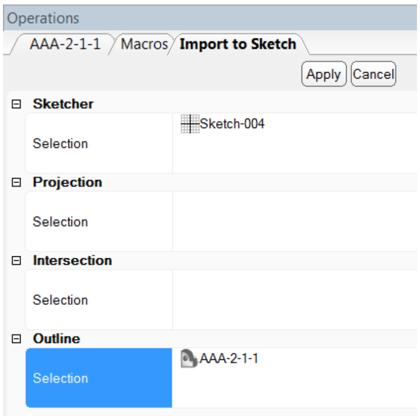


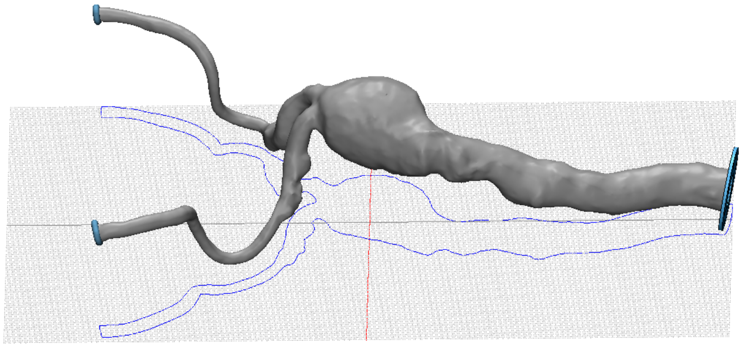
2. **Translate** this new sketch 65 mm down in the Y-direction so it does not intersect with the anatomy anywhere. This will be the sketch that we will design the base on. The Translate tool can be found in the Align menu. Select the sketch as the Entities you wish to move, and the Y-axis as the direction (you can type in a vector number, or click on the Y-axis in the Scene Tree). Click *Apply*.





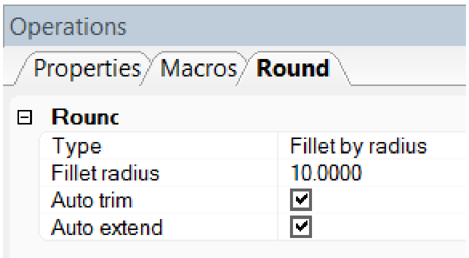
3. Import the outline of the aorta into the sketch using the **Import** option from the Sketch menu. Select the new sketch as the Sketcher and the “AAA” model as the Outline Selection. This will serve as a guide to draw the profile of the base.

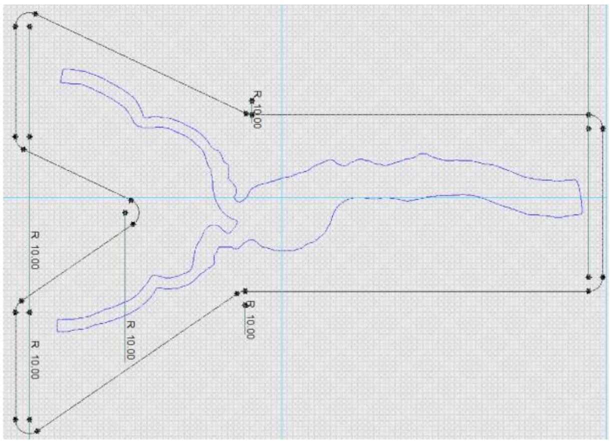




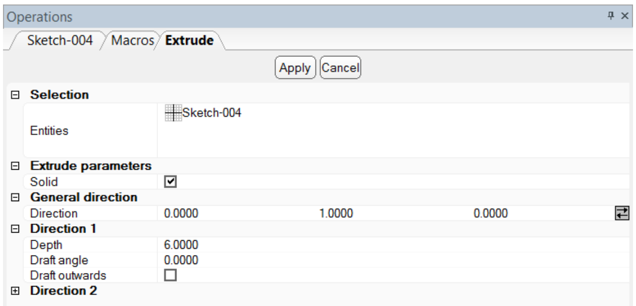
4. Within the Sketch-004 Tab, draw a profile of the base by using the **Line Sequence** option from the Sketch menu (**Add Sketch Entity**). Feel free to be creative, but be sure that it completely contains the aorta profile within the base and is a closed shape.

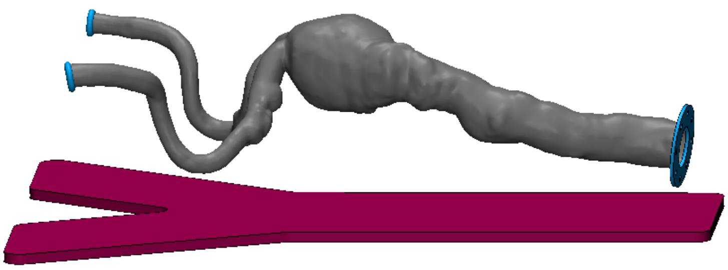
5. Add rounds to the corners using a 10 mm radius. This **Round** tool can be found under the **Tools** option in the Sketch menu. To round a corner, select both edges that meet at that corner.





6. To give the base a thickness, navigate back to the Work Area, and **Extrude** the sketch 6 mm down. This tool can be found under the Design menu. Click *Apply* to perform the operation.





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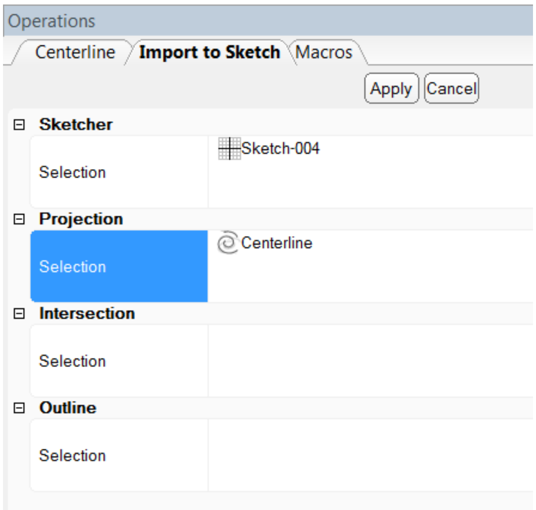
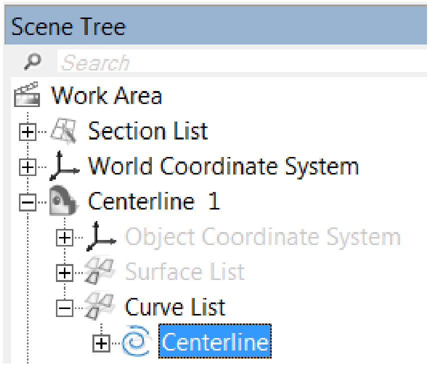
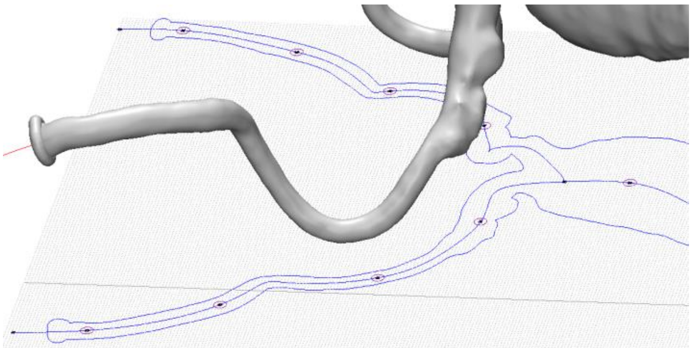
Now, we will design supports to attach the base to the model.

7. To guide us in the design, import the projection of the vessel Centerline into the same sketch we used to draw the base. You can do this by using the Import References option within the Sketch menu (you will need to select the Centerline curve within the Centerline part in the Scene Tree, see below).



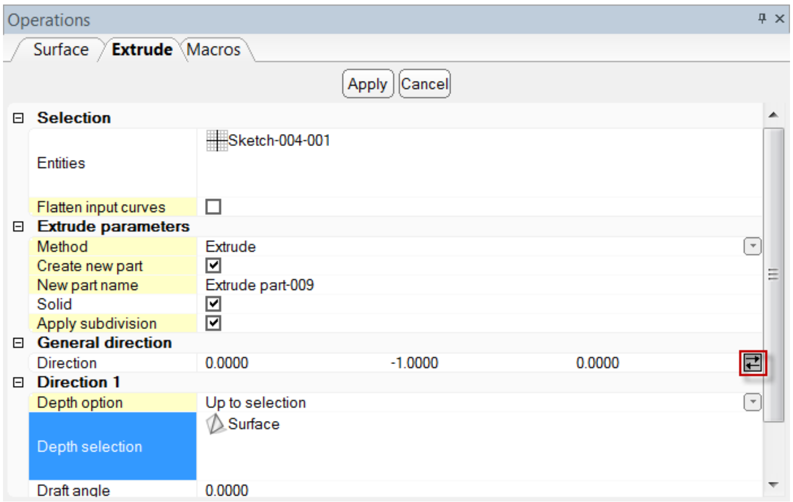


8. On this centerline projection, draw circles with the origin falling on the centerline projection. The **Circle** tool can found under the **Add Sketch Entity** option within the Sketch menu. Constrain these circles to a radius of 2 mm (Sketch → **Add Constraint** → **Set Radius**). We will extrude these circles to make supports for the model.



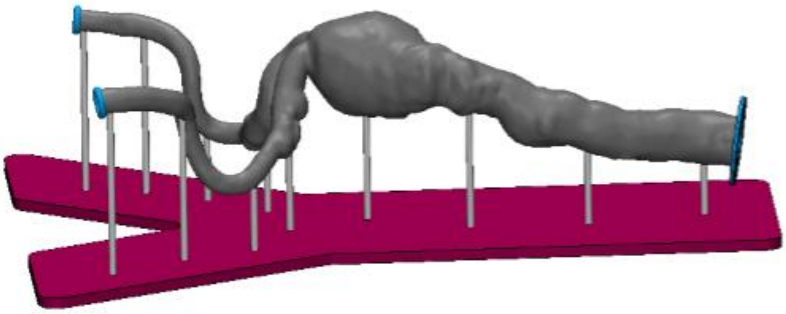
9. Select the lines that we previously used to define the base, and change them to Construction line in the properties window.

10.  Use the **Extrude** tool from the Design menu to extrude the sketch up to the outer surface of the aorta (click on the surface of the AAA in the Work Area). Turn on Expert Mode for more Extrude options. You may have to switch the direction of extrusion by toggling the arrows icon.

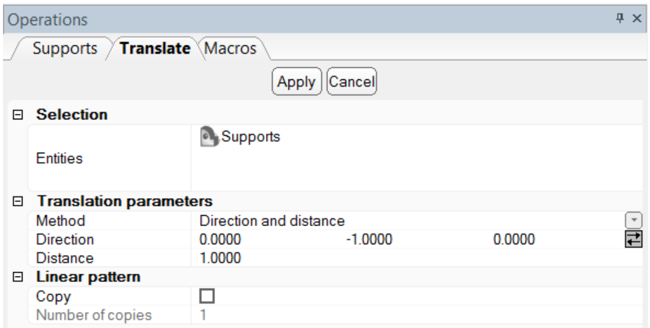


Task 4. Finish the model

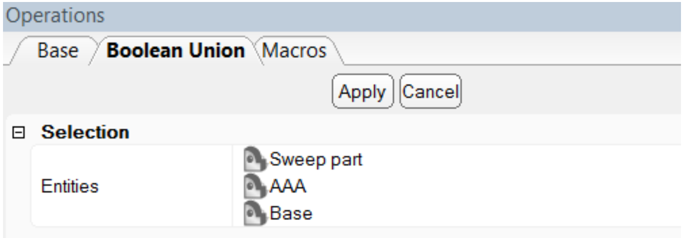
1. Rename the extruded base part “Base” and the extruded supports part “Supports” within the Scene Tree by double-clicking the name.

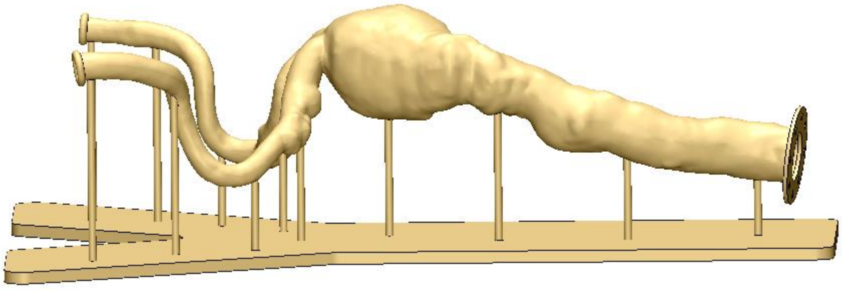


2.  Translate the supports 1 mm up towards the AAA model. This is to ensure some intersection between the “AAA” model, the “supports”, and the “base” to mitigate overlapping surfaces and aid the subsequent Boolean Union operation.

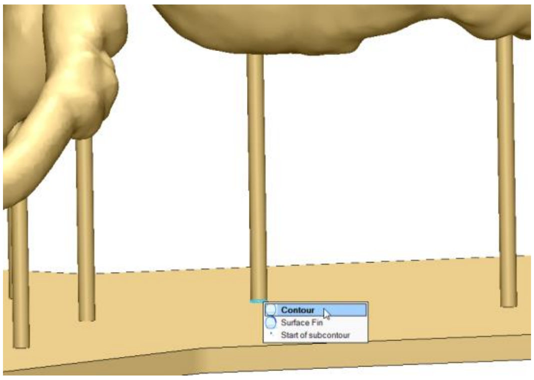


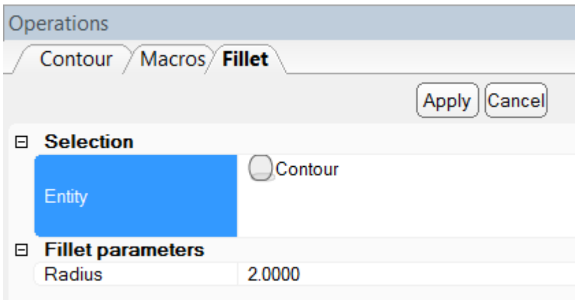
3.  Perform a **Boolean Union** to connect the base, supports, and extruded and swept outlet attachments to the rest of the "AAA" model.





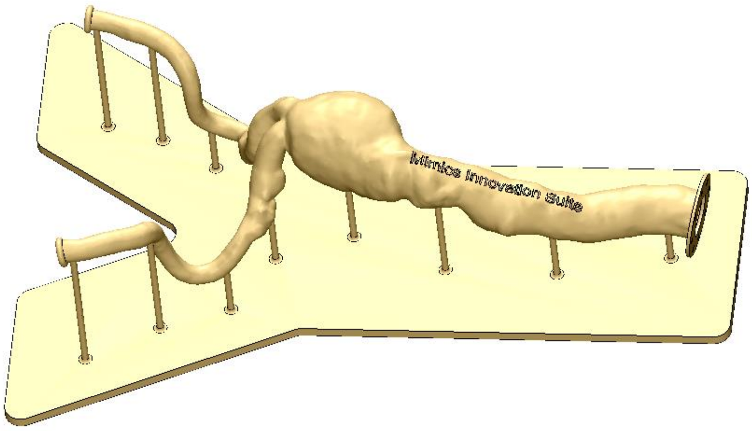
4.  Apply a **Fillet**, which you can find under the Finish menu, to each post where it joins the base. Use a radius of 2 mm and select the contour where each support meets the base as the Entity to fillet.





5.  Apply text to the top on the vessel using the **Quick Label** tool from the Finish menu. Adjust the font, height and alignment to your liking in the Operation window.

The final result of your AAA benchtop model should look similar to the one below.



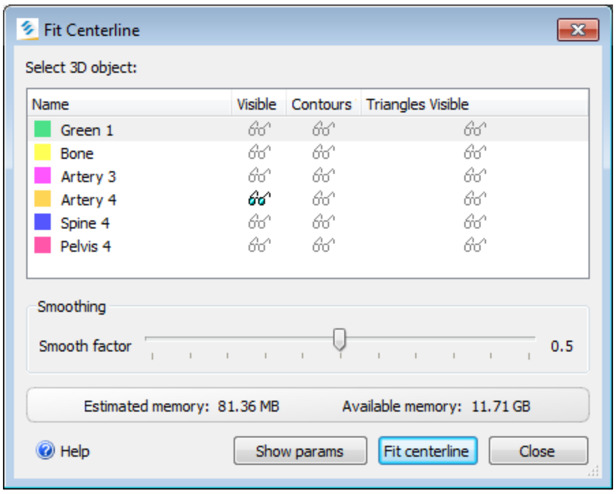
Analysis

Exercise 1. Basic centerline and measurements

Task 1. Calculate centerline of iliac-femoral arteries

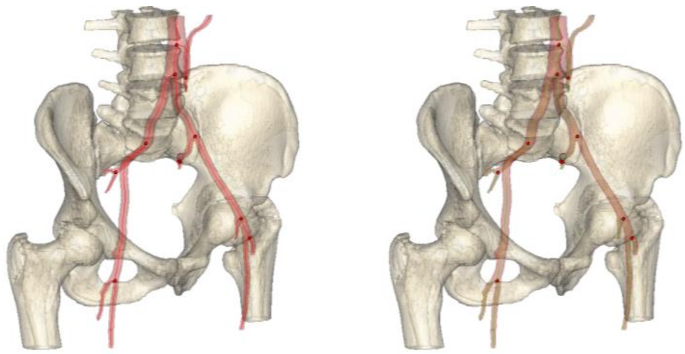
1. Go to the File menu and select **Open project**. Browse to the training folder and open the Iliacs.mcs project.

2. From the Analyze menu, select **Centerline - Fit Centerline**. In the Fit Centerline window select the 3D model “Artery 4”. Click on *Fit Centerline* and close the dialog.

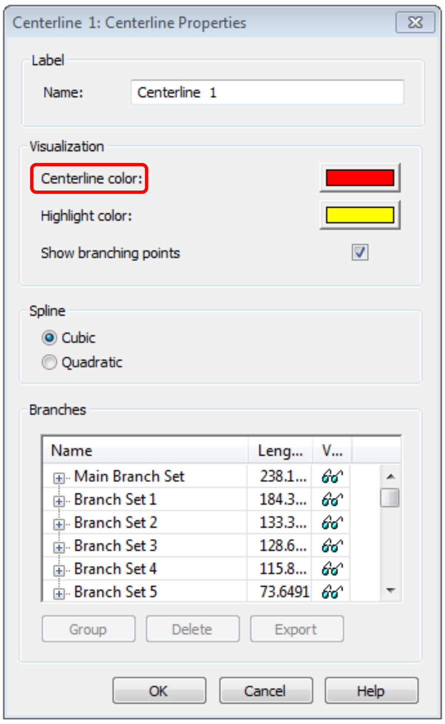


Hint: It is recommended to use the automatic centerline generation parameters. This will result in a centerline with parameters tailored towards the diameter of each branch.

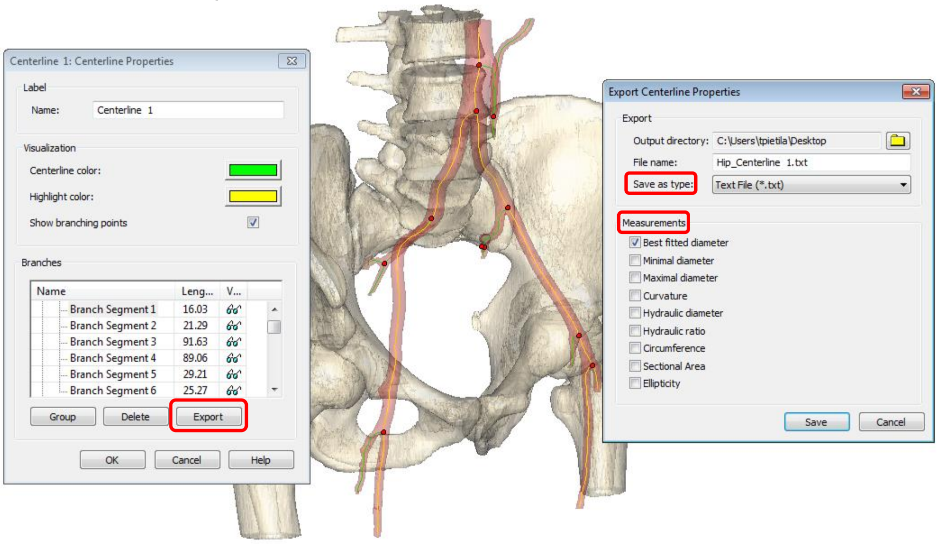
3. To view the results of the centerline, make the 3D model transparent by clicking on the transparency icon next to the 3D view.



4. To better visualize the centerline, the color of the centerline can be changed. Select the Centerline in the Analysis Objects tab and click on the properties icon. Change the color of the centerline. See results above.



5. To export the centerline, select the branches of the aorta, iliac and femoral arteries. The branches can also be selected in the 3D interface. Click on Export to open the export dialogue. The centerline can be exported as an IGES or to a text file with the defined measurements.



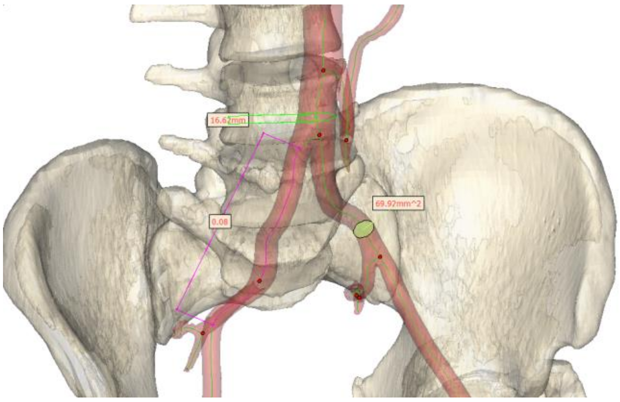
6. Choose to export the Best fitted diameter and select *Save* from the centerline export window. View the exported results in a text file.

Task 2. Centerline measurements

1. Measurements can also be performed locally on the 3D model. From the Measure menu, select **Centerline** and the desired centerline measurement. Measure the **Best Fit Diameter** before the aortic bifurcation.

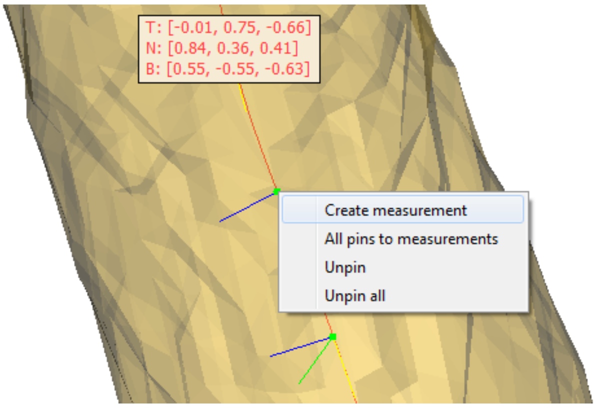
Hint: The label can be dragged away from the measurement for better visualization by clicking and holding the left mouse button.

2. Measure the Tortuosity of an iliac artery by indicating two points.



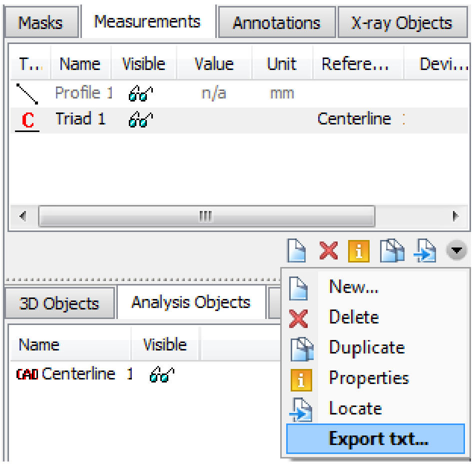
Hint: The Tortuosity will be calculated as Tortuosity = 1 – (linear distance / distance along the branch). That means the smaller the result, the less tortuous the vessel.

3. Use the **Triad** measurement to find abrupt changes in curvature. It can also be used to determine takeoff angles of daughter branches. As measurement result it shows you the tangent (yellow), normal (green) and binormal (blue) vector directions in the selected point on the centerline.



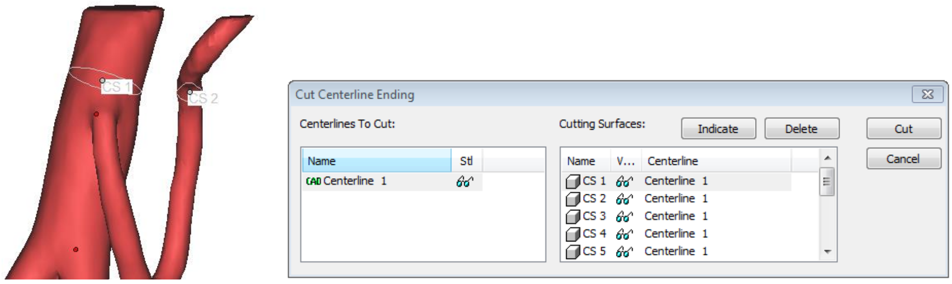
*Hint: To create the measurement, place a point on the centerline and click with the right mouse button on the green colored origin. Then choose **Create measurement**.*

4. Explore some of the other centerline measurements that are available. The individual measurements can be exported via the Measurements tab in the Project Management toolbar.

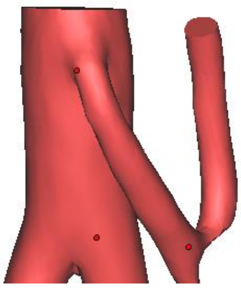


Task 3. Cut centerline and vessel ends

1. Select the centerline in the Analysis Objects tab, click on the action button and select **Cut Centerline Ending**. Indicate cutting planes at the inlets and outlets of the artery.



2. After indicating the cutting planes choose *Cut*. You will notice that the centerline has now been trimmed. A new 3D object is also created with the perpendicular endings.



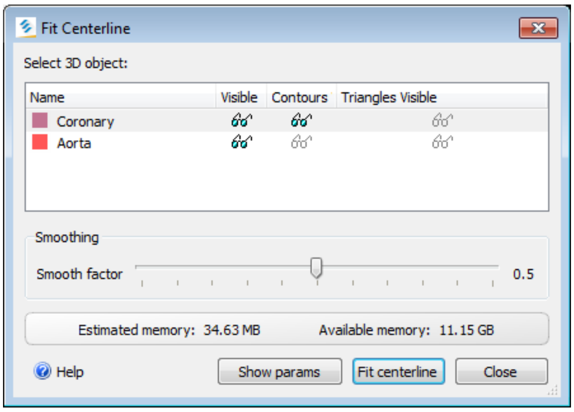
Hint: Cutting the ending of the centerline will also cut the 3D. As such it gives your model perpendicular endings, which is helpful for creating computational models. The perpendicular surfaces can be indicated as in/outlets for flow.

Exercise 2. Advanced Centerline Measurements & Reslice along Centerline

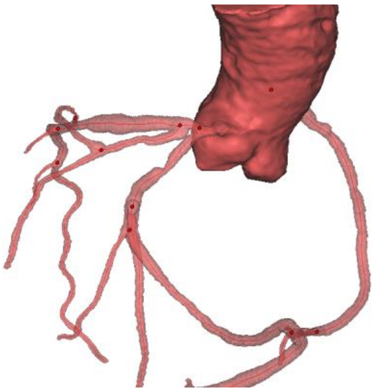
Task 1. Calculate centerline of coronaries

1. Open Mimics. From the File menu, select **Open Project** and open the Coronary.mcs project. The ascending aorta and coronaries have already been segmented in this dataset.

2. Under the Analyze menu, choose the **Fit Centerline** tool. Highlight the coronary model and click *Fit centerline*.

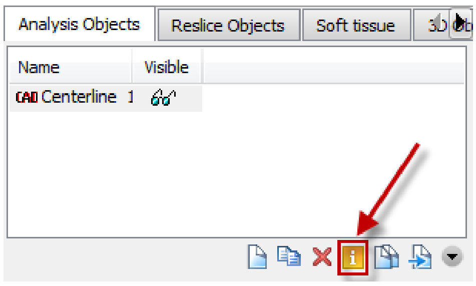


3. Turn on the transparency of the 3D model to visualize the results of the centerline algorithm.

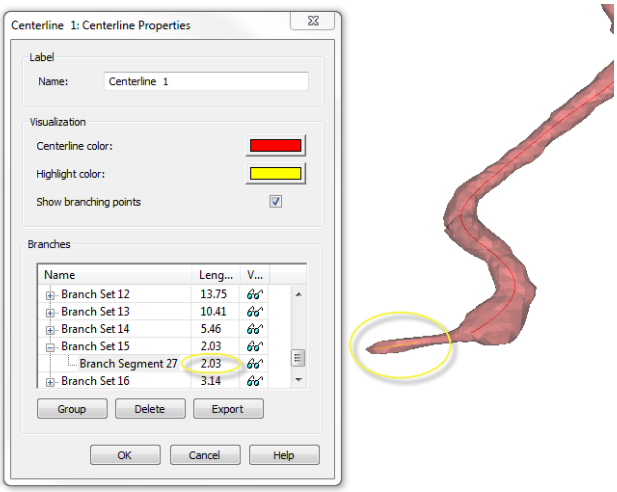


Task 2. Post-processing the centerline

1. Measure the length of hanging branches by choosing the **Properties** icon from the Analysis Objects tab in the Project Management toolbar.

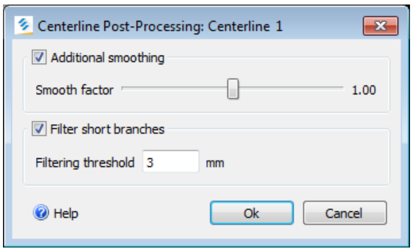


2. Click on a small hanging branch in the 3D view. It will become highlighted both in the 3D view as well as the centerline properties window. This branch has a length of approximately 2mm.



3. Select **Centerline Post-Processing** from the actions arrow in the Analysis Objects tab.

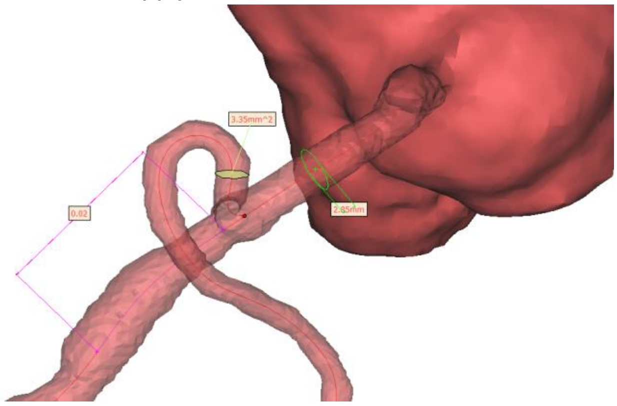
4. Set the **Filtering threshold** to 3mm. All branches smaller than this parameter will be removed upon applying the operation.



Hint: The centerline can also be split and sections deleted using the "Split Centerline" and "Delete Centerline part" under the actions arrow dropdown.

Task 3. Exporting measurements

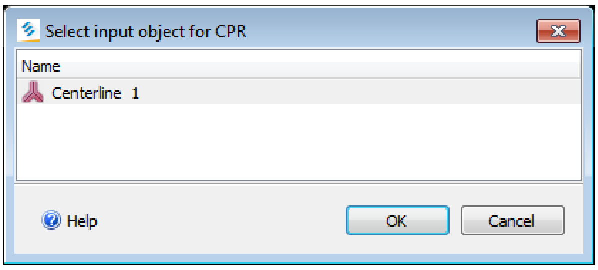
1. Under the Measure menu, select and apply various centerline measurements to the 3D model.



2. These measurements can also be obtained via an automatic export. This is done through the **Properties** icon in the Measurements tab as done in the previous exercise.

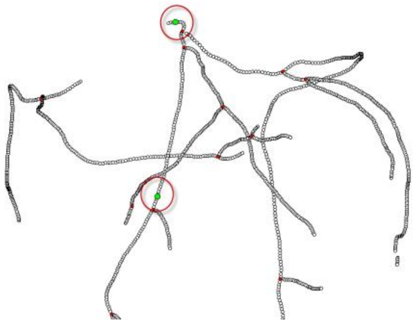
Task 4. Reslice images along centerline

1. From the View menu, choose **Reslice → Along Curve → Select Curve**. In the CPR dialogue, select the coronary centerline and choose *OK*.

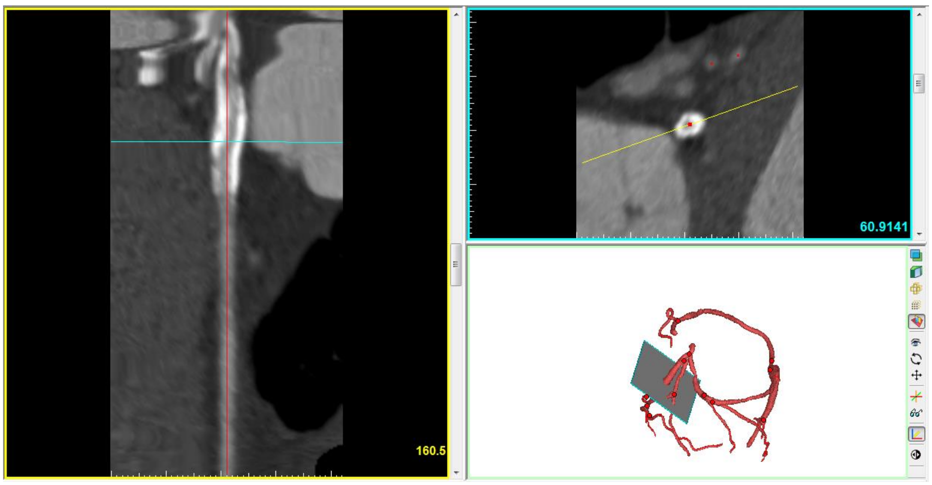


2. You will now notice that the control points of the centerline become visible. This is how we determine the centerline section along which we will reslice the images.

3. Choose the first control point (by left-clicking) near the ostia of the left coronary artery. This point will become illuminated in green. Select a second point down the LAD artery.



4. After the control points are selected, double-click the left mouse button. This will save the CPR view in the Reslice Objects tab of the Project Management toolbar.



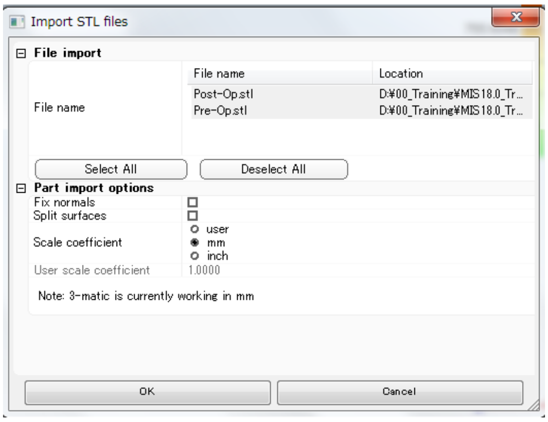
5. Visualize the coronary artery for stenosis and blockages. Perform measurements on the images.

Exercise 3. Part Comparison of the Mandible

The purpose of this exercise is to compare a pre- and a post-operative model using 3-matic, which includes a functionality to compare two STL models for a variety of applications. The part comparison tool will make it possible to visualize the areas that are similar in addition to highlighting those that differ.

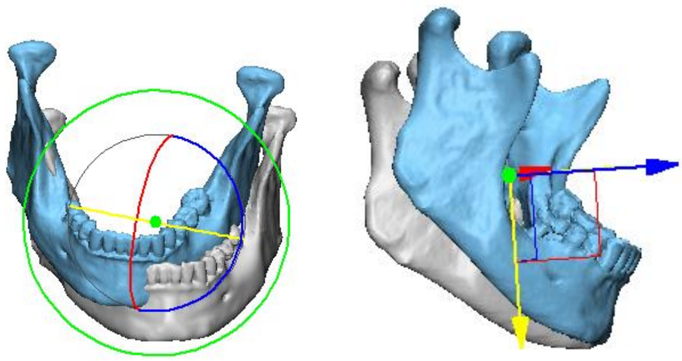
Task 1. Import the Pre- and Post-Operative Parts into 3-matic

1. Click **Import**, via the File menu in 3-matic, to import the STLs named “Pre-Op.stl” and “Post-Op.stl”. These STLs can be found in the training folder.

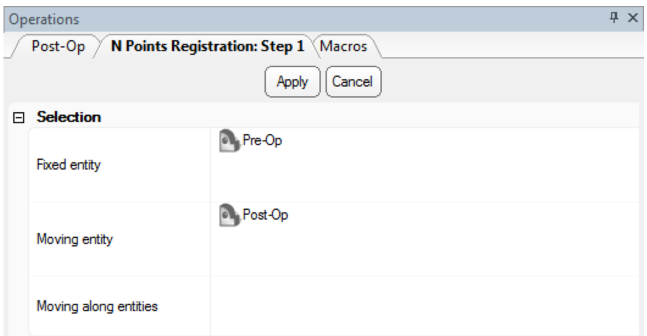


Task 2. Registration of the STLs

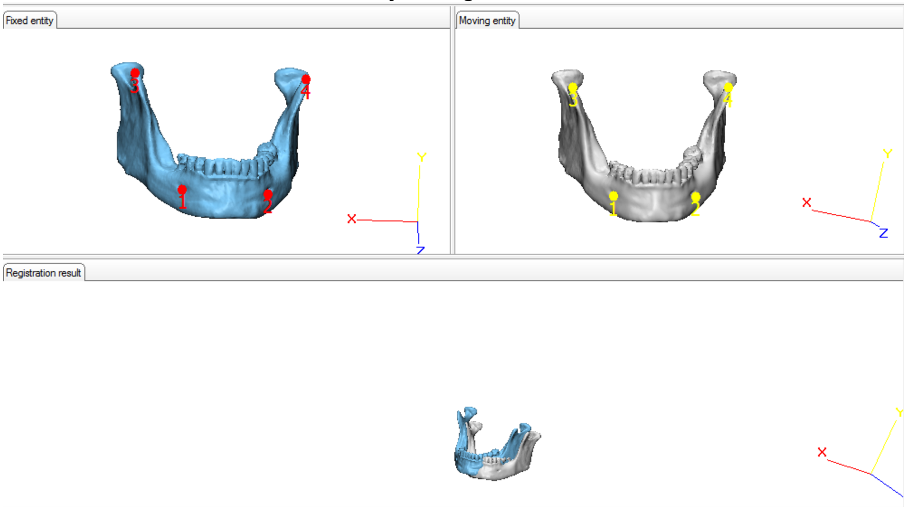
1. Prior to initiating a part comparison, the STL files must first be registered. Use the **Interactive Translate** and **Interactive Rotate** tools from the Align menu to register the STL files together.



2. The registration is not complete yet. Use the **N Points Registration** tool in the Align menu to complete part registration. First, set the Fixed and Moving entities according to the figure below.

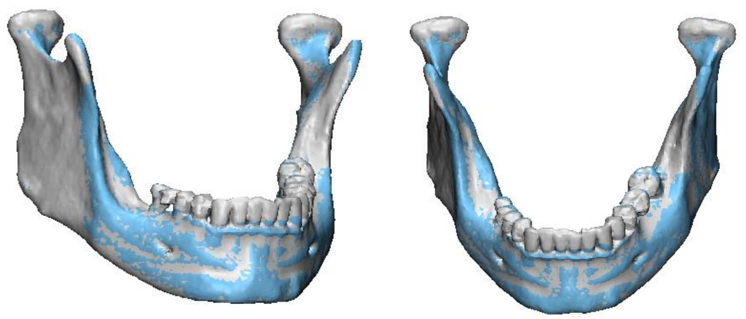


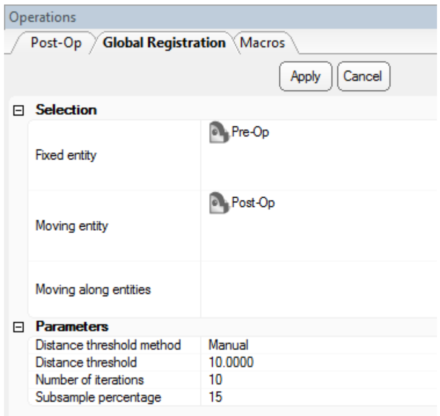
3. After pressing *Apply*, a new 3-matic interface will appear. It is necessary to define at least three (preferably four) corresponding points on the Fixed and Moving entities. Be sure to choose points on anatomical landmarks that are easily recognizable on both models.



Note: The result of the N Points Registration depends highly on the placement of the landmark points.

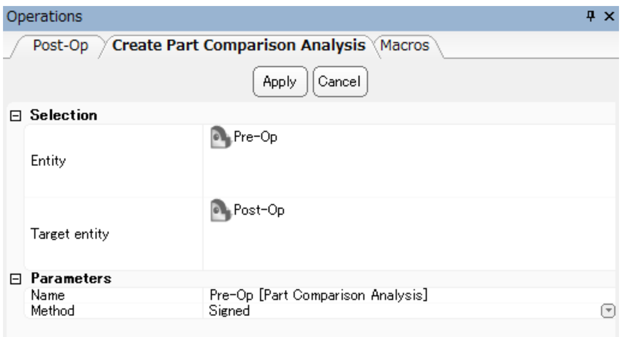
4.  As a final registration step, use the **Global Registration** tool from the Align menu. The end result should look similar to the image presented below:

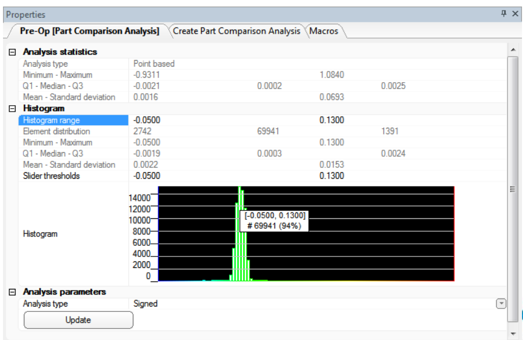


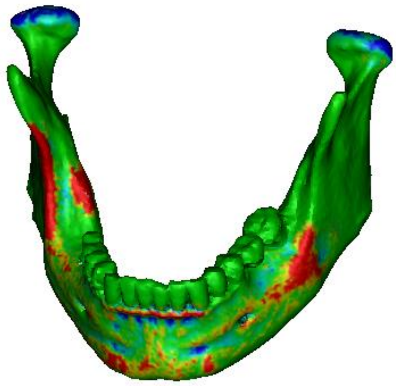


Task 3. Create a Part Comparison

1.  Choose the **Create Part Comparison Analysis** tool from the Analyze menu. For this task, a part comparison analysis will be performed to determine changes between the pre-operative and post-operative models. The Properties page will show a histogram of the results and some statistical properties.

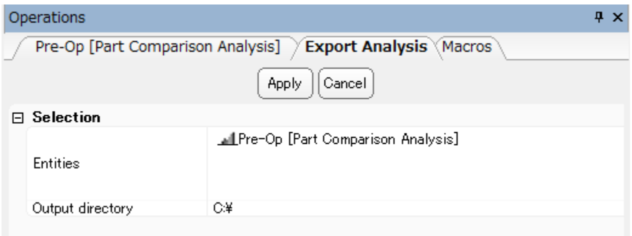






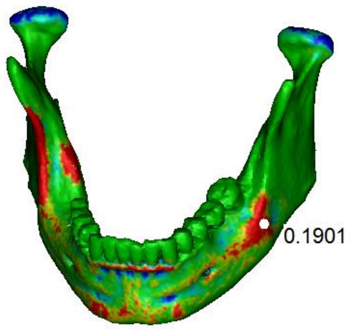
Task 4. Export the Analysis as a Text File

1. Hide the “Post-Op” part. The analysis can be found under the Pre-Op Tree. Go to the **Export** option in the File menu to export the Analysis (File → Export → Analysis). Select the Part Comparison Analysis listed in the Scene Tree under the “Pre-Op” part.



Task 5. Locally Measure the Analysis

1. It is also possible to measure the distance between the two parts locally using the **Measure Analysis Locally** tool from the Analyze menu. Hover over the part to see the value for each triangle node individually.

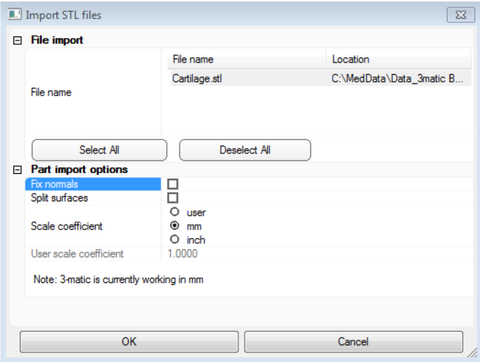


Exercise 4. Wall Thickness Analysis

In addition to Part Comparison and Curvature Analysis, 3-matic also includes a Wall Thickness Analysis algorithm that makes it possible to virtually measure the overall thickness of a model. Knowing the thickness of a bone helps surgeons and engineers make decisions about hardware that might be used during a procedure. For example, it is important to know the thickness of the skull in order to understand and plan the length of screws that will be used in a CMF procedure such as placing a mandibular plate or cranial plate. In this exercise, we are interested in determining the overall thickness of a cartilage model at various points. Once the thickness is determined through the Wall Thickness Analysis, these ‘thick’ and ‘thin’ areas will be highlighted by separating them into different surfaces.

Task 1. Import Cartilage STL File

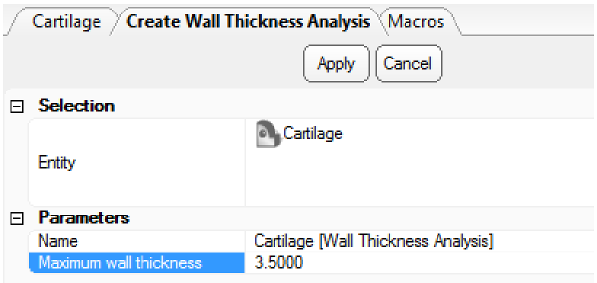
1. Import the Cartilage.stl file via the **Import Part** tool in the File menu

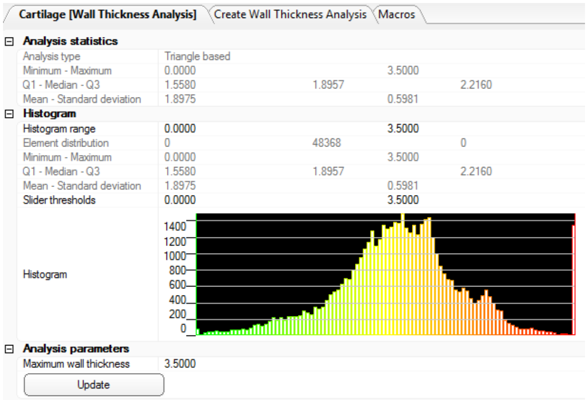


Task 2. Analyze the Wall Thickness of the Cartilage

1. Choose the **Create Wall Thickness Analysis** tool from the Analyze menu and set the maximum thickness to 3.5 mm.

   In this particular case, 3.5 mm has been chosen because the cartilage does not exceed this value in any areas of interest.

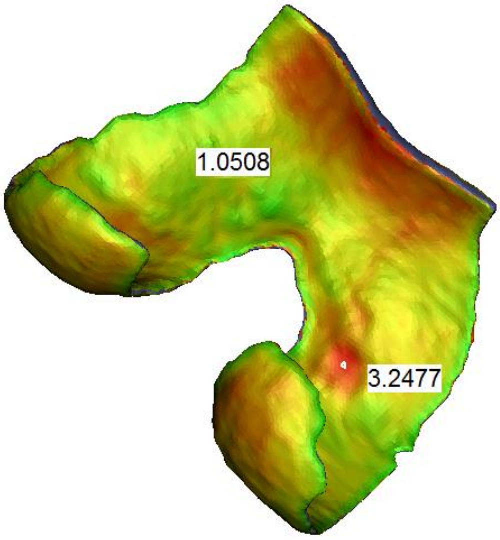




The resulting histogram will show the variation in thickness across different areas, from the very thin (green) to the thickest (red). While the Analysis Statistics will not change, given that they are based on the statistics of the model itself, the Histogram Range and Slider Thresholds can be altered to visualize areas of interest in different colors. For example, it is possible to select the thresholds so that only areas thinner than 1.5 mm are highlighted.

Task 3. Locally Measure the Wall Thickness Analysis

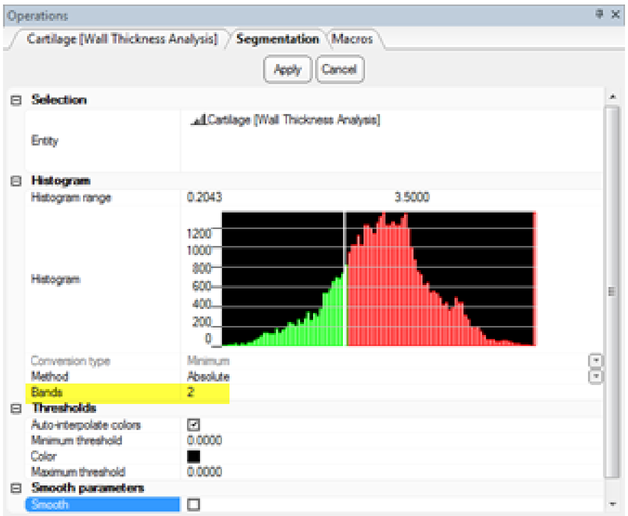
1. It is possible to measure the thickness of the cartilage locally using the **Measure Analysis Locally** tool in the Analyze menu.



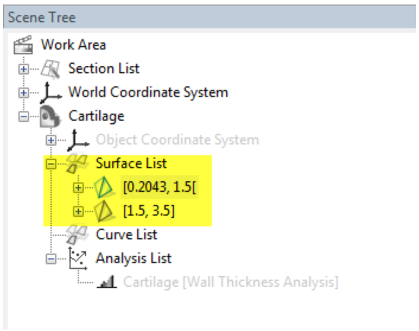
Task 4. Segment the Analysis to Create Separate Surfaces

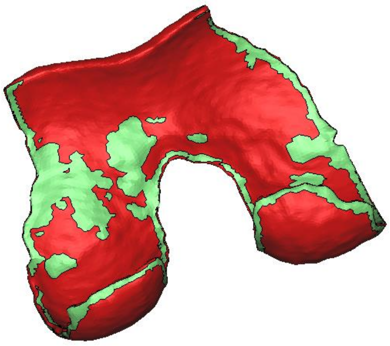
1. Choose the **Segmentation** tool from the Analyze menu. Segmentation will make it possible to segment the surface according to the analysis values into separate surfaces. In this case, we will segment the wall thickness analysis into two surfaces: healthy and unhealthy cartilage thickness.

2. Set the Bands to 2 and move the histogram slider to 1.5 mm. This setting will create a histogram with two surfaces; more specifically, one surface with a thickness above 1.5 mm and another with a thickness below 1.5 mm.



3. Check the new surfaces that are created in the Scene Tree for the cartilage model.





The separated surfaces could be used for further applications. For example, it is now possible to determine the surface area of each defined surface. These separated surfaces could also be used as inputs for localized remeshing via the FEA tools or for designing custom devices.

Note: Be sure to hide the Wall Thickness Analysis on the Analysis List so that the new surfaces are showing.

Congratulations!

You finished the course! We wish you good luck in your future projects with the Mimics Innovation Suite!

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