Universal guide for skull extraction and custom-fitting of implants to continuous and discontinuous skulls

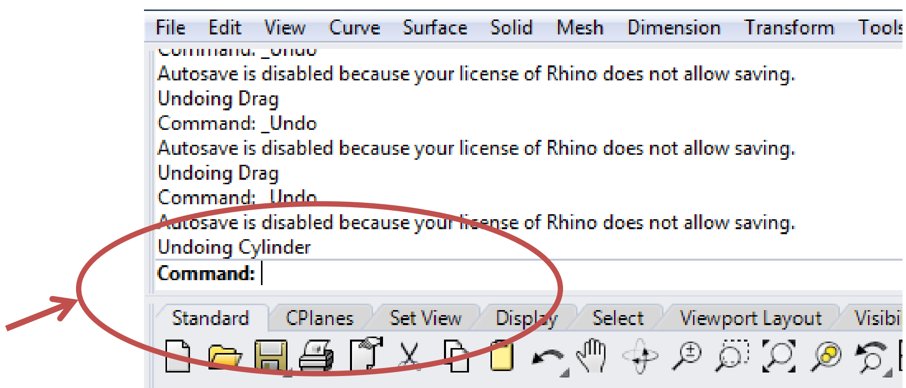
- TUTORIAL -

This tutorial describes how to customize and fit implants using Rhinoceros 6.0 and Fusion 360 (2018). Red numbers in brackets indicate the corresponding video tutorial, if available.

Description of how to reconstruct the 3D skull and brain as well the designing process of the unmolded chamber for wireless recordings can be found in form of video tutorials only and are not further explained.

<u>Rhinoceros 6 -specific pointers:</u>

- All commands can be entered in form of a text (type in command -> press enter)



- right mouse click repeats the last command used
- in quotation mark written words are the respective commands that can be typed in directly in the command line
- To move parts in space right click and drag. This is possible in all views except the "perspective" view. In the latter case press shift key + right click and drag.
- To rotate the view keep the right mouse button pressed while dragging in the "perspective" view

Skull and brain extraction

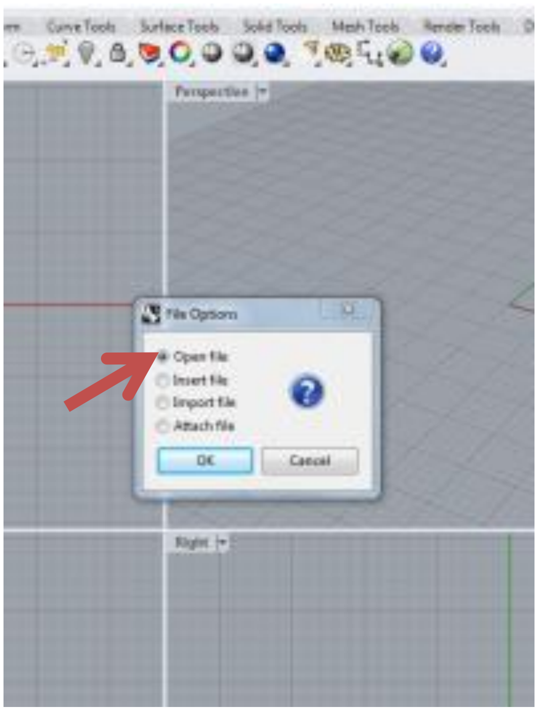
[Step 0-1] Skull extraction using automatic threshold effect from a CT scan

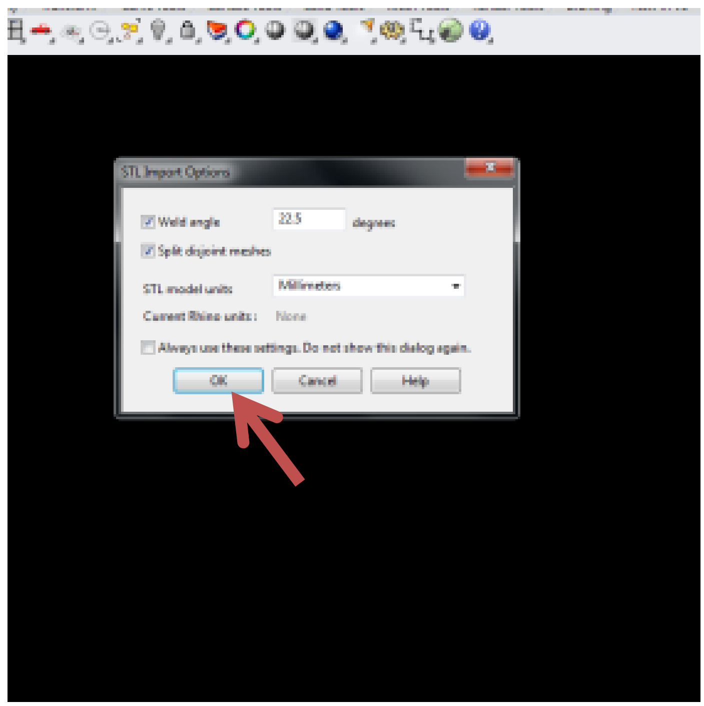
[Step 0-2] Skull and/or brain extraction using automatic threshold effect from a MRI scan

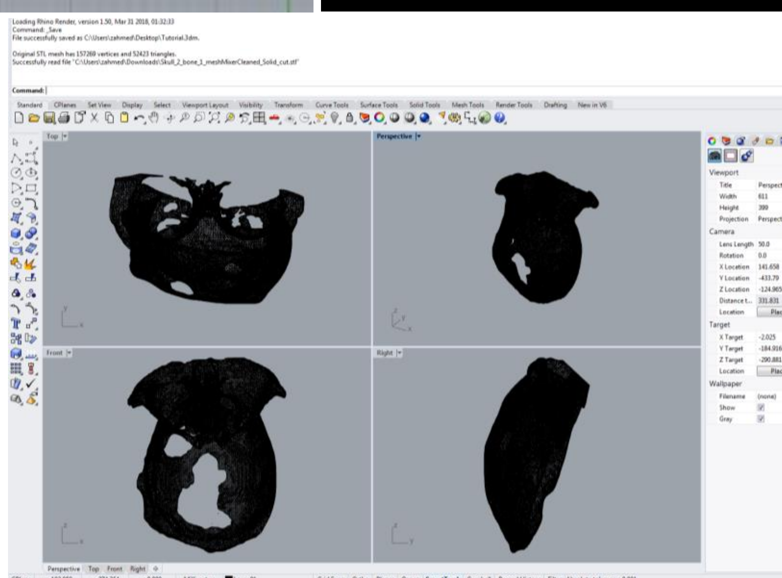
[Step 0-3] Save and export the extracted 3D skull and/or brain model

Preparatory Steps

[Step 1-1] Import the 3D skull model to Rhinoceros 6 (Rhino).

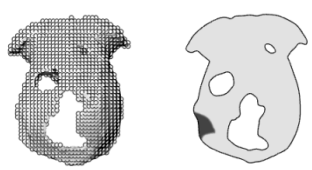
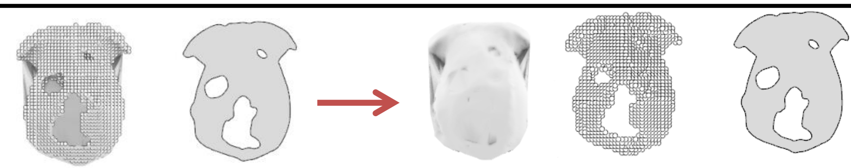




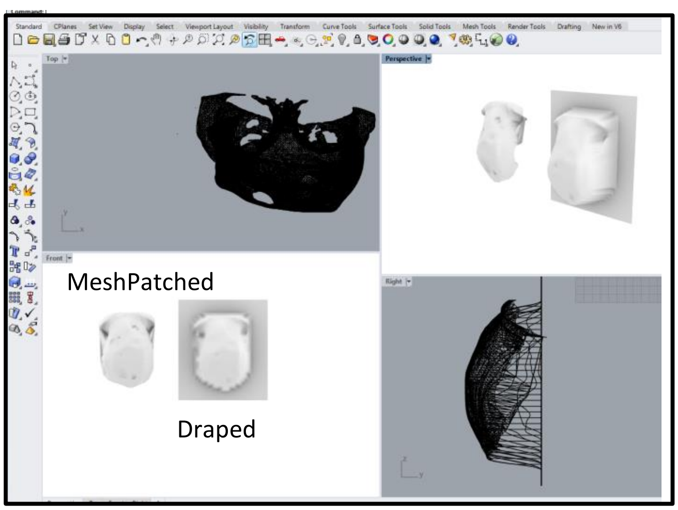


If your animal has an even skull, you can create the 3D reference surface directly (go to point 4 / [Step 3]). If the reconstructed skull contains uneven features, artefacts or holes, you need to patch up and remove them before continuing.

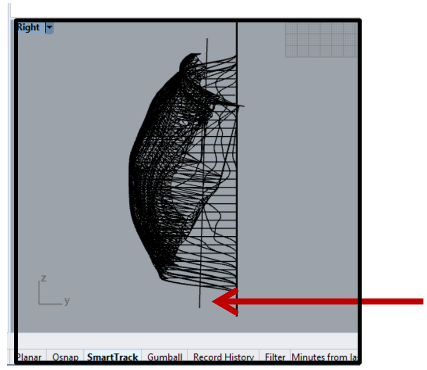
[Step 1-2] Remove unusual or uneven skull condition:
Generate curve points over the reconstructed 3D skull surface by entering the command “***DrapePt***”. A net of points is overlaid with the skull. Remove all points related to the uneven feature and create a newmesh with “***MeshPatch***”. Displace the original imported 3D skull.

DrapePt	MeshPatch
	

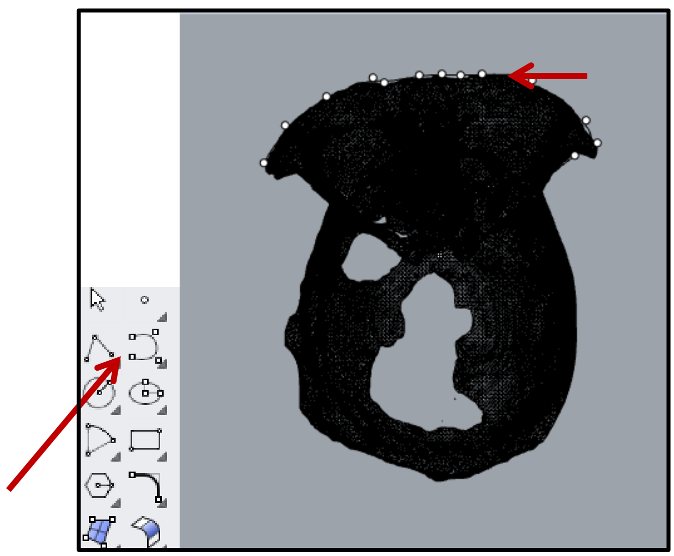
[Step 1-3] Create a 3D reference surface by using the command “***Drape***”.



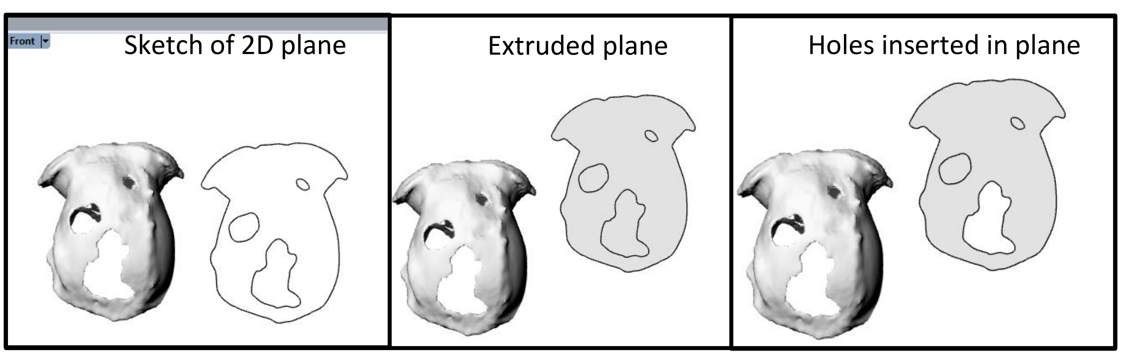
Trim all parts not needed by drawing a planar line, extruding (“***ExtrudeCrv***”) and cutting (“***Trim***”) it.



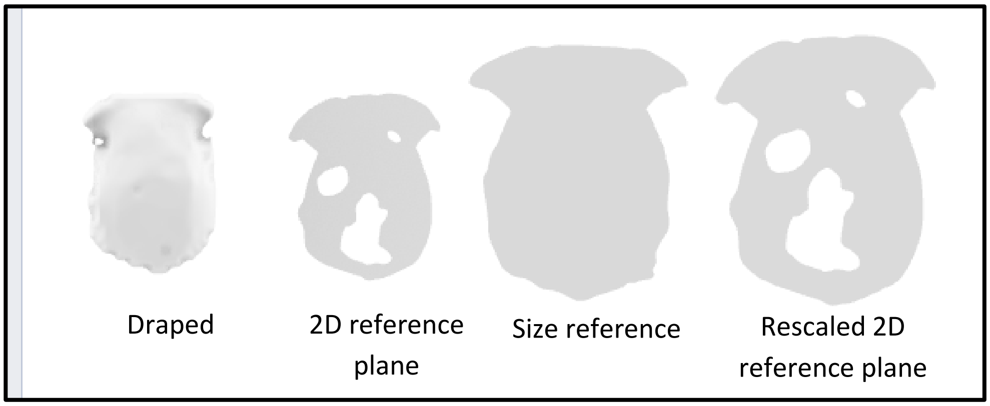
[Step1- 4] Create a 2D reference plane by using "***Control Point Curve***". Make sure to draw the uneven features of your original skull reconstruction, if they are not artefacts and need to be integrated in the designing process (e.g. skull holes).



[Step 1-5] Extrude sketch by entering the command "***PlanarSrf***" Create holes in the 2D reference plane by using "***MakeHole***".

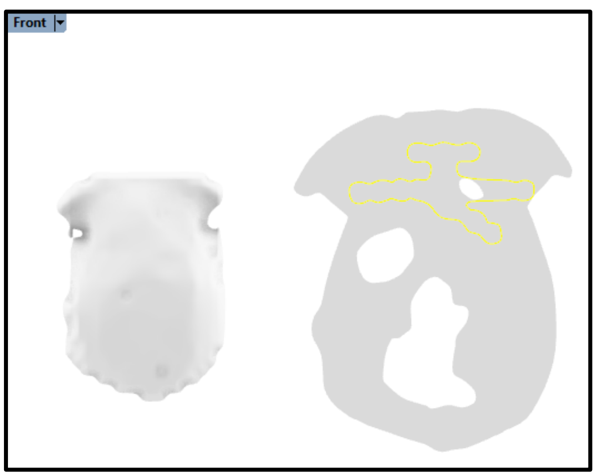


[Step 1-6] Scale the 2D reference plane so it matches the 2D reference plane ("***Scale***"). This plane is provided in the folder "parts_to work with"->06-planarSkullSizeTemplate" can be used as a size reference for an averaged sized male macaque skull.

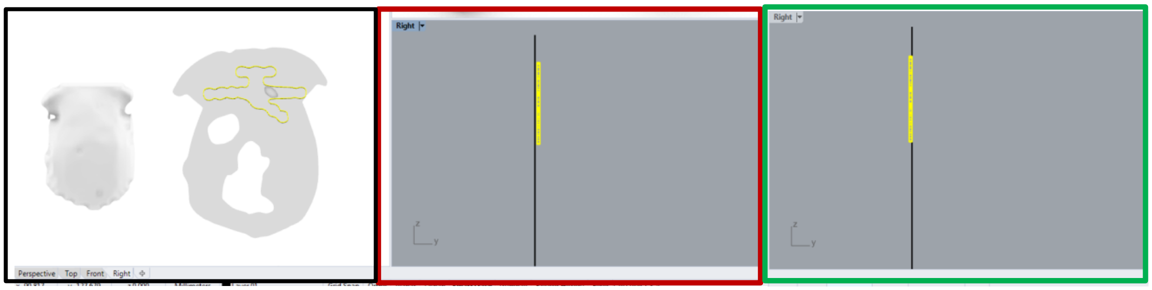


Designing and fitting process - implants with maintained thickness (virtual bending)

[Step 1-7] To design implants where thickness after matching the skull curvature needs to be maintained, draw the sketch on the 2D reference plane (our lab: headposts and chambers' legs width >7mm so M3 screws fit in).



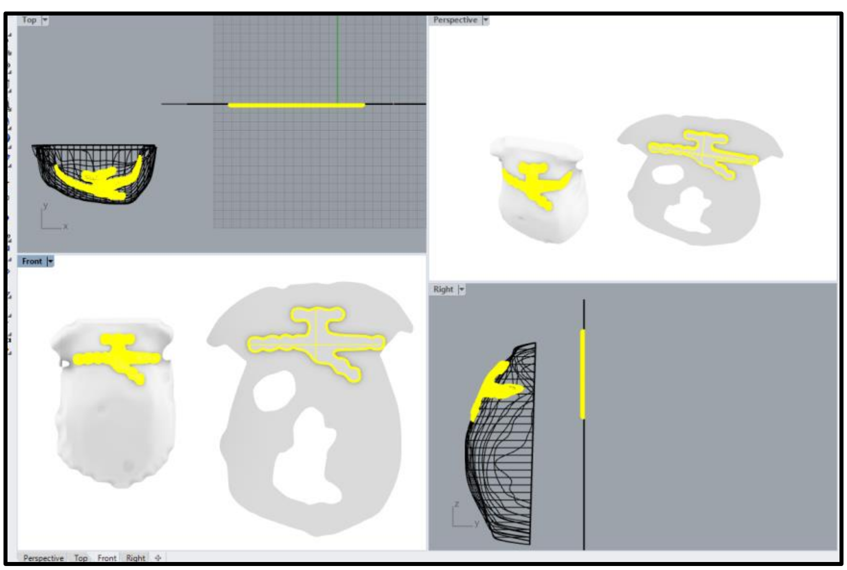
Extrude the sketch by using "***ExtrudeCrv***" to the thickness of your choice (our lab: 2mm). Make sure to create a "solid" extrusion (option during ***"ExtrudeCrv "*** - command). Confirm the correct position of implant on the 2D reference plane and make sure that it is placed on **top** and **not under** the reference plane.



Smooth the edges of your extrusion ("***FilletEdge***"). This step needs to be performed **before** bending the legs to avoid problems in the next steps.

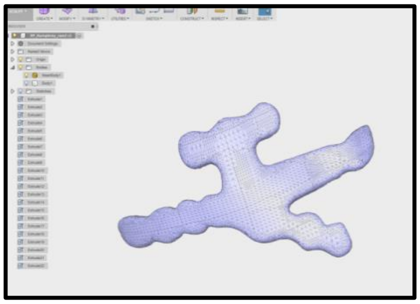
[Step 1-8] virtual bending
To mold the created part while maintaining a constant thickness use "***FlowAlongSrf***" and choose the 2D planar skull surface as the reference plane and the 3D skull surface as target. Check the result by placing it onto the original reconstructed skull.

[Step 1-9] When satisfied, this part can be modified further to create the required screw holes. These modifications can either be done in Rhino or in any other CAD software of your choice. To export for further use in a different CAD program, select the implant and export it in .STEP - format (***File -> Export Selected***).



a. Create the screw holes.using Fusion

[Step 1-10] Import in Fusion 360 and rescale the model (factor 0.1) as Fusion downscales imported models by default.



[Step 1-11 - create screw holes using Fusion] The screw holes are created by drawing circular holes placed on the implant surface which are then extruded with the option "cut".

Measurement summary of our lab:

Screw holes: diameter 3 mm, extrude and cut 0.6 mm depth with taper angle 0°
diameter 3 mm, extrude and cut by 1.00 mm with taper angle 45°

b. Or using Rhinoceros

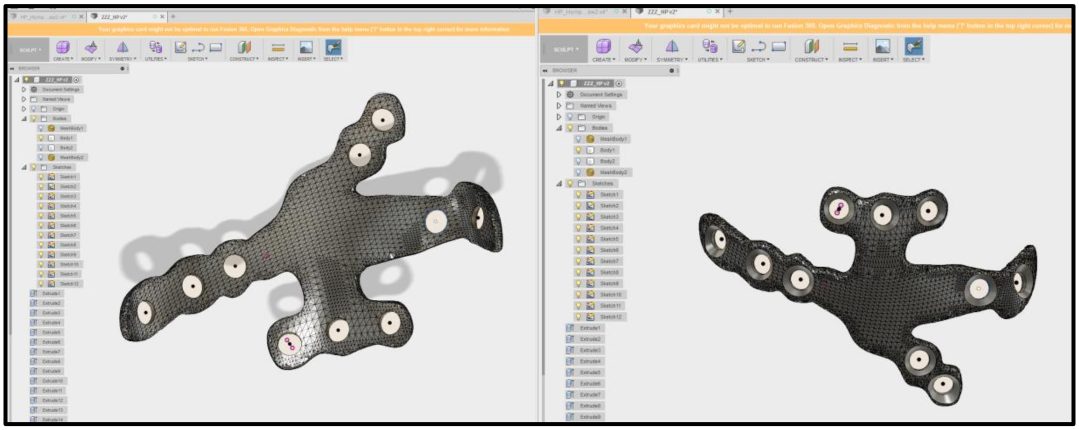
[Step1- 11- create screw holes using Rhino] Use the command ***"RoundHole"*** and select the legs as the target surface. Select the suitable depth and radius for the holes and make sure to set the directions options to **"SrfNormal".** You can create all holes in the same process. When finished, press enter. To create a taper angle use ***"ChamferEdge"*** and set the width (our lab: 1mm). Export implant in the file format suited for the manufacturing process of your choice.

[Step 1- 12] Place top part of implant.

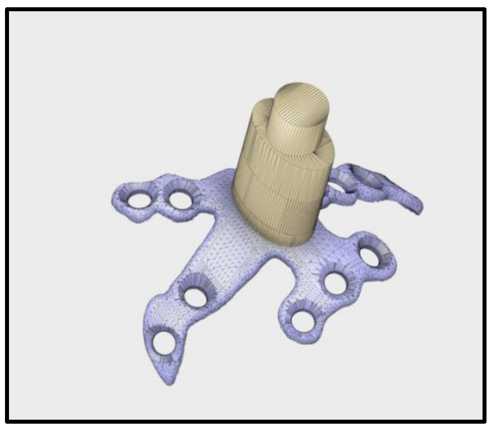
For completion purposes the ellipsoid and cylinder measurements of the headpost's top part are given. If you want to use the standard of our lab, you can simply import the file "12-Clyinder_H" and place it on top of the legs.

Ellipsoid: length 12.7 mm, width 8.00 mm, extrusion 14.00 mm
Top Cylinder: diameter 6.80 mm, extrusion 6.00 mm

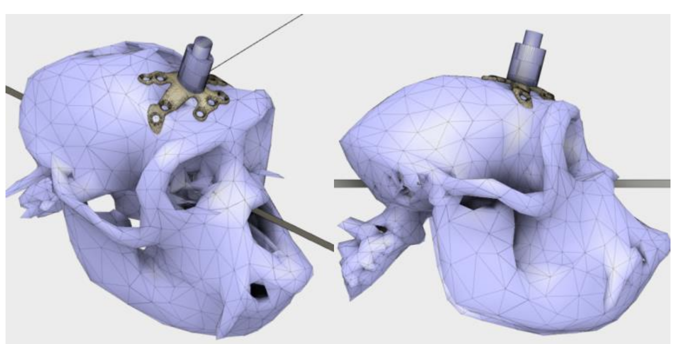
Make sure to angle and rotate the top part so it's perpendicular to your skull and not tilted.



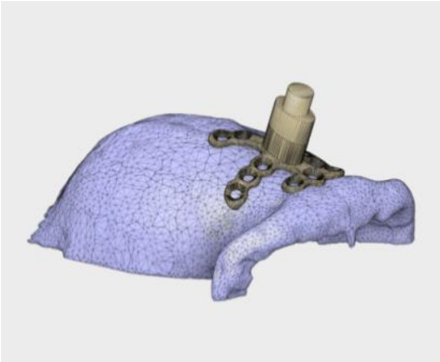
[Step 1-13] Convert the implant from “brep” to “mesh” and export implant in the file format suited for the manufacturing process of your choice. It is recommended to use .STL for 3D printing and .STEP for CNC milling.



[Step 1- 14] Verify fit and location of implant by placing it on the original extracted 3D skull.



Headpost designed for an even, smooth skull of a naïve animal.



Designing and fitting process - broad-spread implants without maintaining the thickness (virtual cutting)

Implants that extend over a large part of the skull and do not require to maintain their thickness are fitted as explained in the following.

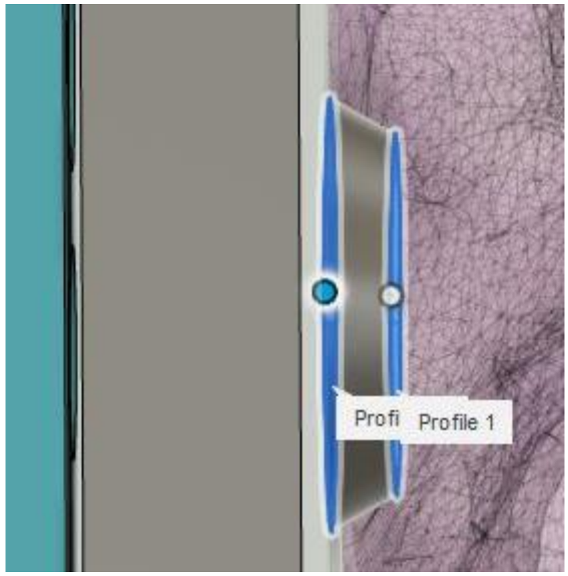
As an example for this type of implant we will show how to design and fit a chamber for wireless recordings. Again, all designing steps can be done in Rhino or any other CAD program of your choice, experience and convenience.

Details about the designing can be found in these video tutorials:

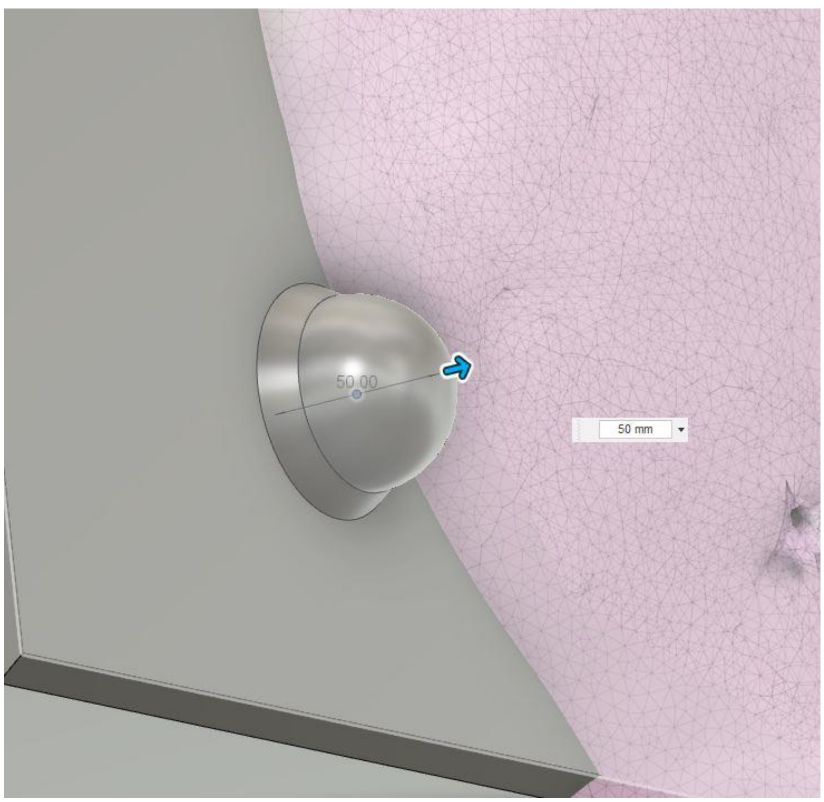
[Step 2-1] Design the main body
https://knowledge.autodesk.com/community/screencast/e2d2ce50-7afa-4d00-a959-b472e75504fd

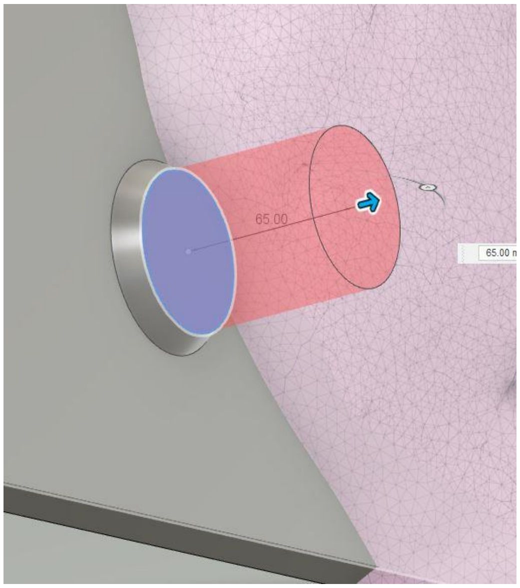
[Step 2-2a] Create eyelets
https://knowledge.autodesk.com/community/screencast/f108f929-814f-4b80-88d4-f1173e3b126e

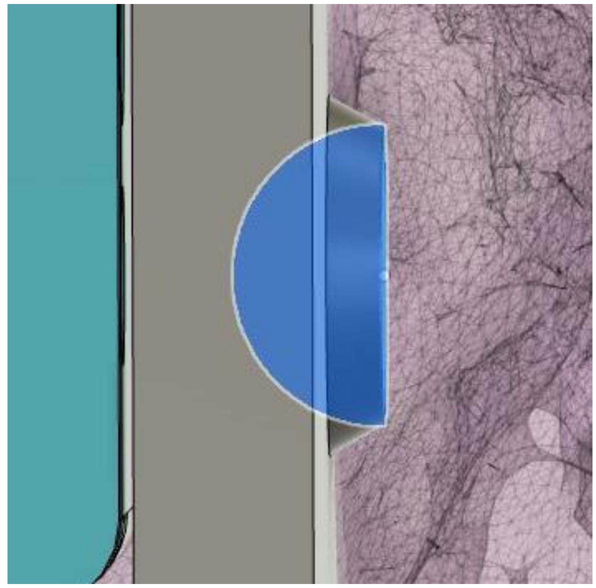
[Step 2-2b] Alternative way of creating eyelets.
Draw two circles on the implant wall with the diameters 6 and 5 mm. Extrude by lofting (Create -> Loft).



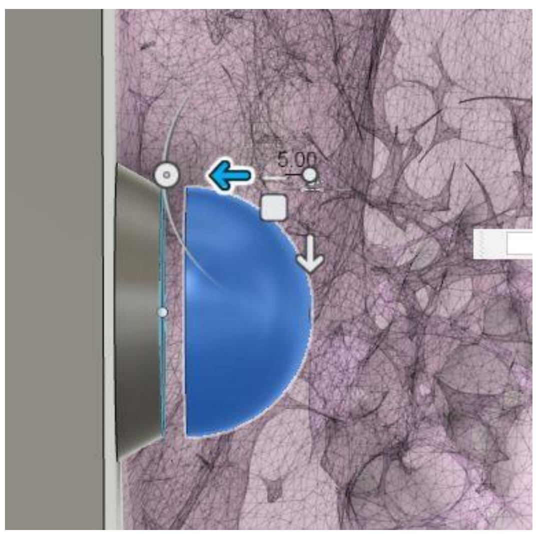
Create a sphere on the surface, which has the diameter 5mm. The sphere should have a radius of 5mm. Cut one half of the sphere by extruding the inner surface.



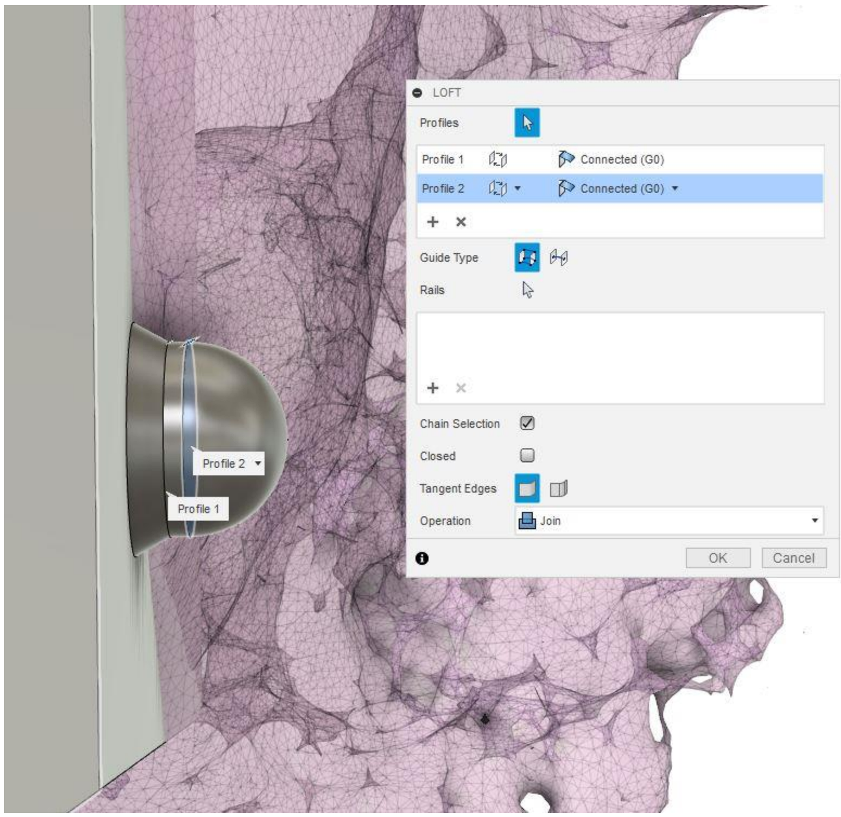




Rotate the Sphere by 180 degrees and create a distance between the cut sphere and the inner surface by 0.5mm.



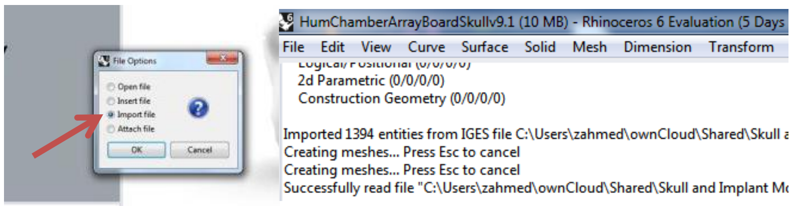
Bridge the gap by creating a Loft.



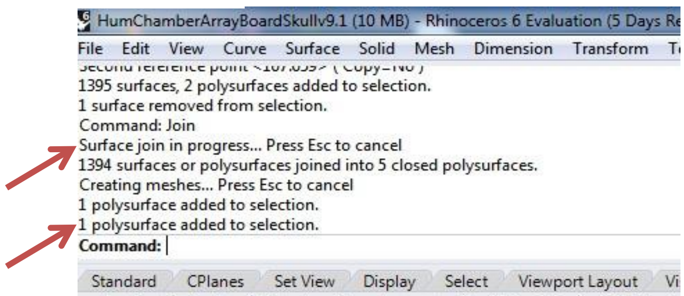
[Step 2-3] How to make a hole through the eyelet of the implant: https://knowledge.autodesk.com/community/screencast/95b632af-a998-497e-ab5f-031518697e4e

[Step 2-4] Before fitting, a 2D and 3D reference plane and surface need to be created (see Preparation). If not designed in Rhino, import the raw (not molded) chamber and all its parts in Rhino after saving them in .IGES. ***'Join'*** all parts.

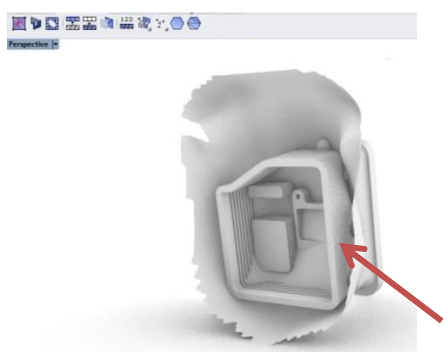
Import to Rhino



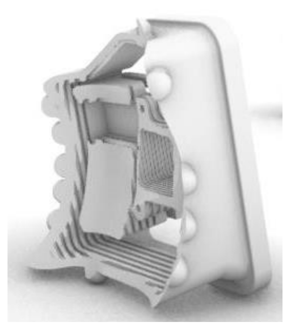
Join imported .iges



[Step 2-5] Place the implant on the 3D reference skull and push it through till an intersection is created between the raw chamber and the 3D skull surface.

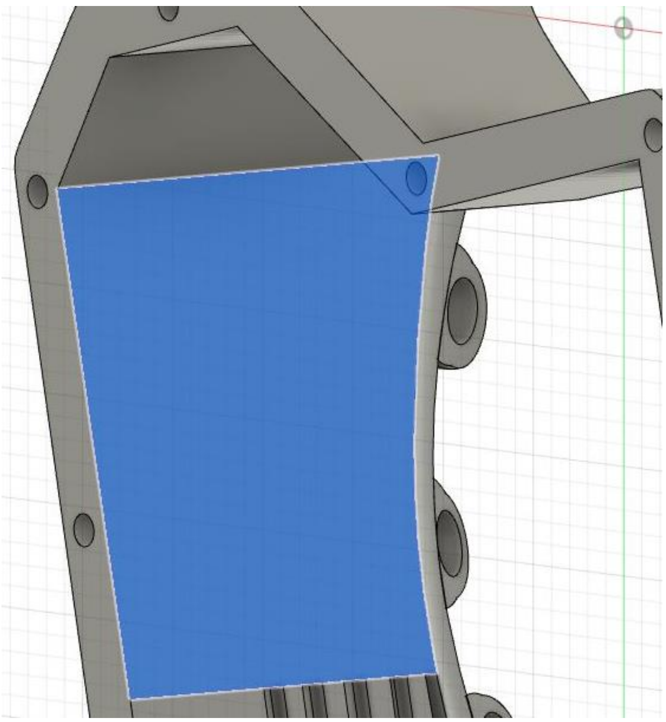
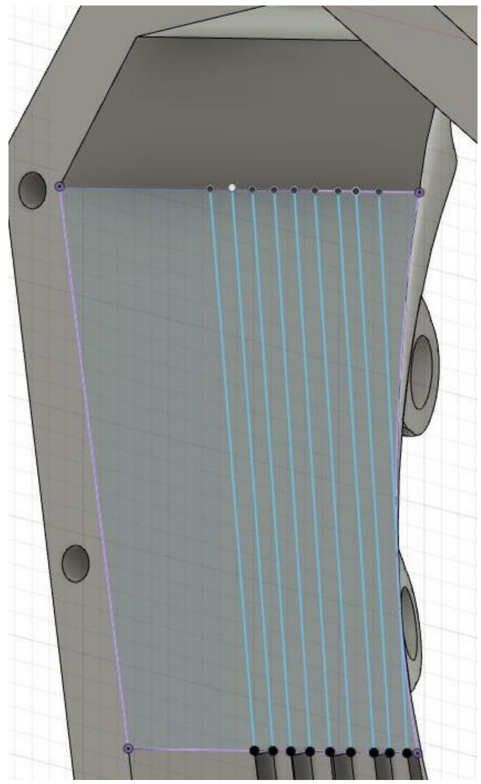


[Step 2-6] For fitting this type of implants use ***"BooleanDifference"***. Detailed description shown in [**Step 15 - create chamber top**]

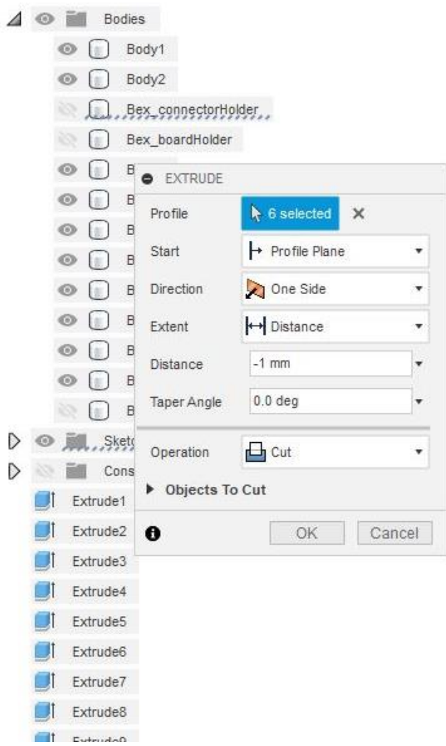


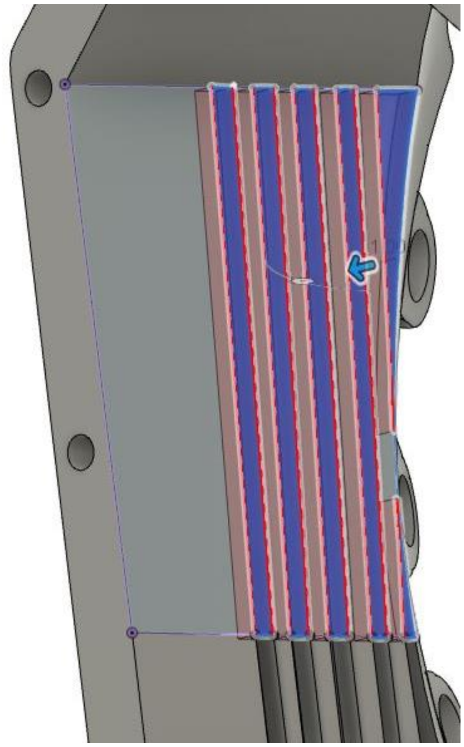
Export the fitted and customized implant in .STP format for CNC milling or importing to other CAD software. Use .STL for 3D printing.

[Step 2-7] Design furrows (can be designed before or after virtual cutting)..
Select inner side walls on which you want to create furrows. Press “Project” (key: P) to create a projection plane onto the wall.
Now draw rectangles that can be extruded into furrows.

Select the rectangles and extrude to 1mm to create the furrows.





Designing and fitting process - Hybrids

Implants requiring a mixture of both methods can be created as well.

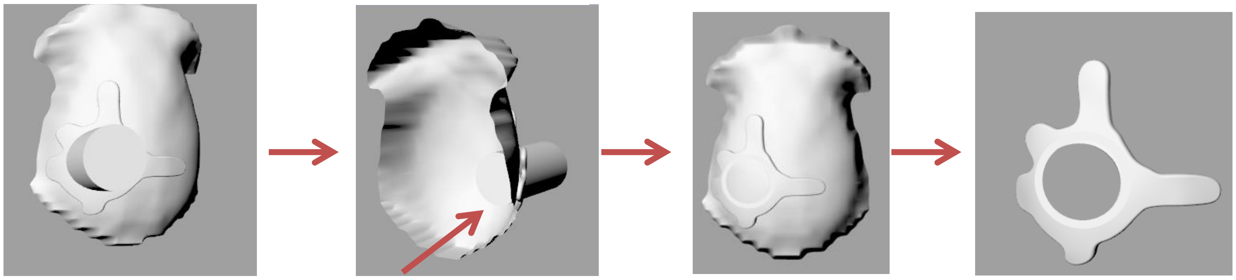
In our example we show how to create a standard chamber.
This type of implant consists of legs, which should maintain their thickness for better osseointegration and a body which allows access to the craniotomy. This body does not need to maintain the same thickness but has to only follow the skull curvature.

For designing the legs the same procedure as described in "Designing and fitting process - implants with maintained thickness" is used.

[Step 3-1] The basis of the top part is a cylinder (command ***"Cylinder")*** that is created on top of the bottom part (here legs). Set the diameter and the height to your choice (our lab: diameter 24mm, end of cylinder 30mm).
Tilt and move till the top part is properly oriented and angled.
Pull the top part through both - the bottom part and the 3D skull surface - to generate an intersection.
Create access to the craniotomy with ***"RoundHole"*** and select the cylinder as the *"target surface".* To cut through the bottom part of the implant use ***"RoundHole"*** again but set direction to *"Pick"* (instead of ***"SrfNormal").***

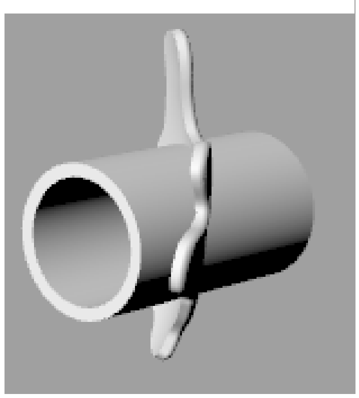
[Step 3-2]

Create cylindric top part | Push cylinder through skull | Create hole in the chamber | Create access to the craniotomy

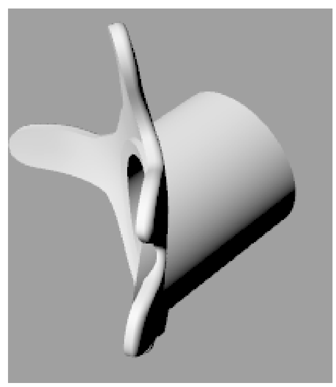


The top part of the chamber can be fitted to the skull curvature by using the ***"BooleanDifference"*** (for details see "Designing and fitting process - broad spread implants without maintaining the thickness").

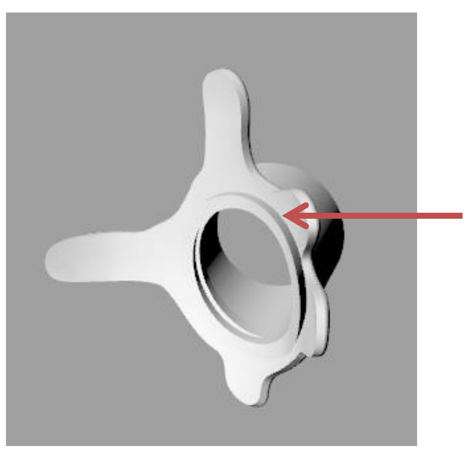
Unfitted hybrid implant



Matched skull curvature



[Step 3-3] As the last step push the molded top part through the legs till around 1mm is sticks out on the other side. This allows a better fit to the craniotomy during surgery.



Export the implant in the appropriate file format. We recommend to use .STL for 3D printing and .STEP for CNC milling.