InVesalius

User Guide

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About InVesalius

InVesalius is public health software that performs analysis and segmentation of Virtual anatomical models, enabling the creation of physical models with the aid of rapid prototyping (3D printing). From two-dimensional (2D) images obtained through Computed Tomography (CT) or Magnetic Resonance Imaging (MRI), the program allows users to create three-dimensional (3D) anatomical representations of patients for further medical use.

InVesalius is named in honour of the Belgian doctor Andreas Vesalius (1514-1564), widely considered the father of modern anatomy. InVesalius software is developed by CTI (Center for Information Technology Center Renato Archer), a unit of the Brazilian Ministry of Science and Technology (MCT), since 2001. Initially, only the installation program was distributed as freeware. In November 2007 InVesalius was made fully available as free software and open source via the Public Software Portal, allowing for communities of users and developers to connect. InVesalius is, in short, a simple yet robust, free cross-platform tool that is easy to use.

The use of visualization technologies and three-dimensional analysis of medical images, when combined with rapid prototyping (3D printing), assists the surgeon in diagnosing pathologies and a detailed surgical planning and simulation of complex process in advance, which may involve, for example, a high degree of facial deformity or integration of prosthetics.

InVesalius has demonstrated great versatility and has applications in different areas, including medicine, dentistry, veterinary medicine, archeology and engineering.

Download options:

- https://www.cti.gov.br/invesalius
- http://invesalius.github.io
- www.softwarepublico.gov.br

Contents

Chapter 1

Introduction

This manual aims to guide end users in the application of InVesalius tools and also presents some concepts to facilitate the use of the software.

InVesalius is software that is designed to assist health professionals on diagnosis and surgical planning. It should be noted, however, that all software in the diagnostic context is fully supplementary, and each and every act committed is the responsibility of health professionals.

In addition to medicine, InVesalius can be utilized in other areas such as archeology, medicine, dentistry, veterinary, or even in industrial applications. As a basic requirement, the images to be analyzed are in DICOM (Digital Imaging Communications in Medicine). To date, InVesalius reconstructs images stemmed from CT scanners and MRI machines. To operate the software, basic computer literacy is essential. Understanding medical images can help to form a better understanding of the operations.

1.1 Important Concepts

Detailed in this section are a list of concepts essential to better understand and operate the software.

1.1.1 DICOM (*Digital Image Communications in Medicine*)

DICOM is a standard the transmission, storage and treatment of medical images. The standard encompasses various origins of medical images, such as images emanating from computed tomography (CT) equipment, magnetic resonance, ultrasound, and electrocardiogram, among others.

A DICOM image consists of two main components, namely, an array containing the pixels of the image and a set of meta-information. This information includes, but is not limited to, patient name, mode image and the image position in relation to the space (in the case of CT and MRI).

1.1.2 Computed Tomography - Medical

Computed tomography indicates the radiodensity of tissues, i.e., the average X-ray absorption by the tissues. The radiodensity reading is translated into an image gray levels, called the Hounsfield scale, named Godfrey Newbold Hounsfield, one of the creators of the first CT scan.

Figure 1.1: Medical CT scanner - www.toshibamedical.com.br

Most modern CT scanning appliances are equipped with a radiation emitter and a sensor bank (with channels ranging from 2 to 256), which circle the patient while the stretcher is moved, forming a spiral. This generates a large number of images simultaneously, with little emission of X-rays.

Hounsfield Scale

As mentioned in the previous section, the CT images are generated in gray levels, expressed in Hounsfield (HU), wherein lighter shades represent denser matters, and the darker, less dense matter such as skin and brain tissues.

Table 1.1 presents some materials and their respective values in Hounsfield Units (HU).

Table 1.1: Escala de Hounsfield

Material	HU
Air	-1000 or less
Fat	-120
Water	0
Muscle	40
Contrast	130
Bone	400 or more

1.1.3 Computed Tomography - Dental (CBCT)

The dental CT commonly works with less radiation emission compared to medical CT, and therefore makes it possible to view more details of delicate regions such as alveolar cortical.

Figure 1.2: Dental tomography - www.kavo.com.br

Image acquisition is performed with the patient positioned vertically (as opposed to medical tomography in which the patient is horizontal). A transmitter X-ray surround the patient's skull, forming an arc of 180° or 360°. The images generated are compiled as a volume of the patient's skull. This volume is then "sliced" by the software into individual layers, being able to generate images with different spacing or fields of view, such as a panoramic view of the region of interest.

The images acquired by dental scanners often require more post processing when it is necessary to separate (segmental) certain structures using other software such as InVesalius. This is because, typically, these images have more gray levels than, which makes use of segmentation patterns (preset) less. Another very common feature in the images of provincial dental CT scanners is the high presence of speckle noise and other forms of noise typically caused by the presence of amalgam prosthetics.

1.1.4 Magnetic Resonance Imaging - MRI

MRI is an examination performed without the use of ionizing radiation. Instead, it use a strong magnetic field to align the atoms of any element present in our body, most commonly hydrogen. After alignment, radio waves are triggered to excite atoms. The sensors measure the time that the hydrogen atoms take to realign. This makes it possible to distinguish between different tissues, as different types possess different quantities of hydrogen atoms.

To avoid interference and improve the quality of the radiofrequency signal, the patient is placed inside a narrow tube encompassed by the coil and scanning unit.

1.1.5 Neuronavigation

Neuronavigation is a technique that allows tracking and localization of surgical instruments relative to neuronal structures through computer visualization. In addition, neuronavigation systems a fundamental tool to aid surgical plan and to increase the accuracy of experiments in neuroscience, such as transcranial magnetic stimulation (TMS), electroencephalography (EEG),

Figure 1.3: Magnetic resonance imaging equipment - www.gehealthcare.com

Figure 1.4: Coil - www.healthcare.philips.com

magnetoencephalography (MEG) and near-infrared spectroscopy (NIRS). Despite the vast field of applications, the use of neuronavigation in research centers is limited by its high cost. InVesalius Navigator offers users a low-cost, open-source alternative to commercial neuronavigation systems. In this sense, it is possible to use specific tools for neuronavigation and still have the possibility of developing features on demand. The software for neuronavigation is distributed in an executable version compatible with Windows 7, 8 and 10 operating system. The chapter 16 goes into details of all features of neuronavigation in InVesalius.

1.2 Resources needed

InVesalius is designed to run on personal computers, such as desktops and notebooks. Currently, it is compatible with the following operating systems:

- Microsoft Windows (Windows 7, 8, 10)
- GNU/Linux (Ubuntu, Mandriva, Fedora)
- Apple Mac OS X

The performance of InVesalius depends mainly on the amount of reconstructed slices (images offered by the software), the amount of random access memory (RAM) available, the processor clock rate & frequency, and operating system architecture (32-bit or 64-bit).

It is important to note that, as a general rule, the greater the amount of RAM available on the system, the greater the number of slices that can be opened simultaneously. For example, with 1 GB of available memory, it can open about 300 slices with a resolution of 512x512 pixels. With 4 GB of memory, around 1000 images can be opened simultaneously at the same resolution.

1.2.1 Minimum settings

- 32-bit Operating System
- Intel Pentium 4 or equivalent 1.5 GHz
- 1 GB of RAM
- 10 GB available hard disk space
- Graphics card with 64 MB memory
- Video resolution of 1024x768 pixels

1.2.2 Recommended settings

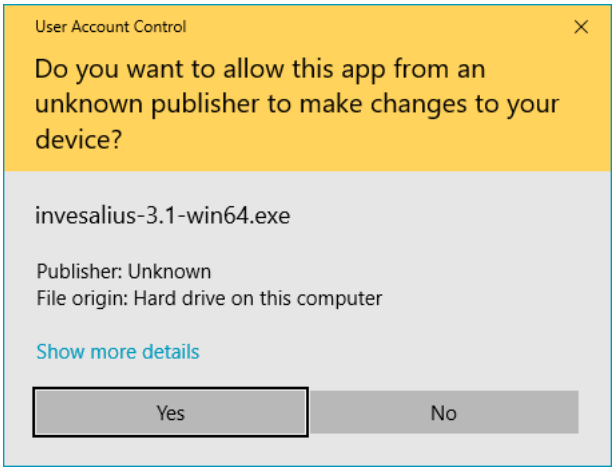
- 64-bit Operating System
- Intel Core 2 Duo processor or equivalent 2.5 GHz
- 8 GB of RAM
- 20 GB available hard disk space
- NVidia or ATI graphics card with 128 MB of memory
- Video resolution of 1920x1080 pixels

Chapter 2

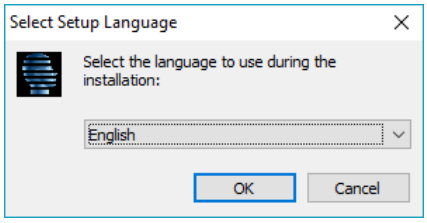
Installation

2.1 MS-Windows

To install InVesalius on MS-Windows, simply run the installer program. When a window asking you to confirm the file execution appears, click **Yes**.

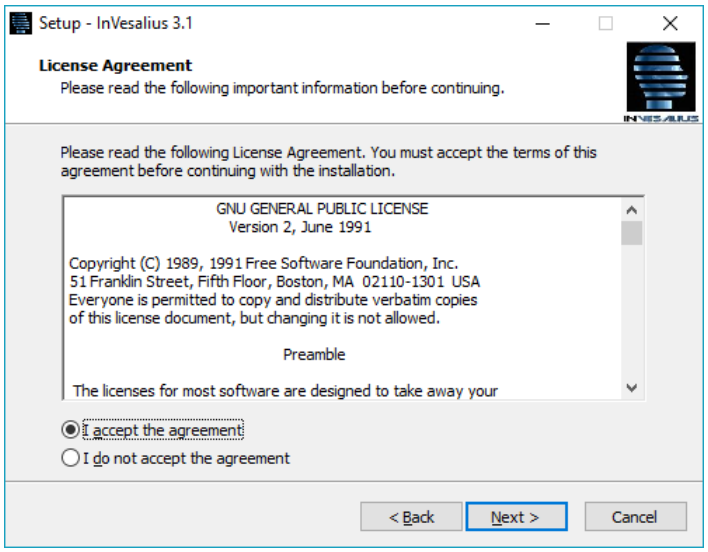


A new window will ask you to select the language of the installer. Select the language and click **OK**.

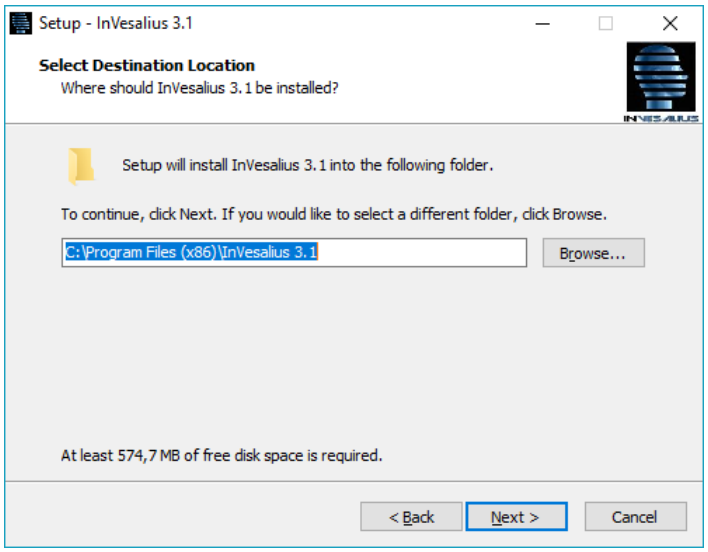


The Setup installer will appear. Click **Next**.

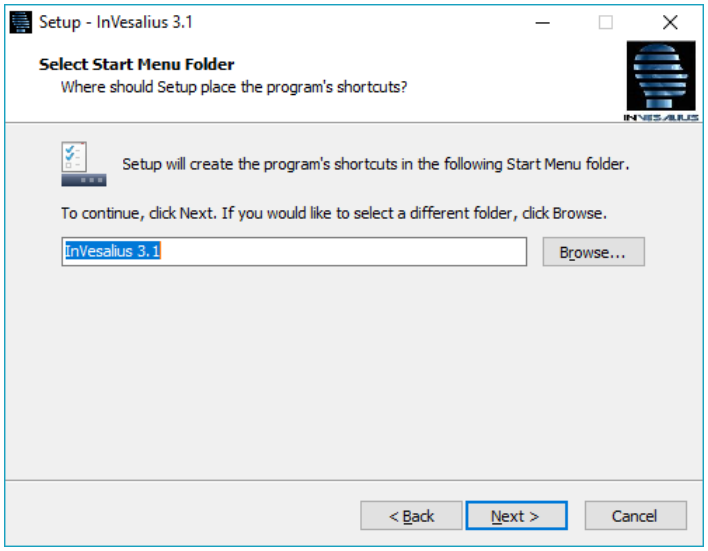
Select **I accept the agreement** and click on **Next** button.



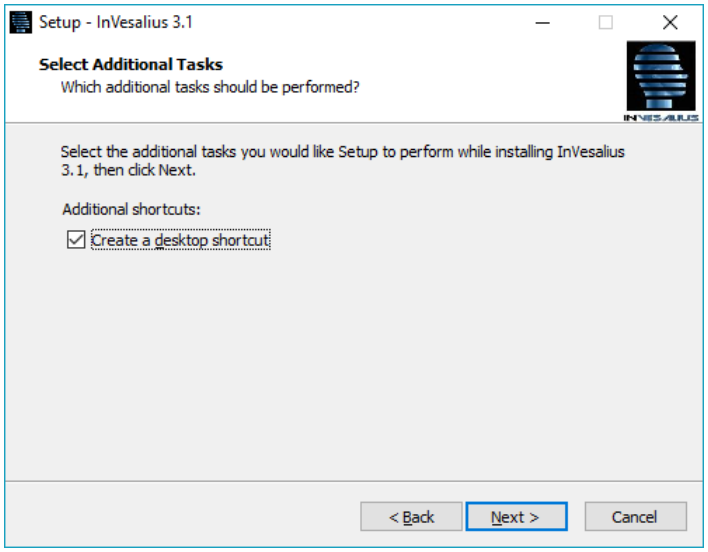
Select the preferred destination for the InVesalius program files, then click **Next**.



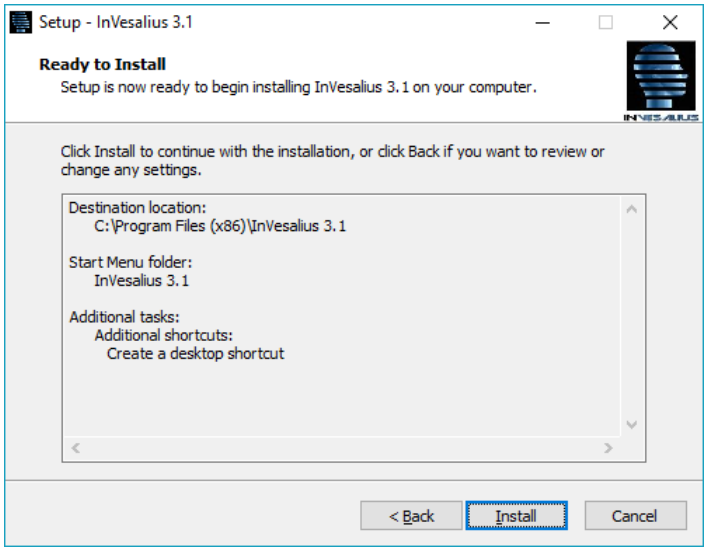
Click on **Next** button.



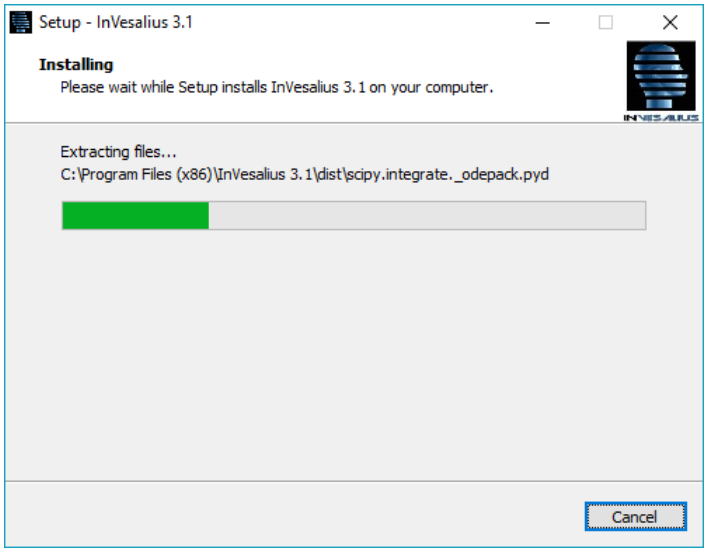
Select **Create a desktop shortchut** and click on **Next**.



Click on **Install** button.



While the software is being installed, a progress window will appear.

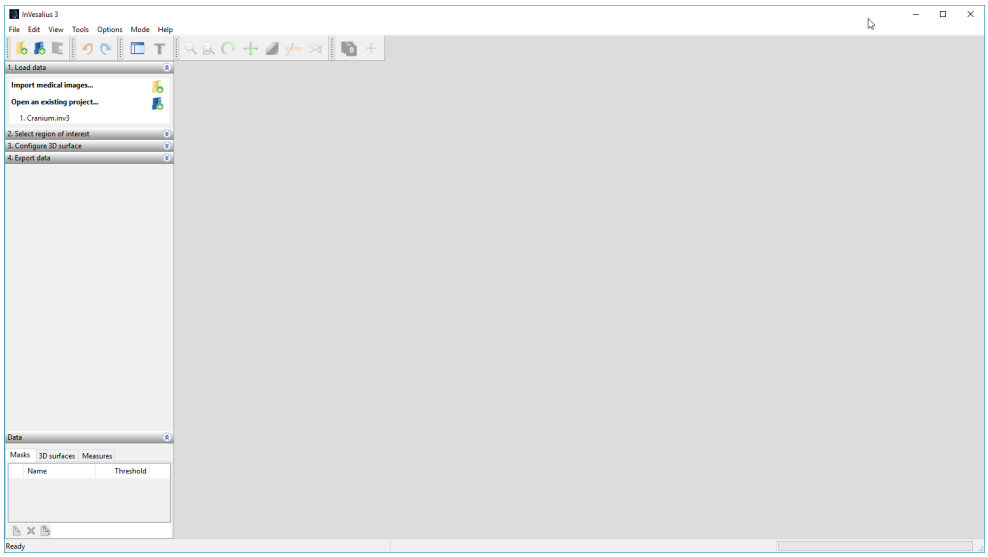


To run InVesalius after installation, check **Lauch InVesalius 3.1** and click on **Finish** button.

When being run for the first time, a window will appear to select the InVesalius language. Select the desired language and click **OK**.

While InVesalius is loading, the opening window shown below will be displayed.

The main program window will then open, as shown below.



2.2 Mac Os X

To start the installation on Mac OS X, double-click the installer with the left mouse button to begin installation.

Hold down the left button on the InVesalius software icon and drag it to the Applications folder. Both are contained in the installer.

The software is already installed, just access through the menu.

Chapter 3

Image import

InVesalius imports files in DICOM format, including compressed files (lossless JPEG), Analyze (Mayo Clinic©), NIfTI, PAR/REC, BMP, TIFF, JPEG and PNG formats.

3.1 DICOM

Under the File menu, click on Import DICOM or use the shortcut Ctrl+I. Additionally, DICOM files can be imported by clicking on the icon shown in Figure 3.1.

Figure 3.1: Shortcut to DICOM import

Select the directory containing the DICOM files, as in Figure 3.2. InVesalius will search for files also in subdirectories of the chosen directory, if they exist.

Once the directory is selected, click **OK**.

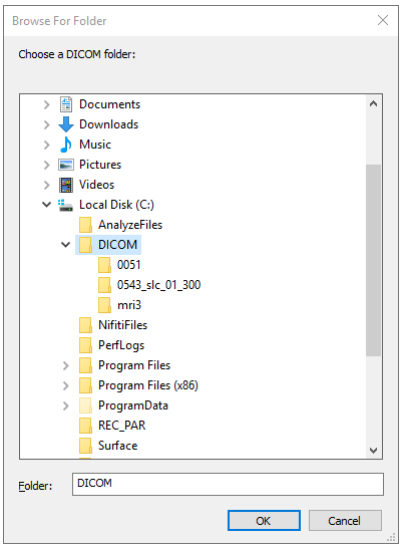


Figure 3.2: Folder Selection

While InVesalius search for DICOM files in the directory, the loading progress of the scanned files is displayed, as shown in the Figure 3.3.

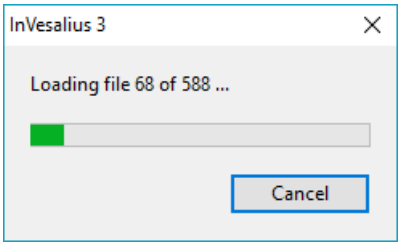


Figure 3.3: Loading file status

If DICOM files are found, a window open (shown Figure 3.4) will open to select the patient and respective series to be opened. It is also possible to skip images for reconstruction.

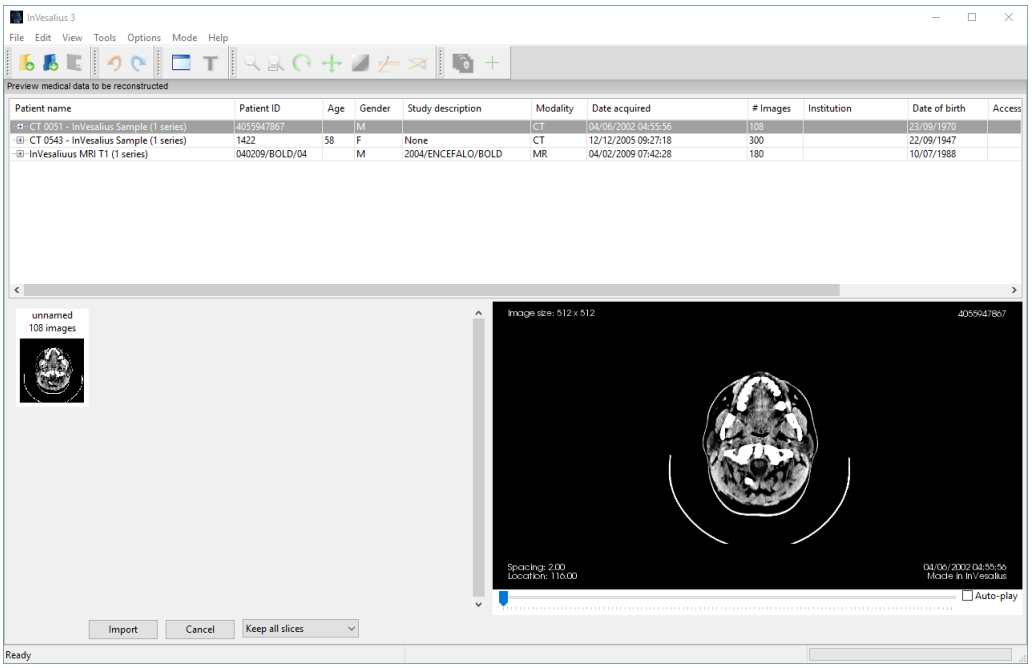


Figure 3.4: Import window

To import a series with all images present, click "+" on the patient's name to expand the corresponding series. Double-click on the description of the series. See Figure 3.5.

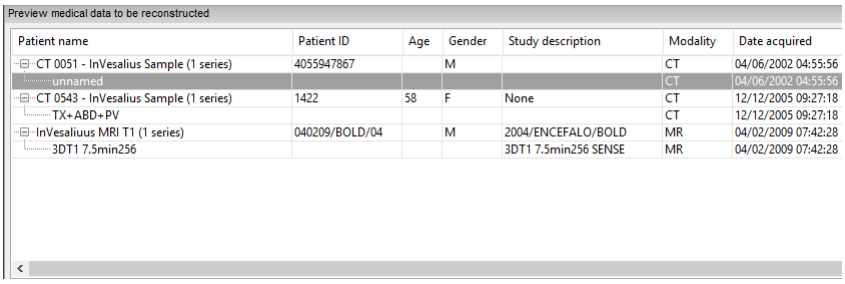


Figure 3.5: Series selection

In some cases, when there is no computer with memory and/or satisfactory processing to work with large numbers of images in a series, it is recommended to skip some of them. To do this, click **once** with the **left** mouse button over the description of the series (Figure 3.5) and select how many images will be skipped (Figure 3.6), then click **Import**.

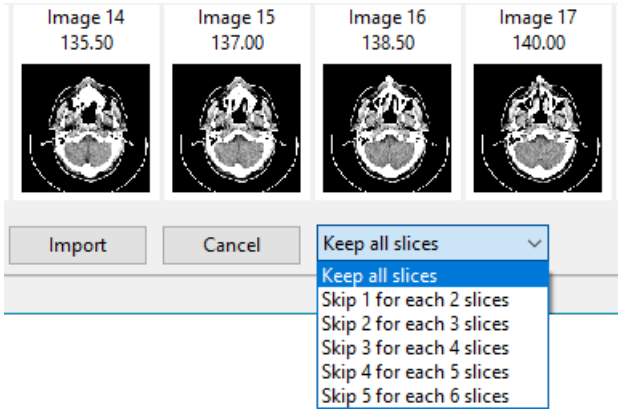


Figure 3.6: Skip imagens option

If there is an insufficient amount of available memory at the time of loading the images it is recommended that the resolution of the slices be reduced to work with volumetric and surface visualization, as shown in Figure 3.7. The slices will be resized according to the percentage relative to the original resolution. For example, if each slice of the exam the dimension of 512 x 512

pixels and the "Percentage of original resolution" is suggested to be 60 %, each resulting image will be 307 x 307 pixels. To open with the original pixel resolution, set the percentage to 100.

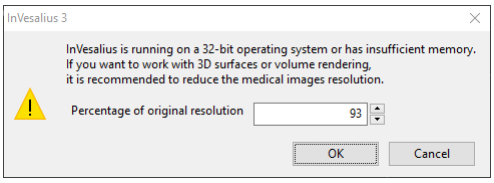


Figure 3.7: Image size reduction

If the image was obtained with the gantry tilted it will be necessary to correct to avoid distortion of any reconstruction. InVesalius allows the user to do this easily. When importing an image with the gantry tilted a dialog will appear, showing the gantry tilt angle. (Figure 3.8). It is possible to change this value, but it is not recommended. Click on the **Ok** to do the correction. If you click on the **cancel** button the correction will not be done.

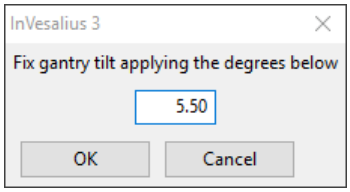


Figure 3.8: Gantry tilt correction

After the above procedure, a window will be displayed (Figure 3.9) with reconstruction (when images are stacked and interpolated).

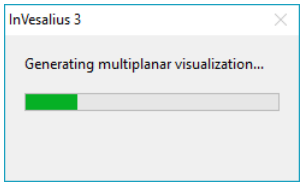


Figure 3.9: Reconstruction progress

3.2 Analyze

To import Analyze files, under the **File** menu, click **Import other files**, then click in the **Analyze** option as show the Figure 3.10.

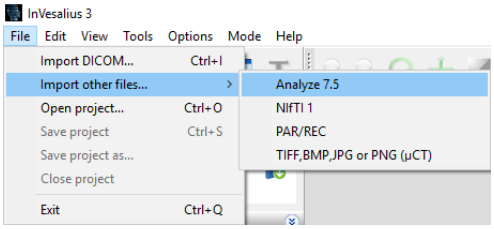


Figure 3.10: Menu for importing images in analyze format.

Select the Analyze file format (**.hdr**) and click on **Open** (Figure 3.11).

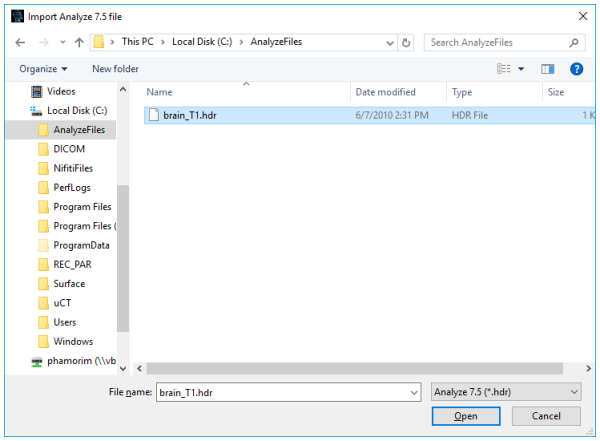


Figure 3.11: Import analyze file format

3.3 NIfTI

To import NIfTI files, under the **File** menu, click **Import other files** and then click **NIfTI** as shown in Figure 3.12.

Select the NIfTI file format, (either **nii.gz** or **.nii**) then click **Open** (Figure 3.13). If the file is in another format as **.hdr**, select **all files(*.*)** option.

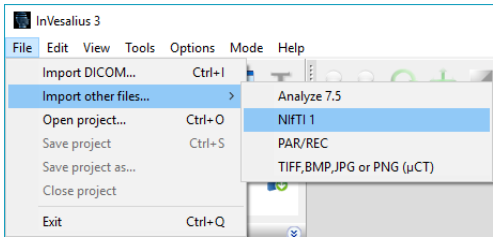


Figure 3.12: Menu to import images in NIfTI format

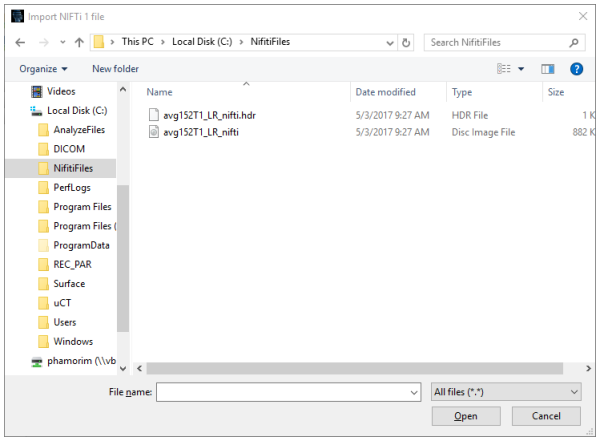


Figure 3.13: Importing images in NIfTI format.

3.4 PAR/REC

To import PAR/REC file, under the **File** menu, click **Import other files**, and then click on **PAR/REC** as shown in Figure 3.14.

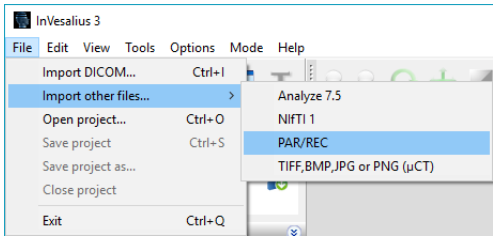


Figure 3.14: Menu for importing PAR/REC images

Select PAR/REC file type, with the file extension **.par** and click **Open** (Figure 3.15). If the file has no extension, select **all files(*.*)** option.

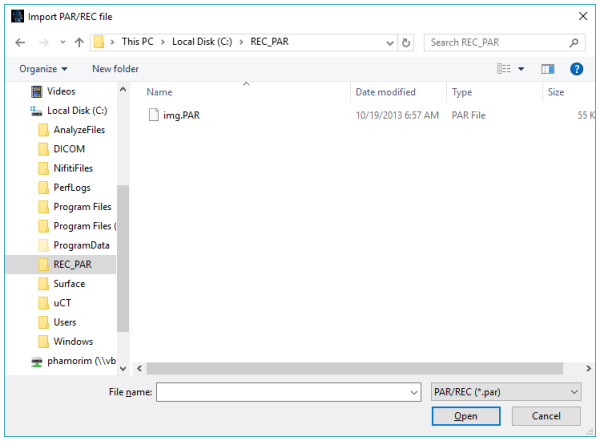


Figure 3.15: PAR/REC import

3.5 TIFF, JPG, BMP, JPEG or PNG (micro-CT)

TIFF, JPG, BMP, JPEG or PNG file format for microtomography equipment (micro-CT or μCT) or others. InVesalius imports files in these formats if pixels present are represented in **grayscale**.

To import, click on menu **File**, **Import other files...** and then click on **TIFF, JPG, BMP, JPEG ou PNG (μCT)** option as shown the figure 3.16.

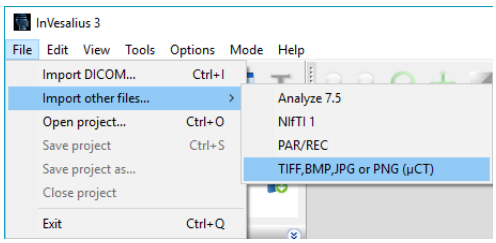


Figure 3.16: Import images in BMP and others formats

Select the directory that contains the files, as shown the Figure 3.17. InVesalius will search for files also in subdirectories of the chosen directory, if they exist.

Click on **OK**.

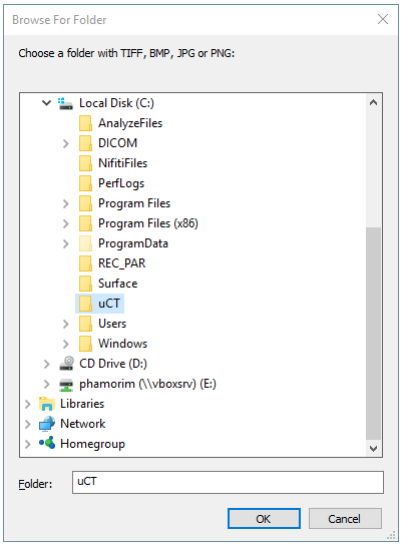


Figure 3.17: Folder selection

While InVesalius is looking for TIFF, JPG, BMP, JPEG, or PNG files in the directory, the upload progress of the scanned files is displayed, as illustrated in Figure 3.18.

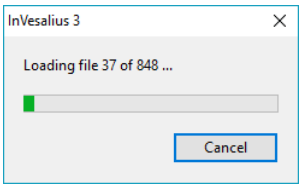


Figure 3.18: Checking and loading files status.

If files in the desired formats are located, a window will open (shown in Figure 3.19) to display the files eligible for reconstruction. Images can also be skipped to remove files from the rebuild list. The files are sorted according to file names. It is recommended that the files are numbered according to the desired rebuild order.

To delete files that are not of interest, select a file by clicking the left mouse button and then pressing the delete key. You can also choose a range of files to delete by clicking the **left mouse button** on a file, holding down the **shift** key, clicking again with the mouse button in the last file of the track and finally pressing the **delete** button.

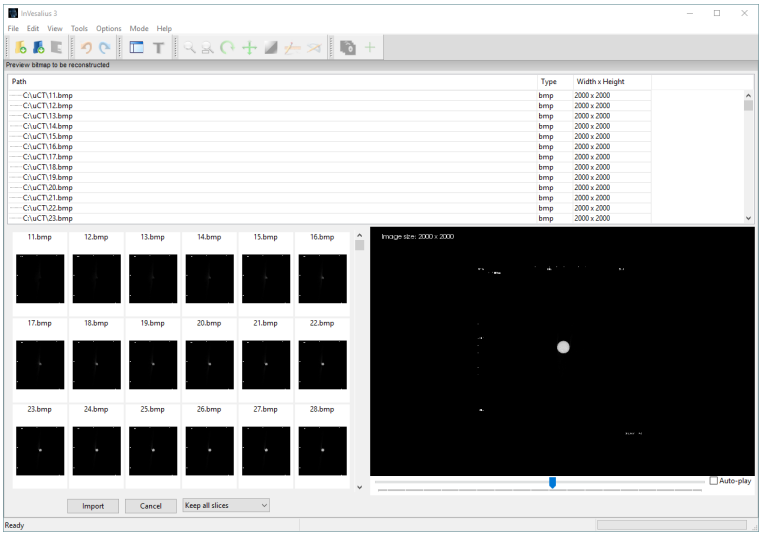


Figure 3.19: Window to import BMP files.

Similar to when importing DICOM files, you can skip BMP images for re-building. In some cases, particularly where a computer with satisfactory memory and/or processing is unavailable, it may be advisable to skip some of them to retain adequate program functionality. To do this, select how many images to skip (Figure 3.20), then click **Import**.

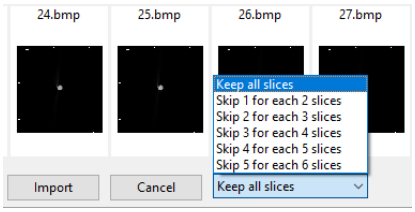


Figure 3.20: Importation window

To reconstruct files of this type, a project name must be defined to indicate the orientation of the images (axial, coronal or sagittal), voxel spacing (X, Y and Z) in **mm** as shown in the Figure 3.21. The voxel spacing in X is the pixel width of each image, Y the pixel length, and Z represents the distance of each slice (voxel height).

If the image set consists of microtomography images, more specifically GE and Brucker equipment, it is possible that InVesalius will read the text file with the acquisition parameters that normally stay in the same folder

as the images and automatically insert the spacing. This verification can be done when the values of X, Y and Z are different from "1.00000000", otherwise it is necessary to enter the values of the respective spacing.

Correct spacing is crucial for correctly importing objects in InVesalius. Incorrect spacing will provide incorrect measurements.

Once all parameters have been input, click **OK**.

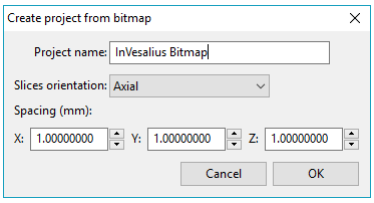


Figure 3.21: Import Screen

If insufficient memory is available when loading images, it is recommended to reduce the resolution of the slices to work with volumetric and surface visualization, as shown in Figure 3.22 window.The slices will be resized according to the percentage relative to the original resolution. For example, if each slice of the exam contains the dimension of $512x512$ pixels and the "Percentage of the original resolution" is suggested at 60, each resulting image will have $307x307$ pixels. If you want to open with the original resolution set the percentage to 100.

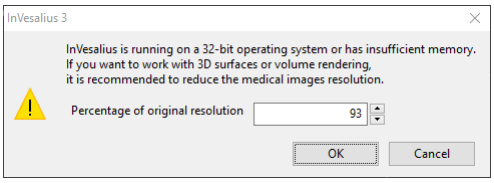


Figure 3.22: Image resize

After the previous steps, wait a moment for the program to complete the multiplanar reconstruction as shown in Figure 3.23.

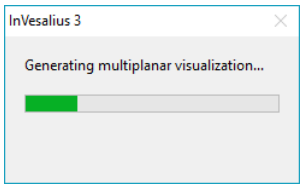


Figure 3.23: Multiplanar reconstruction in progress.

Chapter 4

Image adjustment

InVesalius cannot guarantee the correct image order; images may contain incorrect information, or do not follow the DICOM standard. Therefore, it is recommended to check if a lesion or an anatomical mark is on the correct side. If not, it is possible to use the flip image or swap axes tools. For image alignment, the rotation image tool can be used.

It is possible to mirror the image. To do so, select the **Tools** menu, click **Image**, then **Flip** and click on one of the following options (Figure 4.1):

- Right - Left
- Anterior - Posterior
- Top - Botton

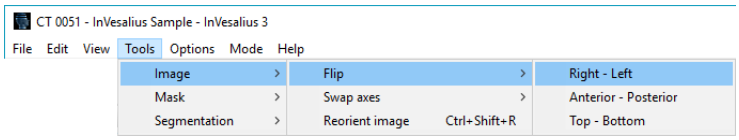


Figure 4.1: Menu to activate flip image tool.

Figure 4.2 shows a comparison between the input image and the flipped image. All other orientations are also modified when the image is flipped.

(a) Input image (b) Flipped image

Figure 4.2: Example of a right-left flipped image.

4.1 Swap axes

The swap axes tool changes the image orientation, in the case that the image has been wrongly imported. To perform this, select the **Tools** menu, click **Image**, then **Swap Axes** and click on one of the following options (Figure 4.3):

- From Right-Left to Anterior-Posterior
- From Right-Left to Top-Bottom
- From Anterior-Posterior to Top-Bottom

The Figures 4.4 and 4.5, shows an example of an image with inverted axes.

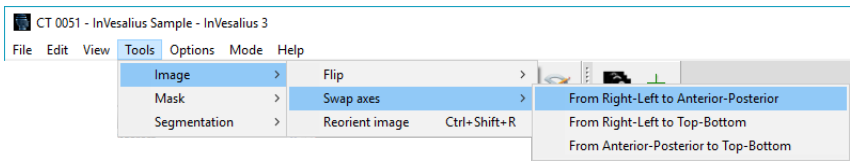


Figure 4.3: Menu to activate swap image tool.

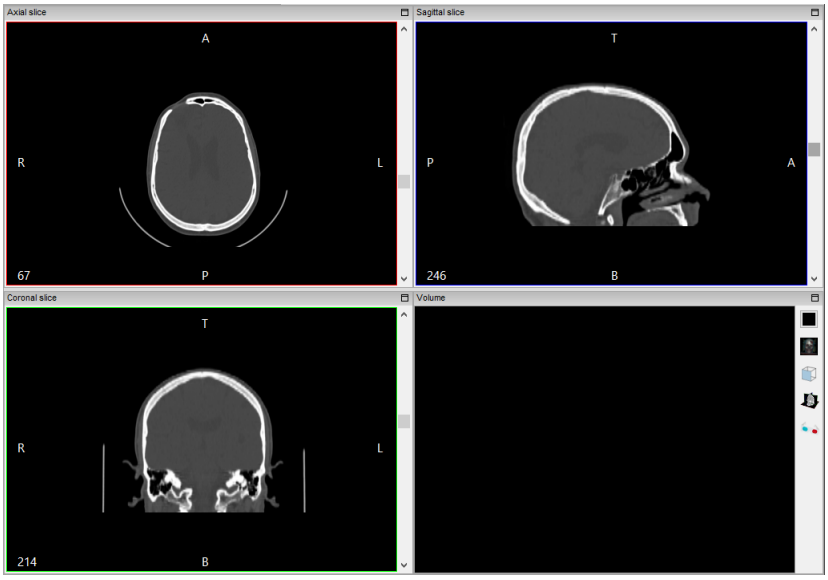


Figure 4.4: Images before swap axes - from Anterior-Posterior to Top-Bottom.

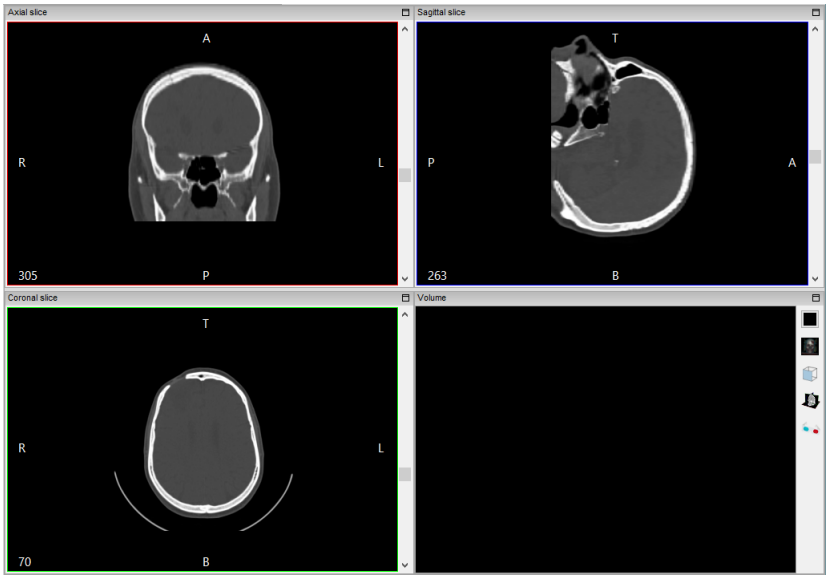


Figure 4.5: Images after swap axes - from Anterior-Posterior to Top-Bottom.

4.2 Reorient image (Rotate)

If it is necessary to align the image with a certain point of reference, e.g. anatomical marker, use the reorient image tool. To open this tool select the

Tools menu, click **Image**, then **Reorient Image** (Figure 4.6).

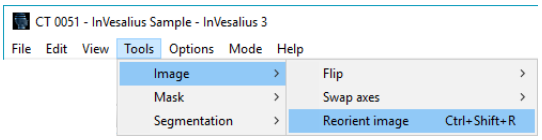


Figure 4.6: Menu to activate reorient image tool.

When this tool is activated a window is opened (Figure 4.7) showing orientation and by how many degrees the image was rotated.

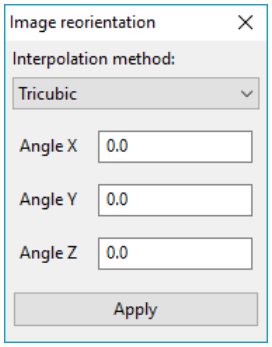


Figure 4.7: Window that shows the reorientation image parameters.

To start reorienting the image, define the interpolation method that will applied after rotation, by default is tricubic interpolation. The interpolation options are:

- Nearest Neighbour
- Trilinear
- Tricubic
- Lanczos

Then, select the rotation point by keeping the **left** mouse button pressed between the two lines intersecting (Figure 4.8) at one orientation, e.g. axial, coronal or sagittal, and **drag** to the desired point.

To rotate the image it is necessary to keep the **left** mouse button pressed and **drag** until the reference point or anatomical marker stays aligned with

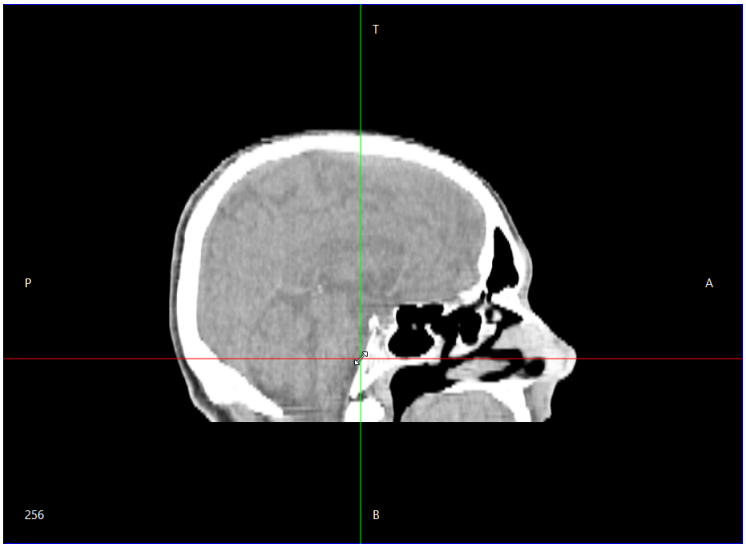


Figure 4.8: Defining the axis of rotation of the image.

one of the lines (Figure 4.9). After the image is in the desired position, click **Apply** in the parameter window (Figure 4.7). This may take a few moments depending on the image size. Figure 4.10 shows an image successfully reoriented.

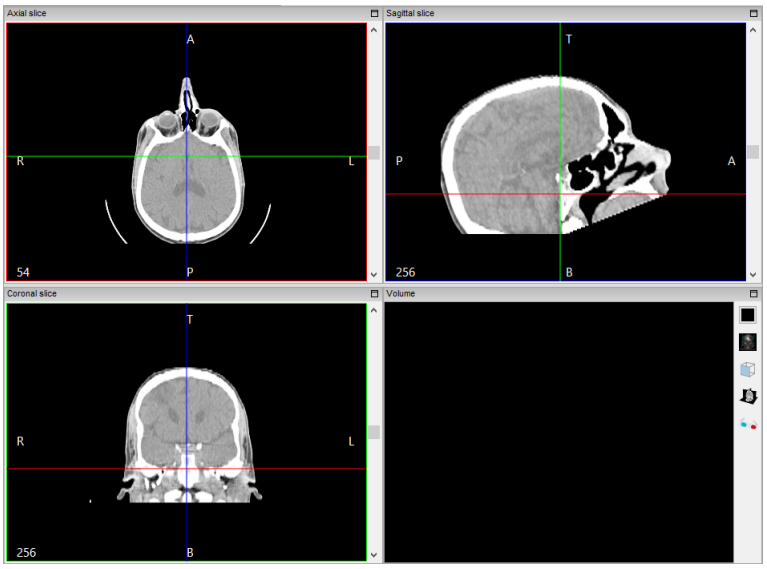


Figure 4.9: Rotated image.

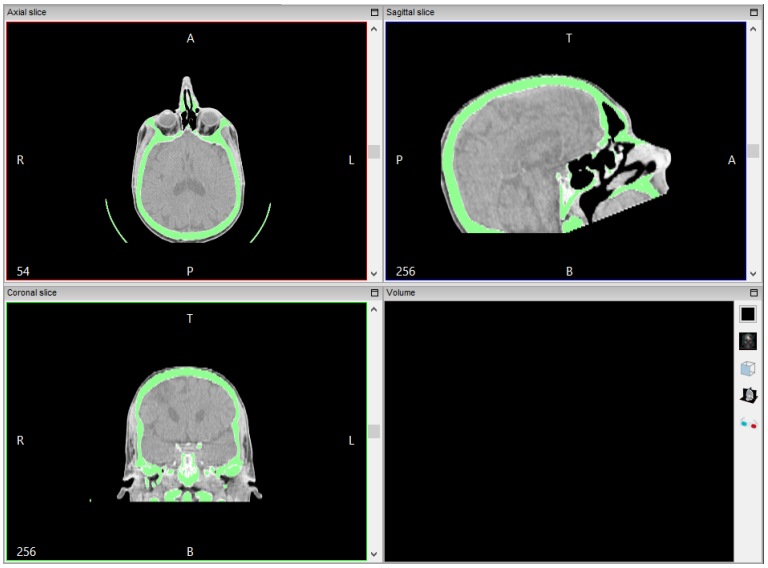


Figure 4.10: Rotated image after reorientation is done.

Chapter 5

Image Manipulation (2D)

5.1 Multiplanar Reconstruction

When images are imported, InVesalius automatically shows its multiplanar reconstruction in the Axial, Sagittal and Coronal orientations, as well as a window for 3D manipulation, as seen in Figure 5.1.

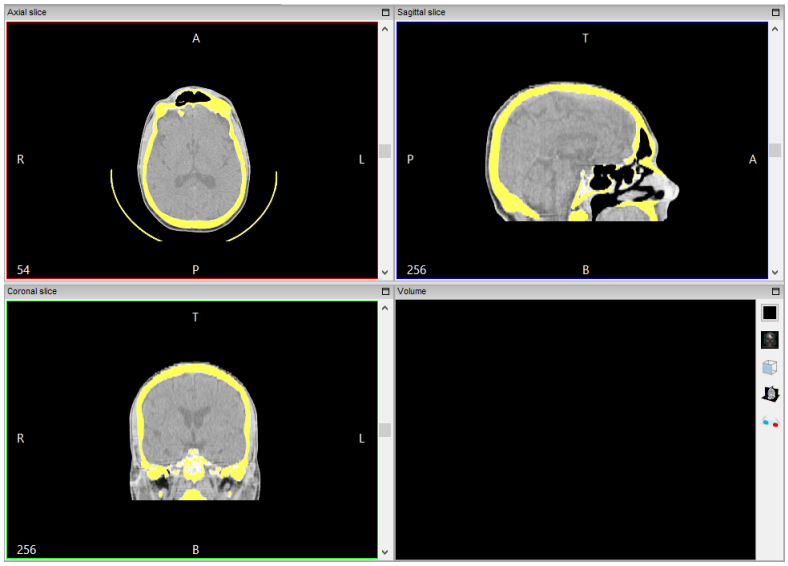


Figure 5.1: Multiplanar Reconstruction

In addition to creating a multiplanar reconstruction, InVesalius segments an image, highlighting for example soft tissue bones. The highlight is represented by the application of colors on a segmented structure so that the colors form a mask over an image highlighting the structure (Figure 5.1).This is discussed in more detail in the following chapters.

To hide the mask, use the data manager, located in the lower left corner of the screen. Select the **Masks** tab and click once using the **left** mouse button over the eye icon next to **"Mask 1"**, as shown in Figure 5.2.

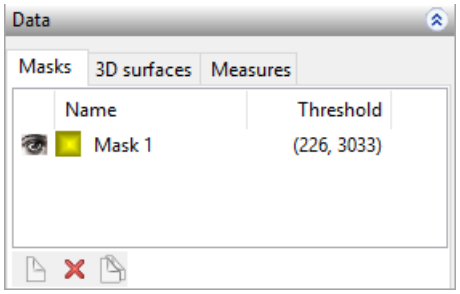


Figure 5.2: Mask manager

The eye icon disappears, and the colors of the segmentation mask are hidden (Figure 5.3).

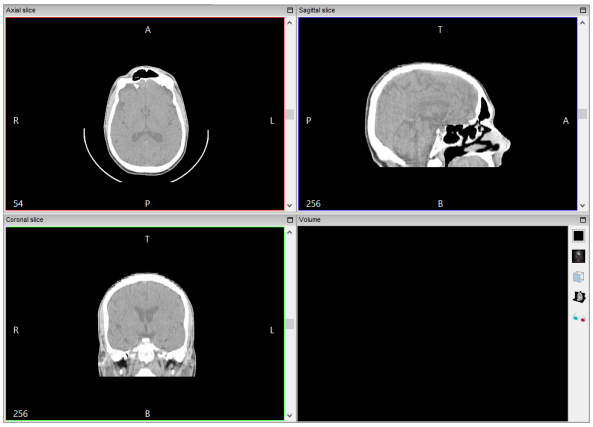


Figure 5.3: Multiplanar reconstruction without segmentation mask

5.1.1 Axial orientation

The axial orientation consists of cuts made transversally to the region of interest, i.e. parallel cuts to the axial plane of the human body. In Figure 5.4, an axial image of the skull region is displayed.

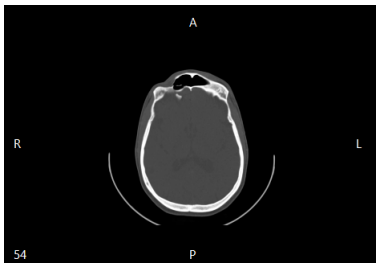


Figure 5.4: Axial slice

5.1.2 Sagittal orientation

The sagittal orientation consists of cuts made laterally in relation to the region of interest, i.e. parallel cuts to the sagittal plane of the human body, which divides it into the left and right portions. In Figure 5.5, a sagittal skull image is displayed.

Figure 5.5: Sagittal slice

5.1.3 Coronal orientation

The coronal orientation is composed of cuts parallel to the coronal plane, which divides the human body into ventral and dorsal halves. In Figure 5.6 is displayed a skull image in coronal orientation.

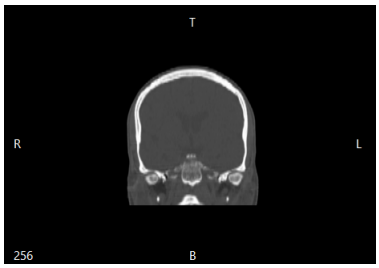


Figure 5.6: Coronal slice

5.2 Correspondence between the axial, sagittal and coronal orientations

To find out the common point of intersection of the images in differents orientations, simply activate the "Slices cross intersection" feature with the shortcut icon located on the toolbar. See Figure 5.7.

Figure 5.7: Shortcut to show common point between different orientations

When the feature is activated, two cross-sections that intersect perpendicularly are displayed on each image (Figure 5.8). The intersection point of each pair of segments represents the common point between differents orientations.

To modify the point, hold down the **left** mouse button and **drag**. Automatically, the corresponding points will be updated in each image.

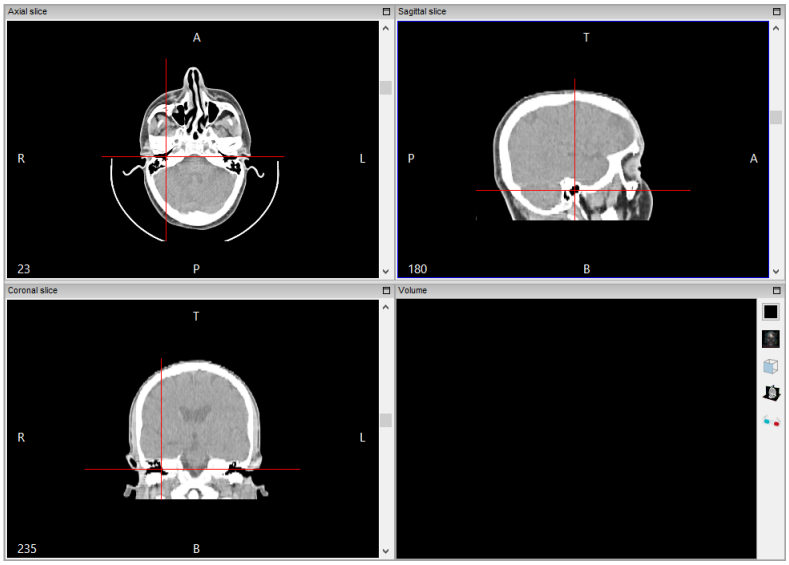


Figure 5.8: Common point between differents orientations

To deactivate the feature, simply click on the shortcut again (Figure 5.7). This feature can be used in conjunction with the slice editor (which will be discussed later).

5.3 Interpolation

By default the 2D images visualization are interpolated (Figure 5.10).a). To deactivate this feature, select the **View** menu and select **Interpolated slices** (Figure 5.9). It will then be possible to visualize each pixel individually as shown in Figure 5.10.b.

This interpolation is for visualization purposes only, and does not directly influence segmentation or 3D surface generation.

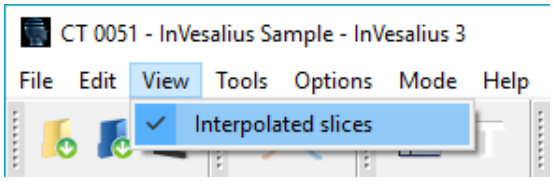
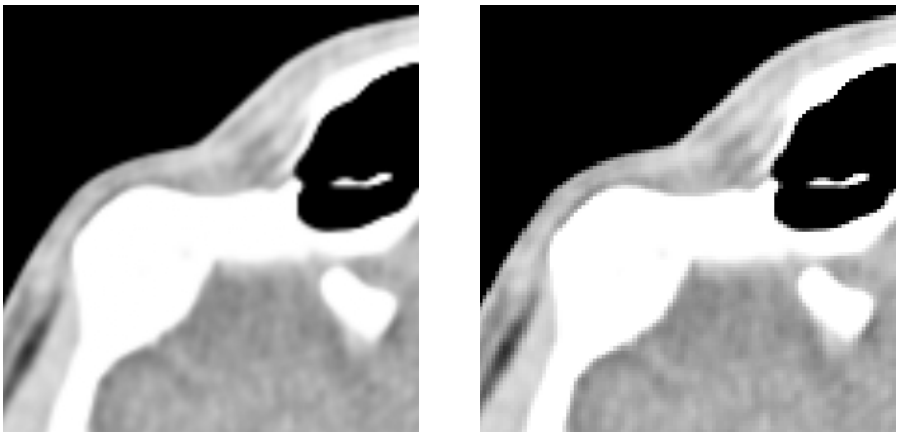


Figure 5.9: Menu to disable and enable interpolation



(a) Interpolated (b) Non-interpolated

Figure 5.10: Interpolated and non-interpolated image visualization.

5.4 Move

To move an image on the screen, use the Move shortcut icon on the toolbar (Figure 5.11). Click on the icon to activate, then with the **left** mouse button on the image, drag it to the desired direction. Figure 5.12 shows a displaced (moved) image.

Figure 5.11: Shortcut to move images

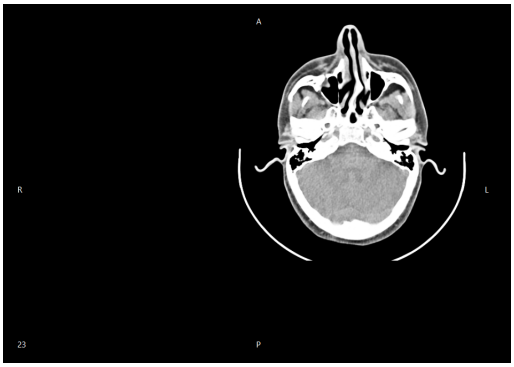


Figure 5.12: Displaced image

5.5 Rotate

Images can be rotated by using the Rorate shortcut on the toolbar (Figure 5.13). To rotate an image, click on the icon and then with the **left** mouse button **drag** clockwise or anticlockwise as required.

Figure 5.13: Shortcut to rotate images

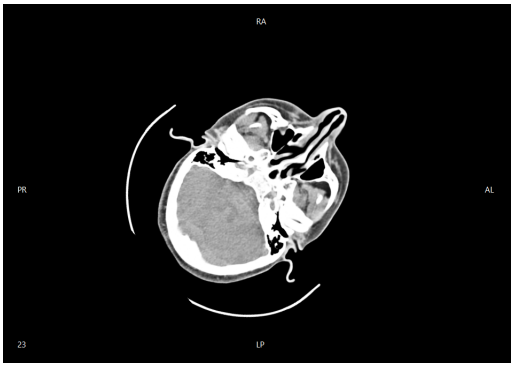


Figure 5.14: Rotated image

5.6 Zoom

In InVesalius, there are different ways to enlarge an image. You can maximize the desired orientation window, apply zoom directly to the image, or select the region of the image to enlarge. Each of these methods are detailed below.

5.6.1 Maximizing orientation windows

The main InVesalius window is divided into 4 sub-windows: axial, sagittal, coronal and 3D. Each of these can be maximized to occupy the entire area of the main window. To do this, simply **left** mouse click on the subwindow icon located in the **upper right corner** (Figure 5.15). To restore a maximized window to its previous size, simply click the icon again.

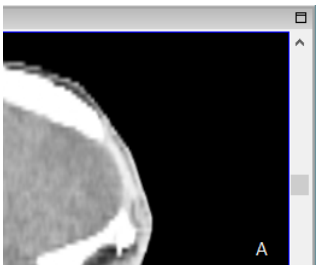


Figure 5.15: Detail of a sub-window (Note the maximize icon in the upper right corner)

5.6.2 Enlarging or shrinking an image

To enlarge or shrink an image, click on the zoom shortcut icon in the toolbar (Figure 5.16). Hold down the **left** mouse button on the image and **drag** the mouse **up** to enlarge or **down** to shrink.

Figure 5.16: Zoom shortcut

5.6.3 Enlarging an image area

To enlarging a certain image area, click on the "Zoom based on selection" icon in the toolbar (Figure 5.17). Position the mouse pointer at the origin point of the selection, click and hold the **left** mouse button and **drag** it to the end selection point to form a rectangle (Figure 5.18). Once the left mouse button is released, the zoom operation will be applied to the selected region (Figure 5.19).

Figure 5.17: Zoom based on selection shortcut

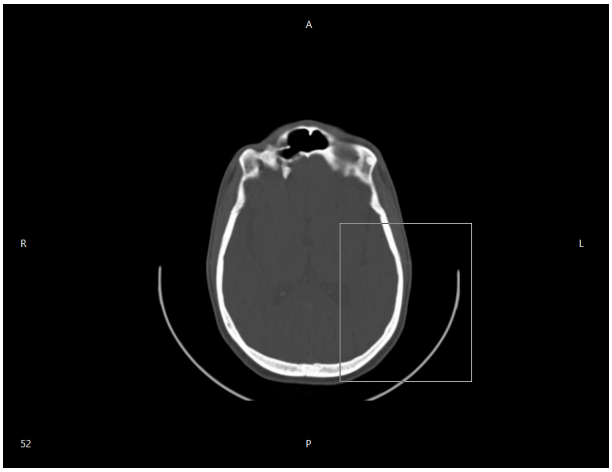


Figure 5.18: Area selected for zoom

5.7 Brightness and contrast (Windows)

To improve image visualization, the *window width* and *window level* features can be used; these are more commonly known as *brightness and contrast* or *window* (for radiologists). With this feature, it is possible to set the range of the gray scale (*window level*) and the width of the scale (*window width*) to be used to display the images.

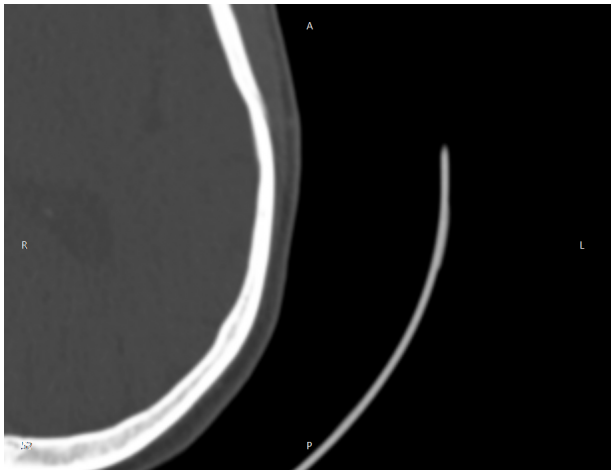


Figure 5.19: Enlarged Image

The feature can be activated by the "Brightness and Contrast" shortcut icon in the toolbar. See Figure 5.20.

Figure 5.20: Brightness and contrast shortcut

To increase the brightness, hold down the **left** mouse button and **drag** horizontally to the right. To decrease the brightness, simply drag the mouse to the left. The contrast can be changed by dragging the mouse (with the **left** button pressed) vertically: up to increase, or down to decrease contrast.

To deactivate the feature, click again on the shortcut icon (Figure 5.20).

Preset brightness and contrast patterns may be used with InVesalius. Table 5.1 lists some tissue types with their respective brightness and contrast values. To use the presets, position the mouse cursor over an image and **right-click** to open a context menu, then select **Window width and level**, and click on the preset option according to the tissue type, as shown in Figure 5.21.

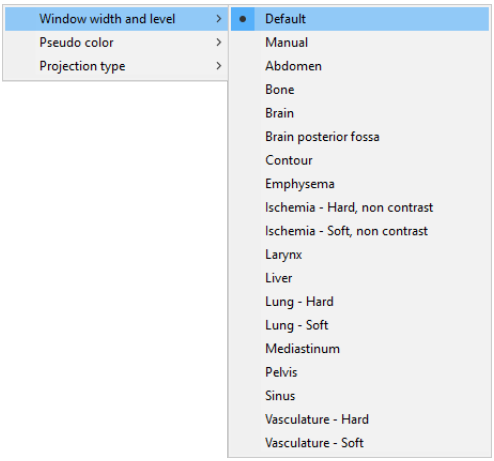
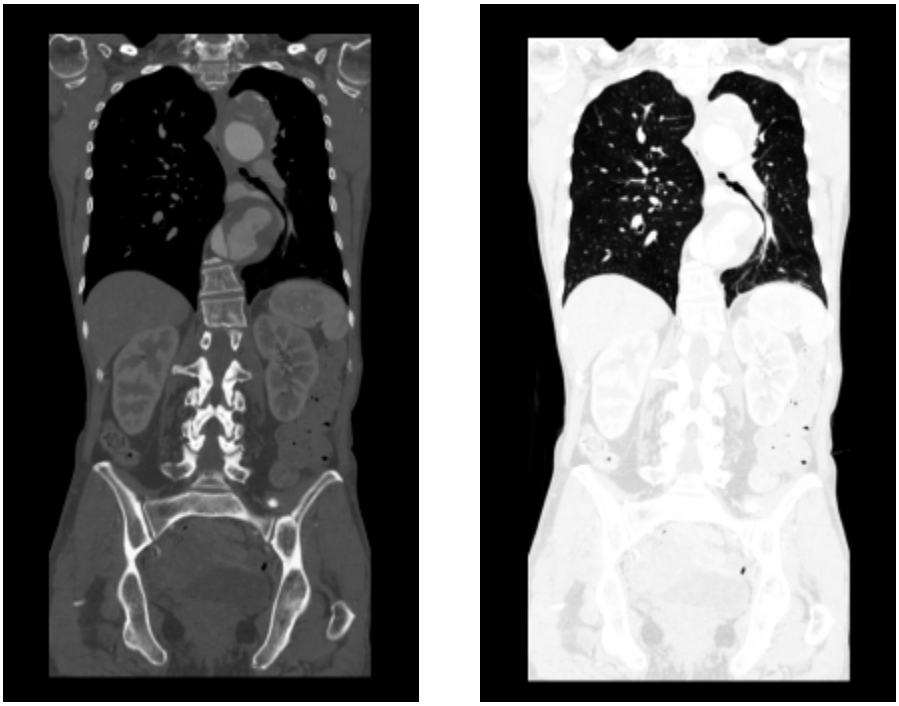


Figure 5.21: Context menu for brightness and contrast selection

Table 5.1: Brightness and contrast values for some tissues

Tissue	Brightness	Contrast
Default	Exam	Exam
Manual	Changed	Changed
Abdomen	350	50
Bone	2000	300
Brain	80	40
Brain posterior fossa	120	40
Contour	255	127
Emphysema	500	-850
Ischemia - Hard, non contrast	15	32
Ischemia - Soft, non contrast	80	20
Larynx	180	80
Liver	2000	-500
Lung Hard	1000	-600
Lung Soft	1600	-600
Mediastinum	350	25
Pelvis	450	50
Sinus	4000	400
Vasculature - Hard	240	80
Vasculature - Soft	680	160



(a) Bone (b) Lung

Figure 5.22: Different types of brightness and contrast

5.8 Pseudo color

Another feature to improve the visualization of the images is the pseudo color. This replaces gray levels by color, or by inverted gray levels. In the latter case, previously clear regions of the image become darker and vice versa.

To change the view using a pseudo color, position the mouse cursor over the image and **right-click** to open a context menu on it. When the menu opens, select the entry **Pseudo color**, and then click on the desired pseudo color option, as shown in Figure 5.23.

Figures 5.24a-g demonstrate the various pseudo color options available.

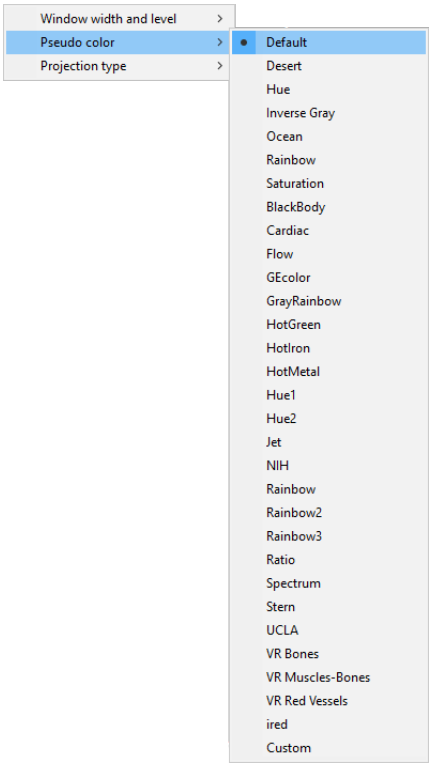
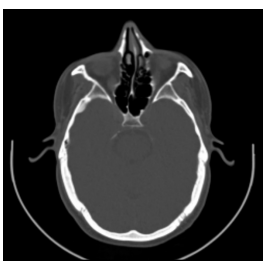
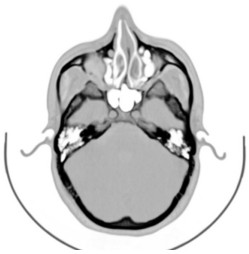


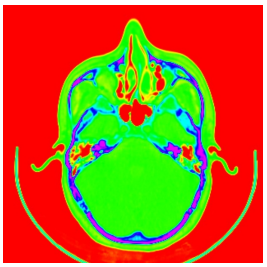
Figure 5.23: Pseudo Color



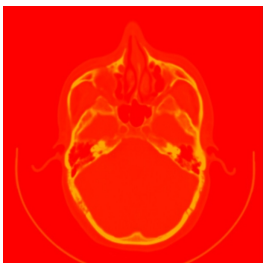
(a) Default



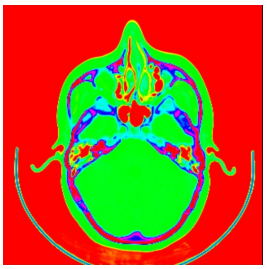
(b) Inverted Gray Image



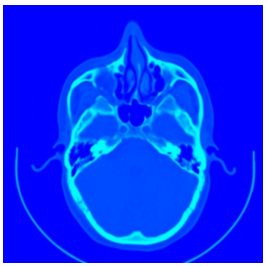
(c) Rainbow



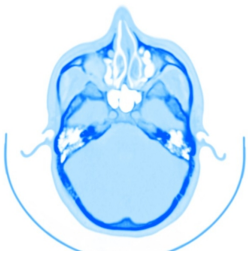
(d) Desert



(e) Hue



(f) Ocean



(g) Saturation

Figure 5.24: Some different types of pseudo-color

5.9 Projection type

It is possible to change the projection type of the 2D images, in addition to the normal mode, InVesalius has six types of projections that can be accessed as follows: Place the mouse over the image and **rigth-click** to open a context menu on it. When the menu opens, select the projection type option, and then click on the desired projection option, as shown in the Figure 5.31.

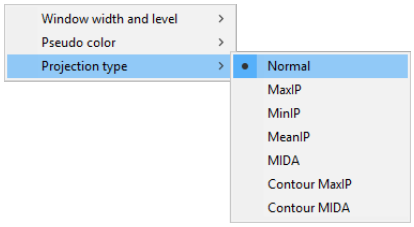


Figure 5.25: Projection Type menu

5.9.1 Normal

Normal mode is the default view, showing the unmodified image as it was when acquired or customized previously with either brightness and contrast or pseudo color. Normal mode is shown below in Figure 5.32.

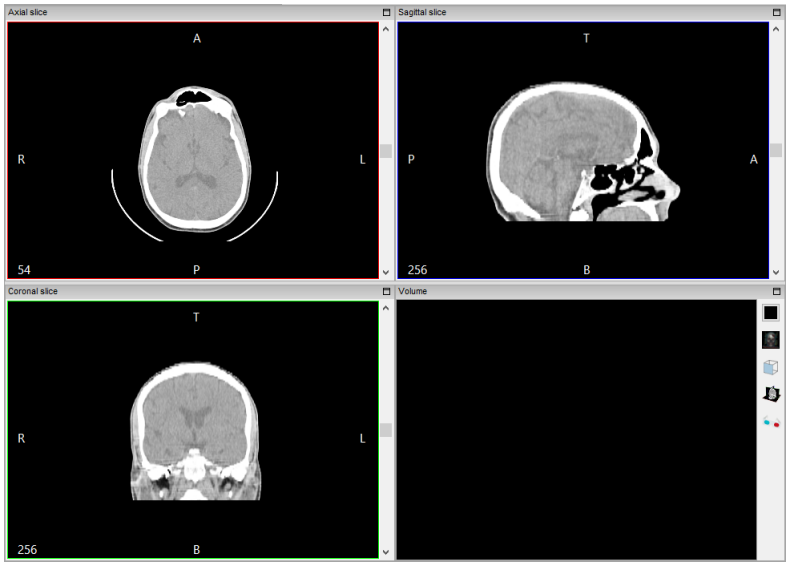


Figure 5.26: Normal projection

5.9.2 MaxIP

MaxIP is also known as MIP (*Maximum Intensity Projection*). MaxIP selects only voxels that have maximum intensity among those visited as shown in Figure 5.33. According to the amount of, or "depth" of MaxIP, each voxel is visited in order of overlap, for example, to select MaxIP of the pixel $(0, 0)$

consisting of 3 slices it is necessary to visit pixel $(0, 0)$ of slices $(1, 2, 3)$ and select the highest value.

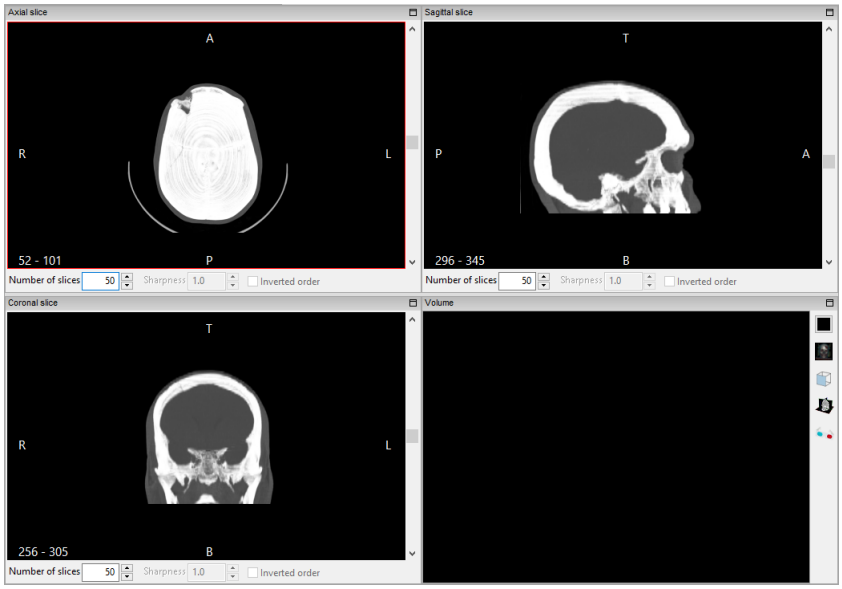


Figure 5.27: MaxIP projection

As shown in Figure 5.34, the number of MaxIP images is set at the bottom of each orientation image.

Figure 5.28: Selection the amount of images that composes the MaxIP or MIP

5.9.3 MinIP

Unlike MaxIP, MinIP (*Minimum Intensity Projection*) selects only the voxels that have minimal intensity among those visited, as shown in Figure 5.35. The image number selection comprising the projection is made at the bottom of each orientation image as shown in Figure 5.34.

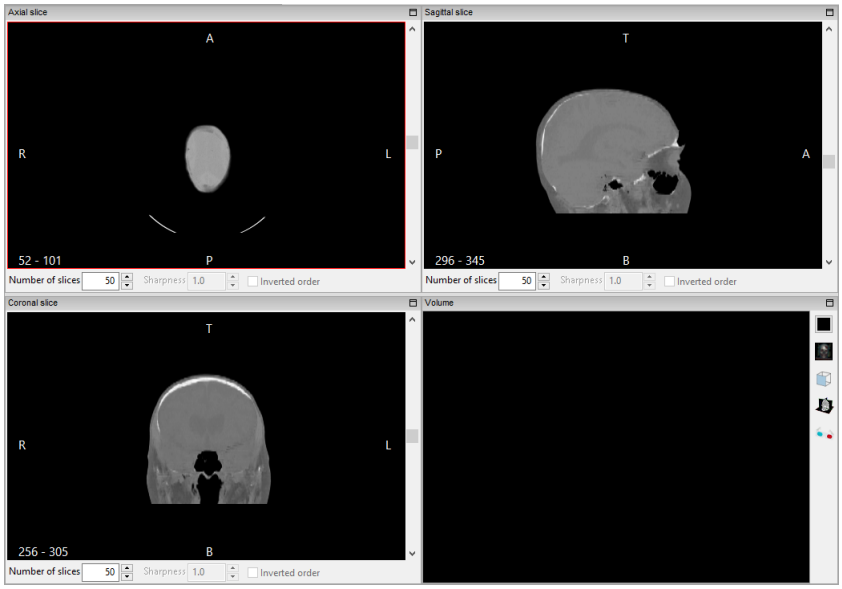


Figure 5.29: MinIP projection

5.9.4 MeanIP

The MeanIP (*Mean Intensity Projection*) technique which is shown in the Figure 5.36 composes the projection by averaging voxels visited in the same way as the MaxIP and MinIP methods. It is also possible to define how many images will compose the projection at the bottom of the image of each orientation as shown in Figure 5.34.

5.9.5 MIDA

The MIDA (*Maximum Intensity Difference Accumulation*) technique projects an image taking into account only voxels that have local maximum values. From each pixel a ray is simulated towards the volume, with each voxel being intercepted by each ray reaching the end of the volume. Each of the voxels visited has its accumulated value, but are taken into account only if the value is greater than previously visited values. Like MaxIP, one can select how many images are used to accumulate the values. Figure 5.37 shows an example of MIDA projection.

As Figure 5.38 shows, it is possible to invert the order that the voxels are

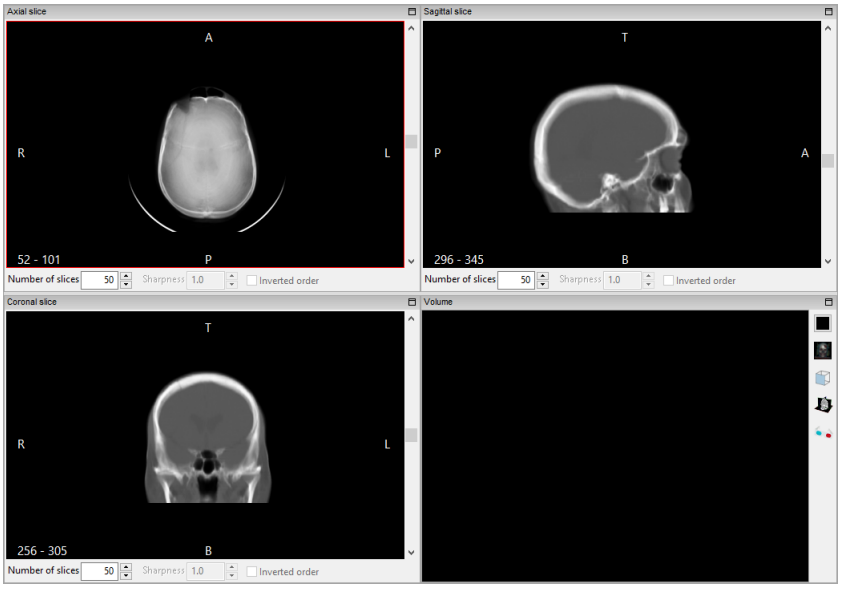


Figure 5.30: MeanIP projection

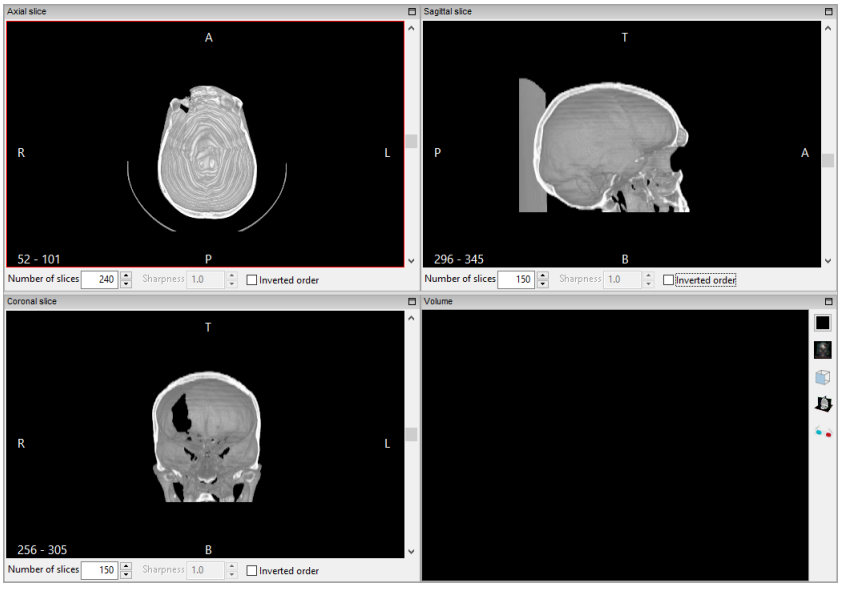


Figure 5.31: MIDA projection

visited by selecting the **Inverted order** option in the lower corner of the screen.

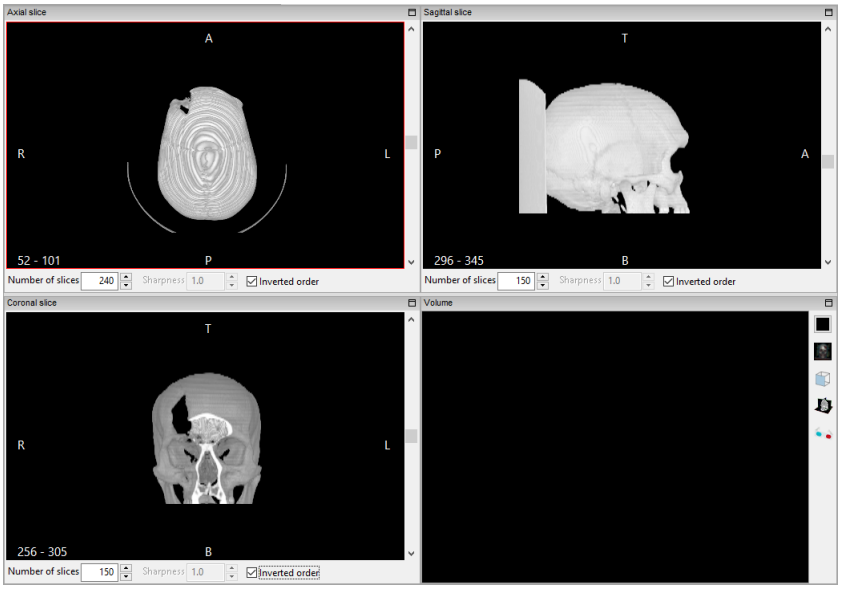


Figure 5.32: Inverted order MIDA projection

5.9.6 Contour MaxIP

The Contour MaxIP function consists of visualizing contours present in the projection generated with MaxIP technique(5.9.2). An example is presented in Figure 5.39.

5.9.7 Contour MIDA

The Contour MIDA function consists of visualizing contours present in the projection generated with the MIDA technique(5.9.5). Like MIDA, you can reverse the order that the volume is visited, as shown in Figure 5.40.

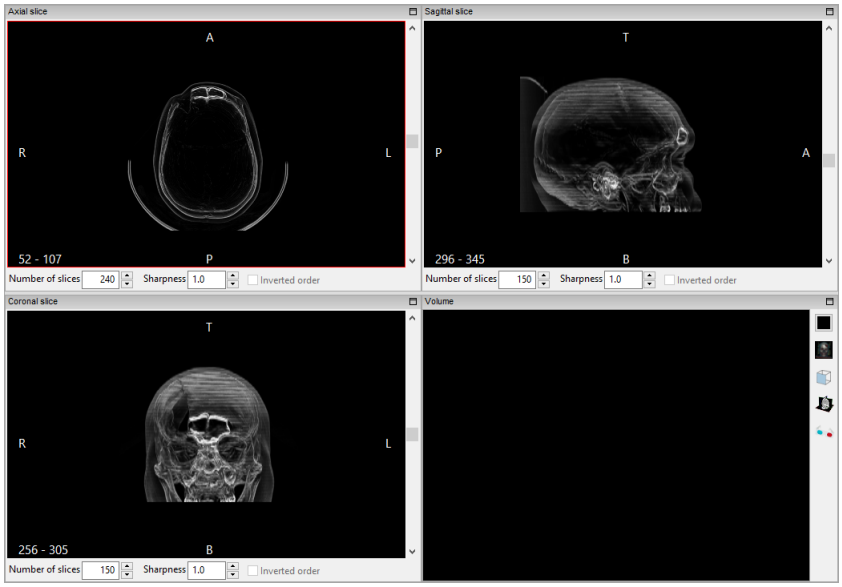


Figure 5.33: Contour MaxIP projection

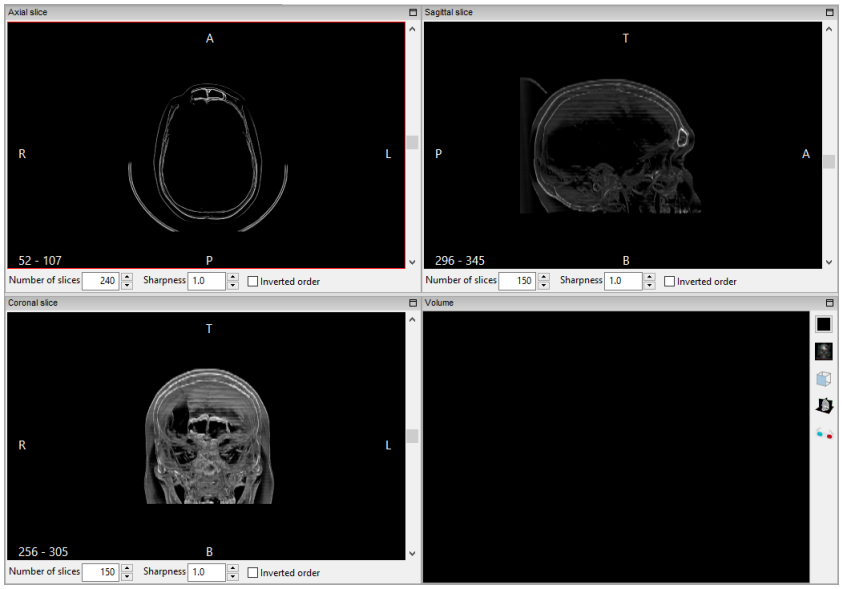


Figure 5.34: Contour MIDA projection

Chapter 6

Segmentation

To select a certain type of tissue from an image it is used the segmentation feature at InVesalius.

6.1 Threshold

When using the thresholding segmentation technique, only the pixels whose intensity is inside the threshold range defined by the user are detected. The threshold is defined by two values, the initial (minimum) and final (maximum) threshold.

In thresholding segmentation technique only the *pixels* whose intensity is inside threshold range defined by the user. Threshold is defined by two number, the initial and final threshold, also known as minimum and maximum threshold. ...

Thresholding segmentation is located the InVesalius left-panel, item **2. Select region of interest** (Figure 6.1).

Before starting a segment it is necessary to configure a mask. A mask is a image over to examine an image where the selected regions are colored. (Figure 6.2).

To change the threshold, use the image greyscale control (Figure 6.3). Move the *left* sliding control to change the initial threshold. Move the **right** sliding control to change the final threshold. It is also possible to to input

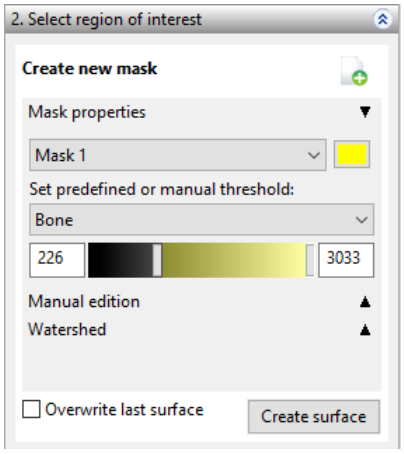


Figure 6.1: Select region of interest - Threshold

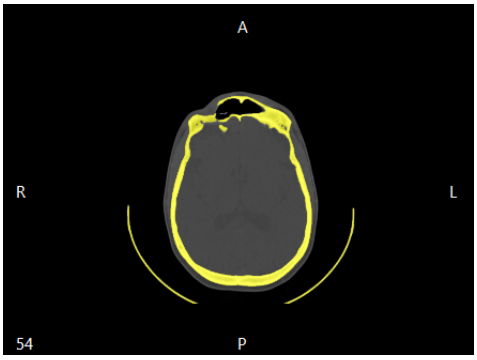


Figure 6.2: Mask - selected region in yellow.

the desired threshold values in the text boxes in the left and right side of the thresholding control. The mask will be automatically updated when the thresholding values are changed, showing in color the pixels inside the thresholding range.

Figure 6.3: Selecting *pixels* with intensity between 226 and 3021 (Bone)

It is also possible to select some predefined thresholding values based on some type of tissues, like those displayed in Figure 6.4. Just select the desired tissue and the mask will automatically update.

Table 6.1 show thresholding values according to some tissues or materials.

Figure 6.4: Selection list with some predefined thresholding values.

Table 6.1: Predefined thresholding values to some materials

Material	Initial threshold	Final Threshold
Bone	226	3021
Compact Bone (Adult)	662	1988
Compact Bone (Child)	586	2198
Custom	User Def.	User Def.
Enamel (Adult)	1553	2850
Enamel (Child)	2042	3021
Fat Tissue (Adult)	-205	-51
Fat Tissue (Child)	-212	-72
Muscle Tissue (Adult)	-5	135
Muscle Tissue (Child)	-25	139
Skin Tissue (Adult)	-718	-177
Skin Tissue (Child)	-766	-202
Soft Tissue	-700	225
Spongial Bone (Adult)	148	661
Spongial Bone (Child)	156	585

Table 6.1 indicates images obtained from medical tomographs. The range of gray values from images obtained from odontological tomographs are greater and non-regular. Thus, it is necessary to use sliding controls (Figure 6.3) to adjust the thresholding values.

To create a new mask, click **Create new mask** (Figure 6.5). Then, click **Select region of interest**.

Figure 6.5: Button to create a new mask.

After clicking on this button a dialog will be shown (Figure 6.6). Select the desired threshold and click on **Ok**.

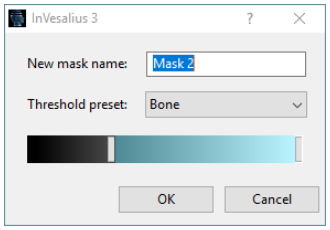


Figure 6.6: Creating a new mask.

After segmentation it is possible to generate a corresponding 3D surface. The surface is formed by triangles. The following chapter will give more details about surfaces.

Click on the **Create surface** button (Figure 6.7) to create a new surface. If there is a surface created previously you may overwrite it with the new one. To do this select the option **Overwrite last surface** before creating the new surface.

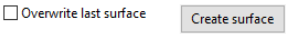


Figure 6.7: Create surface button.

After a few moments the surface will be displayed at the 3D visualization window of InVesalius (Figure 6.8).

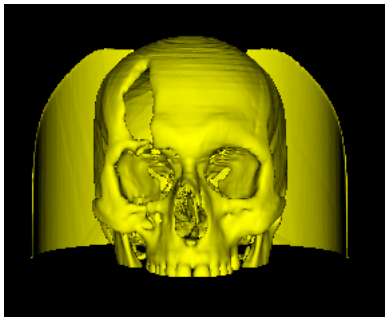


Figure 6.8: 3D surface.

6.2 Manual segmentation (Image edition)

Thresholding segmentation may not be efficient in some cases since it is applied to the whole image. Manual segmentation may be used to segment only an isolated region. Manual segmentation also allows users to add or remove some image regions from the segmentation. To use it click on **Manual edition** (Figure 6.9) to open the manual segmentation panel.

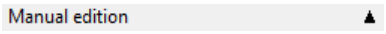


Figure 6.9: Icon to open the Manual segmentation panel.

Figure 6.10 show the Manual segmentation panel.

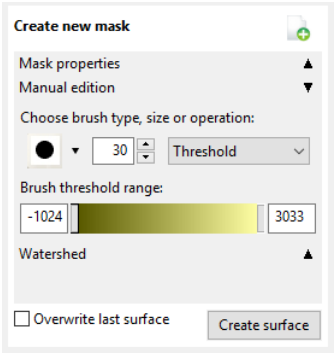


Figure 6.10: Manual segmentation panel.

There are two brushes used for segmentation: a circle and a square. Click on the triangle icon (see Figure 6.11) to show brush types, then click on the desired brush.

Figure 6.11: Brush types.

Brush sizes can also be adjusted, as shown in Figure 6.12.

Figure 6.12: Adjusting the brush size.

The following are available options when using brushes in InVesalius:

- **Draw**: for adding a non-selected region to the segmentation;
- **Erase**: for removal of a non-selected region;
- **Threshold**: applies the thresholding locally, adding or removing a region inside or outside of the threshold range.

Figure 6.13 shows the available brush operations.

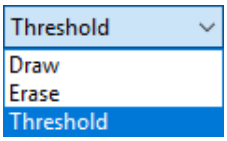


Figure 6.13: Brush operations

Figure 6.14 shows a image with noise caused by the presence of a dental prosthesis. Note the rays emerging from the dental arch: the thresholding segments the noise since its intensity is inside of the threshold of bone.

Figure 6.15 shows a surface created from that segmentation.

In such cases use the manual segmentation with the **erase** brush. Keep the **left** mouse button pressed while dragging the brush over the region to be removed (in mask).

Figure6.17 shows the image from Figure 6.14 after.

A surface can be generated after manual segmentation (Figure 6.18). Since it was used in the manual segmentation procedure, when clicking on Create surface button, a dialog (Figure 6.19) will be opened to to select if the surface will be created with the method **Binary** (blocky) or **Context aware smoothing (smoother)**.

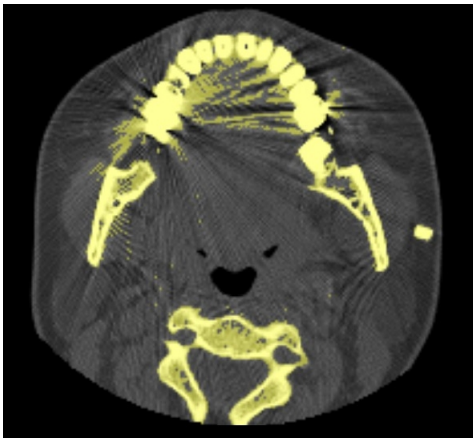


Figure 6.14: Noisy image segmented with threshold.

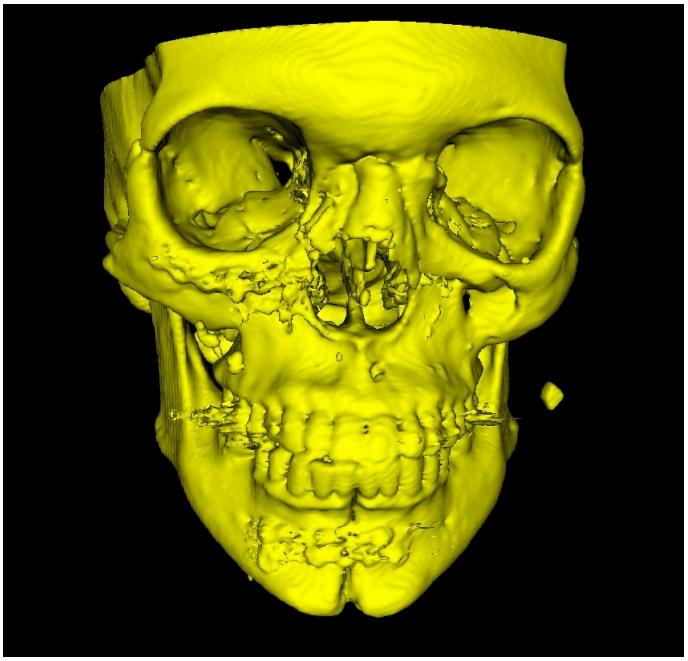


Figure 6.15: Surface generated from noisy image.

6.3 Watershed

In watershed segmentation the user demarcates objects and background detail. This method treats the image as watershed (hence the name) in which the gray values (intensity) are the altitudes, forming valleys and mountains. The markers are water source. The waters fill the watershed until the wa-

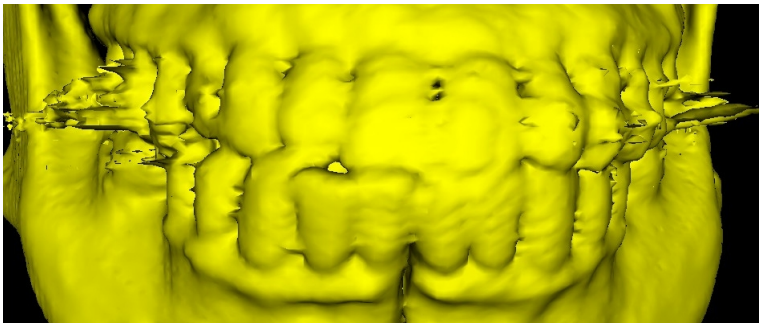


Figure 6.16: Zoom in the noisy area.

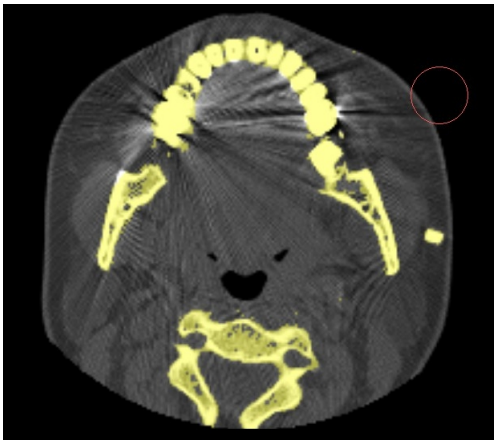


Figure 6.17: After removing the noise.

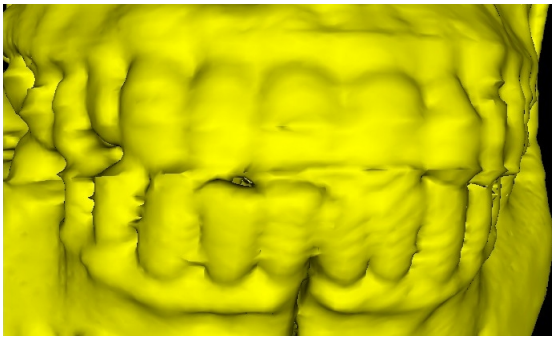


Figure 6.18: Surface generate after removing the noise.

ters gather together, thus distinguishing background from object. To use Watershed segmentation click on Watershed to open the watershed panel (Figure 6.20).

Before segmenting to with Watershed it recommended to clean the mask

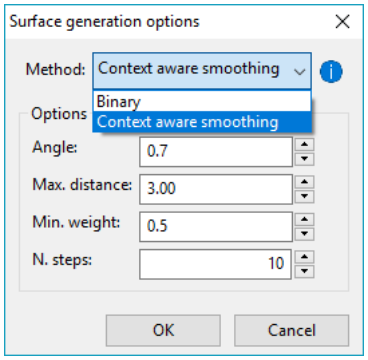


Figure 6.19: Surface creation methods

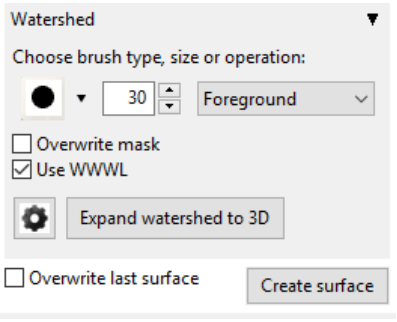


Figure 6.20: Watershed segmentation panel.

(see section 7.2).

To insert a marker (object or background), a brush is used, similar to manual segmenting. You can use a circle or square brush and set its size.

Select brush operations from the following:

- **Object**: to insert object markers;
- **Background**: to insert background markers (not object);
- **Delete**: to delete markers;

The option **Overwrite mask** is used when the user wants the result of watershed segmentation to overwrite the existing segmentation. The option **Use WWWL** is used to make watershed take into account the image with the values of window width and window level (not the raw image) which may result in better segmentation.

Click on the button on the left side of the panel (Figure 6.21) to access more watershed configurations. This button will open a dialog (Figure 6.22). The method option allows to choose the Watershed algorithm to be used to segment. It may be the conventional **Watershed** or **Watershed IFT**, which is based on the IFT (*Image Forest Transform*) method. In some cases, like brain segmentation, the **Watershed IFT** may have a better result.

The connectivity option refers to the pixel neighbourhood (4 or 8 when in 2D, or 6, 18 or 26 when in 3D). **Gaussian sigma** is a parameter used in the smoothing algorithm (the image is smoothed before the segmentation to remove the noise and get better results). The greater this value the smoother the smoother the image will be.

Figure 6.21: Button to open the Watershed configuration dialog.

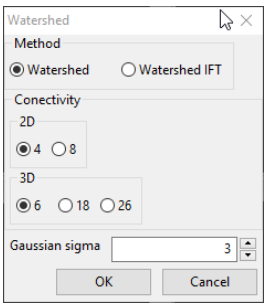


Figure 6.22: Watershed configuration dialog.

Normally the **Watershed** is applied only in one slice, not in the whole image. After adding the markers is possible to apply the watershed to the whole image by clicking on the button **Expand watershed to 3D**. Figure 6.23 shows the result of watershed segmentation in a slice (2D) of brain image.

Figure 6.24 shows the segmentation expanded to the whole image (3D).

Figure 6.23 also shows the object markers (in light green), the background markers (in red) and the segmentation mask (in green) overlaying the selected regions (result).

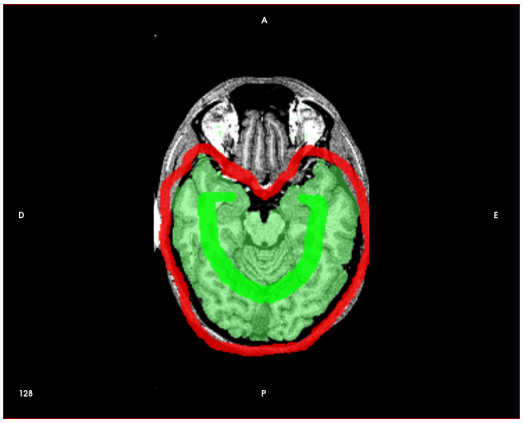


Figure 6.23: Watershed applied to a slice.

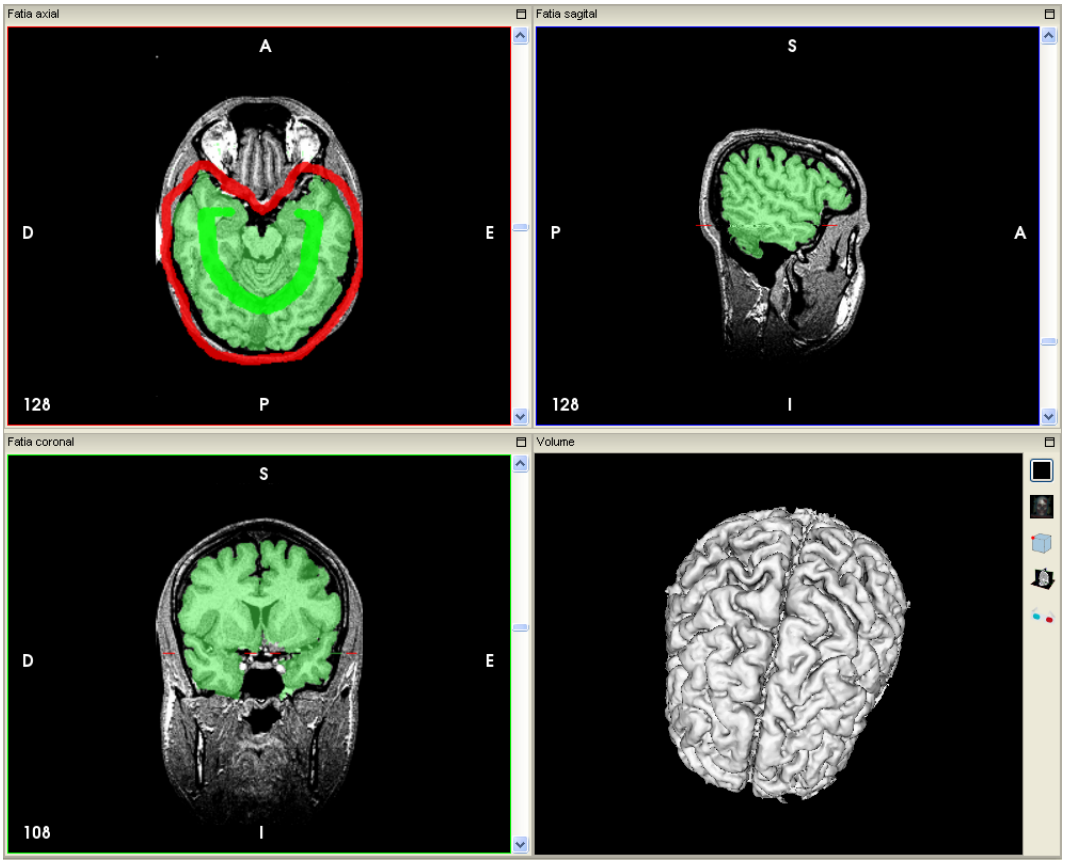


Figure 6.24: Brain segmentation using the watershed method applied to the whole image (3D).

6.4 Region growing

Region growing tool is accessed in the menu **Tools**, **Segmentation**, **Region growing** (figure 6.25). Before segmenting select if the operation will be in **2D - Actual slice** or **3D - All slices**. It is also necessary to select the connectivity: 4 or 8 to 2D or 6, 18 or 26 to 3D. It's also necessary to select the method, which may be **Dynamic, Threshold, or Confidence** (figure 6.26)

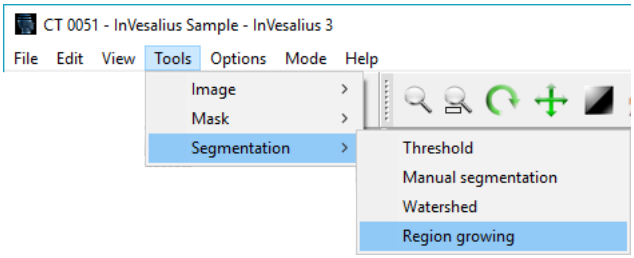


Figure 6.25: Menu to access the region growing segmentation segmentation tool.

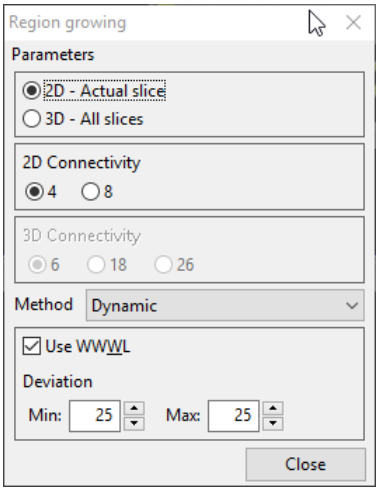


Figure 6.26: Dialog to configure the parameters of region growing segmentation tool.

This segmentation technique starts with a pixel (indicated by the user left-clicking with the mouse). The selection expands by analyzing the neighbourhood of the selected pixels and including those of a given set of qualities. Each region growing method has a different condition of selection:

- **Dynamic**: Uses the value of the pixel clicked by the user. Then every connected pixel inside the lower (min) and the upper (max) range deviation are selected. The option **Use WWWL** is default and takes into account the image with **window width** and **window level** applied not the raw one (figure 6.27).

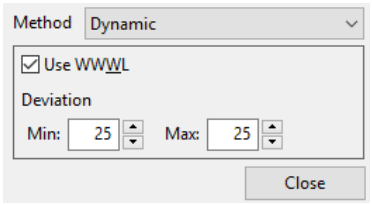


Figure 6.27: Dynamic method parameters.

- **Threshold**: This method selects the pixels whose intensity are inside the minimum and maximum threshold (Figure 6.28).

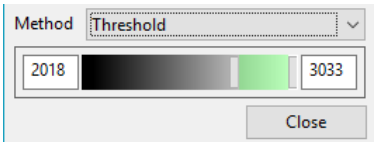


Figure 6.28: Adjust the threshold.

- **Confidence**: This method starts by calculating the standard deviation and the mean value of the pixel selected by the user and its neighbourhood. Connected pixels with value inside the range (given by the mean more and less the standard deviation multiplied by the **Multiplier** parameter). It then calculates the mean and the standard deviation from the selected pixels, then carries out the expansion. This process is repeated according to the **Iterations** parameter. Figure 6.29 shows the parameters for this method.

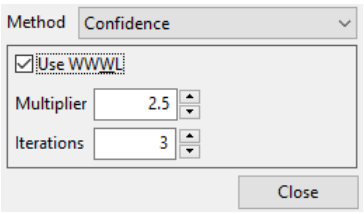


Figure 6.29: Confidence parameter.

Chapter 7

Mask

7.1 Boolean operations

After segmenting, some boolean operations can be performed between masks. The boolean operations supported by InVesalius are:

- **Union**, perform union between two masks;
- **Difference**, perform difference from the first mask to the second one;
- **Intersection**, keeps what is common in both masks.
- **Exclusive disjunction (XOR)**: keeps the regions of the first mask which are not in the second mask and regions from the second mask which are no in the first mask.

To use this tool go to the **Tools**, menu, select **Mask**, and then Boolean operations as shown in Figure 7.1. Select the first mask, the operation to be performed and the second mask as shown in Figure 7.2 then click **OK**.

Figure 7.3 shows some examples of utilization of boolean operations tool.

7.2 Mask cleaning

A mask can be cleaned, as shown in Figure 7.4. This is recommended before inserting Watershed markers. This tool is located on the **Tools** menu. Select

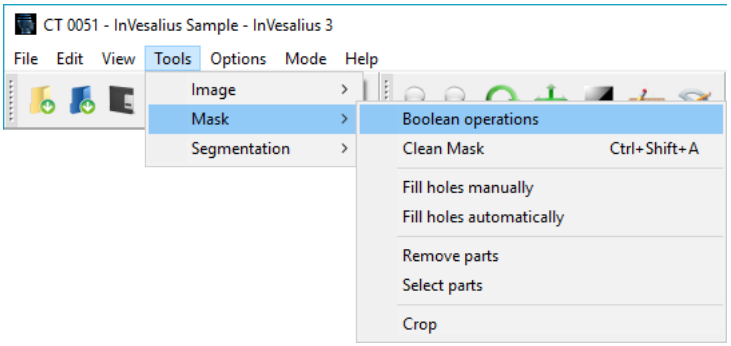


Figure 7.1: Menu to open boolean operations tool.

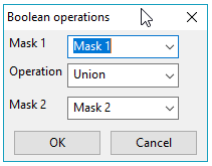


Figure 7.2: Boolean operations tool.

Mask, then **Clean mask**, or use the shortcut **CTRL+SHIFT+A**.

7.3 Fill holes manually

Segmentation may leave some unwanted holes. It's recommended to fill them because the surface generated from this mask may have some inconsistencies. To do this access the menu **Tools**, **Mask**, **Fill holes manually** (figure 7.5). A dialog window will be shown (figure 7.6) to configure the parameters.

It is possible to fill hole on a mask slice (**2D - Actual slice**) or on all slices, selecting the option (**3D - All slices**). The connectivity may also be configured: 4 or 8 for 2D and 6, 18 and 26 for 3D.

After configuring the desired parameters left-click on holes to fill them. Figure 7.7.a shows a mask with some holes and other mask with the holes filled (Figure 7.7.b). Click on the close button or close the dialog to deactivate this tool.

(a) Mask A (b) Mask B (c) Union (A ∪ B)

(d) Difference (A - B) (e) Intersection (A ∩ B) (f) Exclusive disjunction (A ⊕ B)

Figure 7.3: example of boolean operations.

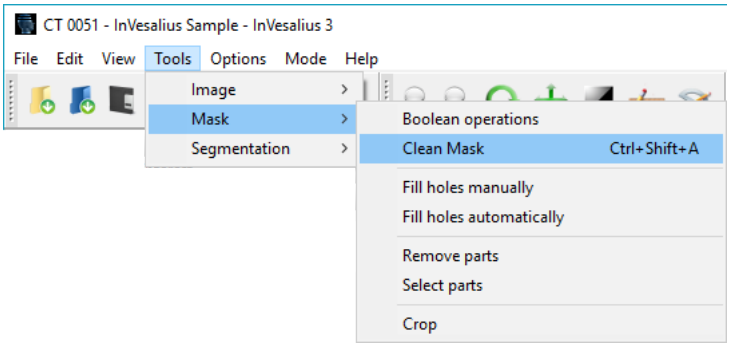


Figure 7.4: Mask cleaning

7.4 Fill holes automatically

To open this tool go to the **Tools** menu, select **Mask** then **Fill holes automatically** (Figure 7.8). This will open a dialog to configure the parameters. This tool doesn't require the user to click on holes he desire to fill. This tool

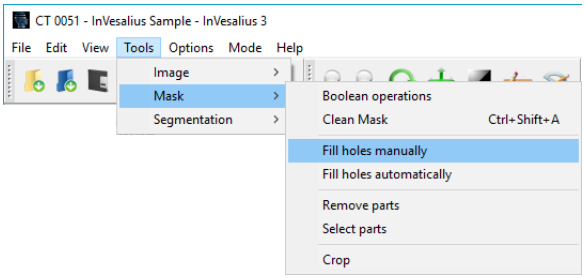


Figure 7.5: Menu to access the tool to fill holes manually.

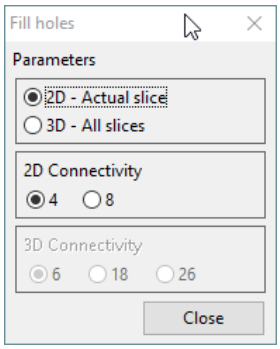
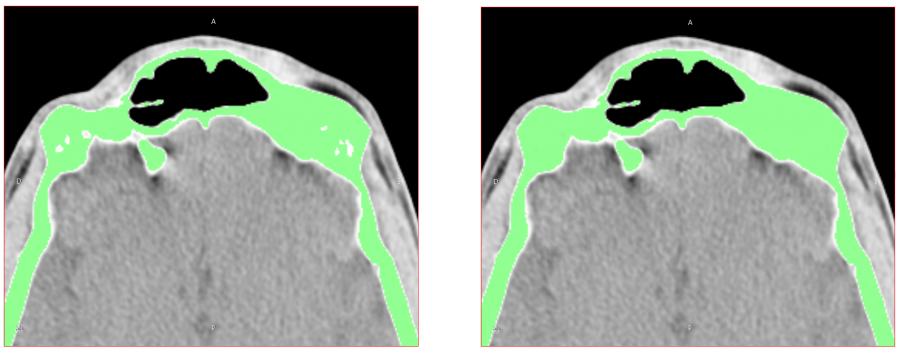


Figure 7.6: Dialog to configure the parameters of Fill holes manually tool.



(a) Holes (b) Holes filled

Figure 7.7: Example of mask with holes filled.

will fill the holes based on the **max hole size parameter** given in number of voxels (Figure 7.9).

Holes can also be filled on a mask slice (**2D - Actual slice**) or on all slices, selecting the option (**3D - All slices**. The connectivity will thus be 4 or 8 to 2D and 6, 18 and 26 to 3D. If 2D, the user must indicate in which

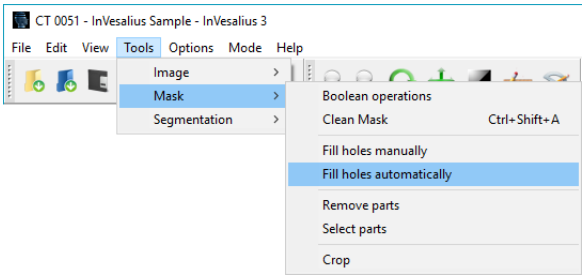


Figure 7.8: Menu to open the Fill holes automatically tool.

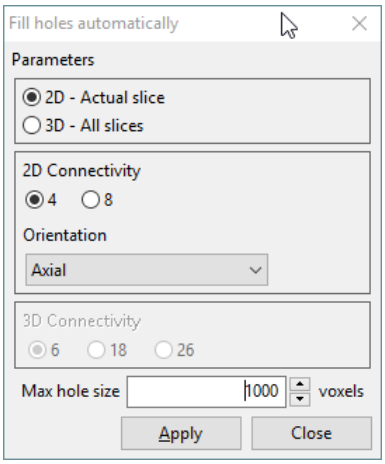


Figure 7.9: Dialog to configure the parameters used to fill the holes.

orientation window the holes will be filled.

After setting the parameters click **Apply**. If the result is not suitable set another hole size value or connectivity. Click **Close** to close this tool.

7.5 Remove parts

After generating a surface, it is recommended to remove the unwanted disconnected parts from a mask. This way the surface generation will use less RAM and make the process quicker. To remove any unwanted parts, go to the **Tools** menu, select **Mask** and then **Remove Parts** (Figure 7.10). A dialog will be shown to configure the selection parameters (Figure 7.11).

It's possible to select disconnected parts only on a mask slice (**2D - Actual slice**) or on all slices (**3D - All slices**); users may also configure

the connectivity at the same time.

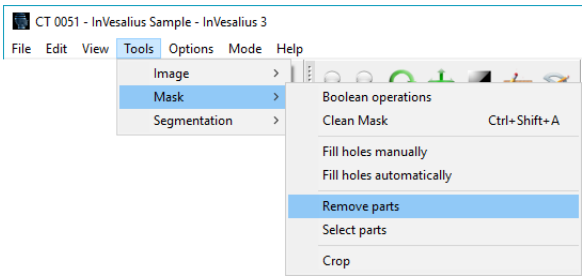


Figure 7.10: Menu to open the Remove parts tool.

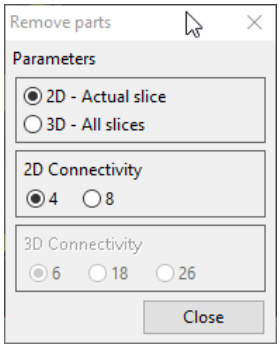


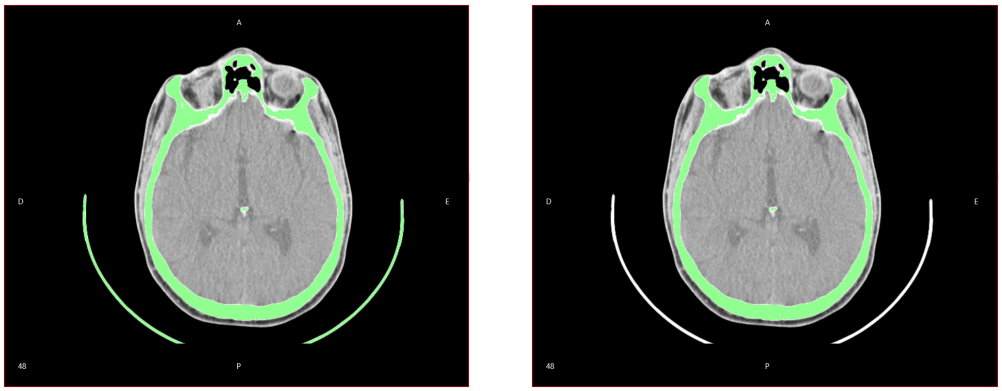
Figure 7.11: Dialog to configure the parameters used in Remove parts.

After selecting the desired parameters click with the **left-button** of the mouse on the region you want to remove. Figure 7.12 shows an example of a mask before and after the removal of unused parts. Click **Close** to stop using this tool.

7.6 Select parts

To open the Select parts tool, access the **Tools** menu, select **Mask** then **Select parts** (Figure 7.13). A dialog will be shown to configure the the name of the new mask and the connectivity (6, 18 or 26).

To select a region, **left-click** on a pixel; multiple regions can be selected. The selected region(s) will be shown with a red mask. After selecting all the wanted regions, click **OK** to create a new mask with the selected regions.



(a) Input image (b) Remove the tomograph support

Figure 7.12: Example of region remove from a mask.

Figure 7.15.a shows a region selected in red. Figure 7.15.b shows the selected region in a new mask.

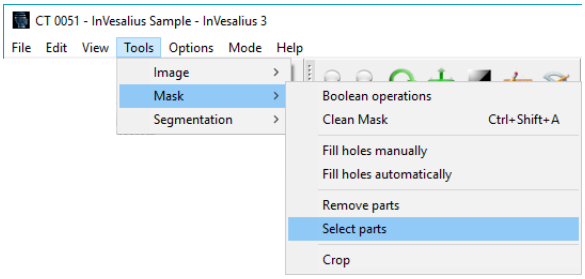


Figure 7.13: Menu to open the Select parts tool.

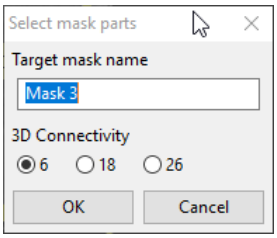
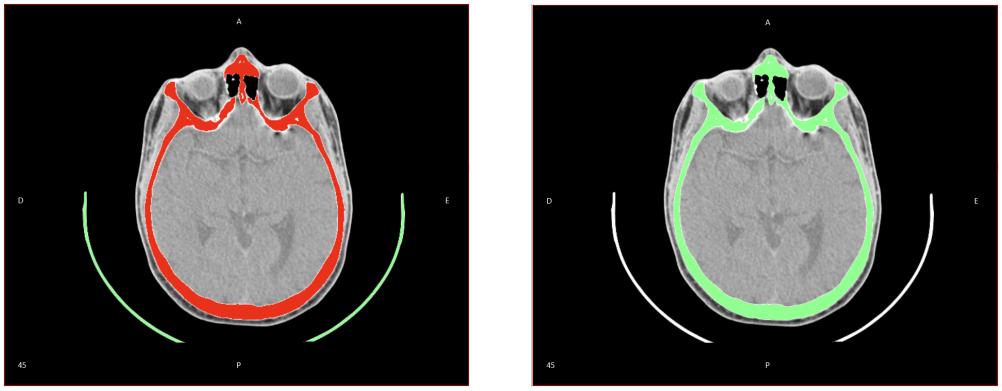


Figure 7.14: Dialog to configure the parameters of Select parts tool.



(a) Region selected in red

(b) Final image with only the selected region

Figure 7.15: Example of mask region selection.

7.7 Crop

The crop tool allows users to select and use a specific section of image of interest. This may reduce the amount of information needed to be processed when generating a surface. To open, access the **Tool** menu, then **Mask** and **Crop** (Figure 7.16).

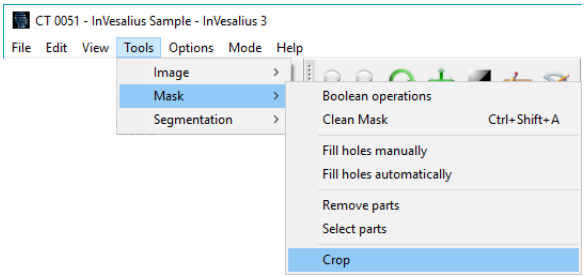


Figure 7.16: Menu open the Crop tool.

A box allowing for the selection of a specific area will then be displayed.

Chapter 8

Surface (Triangle mesh)

InVesalius, generates 3D surfaces based on image segmentation. A surface is generated using the marching cubes algorithm by transforming voxels from the stacked and segmented images to polygons (triangles in this case).

The controls to configure a 3D surface are accessible on the left panel, under **3. Configure 3D surface**, **Surface properties** you have the controls to configure a 3D surface (Figure 8.1).

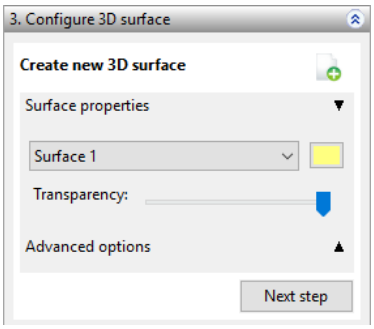


Figure 8.1: 3D surface configuration.

8.1 Creating 3D surfaces

News surfaces can be created using an already segmented mask. To do so, on the left panel under **3. Configure 3D surface**, click on the button shown in Figure 8.2.

Figure 8.2: Button to create a 3D surface.

After clicking this button a dialog will be shown (Figure 8.3). This dialog allows for the configuration of the 3D surface created, including setting the quality of the surface, filling surface holes whilst keeping the largest connected region of the surface intact.

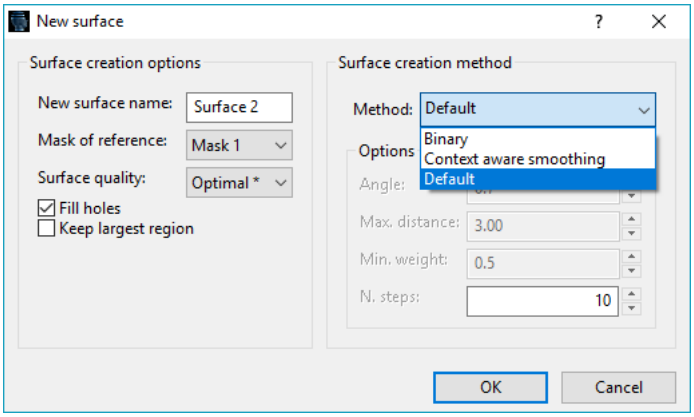


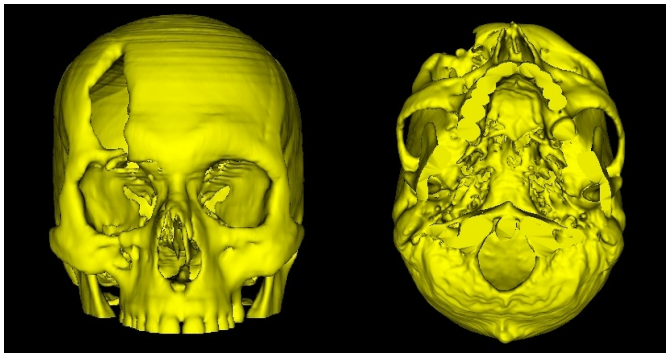
Figure 8.3: 3D surface creation dialog.

The keep largest region option may be used, for instance, to remove the tomograph supports. Figure 8.4 displays a surface created with **Keep largest region** and **Fill holes** activated, whereas Figure 8.5 displays the surface create without activating that options. Note the tomograph support and the holes.

The **Surface creation method** item has the following options: **Binary**, **Context aware smoothing** and **Default**. Figure 8.6 shows an example of surface created using each of these 3 methods.

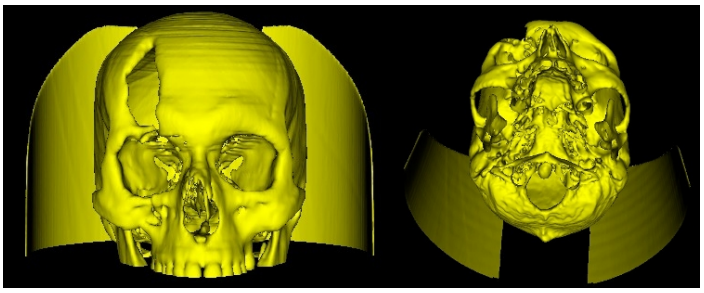
The **Binary** method takes as input the segmentation mask which is binary, where selected regions have value 1 and non-selected have value 0. As it is binary, the surface generated has a blocky aspect, mainly in high curvature areas, appearing staircases.

Context aware smoothing starts generating the surface using Binary, then uses another algorithm in order to smooth the surface to avoid staircase



(a) Frente (b) Baixo

Figure 8.4: Surface created with the options **Keep largest region** and **Fill holes** activated.



(a) Frente (b) Baixo

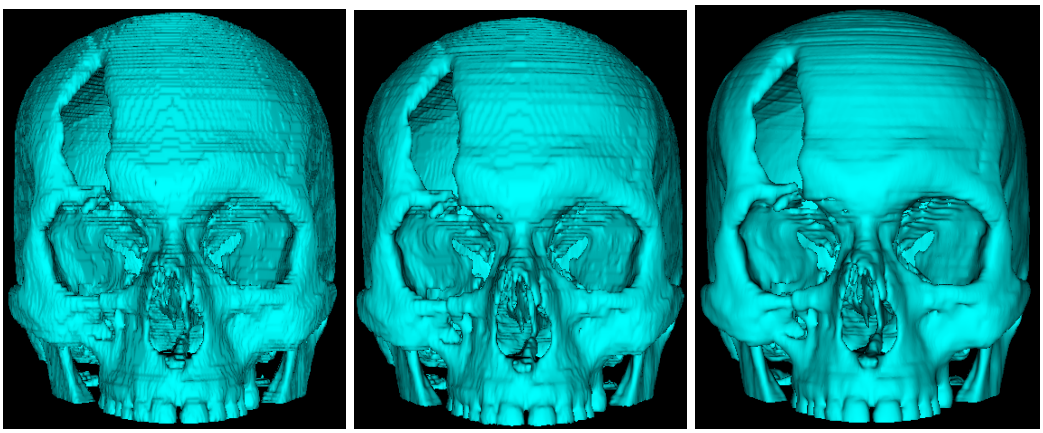
Figure 8.5: Surface created with the options **Keep largest region** and **Fill holes** deactivated.

details. This method has 4 parameters presented below.

The **angle** parameter is the angle between 2 adjacent triangles. If the calculated angle is greater than the angle parameter the triangle will be considered a staircase triangle and will be smoothed. The angle parameter ranges from 0 to 1, where 0 is 0° and 1 is 90°. The **Max distance** is the maximum distance that a non-staircase triangle may be from a staircase triangle to be considered to be smoothed. Non-staircase triangles with distance greater than Max distance also will be smoothed but the smoothing will be determined by the **Min. weight** parameter. This parameter ranges from 0 (without smoothing) to 1 (total smoothing). The last parameter, **N.steps**, is the number of times the smoothing algorithm will be run. The greater this

parameter the smoother the surface will be.

The **Default** method is enabled only when thresholding segmentation was used without any manual modification to the mask. This method does not use the mask image, but the raw image, and generates a smoother surface.



(a) Binary (b) Context aware (c) Default

Figure 8.6: Surface generated by each method.

8.2 Transparency

The Transparency function allows for the displaying of a surface transparently. To do so, select the desired surface from the list of surfaces, in the item **3. Configure 3D surface**, **Surface properties** (Figure 8.7).

Figure 8.7: Surface selection.

Then, to set the level of surface transparency, use the sliding control shown in Figure 8.8; the more to the right, the more transparent the surface will be.

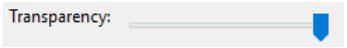


Figure 8.8: Selection of surface transparency.

Figure 8.9 shows 2 surfaces: the external surface in green has some level of transparency which permits to see the internal surface in yellow.

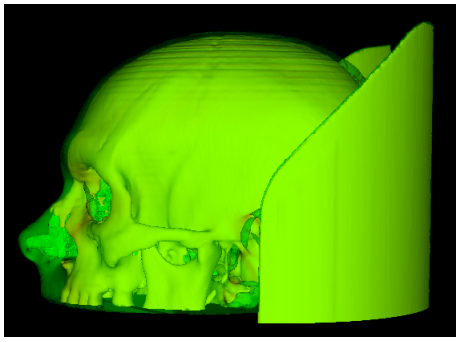


Figure 8.9: Surface with transparency.

8.3 Color

Surface colors can be altered by selecting the surface (Figure 8.7), and clicking on the colored button on the right of the surface selection list. Figure 8.10 displays this button, inside item **3. Configure 3D surface**, **Surface properties**.

Figure 8.10: Button to change surface color.

A dialog will be shown (Figure 8.11). Select the desired color and click on **OK**.

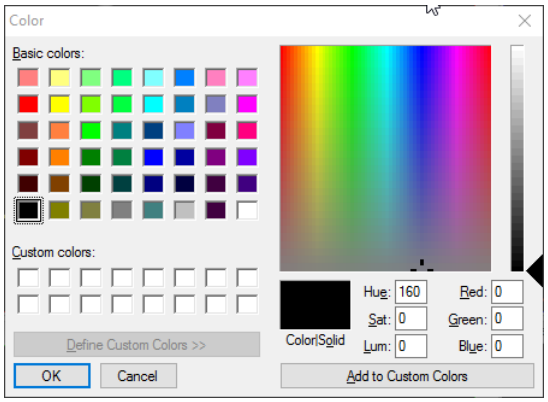


Figure 8.11: Color dialog.

8.4 Splitting disconnected surfaces

To split disconnected surfaces, select **3. Configure 3D surface**, **Advanced options** (Figure 8.12).

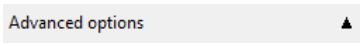


Figure 8.12: Advanced options.

The advanced options panel will be displayed (Figure 8.13).

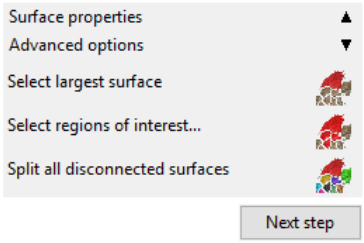


Figure 8.13: Advanced options panel.

8.4.1 Select largest surface

The option **Select largest surface** selects, automatically, only surface with the greater volume. Click on the button illustrated in Figure 8.14. This operation creates new a surface with only the largest surface.

Figure 8.14: Button to split the largest disconnected surface

As an example, the Figure 8.15 shows a surface before **Select largest surface**.

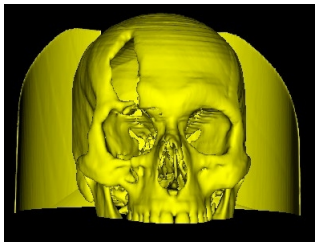


Figure 8.15: Disconnected surfaces.

Whereas the Figure 8.16 shows the surface with largest disconnected region separated.

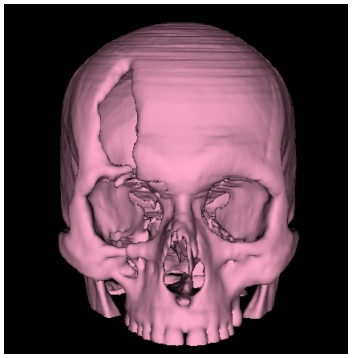


Figure 8.16: Largest disconnected region separated.

8.4.2 Select regions of interest

Another selection option is Select regions of interest. To do this operation click on the button illustrated in Figure 8.17, then click on the desired disconnected surface regions you want to select. Next click on **Select regions of interest**. This operation will create a new surface with only the selected disconnected regions.

Figure 8.17: Button to select the regions of interest.

As an example, the Figure 8.18 shows the surface created after the user selects the cranium and the right part of the tomograph support.

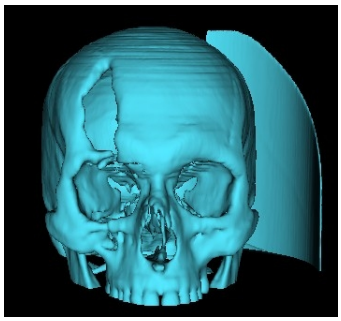


Figure 8.18: Example of selected regions of interest

8.4.3 Split all disconnected surfaces

Disconnected surface regions can also be split automatically. To do this, click on the button illustrated in Figure8.19.

Figure 8.19: Button to split all the disconnected regions surface.

Figure 8.20 shows an example.

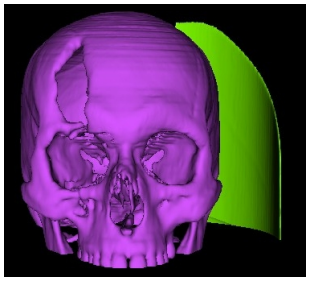


Figure 8.20: Example of split all disconnected regions surface.

Chapter 9

Measures

InVesalius has linear and angular measurements in 2D (axial, coronal and sagittal planes) and 3D (surfaces). It is thus possible to take measurements of volume and area on surfaces.

9.1 Linear Measurement

To perform linear measurements, activate the feature by clicking on the shortcut shown below, located on the toolbar (Figure9.1).

Figure 9.1: Shortcut to activate linear measurement

A linear measurement is taken between two points. With the feature enabled, click **once** on the image to set the starting point. Then position the mouse pointer on the end point and click once again. The measurement is performed and the result is automatically displayed on the image or surface

Figure 9.2 shows a 2D linear measure in the axial orientation, and Figure 9.3 shows another linear measure in 3D (surface).

Once you have made a 2D linear measurement, it can be edited by placing the mouse on one end, holding down the **right mouse button** and dragging it to the desired position.

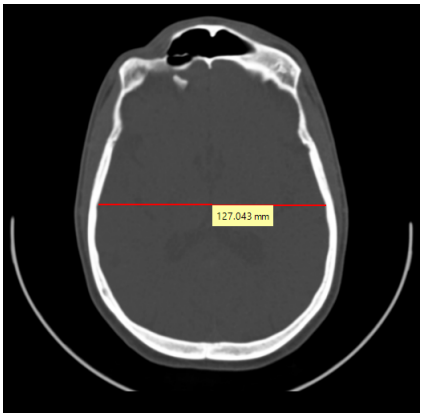


Figure 9.2: Linear measure on image

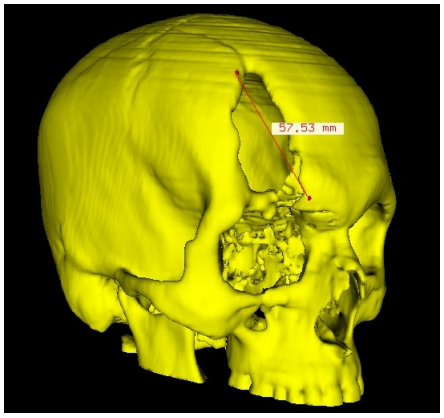


Figure 9.3: Linear measure on surface

Note: The linear measurement is given in millimeters (mm).

9.2 Angular Measurement

An angular measurement in 2D on a surface (3D) can be done by clicking on the shortcut shown in Figure 9.4.

Figure 9.4: Shortcut for angle measurement

To perform the angular measurement, it is necessary to provide the three

points that will describe the angle to be measured, AB̂C. Insert the first point by clicking once to select point A. Insert point B (the vertex or "point" of the angle) by positioning the cursor and clicking once again. Repeat the same actions to determine the endpoint of the angle, C. The resulting measurement is displayed on the image or surface.

Figure 9.5 illustrates an angular measurement on a flat image; Figure 9.6 illustrates an angular measurement on a surface.

In regards to 2D linear measurement, you can also edit the 2D angular measurement. Just position the mouse on one end, hold down the right mouse button and drag it to the desired position.

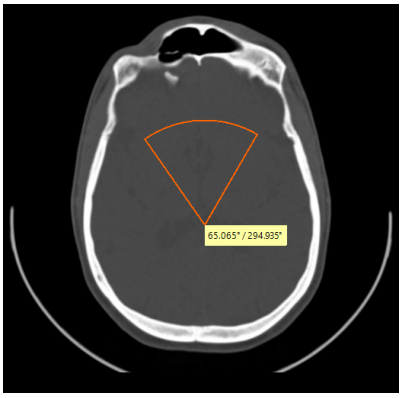


Figure 9.5: Angular measurement

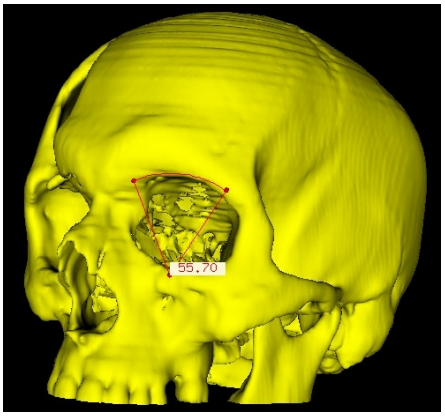


Figure 9.6: Angular measurement on surface

Note: Angular measurement is shown in degrees (°)

9.3 Volumetric Measurement

Volume and area measurements are made automatically when you create a new surface. These are displayed in the **Surfaces 3D** tab in the **Data** management panel, located in the bottom left corner of the screen, as illustrated in Figure 9.7.

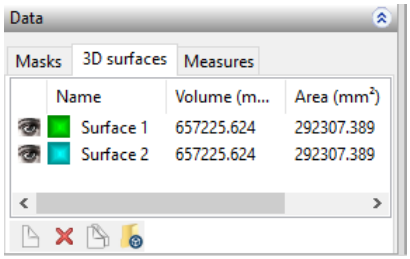


Figure 9.7: Volumetric measurements

Note: Volume measurement is given in cubic millimeter (mm^3)**, already the one of area in square millimeter** (mm^2)

Chapter 10

Data management

We have previously shown how to manipulate surfaces, masks for segmentation and measurements. We can also show or hide, and create or remove these elements in the **Data** management panel, located in the lower left corner of InVesalius. The panel is divided into 3 tabs: **Masks**, **3D Surfaces** and **Measurements**, as shown in Figure 10.1. Each tab contains features corresponding to the elements it refers to.

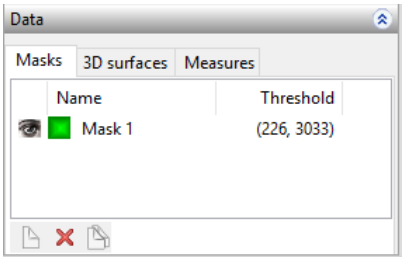


Figure 10.1: Data management

In each tab, there is a panel divided into rows and columns. The first column of each line determines the visualization status of the listed element. The "eye" icon activates or deactivates the masks, surface or measurement displayed. When one of these elements is being displayed, its corresponding icon (as shown in Figure 10.2) will also be visible.

Figure 10.2: Icon indicating the elements visibility

Some operations may be performed with the data. For instance, to remove one element, first select its name, as shown in Figure 10.3. Next, click in the shortcut shown in Figure 10.4.

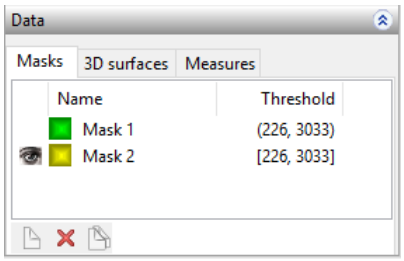


Figure 10.3: Data selected

Figure 10.4: Remove data

To create a new mask, surface or measurement, click on the shortcut shown in Figure 10.5, provided that the corresponding tab is open.

Figure 10.5: New data

To duplicate data, select data to be duplicated and click in the shortcut shown in Figure 10.6.

Figure 10.6: Duplicate data

10.1 Masks

In the Name column, the mask's color and name are shown. The **Threshold** column shows the value range used to create the mask. Figure 10.1 shows an example.

10.2 3D Surface

In the **Name** column, the surface's color and name are shown. The **Volume** column shows the total surface volume. Finally, the **Transparency** column indicates the level of transparency for use for surface visualization. Figure 10.7 shows an example.

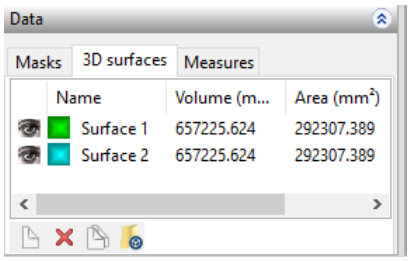


Figure 10.7: Surface manager

10.2.1 Import surface

We can also import STL, OBJ, PLY or VTP (VTK Polydata File Format) files into an active InVesalius project. To do so, click in the icon shown in Figure 10.8, select the format of the corresponding file, (Figure 10.9) and click Open.

Figure 10.8: Shortcut to import surface

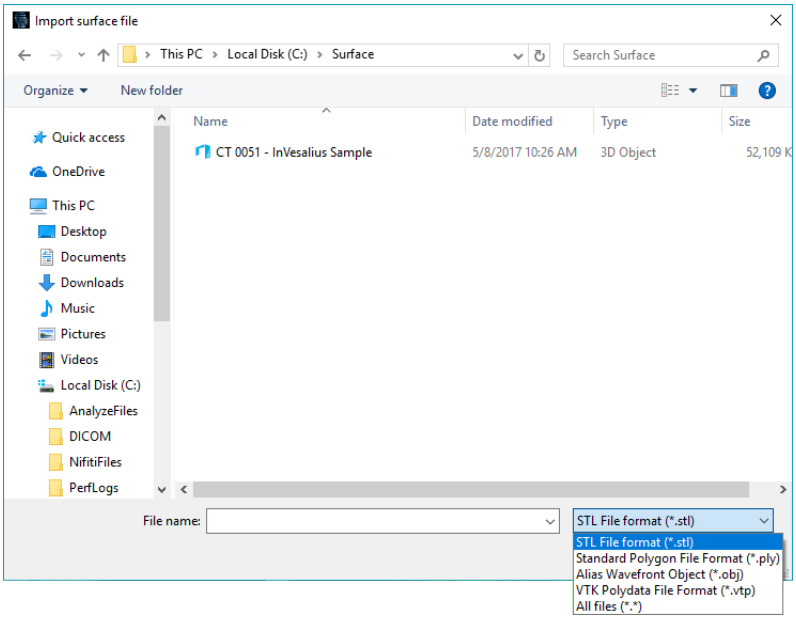


Figure 10.9: Window to import surface

10.3 Measurements

The tab Measurements shows the following information. **Name** indicates the color and measurement name. **Local** indicates where the measurement was taken (image axial, coronal, sagital or 3D), and **Type** indicates the type of measurement (linear or angular). Finally, **Value** shows the measurement value. Figure 10.10 illustrates the **Measurements** tab.

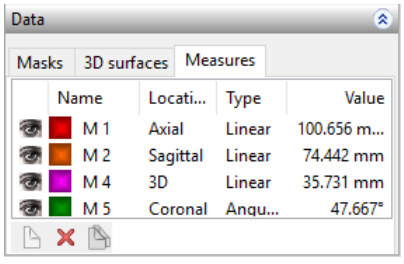


Figure 10.10: Data management

Chapter 11

Simultaneous viewing of images and surfaces

Images and surfaces can be viewed simultaneously by **left-clicking** on the shortcut (Figure 11.1) located in the lower right corner of the InVesalius interface.

Figure 11.1: Shortcut for simultaneous viewing

This feature allows users to enable or disable the displaying of images in different orientations (or plans) within the same display window of the 3D surface. Simply check or uncheck the corresponding option in the menu shown in Figure 11.2.

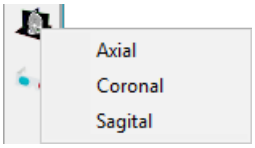


Figure 11.2: Selection of the guidelines (plans) to display

It is worth noting that when a particular orientation is selected, a check is presented in the corresponding option. This is illustrated in Figure 11.3.

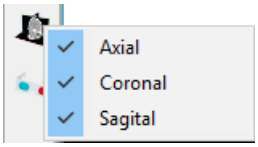


Figure 11.3: Selected Guidelines for display

If the surface is already displayed, the plans of the guidelines will be presented as shown in Figure 11.5. Otherwise, only the plans will be displayed.

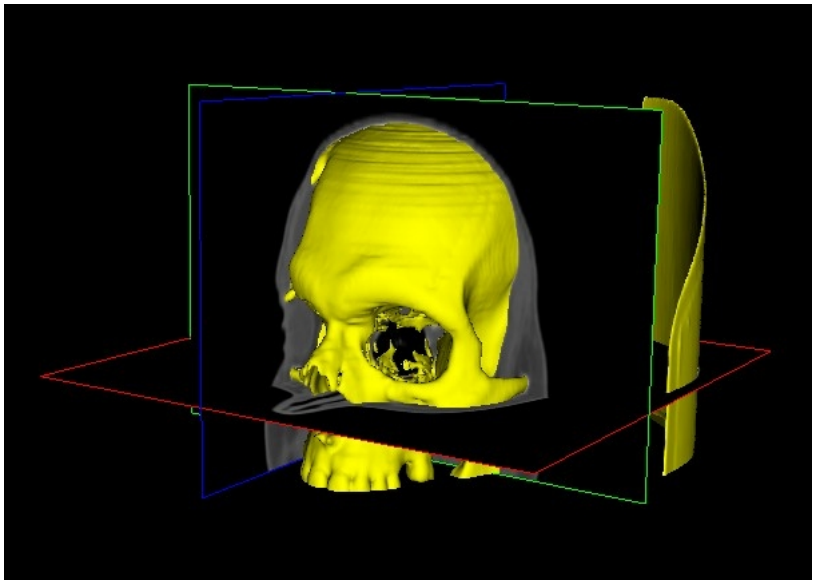


Figure 11.4: Surface and plans displayed simultaneously

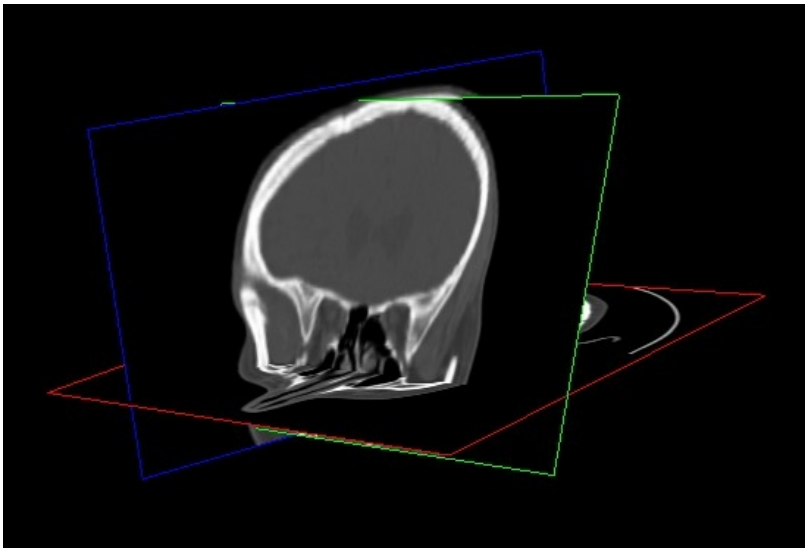


Figure 11.5: Flat display (no surface)

To view the display of a plan, just uncheck the corresponding option in the menu (Figure 11.3).

Chapter 12

Volume Rendering

For volume rendering models, InVesalius employs a technique known as raycasting. Raycasting is a technique that simulates the trace of a beam of light toward the object through each screen pixel. The pixel color is based on the color and transparency of each voxel intercepted by the light beam.

InVesalius contains several pre-defined patterns (presets) to display specific tissue types or different types of exam (tomographic contrast, for example).

To access this feature, simply click the shortcut shown in Figure 12.1 in the lower right corner of the screen (next to the surfaces display window) and select one of the available presets.

To turn off volume rendering, click again on the path indicated by Figure 12.1 and select the **Disable** option.

Figure 12.1: Shortcut to volume visualization

12.1 Viewing Standards

There are several predefined viewing patterns. Some examples are illustrated in the following figures.

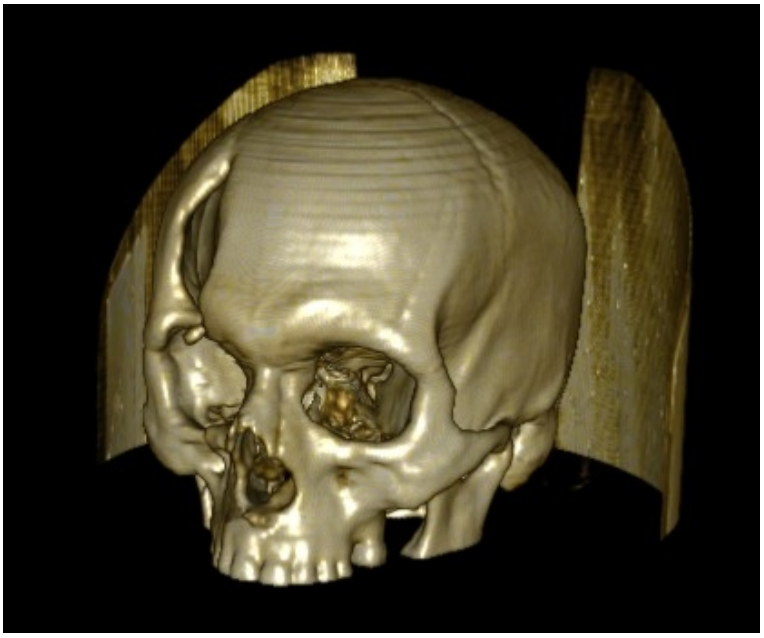


Figure 12.2: Bright

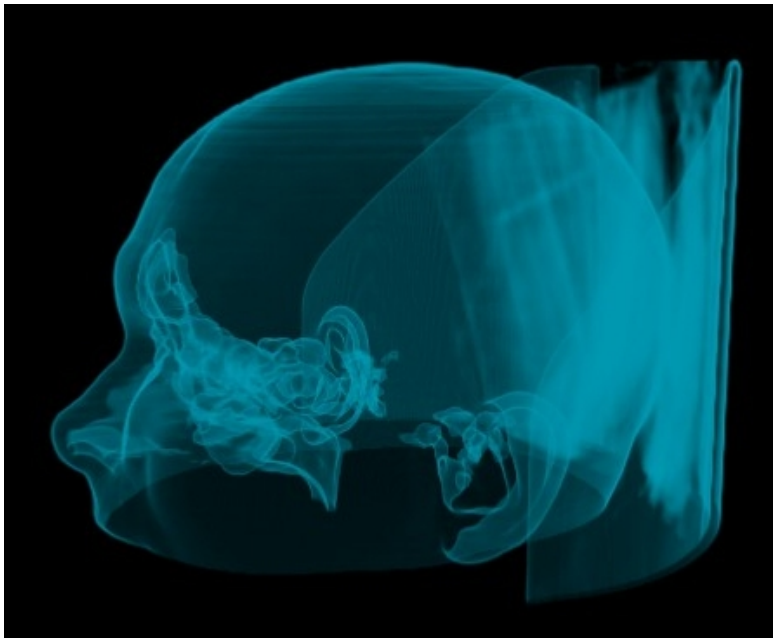


Figure 12.3: Airway II

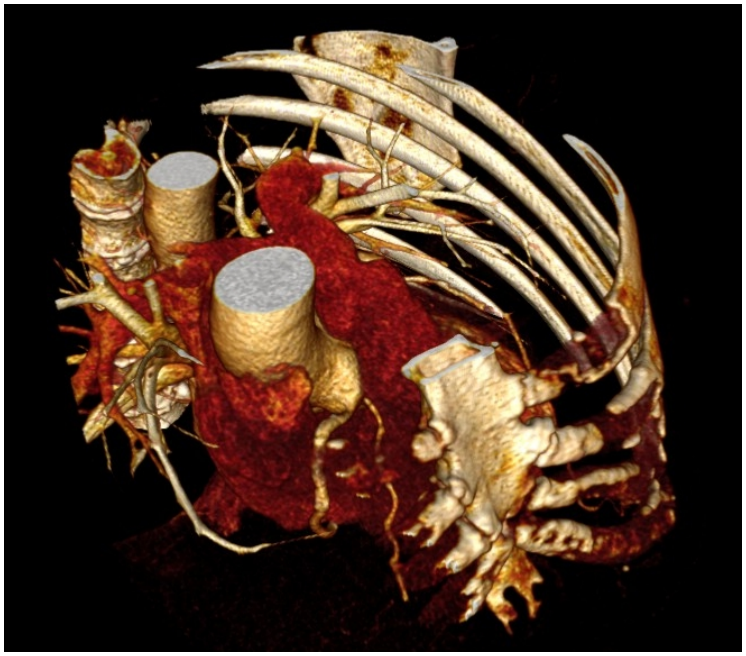


Figure 12.4: Contrast Medium

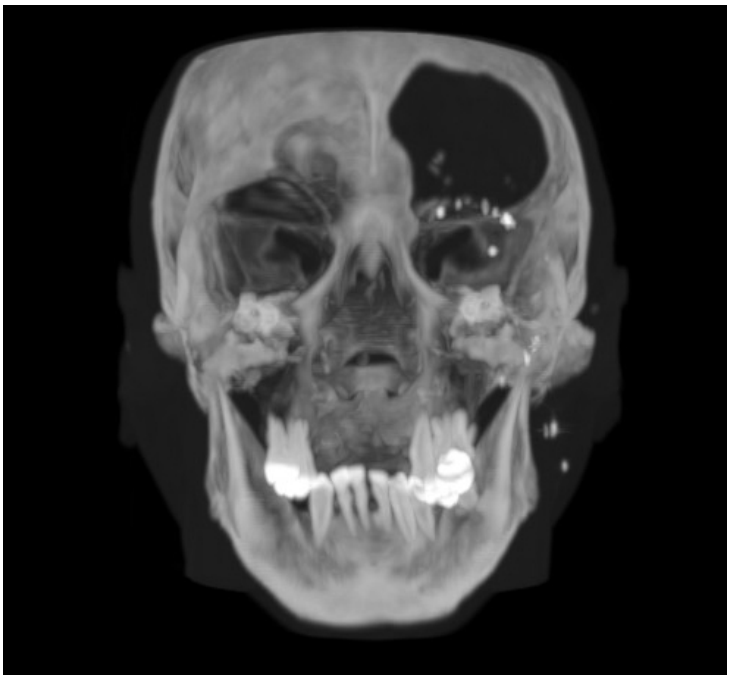


Figure 12.5: MIP

12.2 Standard Customization

Some patterns can be personalized (and customized). Figure 12.6 is exhibiting a pattern and some graphical controls adjustment. With these features, the color of a given structure and its opacity can be altered, determining if and how it will be displayed.

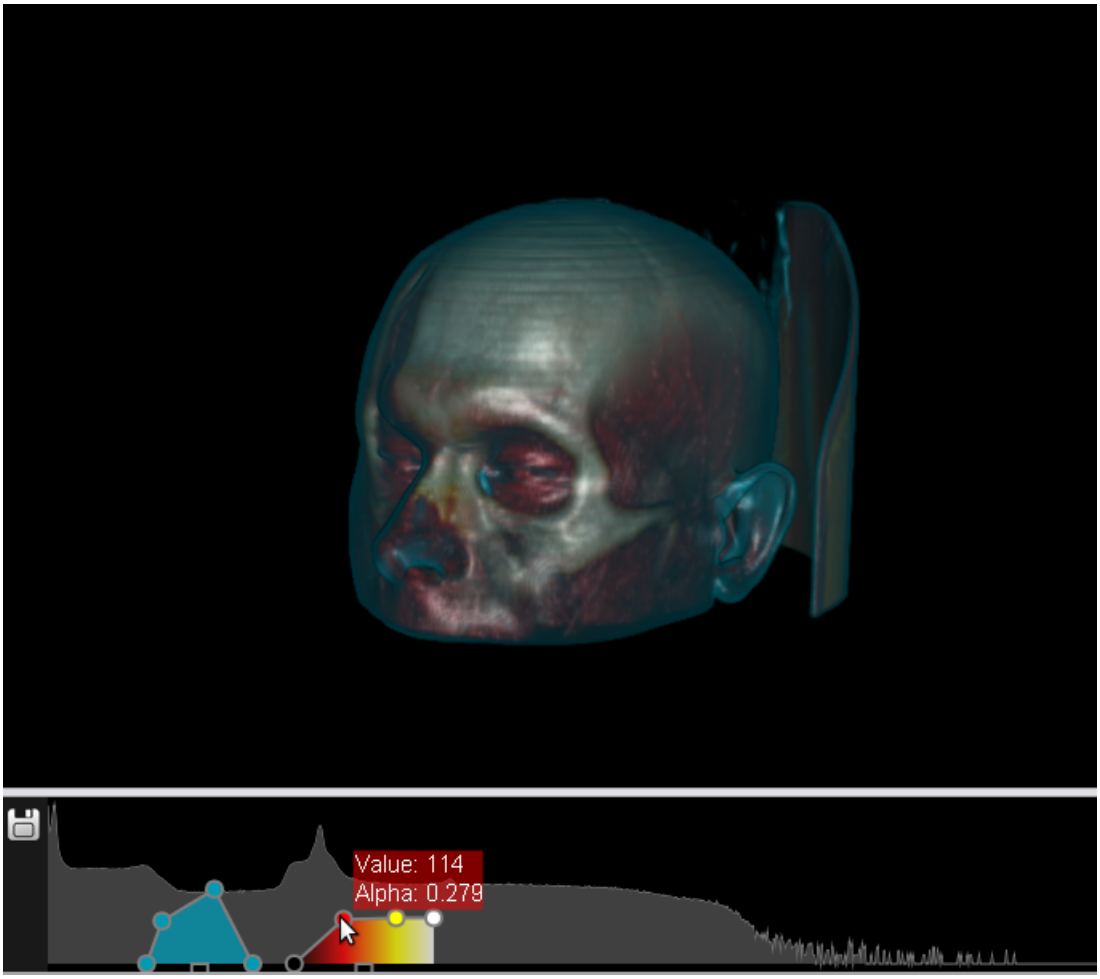


Figure 12.6: Settings for the display pattern Soft Skin + II

To hide a structure, use the control setting chart to decrease the opacity of the corresponding region. In the example in Figure 12.6 suppose we want to hide the muscular part (appearing in red). To do this, simply position the pointer over the muscular part in red and, using the left mouse button, drag the point down to reduce opacity and make the part transparent. Figure 12.7 illustrates the result.

Note: The Alpha value indicates the opacity of the color and the **value**, the color intensity of the pixel.

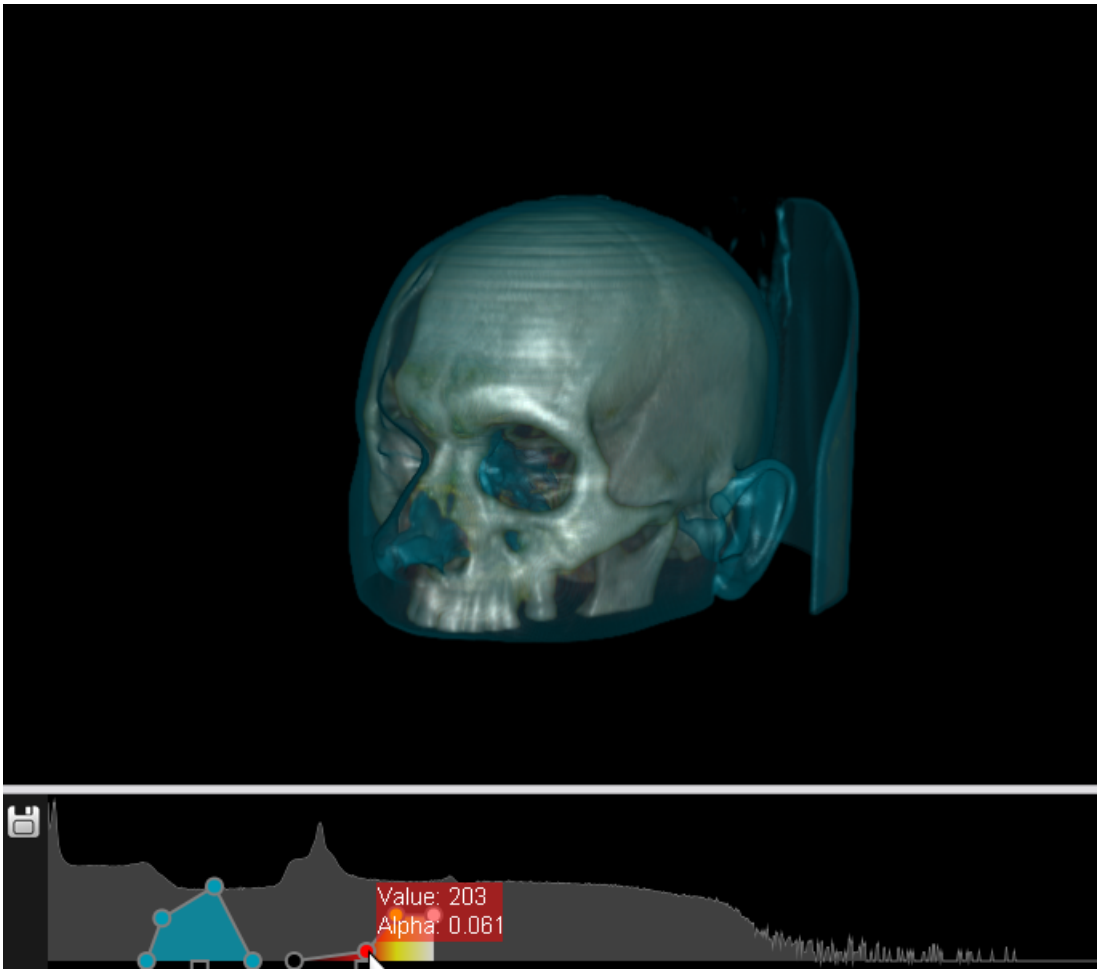


Figure 12.7: Display Standard Soft Skin + II changed

We can also remove or add points on the graph control setting. To remove, simply click with the right mouse button on the point. To add a new point, click the left button on the line graph. One can also save the resulting pattern by clicking the shortcut shown in Figure 12.8.

Figure 12.8: Shortcut to save standard

To save the pattern, InVesalius displays a window like the one shown in Figure 12.9. Enter a name for the custom pattern and **click OK**. The saved pattern will be available for the next time the software is opened.

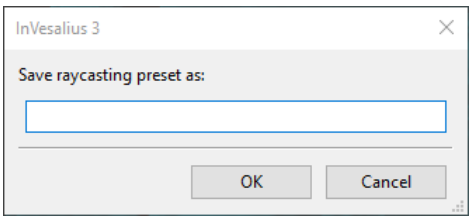


Figure 12.9: Window to save name of pattern.

12.3 Standard Customization with Brightness and Contrast

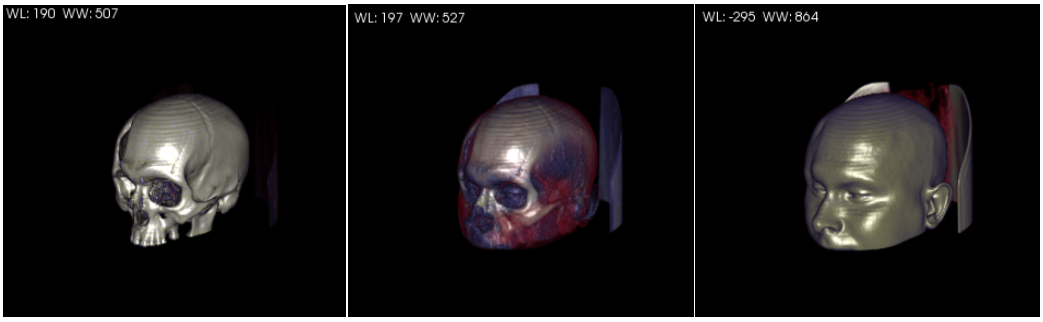
You can customize a pattern without using the graphical control settings presented in the previous section. This is done through the **brightness and contrast** controls on the toolbar. Activate these by clicking the icon shown in Figure 12.10.

Figure 12.10: Shortcut to Brightness and Contrast

Enable the control by dragging the mouse, with the left button pressed on the volume window. This will change the values of the window width and window level. The procedure is the same as with slices applied to 2D

images, which can be seen in section 5.7. Dragging the mouse in a horizontal direction changes the window level value; drag left to decrease and right to increase. Dragging the mouse vertically changes the value of window width; drag down to decrease and up to increase.

Manipulating these values can be useful for different viewing results. For example, to add tissue to the display, **drag** the mouse diagonally with **left button** pressed from the lower right to the upper left corner of the preview window. To remove tissue visualization, do the opposite, (i.e drag the mouse diagonally from top left to bottom right with the left button pressed.). See Figure 12.11.



(a) Bone (b) Muscle (c) Skin

Figure 12.11: Tissue Addition

12.4 Cut

In volume rendering, the cut function is used to view a cross-section of a region. With a volume pattern selected, click **Tools**, and then click **Cut plane** (Figure 12.12).

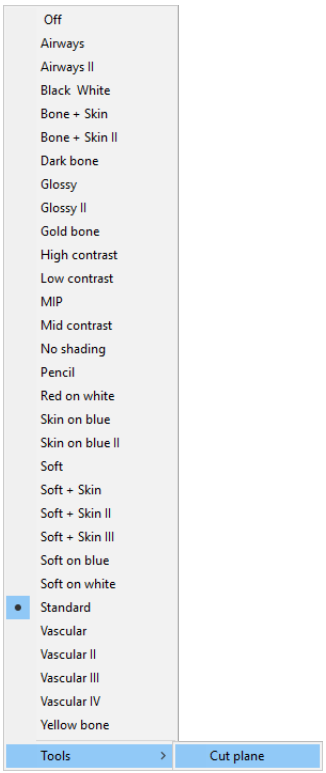


Figure 12.12: Enabling plan to cut

An outline for cutting appears next to the volume. To make the cut, hold the left mouse button on the plane and drag the mouse. To rotate the plane, hold the left mouse button pressed on its edge and move the mouse in the desired direction as shown in Figure 12.13.

When finished using the function, click **Tools** and again click **Cut plane** (Figure 12.13).

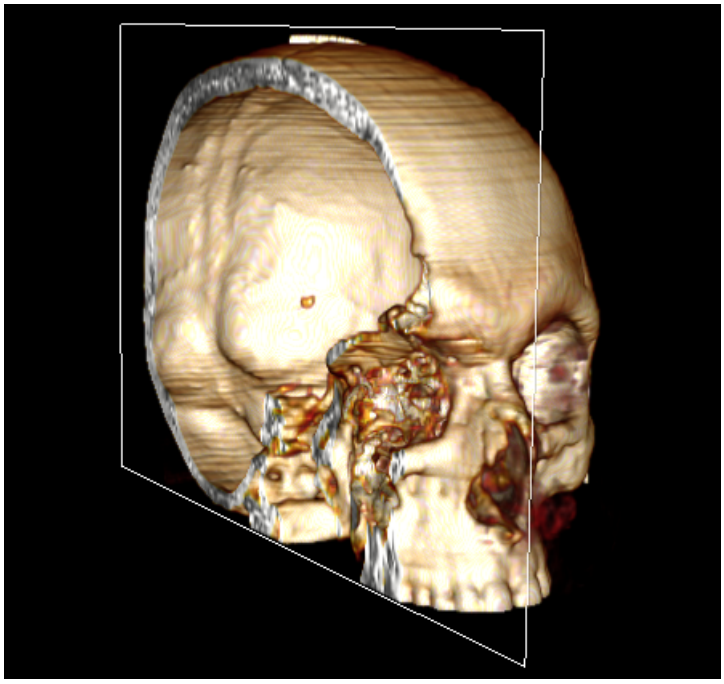


Figure 12.13: Image with clipping plane

Chapter 13

Stereoscopic Visualization

InVesalius supports stereoscopic visualization of 3D models. First a surface (see chapter 8) or an active volumetric visualization (see chapter 12) must be created. Then, click the icon (shown in Figure 13.1) on the bottom right part of the interface and choose the desired projection type (Figure 13.2).

Figure 13.1: Shortcut to activate stereoscopic viewing methods.

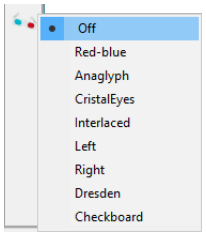


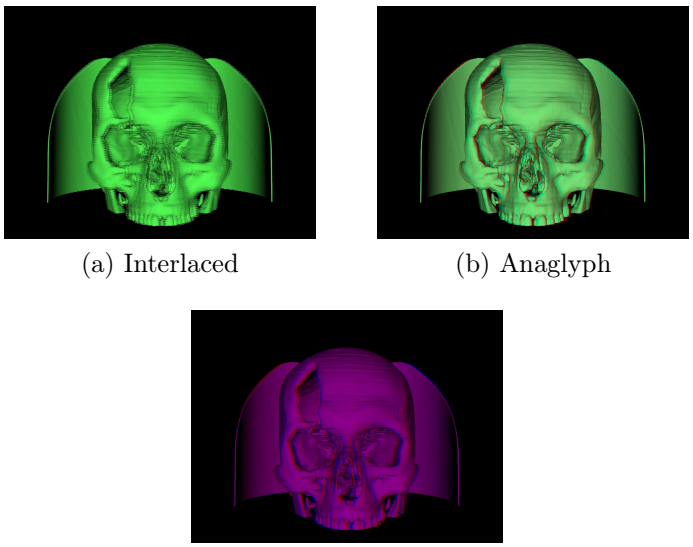
Figure 13.2: Different methods of stereoscopic visualization.

InVesalius supports the following types of stereoscopic viewing:

- Red-blue
- Anaglyph
- CristalEyes

- Interlaced
- Left
- Right
- Dresden
- Checkboard

Figure 13.3 presents three different types of projections.



(a) Interlaced (b) Anaglyph

(c) Red-blue

Figure 13.3: Example of different methods of stereoscopic applied on a surface.

Chapter 14

Data export

InVesalius can export data in different formats, such as OBJ, STL and others, to be used in other software.

The menu to export data is located in the left panel of InVesalius, inside item **4. Export data** (displayed below in Figure 14.1). If the menu is not visible, double-click with the **left** mouse button to expand the item.

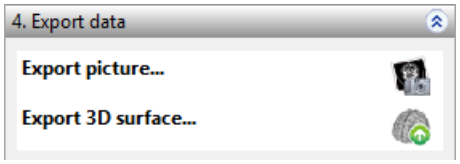


Figure 14.1: Menu to export data

14.1 Surface

To export a surface, select it from the data menu as shown in Figure 14.2.

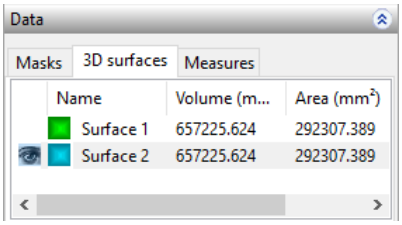


Figure 14.2: Select surface to be exported

Next, click on the icon shown in Figure 14.3.

Figure 14.3: Shortcut to export surface

When the file window displays (as shown in Figure 14.4), type the file name and select the desired exported format. Finally, click **Save**.

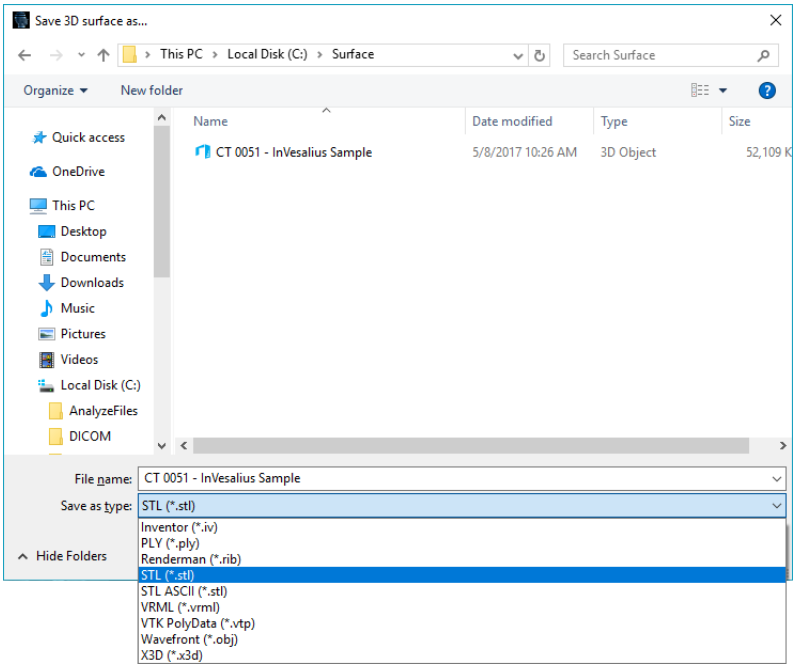


Figure 14.4: Window to export surface

Files formats avaiable for exportation are listed in table 14.1:

Table 14.1: File formats exported by InVesalius

Format	Extension
Inventor	.iv
Polygon File Format	.ply
Renderman	.rib
Stereolithography (formato binário)	.stl
Stereolithography (formato ASCII)	.stl
VRML	.vrml
VTK PolyData	.vtp
Wavefront	.obj

14.2 Image

Images exhibited in any orientation (axial, coronal, sagittal and 3D) can be exported. To do so, **left-click** on the shortcut shown in Figure 14.5 and select the sub-window related to the target image to be exported.

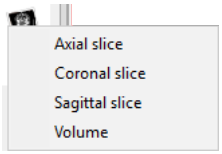


Figure 14.5: Menu to export images

On the window shown (Figure 14.6), select the desired file format, then click **Save**.

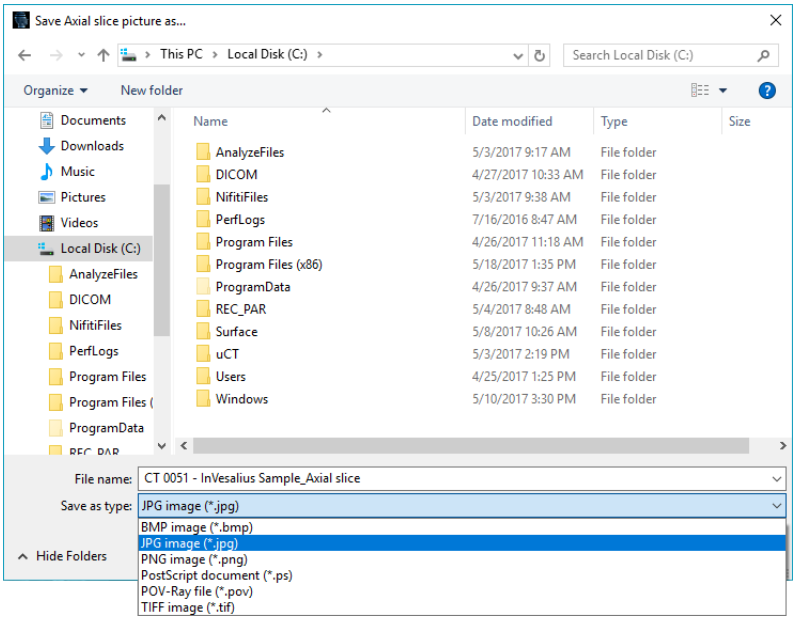


Figure 14.6: Window to export images

Chapter 15

Customization

Some customization options are available for InVesalius users. They are shown as follows.

15.1 Tools menu

To hide/show the side tools menu, click the button shown in Figure 15.1.

Figure 15.1: Shortcut to hide/show side tools menu

With the menu hidden, the image visualization area in InVesalius is expanded, as shown in Figure 15.2.

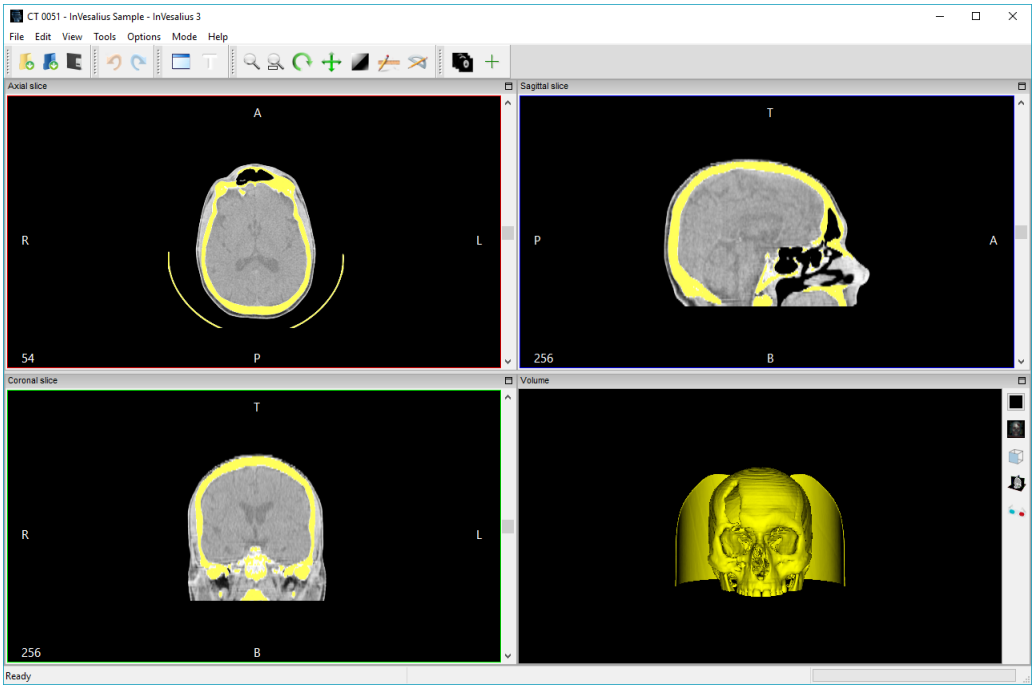


Figure 15.2: Side menu hidden

15.2 Automatic positioning of volume/surface

To automatically set the visualization position of a volume or surface, click on the icon shown in Figure 15.3 (located in the inferior right corner of InVesalius screen) and choose one of the available options for visualization.

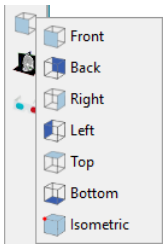


Figure 15.3: Options for visualization positioning

15.3 Background color of volume/surface window

To change the background color of the volume/surface window, click on the shortcut shown in Figure 15.4. The shortcut is also located in the lower right corner of the InVesalius screen.

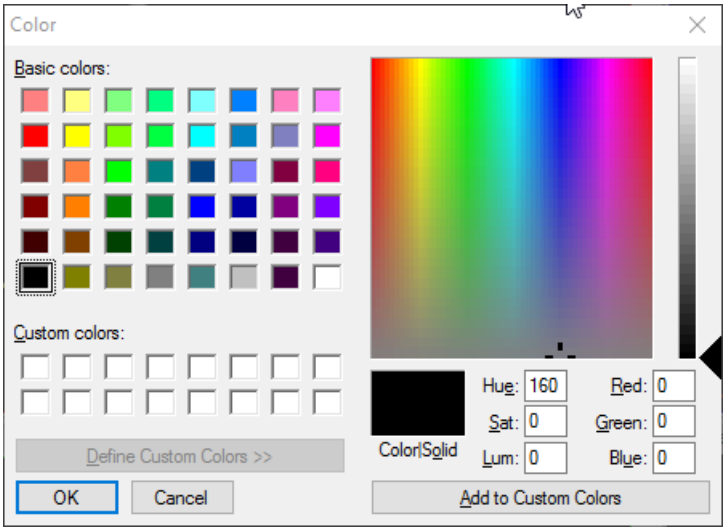


Figure 15.4: Shortcut to background color of volume/surface window

A window for color selection opens (Figure 15.5). Next, simply click over the desired color and then click **OK**.

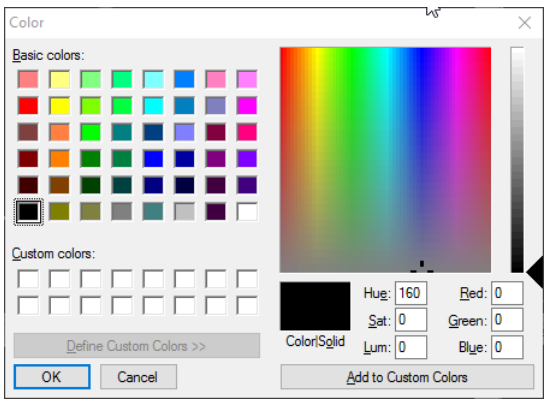


Figure 15.5: Background color selection

Figure 15.6 illustrates an InVesalius window with the background color changed.

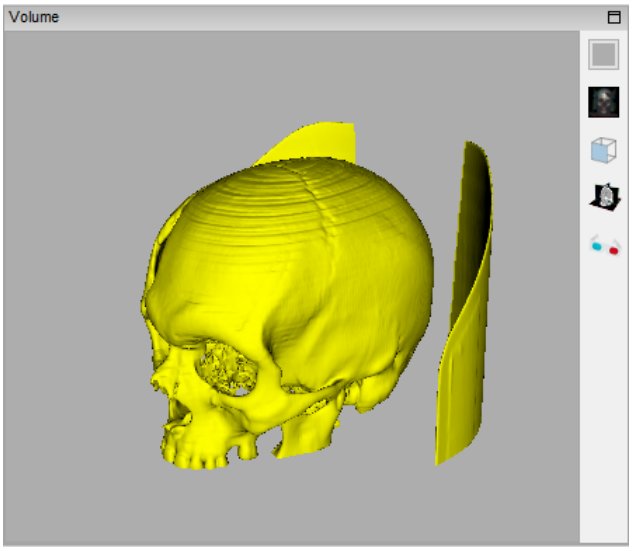


Figure 15.6: Background color modified

15.4 Show/hide text in 2D windows

To show or hide text in 2D image windows, click on the shortcut illustrated in Figure 15.7 on the toolbar.

Figure 15.7: Shorcut to show or hide texts

Figures 15.8 and 15.9 show text enabled and disabled, respectively.

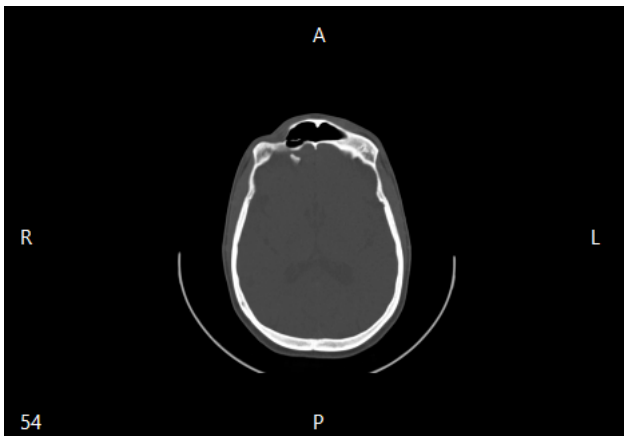


Figure 15.8: Show texts enabled

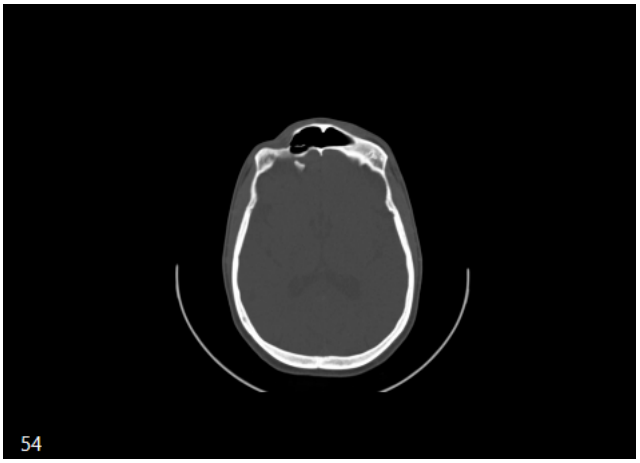


Figure 15.9: Show texts disabled

Chapter 16

Neuronavegation

An introduction to neuronavigation theory was presented in section 1.1.5. Please read that section before using the features detailed below.

To enable the InVesalius neuronavigation mode, select the **Mode** tab in the main menu and then Navigation (Figure 16.1). A **Navigation System** tab will then display in the panel to the left of the main window, as shown in Figure 16.2.

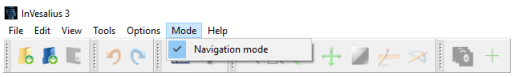


Figure 16.1: Menu to enable neuronavigation mode.

16.1 Spatial trackers and reference mode

Currently, InVesalius Navigator supports four spatial tracking devices from two manufacturers: the MicronTracker from ClaroNav (Toronto, Canada; Figure 16.3) and Fastrak, Isotrak and Patriot from Polhemus (Colchester, United States; Figure 16.4).

First, choose the tracker in the menu **Select tracker** (Figure 16.5). The option **Debug tracker** allows the user to test the system even if there is no spatial tracker connected, instead simulating a spatial tracker by generating random coordinates.

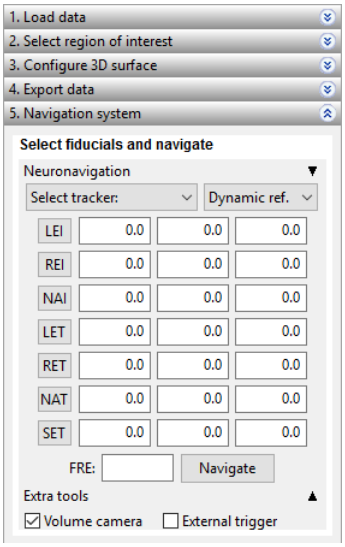


Figure 16.2: Tab for navigation system.

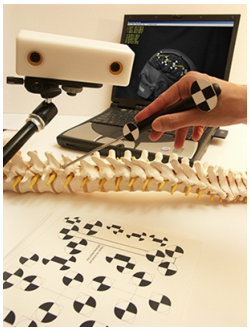


Figure 16.3: ClaroNav MicronTracker - www.claronav.com/microntracker/.

Figure 16.4: Polhemus Patriot tracker - http://polhemus.com/motion-tracking/overview/.

There are two methods to perform the navigation: static and dynamic (Figure 16.6). Static mode uses just one spatial tracker probe. In this mode, the subject's head must stay motionless after registration (for more info about

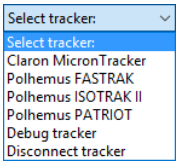


Figure 16.5: Menu to select tracking device.

coregistration see Section 16.2 probes: a reference probe must head (e.g. forehead). during the probe will detect and correct any 16.2). Dynamic mode uses multiple be attached to a static part of the neuronavigation process; the reference movements from the head.

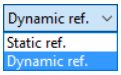


Figure 16.6: Menu to select reference mode.

16.2 Coregistration

The aim of coregistration is to transform a coordinate given in the tracking device space to a coordinate in the virtual space (image). To perform coregistration, the user must use the function **Correspondence between orientations axial, sagittal and coronal** (see section 5.2) and select three anatomical fiducials in the image. Then, collect the same three fiducials with the spatial tracker. The most common anatomical fiducials are the nasion and both tragus (ears). Figure 16.7 shows the fiducials panel. When an image fiducial is selected, a marker (green sphere) is created (shown in Figure 16.8).

Figure 16.7: Buttons and coordinates to select anatomical fiducials.

The buttons acronyms represent:

- LEI: left ear in image
- REI: right ear in image
- NAI: nasion in image
- LET: left ear with spatial tracker
- RET: right ear with spatial tracker
- NAT: nasion with spatial tracker

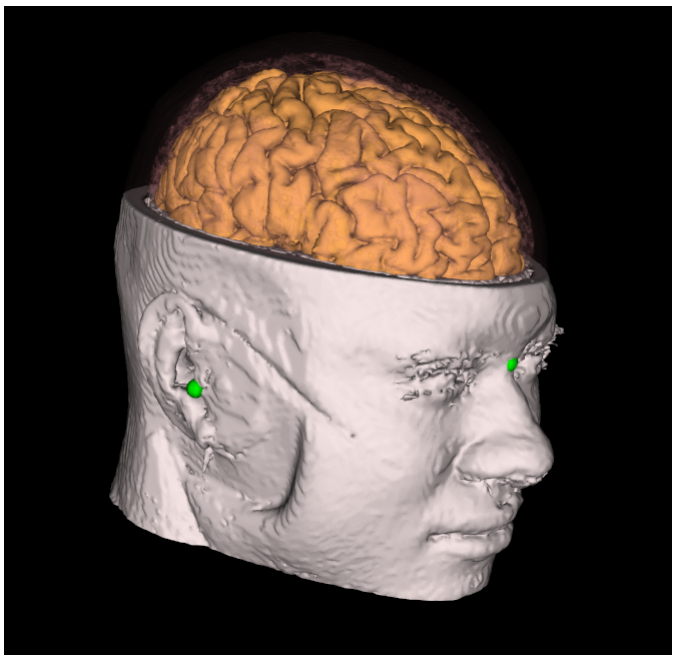


Figure 16.8: Selected fiducial markers represented as green spheres.

16.3 Fiducial registration error and navigation

After all fiducials are selected in both spaces (tracker and image), press the **Navigate** button to start the neuronavigation process. To stop navigation, simply press **Navigate** again. Immediately after the navigation starts, the **Fiducial Registration Error** (FRE) is calculated. The FRE is the root

mean square distance between the image fiducials used before and after registration.

To the left of the Navigate button there is a FRE text box. If FRE is high (greater than 3 mm) the navigation will not be precise and the text box will become red (Figure 16.9). If this occurs, the coregistration should be redone. If FRE is lower than 3 mm, the text box will turn green, showing that the navigation has an acceptable precision (Figure 16.10).

Figure 16.9: Navigation button and high FRE unsuitable for navigation.

Figure 16.10: Navigation button and low FRE suitable for navigation.

16.4 Markers

During navigation, it is possible to create sphere markers in the 3D space. To do so, select the **Extra tools** tools tab (Figure 16.11).

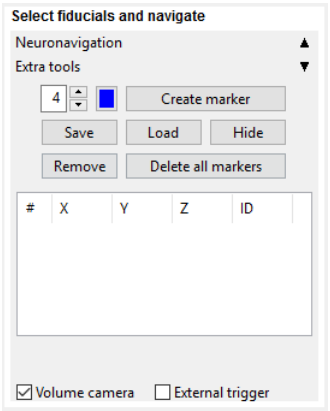


Figure 16.11: Markers manipulation tab.

The marker will be positioned in the current red cross position. The size and color can be changed as needed (Figure 16.12).

When a marker is created, its coordinates will appear in the list control. To identify one marker in the volume, **double-click with the left** mouse button on the target item and the corresponding marker will blink. To stop blinking, select another marker. It is also possible to create an ID for the marker; simply right click and select **Edit ID** (Figure 16.13). Finally, a window will open allowing the user to define the ID (Figure 16.14).

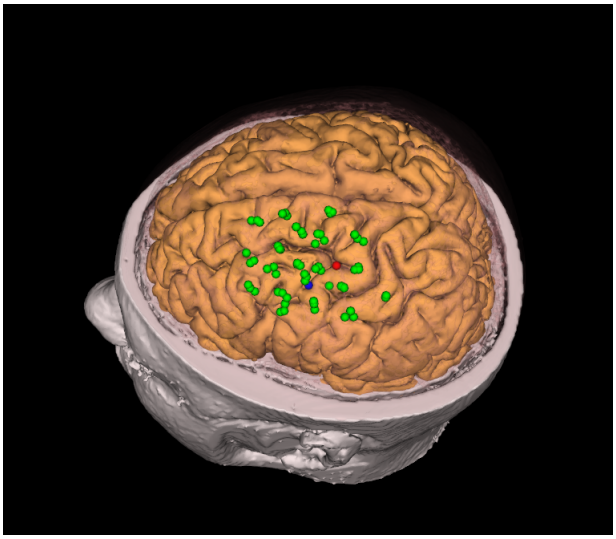


Figure 16.12: Volume with different colors markers.

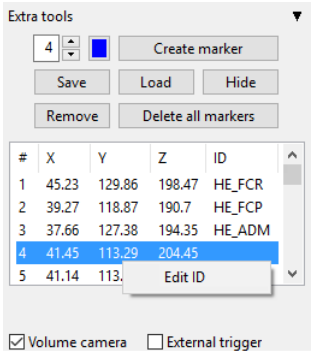


Figure 16.13: Task to manage marker creation.

The marker coordinates may be exported using the **Save** button (the file extension will be *.mks*). This extension can be opened in any word processor, e.g. Notepad or WordPad software. The file will contain the X, Y and Z

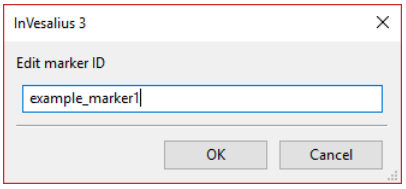


Figure 16.14: Window to label the marker.

coordinates followed by the RGB code, marker size and ID. Afterwards, the markers can be imported into the navigation system using the **Load** button.

To remove markers, **select** one or more markers needing deletion and press **Remove**. It is also possible to remove all markers, with the button **Remove all markers**. All markers can be hidden or shown in the volume using the **show/hide button**.

16.5 External trigger checkbox

Markers can also be created by using an external trigger. To activate this feature, press the checkbox **External trigger** before starting navigation. This function was developed to communicate with TMS devices by creating a marker where the pulses are applied, and can be adapted as the user requires. Communication with an external device requires serial port COM1. If this port receives any RS-232 signal at a 9600 *baud rate* it will create a marker in the current red cross position.

16.6 Camera volume checkbox

The volume camera positioning is updated automatically, both by the red cross and the spatial tracker probe position. The user can disable this function by unchecking the **Camera volume** checkbox. However, the camera has to be manually changed.

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