Software InVesalius

User Guide

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About InVesalius

InVesalius is a 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 by means of Tomography Computerized (CT) or Magnetic Resonance (MRI), the program allows to create three-dimensional (3D) anatomical structures corresponding the patients in medical follow-up.

InVesalius name is a tribute to the Belgian doctor Andreas Vesalius (1514-1564), 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. On the November 2007 InVesalius was made available as free software and open source in the Public Software Portal (www.softwarepublico.gov.br), consolidating communities of users and developers. It is a simple, easy to use, robust, cross-platform and free tool.

The use of visualization technologies and three-dimensional analysis of medical images , perhaps integrated with rapid prototyping, assists the surgeon in diagnosing pathologies and a detailed surgical planning, simulating complex interventions in advance, which may involve, for example, a high degree of facial deformity or of prosthetics.

InVesalius has demonstrated great versatility and has contributed to several areas, including medicine, dentistry, veterinary medicine, archeology and engineering.

Contents

Chapter 1

Introduction

This manual aims to show the use of InVesalius tools and also present some concepts to facilitate the use of the software.

InVesalius is a 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 the medicine, you can use the software in other areas such as archaeology, 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, one needs to posses basic computer skills cos. Understanding medical images can help to form a better understanding of the operations.

1.1 Important Concepts

In this section, we discuss some concepts necessary to better understanding of and operation of the software.

1.1.1 DICOM (*Digital Image Communications in Medicine*)

DICOM is a standard on the transmission, storage and treatment of medical images. The standard provides various types of medical images, such as images emanating from computed tomography equipment, magnetic resonance, ultrasound, 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 radiodensiade is translated into an image in gray levels, called the *Hounsfield* scale, named after Godfrey Newbold Hounsfield, one of the creators of the first CT scan machine.

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

In the most modern appliances, with a radiation emitter and a sensor bank (also called channels, ranging from 2 to 256), which circumvent the patient while the stretcher is moved, forming a spiral, it is possible to generate 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, which are then translated in the range of Hounsfield (HU). The lighter shades represent denser fabrics, and the darker, less dense tissue such as skin and brain.

Table 1.1 presents some materials and their repective values in HU (*Hounsfield Unit*).

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 if compared to medical CT, and therefore makes it possible to view more details of delicate regions such as alveolar cortical.

Image acquisition is performed with the patient in the vertical (as opposed to medical tomography, the patient is horizontal). A transmitter and a sensor X-ray surround the patient's skull, forming an arc of 180° or 360°. The images generated by the scanner can be interpreted as a volume with the skull immersed patient. This volume is "sliced" by the instrument software, being able to generate images with different spacing or other types of images, such as the 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

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

have more gray levels than the study shut Hounsfield, which makes the use of segmentation patterns (preset) less efficient. Another very common feature in the images of provincial dental CT scanners is the high presence of speckle noise type and the presence of other noise typically caused by the use of amalgam prosthesis by the patient.

1.1.4 Magnetic Resonance Imaging - MRI

MRI is an examination performed without the use of ionizing radiation. Instead, it used a strong magnetic field to align the atoms of any element present in our body, commonly the nio hydrogenated. After alignment, radio waves are triggered, and atoms are excited. The sensors measure the time that the hydrogen atoms democratic ram to align again. This makes it possible to determine what kind of fabric, because different tissues have different amounts of hydrogen atoms.

To avoid interference and improve the quality of the radiofrequency signal, and the patient get inside the machine, it is placed a coil in the region of interest.

1.1.5 Neuronavigation

Neuronavigation is a technique that allows tracking and localization of surgical instruments relative to neuronal structures through computer visual-

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

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

ization. In addition, neuronavigation systems have been pointed out as a fundamental tool to aid surgical planinng and to increase the accuracy of experiments in neuroscience, such as transcranial magnetic stimulation (TMS), electroencephalography (EEG), 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 navigation 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

The InVesalius is designed to run on personal computers, such as desktops and notebooks. Currently, it is compatible with the following operating systems:
- MS-Windows (Windows 7, 8 e 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 memory available RAM, the processor frequency and operating system architecture (32-bit or 64-bit).

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

1.2.1 Minimum settings

32 *bits* Operating System
Intel Pentium 4 or equivalent with frequency 1,5 GHz
1 GB RAM
80 GB hard disk
Graphics card with 64 MB de memória
Video resolution of 1024x768 *pixels*

1.2.2 Recommended settings

64 *bits* Operating System

Intel Core 2 Duo processor or equivalent, with a frequency of 2.5 GHz

4GB of RAM

180 GB of hard disk

NVidia or ATI graphics card with 128 MB of memory

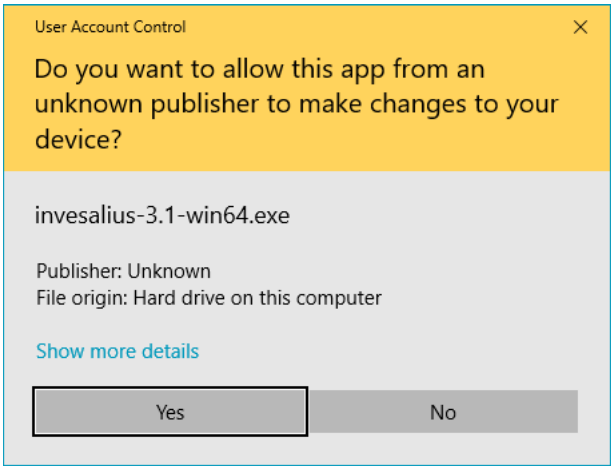
Video resolution of 1024x768 *pixels*

Chapter 2

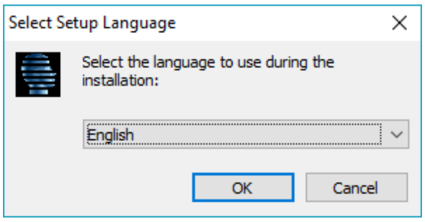
Installation

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**.

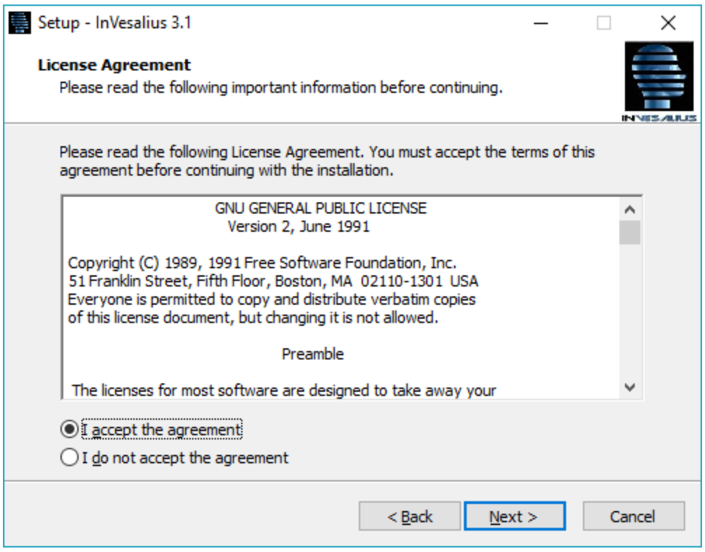


A new window will ask you to select the language of the installer. Select the language and click **OK** button.

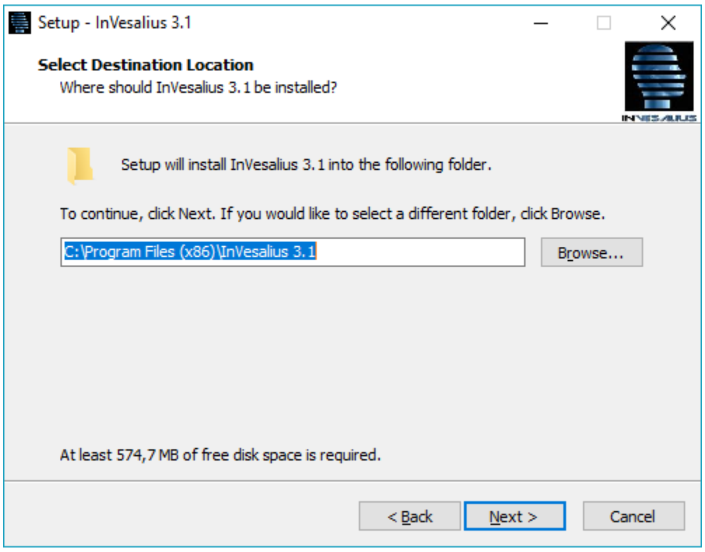


Window installer appears. Click **Next**.

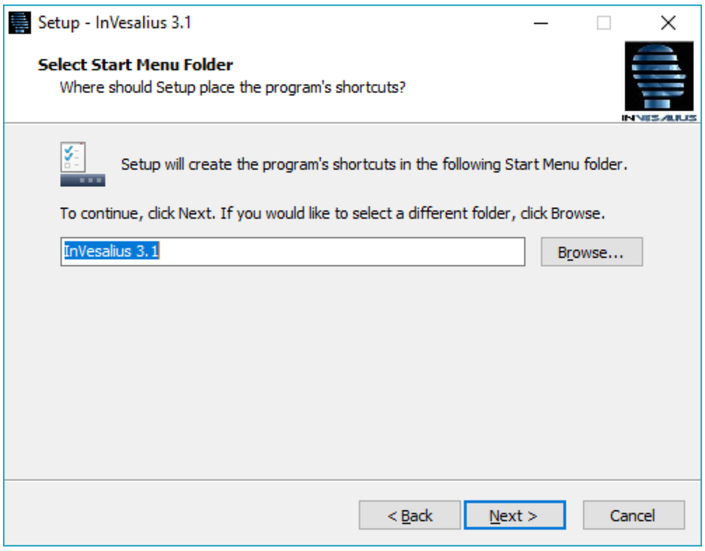
Select **I accept the agreement** and click on **Next** button.



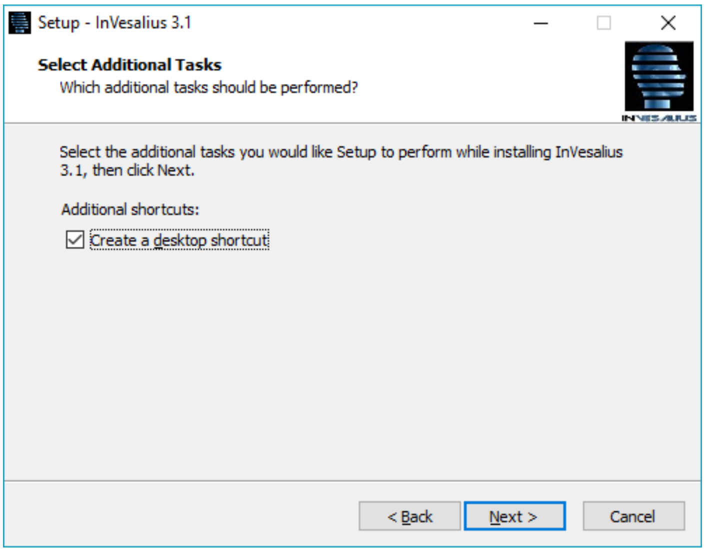
Click on **Next** button again.



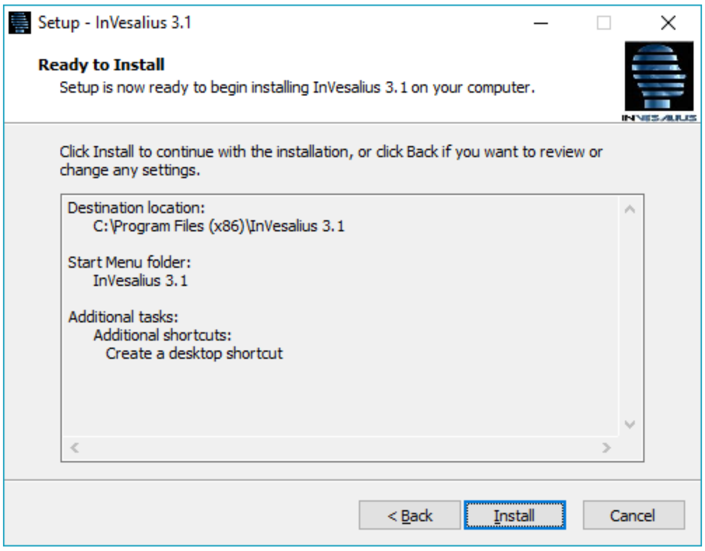
Click on **Next** button.



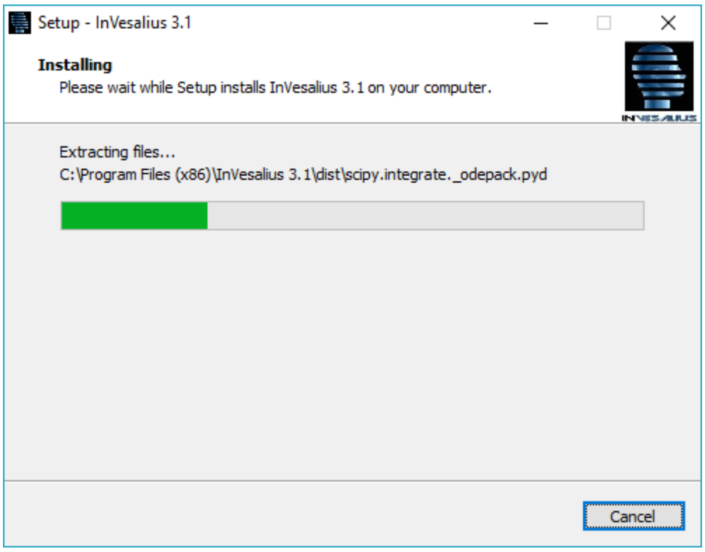
Select **Create a desktop shortchut** and click on **Next**.



Click on **Install** button.



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

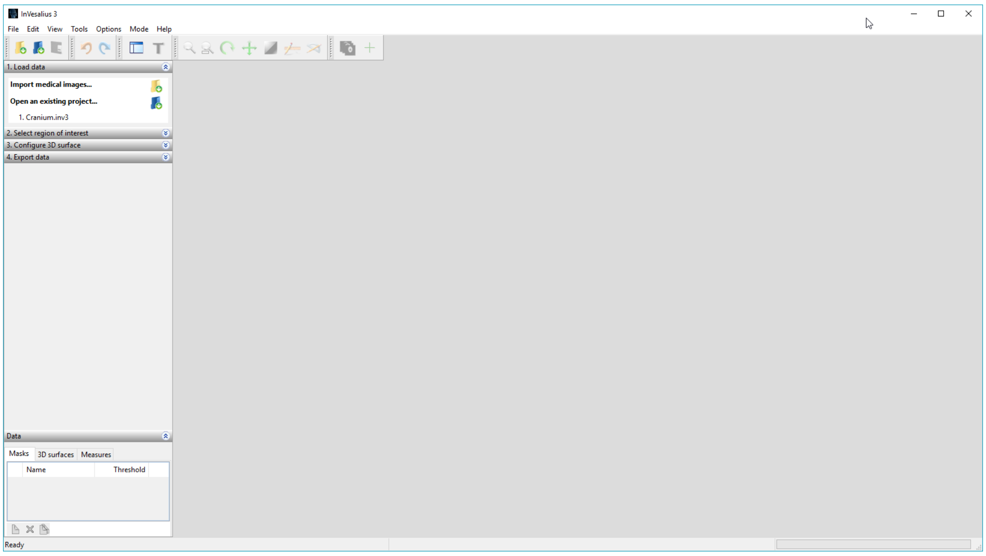


To run InVesalius after installation, check **Lauch InVesalius 3.1** and click on **Finish** button.

If this is the first time the software is installed, a window will appear to select the InVesalius language. Select the language you want and click on **OK** button.

While InVesalius is loaded, an opening window like the one in the next figure is displayed.

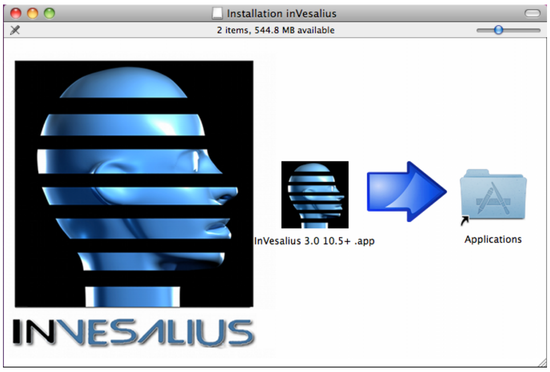
Then, the main program window open.

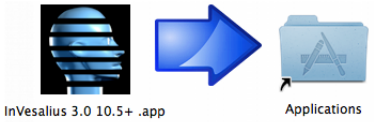


2.2 Mac Os X

To start the installation on Mac Os X, double-click the installer with the left mouse button. Then the installer will be initialized.

Hold down the left button on the InVesalius software icon and drag it to the *Applications*. Both 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

On menu **File**, click on **Import DICOM...**. If you prefer, use the shortcut of keyboard **Ctrl** + **I**. Import DICOM images can also be triggered by the toolbar icon described in the figure 3.1.

Figure 3.1: Shortcut to DICOM import

Then 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.

Click on **OK** button.

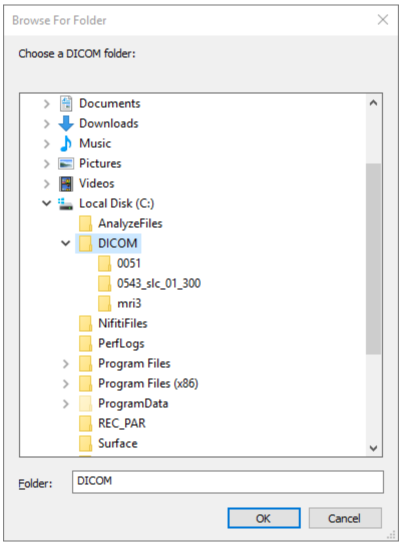


Figure 3.2: Folder Selection

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.

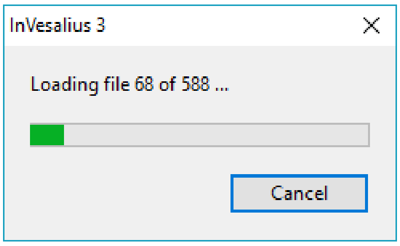


Figure 3.3: Loading file status

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

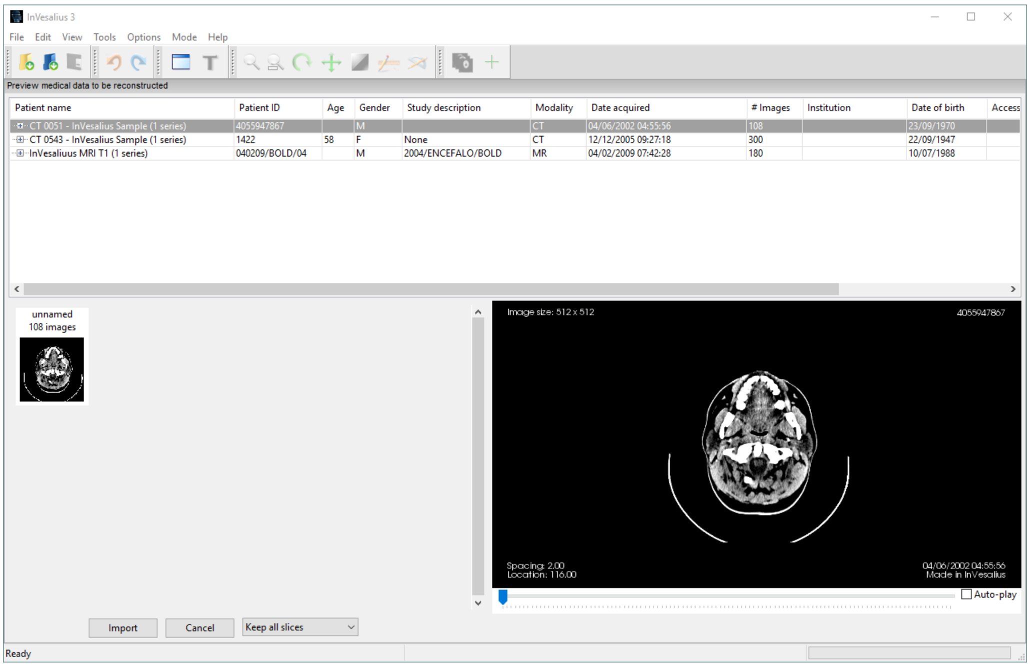


Figure 3.4: Import window

If you want to import a series with all the images present, click "+" on the side patient's name to expand the series belonging to him. **Double-click** with left mouse button on the description of the series. See figure 3.5.

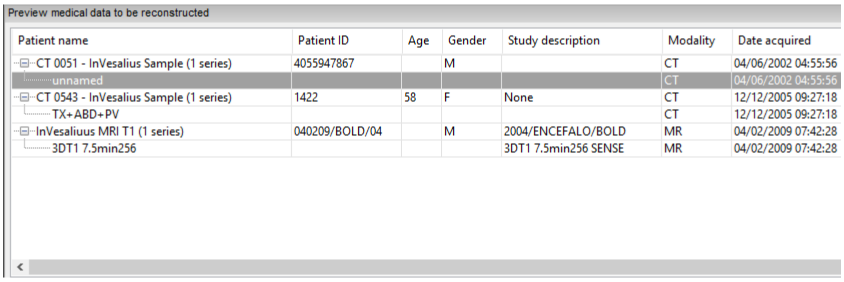


Figure 3.5: Series selection

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

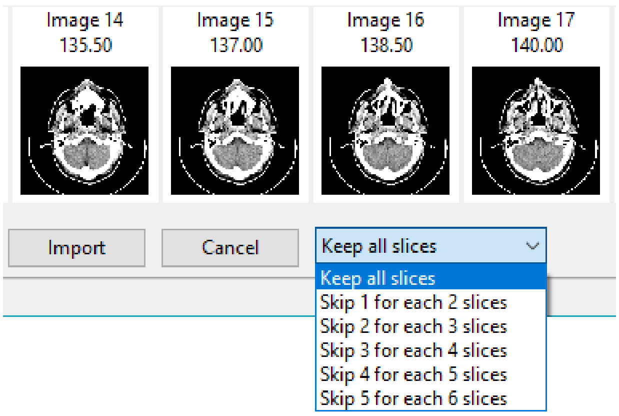


Figure 3.6: Skip imagens option

If insufficient amount of available memory is detected at the time of loading the images it is recommended reduce the resolution of the slices to work with volumetric and surface visualization, as shown in the 3.7 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 512 x 512 pixels and the "Percentage of original resolution" is suggested to be 60 %, each resulting image will be 307 x 307 pixels. If you want to open with the original resolution select the value 100.

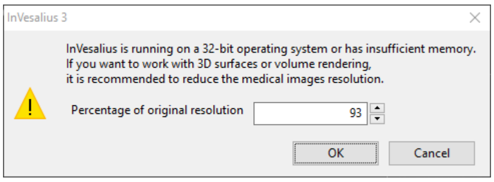


Figure 3.7: Image size reduction

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

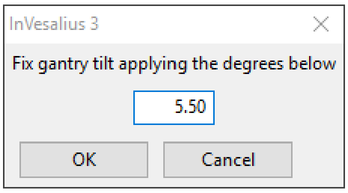


Figure 3.8: Gantry tilt correction

After the previous procedures, a window will be displayed (figure 3.9) with progress reconstruction (when images are stacked and interpolated).

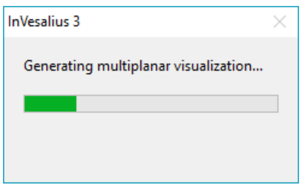


Figure 3.9: Reconstruction progress

3.2 Analyze

To import Analyze files, on menu **File**, click on **Importar other files...**, then click in the **Analyze** option as show the figure 3.10.

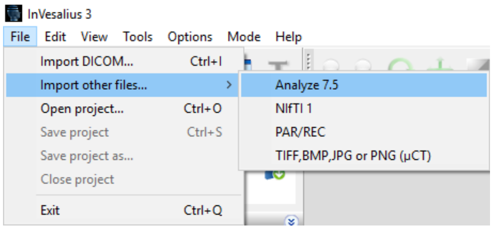


Figure 3.10: Menu for importing images in analyze format.

Select the file of Analyze format, in extension **.hdr** and click on **Open** button (Figure 3.11).

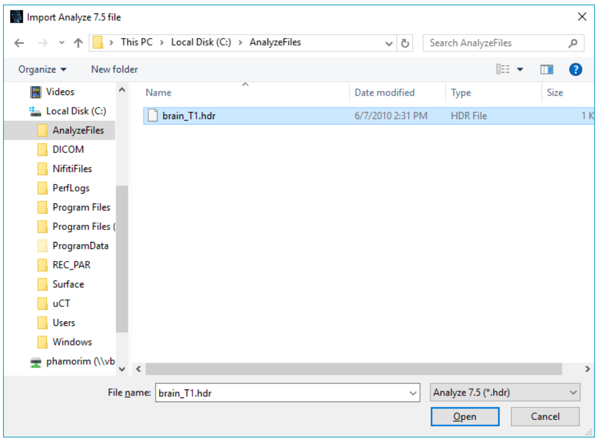


Figure 3.11: Import analyze file format

3.3 NIfTI

To import NIfTI files, on menu **File**, click on option **Import other files...** and then click on **NIfTI** option as shown figure 3.12.

Select the file of type NIfTI, on **nii.gz** or **.nii** extension, click on **Open** (figure 3.13). If the file is in another extension as **.hdr**, select **all files(*.*)** option.

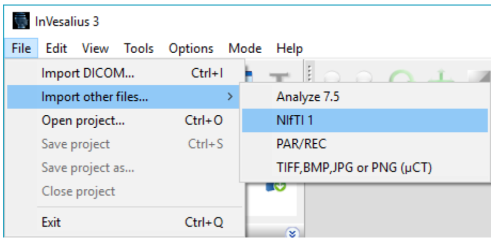


Figure 3.12: Menu to import images in NIfTI format

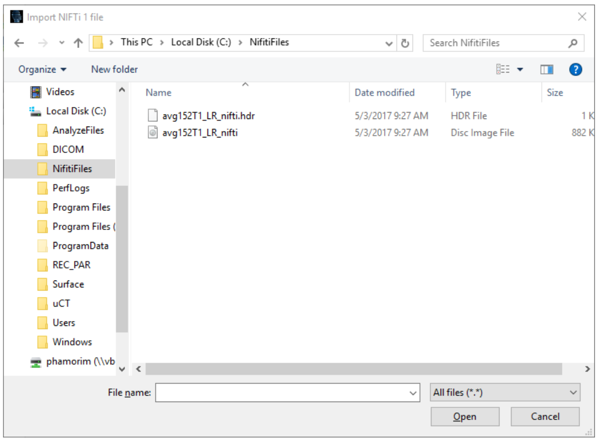


Figure 3.13: Importing images in NIfTI format.

3.4 PAR/REC

To import PAR/REC file, on main menu, click on **File**, **Import other files...** option and then click on **PAR/REC** as shown the figure 3.14.

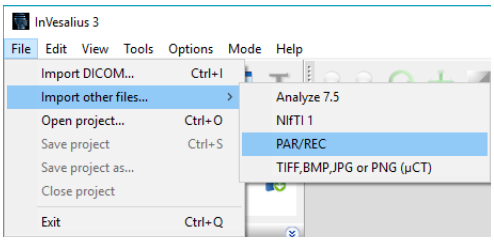


Figure 3.14: Menu for importing PAR/REC images

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

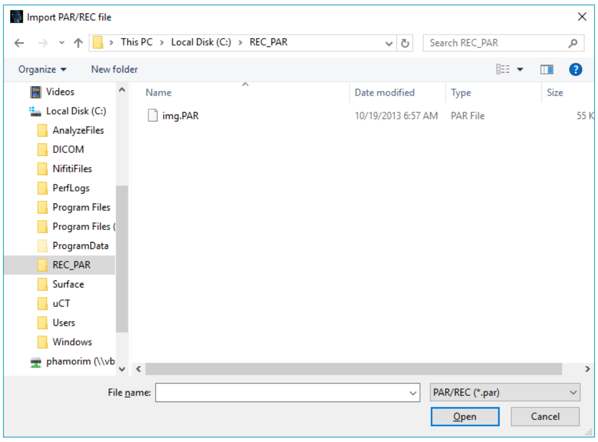


Figure 3.15: PAR/REC import

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

TIFF, JPG, BMP, JPEG or PNG file format for reconstruction can be provided with 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.

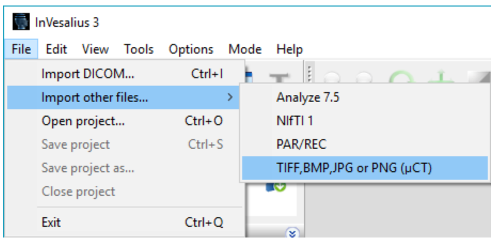


Figure 3.16: Import images in BMP and others formats

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** button.

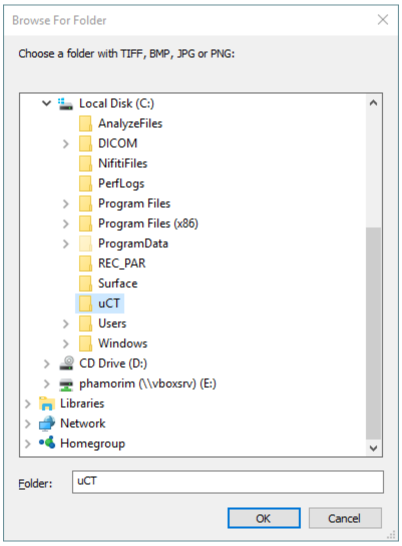


Figure 3.17: Folder selection

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

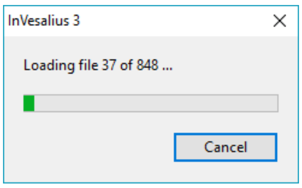


Figure 3.18: Checking and loading files status.

If files of type TIFF, JPG, BMP, JPEG or PNG are founded, a window open (figure 3.19) to display the founded files eligible for reconstruction. You can also skip images to rebuild or remove files from the rebuild list. The files are sorted according to the file name, it is recommended to use numbers in their names according to the order you want to get in the rebuild.

To delete files that are not of interest, you can 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, so you need to click the **left mouse button** on the first file in the track, hold down the **shift** key, click again with the **button Left mouse button** in the last file of the track and finally press the **delete**

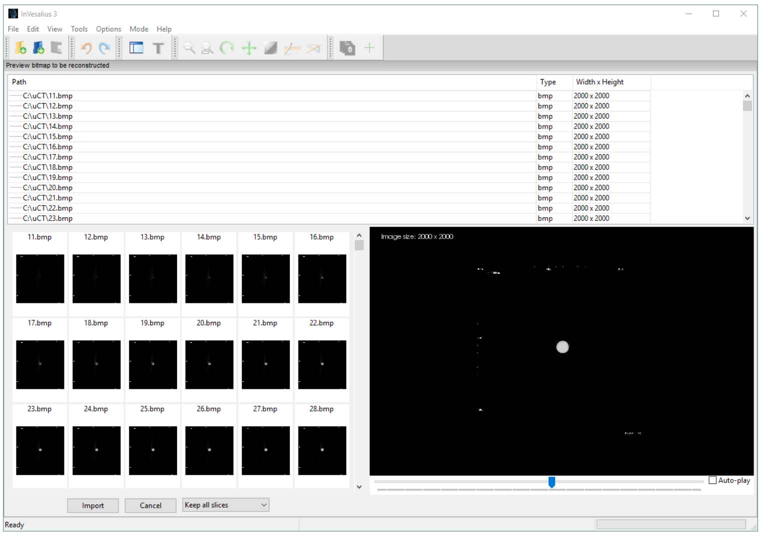


Figure 3.19: Window to import BMP files.

button.

Like importing DICOM files module, you can skip BMP images for rebuilding. In some cases, particularly where a computer with satisfactory memory and/or processing is not available to work with many images in a series, it may be advisable to skip (skip) some of them. To do this, select how many images to skip (figure 3.20). Click **Import** button.

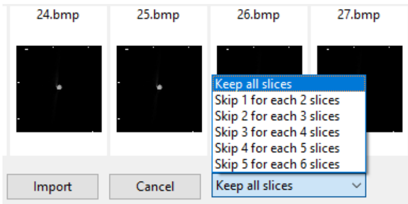


Figure 3.20: Importation window

To reconstruct this file type, it is necessary to define a name for the project, 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.

Attention, the spacing is a paramount parameter for the correct dimension of the objects in the software. Incorrect spacing will provide incorrect measurements.

Once you have completed all the parameters, just click the **Ok** button.

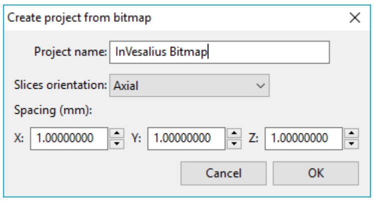


Figure 3.21: Tela de importação

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 the 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 512 x 512 pixels and the "Percentage of the original resolution" is suggested at 60%, each resulting image will have 307 x 307 pixels. If you want to open with the original resolution select the value 100.

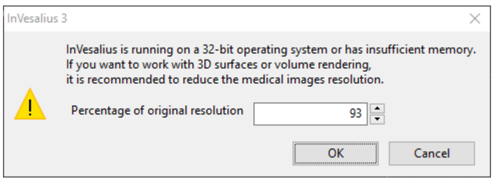


Figure 3.22: Image resize

After the previous steps it is necessary to wait a moment to complete the multiplanar reconstruction as shown in the figure 3.23.

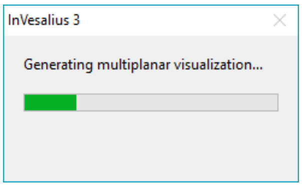


Figure 3.23: Multiplanar reconstruction in progress.

Chapter 4

Image adjustment

InVesalius does not guarantee the correct image order because sometimes these images have wrong 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, making them flip. To perform that, it is necessary to click in menu, **Tools**, **Image**, **Flip** and click in one of the following options (figure 4.1):

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

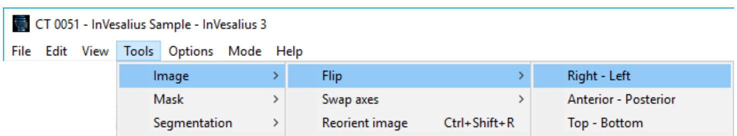


Figure 4.1: Menu to activate flip image tool.

The figure 4.2 shows a comparative between the image without being flipped and the flipped image. Due to all image form the volume, if the flip is applied all other orientation are also modified.

(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 that, it is necessary to click in menu, **Tools**, **Image**, **Swap axes** and click in 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 e 4.5, shows an example of images with inverted axis.

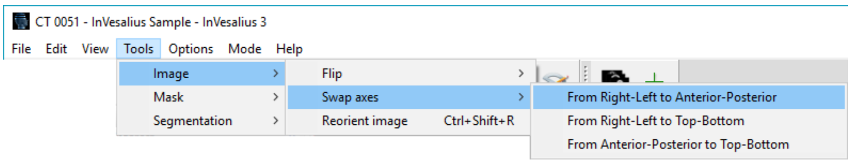


Figure 4.3: Menu to activate swap image tool.

4.2 Reorient image (Rotate)

If it is necessary to align the image taking in account some reference point, e.g. anatomical marker, it is possible by using the reorient image tool. To

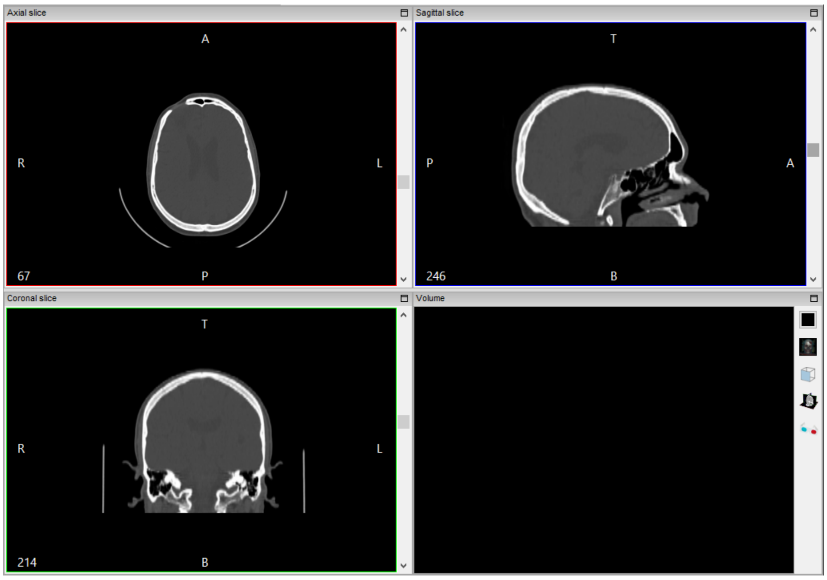


Figure 4.4: Images before swap axes - from Anterior-Posterior to Top-Bottom.

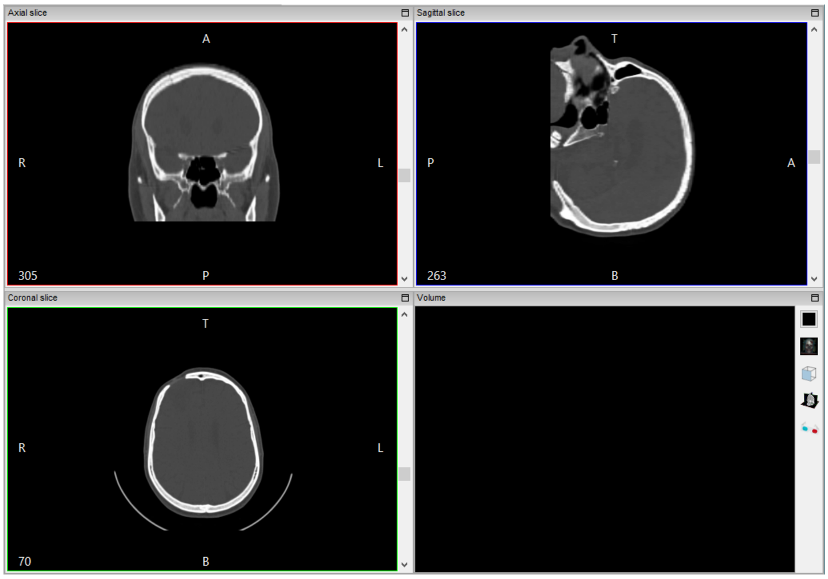


Figure 4.5: Images after swap axes - from Anterior-Posterior to Top-Bottom.

open this tool it is necessary to click in menu, **Tools**, **Image** and **Reorient image** (figure 4.6).

When this tool is activated a window is opened(figure 4.7) that shows which orientation and how much degrees the image was rotated.

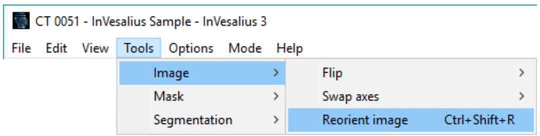


Figure 4.6: Menu to activate reorient image tool.

Figure 4.7: Window that shows the reorientation image parameters.

Initially, it is necessary to define the rotation point, to perfom that **keep the left mouse button pressed** between the two lines intersection (figure 4.8) at one orientation window, e.g. axial, coronal or sagittal, and drag to the desired point.

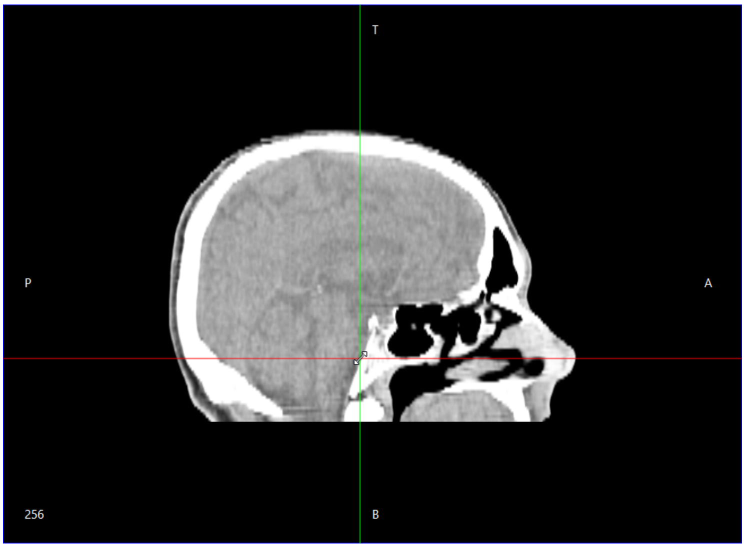


Figure 4.8: Defining the axis of rotation of the image.

To rotate the image it is necessary to **keep the left mouse button pressed** and **drag** until the reference point or anatomical marker stays align with one of the lines (figure 4.9). After the image is in the desired position, it is necessary to click the button **Apply**, in the parameter window (figure 4.7). This task can take some seconds, depends on the image size. The figure 4.10 shows an image with reorient done.

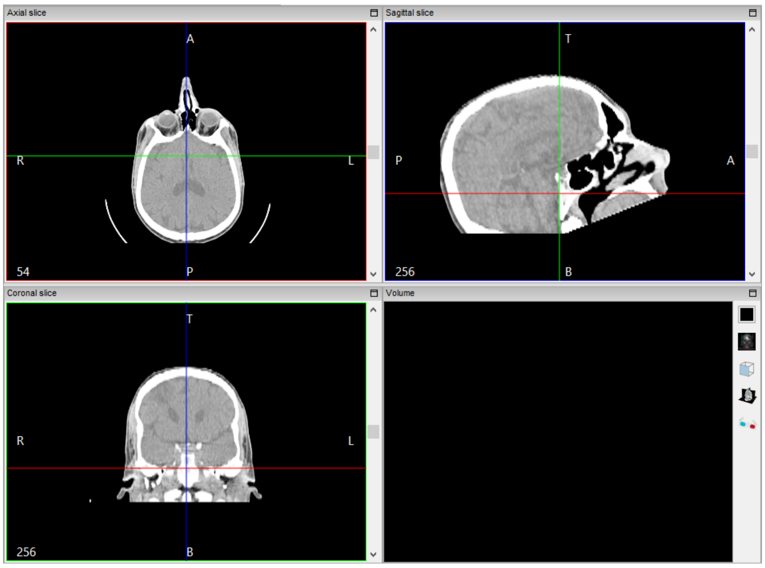


Figure 4.9: Rotated image.

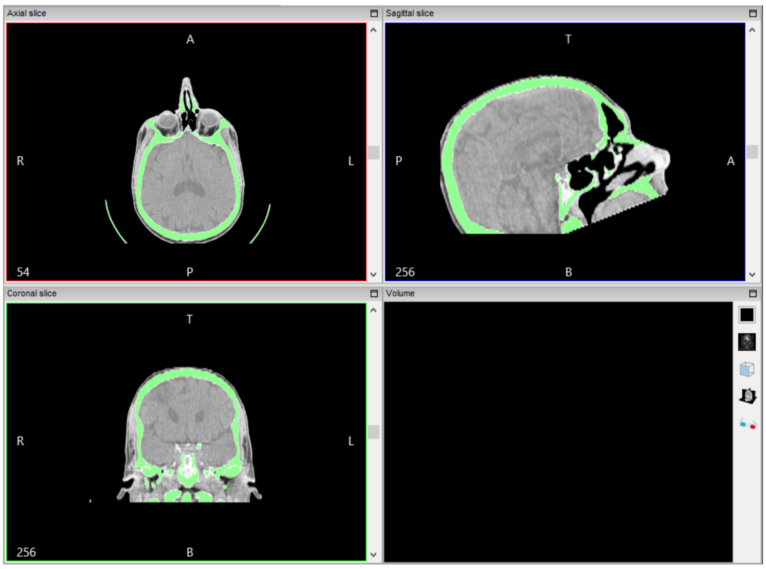


Figure 4.10: Rotated image after reorientation is done.

Chapter 5

Image Manipulation (2D)

5.1 Multiplanar Reconstruction

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

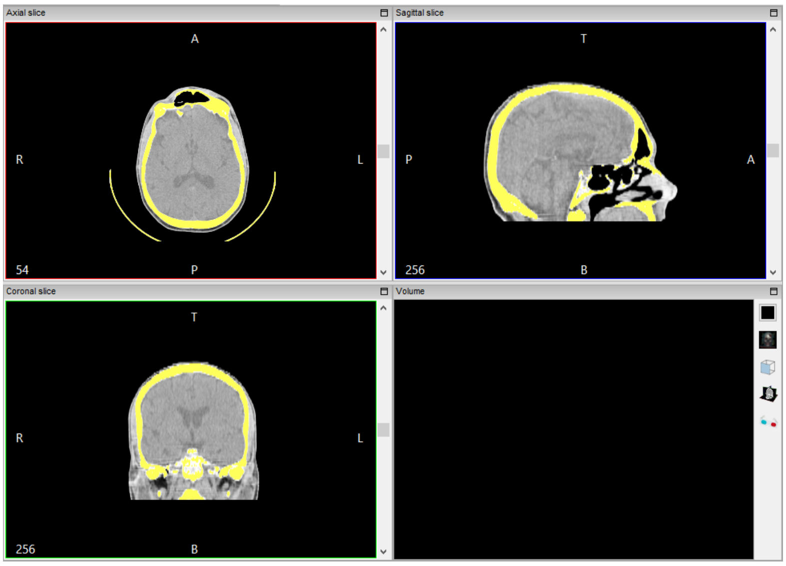


Figure 5.1: Multiplanar Reconstruction

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, i.e., the colors forms 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. Just choose the tab **Masks** and click **once** using the **left** mouse buttom over the eye icon next to **"Mask 1"**. See figure 5.2.

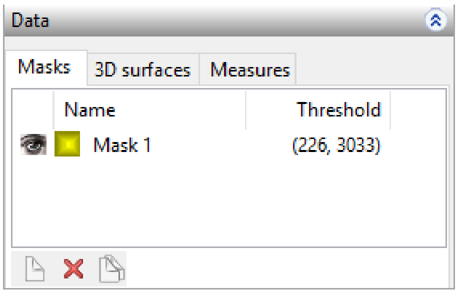


Figure 5.2: Mask manager

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

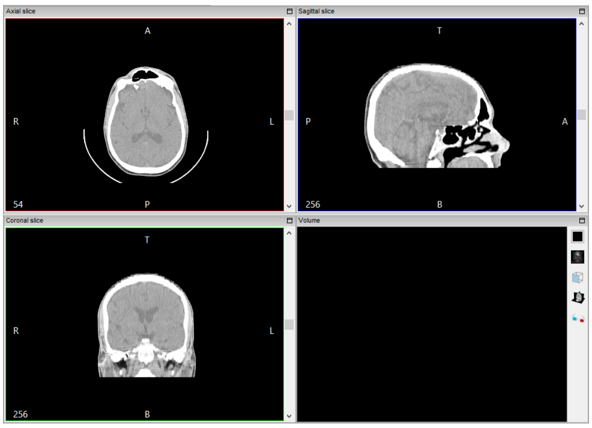


Figure 5.3: Multiplanar reconstruction without segmentation mask

5.1.1 Axial orientation

The axial orientation consists of cuts made transversal in relation 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.

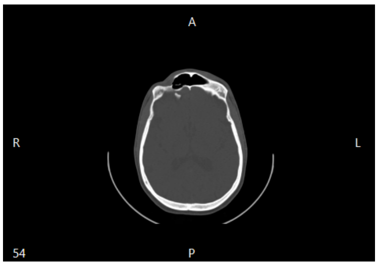


Figure 5.4: Axial slice

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.

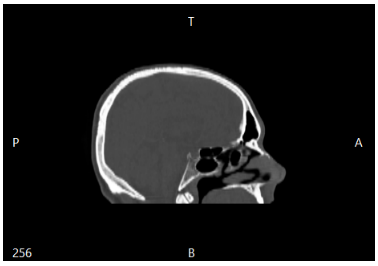


Figure 5.5: Sagittal slice

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.

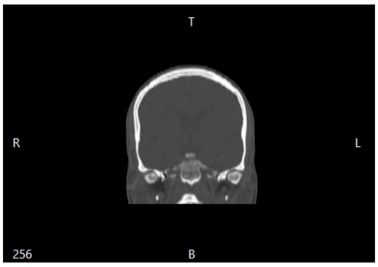


Figure 5.6: Coronal slice

5.2 Correspondence between the axial, sagittal and coronal orientations

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

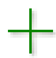


Figure 5.7: Shortcut to show common point between different orientations

When the feature is fired, two cross segments 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, keep **pressed** the **left** mouse button and **drag**. Automatically, the corresponding points will be updated in each image.

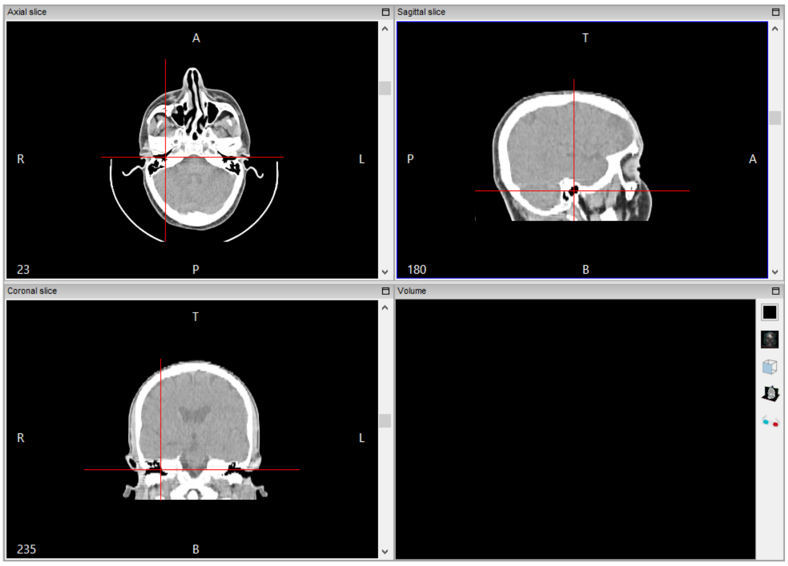


Figure 5.8: Common point between differents orientations

To disable 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, in menu press **View**, **Interpolated slices** (figure 5.9). In this way it will be possible to visualize each pixel individually as shown in the figure 5.10.b.

Note: This interpolation is for visualization purposes only, not directly influencing segmentation or 3D surface generation.

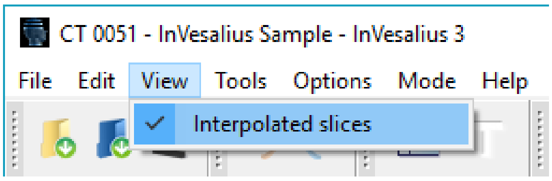


Figure 5.9: Menu to disable and enable interpolation

(a) Interpolated

(b) Non-interpolated

Figure 5.10: Interpolated and non-interpolated image visualization.

5.4 Move

To move an image on the screen, the toolbar's "Move" shortcut icon can be used (figure 5.11). Click on the icon to activate the feature and then with the **left** mouse button on the image, **drag** it to the desired direction. The figure 5.12 shows a displaced (moved) image.

Figure 5.11: Shortcut to move images

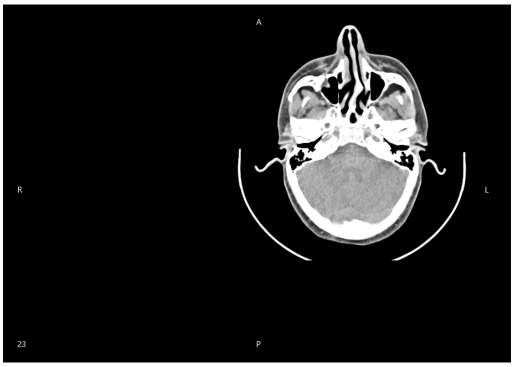


Figure 5.12: Displaced image

5.5 Rotate

The image rotation can be activated by the toolbar's "Rotate" shortcut icon (figure 5.13). To rotate an image, click on the icon and then with the **left** mouse button press on the image, **drag** clockwise or anticlockwise, depending on the desired direction of rotation.

Figure 5.13: Shortcut to rotate images

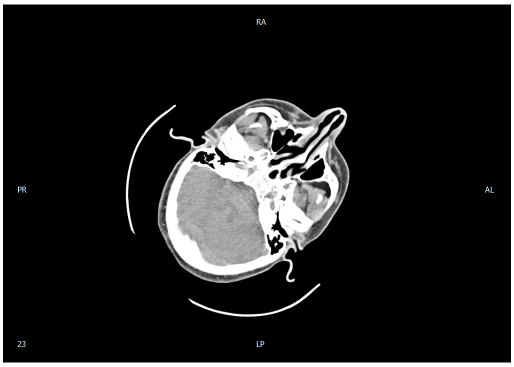


Figure 5.14: Rotated image

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.

5.6.1 Maximizing orientation windows

As we already know, the main InVesalius window is divided into 4 subwindows: 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.

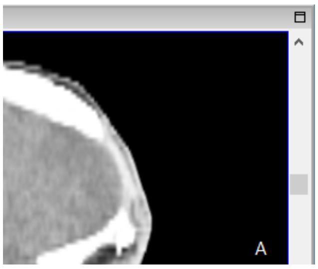


Figure 5.15: Detail of a sub-window (Note the maximize icon in the upper right corner)

5.6.2 Enlarging or reducing an image

To enlarging or reducing 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 to **top** if you want to enlarge it, or **down**, if you want to reduce it.

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 start position of the selection, click and hold the **left** mouse button and **drag** it to the end selection position, forming 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

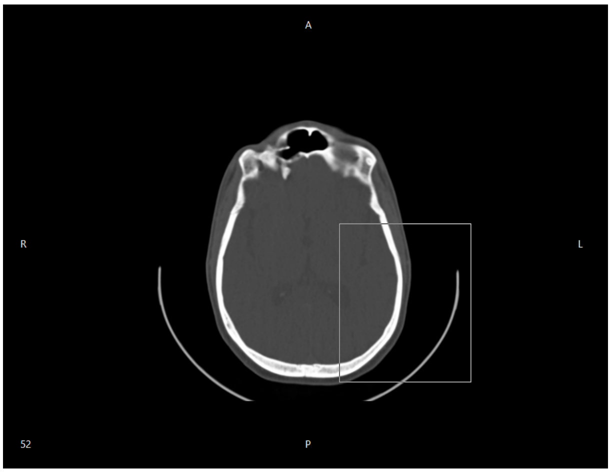


Figure 5.18: Area selected for zoom

5.7 Brightness and contrast (Windows)

To improve images visualization, the feature *window width* and *window level* can be used, popularly 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.

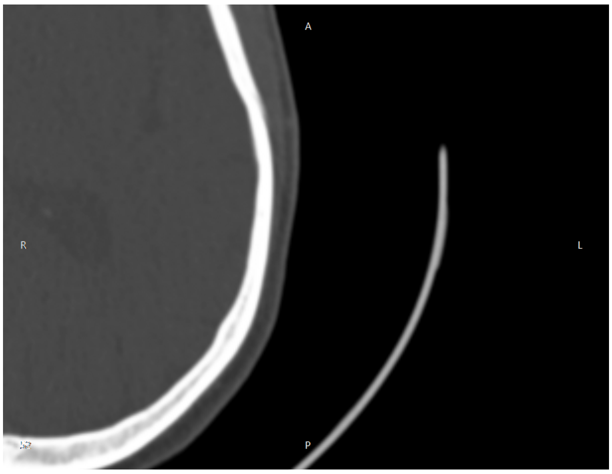


Figure 5.19: Enlarged Image

The feature can be triggered by the "Contrast" shortcut icon in the toolbar. See figure 5.20.

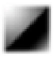


Figure 5.20: Brightness and contrast shortcut

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 the contrast.

To disable the feature, click again on the shortcut icon (figure 5.20).

You can use preset brightness and contrast patterns. The table 5.1 lists some tissues types with their respective brightness and contrast values for the image. To use the presets patterns, position the mouse cursor over the image and **right-click** to open a context menu on it. When the menu opens, select **Window width and level**, and then click on the preset option, according to the tissue type, as shown in the figure 5.21.

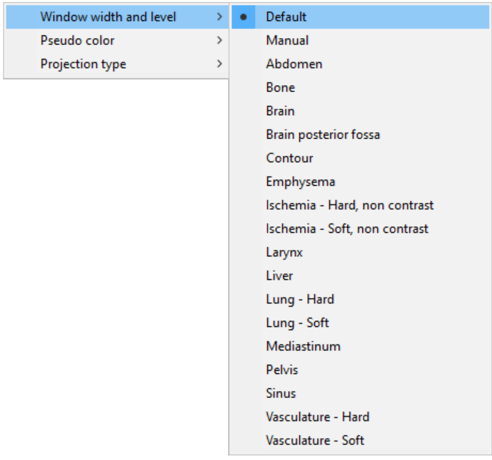
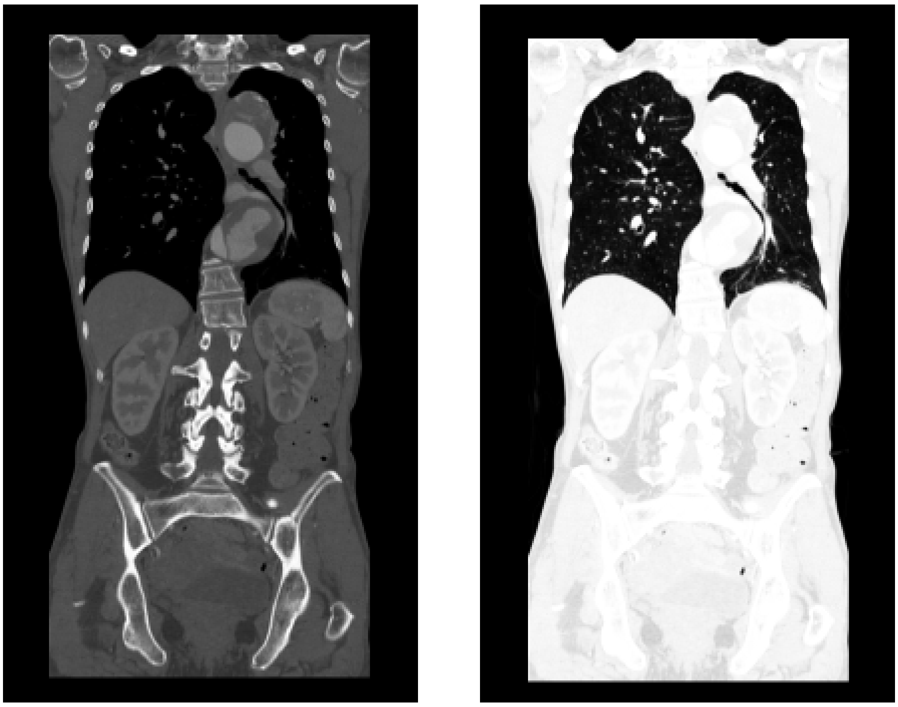


Figure 5.21: Context menu for brightness and contrast selection

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. They replace 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 the figure 5.23.

Figures 5.24a through 5.24g exemplify the various pseudo color options available.

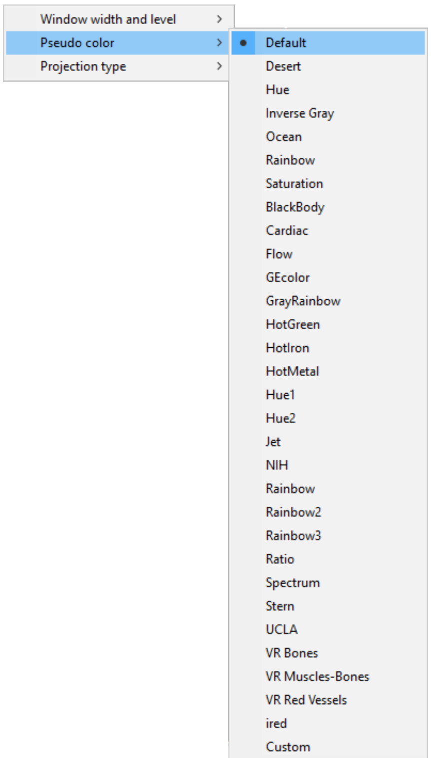
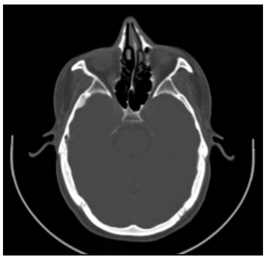
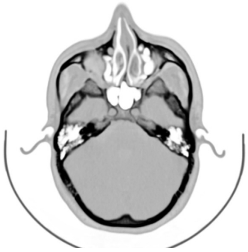


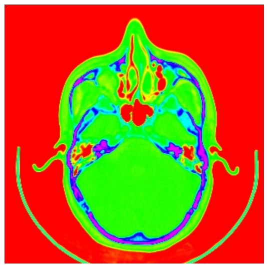
Figure 5.23: Pseudo Color



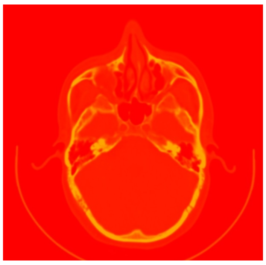
(a) Default



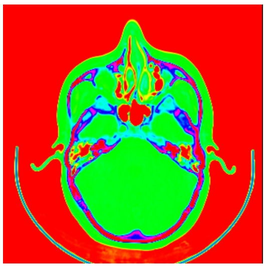
(b) Inverted Gray Image



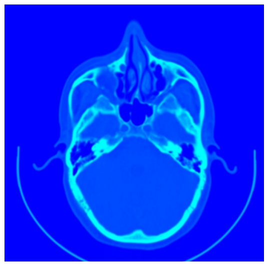
(c) Rainbow



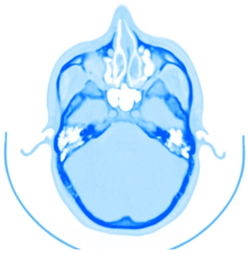
(d) Desert



(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 5.25.

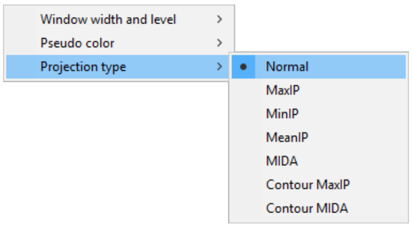


Figure 5.25: Projection Type menu

5.9.1 Normal

Normal mode is the default view, i.e. without any type of projection, originally when the image was acquired or customized previously with either brightness and contrast or pseudo color. As shown in figure 5.26.

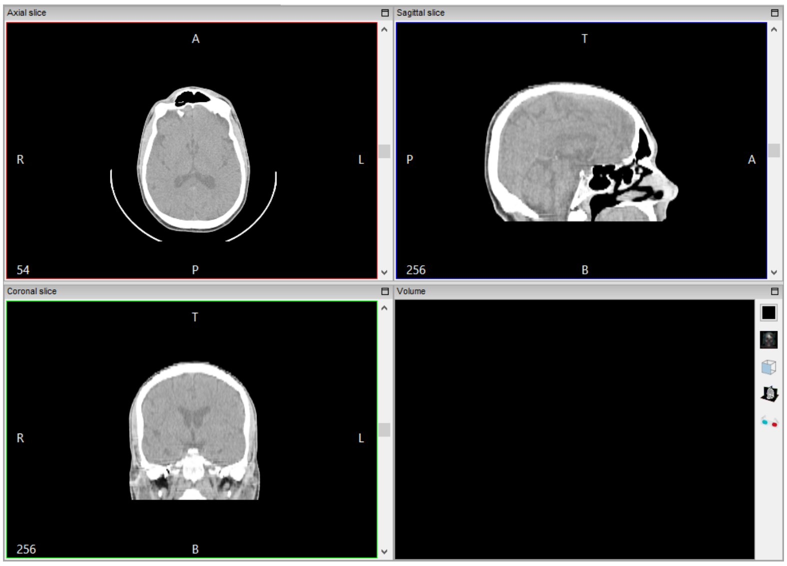


Figure 5.26: Normal projection

5.9.2 MaxIP

MaxIP is also known as MIP (*Maximum Intensity Projection*), the method selects only voxels that have maximum intensity among the visited ones as shown in figure 5.27. According to the amount 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 the pixel $(0,0)$ of slices $(1,2,3)$ and select the highest value.

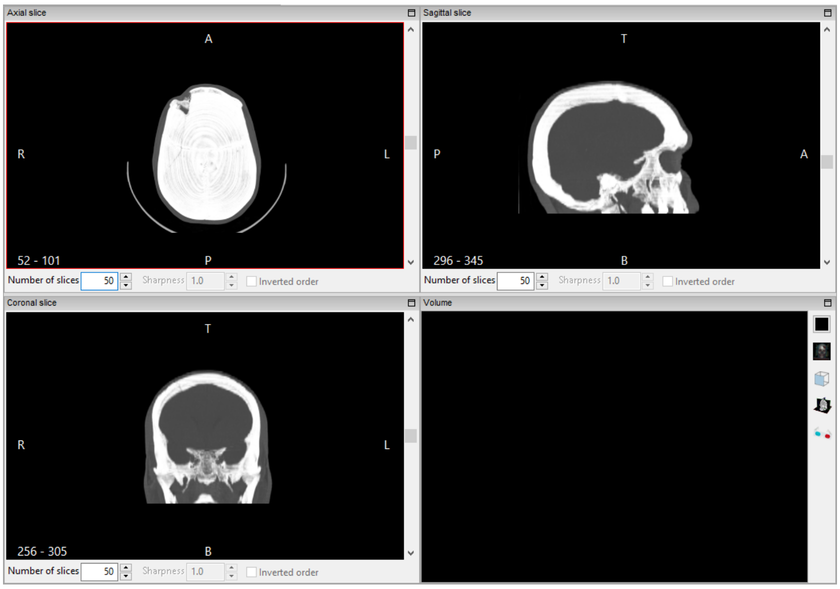


Figure 5.27: MaxIP projection

As shown in the figure 5.28, the number of images that will be composed of MaxIP 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 (*Minimun Intensity Projection*) selects only the voxels that have minimal internsity among the visited ones, an example is shown in figure 5.29. The image number selection that will compose the projection is made at the bottom of each orientation image as shown in figure 5.28.

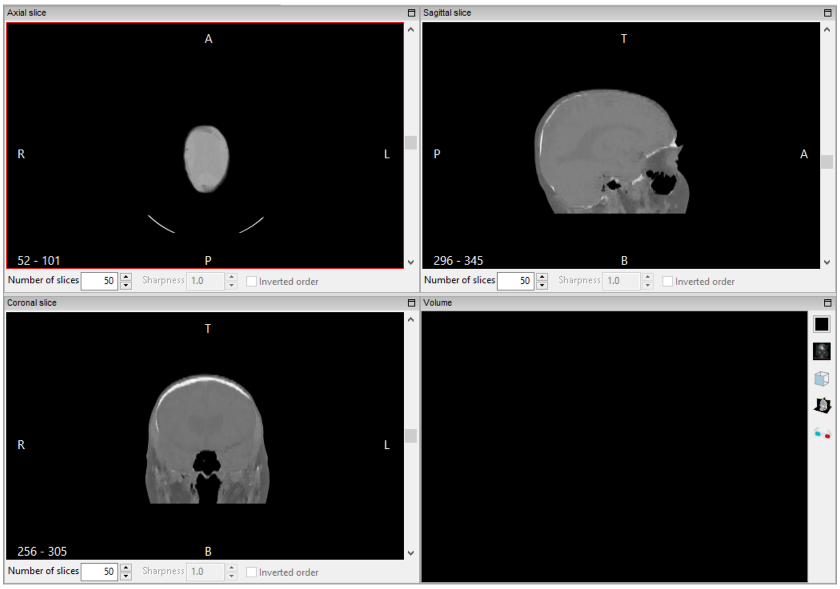


Figure 5.29: MinIP projection

5.9.4 MeanIP

The MeanIP (*Mean Intensity Projection*) technique which is shown in the figure 5.30 composes the projection by averaging the voxels visited. The voxels are 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 the figure 5.28.

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, each voxel is intercepted by each of these rays reaching the end of the volume, each of these voxels visited has its accumulated value, but are taken into account only if the value is greater than previously visited values. Like MaxIP, you can select how many images are used to accumulate the values. The figure 5.31 shows an example of MIDA projection.

As the figure 5.32 shows, it is possible to invert the order that the voxels

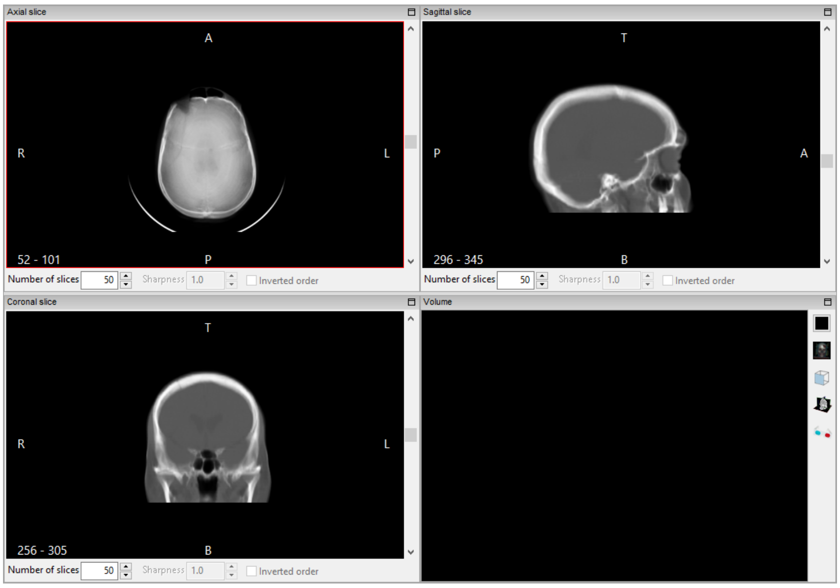


Figure 5.30: MeanIP projection

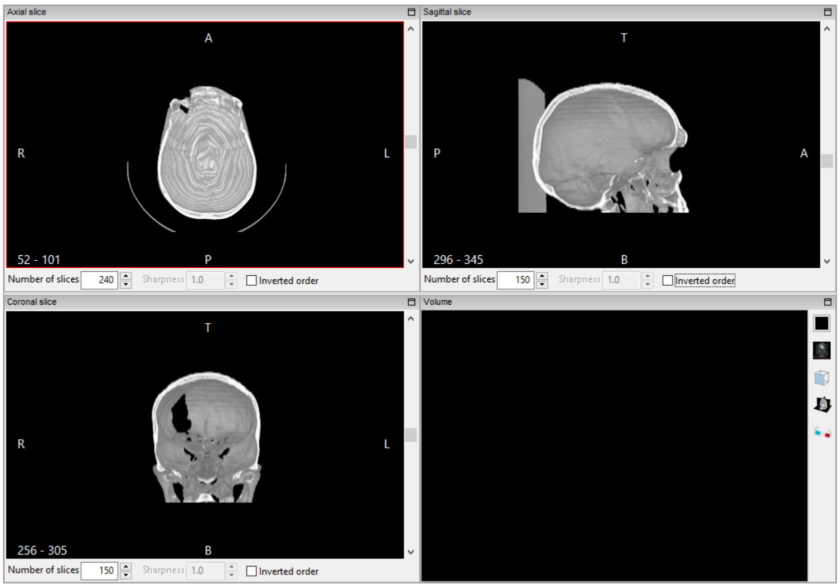


Figure 5.31: MIDA projection

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

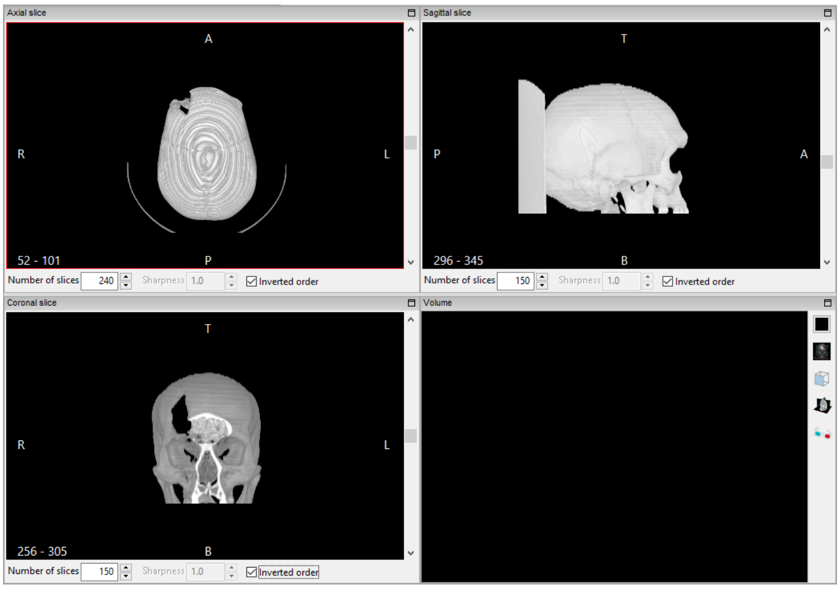


Figure 5.32: Inverted order MIDA projection

5.9.6 Contour MaxIP

The technique consists in visualizing contours present in the projection generated with MaxIP technique(5.9.2). An example is presented in the figure 5.33.

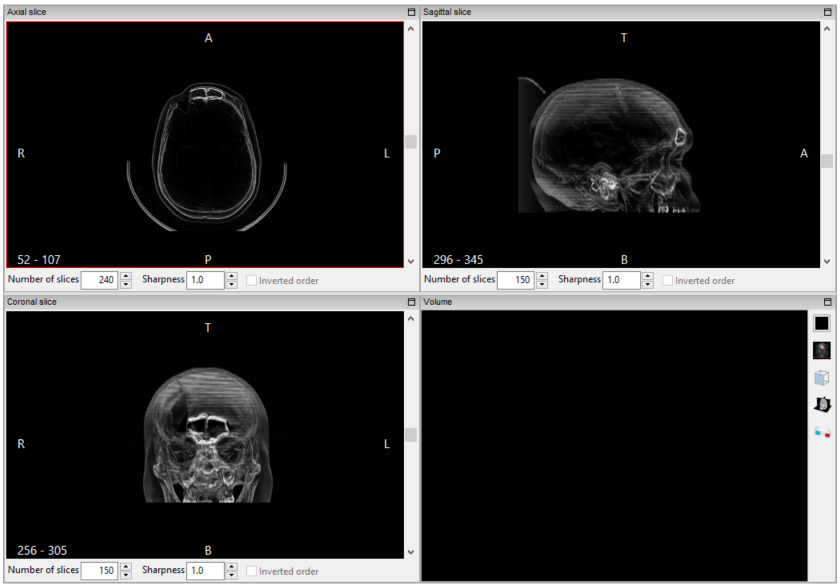


Figure 5.33: Contour MaxIP projection

5.9.7 Contour MIDA

The technique consists in 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. We exemplify in the figure 5.34.

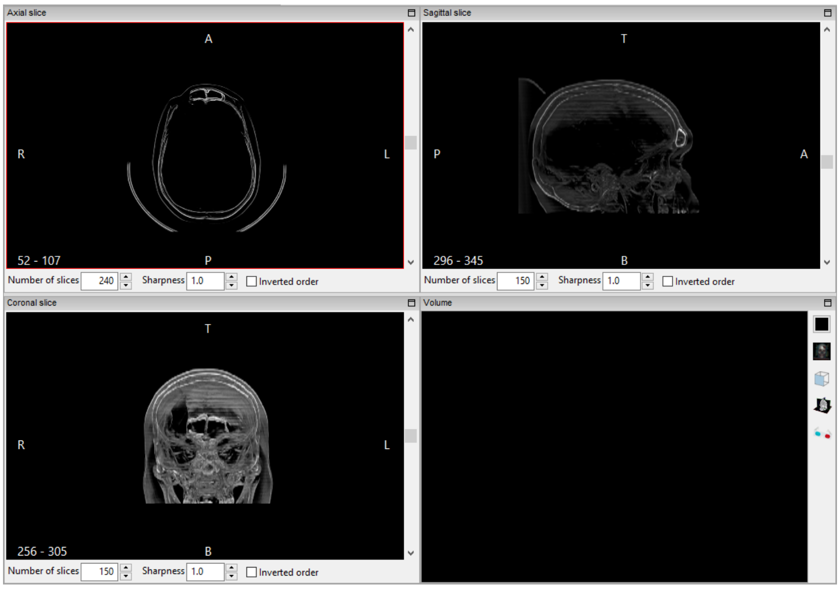


Figure 5.34: Contour MIDA projection

Chapter 6

Segmentation

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

6.1 Threshold

Limiar é uma técnica de segmentação de imagens que permite selecionar da imagem somente os *pixels* cuja intensidade está dentro de um limiar definido pelo usuário. O limiar é definido por dois números, limiares inicial e final, também conhecidos como *thresholds* mínimo e máximo. Como referência para a definição, é utilizada a escala de Hounsfield (tabela 1.1).

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 at the InVesalius left-panel, item **2. Select region of interest** (figure 6.1).

Before starting segment it's necessary to configure a mask. A mask is a image overlayed to exam image where the selected regions are colored. See figure 6.2

To change the threshold you may use the control that represents the image grayscale (figure 6.3). Move the *left* sliding control to change the initial

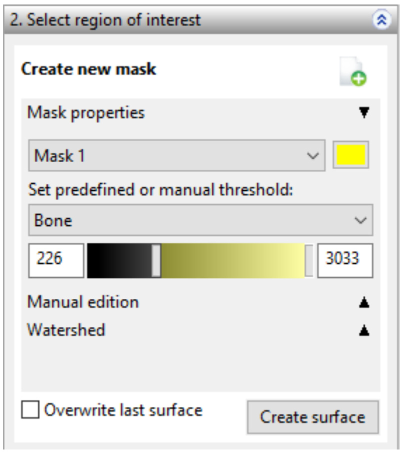


Figure 6.1: Select region of interest - Threshold

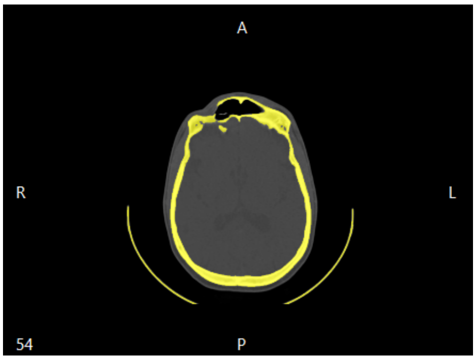


Figure 6.2: Mask - selected region in yellow.

threshold. Move the *right* sliding control to change the final threshold. It's also possible to to digit the desired threshold values in the text boxes in the left and right side of the thresholding control. Changing the thresholding values, automatically the mask will be updated, showing with a color the *pixel* that are inside the thresholding range.

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

It's also possible to select some predefined thresholding values based on some type of tissues, like displayed in the figure 6.4. Just select the desired tissue and the mask automatically updated.

Figure 6.4: Selection list with some predefined thresholding values.

The table 6.1 show thresholding values according to some tissues or materials.

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

The table 6.1 is indicated to images obtained from medical tomographs. The range of gray values from images obtained from odontological tomographs are greater and non-regular. Thus, it's necessary to use sliding control (figure 6.3) to adjust the thresholding values.

If you want to create a new mask click on the button **Create new mask** inside the item **2. Select region of interest**. See the figure 6.5.

Figure 6.5: Button to create a new mask.

Clicando-se nesse atalho, uma nova janela será apresentada (figure 6.6). Selecione a faixa de limiar desejada e clique em **OK**.

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

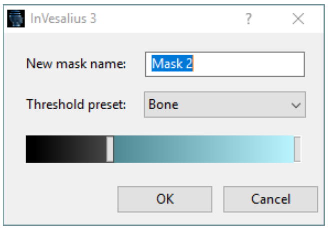


Figure 6.6: Creating a new mask.

After the segmentation it's 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.

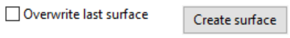


Figure 6.7: Create surface button.

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

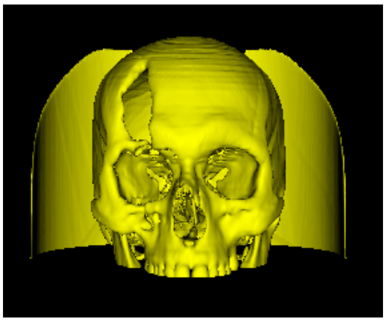


Figure 6.8: 3D surface.

6.2 Manual segmentation (Image edition)

Thresholding segmentation may not be efficient in some case since it's applied to the whole image. Manual segmentation may be used o segment only an isolated image region. Manual segmentation turns possible to add or remove some image regions to the segmentation. Manual segmentation requires more knowledge of human anatomy. To use it click on **Manual edition** (figure 6.9) to open the manual segmentation panel.

Figure 6.10 show the Manual segmentation panel.

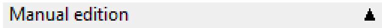


Figure 6.9: Icon to open the Manual segmentation panel.

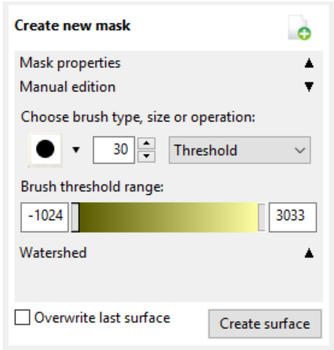


Figure 6.10: Manual segmentation panel.

There are two brushes used to segmentation: a circle and a square. Click on triangle icon (see figure 6.11) to and click on the desired brush.

Figure 6.11: Brush types.

It's also possible to adjust the brush size, like shown in the figure 6.12.

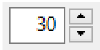


Figure 6.12: Adjusting the brush size.

It's needed to select the operation to be performed by the brush. These are the options:

Draw: to add a non-selected region to the segmentation;

Erase: to remove a selected region from the segmentation;

Threshold: applies the thresholding locally, adding or removing a region if in inside or outside of the threshold range.

Figure 6.13 shows the operations.

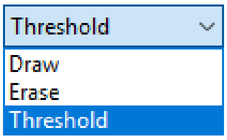


Figure 6.13: Brush operations

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

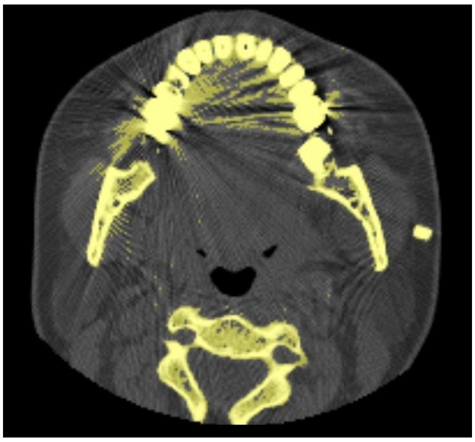


Figure 6.14: Noisy image segmented with threshold.

Figure 6.15 shows a surface create from that segmentation.

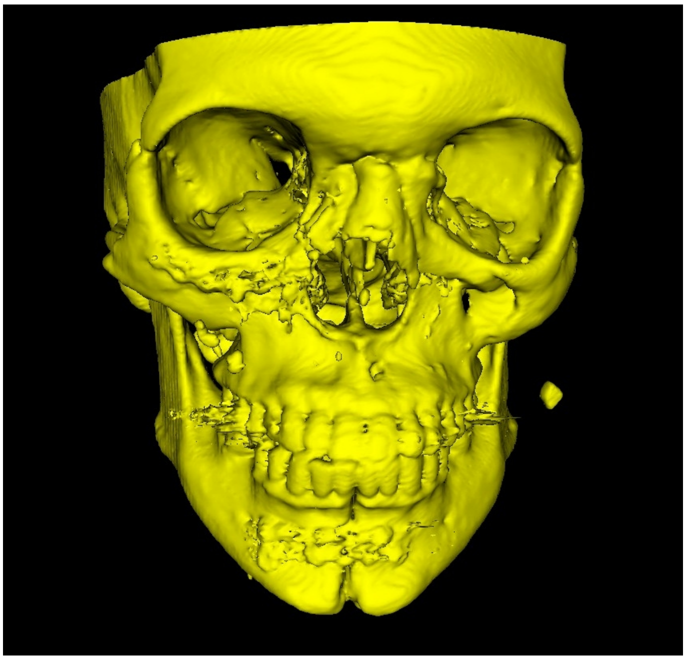


Figure 6.15: Surface generated from noisy image.

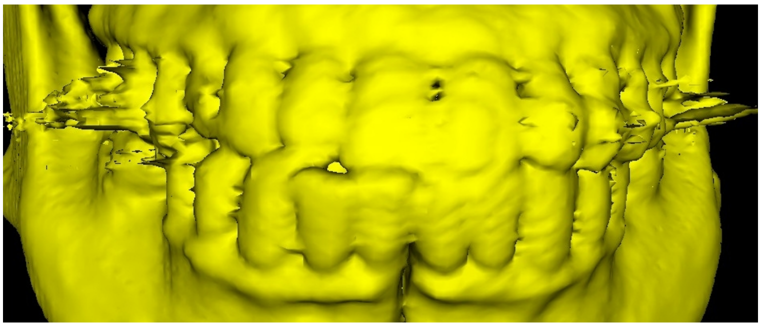


Figure 6.16: Zoom in the noisy area.

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

Figure6.17 shows the image from figure 6.14 after the edition.

Realizada a edição, basta gerar a superfície a partir da imagem editada (figure 6.18). Como houve edição, ao clicar em **Criar superfície**, será requerido se deseja gerar a superfície a partir do método **binário** ou utilizando o método de suavização **Suavização sensível ao contexto** (figure 6.19)

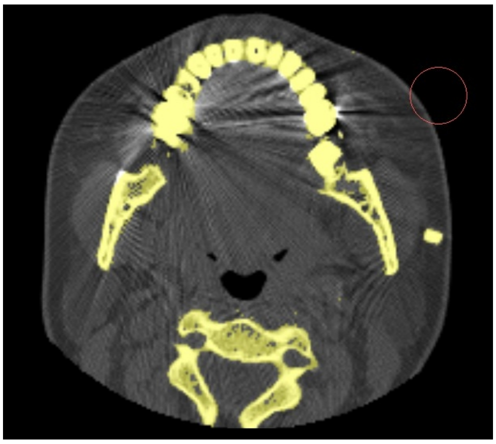


Figure 6.17: After removing the noise.

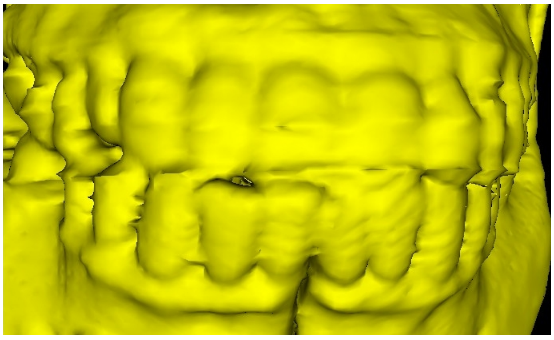


Figure 6.18: Surface generate after removing the noise.

para minimizar os "degraus" na superfície. Demais detalhes serão discutidos no capítulo 8.

It's possible to generate a surface after manual segmentation (figure 6.18). Since it was used the manual segmentation, when you click 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 aspect) or **Context aware smoothing** (smoother).

6.3 Watershed

In watershed segmentation the user indicates with marks what is object and what is background. This method treats the image as watershed (hence

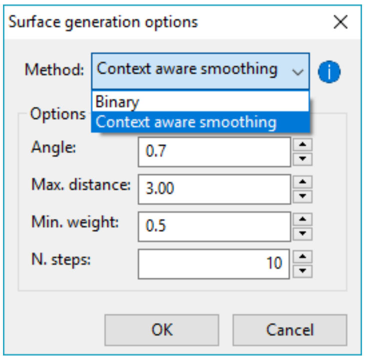


Figure 6.19: Surface creation methods

the name watershed) 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 waters gather together segmenting, this way, the background from the object. To use Watershed segmentation click on **Watershed** to open the watershed panel (figure 6.20).

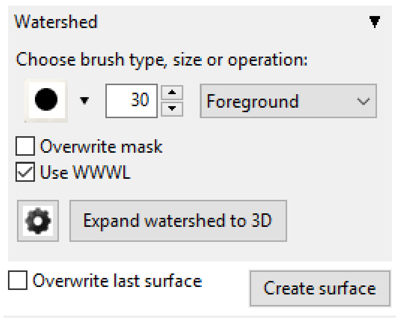


Figure 6.20: Watershed segmentation panel.

Before starting to segment with watershed it recommended to clean the mask (see section 7.2).

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

It necessary to select the brush operation, which are 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 that the result of watershed segmentation overwrites the existent 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 one, 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 which may be 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.

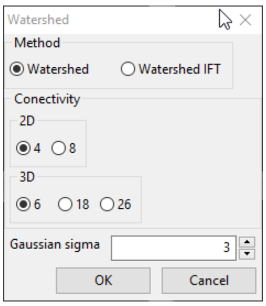


Figure 6.22: Watershed configuration dialog.

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, just click 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).

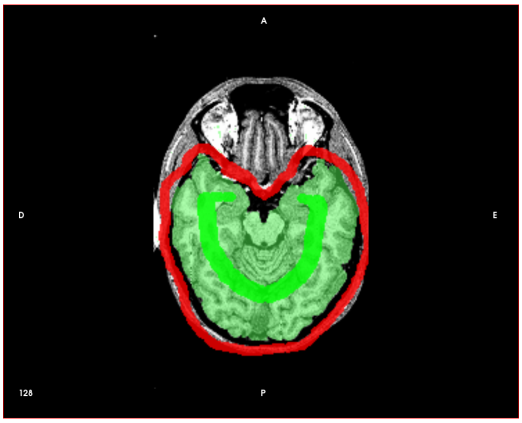


Figure 6.23: Watershed applied to a slice.

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)

A técnica parte de um pixel inicial que é indicado clicando com o **botão direito** do mouse, os pixels vizinhos que satisfazem as condições indicadas anteriormente são selecionados. Cada método leva em consideração diferentes condições, a seguir são apresentadas as diferenças entre cada método:

This segmentation technique starts with a pixel (indicated by the user clicking with the left-button of the mouse). If the neighbour pixels meet some conditions are selected. Iteratively, the selection expands analyzing the neighbourhood of the selected pixels. Each region growing method has a

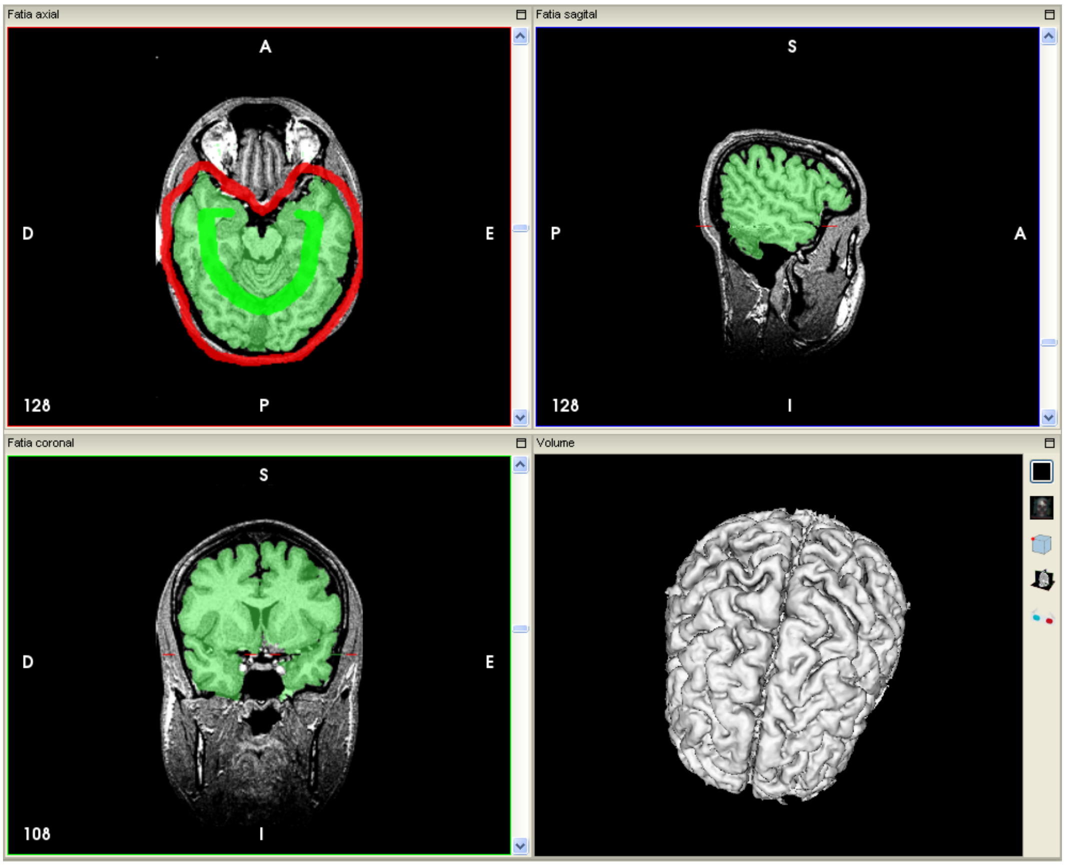


Figure 6.24: Brain segmentation using the watershed method applied to the whole image (3D).

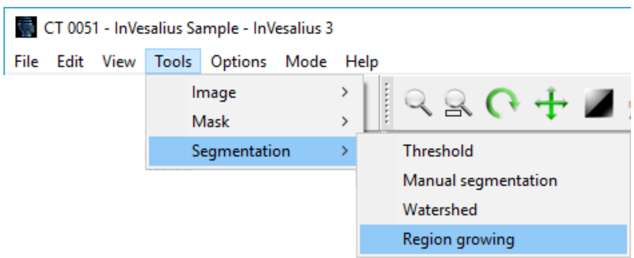


Figure 6.25: Menu to access the region growing segmentation segmentation tool.

different condition of selection:

- **Dynamic**: In this method uses the value of the pixel clicked by the user. Then every connected pixel inside the lower (min) and the up-

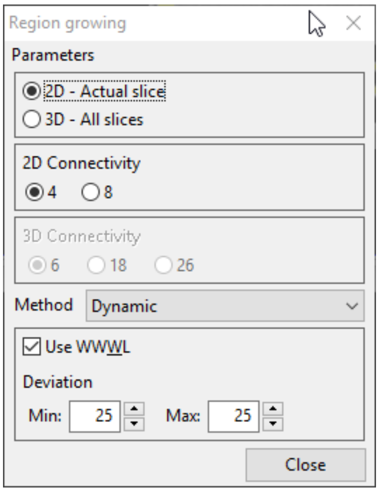


Figure 6.26: Dialog to configure the parameters of region growing segmentation tool.

per (max) range deviation are selected. The option **Use WWWL** is default and makes region growing taking into account the image with **window width** and **window level** applied not the raw one (figure 6.27).

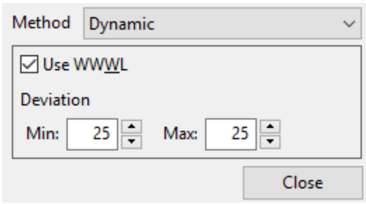


Figure 6.27: Dynamic method parameters.

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

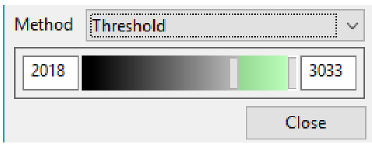


Figure 6.28: Adjust the threshold.

- **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's calculated the mean and the standard deviation from the selected pixels. Which follows by other expansion step. This process is repeated according to the number of **Iterations** parameter. The figure 6.29 shows the parameters for this method.

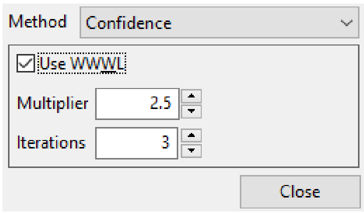


Figure 6.29: Confidence parameter.

Chapter 7

Mask

7.1 Boolean operations

After segmenting it's possible to perform some boolean operations 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, also known as XOR, keeps the regions of the first mask wich 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 menu **Tools**, **Mask**, **Boolean operations** as shown in the figure 7.1.

It's necessary to select the select the first mask, the operation to be performed and the second mask as shown in the figure 7.2. Then click on the **Ok** button.

The figure 7.3 shows some examples of utilization of boolean operations tool.

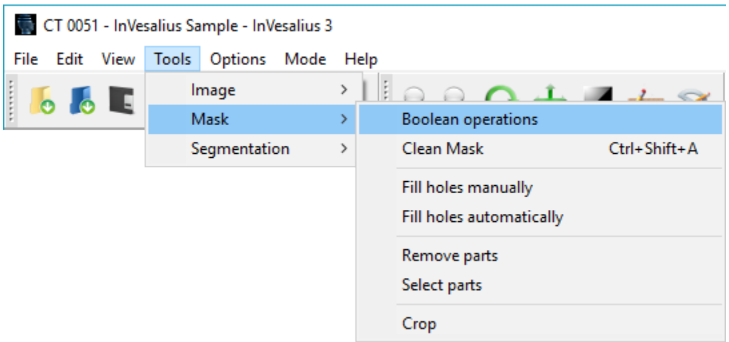


Figure 7.1: Menu to open boolean operations tool.

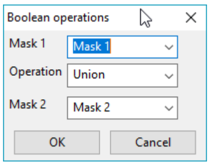


Figure 7.2: Boolean operations tool.

7.2 Mask cleaning

It's possible to clean a mask (figure 7.4). This is recommended before starting to insert Watershed markers. This tool is located on menu **Tools**, **Mask**, **Clean mask**. Also, it possible to use keyboard 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's possible to fill hole on a mask slice (**2D - Actual slice**) or on all slices, selecting the option **3D - All slices**. It's also possible to configure the connectivity used. It may be 4 or 8 to 2D and 6, 18 and 26 to 3D.

After configuring the desired parameters click with the **left-button** of the mouse on holes to fill them.

The figure 7.7.a shows mask with some holes and other mask with the

(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.

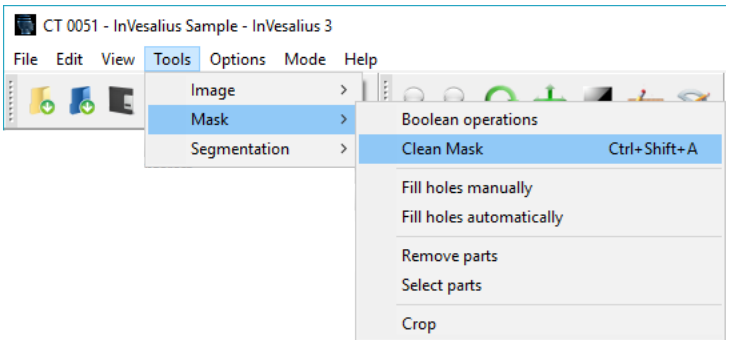


Figure 7.4: Mask cleaning

holes filled (figure 7.7.b). Click on the **close** button or close the dialog to deactivate this tool.

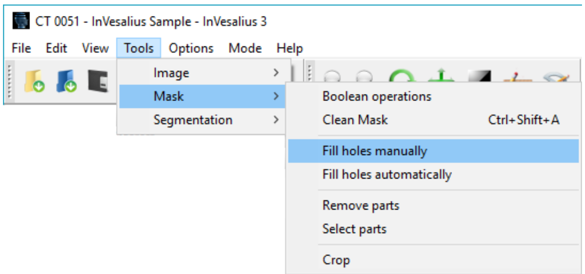


Figure 7.5: Menu to access the tool to fill holes manually.

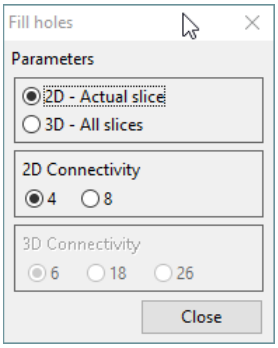
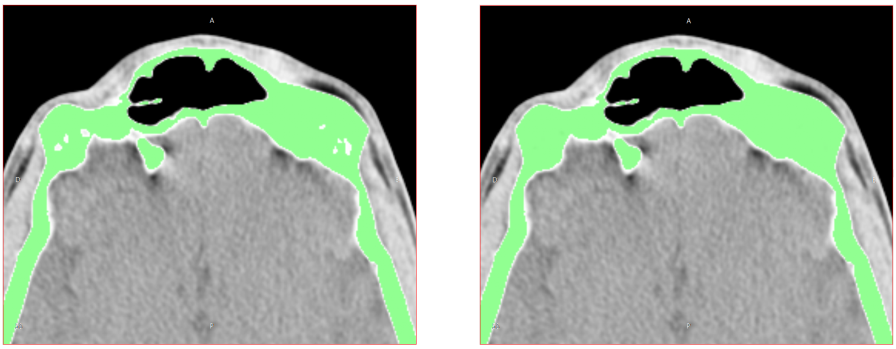


Figure 7.6: Dialog to configure the parameters of Fill holes manually tool.



(a) Holes

(b) Holes filled

Figure 7.7: Example of mask with holes filled.

7.4 Fill holes automatically

To open this tool go to the menu **Tools**, **Mask**, **Fill holes automatically** (figure 7.8). It'll open a dialog to configure the parameters. This tool doesn't require the user to click on holes he desire to fill. This tool will fill the holes based on the **max hole size parameter** given in number of voxels (figure 7.9).

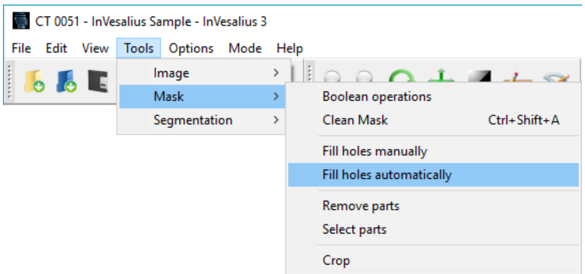


Figure 7.8: Menu to open the Fill holes automatically tool.

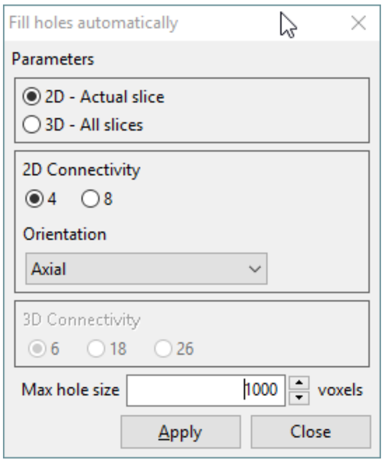


Figure 7.9: Dialog to configure the parameters used to fill the holes.

It's possible to fill hole on a mask slice (**2D - Actual slice**) or on all slices, selecting the option **3D - All slices**. It's also possible to configure the connectivity used. It may be 4 or 8 to 2D and 6, 18 and 26 to 3D. In 2D case it's needed to indicate in which orientation window the holes will be filled.

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

7.5 Remove parts

After generating a surface is recommended to remove the unwanted disconnected parts from mask. In this way the surface generation will use less RAM and the process will be quicker. To remove the unwanted parts go the menu **Tools**, **Mask** e **Remove Parts** (figure 7.10). A dialog will be shown to configure the parameters of selection (figure 7.11).

It's possible to select disconnected part only on a mask slice (**2D - Actual slice**) or on all slices, selecting the option **3D - All slices**. It's also possible to configure the connectivity used. It may be 4 or 8 to 2D and 6, 18 and 26 to 3D.

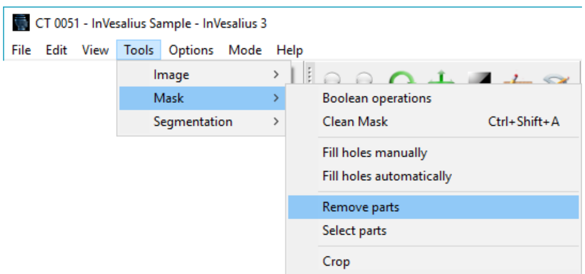


Figure 7.10: Menu to open the Remove parts tool.

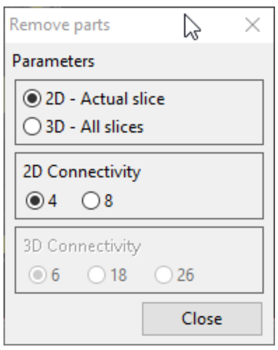
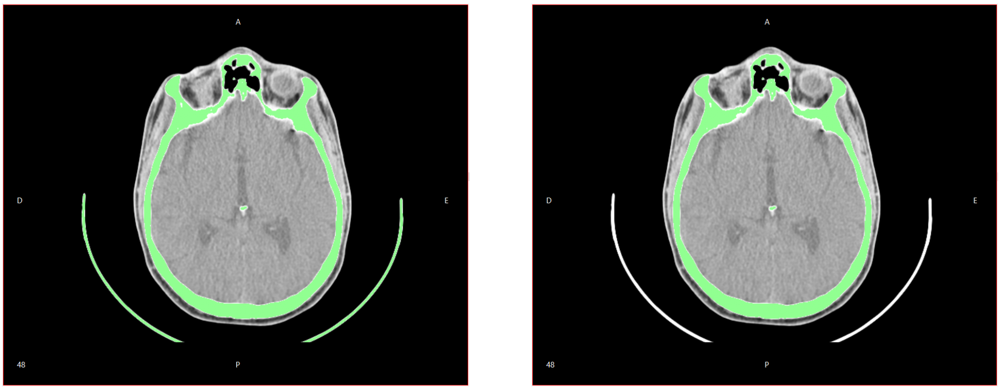


Figure 7.11: Dialog to configure the parameters used in Remove parts.

After selecting the desired parameters click with the **left-button** of the mouse on the region you want to remove. The figure 7.12 an example of mask before and after remove a disconnected part. Click on **Close** button to close this tool.



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

Figure 7.12: Example of region remove from a mask.

7.6 Select parts

To open Select parts tool go to menu **Tools**, **Mask**, **Select parts** (figure 7.13). A dialog will be shown to configure the parameters which are the name of the new mask and the connectivity (6, 18 or 26).

Click with **left-button** of the mouse on the wanted pixel of the region you want to select. It's possible to select more than one region. The selected region(s) will be shown with a red mask. After selecting all the wanted regions click on the **Ok** button to create a new mask with regions selected. The figure 7.15.a shows a region selected in red color. The figure 7.15.b shows the selected region in a new mask.

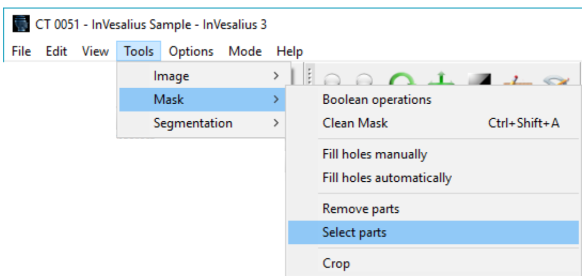


Figure 7.13: Menu to open the Select parts tool.

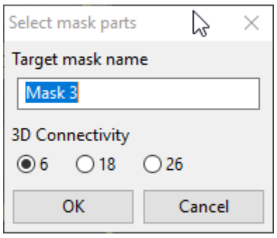
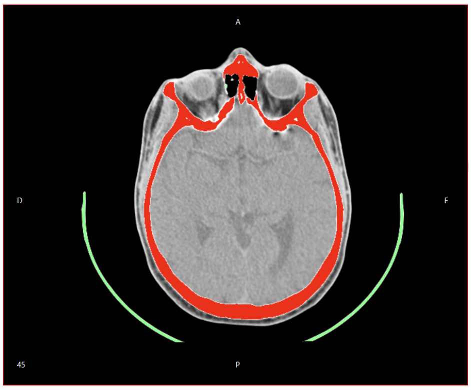
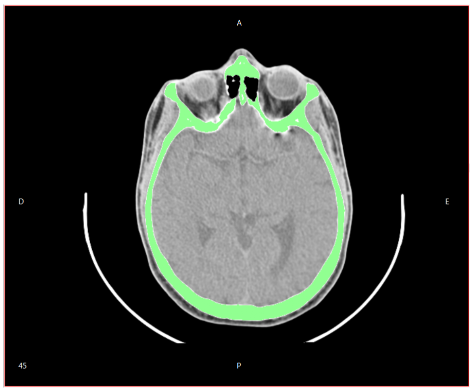


Figure 7.14: Dialog to configure the parameters of Select parts tool.



(a) Region selected in red



(b) Final image with only the selected region

Figure 7.15: Example of mask region selection.

7.7 Crop

It's possible to cut part of a mask in order to select an region of interest. This may reduce the amount of information to processed when generating a surface. To open this tool go to the menu **Tool**, **Mask**, **Crop** (figure 7.16).

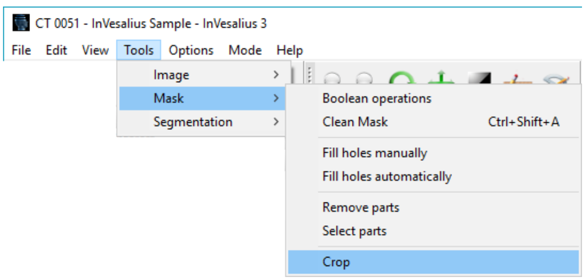


Figure 7.16: Menu open the Crop tool.

It will be shown a bounding boxes in each orientation window.

Chapter 8

Surface (Triangle mesh)

At InVesalius, a 3D surface is generated based on a image segmentation. A surface is generated using the *marching cubes* algorithm. In a nutshell, this algorithm transforms *voxels* from the stacked and segmented images to polygons (triangles in this case).

On the left panel, inside **3. Configure 3D surface**, **Surface properties** you have the controls to configure a 3D surface.

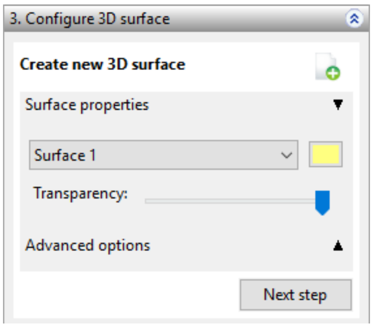


Figure 8.1: 3D surface configuration.

8.1 Creating 3D surfaces

It's possible create a new surface based on a already segmented mask. To do that, on the left panel, **3. Configure 3D surface**, click on the button shown at the 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 to configure the 3D surface creation. It allows to set the quality of the surface, to fill the surface holes and to keep only the largest connected region of the surface.

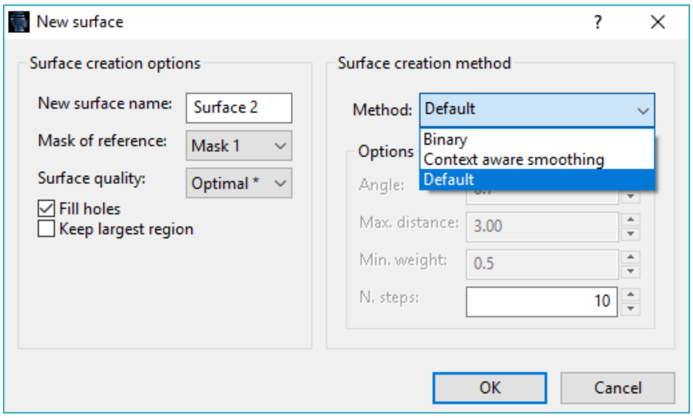


Figure 8.3: 3D surface creation dialog.

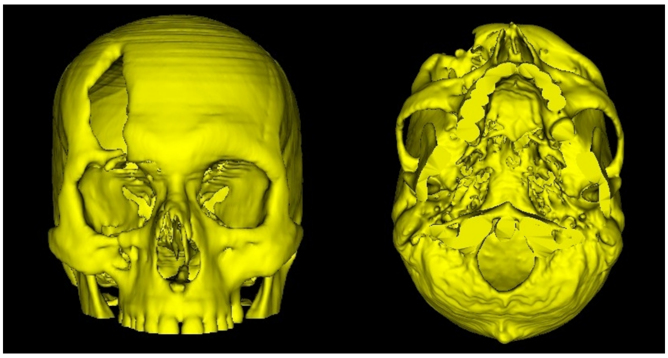
The keep largest region option may be used, for instance, to remove the tomograph support. Figure 8.4 displays a surface created with **Keep largest region** and **Fill holes** activated.

Whereas the figure 8.5 displays the surface create without activating that options. Note the tomograph support and the holes.

The item **Surface creation method** 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.

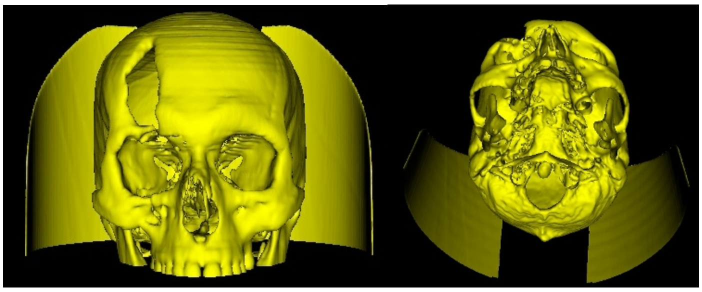
The **Binary** method takes as input the segmentation mask which is binary, where selected regions have value 1 and non-selected have value 0. As it is binary, the surface generated has a blocky aspect, mainly in high curvature areas, appearing staircases.

Context aware smoothing starts generating the surface using binary method. After that it uses the algorithm **Context aware smoothing** to



(a) Frente (b) Baixo

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



(a) Frente (b) Baixo

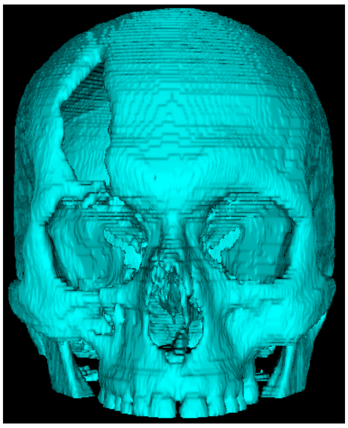
Figure 8.5: Surface created with the options **Keep largest region** and **Fill holes** deactivated.

smooth the surface to avoid the staircase artifacts. This method has 4 parameters presented bellow.

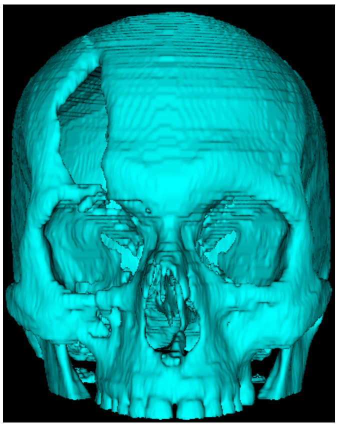
The **angle** parameter is the angle between 2 adjacent triangles. If the calculated angle is **greater than** the angle parameter the triangle will be considered a staircase triangle and will be smoothed. The angle parameter ranges from 0 to 1. Where 0 is 0° and 1 is 90°. The **Max distance** is the maximum distance that a non-staircase triangle has to 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 weighted 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.

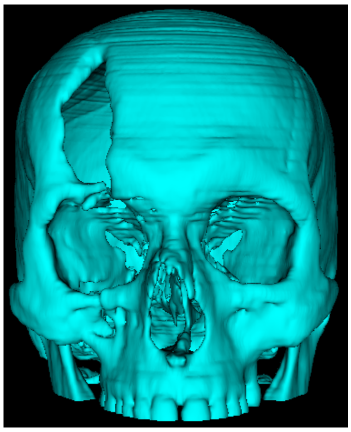
The **Default** method is enable only when **it was used thresholding segmentation and there is not a manual edition in the mask**. This method doesn't use the mask image, but the exam image, and generates a smoother surface.



(a) Binary



(b) Context aware



(c) Default

Figure 8.6: Surface generated by each method.

8.2 Transparency

It's also possible to display a surface with some level of Transparency. To do that, first 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 de sliding control shown in the figure 8.8. The more to right the more transparent the surface will be shown.

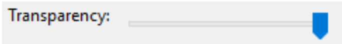


Figure 8.8: Selection of surface transparency.

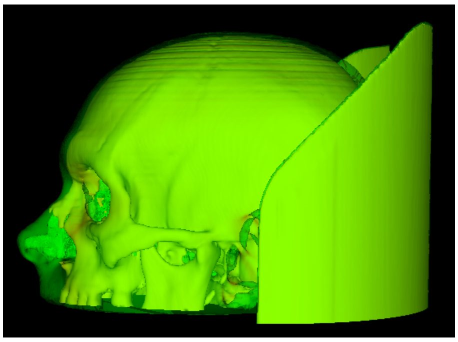


Figure 8.9: Surface with transparency.

Figure 8.9 shows 2 surfaces: the extern surface (green color) has some level of transparency which permits to see the intern surface (yellow color).

8.3 Color

It's possible to change a surface color. Select the surface (see figure 8.7). Click on the colored button on the right to the surface selection list. Figure 8.10 displays this button, inside the 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**.

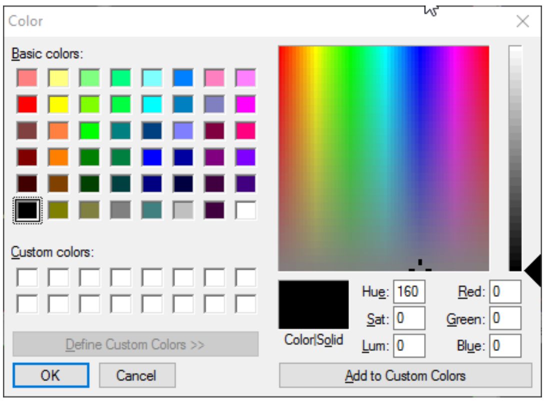


Figure 8.11: Color dialog.

8.4 Splitting disconnected surfaces

To split disconnected surfaces it's necessary to go to **3. Configure 3D surface**, **Advanced options** (figure 8.12).

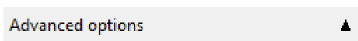


Figure 8.12: Advanced options.

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

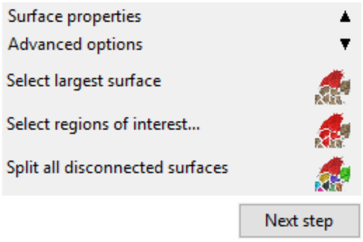


Figure 8.13: Advanced options panel.

8.4.1 Select largest surface

The option **Select largest surface** selects, automatically, only surface with the greater volume. To do this operation click on the button illustrated in the figure 8.14. This operation creates new surface with only the largest surface.

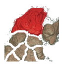


Figure 8.14: Button to split the largest disconnected surface

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

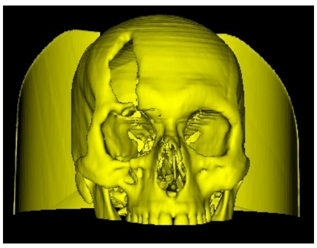


Figure 8.15: Disconnected surfaces.

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

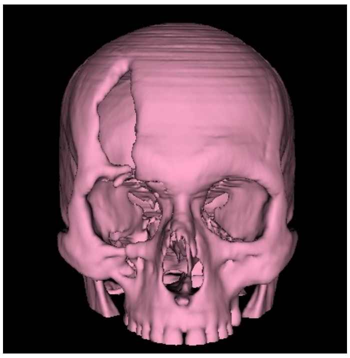


Figure 8.16: Largest disconnected region separated.

8.4.2 Select regions of interest

Other selection option is **Select regions of interest ...**. To do this operation click on the button illustrated on the figure 8.17. Then click on desired disconnected surface regions you want to select. Next click on **Select regions of interest ...**. This operation will create 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.

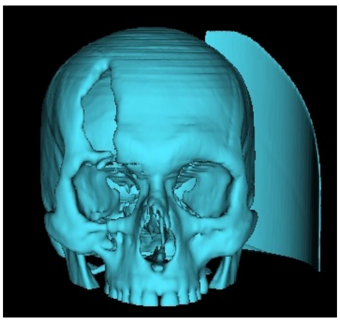


Figure 8.18: Example of selected regions of interest

8.4.3 Split all disconnected surfaces

It's also possible to split all the disconnected surface regions automatically. To do this, click on the button illustrated in the figure 8.19.

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

Figure 8.20 shows an example.

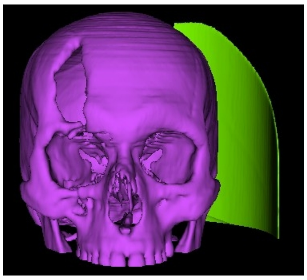


Figure 8.20: Example of split all disconnected regions surface.

Chapter 9

Measures

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

9.1 Linear Measurement

To perform linear measurements, it is necessary to activate the feature by clicking on the shortcut corresponding toolbar located (figure9.1).

Figure 9.1: Shortcut to activate linear measurement

A linear measurement is defined 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 **one** again. The measurement is performed and the result is automatically displayed on the image or surface.

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

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

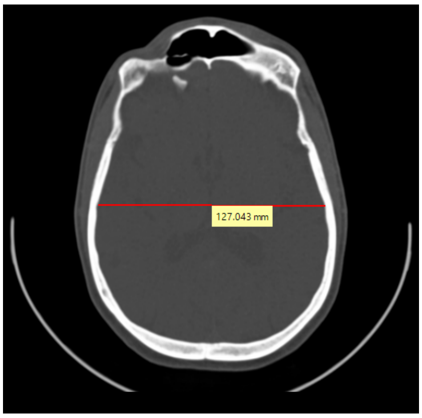


Figure 9.2: Linear measure on image

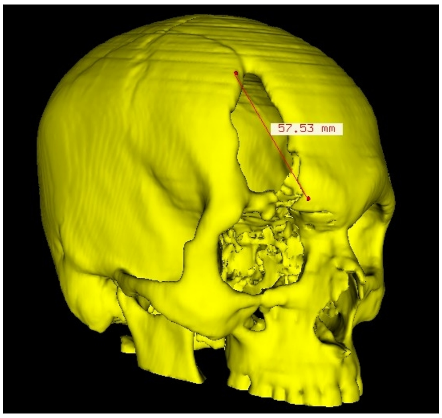


Figure 9.3: Linear measure on surface

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, is necessary to provide the three points that will describe the angle to be measured, $A\hat{B}C$. Click **one** instead with the left button to determine the first point, A. To insert the second point, B (the vertex of the angle or the "center"), position the mouse pointer and click **one** again. Repeat the same actions to determine the third point, C. The resulting measurement is displayed on the image or surface.

The figure 9.5 illustrates an angular measurement on a flat image, and the figure 9.6 illustrates an angular measurement on a surface.

As 2D linear measurement, you can also edit the 2D angular measurement, so you need to position the mouse on one end, hold down the **right mouse button** and drag it to the desired position.

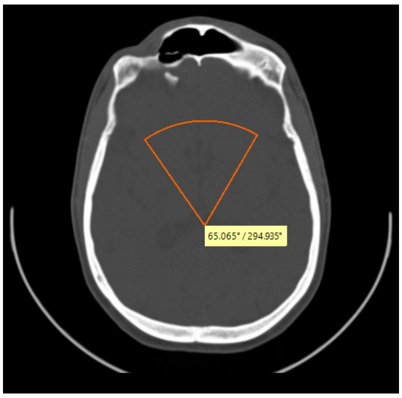


Figure 9.5: Angular measurement

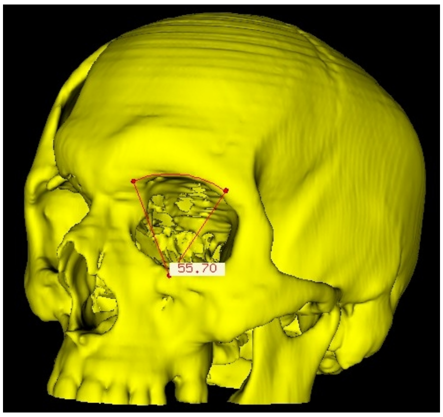


Figure 9.6: Angular measurement on surface

Note: Angular measurement is shown in degrees (°)

9.3 Volumetric Measurement

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

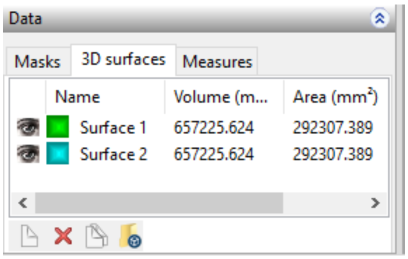


Figure 9.7: Volumetric measurements

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

Chapter 10

Data management

Previously, it was shown how to manipulate surfaces, masks for segmentation and measurements. It is possible to show or hide, and create or remove these elements at the **Data** management panel, located in the left inferior corner of Invesalius. The panel is divided in 3 tabs: **Masks**, **3D Surfaces** and **Measurements**, shown in figure 10.1. Each tab contains features corresponding to the elements it referes to.

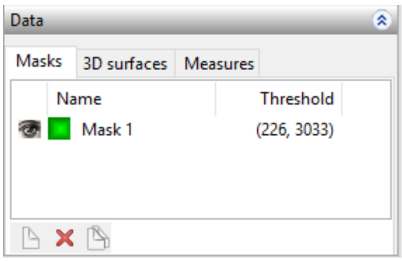


Figure 10.1: Data management

In each tab, there is a panel divided in rows and columns. First column of each line determines the visualization status of the listed element. It means that the "eye" icon activates or deactivates the masks, surface or measurement exibition. In case one of these elements is being exhibited, its corresponding icon 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, it is necessary to first select its name, show in figure 10.3 and next click in the shortcut illustrated in figure 10.4.

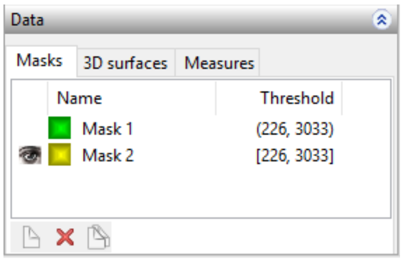


Figure 10.3: Data selected

Figure 10.4: Remove data

To create a new mask, surface or measurement, click in the shortcut show in figure 10.5, considering that the corresponding tab must be open.

Figure 10.5: New data

To duplicate a data, select it and click in the shortcut shown in figure 10.6.

Figure 10.6: Duplicate data

10.1 Masks

At column **Name**, the mask's color and name are show. In turn, column **Threshold** show the value range used to create the mask. Figure 10.1 exhibits an example.

10.2 3D Surface

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

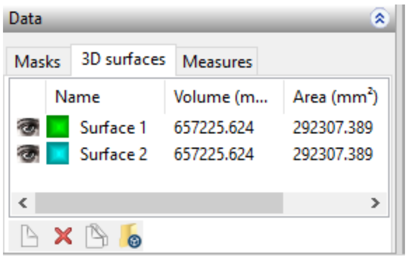


Figure 10.7: Surface manager

10.2.1 Import surface

It is possible to import a file of type STL, OBJ, PLY or VTP (VTK Polydata File Format) with 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

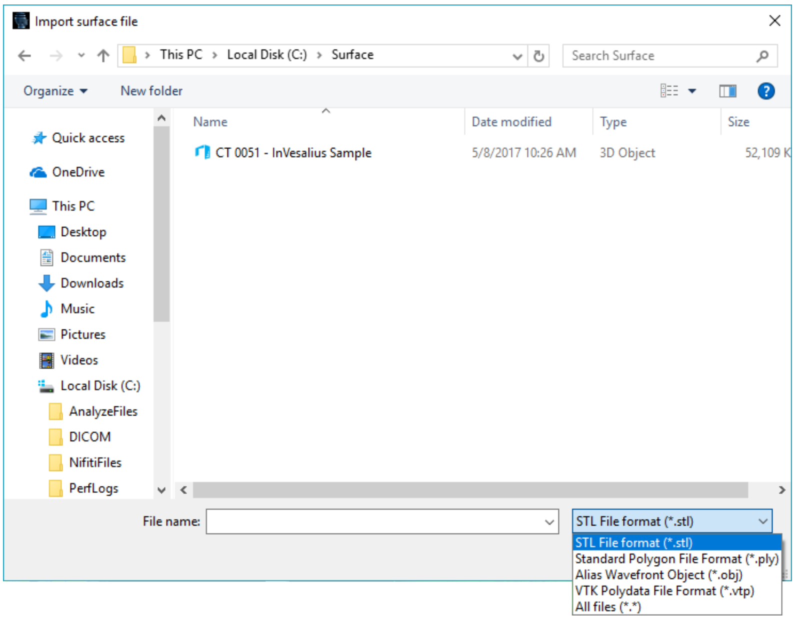


Figure 10.9: Window to import surface

10.3 Measurements

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

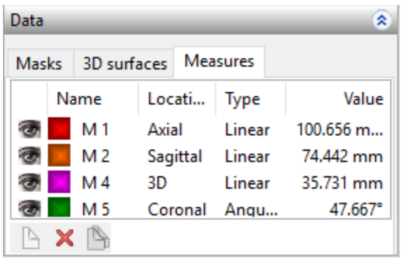


Figure 10.10: Data management

Chapter 11

Simultaneous viewing of images and surfaces

The simultaneous viewing of images and surfaces can be activated clicking the **left** mouse button on the shortcut located in the lower right corner of the InVesalius screen. See figure 11.1.

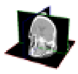


Figure 11.1: Shortcut for simultaneous viewing

This feature allows enable or disable the display of images in different orientations (or plans) within the same display window of the 3D surface. To do this, simply check or uncheck the corresponding option in the menu shown in figure 11.2.

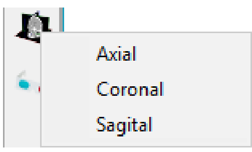


Figure 11.2: Selection of the guidelines (plans) to display

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

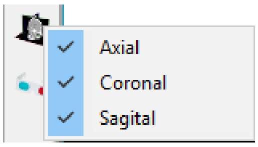


Figure 11.3: Selected Guidelines for display

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

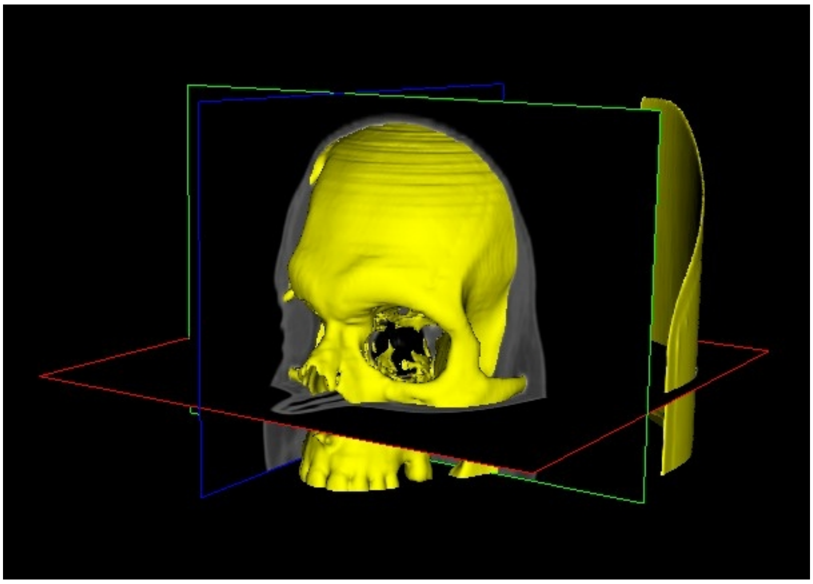


Figure 11.4: Surface and plans displayed simultaneously

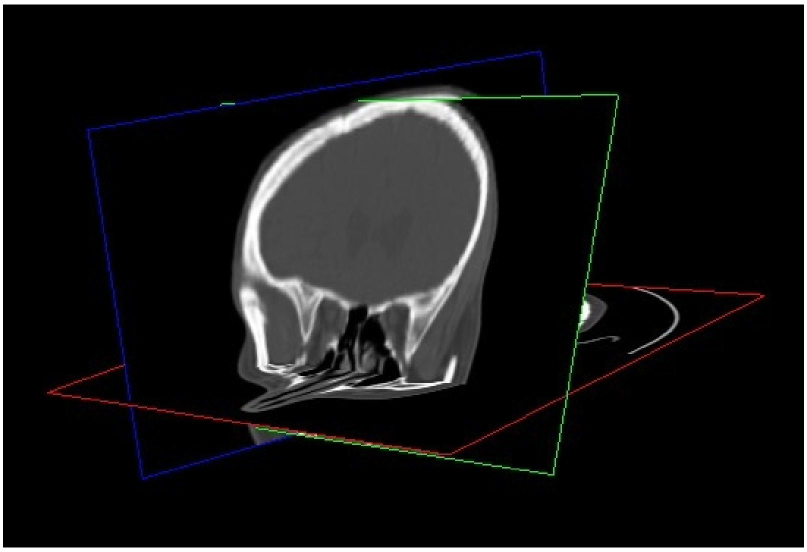


Figure 11.5: Flat display (no surface)

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. In summary, raycasting is it a technique to simulate the trace a beam of light toward the object for each screen pixel. The pixel color is based on the color and transparence of each voxel intercepted by the light beam.

InVesalius there are 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 display window surfaces) and select one of the available standards.

To turn off the volume rendering, click again on the path indicated by the figure 12.1 and select the **Disabled** 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.

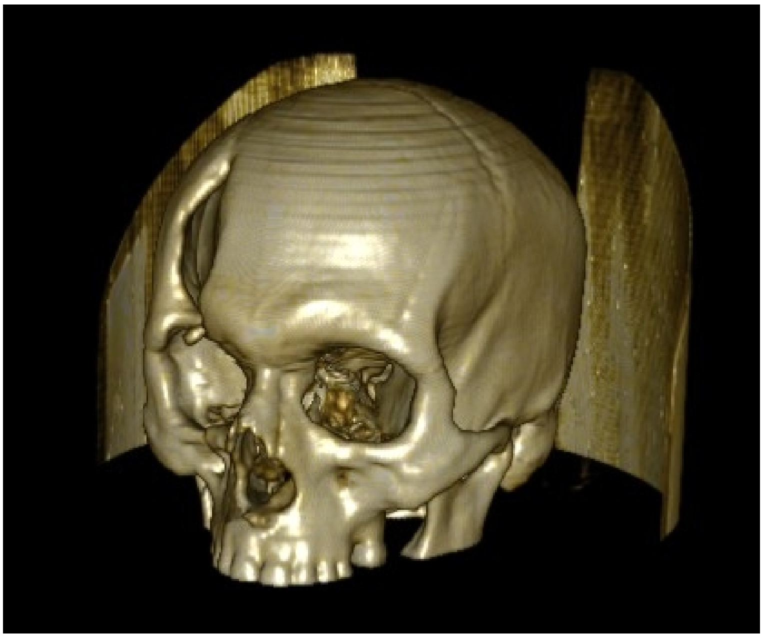


Figure 12.2: Bright

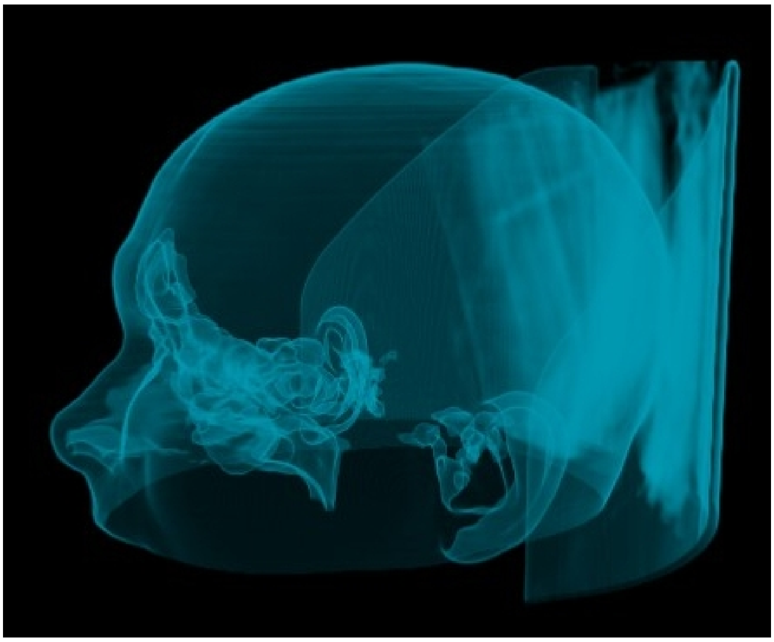


Figure 12.3: Airway II

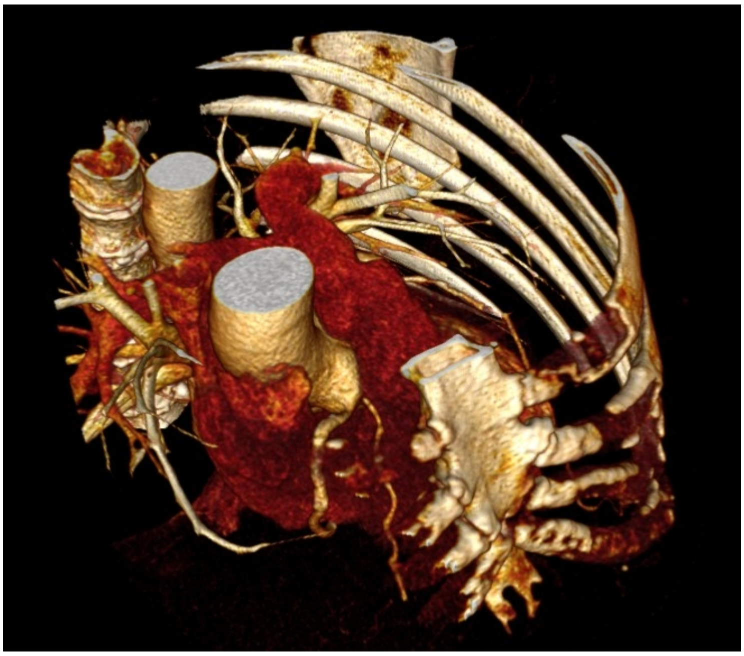


Figure 12.4: Contrast Medium

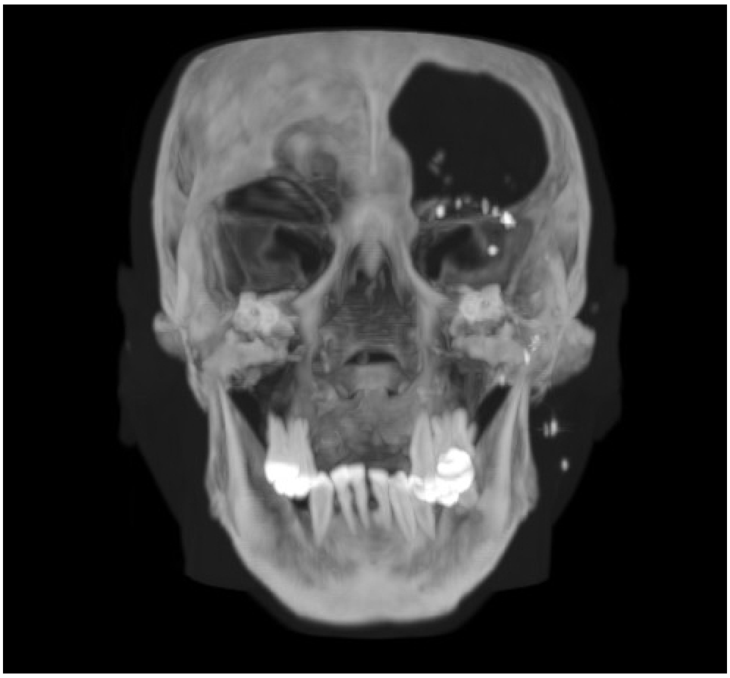


Figure 12.5: MIP

12.2 Standard Customization

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

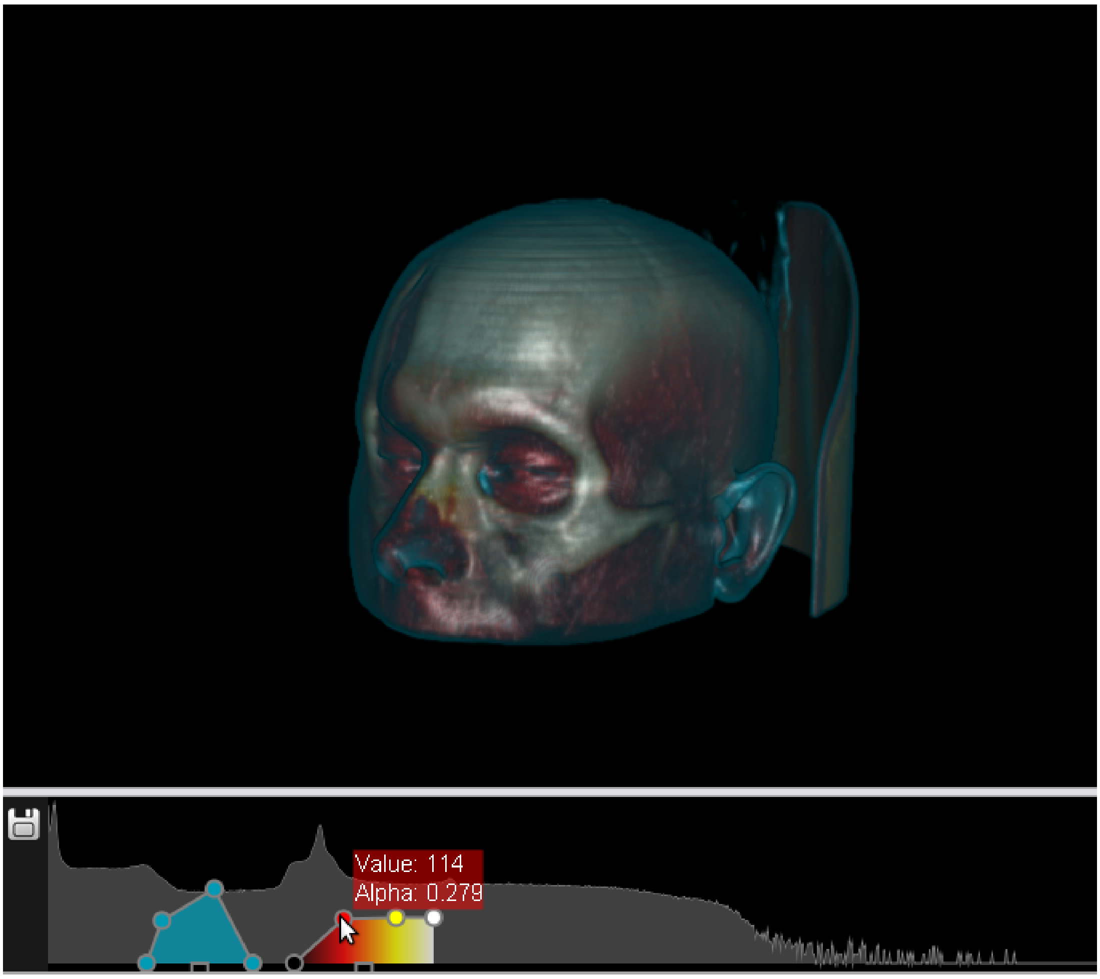


Figure 12.6: Settings for the display pattern Soft Skin + II

To hide a structure, you must use the control setting chart keeping low the opacity of the corresponding region. In the example in figure 12.6 for example, suppose you want to hide the muscular part, which appears in red. To do this, one can simply position the pointer over the point in red and using the left mouse button, drag the point down in order to reduce the opacity (which is equivalent to increasing transparency). Figure 12.7 illustrates the result.

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

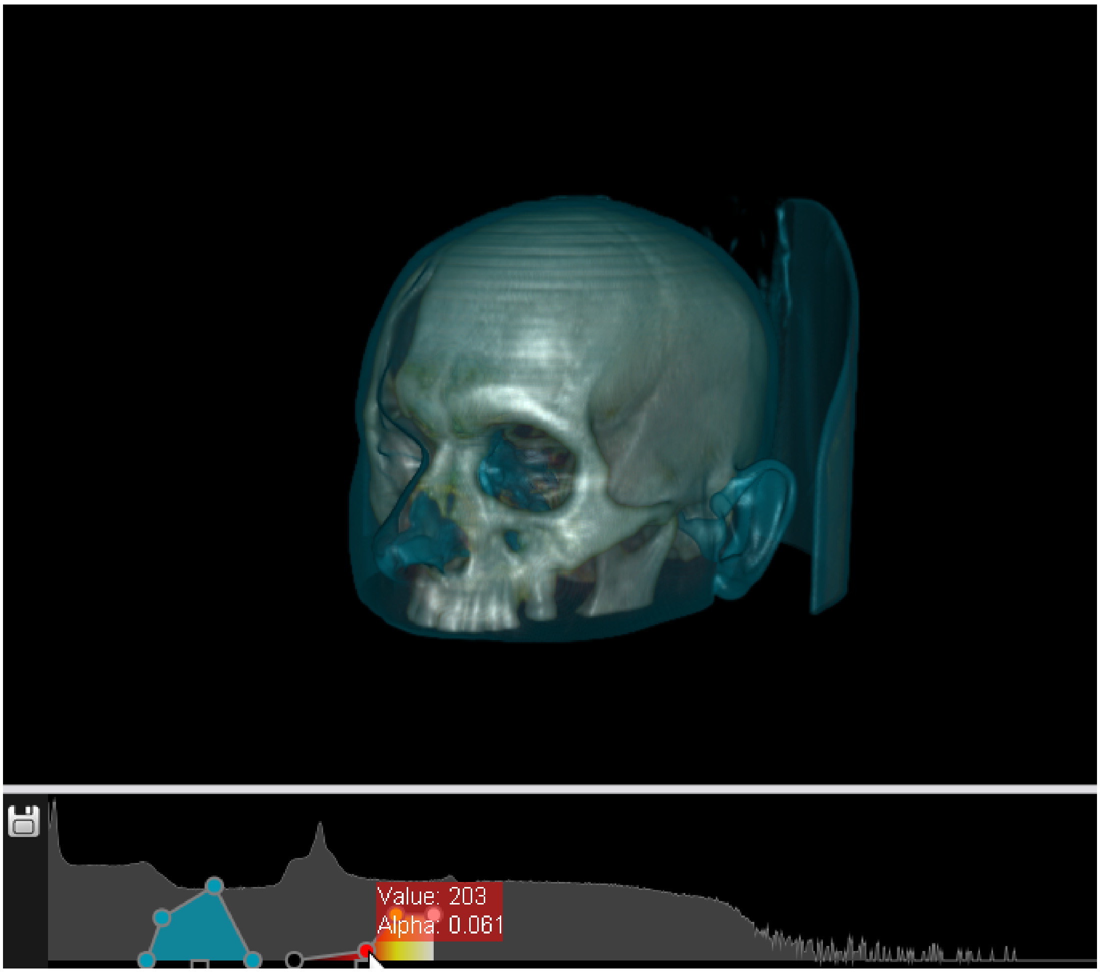


Figure 12.7: Display Standard Soft Skin + II changed

It can remove or add points on the graph control setting. For removing, simply click with the right mouse button on the point. For adding a new point, click the left button on the line graph. One can also save the resulting pattern by clicking the shortcut. Figure 12.8 illustrates.

Figure 12.8: Shortcut to save standard

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

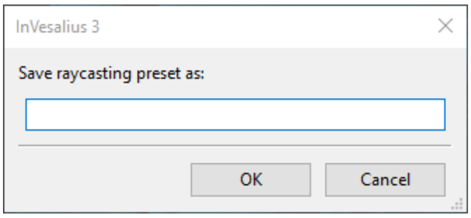


Figure 12.9: Window to save name of pattern.

12.3 Standard Customization with Brightness and Contrast

You can customize a pattern without using the graphical control setting, which is presented in the previous section. This is done through the control **brightness and contrast** which is present in the toolbar. To activate the control, click the shortcut shown in figure 12.10.

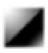
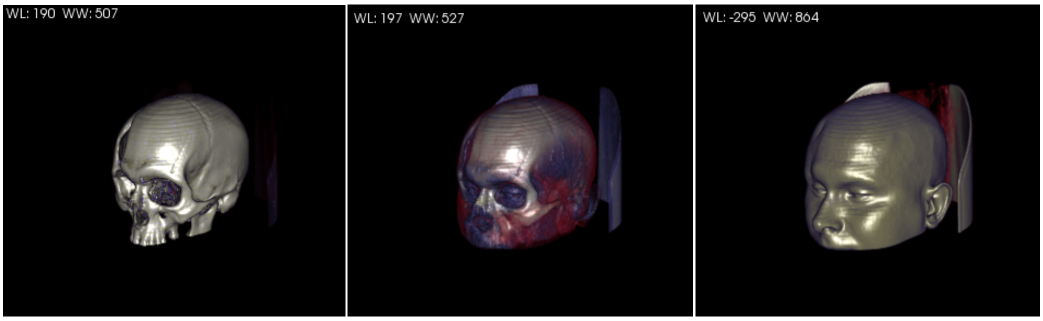


Figure 12.10: Shortcut to Brightness and Contrast

Enable the control by dragging the mouse, with the left button pressed on the volume window, this can change the values of the window width and window level. The procedure is the same as the slices applied to 2D, which can be seen in section 5.7. Dragging the mouse in the horizontal direction changes the window level value. To the left, it decreases its window value, and for the right, it increases its window value. Dragging the mouse in the vertical direction changes the value of window width. If dragged down, the value is diminished and, dragging upwards increases its value.

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 **left button** presseds.). See figure 12.11.



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

Figure 12.11: Tissue Addition

12.4 Cut

In volume rendering, the cut is used to view a region of the internal volume. InVesalius has a cut for tool for this based on a reference plane. With a volume pattern selected, click **Tools**, and then click **Cut plane** (figure 12.12).

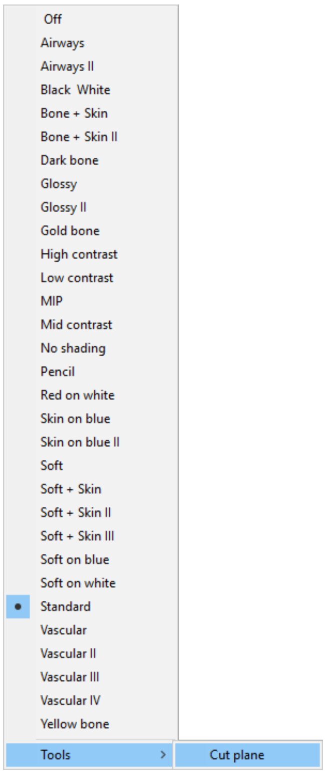


Figure 12.12: Enabling plan to cut

A plan of representation 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 plan, hold the **left** mouse button pressed on its edge and move the mouse in the desired direction. See an example in figure 12.13.

To disable the cut feature, click **Tools** and then again **Cut plan** (figure 12.13).

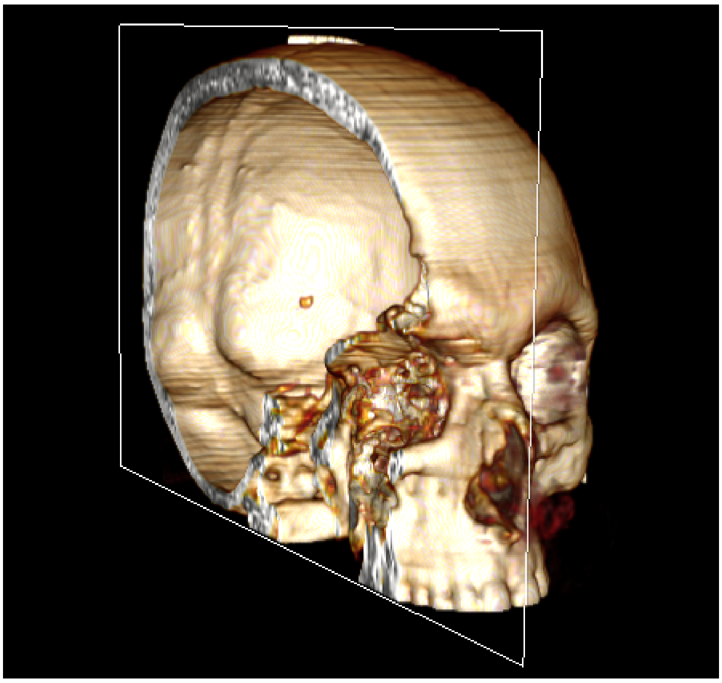


Figure 12.13: Image with clipping plane

Chapter 13

Stereoscopic Visualization

InVesalius supports stereoscopic visualization of 3D models, so it is necessary to create a surface (see chapter 8) or an active volumetric visualization (see chapter 12), then click the icon That the figure 13.1 shows on the right side the bottom part of InVesalius and choose the desired projection type (figure 13.2).

Figure 13.1: Shortcut to activate stereoscopic viewing methods.

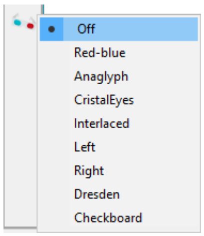


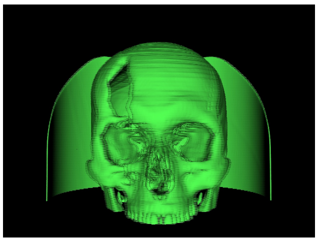
Figure 13.2: Different methods of stereoscopic visualization.

InVesalius supports the following types of stereoscopic viewing:

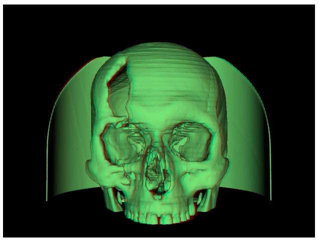
- Red-blue
- Anaglyph
- CristalEyes

- Interlaced
- Left
- Right
- Dresden
- Checkboard

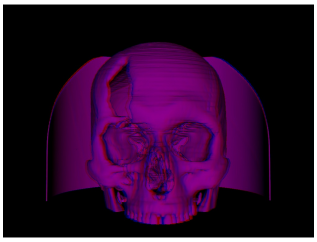
Figure 13.3 presents three different types of projections.



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

Menu to export data is located in the left panel of InVesalius, inside item **4. Export data**. If the menu is not visible, double-click with **left** mouse button to expand the item. Figure 14.1 exhibit this menu.

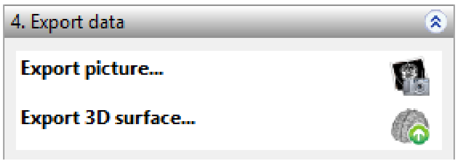


Figure 14.1: Menu to export data

14.1 Surface

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

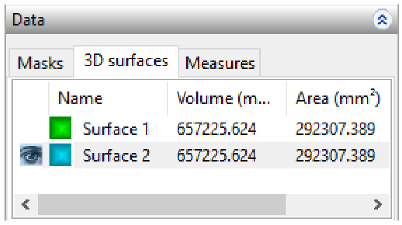


Figure 14.2: Select surface to be exported

Next, click on the icon shown in figure 14.3.

Figure 14.3: Shortcut to export surface

In the correspondent window (figure 14.4), tyoe the file name and select the desired exported format. Finally, click **Save**.

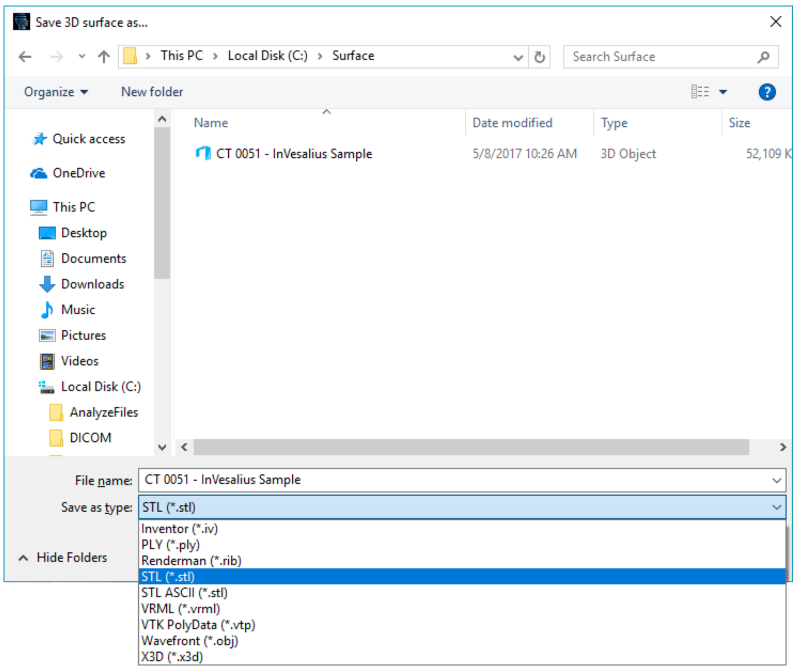


Figure 14.4: Window to export surface

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, click with mouse **left** button on the shortcut shown in figure 14.5 and select the sub-window related to the target image to be exported.

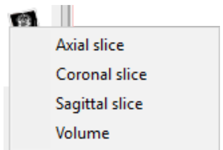


Figure 14.5: Menu to export images

On the windown shown (figure 14.6), select the desired file cormat and click on the button **Save**.

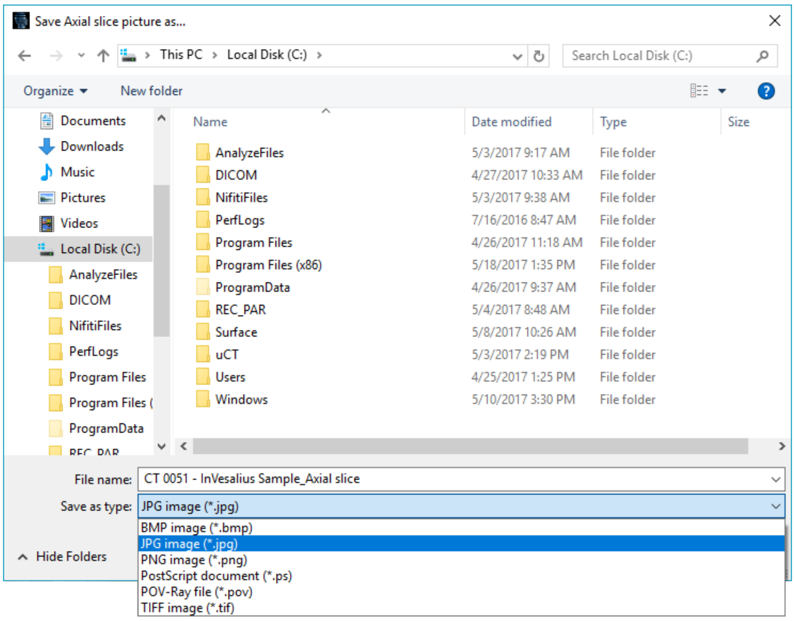


Figure 14.6: Window to export images

Chapter 15

Customization

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

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 InVeslaius is expanded, as illustrated in figure 15.2.

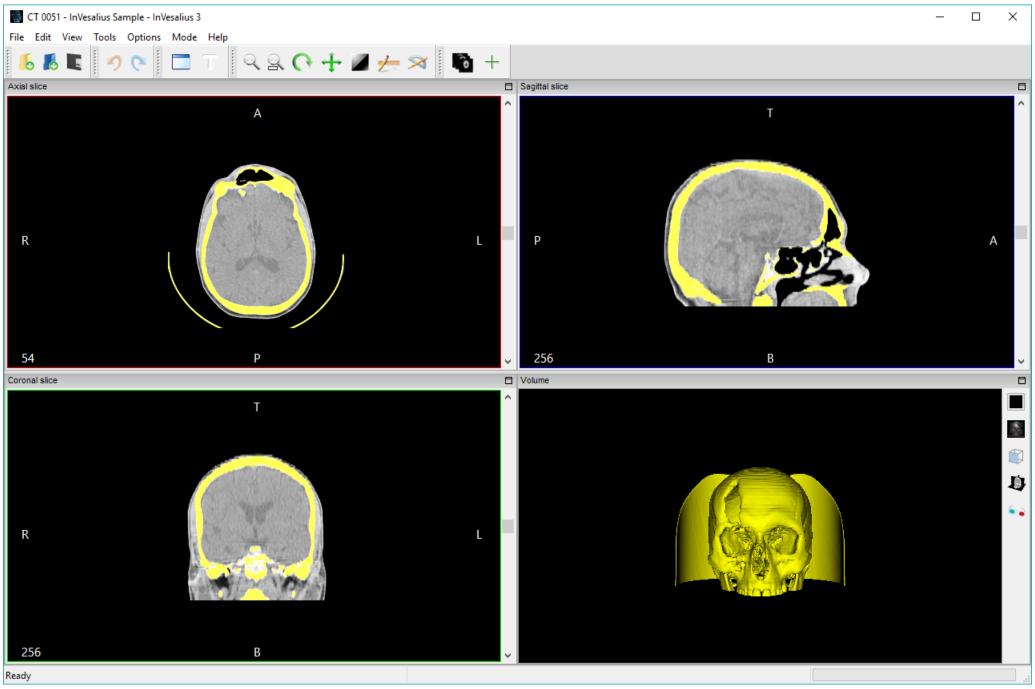


Figure 15.2: Side menu hidden

15.2 Automatic positioning of volume/surface

To automatic 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.

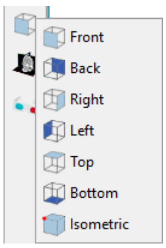


Figure 15.3: Options for visualization positioning

15.3 Background color of volume/surface window

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

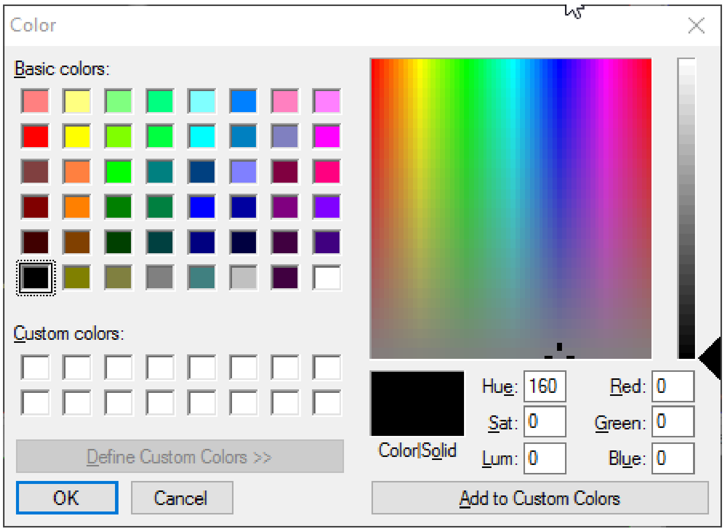


Figure 15.4: Shortcut to background color of volume/surface window

A window for color selection opens, as in figure 15.5. Next, just click over the desired color and then click **OK**.

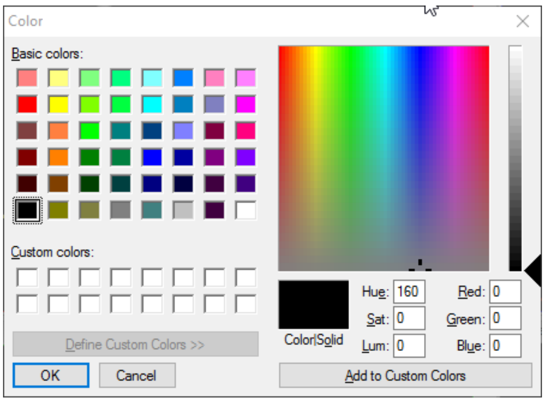


Figure 15.5: Background color selection

The figure 15.6 illustrates the correspondent window with modified background color.

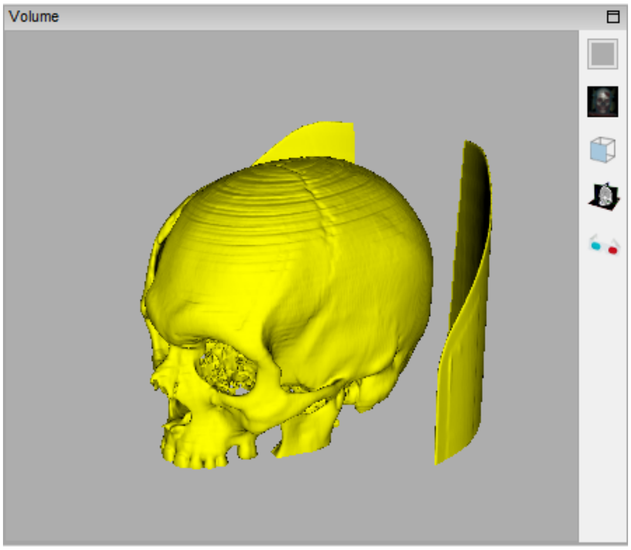


Figure 15.6: Background color modified

15.4 Show/hide text in 2D windows

To show or hide the texts in 2D image windows, click in the shortcut illustrated in figure 15.7, located in tools bar.

Figure 15.7: Shorcut to show or hide texts

Figures 15.8 and 15.9 exhibit texts enabled and disabled, respectively.

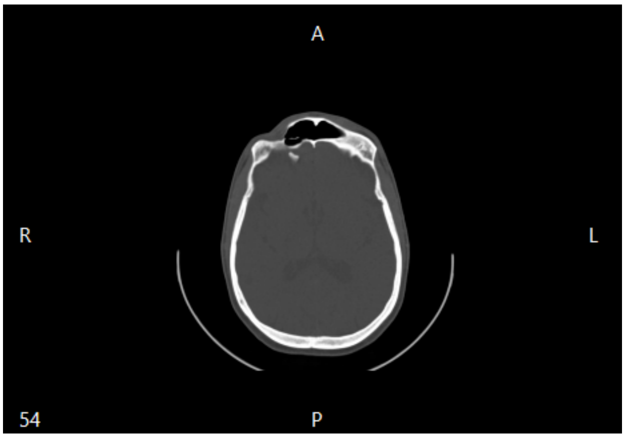


Figure 15.8: Show texts enabled

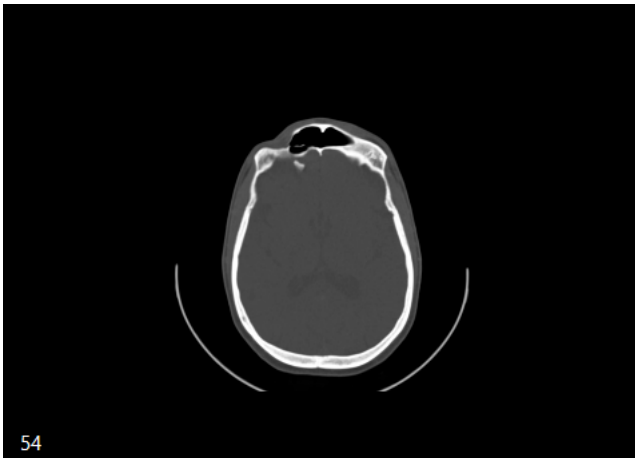


Figure 15.9: Show texts disabled

Chapter 16

Neuronavegation

An introduction to neuronavigation theory was presented in section 1.1.5. Reading is recommended before its use.

Enable the InVesalius neuronavigation mode by selecting the **Mode** tab in the main menu and then **Navigation**, figure 16.1. A **Navigation System** tab will be visible in the panel in the left of the main window, as shown in figure 16.2.

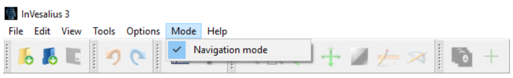


Figure 16.1: Menu to enable neuronavigation mode.

16.1 Spatial trackers and reference mode

Currently, InVesalius Navigator supports three 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).

After this, the first step is to choose the tracker in the menu **Select tracker:**, figure 16.5. The option **Debug tracker** allows the user to test the system even if none spatial tracker is connected. This option simulates a spatial tracker by generating random coordinates.

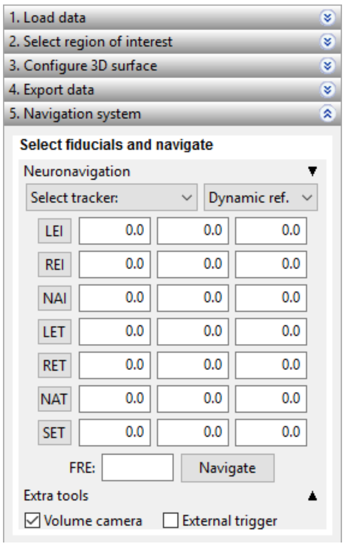


Figure 16.2: Tab for navigation system.

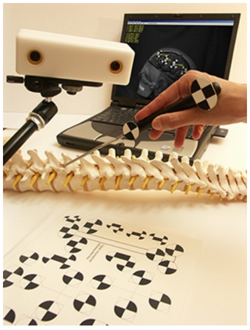


Figure 16.3: ClaroNav MicronTracker - www.claronav.com/microntracker/.

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

There are two references types to perform the navigation, static and dynamic (figure 16.6). Static mode uses just one spatial tracker probe. In this mode, the subject head must stay motionless after registration (for more info

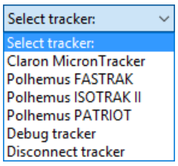


Figure 16.5: Menu to select tracking device.

about coregistration see section 16.2). To avoid head movements artifacts, a reference probe attached to some static part of the head is required, e.g. forehead. During neuronavigation procedures, the reference probe will detect and correct the translation and rotation from the head. This mode is known as dynamic reference.

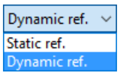


Figure 16.6: Menu to select reference mode.

16.2 Coregistration

The aim of coregistration procedure is to find a relation that transforms a coordinate given in the tracking device space to a coordinate in the virtual space (image). To perform the coregistration, the user must use the function of **Correspondence between orientations axial, sagittal and coronal** (see section 5.2) and select three anatomical fiducials in the image and 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 some image fiducial is selected, a marker (green sphere) is created in the volume, 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

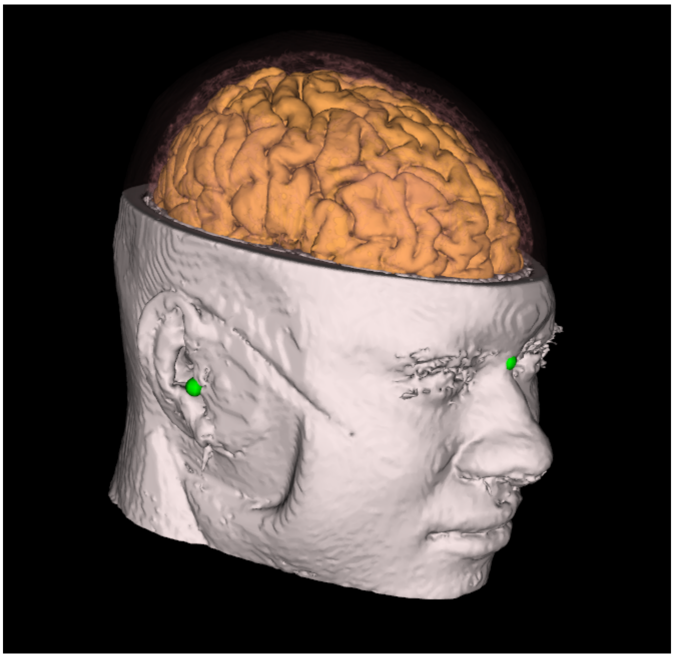


Figure 16.8: Selected fiducial markers represented as green spheres.

16.3 Fiducial registration error and navigation

After all fiducials are selected in both spaces (tracker and image) the next step is to press button **Navegate** button to start the neuronavigation. To stop navigation just press the button **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 for and after registration.

In the left side of 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, it is recommended that the coregistration is redone. Otherwise, if FRE is lower than 3 mm, the text box becomes 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 volume. To do that, the user needs to select **Extra tools** tab, figure 16.11.

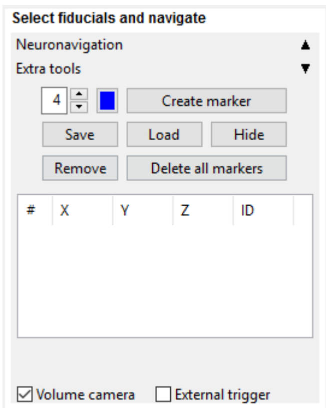


Figure 16.11: Aba para manipulação de marcadores.

The marker creation will be positioned in the current red cross position. The size and color can be changed, figure 16.12.

When a marker is created, its coordinates appear in the list control. To identify one marker of the list control in the volume, **double-click with left mouse button** the target item and the corresponding marker will blink. To stop blinking the markers, the user just needs to select another marker, i.e. press once in another item. It is also possible to create an ID to the marker, and to do that right click and select **Edit ID**, like in figure 16.13. Finally, a window will open allowing the user to create the ID, figure 16.14.

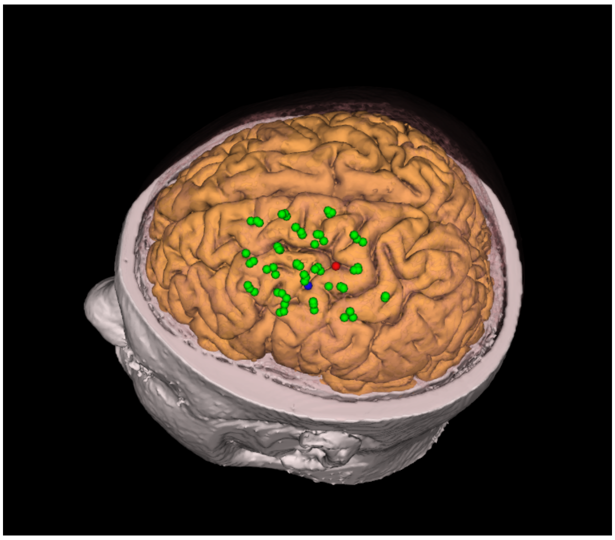


Figure 16.12: Volume with different colors markers.

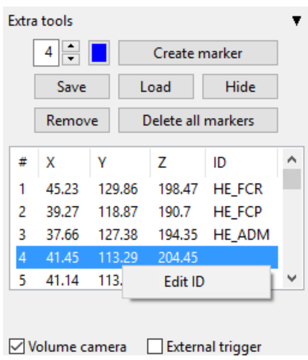


Figure 16.13: Task to manage marker creation.

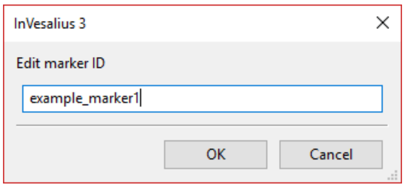


Figure 16.14: Window to label the marker.

The marker coordinates may be exported using the button **Save**. File extension is *.mks*. This extension can be opened in any word processor, e.g. Notepad or WordPad software. The file has the X, Y and Z coordinates followed by the RGB code, marker size and ID. Posteriorly, the markers can be importated to the navigation system using button **Load**.

To remove markers, **select** one or as much markers needed to be deleted and press button **Remove**. It is also possible to remove all markers, with the button **Remove all markers**. Another functionality is to hide/show the markers in the volume using the **button show/hide**.

16.5 External trigger checkbox

Another way to create markers is using an external trigger. To activate this feature, just press the checkbox **External trigger** before the navigation starts. This function was developed to communicate with TMS devices, to create a marker whereas the pulses are applied. Besides, it is possible to adapt this function as the user needs. The communication with the external device requires a serial port COM1. If this port receives any RS-232 signal in 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 positioning. The user can disable this function by unchecking the **Camera volume** checkbox. Therefore, the camera has to be manually changed.

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