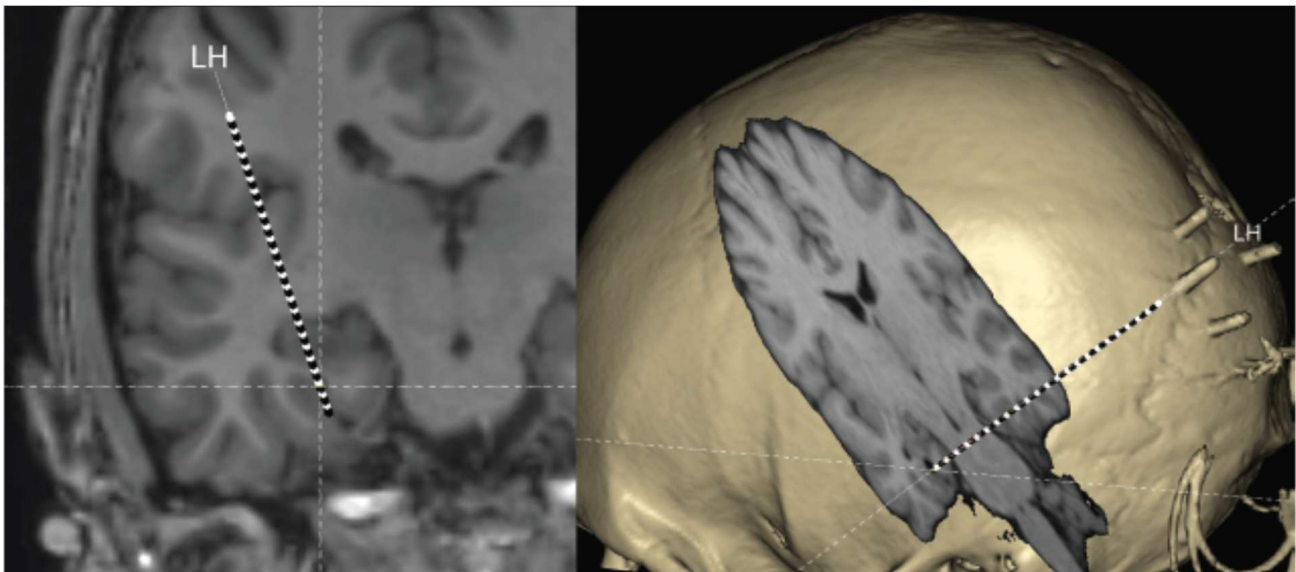# Depth Electrode Navigation Software
DENS

User Manual

DISCLAIMER: This software product was developed at 'Stichting Kempenhaeghe' as part of the as part of the Devices for NeuroControl and NeuroRehabilitation (DeNeCor) project that has received funding from ENIAC Joint Undertaking (grant no. 324257).

DISCLAIMER: Please note that the results obtained by using DENS do not in any way constitute medical advice and Clinical Neuro-Science projects cannot be held liable for any consequences (including any damages) resulting from a misinterpretation of the results by the user.

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Contents

I Preliminaries

➢ Installation

The software is written in C++. The software was developed using state-of-the-art code libraries for analysis and visualization using stable releases, which are possible to be updated when bugfixes or improvements become available. The following opensource libraries or tools were used for MIND: Visualization Toolkit (VTK) and Insight Toolkit (ITK) by Kitware, NiftyReg by Center for Medical Imaging Computing, and Robust Brain Extraction (ROBEX) available on NITRC.

The software can be installed by using provided installers. The pre-compiled packages include all dependencies and have been prepared for:

|		
Windows 7* or higher	64-bit	MIND_install_win64.exe

*Microsoft C++ Redistributable 2019.

The best equipment for visualisation of the medical imaging datasets by MIND is listed here:

- Operating System: Windows 7 or higher, 64bit
- CPU: any modern Multi-Core CPU (like Intel i5 or i7 processors)
- Memory RAM: 8 GB or more
- Graphics Card: dedicated video card with memory 256MB or more
- Hard Drive: any modern choice will do (SSD improves performance processing large data sets)
- Monitor: 1600×1200 or more (full HD 1920 x 1080 is recommended)
- Wheel mouse

License

Before the software can be used, it has to be configured correctly in terms of user information and license. When the software is started for the first time, a settings window will appear for providing a valid license in order to be used. After providing the license username, expiration date and key, click the **Check** button to verify the license information. After successful verification, the software can be used.
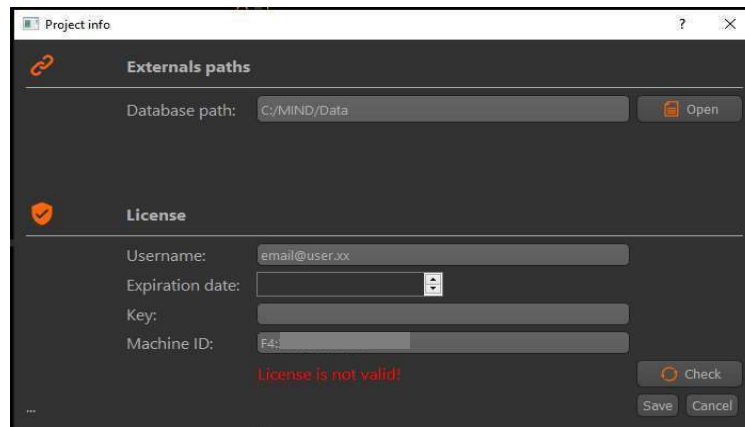
When the license is about to expire within 30 days, a warning will be displayed during start- up. For obtaining a (new) license, please contact: info@cnsprojects.nl.

➢ Conceptual design

Intended use

The 'Depth Electrode Navigator Software' (DENS), denoted in the following as 'software product (SP)', is designed for detection of depth electrodes. The detected electrodes are visualized together with the pre-operative MRI images, which enables the physician to assess the position of the electrodes in relation with the expected anatomical location. The SP itself does not perform source mapping of epileptic events, but may be used for the visualization of the source mapping results.

- Definitions, Acronyms, and Abbreviations
  - SP (Software product)
  - MRI (Magnetic Resonance Imaging)
  - CT (Computed Tomography)
  - EEG (Electroencephalography)
  - SEEG (Stereo-electroencephalography)

- User Characteristics

The SP is a medical tool and is designed to be accessible to medical doctors. No prerequisite knowledge of the internal workings of the software or medical data preprocessing should be required.

- **Product Functions**

The summary of functions that the SP will perform is as follows:

☐ Pre-processing of medical data from CT and MRI modalities.

☐ Easy loading and saving the results as a project file.

☐ Presentation of medical data from both modalities in 2D and 3D viewports.

☐ Detection of depth electrodes.

☐ Tools for the manual adjustment of the depth electrode placement.

☐ Visualization of source mapping results at the depth electrodes.

➢ **Data I/O**

This section describes the different types of data that can be imported and exported by the application.

- Data input

▬ Patient information, such as patient name, date of birth and ID. This information is stored in the application database and used to save and access all imported datasets of the given patient.

▬ 3D brain images in DICOM format. The application internally uses the NIfTI format for all operations and is able to convert imported DICOM files into the NIfTI format.

▬ 3D data, in NIfTI format. This dataset can either contain a pre-/ post- operative MRI- scan or a CT- scan.

- Data output

▬ Report in pdf format, containing patient data which are available in the project file, information provided by the clinicians about labeling and positioning against the anatomy of the depth electrodes and screen dumps of the 2D- and 3D-viewport visualization of the images created by the SP.

▬ Medical data in DICOM format, anatomical images and the overlay of the depth electrodes with the source mapping results can be exported as DICOM files.

▬ Positions of the Depth electrodes, defined in the patient coordinate system can be exported as a csv-file.

➢   **Database structure**

• Application database

All imported datasets and patient information are saved in the application database. When importing data, the application saves a copy of the dataset in the application data base. In case of a DICOM series, the data is first converted into a NIfTI file before being copied to the database. Patient and project information is also saved in the database, together with the copied datasets.

• Project file (details.proj)

The project file in each entry contains the patient information (name, ID, date of birth, etc.) as well as the project information (project ID and description). Furthermore, the project file contains a list of references to all the imported data, together with their visual settings and registration information. In case of manually created regions or detected depth electrodes, the information of the datasets is saved in the project file itself.
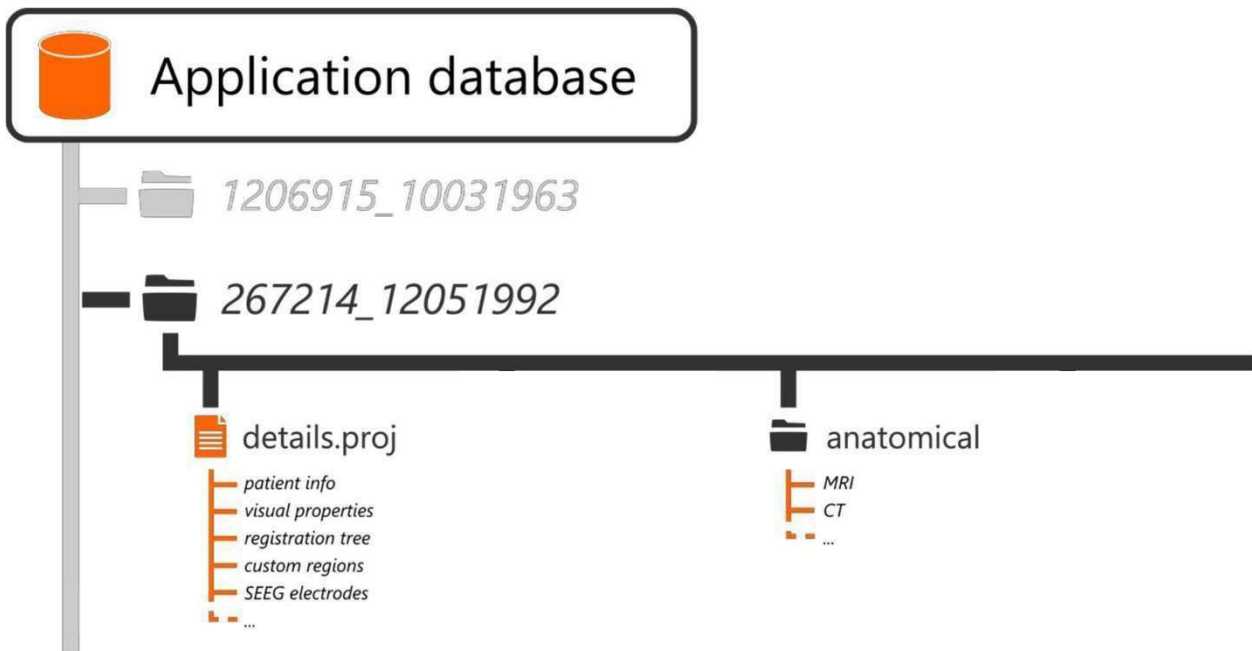

Figure 1 – Schematic overview of the application database structure.

•   Anatomical

This folder contains all the imported medical imaging datasets, such as: MRI or CT tomography volumes.

➢ User interface

The main user interface of the application is shown in Figure 2. It consists of three 2D-viewports and a 3D-viewport that visualizes the imported datasets.

Each of the three 2D-viewports shows an anatomical plane slicing the datasets with a specific orientation, providing sagittal, coronal and axial views that are commonly used in medical visualization software. The 3D-viewport shows renderings of patient-specific models, e.g. the cortex or skull or orthogonal slices of the volumes
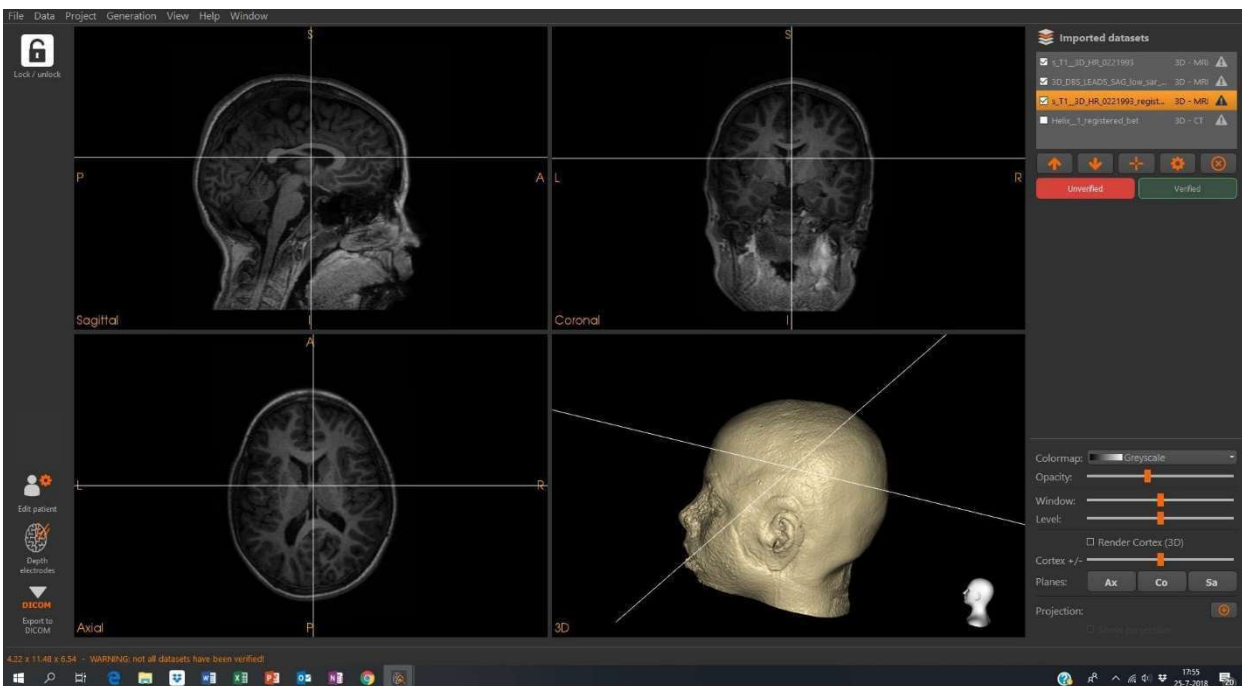
Figure 2 - Main user interface of the application, showing three 2D-viewports and a 3D-viewport (bottom right) and the supporting controls.

II Data preparation

➢ Getting started

This section describes a test scenario that includes the most important tasks during the data preparation phase, which is preceding the visualization of the depth electrodes versus the cortical anatomy. These test cases can be run with the example data in the folder 'C:\Data Depth Electrode Navigator'

The test data should contain at least the following files: the post-implant CT for depth electrode detection (mandatory), misaligned with MRI, and the preoperative and post-implant anatomical MRI (not mandatory).

➢ Choose one of the options (Figure 3):

☐ Import: Create a new project

Reads DICOM files and transfers these into NifTI format and starts with the preprocessing of the data

☐ Database: Continue with an existing project

In the Database medical data in NifTI format can be selected which are already preprocessed
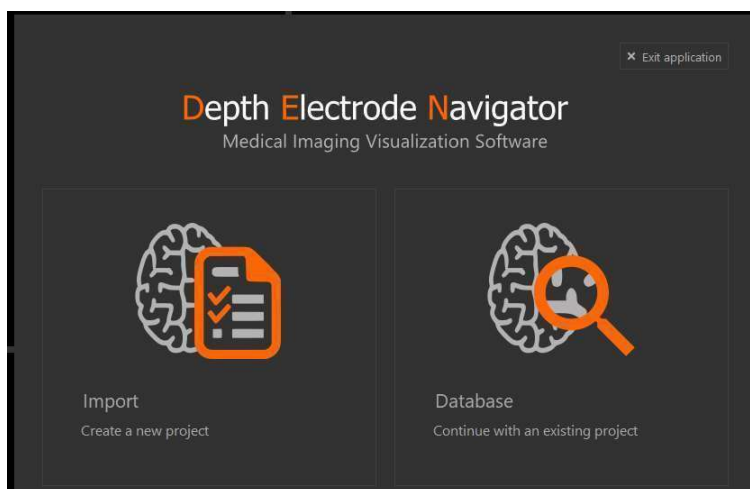
Figure 3 - Window to start the selection of medical datasets.

Locked   Unlocked

At the moment that
one of these options is
chosen the
Lock/unlock button in
the upper left corner
of the User interface
changes from locked
to unlocked.
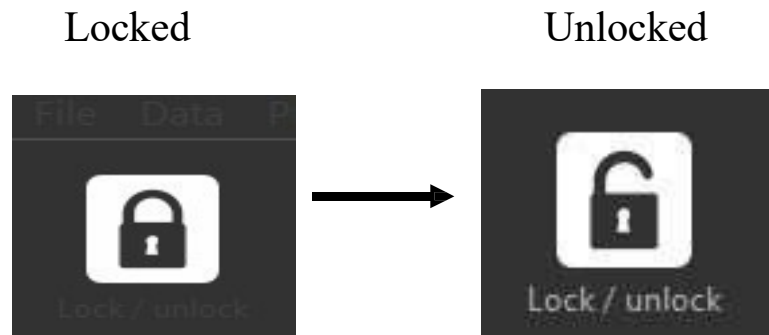
➢ **Import: Create new project**

By selecting the left option in Figure 3 the preparation of the medical data which are available in
DICOM format will be started. This opens a dialog in which the option:

< Auto-fill from DICOM> can be selected.

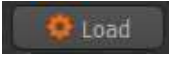□ Select the folder to import files from, e.g.

    C:<Data Depth Electrode Navigator/TestCase#>

    "After specifying a folder, the software will scan

    the folder and the patient data will be filled in

    automatically in the dialog box."
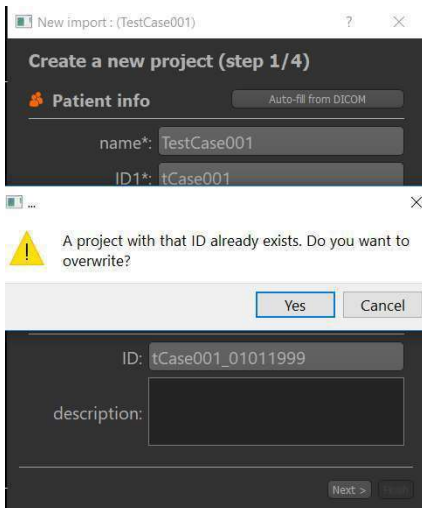
If the project file already exists you get a warning and may choose either to overwrite the file by selecting *Yes* or not by selecting *Cancel*.

"After choosing Cancel the user can edit ID1, e.g. ad a consecutive number to ID1"
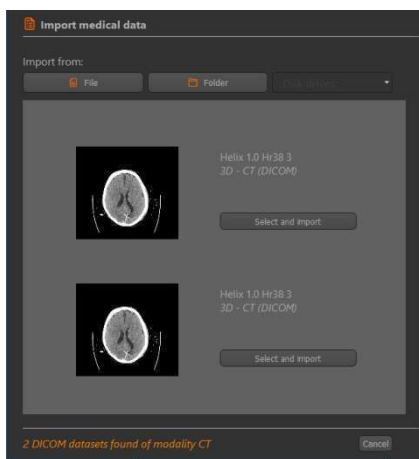
➢ By selecting Next, a dialog will be opened in which the medical datasets can be selected.

☐ Click on the Load button.

➢ The SP selects automatically the post-implant CT (which is mandatory)

☐ By selecting Next, a dialog will be opened in which the post- implant CT can be selected.

☐ Import (one of) the datasets by clicking Select and import.
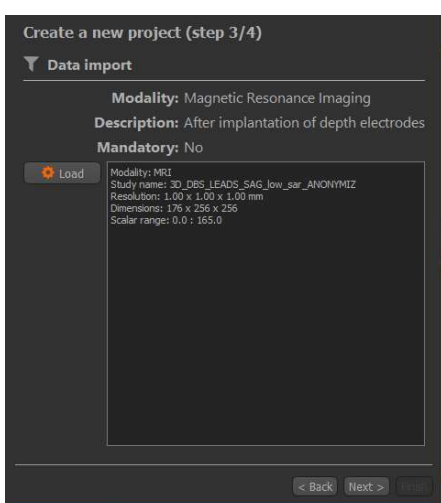
➢ By selecting Next, a dialog will be opened in which, subsequently the pre- and post-implant MRI can be selected (which are not mandatory).

☐ Click on the Load button

"The SP selects automatically the available MRI data"
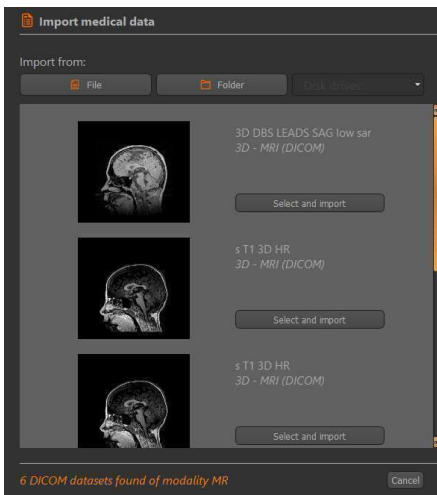
> ➢ Import (one of) the datasets by clicking Select and import "When neither of these datasets are available the following warning will be shown in the status bar at the bottom of the interface: "The user is unable to verify the left-right correctness""
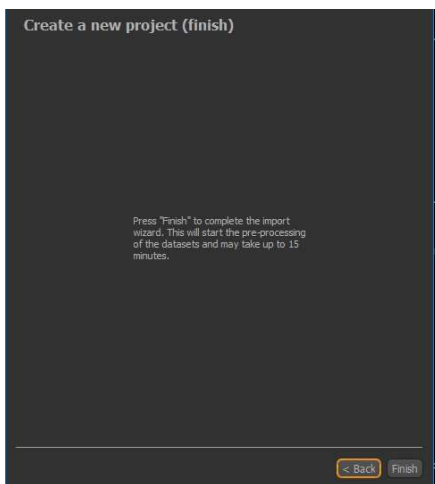
☐ By selecting Next, the left dialog box appears.

☐ Press the button Finish and the SP starts immediately the pre-processing of the medical data.

- **The following preprocessing steps are performed in chronological order:**

☐ The SP starts automatically Volume alignment (patient-based).

  • Co-registration of MRI pre- and/or post-implant datasets
 • Co-registration of MRI pre- and CT post-implant dataset

☐ The SP starts automatically Brain extraction, with:

  - Removal of cables in the CT datasets.
  - Brain extraction of the post-implant MRI
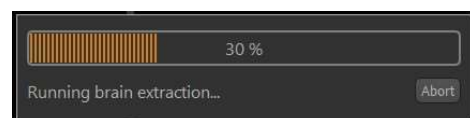
□   After preprocessing three medical datasets are available:

- the brain extracted CT;
- the brain extracted post-implant MRI;
- the pre-implant MRI

□   The main user interface after preprocessing is shown in Figure 4coms up, showing three 2D-viewports and a 3D-viewport (bottom right) and the supporting controls.

- Data overview
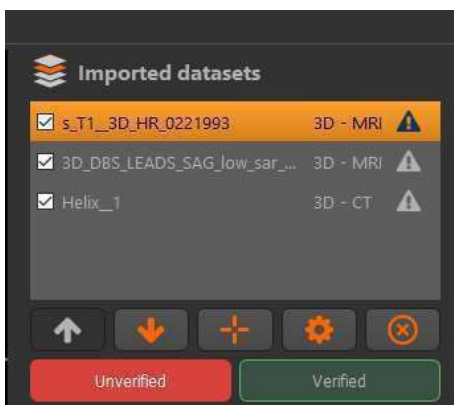
▪   The panel in the top-right corner of the interface displays a list of selectable datasets that can be added or removedfrom the current visualization. The overview also displays the data type and status of each dataset.

▪   The buttons below the list can be used (f r o m l e f t t o r i g h t) to re-order the currently selected dataset (arrow up and down), select plus to select the center of gravity of the selected dataset, wheel to edit the currently selected dataset and x to remove the selected dataset. Reordering the datasets will reorder their visualizations in the viewports accordingly.
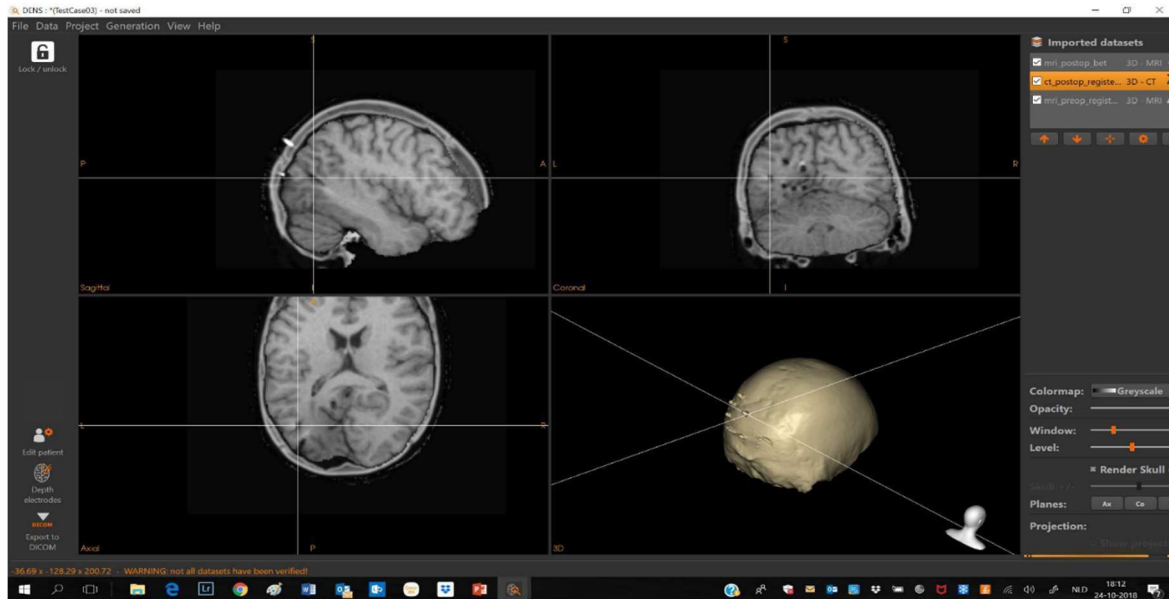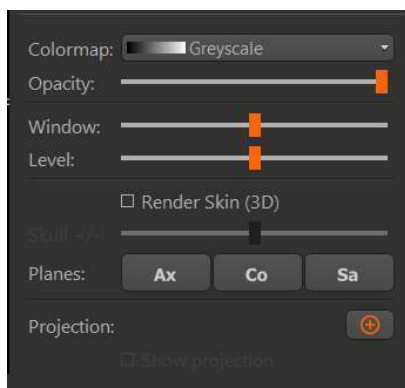
Figure 4 The main user interface after preprocessing, showing three 2D-viewports and a 3D-viewport (bottom right) and the supporting controls.

- Visual settings

The panel in the bottom-right corner of the interface contains the visualization settings for the currently selected dataset. Specific settings are available for each type of dataset. For more details, see Chapter III Data Visualization on page 21.

- Status bar

The status bar at the bottom of the interface is used to display the current position in the 2D-viewports, together with messages to the user, i.e when not all currently loaded datasets are verified, a warning will be shown in the status bar at the bottom of the interface.

> ➢ Database: continue an existing project

☐ By selecting the right option in Figure 3 "**Database Continue with an existing project**" a dialog will appear with a list of existing projects.
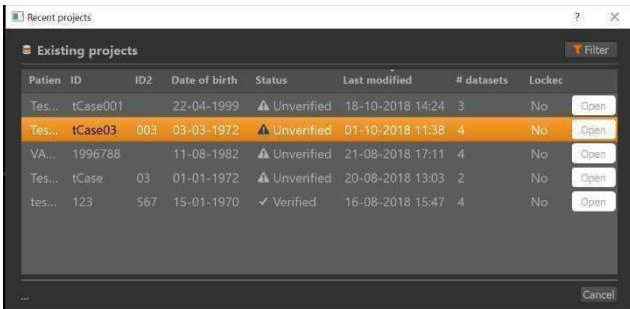

☐ Select the project that you want to open and Click on <Open>

"The imported datasets will be listed in the panel in the top-right corner of the user interface (see Figure 2)."

> ➢ Labelling a dataset as verified

Labelling a dataset as verified indicates to the software and other users that this dataset is correct and can safely be used in further steps of the application.

Things to check include:

- Sufficient image quality
- Absence of artefacts
- Left-right correctness
- Correct type (MRI or CT) of the dataset
- Correct label of the dataset
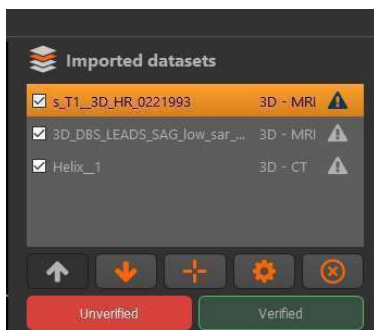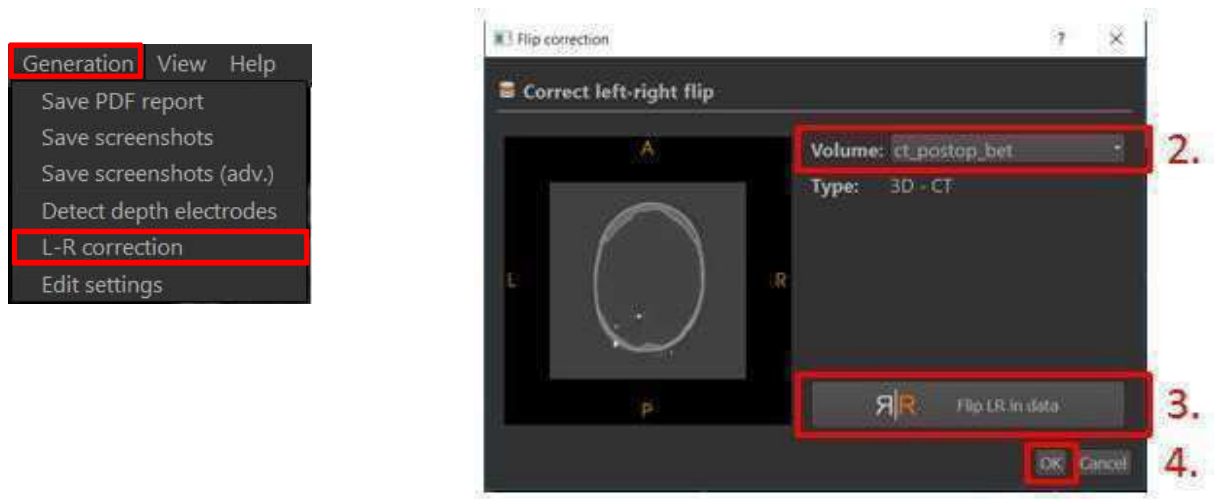

1. Select the dataset.

2. Click on Verify.

   Note that the icon next to the selected dataset will change depending on its status.

14

➢ Correcting a left-right flip in a dataset

When working with NIfTI datasets, the correctness of left and right is not guaranteed and must be verified. When these datasets are flipped with respect to left and right, this has to be corrected before continuing to other steps. Important: use the pre-implant MRI imported as DICOM for the L-R correction.
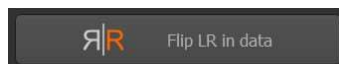
1. Menu bar □□Generation □□L-R correction.
   "A dialog will appear."
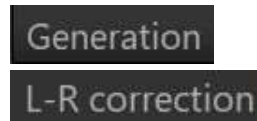
2. Select the volume for correction.

3. Click on the flip button.
   *"The thumbnail on the left will be updated."*

4. Press Ok.
   "The software will now create a flipped version of the selected dataset."

"After the correction, the newly created, flipped volume will be saved in the application database. After saving the file, the application will import the new, flipped volume and remove the old version from the application."

➢ Changing the label of a dataset

The label of an imported dataset is set by default to its filename. It is recommended to change this to a more readable name.
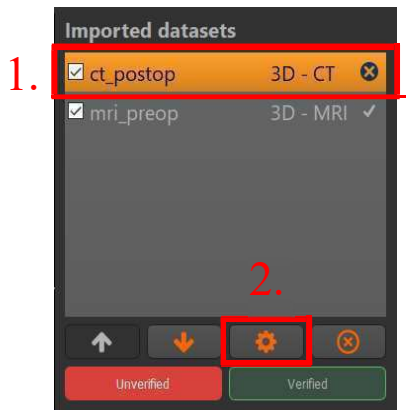
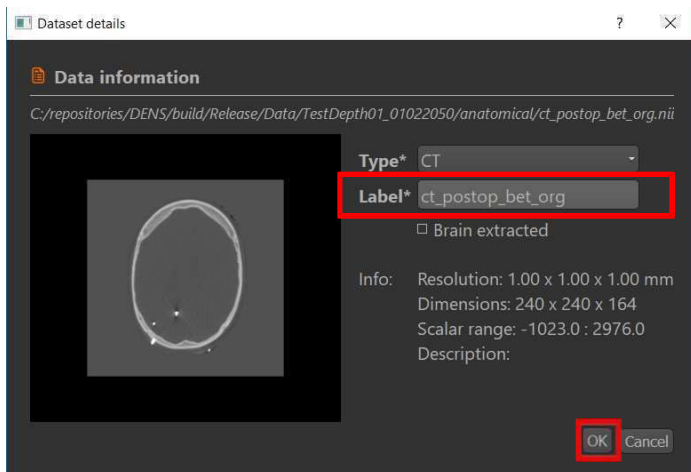1. Select the dataset.

2. Click on the Rename button.

3. Provide a new label.

   "Note that the label has to be unique: no other datasets can have the same label. Special characters are not allowed (!@#$%^&()_+-=`~)."*

4. Click Ok.

   "The label of the selected dataset will be updated in the overview."

➢ Changing the modality of a dataset

The type of 3D rendering that can be generated from a 3D- scan depends on its modality. Two options are supported: CT and MRI. The value for brain-extractedness can be set for only the CT and MRI volumes.

1. Select the dataset.

2. Click on the Edit button.

   1. Provide a newmodality. *"Two options are supported: CT and MRI"*
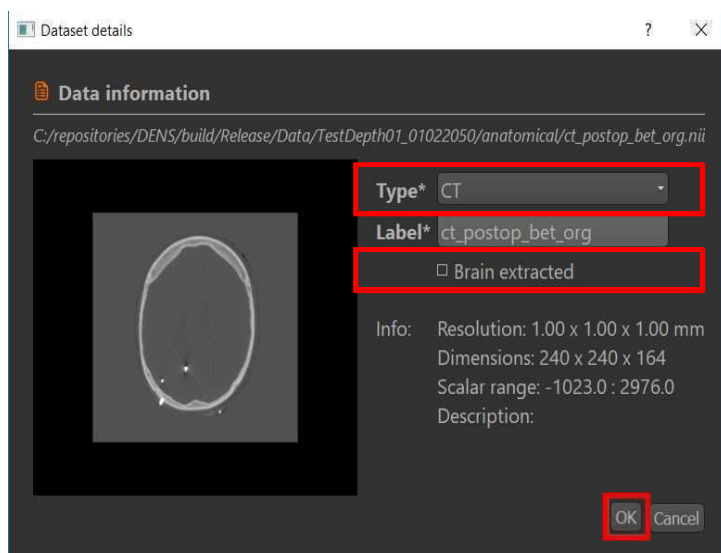
2. Provide a new value for brain-extractedness.

   "This can only be set for MRI or CT Volumes."

3. Click Ok.

   "The type of the selected dataset will be updated in the overview."

➢ Depth electrode detection

Depth electrodes can be detected in post-implant CT volumes. It is recommended to perform the detection using also a brain-extracted MRI volume.

□ The toolbar on the left of the interface (s e e F i g u r e 5) provides quick navigation to the functionality of detecting depth electrodes.

"The selection of the post-op CT and brain-extracted Post-Implant MRI volume will automatically be set when only one CT and one MRI volume are imported. When the number of electrodes is set to 0, the algorithm will automatically determine the number of electrodes."

➢ As alternative, use:
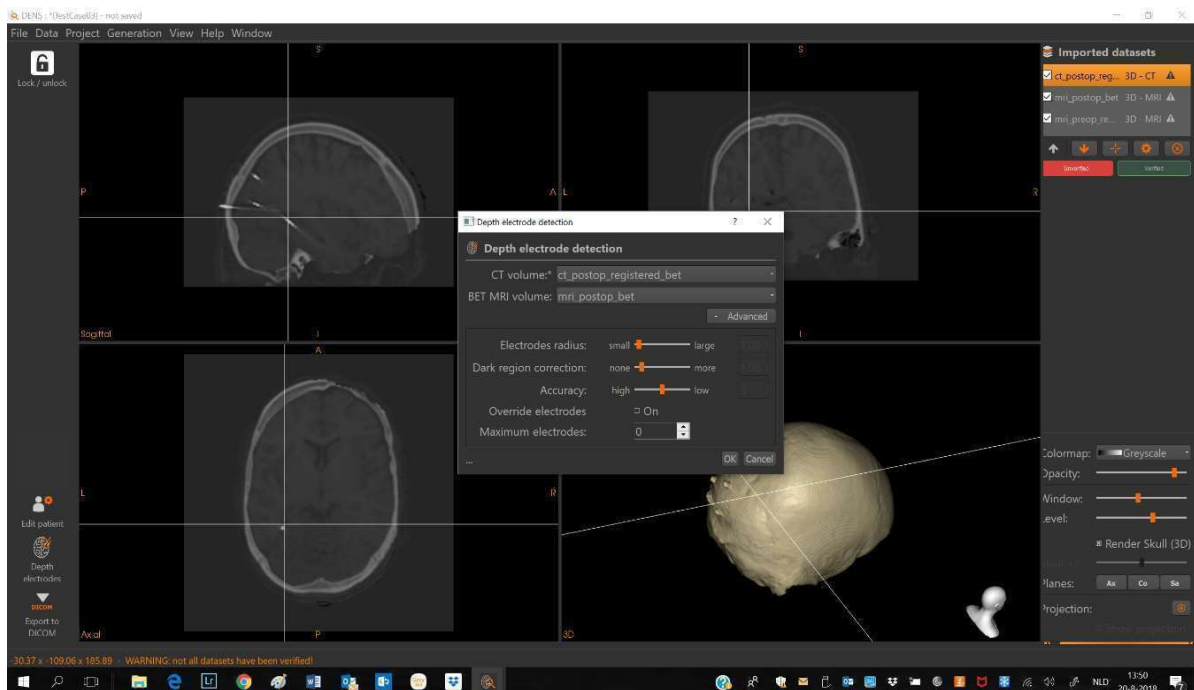1. Menu-> Generation ->Detect depthelectrodes.

Figure 5 - Window to start the detection of depth electrodes.

2. Select the post-op CT and brain-extracted MRI volume.
   "The selection will automatically be set when only one CT and one MRI volume are imported. When the number of electrodes is set to 0, the algorithm will automatically determine the number of electrodes."

O.   Optional: Specify advanced options.

"Increase of the Electrode radius *helps you to find the right number of depth electrodes"*
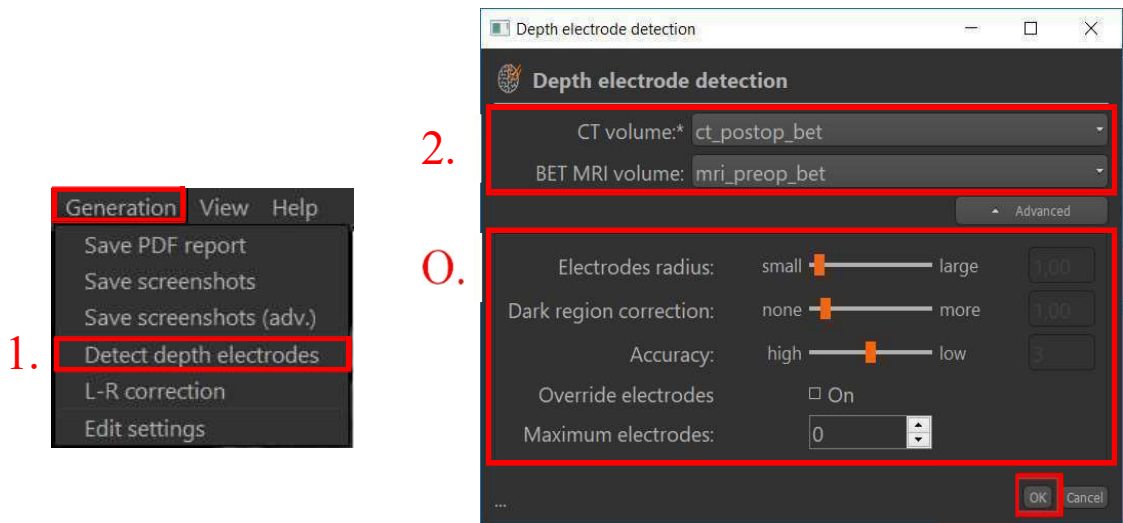
> Press Ok.

"When the depth electrode detection is finished, the electrode positions will be saved to the current project file in the local application database. If the algorithm did not detect all the electrodes in the post-implant CT, the detection can be re-run with different settings to find the remaining undetected electrodes."

Correcting depth electrode detection results

"It is possible that the electrode detection will place inaccurate or an incomplete number of depth electrodes or is unable to detect a particular electrode. This can be manually corrected or improved."
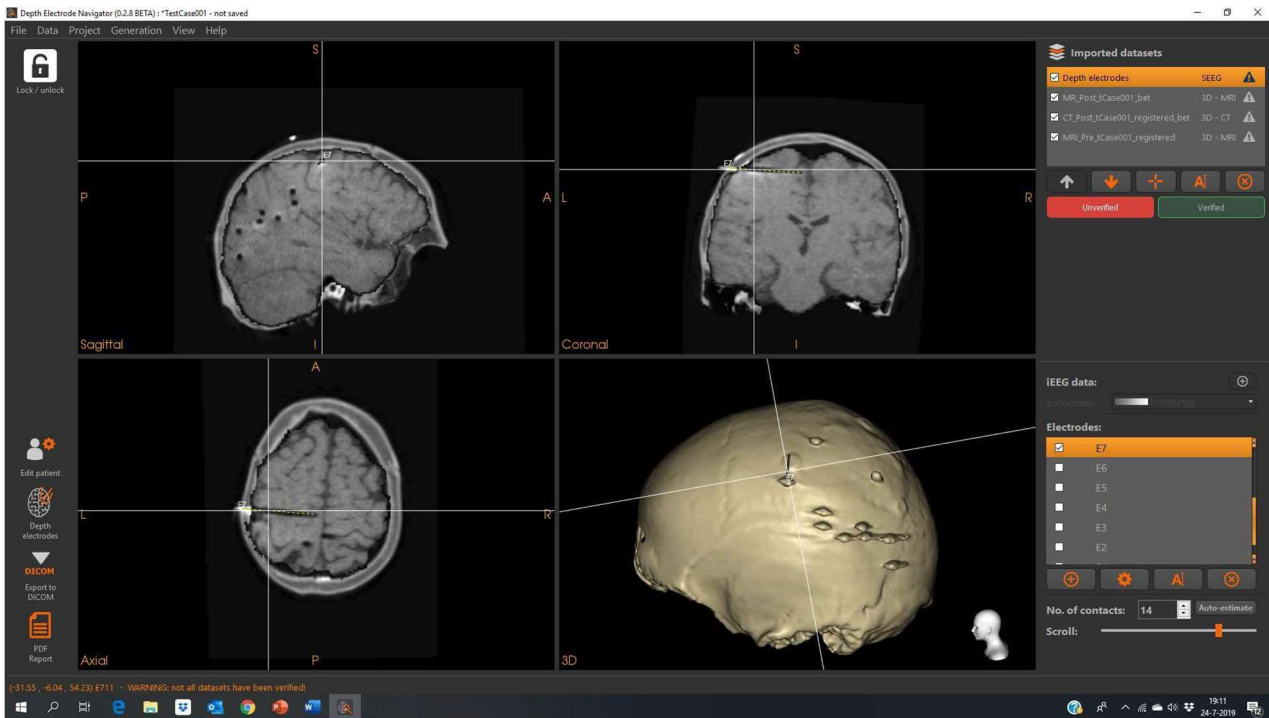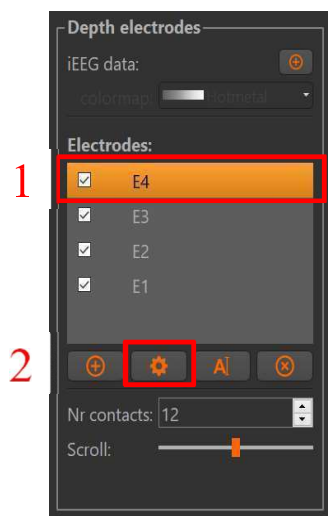
Figure 6: Display when correcting the position of the depth electrodes: The menu options for
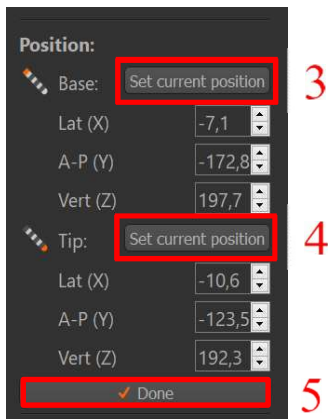depth electrode positioning and for visualization are shown.

1.   Select the incorrect electrode.

*"Double clicking on the selected electrode will toggle
between display of the selected electrodes and all the
electrodes."*

2.   Click on the Edit button.

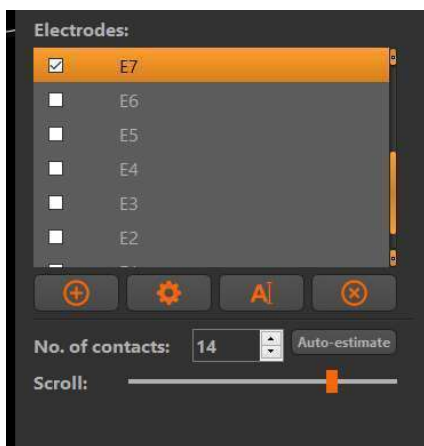*An additional frame will appear with controls for correcting the
position.*

3. Go to the correct position in the 2Dviewports.

4. Click on the Set current position button (base or tip).

Set current position

"Alternatively, the location can be manually specified in the control boxes."

5. Press "Done" to confirm the updated position

"When checking and correcting the position of the depth electrodes it is helpful to scroll along the electrodes versus the anatomy, as shown in Figure 6. Furthermore, Auto estimate the number of contact points."

☐ Add or remove depth electrodes or change the label names (see Figure below)
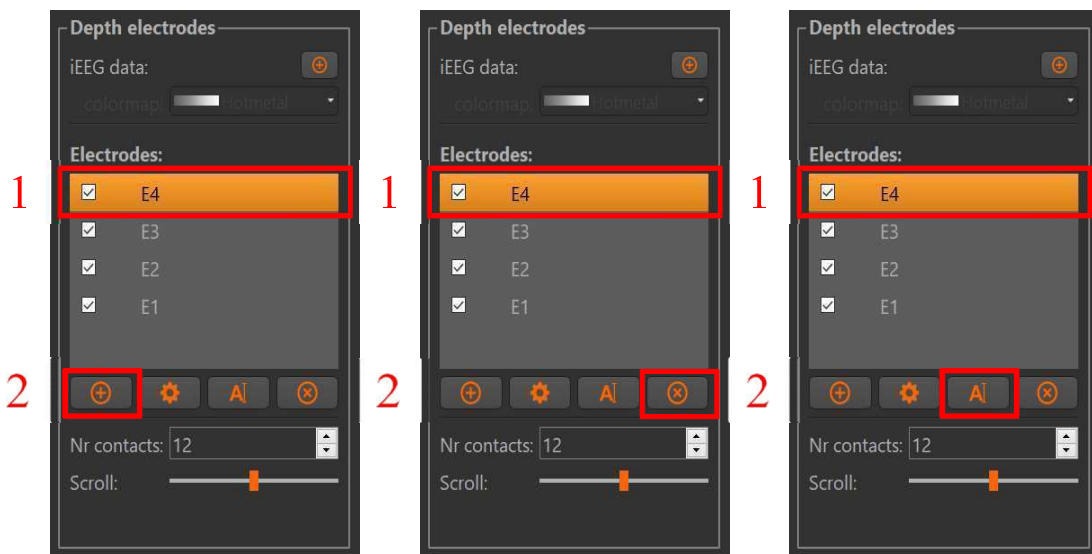
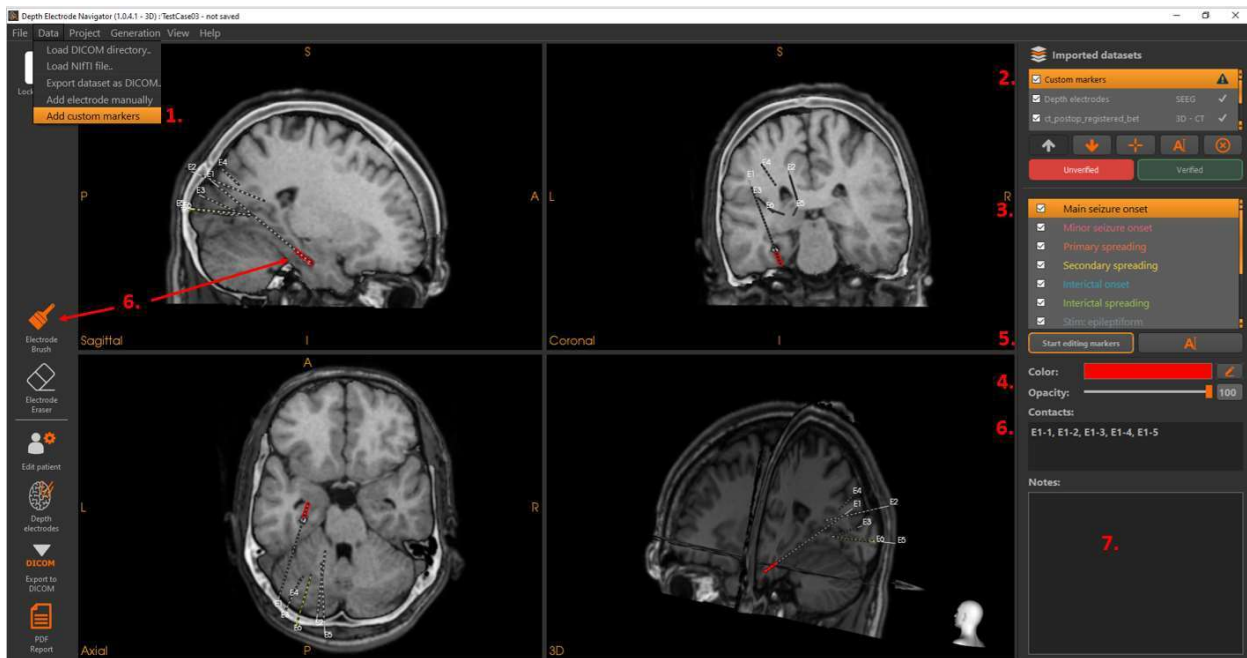➢ Add annotations to depth electrodes

Figure 7: Option I: Add annotations by searching in the 2D/3D MRI viewports for the depth
electrode to annotate.

Option I: follow in Figure 7 steps 1 to 7 to add the annotation:

1. Select the menu item <Data/Add custom markers>
2. Select in the list of datasets the dataset < Custom markers>
3. Select the category e.g. Main seizure onset.
4. Adapt if needed color or opacity
5. Select the button < Start editing markers> (is a toggle). In the left panel the buttons appear:
    Electrode brush for adding markers and Electrode erase, for erasing markers.
6. Brush the contact points of the electrode searched for in the 2D/3D MRI viewports . The names of
    the electrodes and the numbers of the contact points are listed in the right panel of the user
    interface, below the heading Contact points.
7. Add free text.

Option II: If electrodes are close or even crossing it will be difficult to mark by searching through the
2D/3D-MRI viewports the contact points of your choice. Follow in this case, the procedure as illustrated
in Figure 8:

1. Select the dataset <Electrodes> and select the electrode to be annotated, e.g. E3 as indicated in
    Figure 8 and scroll to the contact point.
2. Select the dataset < Custom markers> and follow the steps in Figure 8.
3. Select the category e.g. Stim: Motor (i.e. response to motor stimulation) and change the label to
    Stim:Visual.

4. Select the button < Start editing markers> and brush the contact points of E3.

5. Add free text.

6. If you are ready: verify the dataset <Custom markers> and press <Stop editing markers>

7. Create a pdf (patient) report, which contains apart from the pat identification, the listing of the brushed markers plus free text and a print screen of the 2D/3D-MRI viewport.

Figure 8: Option II: Add annotations after selecting the electrode and contact point of your choice.

III Data visualization

➢ Anatomical data

When multiple datasets have been loaded, they can be visualized together in a multi-modal visualization. This task requires that the datasets have been pre-processed and verified. This section describes the different visualizations options and settings for 3D volume anatomical datasets.

1.   Show an anatomical dataset by turning the dataset on in the overview.

Slices through the datasets are shown in the 2D viewports. Volume datasets are visualized in the 3D viewport by a 3D rendering and/or anatomical planes.
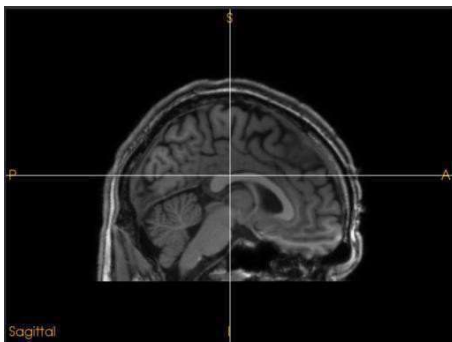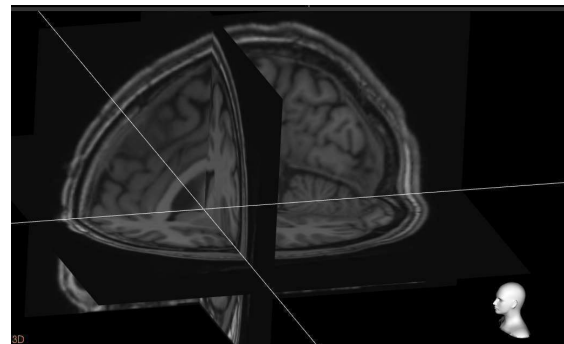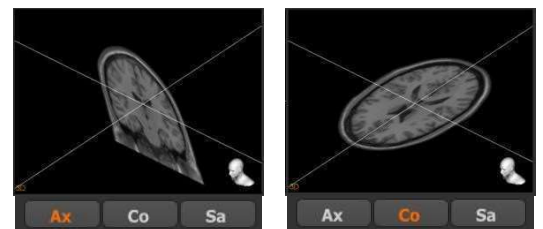

| 2D visualization | 3D visualization |

Planes

Shows or hides a splice plane in the 3D viewport. A plane can be shown for each anatomical direction: axial, coronal and sagittal. When depth electrodes have been imported, an additional option is available that shows a slice orthogonal to the currently selected electrode.


2.   Adjust the visual settings of the anatomical datasets. The panel in the bottom-right corner of the interface contains the visualization settings for the currently selected dataset. Specific settings are available for each
type of dataset. Some of the visualization options depend on the modality of the dataset.
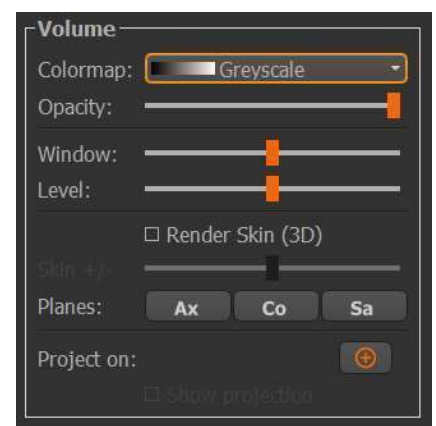
Color

Changes the color mapping of the values in the dataset. When a Colormap starts from black, the lowest intensity will be set to transparent.
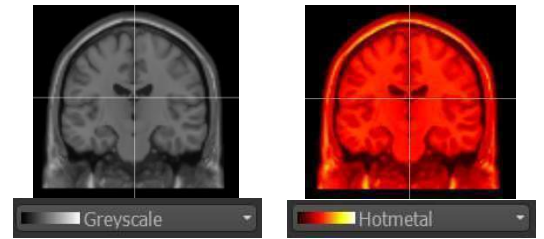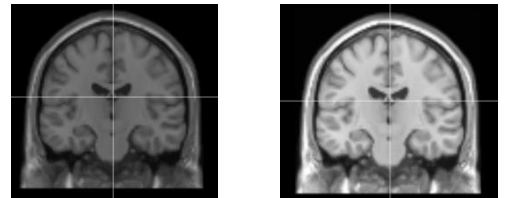
Opacity

Changes the transparency or opacity of the dataset. A value of 100% means no transparency. This setting affects all the visuals of the dataset, including its 3D renderings.
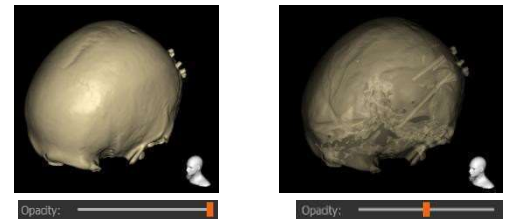
Window, Level

Changes the contrast and saturation of the dataset. Indirectly changes the values used in the color mapping.
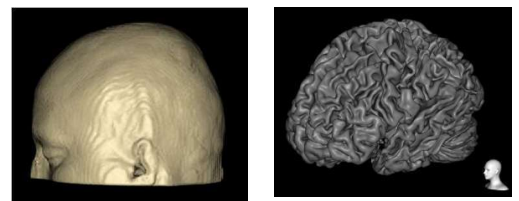
□ Depending on the selected medical dataset, different rendering options will be available:

-        CT: skin   rendering
-        MRI: skin   rendering
-        MRI (brain extracted):   brain cortex rendering
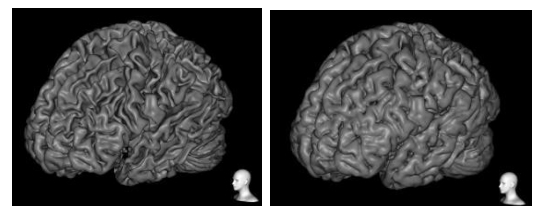
Render 3D (Skin, Cortex)

Shows or hides the 3D rendering of the dataset. The type of 3D rendering depends on the modality of the dataset:

- Skin (CT, MRI)
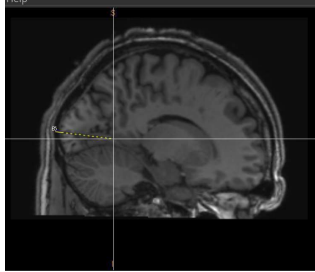- Cortex (brain-extracted MRI)

Render +/- (Cortex)

Increases or decreases the size of the 3D rendering. This is only available for the Cortex renderings and can be set to include more or fewer cortex structures.
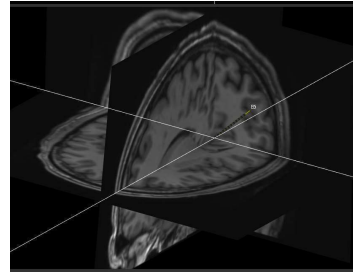
➢ Depth Electrodes

This section describes the different visualization options and settings for depth electrodes.

2D visualization   3D visualization

Depth electrodes are visualized as a straight line containing a number of contacts. This visualization is shown in all four viewports similarly.

After the automatic detection of the depth electrodes these can be visualized relative to the anatomy provided by the pre-implant MRI in the 2D- and 3D MRI viewport, as shown in Figure 9.
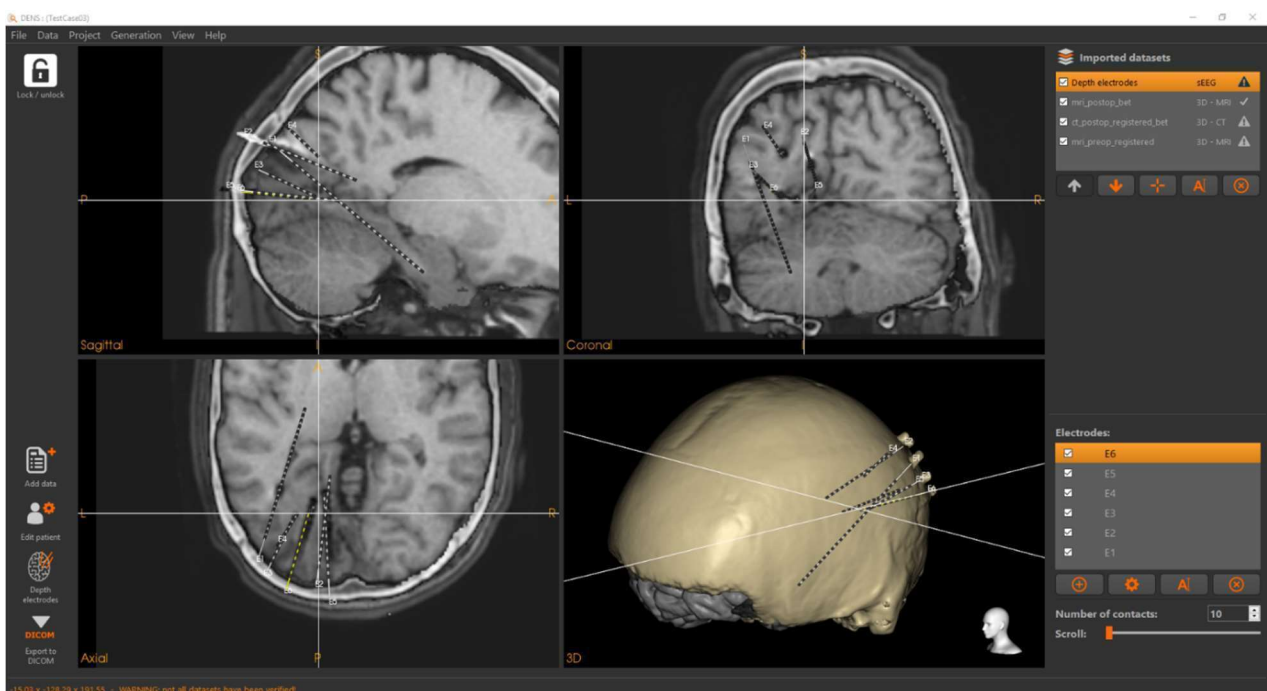

Figure 9: Display of depth electrodes in the 2D- and 3D viewports.

Or if there is no post-implantation MRI available, check the positions of the depth electrodes using the CT-scan, while the targeting of the depth electrodes can be checked by the perpendicular projection of the depth electrodes on the anatomical MRI, as shown in Figure 10, bottom right quadrant.
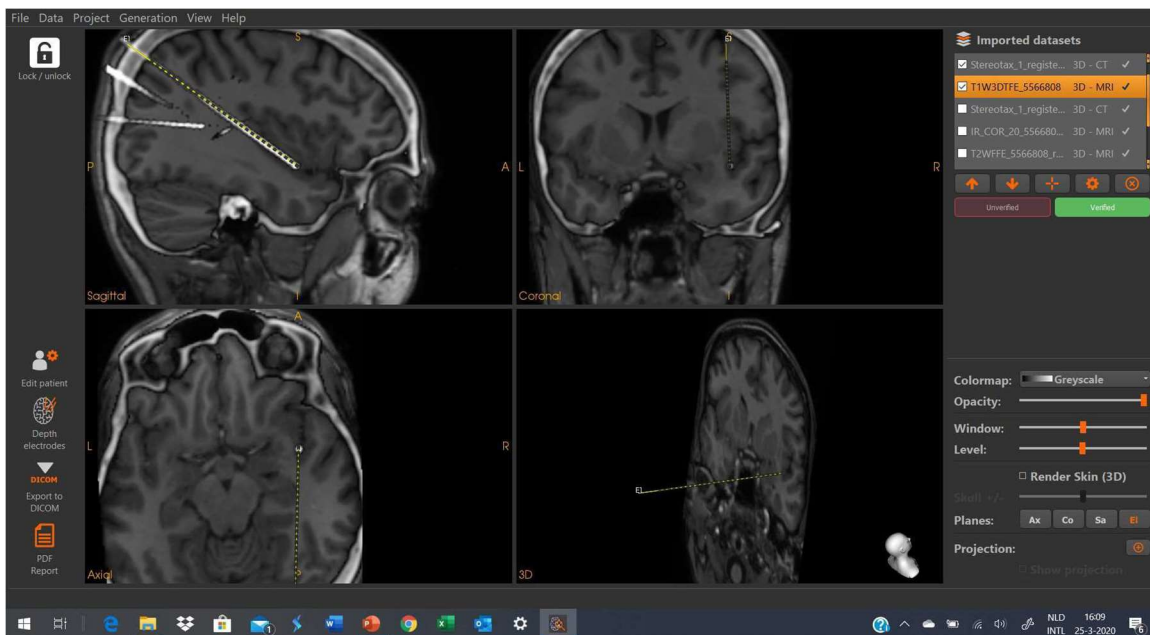
Figure 10: Display of a selected depth electrode shown with the CT, and in the bottom right corner perpendicular to the anatomical MRI slice.

IV Output of the software

➢ Data output

▬ Report in pdf format, containing patient data and screen dumps of the visualizations in the 2D and 3D viewports 3D data created in the application can be the SP uses internally

▬ Medical data in DICOM format, imported NIfTI volumes can be exported as DICOM files.

▬ Positions of the Depth electrodes, defined in the patient coordinate system can be exported as a csv-file.

➢ Patient report as pdf-file
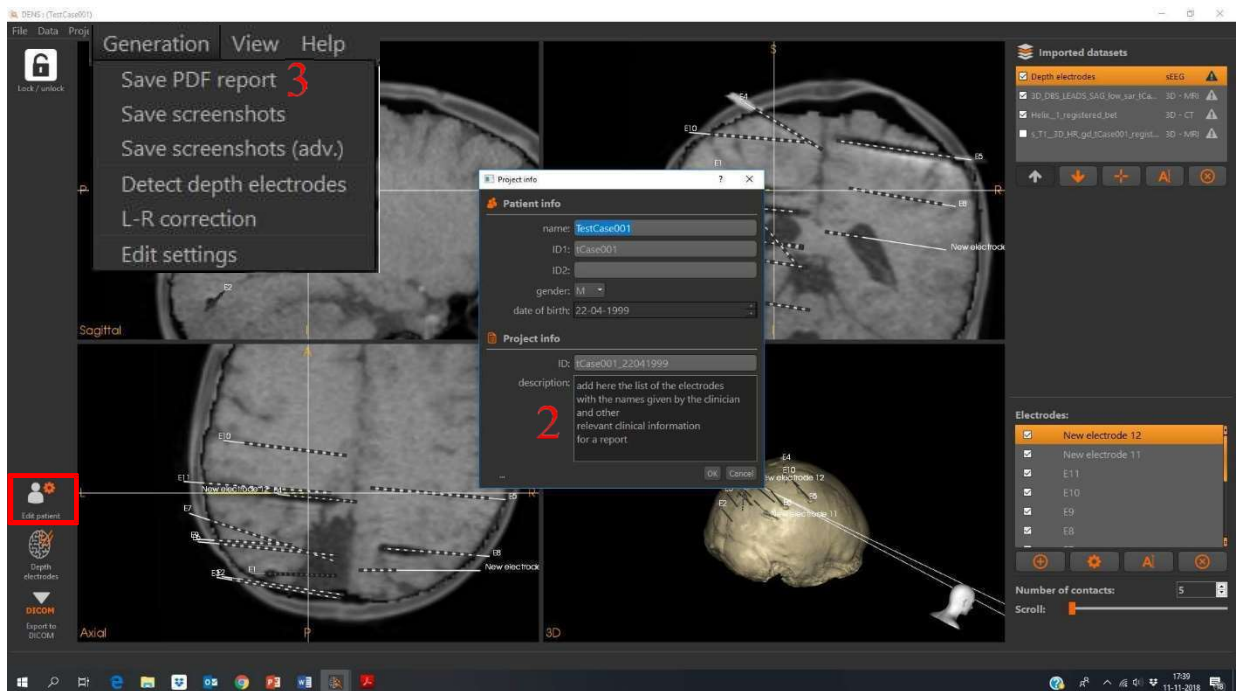
3. Click "Edit patient"
4. Add description of the depth electrodes
5. Menu-> Generation ->Save pdf report

➢ Exporting volumes as DICOM

"*Three dimensional volumes can be exported as DICOM files.*"

▢ The toolbar on the left of the interface provides quick navigation to the feature for export of DICOM files.
▢ Click on Export to DICOM.

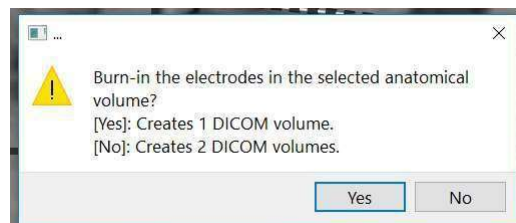▢ Select the depth electrodes for export
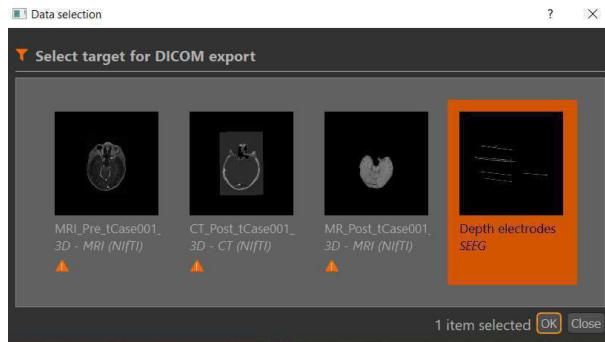
☐ Click Ok and select in the pop/up window an output directory

☐ Select the volumes for export.

"For some volume datasets, a conversion of values is needed in order to export the data as DICOM format. In these cases, a warning will appear indicating the values will be converted."
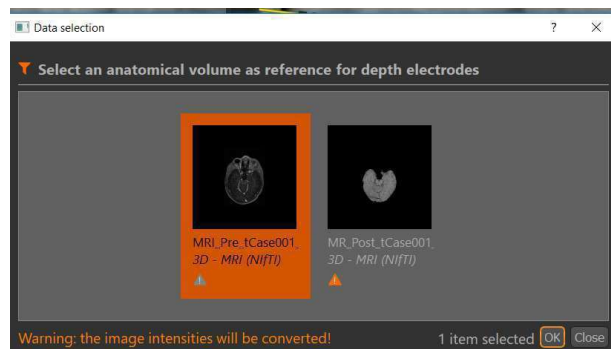
☐ Click Ok and select in the pop/up window one of the options:

- Yes: a DICOM is created with the electrodes burned into the MRI
- No: two DICOMS are created, one with the MRI and the other with the depth electrodes, thus enabling the overlay of the electrodes.

"The DICOM files will be exported while their volumes will stay aligned after export."

V Integrate MIND and DENS

MIND is developed to bring all medical imaging datasets into the same coordinate system using rigid body re-alignment (Figure 11).
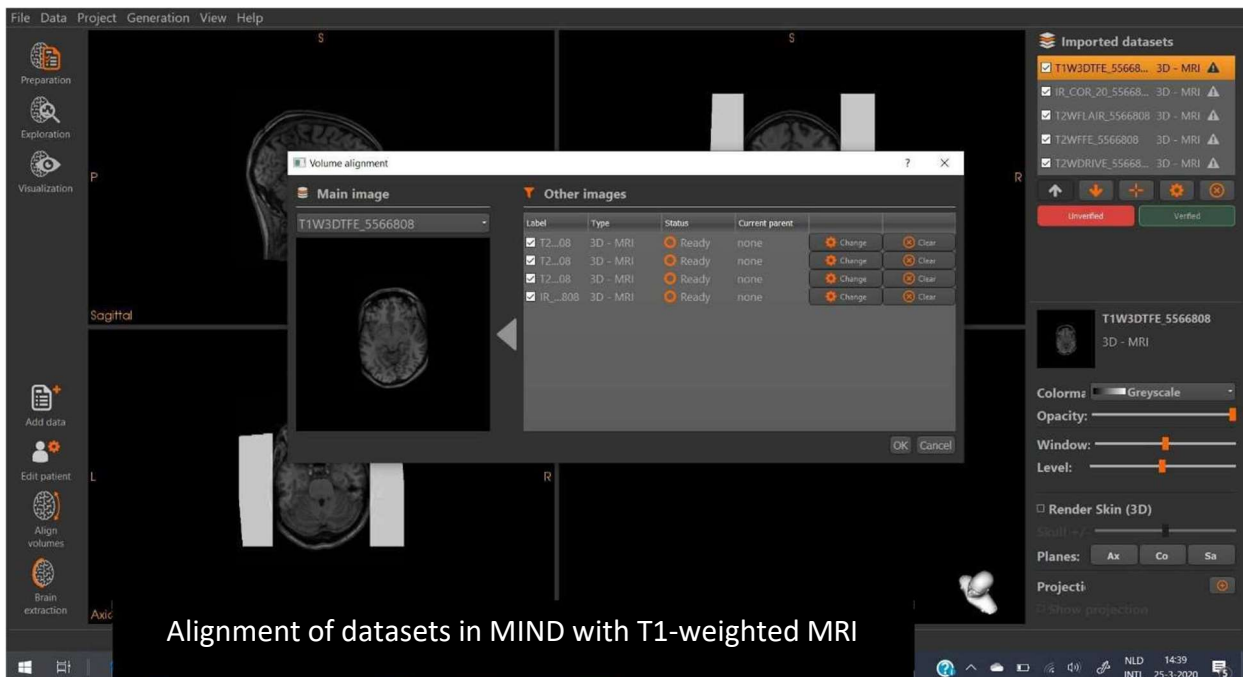

Alignment of datasets in MIND with T1-weighted MRI

Figure 11 The medical imaging datasets imported in MIND (listed here at the right in the pop=up window 'volume alignment') are aligned with the main image, commonly the T1-weighted anatomical MRI (left in the pop-up window).

➢ Integrate in MIND the post-implantation datasets

For integrating the medical imaging datasets in MIND with the post-implantation data of the depth electrodes follow the next steps.

1. Import the post-implantation CT and if available the post-implantation MRI (Figure 12).
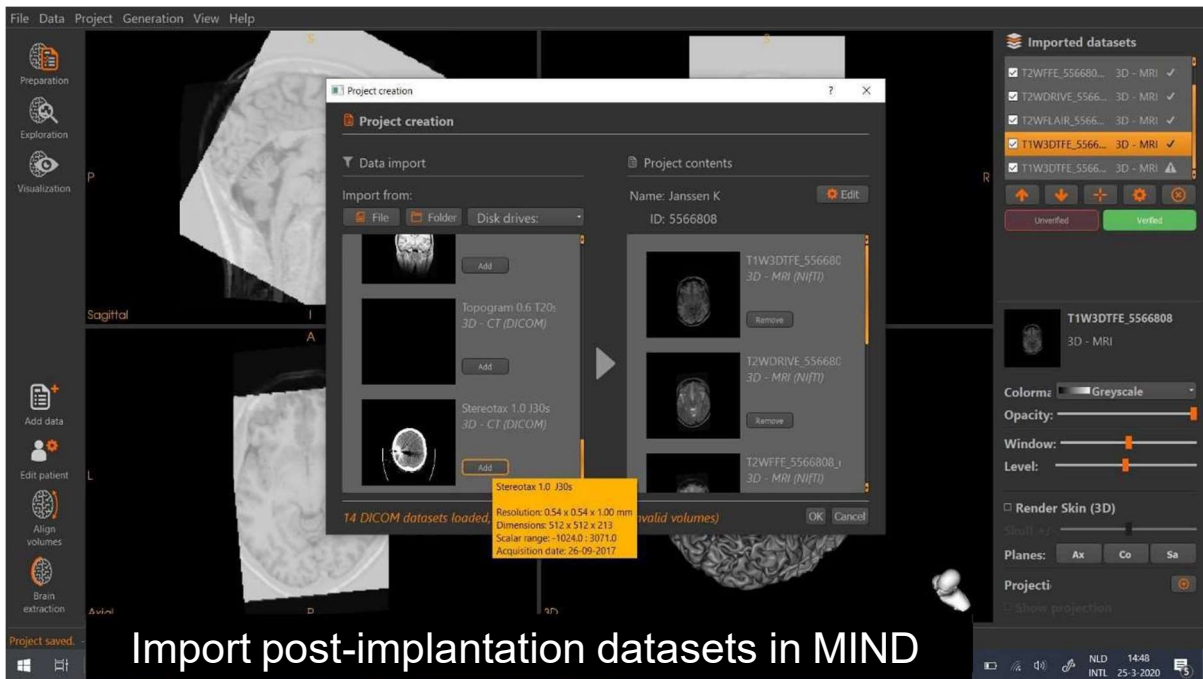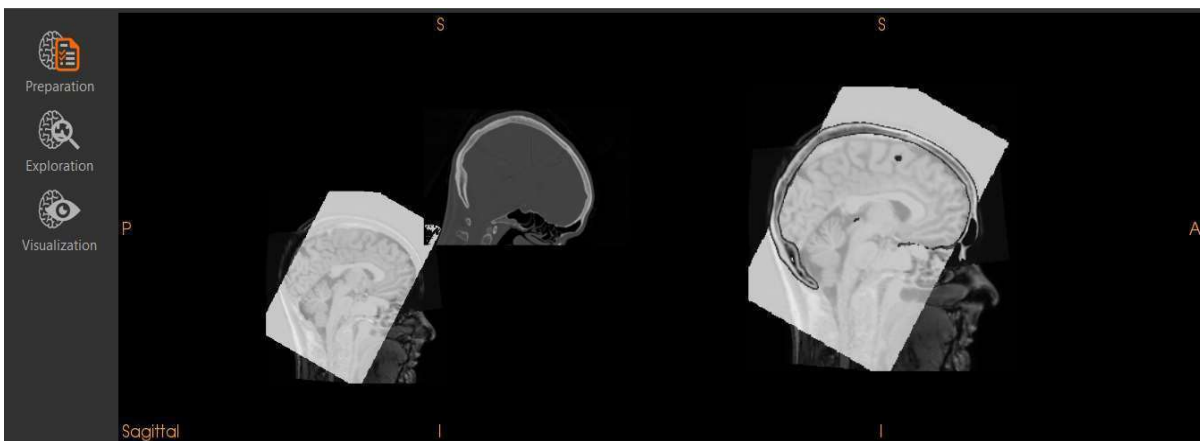
Figure 12 Import post-implantation CT and (if available) post-implantation MRI in MIND.

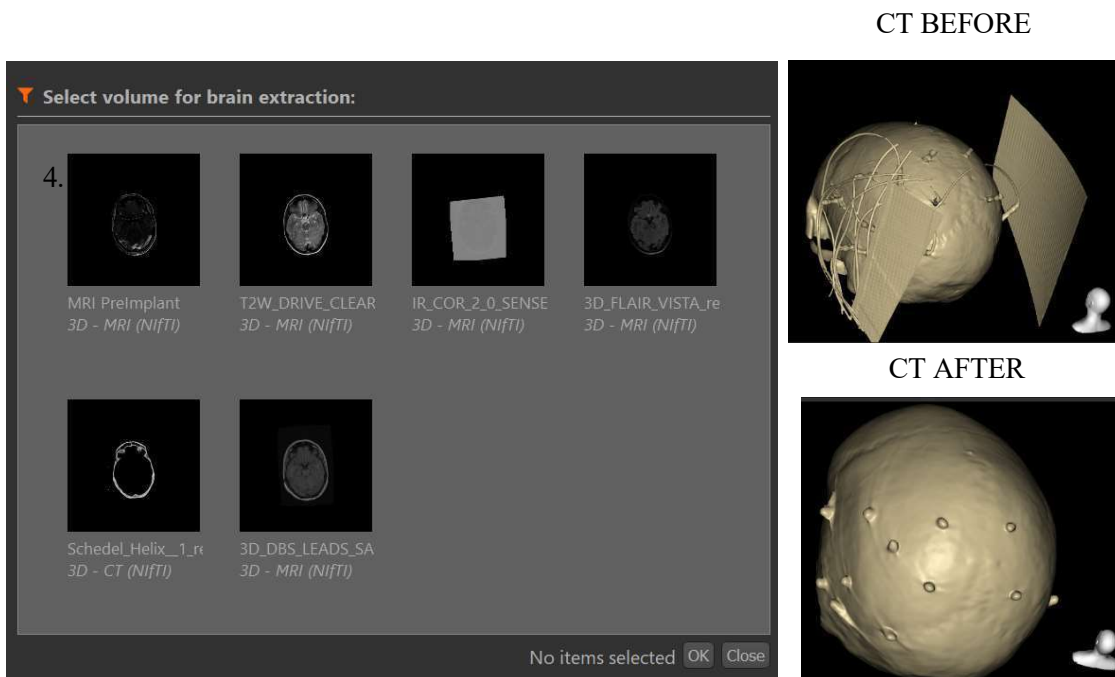2.   Re-align the post-implantation CT and (if available) the post-implantation MRI with the main image.

BEFORE   AFTER

3.   Perform a brain extraction of the CT and the post-implantation MRI.

CT BEFORE

CT AFTER

4.   Save project file in MIND

> ➢ Detect the depth electrodes in DENS

The project file which was created in MIND can be opened in DENS choosing " Database Continue with an existing project"

To detect the depth electrodes in DENS and visualise them together with the imaging datasets of the patient follow the next steps.

1. Detect the positions of the depth electrodes (Figure 13) as explained at page 17-18 of this manual.

2. Edit the number (add or delete) and the position of the detected electrodes and the number of contact points (Figure 14), as explained at page 18-20 of this manual.
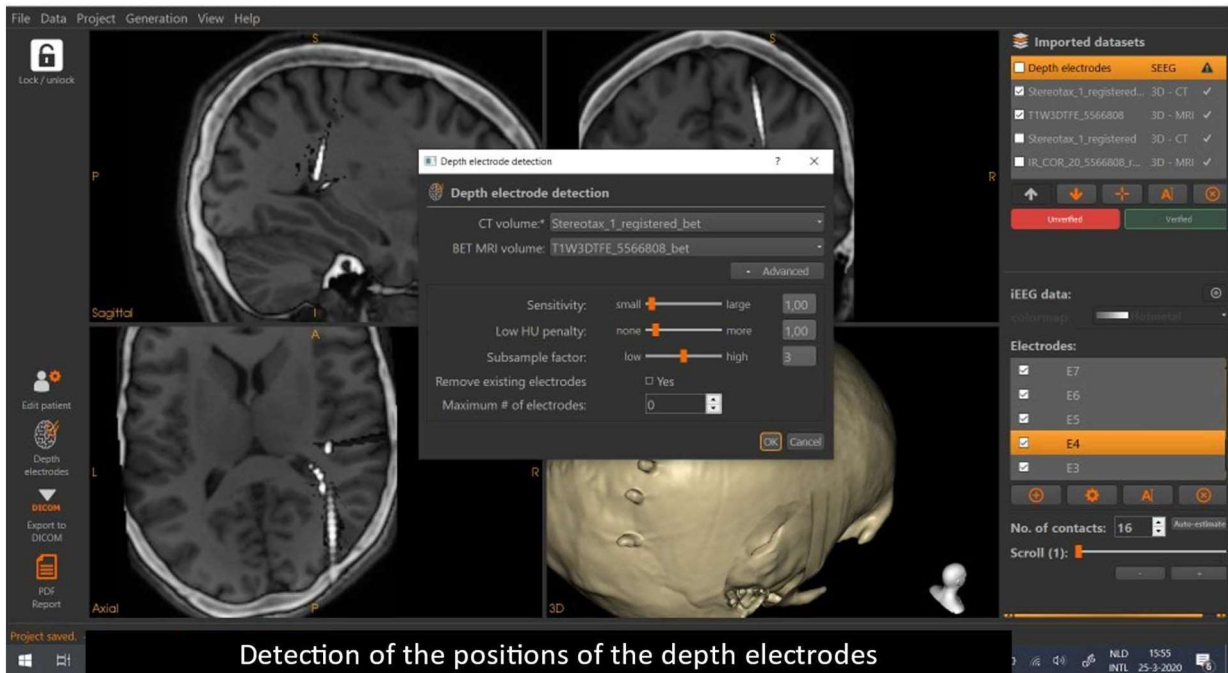
Figure 13 Select in the pop-up window " Depth electrode detection" the CT volume and a BET
MRI volume (if available the BET of the post-implantation MRI or the BET of the pre-
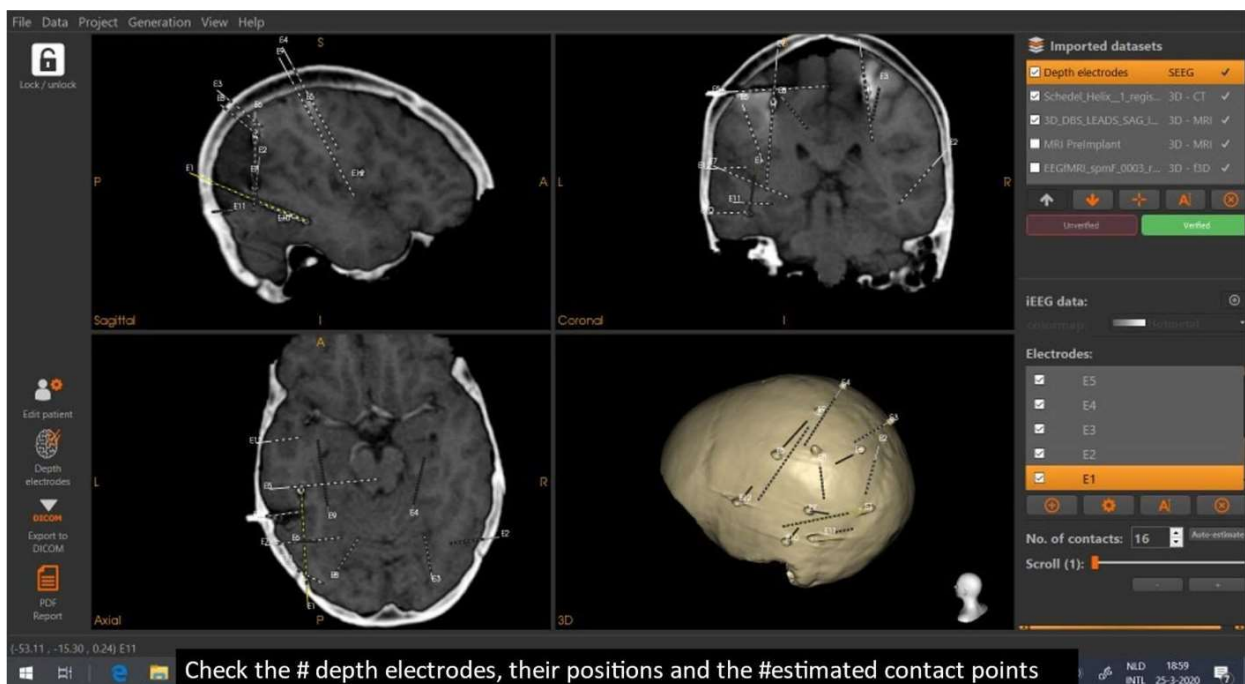implantation MRI) and choose detection parameters.

Figure 14 Select in the upper right column the dataset ' Depth electrodes' and edit in the lower
part of the right column underneath the list of 'Electrodes' (from left to right) the symbol for
adding, editing positions, editing labels and for deleting.

Visualisation: VIEWER

The project file created with DENS can be imported by the viewer software (VIEWER). In the viewer software the user has the same functionality for visualizing the medical imaging datasets as in DENS (Figure 15). The intended use of the viewer software is that multiple users are able to edit and visualise the content of a prepared project. For example, technical staff prepares a project, including the pre-processing, electrode detection and creating a custom markers file. The clinical neurophysiologist who is reviewing the SEEG recordings may subsequently edit in VIEWER the positions of the depth electrodes, as explained in paragraph 'Correcting depth electrode detection results' (page 19), change the labels of the depth electrodes etc. and add or remove custom markers, as explained in the paragraph 'Add annotations to depth electrodes' (page 22). The VIEWER software also allows to create as output of the project DICOM files and a patient report, as explained in the section < IV Output of the software> (page 27-30).
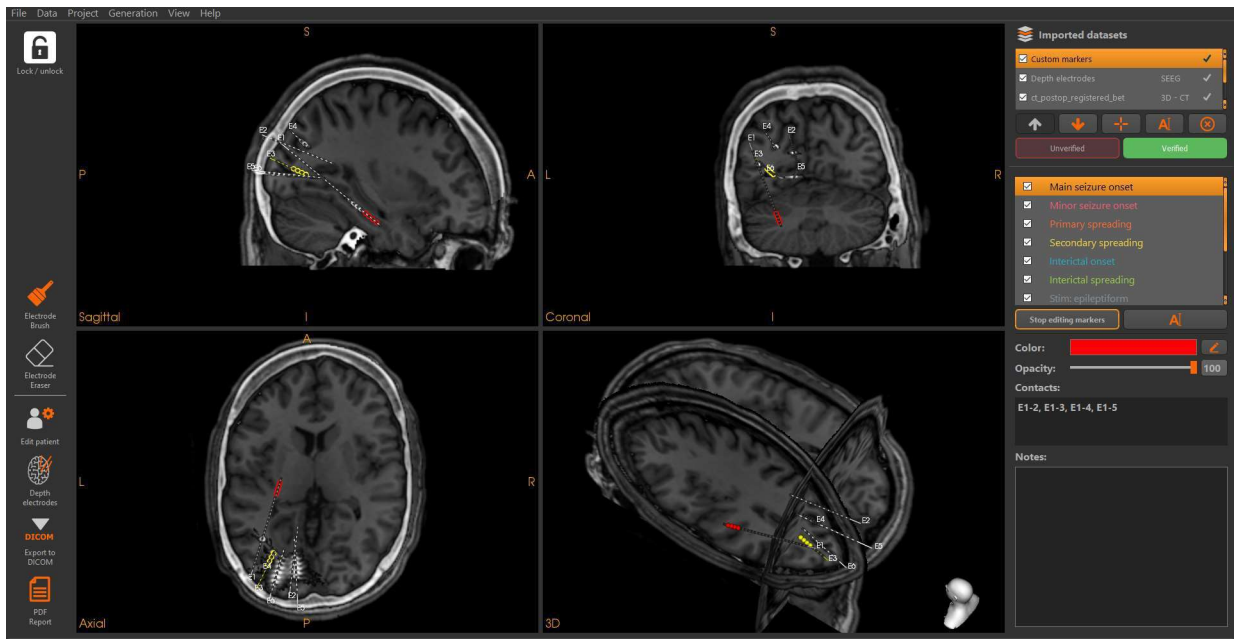
Figure 15 – User interface of VIEWER with the results of a prepared project, including the depth electrodes and custom markers, ready to be edited by the clinician.