Software support for a new stereotaxic frame

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Abstract: - It has been conceived and designed a stereotaxic frame, which is characterized for being particularly light, dismissible, comfortable portability, that is, it settles in the zone of the skull that has been chosen to access to the brain lesions. The support system assists the neurosurgeon, who will introduce the parameters of the frame. There is also another system to verify the precision reached, to guaranty that the processes is consistent with the planning previously made by the surgeon.
An image 3D is made with the base of the frame fixed to the skull, and then the neurosurgeon plans the procedure. Nine fiducial points allows relating both referential systems – the 3D image and the frame –. These points are set in a way that the identification can be assisted. For the planning, the software shows different 3D image cuts to help the surgeon to locate the lesion and to determine the direction of entry of the instrument. Then, the system calculates the 5 parameters that allow the surgical instrument to reach the lesion after traveling the way chosen by the neurosurgeon. The software includes other functionalities.
These tools have been developed in order to facilitate the diagnosis of cerebral lesions and the planning of diverse invasive proceedings like biopsies, surgical interventions, etc. This development is also useful for training and as a didactic support for students and neurosurgery residents. It consists, essentially, in the possibility of visualizing virtual sections, in any desired angle, of a 3D image (RMN, TM, etc), including or not the Brain Atlas, and the surgical instrument position, -and/or its trajectory-, in many different ways.

Key-Words: - Stereotaxic frame; 3D Image; Brain Atlas; Stereotaxic neurosurgery, Images's registration. Neuronavigator.

1 Introduction

Software, support of a new stereotaxic frame has been developed. It allows accessing to the inner brain lesions with precision and efficiently. This stereotaxic brain has been conceived and designed recently.

As it is known, this kind of device allows performing different types of treatments in stereotaxic conditions. Once the 3D image is shooting, the developed software enables the display of fiducial points, in order to identify them, this transaction can be assisted. Then the I3D referential and the frame referential can be related.

Careful preoperative planning for the neurosurgery is, therefore, necessary to minimize these risks. For example, the approach to the lesion, which can be stereotaxic, endovascular or for microsurgery in exposed brain.

Images, obtained by different methods, such as, Computed Tomography Scan (CT), functional magnetic resonance images (fMRI), positron's emission tomographies (PET), single photons emission computed tomographic (SPECT), angiographies, etc., allow to confirm and locate the neurofunctional systems [1] and the blood flows. This vital information results in more precise diagnoses, facilitating the preoperative analysis and also during the surgical intervention, providing guides and opportune references.

The tools developed in the present paper give virtual brain representations for these purposes.

The software also allows planning the surgical procedure showing several cut planes. The surgeon may locate the lesion and choose the surgical instrument direction, minimizing collateral damage.

When the planning is done the system provides the five parameters that are necessary to place the frame components in the proper way to guide the surgical instrument to the target.

The rest of the paper is organized as follows: In section 2 the basic elements of the system are

exposed; a general introduction to stereotaxic technique related to 3D images and to Brain Atlas.
In section 3 the Visualization Tools are described; the techniques for positioning sections of the Brain and its lesions in space by means of stereotaxic frames. Section 4 presents the proposed Stereotaxic Frame. Section 5 shows the proposed Stereotaxic Frame Tools, that means the functionality of the Brian Navigator. Section 6 exposes finally Additional Tools; others facilities are described. And Section 7 conclusions and future works are given.

2 Background and characteristics of stereotaxic techniques

The use of mechanic guides to reach intracranial points with a surgical instrument, (probe, electrodes, needles for biopsies, etc.), was proposed in 1873, when carrying out experiments with animals.

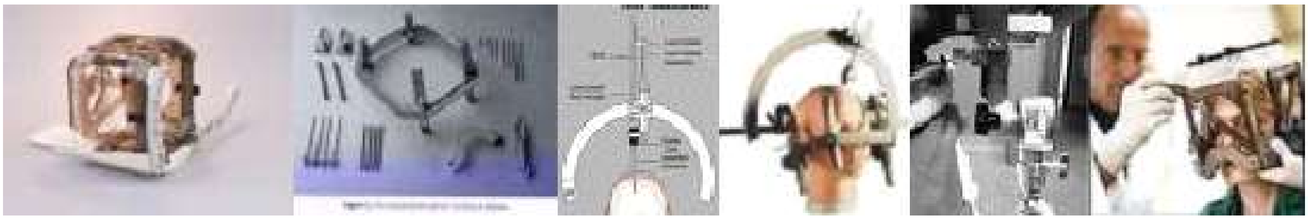


Fig. 1: Stereotaxic frames

Henry Clarke and Victor Horsley described, in 1906, the first elements and stereotaxic principles. They affirmed that "for these means each millimeter cubes of the brain could be studied and registered."

A stereotaxic frame is a mechanism used to position instruments with great precision, in a three-dimensional space. Although these instruments have been improved since then, they have the following characteristics [2]:

- A support (frame) fixed to the head.
- A system to direct an instrument mechanically to a defined point inside the skull.
- A system for the obtaining of stereo data, that is to say, the position of the different structures, injuries, etc., in terms of 3D coordinates.
- A probe or another surgical instrument, which is supported by the frame in such a way it may be directed to a predetermined point.
- A method to confirm the location of the probe or instrument inside the skull.

To locate an intracranial target in the space defined by the frame, we need to know its 3D coordinates referenced to the stereotaxic frame. Then, three important points should be satisfied:

- The target should already be visualized by some means of those mentioned. (MRI, CT, etc.)
- The coordinates of the target group of points, located in the image, have to be known in the frame referential system. That is to say, it should be possible to relate the frame referential system with the image referential system. The later can include the Cerebral Atlas.
- A method should exist to verify the position of the objective with regard to the frame and so, to confirm the position of the instrument estereotaxically guided.

Frames use different systems of coordinates: Cartesian, polar, etc. The choice depends on mechanical reasons. Many systems have been elaborated. We can mention among others the simple orthogonal system and the one mounted on the approach perforation.

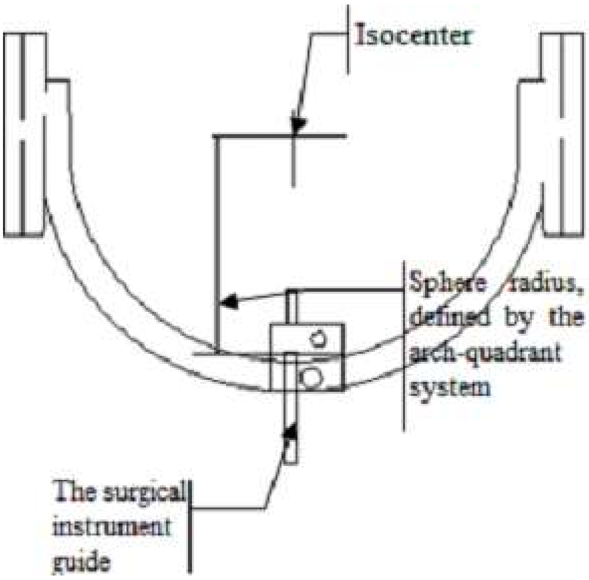
Researches have been done, based on the first stereotaxic systems, improving their benefits according to each need and so a wide variety of instruments exist today. These have their respective advantages and disadvantages. In general, almost all, present difficulties for approaching certain lesions and one can affirm that an instrument with satisfactory application in all the cases has not been achieved. Also, most of them satisfy the primitive elements described by Clarke and Horsley (Fig.1).

2.1 Applications

These frames [3] [4] are important to help various different surgical procedures [5] [6] in stereotaxic conditions:

a) Interbrain biopsies,
b) Permanent electrode implantation for registration or stimulation for the treatment of movement disorders (v.g. Parkinson, dysphonia, epilepsies, same kind of depressions, aggressiveness, TOCs and other psychiatric diseases),
c) Transitory electrode implantation for registration or stimulation for deep electroencephalographic study in cases of epilepsy refractory to medical treatment,

d) Implantation of radioactive material (brachytherapy),
e) Implantation of genetically manipulated cell colonies for the treatment of degenerative diseases,
f) Intratumoral treatment by injection of substances,
g) Guide for brain endoscopic procedures,
h) Radiosurgery,



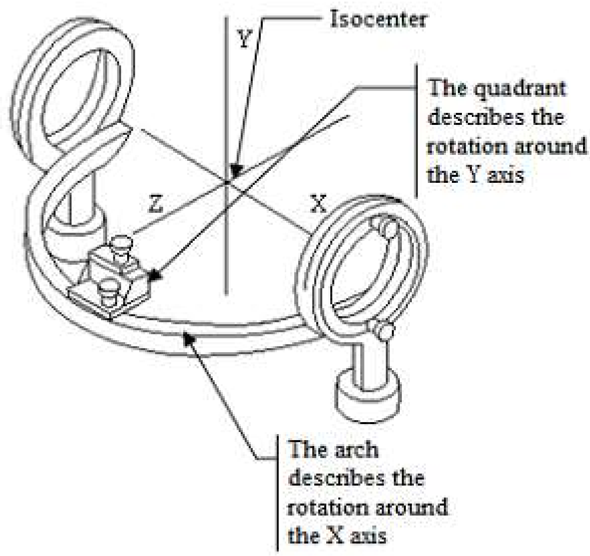


Fig. 2: Arc-quadrant system description

i) Laser surgery [7]

Some market frameworks including the one presented here does not allow radiosurgery treatment, except if additional equipment is used [8].
The above list is not exclusive. There are other applications like brain implants of electrodes in cases of: pain, drug addiction, etc. These frames are also used with animals. [9].
In brain surgery, when a stereotaxic frame is used [10], often the procedure is as follow:
1st - to request a RMN to have an anatomic image of the target and the entry area.
2nd - to place the frame.
3th - to request a TAC.
4th - possibly one image is registered [11] in the other because the better geometric precision of the TAC and the more anatomic detail of the RMN [12].
The localization, in the 3DI of the fiducial points which coordinates are known in the frame, since they are integral with the frame, allows relating both referential systems. Then, with the lesion (target) localizes, the parameters to be apply to the frame components can be determined, and thus achieve the surgical instrument access the lesion by the planned route [13].
Between taking the 3DI and the surgical procedure there is a lapse. During this lapse the physician plans the surgery and the patient must remain with the frame fixed to the skull.
Most of these devices [14] aren't disposable, neither lightweight nor easily portable and because in general it cover all the head they are bulky and annoying (Fig. 1). The frame proposed here satisfies all these requirements, the patient must remain only with the base of the frame fixed to the skull (see Fig. 11).

2.2 The Brain Atlas

A Brain Atlas allows the neurosurgeon to recognize and to locate cerebral structures in a three-dimensional space, to see relationships among them and besides, to confront it with the brain 3D image of a particular individual (Fig. 3). It describes aspects of the structure of the brain, their functions and their relationships, to which outlines and nomenclatures are added [15].
The Brain Atlas [16] [17] is elaborated starting from the anatomical observations of a number of cerebral preparations. In human and other species, the complexity of the brain and variability among individuals are so large that the atlas is used essentially, to analyze the topological information but the geometric information cannot be considered because of the differences between individuals. The utility of the Brain Atlas depends on a correct adaptation to the individual 3D image.

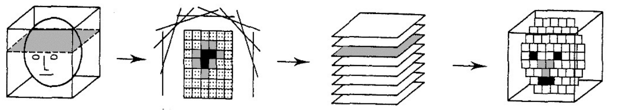


Fig. 3: Stages in the construction of a 3D image: a model of three-dimensional voxels is built from projections of two-dimensional images.

2.3 3D Images

Also called volume visualization images, they arise as a result of the transformation of real volumes in a group of rectangular prisms denominated voxels. A voxel is the visualization unit in a 3D-image (I3D), and the extension of the pixel notion three dimension (Fig 3).

Among the medical images, the 3D images are of great utility and there has been considerable development of automatic process in recent years. The information is composed of several sections (Fig. 3). The height of the voxels is given by the separation between these planes.

The resolution in a section slice is, bigger than the resolution for the separation between the slices. This directional difference is known as the anisotropy.

The RM images have the advantage of three dimensions, but they have -relatively-, poor resolution and they lack anatomical contrast in important organs. The resolution doesn't allow the description of the complexity of some anatomic structures with enough precision and details

3 Visualization Tools

3.1 Visualization Ways

To visualize sections of the 3DI, in arbitrary planes, we determine the intersection of the 3D image with the chosen plane [6] [21]. Then, we show in each pixel of this plane section, the values of gray corresponding to the intercepted voxel. The section divides the 3DI in two parts and the slice show the 2D image (Fig. 4). This figure is called a virtual cut. The position of the surgical instrument guided by the stereotactic frame and the position of the lesion or objective point allows definition of the section planes. The stereotactic frame gives the parameters defining the surgical instrument position. The target point -the intracranial lesion- determines the position to be reached with the instrument.

The parameters can be defined by means of the computer mouse in an interactive way. In each section there are lines that indicate the positions of the lesion or/and the position of the instrument.

3.2 The relation of the frame referential and that of the 3DI

To use the parameters of the frame is necessary to express the 3DI in the frame referential system. To know the relative translation and the rotation between both referential systems it is necessary to relate a series of identifiable points to the patient's head, which should be registered in the magnetic resonance images or in the CT Scan image. Then, when the patient has the frame fixed to his head, those points are known in the referential system of the frame. Note that those coordinates are known in the referential system of the image. The number of points should have enough redundancy, and they should have a good distribution in the space.

To solve de relative position of a referential system in relation to the other, we use de Thomson expression of a rotation deducted from the D'Olindez Rodriguez formula:

$$R^T = e^{A\phi} = I + A.\sin\phi + A^2(1-\cos\phi$$

Where R is a rotation 3D array,

$$A = \begin{pmatrix} 0 & -\gamma & \beta \\ \gamma & 0 & -\alpha \\ -\beta & \alpha & 0 \end{pmatrix} \text{ y } u = \begin{pmatrix} \alpha \\ \beta \\ \gamma \end{pmatrix}$$

Where u is the unitary vector defining the rotation axis. The Thompson rotation expression is

$$(I - Atg\frac{\phi}{2})^{-1}(I + Atg\frac{\phi}{2}) = R^T$$

Multiplying by a point v'_i

$$(I - Atg\frac{\phi}{2})^{-1}(I + Atg\frac{\phi}{2})v'_i = v_i$$

Operating and simplifying (with several points)

$$(v'_i - v_i)Atg\frac{\phi}{2} = v_i - v'_i$$

And, of course with $\phi \neq \pi$

3.3 The registration of the Atlas and the 3DI

Since the Atlas can be stored as a 3D image, it is also possible to visualize in the atlas, the appropriate sections depending on the parameters given by the frame, including the target or the end of the surgeon instrument. In this case the surgeon is also looking for the most convenient way of carrying out the intervention but this time keeping in mind, that he can see the sensitive structure shown by the Atlas and not visible by means of 3DI.

To have both, the lesion and the structures of the Brain Atlas in the same slice, it is necessary to carry out the registration of the atlas and of the 3DI of the particular patient, registration that could be a very complicated operation. That is the registration [18] [19] [20] that applies good methods of deformation and an appropriate visualization strategy, which is closely linked with the central topic of our work.

Since the virtual sections of the 3DI and of the atlas are given in function of the same parameters coming from the frame, with the purpose of improving the interpretation of the images both section slices are superimposed visualizing simultaneously the 3DI and the Atlas. The registration is necessary to contribute, with a precise metric of the Brain Atlas information, to the 3D image of a particular patient. The success of this operation depends on a good geometric adaptation of the anatomy described in the Brain Atlas to the 3D image.

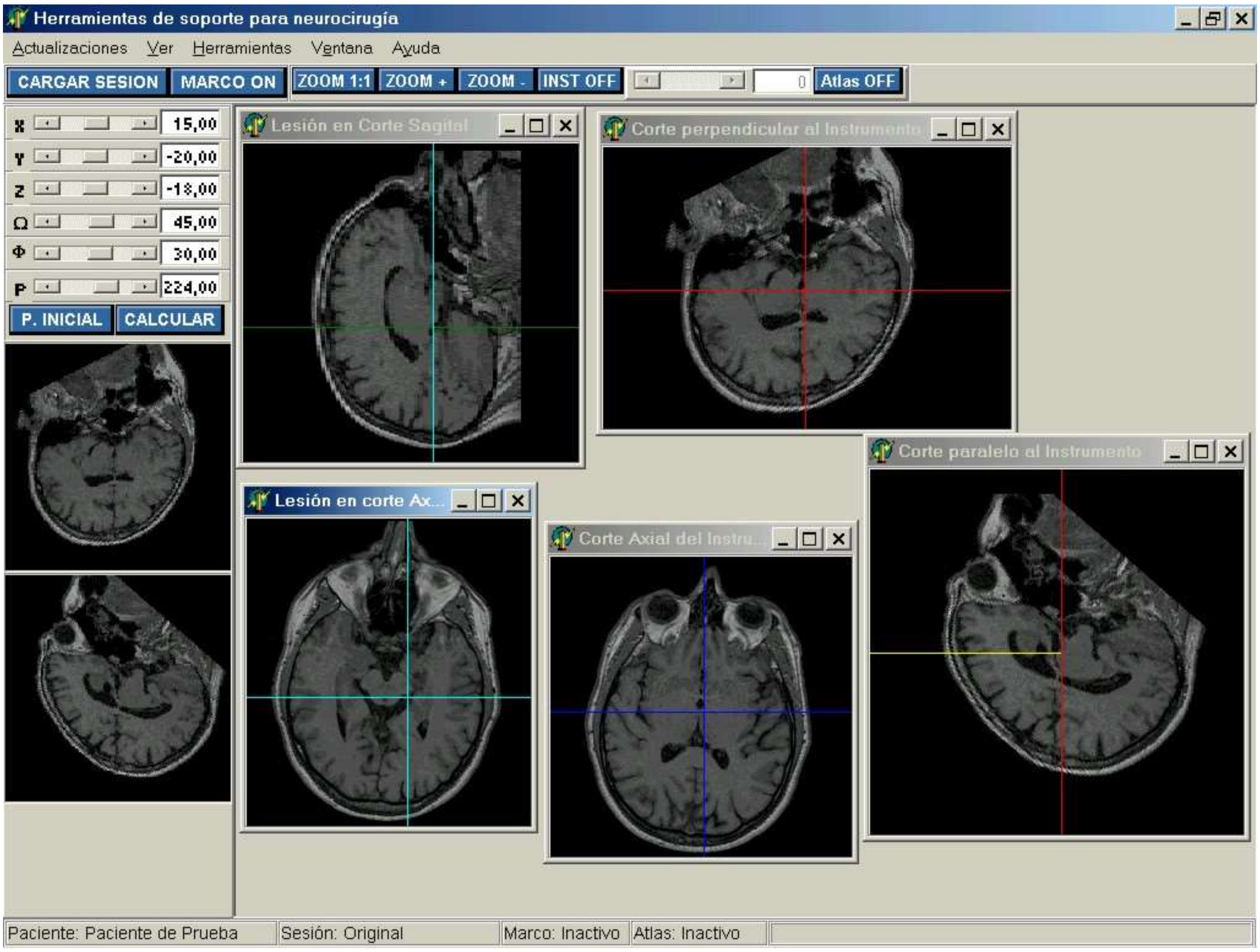


Fig. 4: Main Screen

3.4 Generated Slices

In the arc-quadrant system the approach direction is given by two angles, around the first and the second axis, and the position of the intracranial lesion, or the distance traveled by the instrument from the border of the arc. This distance is known as depth.
According to these parameters the following cuts are generated:

- *Parallel section: it is the one that contains the straight line on which the instrument moves* (Fig 6). Any section that contains this straight line is determined by means of an additional parameter that indicates a rotation angle around the approach direction. On the section, the approach direction and the target point, -the lesion-, are observed together with the brain structures that are affected by the instrument approach. In this section it is possible to modify the depth visually.
- *Perpendicular or normal section: it is the one that contains the point defined by the instrument end and it is normal to their trajectory* (Fig. 7). This section slice allows seeing a general panorama of the structures

crossed by the instrument. The end instrument position can also be modified in this case with the mouse, in a visual way.

Fig. 5: Fiducial points

- *Axial section: it is the axial section that contains the position of the instrument* (Fig. 8). It allows seeing the areas affected by the instrument on a traditional section.
- *Axial (Fig. 9) and Sagital (Fig. 10) section at the lesion level: Both, the axial and the sagital section contain the intracranial target*. In each section we can observe the target point and the affected brain region. Also in this case, the end instrument position can be modified with the mouse in a visual way.

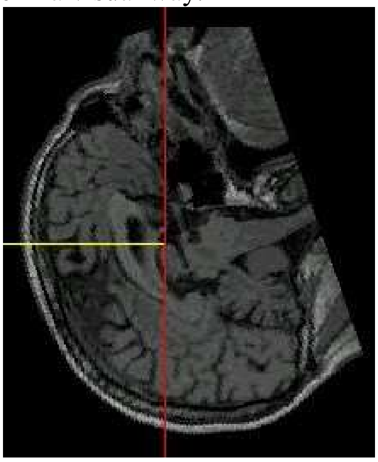


Fig. 6: Parallel slice

In practice, the neurosurgeon is trained to recognize the brain structures on the axial sections. The neurosurgeon will generally have much more difficulty in recognizing structures in the sagital sections, when they don't belong to the half line, and in general in the coronal sections. Of course, it is he very difficult to recognize structures when the sections correspond to planes of arbitrary directions. It is for this reason that one of the cuts generated is the axial section centered in the end of the instrument, when the instrument has an arbitrary approach. That is to say it is possible to visualize simultaneously, while the instrument enters, the normal section to the instrument in its end, the axial section centered in the end of the instrument and any section parallel to the trajectory. In the latter case the surgeon can elect a particular angle.

Fig. 7: Perpendicular Slice

4 Description of the proposed Stereotaxic Frame

One of features of the proposed framework is to be local, as shown in Figure 11. The device consists of (figure 12):

- A base that is fixed to the skull with 3 screws,
- A ring which can rotate around the base,
- An element called carriage which moves tangentially to the ring,
- Another year rotating about an axis normal to the center of the carriage,
- In this ring there is an arch on which a component of several elements guides the surgical instrument,
- Only for taking 3DI, there is a ring with three set of three fiducial points making different triangles.

There are, then, 9 fiducial points, three of them, at the end of the triangles are arranged symmetrically, the remaining 6 dots are positioned so to break the symmetry.

The figure 12 shows: 1 base, 2 ring, 3 fiducial points, and fixing screws.

The figure 13 shows the stereotaxic frame components: 1 base, 2 carriage ring, 3, 6, 7 elements that guides the surgical instrument, 4 fixing part, 5 ring carriage, 8 carriage.

All these components are made with disposable and biocompatible materials used to make 3D prints with accuracy equipment. These material may be the PC-ISO (polycarbonate-ISO) biocompatible, or ABS-M30i, biocompatible with higher mechanical resistance (both material are ISO 10993 USP Class VI).

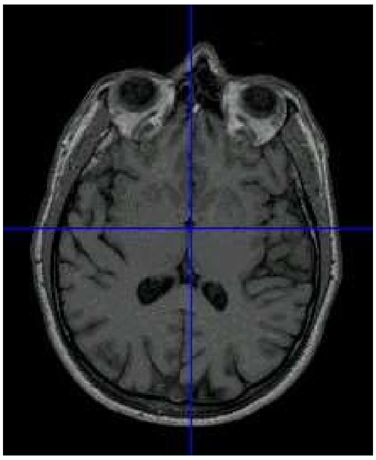


Fig. 8: Axial Slice

5 Cerebral Navigator and Software tools functionalities

Due to the features of the frame and how to meet the requirements of the operation, the following main features were established:

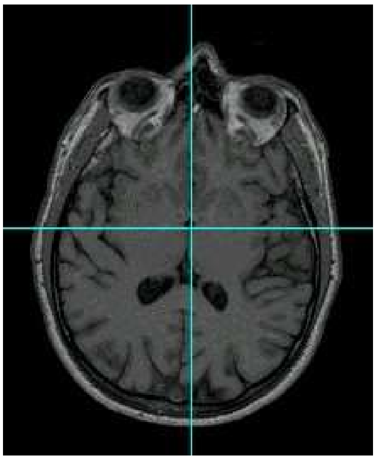


Fig. 9: Target on Axial Slice

a) Generation of slices from the 3DI: axial, sagittal and coronal sections.
b) Generation of parallel and normal sections: the parallel sections are the ones containing the straight line on which the instrument moves; the normal sections are the ones containing the ending point of the instrument when the instrument is moving.
c) Visualization: in each case the surgeon can visualize the series of slices, and the target (lesion point).
d) Obtaining the coordinates of the target.
e) Identification of the fiducial points.
f) Obtaining the translation and rotation between both referential systems (the 3DI referential system and the frame referential system).

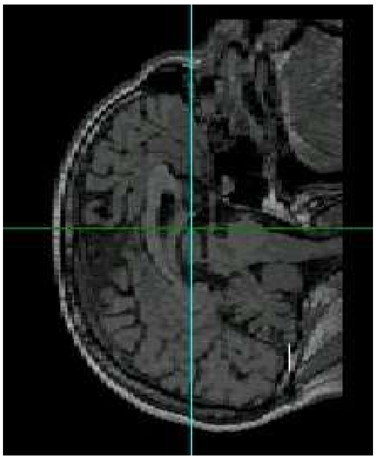


Fig. 10: Target on Sagittal Slice

g) Calculation of the five frame parameters, so the surgical instrument will be able to reach the target.

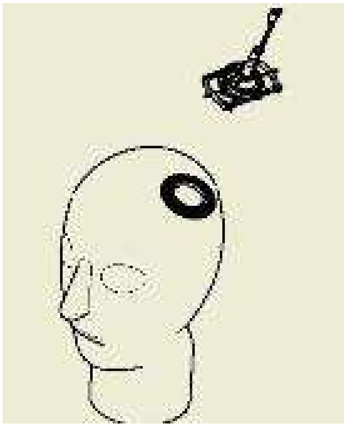


Fig. 11: only the base fixed to the skull

After software relates the frame referential with the one related to de image it gives the five parameters to position each frame piece. The intracranial lesion determines the target point to be reached with the surgical instrument.

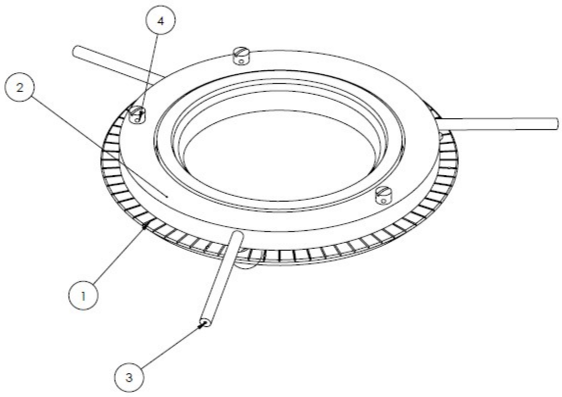


Fig. 12: Frame and Drive with Rods and Fiducial Points.

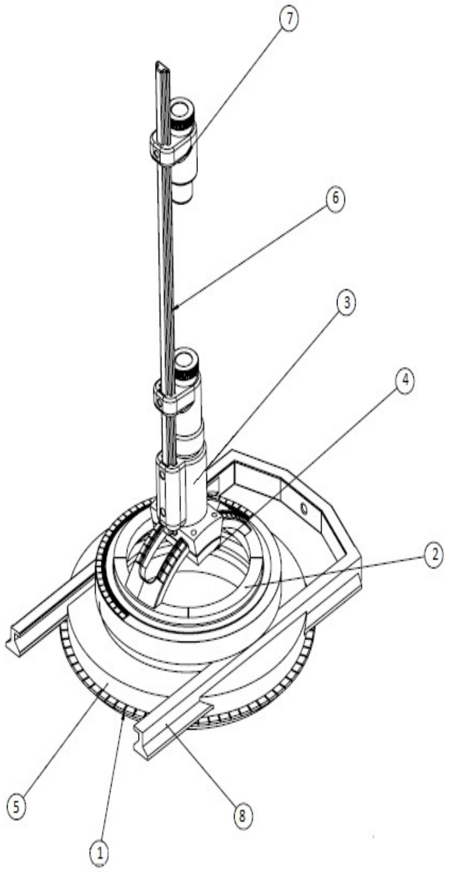


Fig. 13: Frame perspective view

5.2 Frame parameters

With the target coordinates and the instrument direction in the frame referential system, it is possible to determine the five parameters defining the conformation of the exterotaxic frame.

The five parameters are:

- ring rotation around the base,
- carriage translation,
- rotation of the ring that is inside the carriage,
- angular displacement of the guide component on the arc, and
- the deepness the instrument has to go to access to the target.

These five parameters allow locating the instrument in the right position and reaching the lesion.

Same constants have to be stored in a file like fiducial point coordinates, rotation center coordinates and values of initial positions.

6 Aditional Tools

An additional tool is that of generation of videos. These are sequences of sections. With them the surgeon carries out preoperative works and diagnose. The preoperative works help the planning of the approach, showing, quickly, the neurofunctional structures affected by a certain surgical approach or intervention. The diagnose allows visualizing deformations or other type of anomalies in the brain, among other possibilities. Another tool is the storage of any section, with the purpose of being able to carry out comparisons among the same patient's section or other evolution control, also, evaluation of cases, etc. This storage is carried out with the frame parameters and approach instrument. It allows reproduction of a particular situation to make comparisons later on.

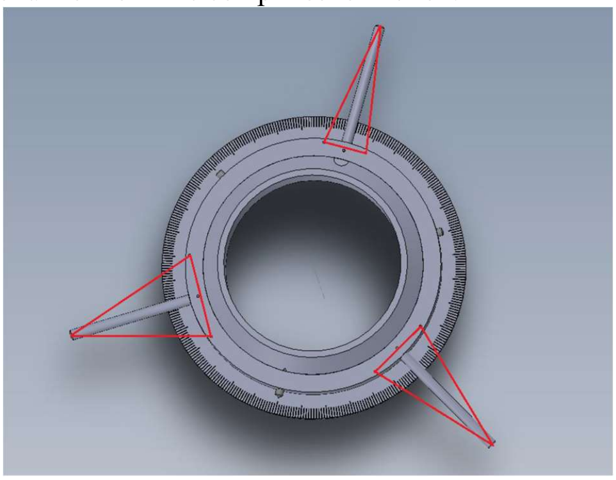


Fig. 14: Fiducial points in the frame

7 Conclusions and perspectives

Starting from the visual sections of the 3DI, the neurosurgeon can compare and recognize structures. Then, he can evaluate different approaches comparing their risks, to obtain precise and immediate information on the neurofuncional systems affected by a certain approach direction. The surgeon can analyze and plan the more convenient approach.

This group of tools gives a bigger solvency in the diagnosis and in the treatment of cerebral lesions when invasive methods are required. It is also necessary to mention that they have a very important utility as a didactic tool.

Then, the specific tools developed for the use of the proposed stereotaxic frame allow taking full advantages: disposable, portable, lightweight, etc.

Shortly we will present a work in which the accuracy achieved during surgery is evaluated.

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