Software support for a new stereotaxic frame

José Francisco Zelasco, Adriana Echeverría, Eduardo Pasqualini, Gustavo Sánchez,
Tomás Kelly, Judith Donayo
jfzelasco@fi.uba.ar, adelacrena@yahoo.com.ar, eduardo_pasqualini@yahoo.com.ar,
sancheztavo@gmail.com, tomaskelly87@gmail.com, juddonay@gmail.com

*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.

Keywords: Stereotaxic Techniques, Brian Navigator, Fiducial Points, Stereotaxic Frame.

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.
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. Section 2. - Basic elements: A general introduction to stereotaxic technique related to 3D images and to Brain Atlas. Section 3.- Description of the proposed Stereotaxic Frame. Section 4. - Proposed Stereotaxic Frame Tools: functionality of a Brian Navigator. Section 5.- Conclusions and future works.

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.
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 (Gildenberg 1998):

- 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 (Image 1).

Image 1: extereotaxic frames.

2.1 Applications

These frames (Levy 1992) (Talairach 1988) are important to help various different surgical procedures (Heilbrun 1983, Zelasco 2001) 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,
i) Laser surgery (Kelly, 1982)

Some market frameworks including the one presented here does not allow radiosurgery treatment, except if additional equipment is used (Bernett 2007 y RTCTG 1995).

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. (Kirby 2012).

In brain surgery, when a stereotaxic frame is used (Thomas 1984), 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 (Zelasco 2000) in the other because the better geometric precision

of the TAC and the more anatomic detail of the RMN (Lozano 2009).
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 using by the planned route (Kall1986).

Between taking the 3DI and the surgical procedure there is a lapse of certain duration, during this lapse the physician plans the surgery and the patient must remain with the frame fixed to the skull.
Most of these devices (Couldwell 1990) aren't disposable, neither lightweight nor easily portable and because in general it cover all the head they are bulky and annoying (image 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 figure 1 and 2).
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. It describes aspects of the structure of the brain, their functions and their relationships, to which outlines and nomenclatures are added. After an appropriate registration, with a 3D image of a patient's brain, the surgeon disposes, in the image, of all the information mentioned, and so, the lesion is shown within a complete outlook of its environment.

2.2 The Brain Atlas

The Brain Atlas (Scarabino 2003, Nowinski 2005) 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. That is the registration (Salgado 2000, Hill 2000, Helminen 2003) that applies good methods of deformation and an appropriate visualization strategy, which is closely linked with the central topic of our work.
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 segmented 3D image.

3. Description of the proposed Stereotaxic Frame

One of features of the proposed framework is to be local, as shown in Figure 1. The device consists of (figure 2):

- 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 round rods, and at its end, each one has a fiducial point.

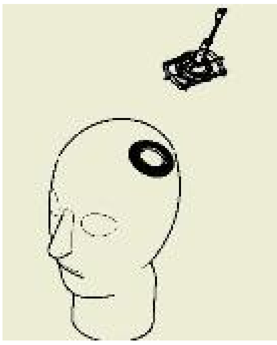

Figure 1: only the base fixed to the skull

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

The figure 2 shows: 1 base, 2 ring, 3 fiducial points, 4 fixing screws.

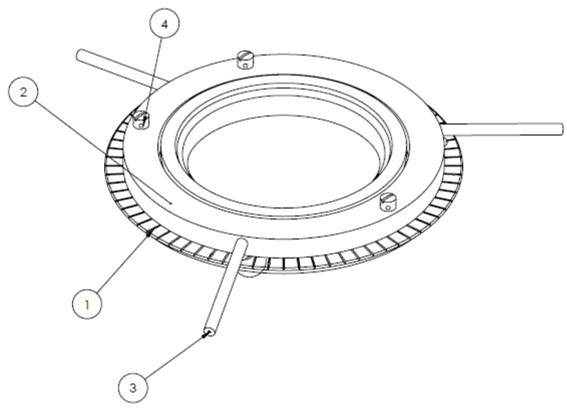

Figure 2: Frame and Drive with Rods and Fiducial Points.

The figure 3 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).

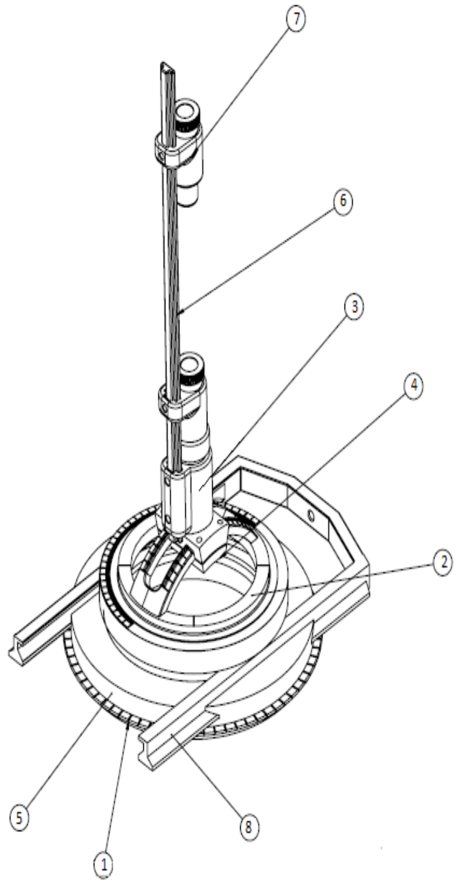

Figure 3: Frame perspective view

4. 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:

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

This brain navigator (Zelasco 2001, 2002) allows visualizing sections of the 3DI in different planes. The software determines the intersection of the 3D image with the chosen plane. Then, it shows 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. This is called a virtual cut. The direction of the surgical instrument guided by the stereotactic frame and the position of the lesion or objective point determine the choice of two section planes.

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.

The parameters of the frame can be defined by means of the computer mouse in an interactive way. In each section plane there is a line showing the direction of the instrument and intersection lines presenting the positions of the lesion or/and the position of the instrument.

4.1 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 mark a series of identifiable points in 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 should be expressed 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 be, at least, three, and they should not be aligned.
To solve the 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,

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

$$u = \begin{pmatrix} \alpha \\ \beta \\ \gamma \end{pmatrix}$$

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

$$(I - A\,\mathrm{tg}\frac{\phi}{2})^{-1}(I + A\,\mathrm{tg}\frac{\phi}{2}) = R^T$$

Multiplying by a point v'_i

$$(I - A\,\mathrm{tg}\frac{\phi}{2})^{-1}(I + A\,\mathrm{tg}\frac{\phi}{2})v'_i = v_i$$

Operating and simplifying (with several points)

$$(v'_i - v_i)A\,\mathrm{tg}\frac{\phi}{2} = v_i - v'_i$$

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

4.2 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.

5. 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 present a work in which the accuracy achieved during surgery is evaluated.

6. Bibliography

Kelly P.J., Alker G.J., and Goers S.: “Computer assisted stereotactic laser microsurgery for the treatment of intracranial neoplasms.” Neurosurgery, 1982

Kall B.A., Kelly P.J., Goers S.J.: “The computer ace to stereotactic surgical instrument;” Neurol Head, 1986.

Talairach J.: "Co-Planar Stereotaxic Atlas of the Human Brain;" Thieme, 1988.

Gildenberg P.L. and Tasker R.R.: "Textbook of Stereotactic and Functional Neurosurgery; " McGraw-Hill, 1998.

Salgado L. et al, “Efficient Image Segmentation for Region-Based Motion Estimation and Compensation”, IEEE TRANSACTIONS, 2000.

Hill D., et al, “Medical image registration”, Institute of Physics Publishing, 2000.

Helminen H. et al, “Comparison of Local External Force Functions for Non-rigid Registration of 3D Medical Images”, MICCAI 2003

Nowinski W. et al, “Three-dimensional Atlas of the Brain Anatomy and Vasculature”, Informatics in Radiology, 2005

Scarabino T. et al, “Atlas of Morphology and Functional Anatomy of the Brain”, Gruppo Editoriale IDELSON-GNOCCHI, 2003

Zelasco J.F., Álvarez M., González G., "Estado del Arte en Segmentación de Imagenes 3D" (3DI segmentation, state of the art); Annals of the Argentinian Scientific Society 2000.

Zelasco J.F. et al, 2002, “Herramientas para neurocirugía estereotáxica”, revista Informática Médica editada por la Asociación Médica Argentina, diciembre, 2002.

Zelasco, J.F., Pasqualini, E., Castelao, D.H., Fernandez Ausinaga, J.L., Malisia, F.N., 2001, “Tools for Stereotaxic Neurosurgery”, Proceedings of the IASTED International Conference, February 2001, Innsbruck, Austria