Advanced Neuroimage Processing for the Study of the Neurovascular System

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ABSTRACT
Background. Medical images have passed from static and printed images with no possibility of modifying many technical parameters to volumetric data that allow its manipulation and advanced processing for surgical or pedagogical purposes. **Aim**. The aim of this paper is to demonstrate the major role and potential of OsiriX^{TM}, a new open-source computerized tool for the advanced processing of medical images, in the study of neurovascular anatomy. **Methodology**. DICOM images were acquired with radio diagnostic equipment using 1.5 Tesla Magnetic Resonance (MR) images from a 34-year-old and right-handed female. Images were further processed using OsiriX^{TM} version 4.0 32 bits for OS, one of the most versatile technologies within the field of medical imaging. **Results.** Key features required for processing neurovascular images such as segmentation and three-dimensional reconstruction of vascular elements (cerebral arteries and Willis polygon) are visually illustrated and described. **Conclusion**. The application of this technology in medical imaging has enhanced the accessibility and availability of neuroimaging, reducing the need for sophisticated and expensive workstations for image processing. Advanced image processing allows overcoming limitations inherent to classical techniques based on two-dimensional sections. Three-dimensional reconstructions of vascular elements are already used in daily clinical practice, including diagnostic protocols. Also, interactivity and virtual visualization makes it simple, cost-effective and easy to understand complex vascular elements. **Discussion**. Implications for teaching and learning neurovascular concepts and diagnostic value are discussed.

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1. INTRODUCTION
The traditional approach to the study of brain images has based on the exploration of individual two-dimensional (2D) images acquired by devices such as Magnetic Resonance (MR). However, recent developments in the field of medical informatics for advanced image processing have grown significantly and allow us to enhance the basic and clinical information that we can obtain from those images [1-2].
Processing of complex brain images are no longer the domain of expensive and inaccessible workstations. New powerful applications provide tools for their effective visualization and manipulation in neuroanatomy [3-4]. Mentioned applications deal with specific tasks of visualization or image processing; packages able to address many different areas; client-side applications, which are generally easier for the end user; or server-side applications, which are generally more stable but less user friendly [5-7]. For a detailed technical review of advanced image processing applications, readers are recommended to consult Neuroimaging Informatics Tools and Resources Clearinghouse (NITRC).

In recent years, there has also been a growing interest in three-dimensional visualization of anatomical structures. The development of tools for the study of bone and joint anatomy using Computerized Tomography images has been relatively easy since density is significantly different from soft tissue [8]. In particular, OsiriX has shown high accuracy and reliability in length measurements on this kind of reconstructions [9]. Similarly, a study published in 2009 by Miller et al. applied

OsiriX to the study of the anatomy of specific cranial nerve [10]. The aim of this paper is to demonstrate the major role and potential of OsiriX™, a new open source computerized tool for the advanced processing of medical images, in the study of neurovascular anatomy.

2. METHODOLOGY

2.1 Image acquisition

All the images included in this study were obtained from the *Santísima Trinidad* Hospital in Salamanca. Normal images included in this study belong to a 34 years old right-handed female with no previous. Pathological images were obtained to clinical cases explored in the radiological service of Santisima Trinidad Hospital. Ages ranged from 31 to 45 years old.

All participants gave their informed consent to participate in the study, which was approved by the local ethics committee following the principles established in the Declaration of Helsinki.

2.2 Image processing

OsiriX™ version 5.5.1 32 bits was used for this study. This is an image-processing application dedicated to DICOM images (.dcm) obtained from Magnetic Resonance. In fact, it was selected because is considered to be the fastest open-source application in the world for DICOM images acquired from RM [4]. It allows a large volume of data to be imported immediately and the visualization of large numbers of images since the Mac OS X creates a "virtual" additional memory on the hard drive, although it is significantly slower than the RAM. It also allows to export images to multiple formats: JPEG, MPEG, MPEG4 and AVI), Quicktime VR (as a 3-D object that can be manipulated without rendering software and hence useful for teaching purposes) or DICOM images. It was developed in 2004 at UCLA by Dr. Antoine Rosset, Prof. Osman Ratib and Joris Heuberger [11-14].

OsiriX was installed in an iMac (21.5") with an Intel Core i5 2.5 GHz processor, a hard drive of 500 Gb (72000 rpm), 4 CG or RAM and a screen with a resolution of 1920- 1080 pixels. The operative system was Snow Leopard 10.6.8.

3. RESULTS

3.1 Image visualization

One of the key features of the OsiriX™ is its flexible user interface allowing users to customize the program by adding and removing tools and functions from the tool bar and menus of the program by a "drag-and-drop" system. This also allows the creation of ''customized'' versions of the program for specific groups of users such as heath care students or professionals.

Basically, the user interface comprises three navigation windows that allow access to different tools and functionalities: The first one allows administrating the local database and import DICOM images. Images contained in a single DICOM file can be shown in the form of a film and patient identification data can be easily anonymize. The second and third windows provide a 2D and 3D window for the 2D and 3D visualization and manipulation of MR images respectively for both normal and pathological MR images of neurovascular anatomy.

An interesting modality of visualization of orthogonal MR images is the 3D multi-planar reformatting mode (MPR) where axial, sagittal and coronal are displayed simultaneously and the correspondence in a specific point is highlighted (Figure 2).

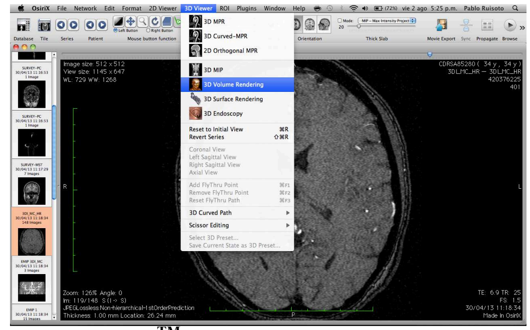

Figure 1. OsiriX™ interface showing main tools for MR images. Advanced 3D options appears extended

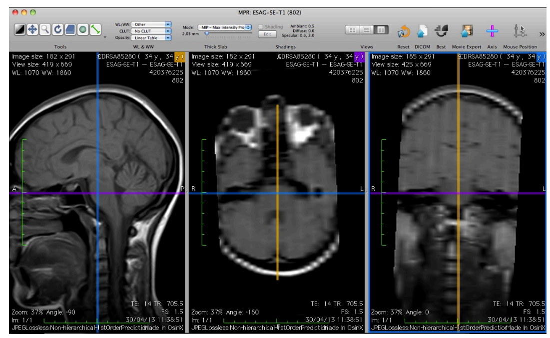

Figure 2. 3D multiplanar reformatting mode using from orthogonal MR images

3.2 Segmentation of neurovascular system

The segmentation of regions of interest (ROIs) allows the manual delimitation of vascular structures or semi-automatic using "growth region". However this tool is most suitable when the density of the structure is clearly different from the rest. The application also includes tools for the measurement of distances and volumes (Fig. 3).

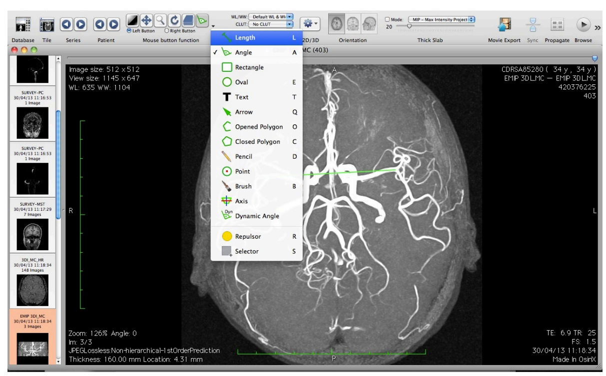

Figure 3. Measurement tools included in Osirix for length and angles of neurovascular elements

3.3 Volumetric reconstruction

Only most common volume rendering techniques used for neurovascular study have been described in this study.

The volume rendered with Maximum Intensity Projection consists of the formation of a 3D image according to the intensity and position of each voxel, using the "volume ray casting" algorithm. However, it is generally used for the rendering of bones but it can also be used in the study of vascular elements from MR (Fig 4.).

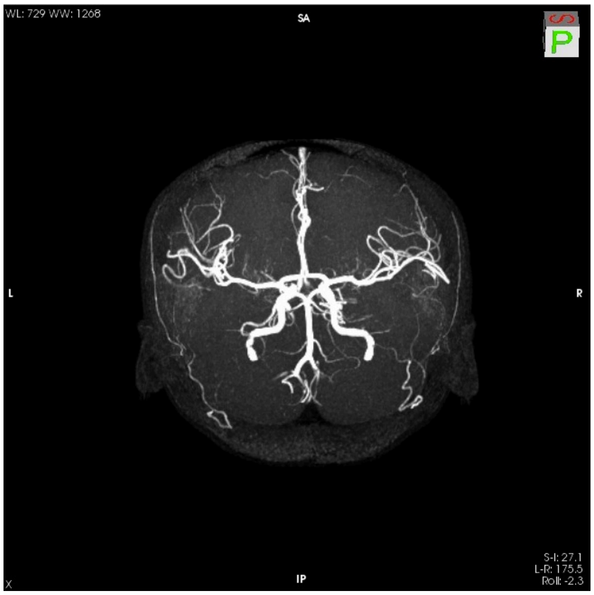

Figure 4. MIP. Example of maximum intensity projection rendering of cerebrovascular elements obtained from MR image set using OsiriX$^{TM.}$ A complete view of Willis Polygon, including anterior and, cerebral, basilar and internal carotid arteries are visible from this view

The Volume Rendering function consists of the formation of 3D images according to the opacity and RGBA color of each voxel. It is the 3D technique most widely, used and provides good images of neurovascular tissues in MR (Fig. 5).

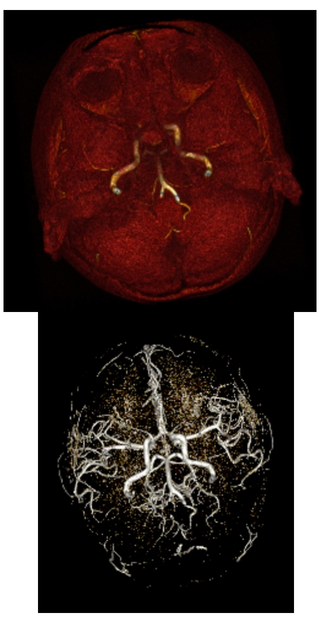

Figure 5. Thesholding tecnique for the 3D modeling of soft tissues by direct volume rendering in a normal neurovascular study. A veins level of transparency is displayed

Complementarily, 3D volume rendering was also used for the pathological studies. For illustrative purposes, a 3D volume renderization of pathological case is included next, facilitating the identification and interpretation of the lesion (Fig. 5 and 6).

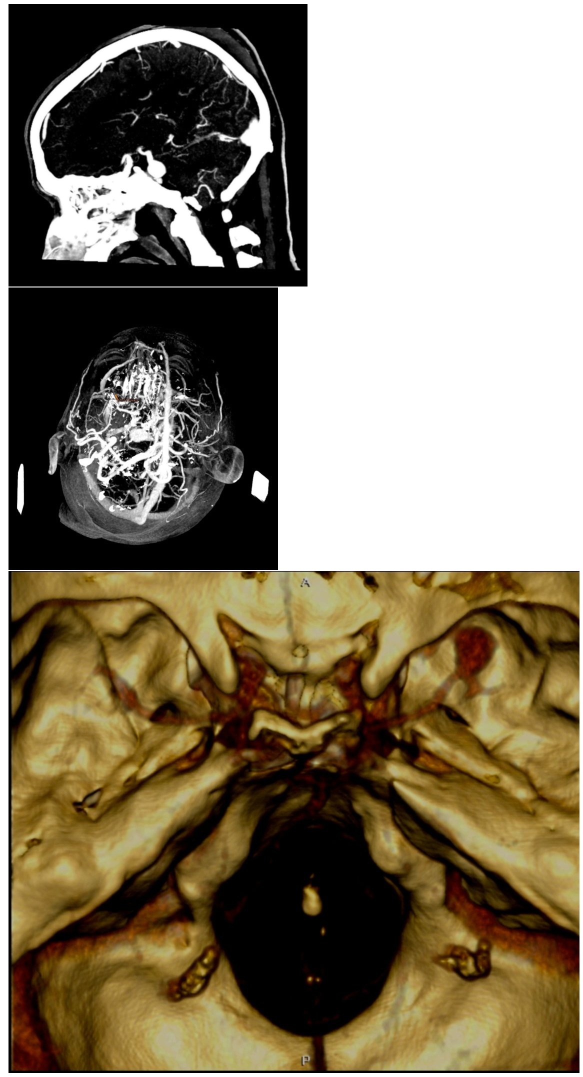

Figure 6. Volume Renderization illustrating pathology in the basilar artery (upper images) and right medial cerebral artery (image below)

The Surface Rendering modality allows the reconstruction of surfaces based on "isosurface" intensity curves, defined a priori. It is a useful technique for virtual endoscopy (positioning a camera inside the volume). This technique allows to adjust a high contrast for remove the soft tissues, leaving only the high-density bone structures, or low contrast, to show soft tissues such as skin and muscles.

OsiriX^{TM} also includes many features suitable for educational purposes. For example, iChat AV allows video-conferences and iCloud as a file storage system. Additionally, individual images or complete database can be shared using iTunes library or iPhoto or even be published with iWeb as other studies have shown [15].

4. CONCLUSION

This study shows that 3D visualization of vascular elements provides a highly realistic and interactive visualization of neurovascular anatomy independently of the method of reconstruction. In addition it allows rotation of the model, a zoom-in view, and changes in transparency level, producing a true virtual anatomical dissection.

OsiriX^{TM} has provided easy-to-use tools for the advance visualization and study of neurovascular elements from sectional MR images suitable for training or education purposes and without the need for costly workstations and without losing efficiency.

5. DISCUSSION

This paper offers a general overview of the main utilities included in OsiriX^{TM} that facilitate the study of neurovascular system from MR images, performing complex tasks from the data contained in volumetric data [16-18].

Furthermore, this application allowed us to develop more ergonomic and realistic environments and resources suitable for educational purposes in the study of neurovascular elements, a field traditionally limited to the exploration of dissection planes and restrictive work-stations expensive commercial workstations that restricted their use to specialist radiologists [15-17].

Anatomical dissections of cadavers and photographs or anatomical drawings made during dissection have been one of the classical techniques for the study of vascular anatomy. However, new tools of based on the creation of virtual human anatomy are constantly been developed allowing a true virtual dissection of blood vessels.

OsiriX is one of the most well known software in modeling interactive 3D reproductions of vascular structures and other anatomical structures with different density. The result is a reconstruction easy to see and very useful for detailed anatomical study. It provides methods for 3D model reconstruction or surface rendering that requires manual segmentation. The result is the creation of the shape of anatomical structures which enables 3D mapping of the anatomical structure studied. However this is not the technique most suitable for vascular anatomy.

In this study we have shown that the study of vascular elements is better done using the technique called volume rendering or direct volumetric 3D reconstruction or the volume rendering technique uses ray tracing of voxel data. In this case, the segmentation process is performed automatically. This process is not only more rapid and simple but allow a complete utilization of acquired data.

In particular, when studying or handling vascular tissue, we can vary the transparency level, creating a correspondence between the different tissue densities and a color, a transparent-cy, and a luminosity for each voxel in the reconstructed 3D model.

Finally, this study illustrate the educational potential of OsiriX for the study of the complex human neurovascular system and enhance the its understanding in angiology [19-20].

3D constructions of neurovascular elements facilitate the task of understanding their morphological details, possible pathologies and location within the brain of the complex elements that constitute the neurovascular system. Therefore, this study provides visually rich images useful for educational purpose, contributing to previous publications in this line of work [20].

OsiriX^{TM}, as a client-side open-source application, which permits access to the software and its source code offers additional value with respect to other proprietary and costly workstations. In fact, open-source applications represent one of the major current trends in research into applications dealing with medical images [21-25]. For a revision of what is open source, types of open source applications, and pros and cons of these tools for medical imaging consult [26].

New features such as versions for portable devices like iPads called OsiriX^{TM} HD provides a true DICOM viewer accessible at an affordable price. As consequence, it is not surprising that OsiriX^{TM} has dozens of thousands of users and more than 700,000 downloads have been made throughout the world, including from academic institutions and prestigious medical centers.

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