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COMPUTER APPLICATIONS

# Open source software in a practical approach for post processing of radiologic images

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**Abstract**
*Purpose* The purpose of this paper is to evaluate the use of open source software (OSS) to process DICOM images.
*Materials and methods* We selected 23 programs for Windows and 20 programs for Mac from 150 possible OSS programs including DICOM viewers and various tools (converters, DICOM header editors, etc.). The programs selected all meet the basic requirements such as free availability, stand-alone application, presence of graphical user interface, ease of installation and advanced features beyond simple display monitor. Capabilities of data import, data export, metadata, 2D viewer, 3D viewer, support platform and usability of each selected program were evaluated on a scale ranging from 1 to 10 points.
*Results* Twelve programs received a score higher than or equal to eight. Among them, five obtained a score of 9: 3D Slicer, MedINRIA, MITK 3M3, VolView, VR Render; while OsiriX received 10.
*Conclusions* OsiriX appears to be the only program able to perform all the operations taken into consideration, similar to a workstation equipped with proprietary software, allowing the analysis and interpretation of images in a simple and intuitive way. OsiriX is a DICOM PACS workstation for medical imaging and software for image processing for medical research, functional imaging, 3D imaging, confocal microscopy and molecular imaging. This application is also a good tool for teaching activities because it facilitates the attainment of learning objectives among students and other specialists.

**Keywords** Open source · Post processing · Diagnostic imaging

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## Introduction

Open source software (OSS) is a model for development, dissemination and cooperation in the field of information technology, created in 1985 with the establishment of the Free Software Foundation (FSF) and formalised in the so-called General Public License (GPL) [1, 2]. According to that document, a developer must make available all the source code and information necessary to compile (dependencies, libraries, technical documentation) the application to allow others to: duplicate/install multiple copies within their organisation; change/extend or incorporate it into other systems; commercialise the extensions made, being only constrained to provide the source code of the extensions made [3, 4].

Over the years, it became clear that an ideological redefinition of free software was needed to highlight the advantages both as a model of development and in terms of commercial prospects; FSF duly created the open source initiative which coined the term "Open Source" and has encouraged the spread of less restrictive licenses than the GPL [5].

OSS software is free but not necessarily freeware; OSS is not an alternative to commercial software; their model does not preclude the presence of commercial distribution, suppliers of added value or support services. It is more correct to define OSS as an alternative to the conventional licensing model (closed source), where access to the source code is not granted and in which the software developer retains the rights to their own product, selling the user a temporary or permanent "license to use", which allows them to use it without, in any way, acquiring property rights [6].

The process of sharing applications and their source code has played an important role in the management and dissemination of digital images in the biomedical field. The processing of medical images implies, in fact, a series of activities that must be performed by specific software: first, applications need to read the input data from one or more files, previously created by a diagnostic imaging device [7]. This is not always easy because the data may be available in many different proprietary formats even though the introduction of the DICOM standard is now an indispensable element of uniformity of the format of radiological images, allowing shared management between systems with different hardware and software [8].

Moreover, several frameworks and support structures have been developed in which software can be arranged and designed and then used in different applications, facilitating the work of programmers by avoiding unnecessary duplication of effort. This operating model has created a huge number of freely available libraries and application program interfaces for the analysis and management of medical images, present in many programs, in terms of cross-platform applications [9]. Among the various frameworks for reading and writing common image formats, it is appropriate to mention the Insight Tool Kit (ITK), designed to be easily extensible to different types of files that are used in medical image processing, such as DICOM, interfile or other proprietary formats [10]. Another item of OSS is the VTK library which contains many algorithms for 2D/3D image design visualisation and processing, and allows both volume rendering and various surface rendering techniques.

In this paper, the authors attempt to verify the number of and describe the functionality offered by, freely available and accessible OSS applications, as well as their potential in the management (production, storage, processing and transmission) of biomedical images to assess their abilities in comparison to those offered by proprietary software (closed source).

## Materials and methods

The study was carried out with methods similar to those used in an earlier scientific paper that tried to collect, describe and compare the characteristics of software applications freely available and accessible on the internet [11].

The basic software requirements were:

- Free availability, that is, applications must be freely downloadable from the net;
- Stand-alone, i.e., the software is not just a plug-in for a generic image viewer;
- The presence of a graphical user interface (GUI), to allow the interaction of the user with the software without the need for a command line interface;
- Easy installation: applications were excluded if their installation involved the execution of commands from the terminal or required other programs.
- Advanced features beyond simple monitor display.

The selected programs (split into two categories: Windows-Linux and Macintosh) are shown in Tables 1 and 2. The applications were evaluated by comparing their characteristics (Table 3). In particular, the presence or otherwise of functions (data import, data export, metadata, 2D viewer, 3D viewer) is listed, and an assessment of Usability was made with a score from 0 to 10 in terms of GUI, speed and simplicity.

The overall evaluation was scored from 0 to 10 based on the average value of the item usability with the increase or decrease of one point because of presence or otherwise of 2D and 3D functions of each program.

The programs were tested using four different sets of images (Table 4) on personal computers having the characteristics shown in Table 5.

## Results

The results of the comparison are shown in Tables 6 and 7. Most of the applications considered perform the basic operations of import and export of images, in addition to the elementary functions of 2D displays.

Based on the parameters listed above, we highlight the main features of the more interesting applications.

For the Windows-Linux platform:

### 3D Slicer

3D Slicer (Fig. 1) is a software platform developed by Slicer Community, implemented in the C++ language and based on VTK [12]. The software provides a very comprehensive and intuitive GUI, able to immediately show different images in various anatomical planes with various

**Table 1** Selected applications for the Windows-Linux platform

| Name | URL | Version |
|---|---|---|
| 3D Slicer | http://www.slicer.org | 3.6.3 |
| Aeskulaps | http://aeskulap.nongnu.org | 0.2.2-beta1 |
| Amide | http://amide.sourceforge.net | 1.00 |
| BioImageXD | http://www.bioimagexd.net | Beta-1537 |
| Dicompyler | http://code.google.com/p/dicompyler | 0.4a2 |
| Endrov | http://www.endrov.net | 2.18.0 |
| EViewBox | http://eviewbox.sourceforge.net/EViewBox.html | Non definita |
| Fusion viewer | http://fusionviewer.sourceforge.net | 1.0 (beta) |
| Gimias | http://www.gimias.org | 1.3.0 |
| Ginkgo CADx | http://ginkgo-cadx.com/en | 2.5.4 final |
| ImageJ | http://rsbweb.nih.gov/ij | 1.44i |
| ImageVis3D | http://www.sci.utah.edu/cibc/software/41-imagevis3d | 2.0.1 |
| InVesalius | http://svn.softwarepublico.gov.br/trac/invesalius | 3.0.0 beta 2 |
| ITK-SNAP | http://www.itksnap.org | 2.2.0 |
| Mayam | http://www.dcm4che.org/confluence/display/OV/MAYAM | 0.8 |
| Mango | http://ric.uthscsa.edu/mango | 2.5 |
| Micro view | http://microview.sourceforge.net | 2.1.2 |
| Mito | http://sourceforge.net/projects/mito | 1.0 beta |
| MITK 3M3 | http://www.mint-medical.de | 1.1 |
| MVE | http://www.mve.info | 0.9.1.1 |
| Nukak 3D | http://nukak3d.sourceforge.net | 4.0 |
| Santec/Tudor DICOM | http://santec.tudor.lu/project/dicom/download | 1.9.1 |
| Seg 3D | http://www.sci.utah.edu/cibc/software/42-seg3d.html | 2.1.2 |

**Table 2** Selected applications for the Macintosh platform

| Name | URL | Version |
|---|---|---|
| 3D Slicer | http://www.slicer.org/ | 4.1.1 |
| Amide | http://amide.sourceforge.net/ | 1.0.2 |
| Dicompyler | http://code.google.com/p/dicompyler/ | 0.4.1 |
| Ginkgo CADx | http://ginkgo-cadx.com/en/ | 2.8 |
| ImageVis3D | http://www.sci.utah.edu/cibc/software/41-imagevis3d.html | 2.1.1 |
| iRad | http://irad.sourceforge.net/ | 1.6.6 |
| ITK-SNAP | http://www.itksnap.org/pmwiki/pmwiki.php?n=Main.HomePage | 2.2.0 |
| Madena | http://www.eyephysics.com/Madena/TOC.html | 3.25 |
| Mango | http://ric.uthscsa.edu/mango/ | 2.6 |
| MAYAM | http://www.dcm4che.org/confluence/display/OV/MAYAM | 0.8 |
| MedINRIA | http://med.inria.fr | 2.0.1 |
| Micro view | http://microview.sourceforge.net/ | 2.5.0 |
| Mipav | http://mipav.cit.nih.gov/ | 5.4.4 |
| MITK 3M3 | http://mint-medical.de/mitk-3m3 | 1.1.0 |
| OsiriX | http://www.osirix-viewer.com/ | 5.0.2 |
| Seg3D | http://www.sci.utah.edu/cibc/software/42-seg3d.html | 2.1.4 |
| Tudor DICOM tools | http://santec.tudor.lu/project/dicom/download | 1.9.14 |
| VolView | http://www.kitware.com/products/volview.html | 3.4 |
| VR Render | http://www.ircad.fr/recherche/rd/rd.php | 0.8 |
| Weasis | http://www.dcm4che.org/confluence/display/WEA/Home | 1.2.2 |

**Table 3** Evaluation criteria

| | | |
|---|---|---|
| 1 | Data import | |
| | Images | Import individual images |
| | Set | Importing an arbitrary selection of images |
| | Series | Automatic import of whole series |
| | Directory | Import one or more folders of images |
| 2 | Data export | |
| | Images | Export single image in various formats |
| | Series | Exporting the whole series as DICOM series |
| | Anonymizer | Function anonymity images/series |
| 3 | Metadata | |
| | Images | Ability to display the header of the single image |
| | Study | Ability to display the header of the entire study |
| 4 | 2D viewer | |
| | Windowing | Adjusting the level and breadth of the window |
| | CLUT | Setting the colour lookup table 2D |
| | Histogram | Display the histogram of the image or ROI |
| | Information | Viewing additional information overlay |
| | Measurements | Measurements can be performed |
| | Remarks | Ability to put annotations on the images |
| 5 | 3D viewer | |
| | Slice scrolling | Scroll function of a series of images |
| | MPR | Ability to perform orthogonal multiplanar reconstructions |
| | CPR | Ability to perform curved multiplanar reconstructions |
| | MIP | Display in maximum intensity projection |
| | VR | Ability to perform processing in volume rendering |
| | CLUT | Possibility to change the colour lookup table in VR mode |
| | SSD | Ability to perform processing in shaded surface display |
| 6 | Support | |
| | Documentation | Presence of supporting documentation (manuals, guides) |
| | Wiki | Presence of support as Wiki |
| | Forum | Presence of a dedicated forum (discussion group) |
| | Source code | Availability of source code |
| 7 | Platform | |
| | Windows | Application is compatible with Windows systems |
| | Linux | Application compatible with Linux systems |
| | Macintosh | Application compatible with Macintosh OSX |
| | Java | Program supported by the Oracle Java |
| 8 | Usability | |
| | GUI | Care and usability of the graphic user interface |
| | Simplicity | Easy to set the desired operations |
| | Speed | Execution speed |
| 9 | Overall | Overall evaluation of the applications |

drop-downs from which you can select the method of processing or analysis. Its modular organisation allows the easy addition of new plug-ins. The interactive visualisation capabilities of 3D Slicer include the management of arbitrarily oriented images, the construction of surface models and visualisation of volume rendering in which you can modify the thresholds and colour scales (CLUT).

### Ginkgo CADx

Ginkgo CADx (Fig. 2) is a multi-platform OSS program that, in addition to a DICOM viewer offers features such as DICOM conversion (JPEG, PNG, GIF and TIFF to DICOM), complete integration with the HL7 standard, XML-RPC and IHE compliant workflows and PACS

**Table 4** Parameters of CT examinations

| Study description | Abdomen CT angiography | Contrast-enhanced abdomen CT | Brain CT angiography | Run-off CT angiography |
|---|---|---|---|---|
| Series overview | Arterial | Aortic CT angiography | CT angiography | CTA 3.0 CE |
| CT builder | Philips | GE medical system | GE medical system | Toshiba |
| CT model | Brilliance 16 | LightSpeed VCT | LightSpeed VCT | Aquilion |
| Scan type | Helix | Helical mode | Helical mode | Helical_CT |
| Slice thickness (mm) | 2.0 | 1.25 | 0.625000 | 3.0 |

**Table 5** Hardware characteristics of personal computers

| Model | Platform | CPU | RAM | Graphics card | Video memory |
|---|---|---|---|---|---|
| Sony Vaio VGN-FW11E | Windows 7 Ultimate SP1<br>Ubuntu 11.04 Natty Narval | Intel Core 2 Duo 2,26 GHZ | 4 Gb 800 MHz | ATI Radeon 4320 HD | 256 Mb |
| Apple MacBook | Mac OSX 10.7.5 | Intel Core 2 Duo 2,26 GHZ | 4 Gb 1067 MHz | Nvidia GeForce 9400 M | 256 Mb |

Workstation functionality (C-FIND, C-GET and C-MOVE, C-STORE). The software has been developed with various open source tools: VTK, ITK, DCMTK, OpenSSL and SQLite.

InVesalius

InVesalius (Fig. 3) is an application developed by the InVesalius Community and includes a searchable database of patients. In this application, the selection of a series allows the reconstruction of multiplanar reformation (MPR) type images. It also performs processing in 3D such as maximum intensity projection (MIP), volume rendering (VR) and shaded surface display (SSD) on which can be applied, by selecting the relevant anatomy, levels of transparency and CLUT changes.

Mito

Mito (Fig. 4) is an application developed by iHealt Lab exclusively for the Windows platform, which integrates a searchable database of patients, and is able to communicate with a PACS server and other DICOM nodes. The software allows you to select three different types of processing, the 2D viewer, 3D direct VR and 3D indirect VR. In the 3D direct VR menu, you can perform MIP. The 3D indirect VR menu allows visualisation of SSD.

MITK 3M3

MITK 3M3 (Fig. 5) is developed by the German Cancer Research Centre (DKFZ) and the Medical Mint, with C++ libraries and DCMTK, based on the MITK, ITK and VTK toolkits. The application is platform-independent (Windows, Linux or Mac OSX) and has an intuitive and user-friendly interface (for example, it allows you to load data using drag and drop). The availability of many menus enables easy access to all kinds of image data and import and export of DICOM files directly from/to a directory.

For the Macintosh platform:

MedINRIA

MedINRIA (Fig. 6) is a collection of software developed within the Asclepios research project at INRIA (Institut National de Recherche en Informatique et Automatique in Sophia Antipolis, France) which allows you to process and analyse a wide variety of images, allowing 2D/3D visualisation and VR.

OsiriX

OsiriX (Figs. 7, 8) is an image processing application specifically for DICOM images, developed by the Department of Radiology and Medical Informatics, University Hospital of Geneva in collaboration with the University of California at Los Angeles (UCLA) and is implemented with OSS tools such as ITK, VTK and DCMTK [13, 14]. Among its strengths are tools for navigation and visualisation of multimodal and multidimensional images: 2D/3D viewer, 4D viewer (3D series with temporal dimension, e.g., Cardiac-CT) and 5D viewer (3D series with temporal and functional dimensions, e.g., Cardiac-PET-CT). The 3D viewer offers all modern rendering tools: MPR, SSD, VR and MIP. These are also able to merge images from different modalities (CT, MRI, PET-CT, PET-MRI).

**Table 6** Results of the evaluation of the Windows-Linux platform applications

| Program | Data import | | | | Data export | | | Metadata | | 2D viewer | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Images | Set | Series | Directory | Images | Series | Anonymizer | Images | Study | Windowing | CLUT | Histogram | Info | Measure | Annotations |
| 3D Slicer | X | X | X | X | X | | | X | X | X | X | X | X | X | X |
| Aeskulaps | X | X | | X | | | | X | X | X | | | | | |
| Amide | | | X | | | X | | X | | X | | X | X | | |
| BioImageXD | Nota 1 | | | | X | X | | | | X | X | | | X | X |
| Dicompyler | | | X | X | | | X | X | X | X | | | X | | |
| Endrov | X | X | | | | | | | | X | | | X | | |
| EViewBox | | | X | X | | X | | | | | | | | | |
| Fusion viewer | X | | | | | | | X | | X | X | | | X | |
| Gimias | | | | X | | | | | | X | | | | X | X |
| Ginkgo CADx | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X |
| ImageJ | X | | X | | X | | | | | X | | X | X | X | X |
| ImageVis3D | | | | | X | | | | | | | | | | |
| InVesalius | X | X | X | X | X | X | | | | X | X | | X | X | X |
| ITK-SNAP | | | X | | X | | | X | X | X | X | X | | X | |
| Mayam | X | X | X | X | X | X | | X | X | X | | | X | X | X |
| Mango | X | | | X | | | | X | | X | | X | X | X | X |
| Micro view | X | | X | X | X | | | | | X | | | | X | X |
| Mito | X | | X | X | X | X | X | X | X | X | | | X | X | X |
| MITK 3M3 | X | X | X | X | X | | | X | X | X | X | X | X | X | X |
| MVE | X | X | | | X | | | X | X | X | X | | X | X | X |
| Nukak3D | | | | X | X | | | | | X | X | | | | |
| Santec/Tudor | X | X | X | X | | | X | X | X | X | | X | X | X | X |
| Seg3D | X | X | X | | X | | | | | X | X | X | X | X | X |

| Program | 3D viewer | | | | | | | Support | | | | Platform | | | | Usability | | | Overall |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Slice scrolling | MPR | CPR | MIP | VR | CLUT | SSD | Documents | Wiki | Forum | Source code | Windows | Linux | Macintosh | Java | GUI | Simplicity | Speed | |
| 3D Slicer | X | X | | X | X | X | X | X | X | X | X | X | X | X | | 9 | 8 | 6 | 9 |
| Aeskulaps | X | | | | | | | X | | | X | X | X | | | 6 | 5 | 7 | 6 |
| Amide | X | X | | X | | X | | X | | X | X | X | X | X | | 7 | 7 | 6 | 7 |
| BioImageXD | X | X | | X | X | | | X | X | | X | X | | X | | 7 | 6 | 6 | 5 |
| Dicompyler | X | | | | | | | X | X | X | X | X | | X | | 6 | 6 | 7 | 6 |
| Endrov | X | | | | | | | X | X | | X | | | | X | 4 | 5 | 4 | 4 |
| EViewBox | X | X | X | | | | | | | | X | | | | X | 4 | 5 | 5 | 4 |
| Fusion viewer | | | | | | | | X | | | X | X | | X | X | 3 | 3 | 5 | 3 |
| Gimias | X | X | | | X | X | | X | X | | X | X | X | | | 7 | 6 | 5 | 6 |

**Table 6** continued

| Program | 3D viewer | | | | | | | Support | | | | Platform | | | | Usability | | | Overall |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Slice scrolling | MPR | CPR | MIP | VR | CLUT | SSD | Documents | Wiki | Forum | Source code | Windows | Linux | Macintosh | Java | GUI | Simplicity | Speed | |
| Ginkgo CADx | X | | | X | X | X | X | X | | | X | X | X | X | | 8 | 7 | 8 | 8 |
| ImageJ | X | X | | | | | | X | X | | X | | | | X | 4 | 5 | 5 | 5 |
| ImageVis3D | X | | | | X | X | X | X | X | | | X | X | X | | 4 | 5 | 7 | 5 |
| InVesalius | X | X | | X | X | X | X | X | X | X | X | X | X | X | | 8 | 7 | 6 | 8 |
| ITK-SNAP | X | X | | | X | X | | X | | X | X | X | X | X | | 7 | 7 | 7 | 7 |
| Mayam | X | X | | X | X | | X | | | X | X | | | | X | 7 | 6 | 6 | 7 |
| Mango | X | X | | | | | X | | | X | X | X | X | X | X | 5 | 5 | 5 | 5 |
| Micro view | X | X | | | | | | X | | | | X | X | X | | 6 | 6 | 6 | 6 |
| Mito | X | | | X | X | X | X | X | | X | X | X | | | | 7 | 8 | 7 | 8 |
| MITK 3M3 | X | X | | X | X | X | | X | | | | X | X | X | | 8 | 8 | 7 | 8 |
| MVE | X | X | | X | | | | X | | | | X | | | | 6 | 6 | 7 | 6 |
| Nukak3D | X | X | | X | | X | X | X | | | | X | | | | 5 | 7 | 6 | 6 |
| Santec/Tudor | X | | | | | | | X | | | | | | | X | 5 | 5 | 5 | 5 |
| Seg3D | X | X | | | X | X | | X | | | | X | X | X | | 7 | 7 | 6 | 7 |

VolView

Volview (Fig. 9) is a graphical interface for volume rendering and visualisation of data based on ITK and VTK, and is primarily designed to allow exploration of 3D datasets. It is developed by Kitware Inc which distributes it both as freeware and as a commercial product. The application is versatile and fast, and is able to perform a large number of operations.

VR-Render

VR-Render (Fig. 10) is free software made available by IRCAD (Institut de Recherche Contre les Cancers de l'Appareil Digestif, Strasbourg, France) for rendering images based on VTK, ITK and DCMTK. It allows you to manage DICOM images; it supports 2D/3D views as well as multiplanar rendering, MIP and VR. It is extremely simple and intuitive.

## Discussion

The features supported by most software analysed rarely meet all the real needs of operators: some have simple and intuitive interfaces, but lack basic operations in 2D (ImageVis3D), or while supporting the viewer function do not offer additional tools (Aeskulaps, Amide, Dicompyler, Endrov, EViewBox, ImageVis3D, iRad, ITK-SNAP, Nukak3D, Tudor DicomTools and Weasis). Others support multiplanar views (MPR), but have no 3D tools (Micro View and EViewBox). In other cases, programs do not offer satisfactory direct import of DICOM images, resulting in significant information loss, and need conversion tools (BioimageXD and ImageVis3D). Among those that have integrated almost all the post-processing tools, some require a large amount of memory and high performance hardware (Gimias, ImageVis3D, Mayam, MIPAV and MITK 3M3) or do not offer practical possibilities for volumetric analysis (Madena). With regard to Linux-Windows systems (Table 6), many applications are developed in Java (Oracle) since this is a platform available for all operating systems (Windows, MAC OS X and Unix) and is easily accessible to all programmers.

By analysing the different programs and testing them on the operating systems described above, it was found that most applications perform better on Windows than on Linux. This situation does not depend on issues in software development, but on the fact that software is usually developed on Linux or Unix machines by users with medium–high experience who are able to interact with the software by command line. In contrast, on Windows systems, with users typically with low-to-medium knowledge,

**Table 7** Results of the evaluation of Macintosh platform applications

| Program | Data import | | | | Data export | | | Metadata | | 2D viewer | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Images | Set | Series | Directory | Images | Series | Anonymizer | Images | Study | Windowing | CLUT | Histogram | Info | Measure | Annotations |
| 3D Slicer | X | X | X | X | X | | | X | X | X | X | X | X | X | X |
| Amide | X | | X | | X | X | | X | | X | | X | X | | |
| Dicompyler | | | X | X | | | X | X | X | X | | | X | | |
| Ginkgo CADx | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X |
| ImageVis3D | X | | | X | X | | | | | | | | | | |
| iRad | X | X | X | X | X | | | X | X | X | X | | X | X | X |
| ITK-SNAP | | | X | | X | | | X | X | X | X | X | | X | |
| Madena | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X |
| Mango | X | | | X | | | | X | | X | | X | X | X | X |
| MAYAM | X | X | X | X | X | | | X | X | X | | | X | X | X |
| MedINRIA | X | X | X | | X | | | | | X | X | | | | |
| Micro view | X | | X | | X | X | | X | | X | | X | X | | |
| MIPAV | X | X | | | X | | X | X | X | X | X | X | X | X | X |
| MITK 3M3 | X | X | X | X | X | | | | | X | X | | X | X | X |
| OsiriX | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X |
| Seg3D | X | X | X | | | X | | | | X | | X | | | |
| Tudor | X | X | X | X | X | | X | X | X | X | X | X | X | X | X |
| VolView | X | X | X | X | X | | | X | X | X | X | X | X | X | X |
| VR Render | X | | X | X | X | X | | X | | X | X | X | | X | X |
| Weasis | X | X | X | | X | X | | X | X | X | X | X | X | X | |

| Program | 3D viewer | | | | | | | Support | | | | Platform | | | | Usability | | | Overall |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Slice scrolling | MPR | CPR | MIP | VR | CLUT | SSD | Documents | Wiki | Forum | Source code | Windows | Linux | Macintosh | Java | GUI | Simplicity | Speed | |
| 3D Slicer | X | X | | X | X | X | X | X | X | X | X | X | X | X | | 9 | 8 | 6 | 9 |
| Amide | X | X | | X | | X | | X | | X | X | X | X | X | | 7 | 7 | 6 | 7 |
| Dicompyler | X | | | | | | | X | X | X | X | X | | X | | 6 | 6 | 7 | 6 |
| Ginkgo CADx | X | | | X | X | X | X | X | | | X | X | X | X | | 8 | 7 | 8 | 8 |
| ImageVis3D | | | | | X | X | X | X | X | | | X | X | X | | 4 | 5 | 7 | 5 |
| iRad | X | X | | | | | | | | X | X | | | X | | 6 | 7 | 8 | 7 |
| ITK-SNAP | X | X | | | X | X | | X | | X | X | X | X | X | | 7 | 7 | 7 | 7 |
| Madena | X | X | | | | | | X | | | | | | X | | 5 | 7 | 7 | 7 |
| Mango | X | X | | | | | X | X | | X | X | X | X | X | X | 5 | 6 | 6 | 7 |
| MAYAM | X | X | | X | X | | X | X | | X | | X | X | X | | 7 | 7 | 6 | 7 |
| MedINRIA | X | X | | X | X | X | | X | X | X | | X | X | X | | 8 | 9 | 8 | 9 |
| Micro view | X | X | | | X | | X | X | | X | | X | X | X | | 6 | 6 | 7 | 6 |

**Table 7** continued

| Program | 3D viewer | | | | | | | Support | | | | Platform | | | | Usability | | | Overall |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Slice scrolling | MPR | CPR | MIP | VR | CLUT | SSD | Documents | Wiki | Forum | Source code | Windows | Linux | Macintosh | Java | GUI | Simplicity | Speed | |
| MIPAV | X | X | | | X | X | X | X | X | | | X | X | X | X | 7 | 7 | 7 | 7 |
| MITK 3M3 | X | X | | X | X | X | | X | | | | X | X | X | | 9 | 8 | 8 | 9 |
| OsiriX | X | X | X | X | X | X | X | X | X | X | X | | | X | | 10 | 10 | 10 | 10 |
| Seg3D | X | X | | | X | X | | X | X | | X | X | X | X | | 7 | 7 | 7 | 7 |
| Tudor | X | | | | | | | | | | | | | X | | 4 | 6 | 0 | 3 |
| VolView | X | X | | X | X | X | | | | | | X | X | X | X | 9 | 9 | 8 | 9 |
| VR Render | X | X | | | X | X | | X | | | | X | X | X | | 8 | 9 | 8 | 9 |
| Weasis | X | | | | | | | X | | X | X | X | X | X | X | 8 | 8 | 8 | 7 |

the community usually develops "stable" software with a GUI and therefore does not require interaction from the terminal.

It should be pointed out that no software was awarded the maximum score, because none fulfils all the real application requirements. The most interesting applications appear to be Ginkgo, CADx, Invesalius, Mito, and MITK 3M3, which meet the basic needs of a workstation, allowing automatic 3D analysis and discrimination of the different anatomical structures.

InVesalius, Mayam Myth and Mito also have a database where you can search for the examinations (the default directory, DICOM PACS server or CD), in a similar manner to a proprietary workstation.

Particular attention should be paid to 3D Slicer, the only program that was awarded the highest rating (9). This application has all the characteristics of a suitable tool for post-processing: able to analyse the images in the different representations, very fast in drawing 3D, most complete and interactive menu, but it fails to integrate all the functionality of a workstation, such as curved planar reformation.

As for the Macintosh platform (Table 7), VR Render, Volview and MedINRIA deserve special mention, and appear to be the most mature and fully functional projects, offering comprehensive tools associated with easy and accessible interfaces. Each one has various possibilities for improvement that the community certainly will not take long to implement (ability to perform MPR curves or SSD) [15].

OsiriX deserves a separate discussion; the analysis shows it to be the only software able to perform all operations on par with dedicated workstations with proprietary software.

In view of the undoubted potential of OSS applications, it should be emphasised that an essential regulatory aspect is crucial for the diagnostic use of such software [16]. According to the definition of EEC Directive 93/42 on medical devices, implemented in Italy by Legislative Decree n.46/1997, PACS systems are medical devices, by virtue of being used for diagnostic purposes. The main factor that prevents the certification of OSS applications distributed with the source code is because there is no guarantee that the certified software is the same device that you are using since anyone—even the same user—could change the code and consequently invalidate its certification. With proprietary software there is no possibility of changing the code because no one can access the source code and modify it, thus there is no possibility of making unauthorised changes. An OSS application will be approved for diagnostic use if the developer (or the distributor of the product) has fine-grained control of the distributed version and inhibits access to the source code, failing which the penalty would be loss of certification [17].

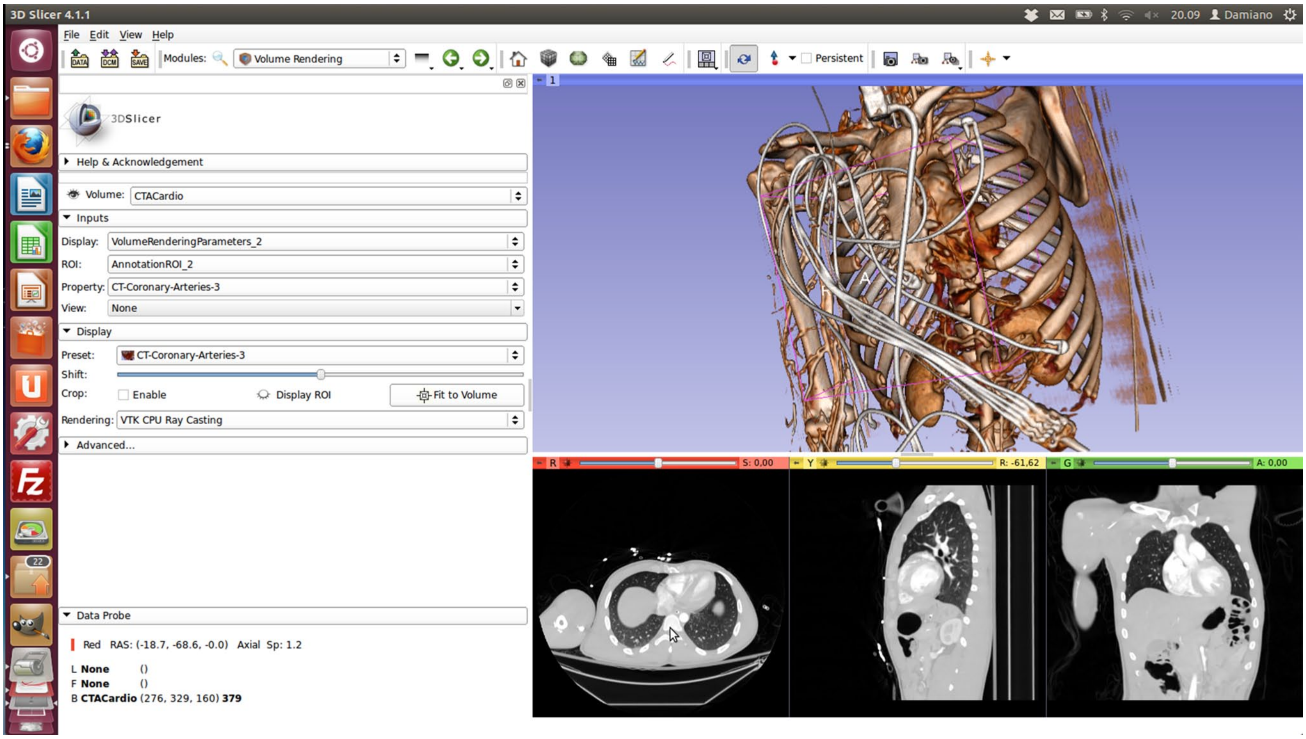
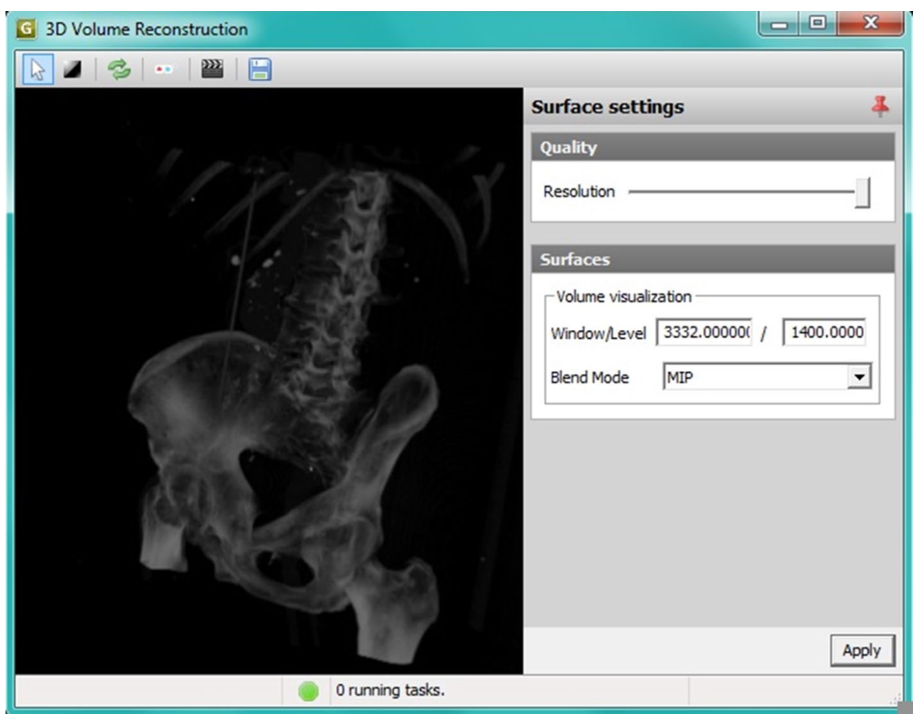



**Fig. 1** 3D Slicer: multiplanar reconstruction and volume rendering

**Fig. 2** Ginkgo CADx: maximum intensity projection




It should also be pointed out that these OSS applications, even the most complete (which include all classes of a PACS DICOM services), lack the security guarantees described above and currently do not support all the functions necessary for the management of digital imaging in the healthcare field [18].

The text above should not however detract from the enormous value of OSS applications in contexts that are

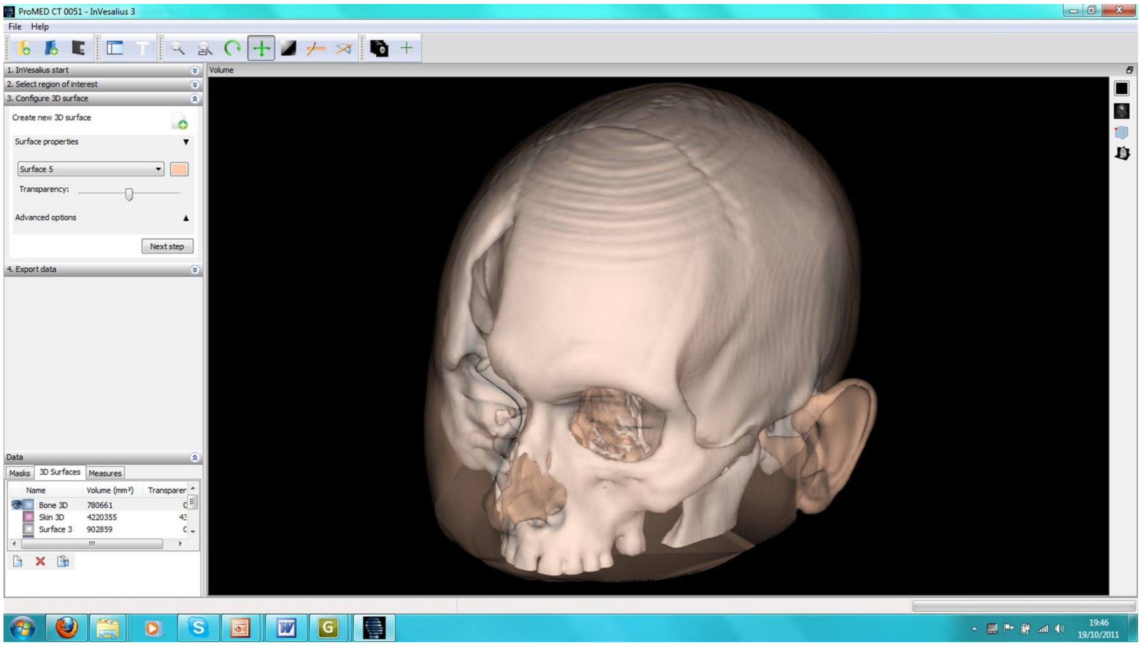



Fig. 3 Invesalius: shaded surface display

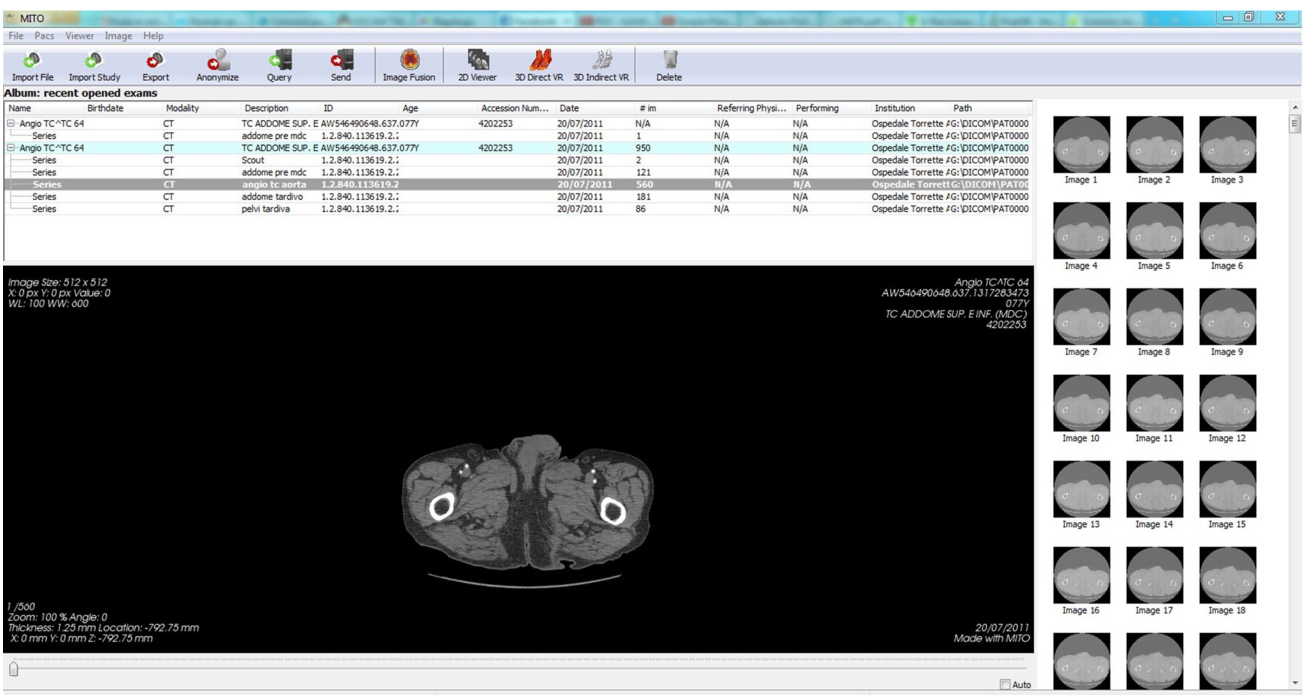



Fig. 4 Mito: screen display

not exclusively diagnostic: to have software that can compete with expensive proprietary versions is extremely useful for students and health professionals who want to practise and extend their skills in an ever-changing industry [19].

## Conclusions

The advantages of OSS are: low initial cost (for both licenses and updates); independence from suppliers (it prevents a monopoly by software producers, allowing for more

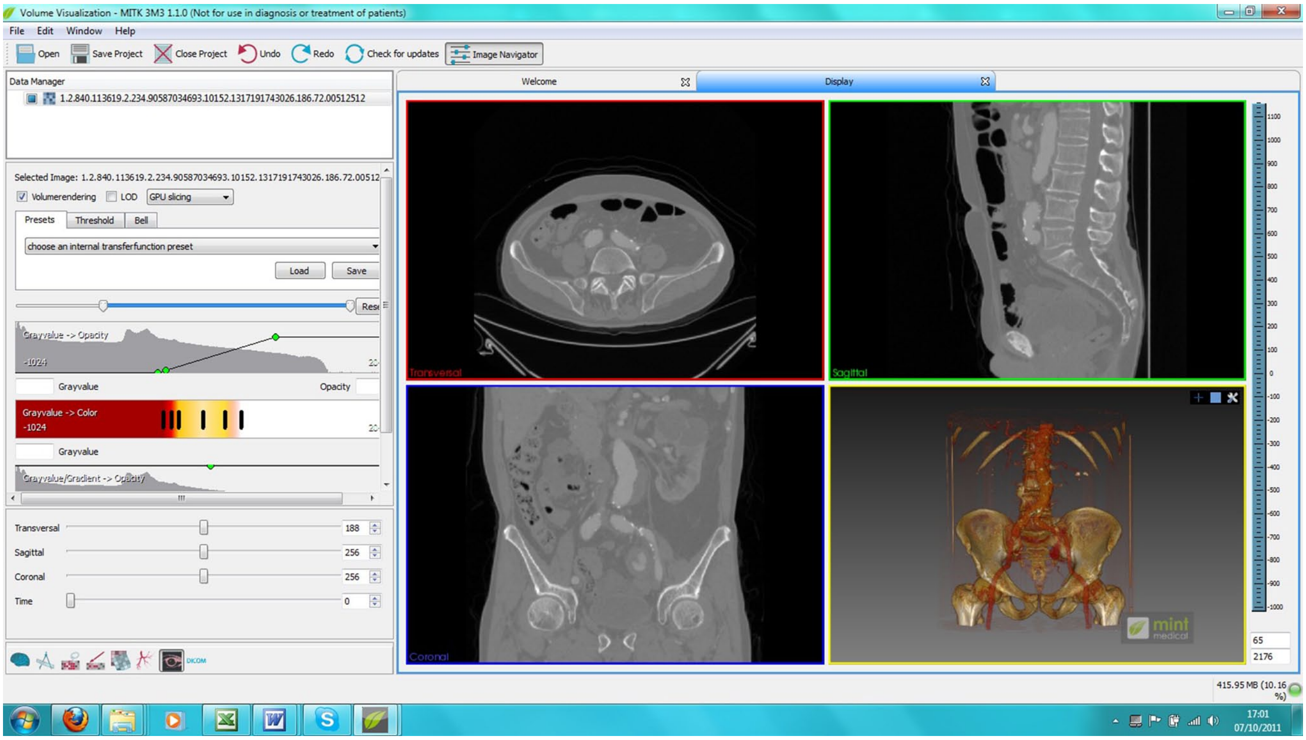


Fig. 5 MITK 3M3: multiplanar reconstruction and volume rendering

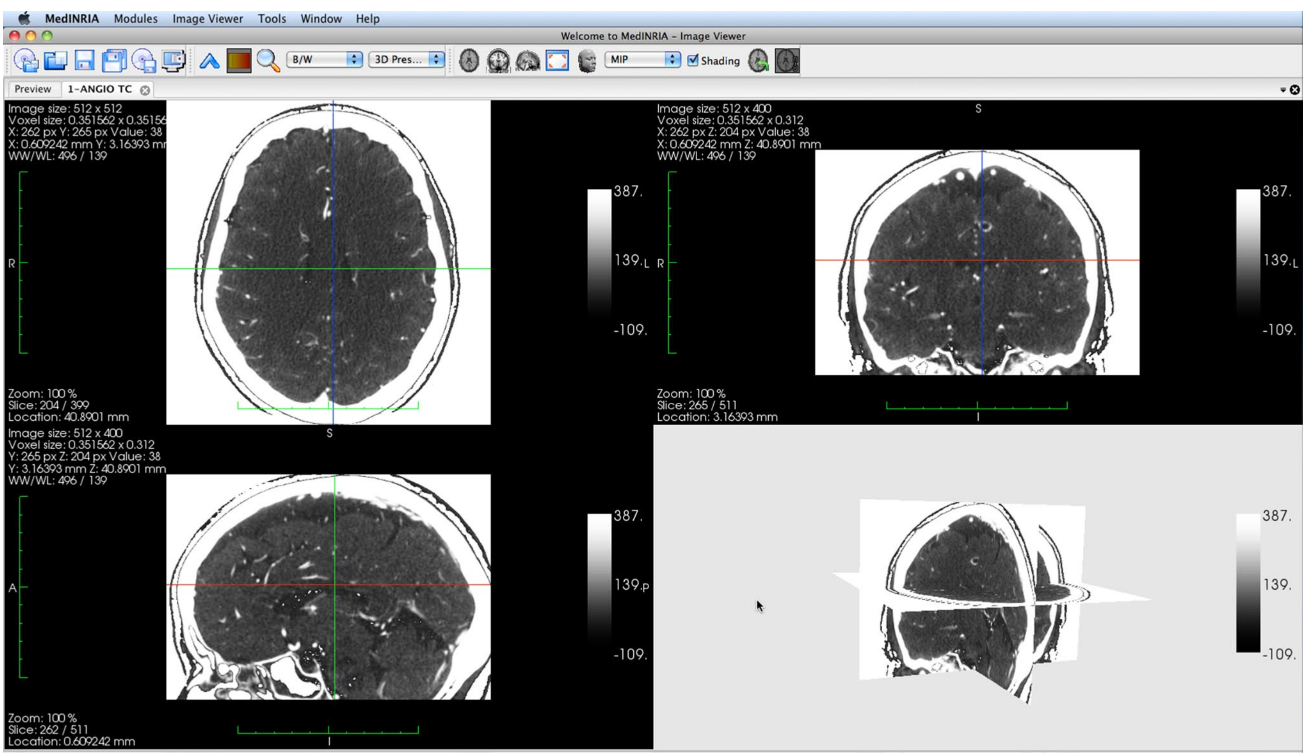


Fig. 6 MedINRIA: multiplanar reconstruction

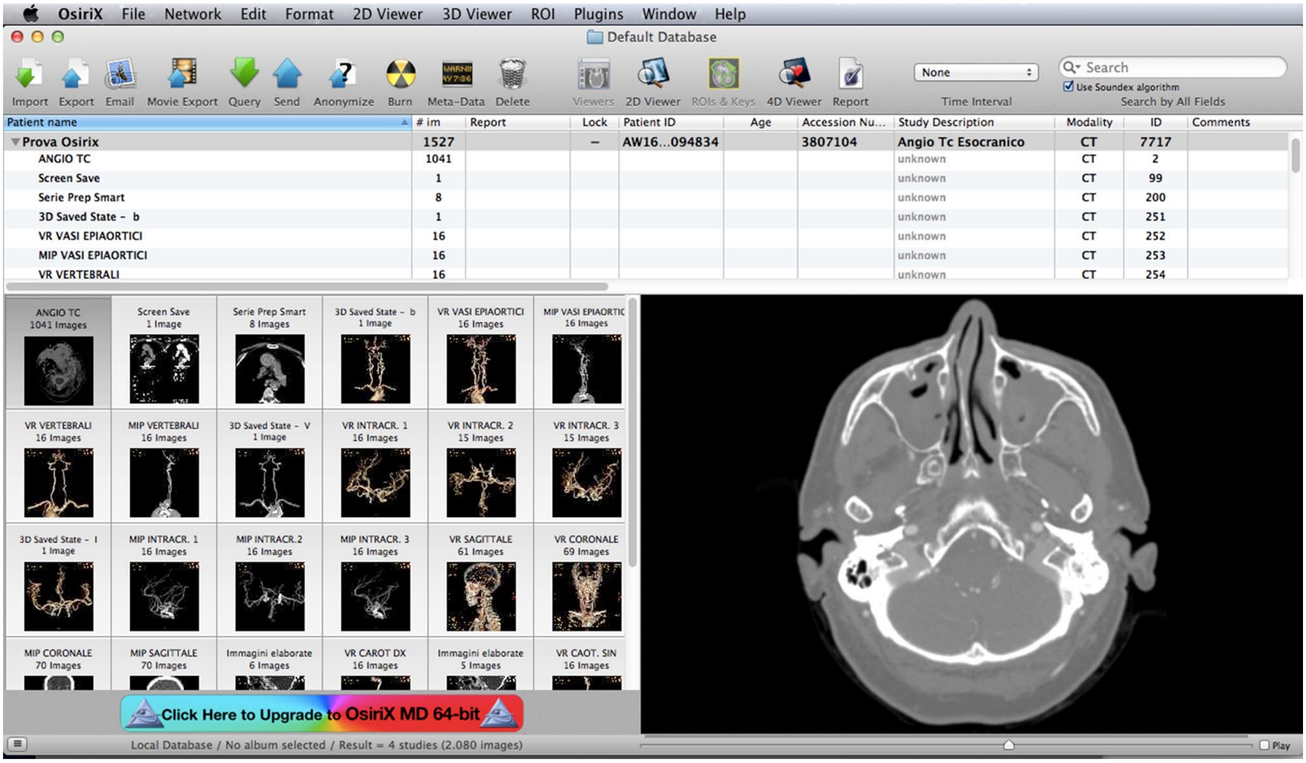



**Fig. 7** OsiriX: screen display

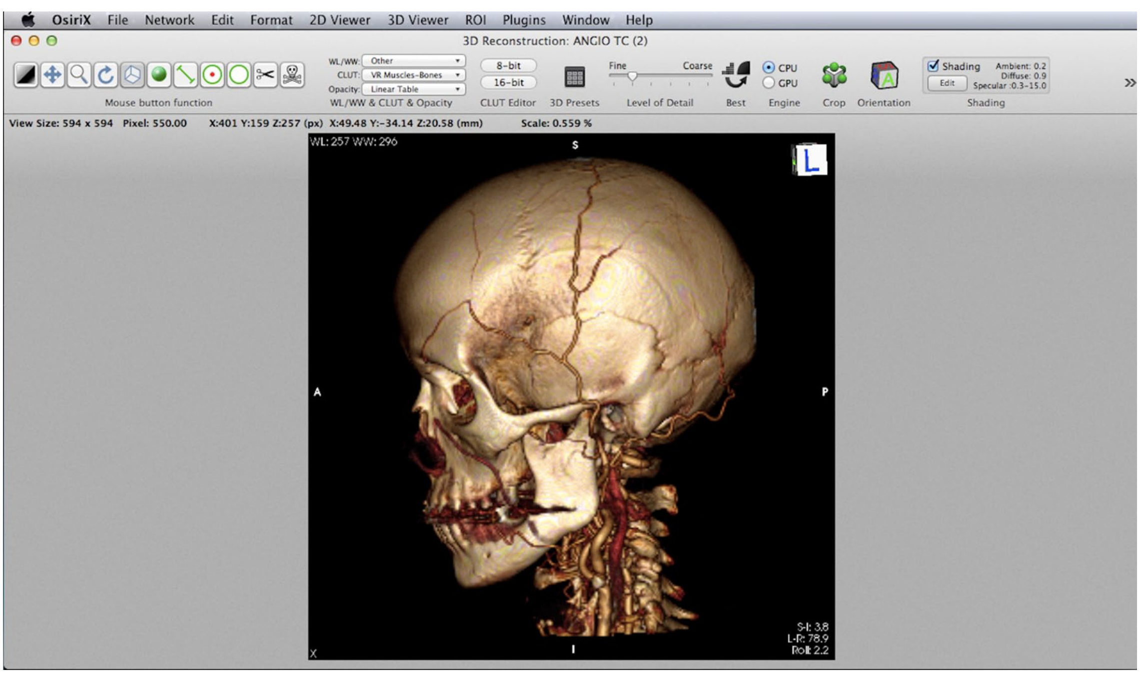



**Fig. 8** OsiriX: volume rendering

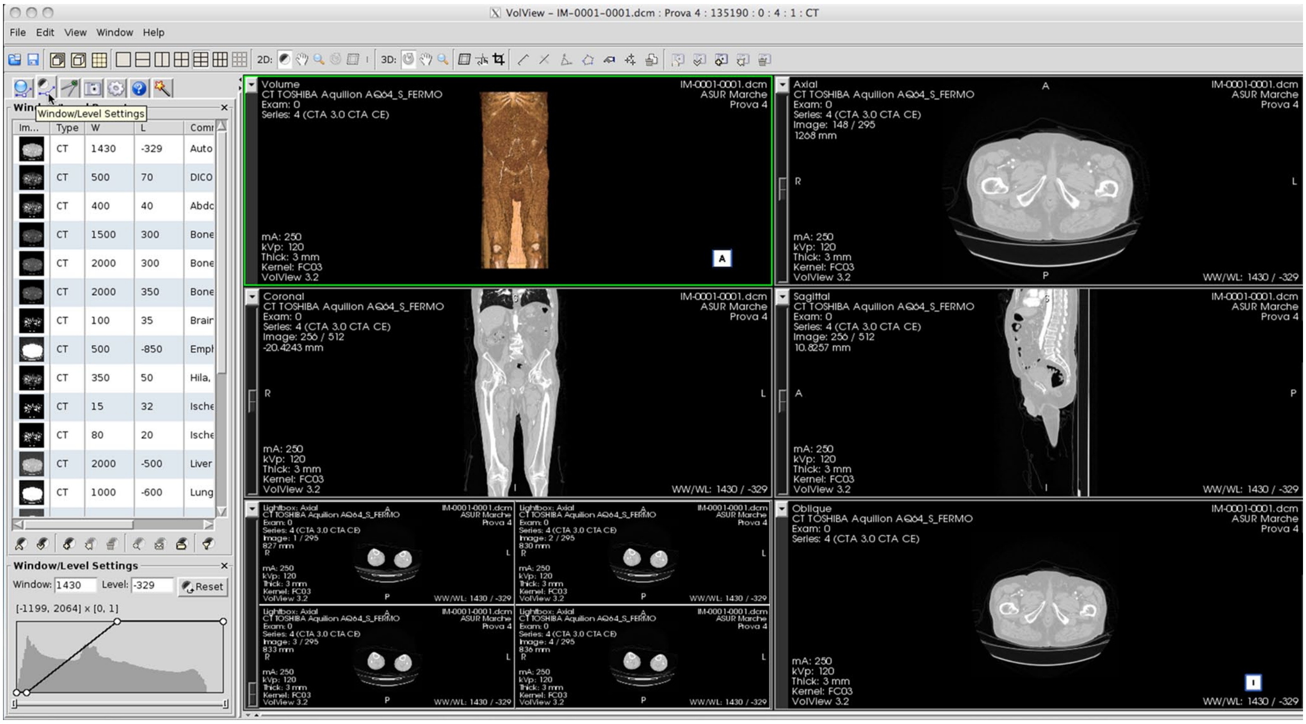



**Fig. 9** VolView: screen display

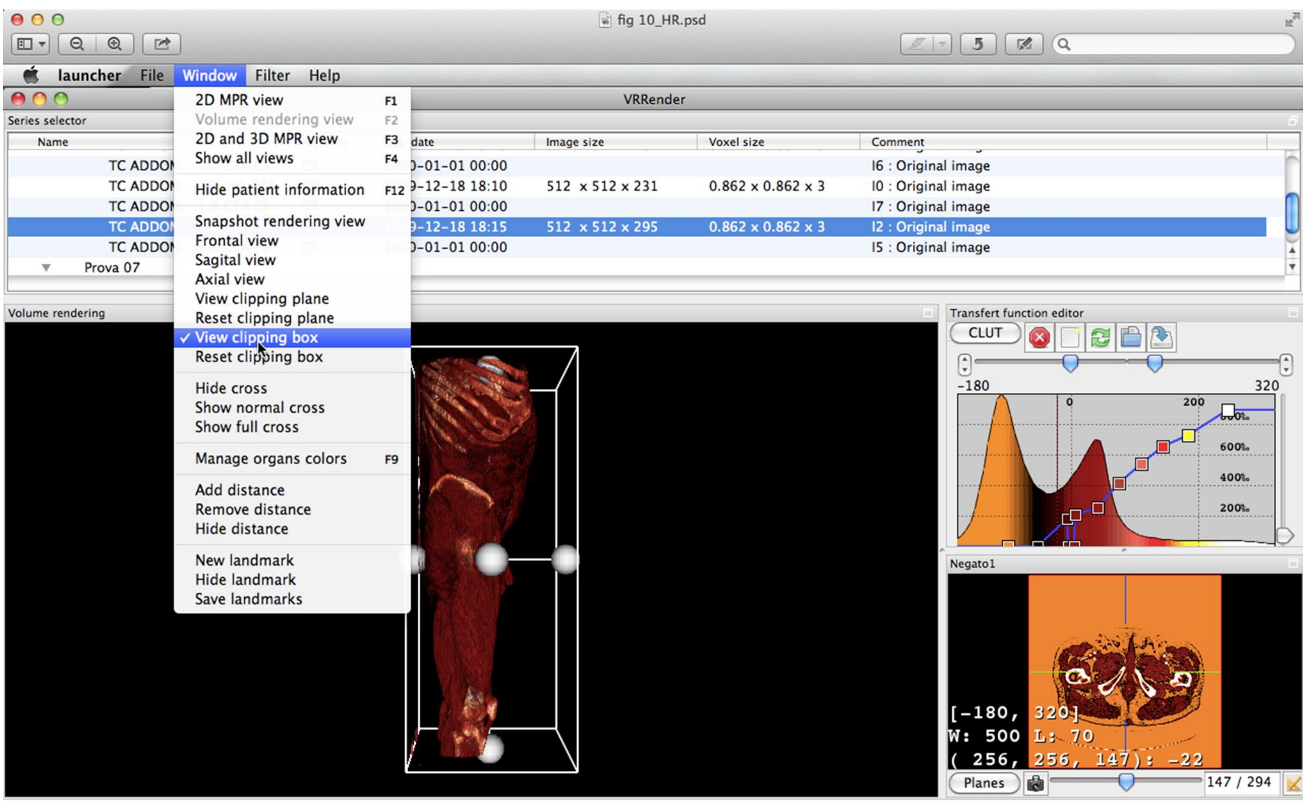



**Fig. 10** VR-Render: screen display

control by the client), data security (particularly of confidential information, a paramount need for public administration), flexibility (more suitable for targeted customisations compared to proprietary software), interoperability (the availability of the source code facilitates implementation of interfaces that allow the exchange of data between different programs and functions).

The disadvantages are: low compatibility with commercial standards (proprietary systems that have become de facto standards), technical support is not guaranteed; instability of the market and lack of business applications and drivers.

Regarding the management of biomedical images, in recent years, we have witnessed an exponential growth of ever more efficient and focussed applications, seeking to facilitate the work of employees in the sector, especially regarding the processing of various types of three-dimensional clinical images and postprocessing in general.

For the management of such images, OSS applications have emerged as a real and revolutionary development model, able to offer highly competitive tools and support for the processes of production, storage, processing and transmission of diagnostic information in spite of the possible lack of appropriate certifications (as medical devices) that limit their use in clinical practice [20].

These applications represent an effective means for simulation, can improve the operating performance of health personnel and are the tools of choice in teaching because they can greatly expand the effectiveness of workshops and clinical training, facilitating the achievement of specific objectives.

**Conflict of interest** Valeri Gianluca, Mazza Francesco Antonino, Maggi Stefania, Aramini Daniele, La Riccia Luigi, Mazzoni Giovanni, Giovagnoni Andrea declare that they have no conflict of interest related to the publication of this article.

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