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Recent advances in visualization, volumetric analysis and 3D reconstruction in musculoskeletal imaging using the OsiriX open source DICOM software

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Abstract— For decades, diagnostic imaging in rheumatology has used conventional radiography. The development of imaging techniques, such as magnetic resonance imaging (MRI) scanning, ultrasonography, computed tomography (CT), positron emission tomography (PET), and image processing methods provide rheumatologists with powerful tools that may hopefully lead to reliable diagnosis, quantitative evaluation and intuitive visualization. The standard open-source functional Digital Imaging and COmmunication in Medicine (DICOM) software, provides the tools for interactive reconstruction of 3D images and multiplanar reformatting of data from any imaging modality. OsiriX is a free and open-source DICOM software that allows anyone to reconstruct and manipulate 3D images. It is highly practical from the perspective of user-friendliness, and its high performance processing power allows rheumatologist to easily generate a variety of images in real time and select the most adequate view of the specific anatomical structures that are of interest. The present article aims to discuss the key issues related to diagnostic imaging in patients with inflammatory arthritis, connective tissue diseases (CTDs) or systemic vasculitis, and to increase the awareness of rheumatologists about this field.

Index Terms— Rheumatology, imaging techniques, DICOM, open source, OsiriX

1 INTRODUCTION

Imaging in rheumatology was in the past largely confined to radiographs of the hands and sacroiliac joints (SIJs) helping to establish the diagnosis and then monitoring disease progression [1]. This perspective continues to be relevant, but with the introduction of advanced modalities, imaging has recently assumed another and equally important role as a non-invasive means to investigate joint pathology. Increasingly, magnetic resonance imaging (MRI) scanning, ultrasonography, computed tomography (CT) and positron emission tomography (PET), are taking the place of conventional radiography (CR) for the assessment of rheumatoid arthritis (RA), spondyloarthritis (SpA), connective tissue diseases and systemic vasculitis. These more sensitive imaging modalities will provide information to assist in the early diagnosis, identify poor prognostic factors, and aid in the monitoring of response to therapy [2].

Efficient methods for diagnosis, monitoring and prognosis are essential in early RA [3], [4]. With the advent of new disease-modifying therapy for inflammatory arthritis, patients have great advantages and benefits from an early diagnosis because the therapies show good results if used promptly, before severe disability secondary to RA has occurred [5]. Imaging modalities capture the two main features of arthritis: the structural damage and inflammation. Structural damage can be assessed by CR, CT, ultrasonography and MRI [6], [7], while inflammation can mainly be assessed by ultrasonography or colour Doppler ultrasonography, MRI and PET; this latter is a nuclear medicine imaging technique that visualises functional processes in the body [8]. The use of multi-detector CT with multi-planar reconstruction, allows the three-dimensional visualization of joints, whereas radiography is just a projection technique offering only a two-dimensional visualization of the three-dimensional anatomy [9]. The technology to quantify synovitis and erosions is developing rapidly and now allows change in the modalities used for the assessment of the diseases. Advances in MRI of arthritis include contrast-enhanced, dynamic, and quantitative imaging techniques [10]. With these advances, MRI may become the gold standard for detecting arthritic joint pathologies, for monitoring the response to therapy and prognosis of early RA.

Over the past decades, MRI has proven capable of detecting inflammatory lesions seen in SpA patients [11]. SpA is a rheumatologic disease that comprises the different disease entities of ankylosing spondylitis (AS), reactive arthritis, psoriasis arthritis, spondyloarthritis associated with inflammatory bowel disease, and undifferentiated SpA. The main symptoms are chronic back pain, associated with extra-spinal manifestations and particular laboratory findings. It is likely that attention will now focus on patients with early disease to further understand the prognostic capacity of MRI. In particular, the development of the new Assessment of SpondyloArthritis International Society (ASAS) classification criteria has broadened the spectrum of disease to include patients with non-radiographic disease [12]. An accurate and perceptive measure of the rate of syndesmophyte growth is important because it would permit the evaluation of new drugs that may slow the progression of spinal fusion in AS. High-resolution CT (HRCT) appears to be an appropriate modality for obtaining

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precise measurements. Previous work has mainly relied on manual 3-D segmentation of vertebral bodies and syndesmophytes model based methods [13].

Connective tissue diseases (CTDs) are a diverse group of immunologically mediated systemic disorders that often lead to thoracic changes, although the frequency of lung manifestations varies according to the type of CTD. Interstitial lung diseases (ILD) are frequently seen in CTDs, particularly systemic sclerosis (SSc), polymyositis/dermatomyositis (PM/DM) and RA, accounting for a significant proportion of deaths. ILD constitute an important group in this respect and it is estimated that the overall incidence is 15%. Today, still diagnosis, treatment, follow-up, prognosis of CTD-ILD related clinical problems have been experienced. In particular, because ILD may be the presenting manifestation of SSc and/or the dominant manifestation of disease [14], clinical extra-thoracic manifestations should be systematically considered in the diagnostic approach.

SSc is a heterogeneous autoimmune disorder of unknown aetiology that is characterized by musculoskeletal involvement, vascular dysfunction, cutaneous and visceral fibrosis. ILD was reported in up to 70% of patients with SSc and frequently it can be cause of death of these patients [15]. HRCT is currently the most accepted imaging tool for the detection, characterization and treatment monitoring of ILD [16]. Consequently, the CTD-ILD working group of the Outcome Measures in Rheumatology (OMERACT) international consensus initiative convened to propose HRCT as the outcome measures to be used in future RCTs and registries in CTD-ILD [17]. Despite these recommendations, the correct interpretation of HRCT findings often still represents a problem for the inexperienced rheumatologists since there is a wide inter-observer variability even among expert radiologists. Therefore, in SSc is highly desirable a quantitative, non-invasive and reliable imaging method that could permit an accurate assessment of ILD.

The importance of imaging is encountered even in patients with systemic vasculitis, a problem that affects large, medium, small, or variable-sized vessels. With the aid of imaging in small vessels, it is possible to determine the extent of the vascular problem and activity, localization for biopsy, and the monitoring of disease [18]. MRI is sensitive because can well depict ANCA-related vasculitis, mastoiditis, and mucosal inflammation of earnoseand throat, but for the detection of cerebral vasculitis it is not specific. CT can reliably detect osseous facial lesions, the chest radiography in two planes is the standard method of investigation for the lower respiratory tract, and the best way for detecting the major part of interstitial pathologies is HRCT [18]. The classification criteria for polyarthritis nodosa involve the angiographic detection of visceral aneurysms: in fact medium-sized vasculitis frequently occur with aneurysms. Echocardiography or angiography,according to the diagnostic criteria, could identify a coronary aneurysm, which affect many patients with Kawasaki disease. In large-vessel vasculitis such as giant cell arteritis and Takayasu arteritis, in order to delineate characteristic homogenous wall thickening, with or without stenosis, in the aorta and other arteries MRI, MR-angiography, CT, CT-angiography, and duplex sonography can be used [19]. In some cases a PET using 18F-FDG may aid to detect active large vessel vasculitis in patients examined for symptoms of fever of uncertain origin [20].

The development of imaging techniques and image processing methods provide rheumatologists with powerful tools that may hopefully lead to reliable diagnosis, quantitative evaluation and intuitive visualization. The open-source functional DICOM software provides the tools for interactive reconstruction of 3D images and multiplanar reformatting of data from any imaging modality [21]. OsiriX offers advanced 3D post-processing tools such as surface and volume rendering, Multi-Planar Reconstruction (MPR), and Maximum Intensity Projection (MIP) [22]. It is highly practical from the perspective of user-friendliness and highly performance processing power allows rheumatologist to easily generate a variety of images in real time and select the most adequate view of the specific anatomical structures that are of interest. Much of the literature on advanced imaging in inflammatory arthritis and CTD/systemic vasculitis appears in radiological journals and may not be familiar to rheumatologists. The present article aims to increase the awareness of rheumatologists about this field and to encourage them to participate and contribute to the ongoing development of these multimodality compliant software programs.

2 Dicom

The increasing development of Imaging applications was made possible also by the adoption of the Digital Imaging and Communications in Medicine (DICOM) standard [23]. This is an international standard for handling, storing, printing, and transmitting medical images, created in 1983 by the American College of Radiology (ACR) and the National Electrical Manufacturers Association (NEMA) [23]. It arises from the need to have a standard for the communication between different devices, which use different hardware and software tools for the acquisition and manipulation of medical images that, mainly for commercial reasons,are incompatible with each other. DICOM adopts a TCP/IP network protocol that defines the format for the transfer of medical images on a PACS (Picture Archiving and Communication System) or on another workstation together with the information and quality necessary for clinical use. A DICOM file is composed of two main parts, header and the image data. The header contains all the information related to the patient (name, age, sex,..), and other information like the name of the physician, the technique of data acquisition, the image size, and so on. The image data contains all the attributes related to the image (number of pixels, slice depth, type of image format (bitmap, jpeg, gif, etc..)). DICOM is continuously evolving and is updated under the directions of the Procedures of the DICOM standards committee. Moreover, it also revolutionized the practice of radiology, allowing the replacement of X-ray films with digital image files. Unfortunately, in order to read these files, a DICOM Viewer is necessary, but today there is a variety of viewer choices thanks to the increasing availability of the Open Source software packages [21].

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3 OPEN SOURCE VIEWERS

With the advent of personal computers, the field of software development was in the hands of very few large Companies that imposed their standards and projected the software evolution according to their convenience, rather than for the advancement of community. To fix this limitation, researchers and companies created the "open source" initiative [21], [24]. An open source software is a software that can be freely used, changed, and shared (in modified or unmodified form) by anyone. It is a computer program where the source code of the software application is freely available so that every programmer can study, analyse, modify and extend it [21], [24]. Usually, programs where users have the possibility to have access at the source code are most often more intuitive than others. Researchers and companies have every day the possibility to develop different types of image processing software, in order to replace traditional image viewers available on PACS workstation, adapting them to the new features of multidimensional image display and manipulation, so that radiologists and rheumatologists can more and more efficiently analyse these image data sets. Today there are a lot of open source software packages for the study and manipulation of radiographs [21], [22], [24], [25], [26]; Table 1 compares some of the programs available regarding their usability, type of platform and support [26], focusing on these parameters:

- **Data import**
  - -Images: Import individual images
  - -Set: Import an arbitrary selection of images
  - -Series: Automatic import of whole series
  - -Directory: Import one or more folders of images
- **Data export**
  - -Images: Export single image in various formats
  - -Series: Exporting the whole series as DICOM series
  - -Anonymizer: Function anonymity images/series
- **Metadata**
  - -Images: Ability to display the header of the single image
  - -Study: Ability to display the header of the entire study
- **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: Measurement can be performed
  - -Remarks: Ability to put annotations on the images
- **3D viewer**
  - -Slice scrolling: Scroll function of a series of images
  - -MPR: Multiplanar Reconstructions
  - -CPR: Curved Multiplanar Reconstructions
  - -MIP: Maximum Intensity Projection
  - -VR: Volume Rendering
  - -CLUT: Possibility to change the colour lookup table in VR mode
  - -SSD: Shaded Surface Display
- **Support**
  - -Documentation: Presence of supporting documentation (manuals, guides)
  - -Wiki: Presence of support as Wiki
  - -Forum: Presence of forums
  - -Source code: Availability of source code
- **Platform**
  - -Windows: Compatible with Windows systems
  - -Linux: Compatible with Linux systems
  - -Macintosh: Compatible with Macintosh OSX
- **Usability**
  - -GUI: Care and usability of the graphic user interface
  - -Simplicity: Easy to set the desired operations
  - -Rapidity: Speed Execution

Overall evaluation of the applications

TABLE 1
COMPARISON BETWEEN SEVERAL OPEN SOURCE SOFTWARES

PROGRAM	Data Import				Data Export			Metadati	
	Image	set	Serie	Directory	Image	Serie	Anonymisation	Image	Study
1- 3DSLICER	X	X	X	X	X			X	X
2- AMIDE			X			X		X	
3- IMAGE J	X		X		X				
4- INVESALIUS	X	X	X	X	X	X			
5- iRAD	X	X	X	X	X			X	X
6- MADENA	X	X	X	X	X	X	X	X	X
7- MAYAM	X	X	X	X	X	X		X	X
8- MANGO	X			X				X	
9- MITO	X		X	X	X	X	X	X	X
10- OSIRIX	X	X	X	X	X	X	X	X	X
11- RADIANT	X	X	X	X	X	X	X	X	X
12- VOLVIEW	X	X	X	X	X			X	X

Part 1.a

PROGRAM	2D Viewer						3D Viewer						
	Windowing	CLUT	Histogram	Info	Measures	Annotations	Slice Scrolling	MPR	CPR	MIP	VR	CLUT	SSD
1-	X	X	X	X	X	X	X	X		X	X	X	X
2-	X		X	X			X	X		X		X	
3-	X		X	X	X	X	X	X					
4-							X	X		X	X	X	X
5-	X	X		X	X	X	X	X					
6-	X	X	X	X	X	X	X	X					
7-	X			X	X	X	X	X		X	X		X
8-	X		X	X	X	X	X	X					X
9-	X			X	X	X	X			X	X	X	X
10-	X	X	X	X	X	X	X	X	X	X	X	X	X
11-	X	X		X	X	X	X	X		X	X	X	X
12-	X	X	X	X	X	X	X	X		X	X	X	

Part 1.b

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	Support				Platform			Usability			
PROGRAM	Documents	Wiki	Forum	Source Code	Windows	Linux	Macintosh	GUI	Simplicity	Rapidity	Final Judgment
1-	X	X	X	X	X	X	X	8	7	6	**7**
2-	X		X	X	X	X	X	6	5	6	**6**
3-	X	X		X	X	X	X	5	5	6	**5**
4-	X	X	X	X	X	X	X	8	7	6	**7**
5-			X	X			X	6	8	8	**8**
6-	X						X	6	6	7	**7**
7-			X	X	X	X	X	8	9	8	**9**
8-			X	X	X	X	X	5	6	6	**6**
9-	X		X	X	X			8	9	8	**9**
10-	X	X	X	X	X	X	X	10	10	10	**10**
11-	X		X		X			9	8	7	**9**
12-					X	X	X	9	8	8	**9**

Part 1.c

This comparison shows that the Open Source software that provides the best performance from those taken into consideration is OsiriX. This software is the perfect combination of functionality and economy, because it offers an enormous improvement in manipulation and processing of radiographs, providing enhanced performance to radiologists and healthcare providers, avoiding excessive costs [22], [25]. It's important to mention also two software analysed, the software MITO (Medical Imaging TOolkit) (Figure 1), developed by iHealt Lab exclusively for the Windows platform and the Multi-platform InVesalius (Figure 2), developed by the InVesalius Community. These two softwares have a particular feature that is not present in OsiriX, they have the possibility to work with a Kinect or a Wii. In Table 2 are shown some peculiarities of these programs.

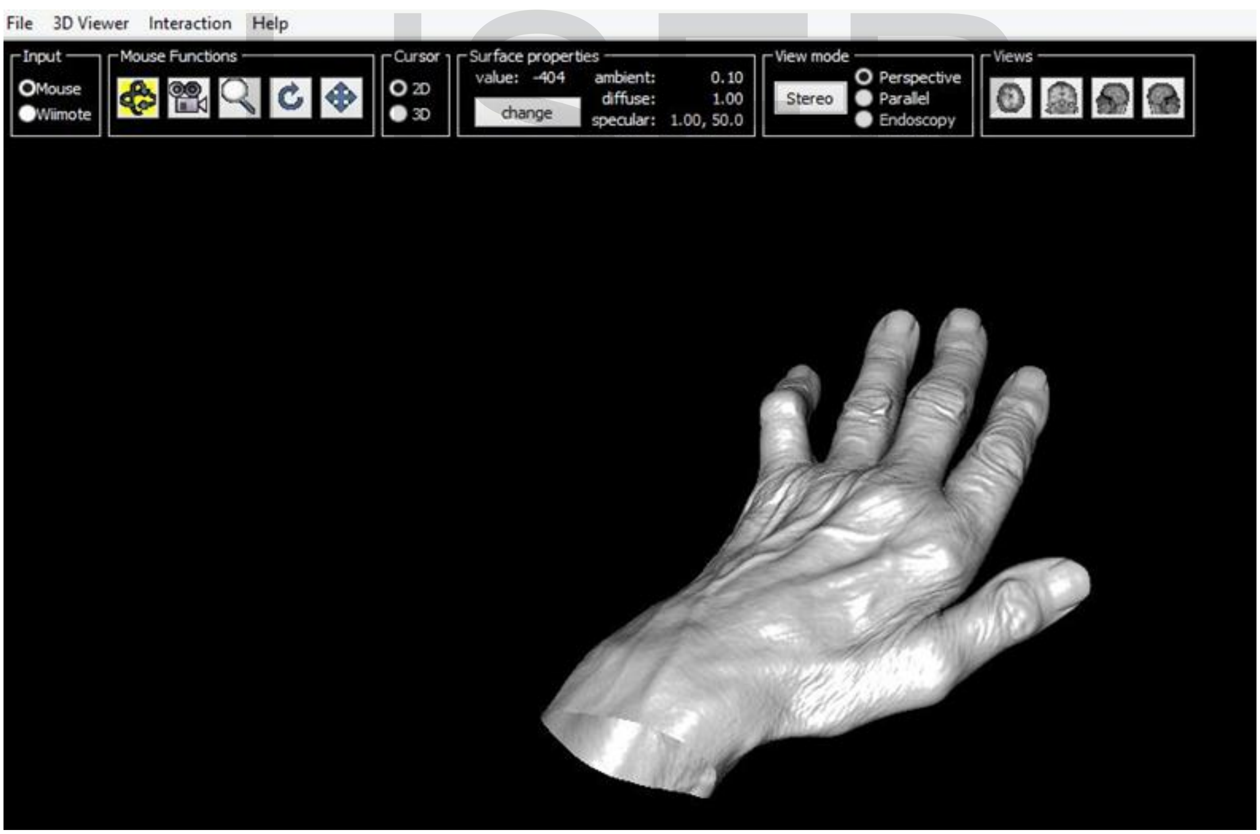

Figure 1. *Reconstructed 3-D from hand CT with MITO.*

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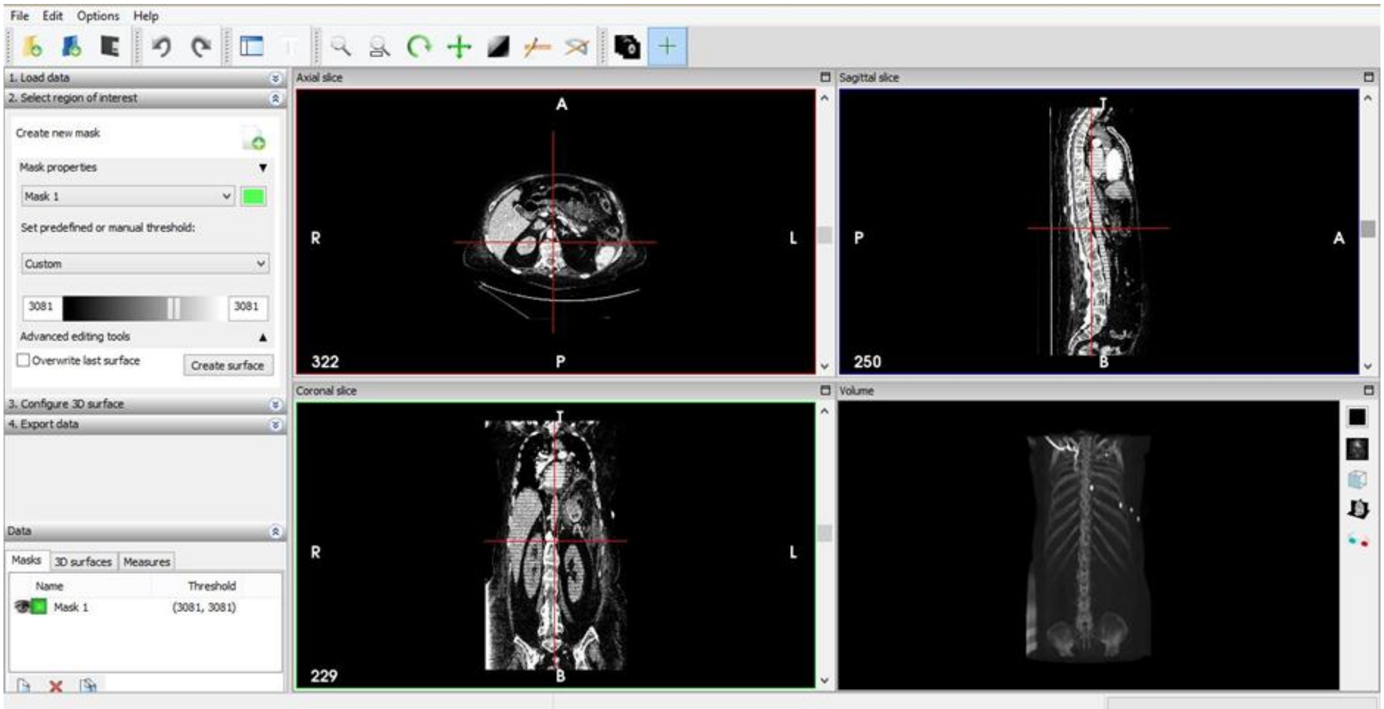

Figure 2. *An example of MPR and VR from thorax CT with InVesalius.*

TABLE 2
COMPARISON BETWEEN MITO, OSIRIX AND INVESALIUS

TOOLS	***MITO***	***OsiriX***	***InVesalius***
Load DICOM	X	X	X
Load no-DICOM	NO	X	X
Interact with PACS	X	X	NO
ROI	X	X	X
Segmentation	X	X	X
Fusion	X	X	NO
Volume rendering	X	X	X
Surface rendering	X	X	X
CLUT	X (8 bit)	X (16 bit)	X
MPR	NO	X	X
VOI	X	X	NO
Stereoscopy	X	X	X
HIC Interaction with mobile devices	X	NO	X

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4 OSIRIX

OsiriX is a project that started in 2004 at the University of California at Los Angeles (UCLA) from the collaboration between Dr. Antoine Rosset and Professor Osman Ratib, but was mainly developed by Rosset at the University of Geneva together with Joris Heuberger, a computer scientist [22].

OsiriX software has been designed for the visualization of multimodal and multidimensional images. It allows: 2D and 3D viewers, 4D viewer (i.e. 3D series together with temporal dimension), and 5D viewer (i.e. 3D series with temporal and-functional dimensions). It offers all the modern rendering tools, 3D post-processing tools such as Multi-Planar Reconstruction (MPR), Surface Rendering, Volume Rendering and Maximum Intensity Projection (MIP) [22].

The 3D MPR allows the user to dissect the image volume into three planes. Each plane can be tilted individually allowing the user to have three simultaneous views of three planes around a point of interest (Figure 3). When 2D viewers are open, OsiriX allows the user to synchronize the slice position across them. This option is called “synchronization”. This function works automatically if the series belongs to the same study.

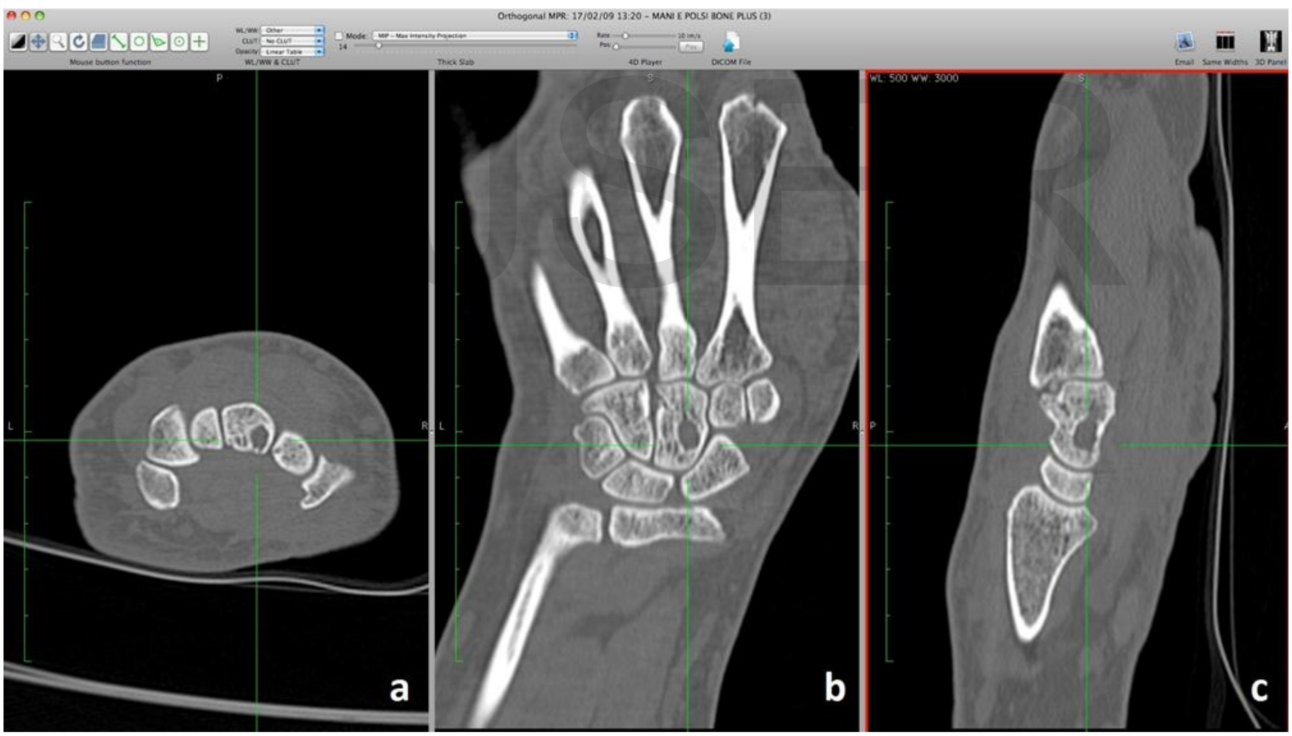

***Figure 3**. An example of bone erosion of the capitate bone seen on axial (a), coronal (b) e sagittal (c) reconstruction of wrist. The synchronization in three planes allows the correct quantification of erosive damage.*

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The Surface Rendering technique in general draws a 3D surface within a volumetric dataset, corresponding to points with a specific intensity value. It treats objects like having a surface of a uniform colour, using shading is possible to show the location of a light source, where some regions are illuminated while other regions are darker. The greatest benefit of Surface Rendering is that it is very fast, in fact are manipulated only the points on the surface and not every single voxel.

The Volume rendering is a set of techniques, such as segmentation, gradient calculation, resampling, classification, shading and illumination models, used to display a 2D projection of a volume dataset (Figure 4a, 4b). The Maximum Intensity Projection (MIP) is used in order to evaluates from the observer's point of view through the volume of data each voxel along a line, and select the maximum voxel value.

Figure 4a. *3-D volume-rendered images by OsiriX of the left shoulder in a patient with rheumatoid arthritis*

Figure 4b. *3-D volume-rendered images by OsiriX of the right shoulder in a patient with rheumatoid arthritis*

Some advanced features are also possible, such as image subtraction and image fusion. Some imaging modalities such as digital angiography can benefit from the subtraction of a mask image that allows us to remove those parts of the image that do not change over time thus showing only the time varying parts of the image.

Image fusion is the technique that allows to combine relevant information from two or more images into a single image. The source images can be of the same imaging modality, or may be multiple modalities images, such as magnetic resonance image (MRI), computed tomography (CT), positron emission tomography (PET), and single photon emission computed tomography (SPECT). The most common use is for PET-CT reading, where the PET series is fused on the CT series. PET is a nuclear medicine imaging technique that visualises functional processes in the body. In modern PET scanners, CT or MRI scans are used to produce three-dimensional (3-D) imaging in association with anatomic and metabolic (biochemical) information. The overlapping in real-time of different modalities images provided by different imaging machinery can enhance information provided by each single technique. Various colour blending and transparency techniques may be used to achieve image fusion.

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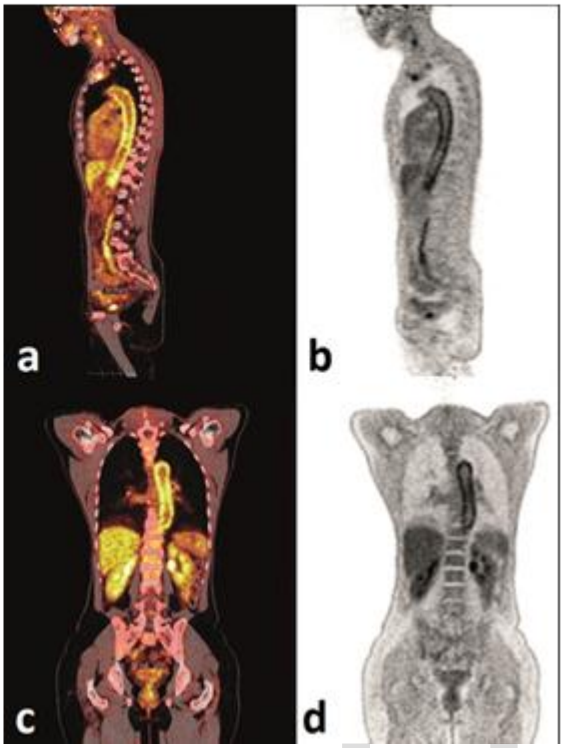

Figure 5. Takayasu's arteritis: PET/TC fusion (a,c) and PET (b,d) images obtained with the use of OsiriX software show uptake in ^{18}F-FDG in the thoracic aorta.

Investigators in a number of clinical studies have shown that the interpretation of combined PET/CT images results in an improvement of overall diagnostic accuracy beyond that achieved with the interpretation of PET images and CT images separately [28], [29]. Whereas PET/CT is the most widely known hybrid imaging modality which allows concomitant acquisition of morphologic and functional information able to increase both sensitivity and specificity of diagnostic findings in inflammatory arthritis and large-vessel vasculitis, little attention has been given to the application of fusion techniques to MR images acquired with different modalities in the same examination. MRI provides multi-planar imaging with unprecedented soft tissue contrast, without the use of ionizing radiation, and allows assessment of all the structures involved in arthritic disease, i.e. synovial membrane, intra- and extra-articular fluid collections, cartilage, bone, ligaments, tendons and tendon sheaths [30]. It has been shown to be more sensitive than clinical examination and X-ray for the detection of inflammatory and destructive joint changes in early RA and the quantification of synovial volume may play an important role in the diagnosis and follow-up of RA. In particular, synovitis in MRI has been shown to relate to the histological degree of synovial inflammation in human RA [31]. Different MR imaging techniques can provide high-definition anatomic information as well as functional and biologic information. Pulse sequences used in musculoskeletal MR imaging include T1 weighted images that provide good anatomic detail of bone, for example, erosive bone change and synovial thickening, but poor detection of soft-tissue edema and other T2-sensitive pathology. T2 fat suppressed and short tau inversion recovery (STIR) sequences allow detection of fluid and bone marrow edema. Fusion of MR images can be generated with the same technique used to obtain PET/CT images, by superimposing the color-coded functional T2-weighted image over the gray-scale T1- weighted anatomic image. Figures 6 and 7 show different examples of the fusion of T1- and T2-weighted short inversion time inversion recovery images.

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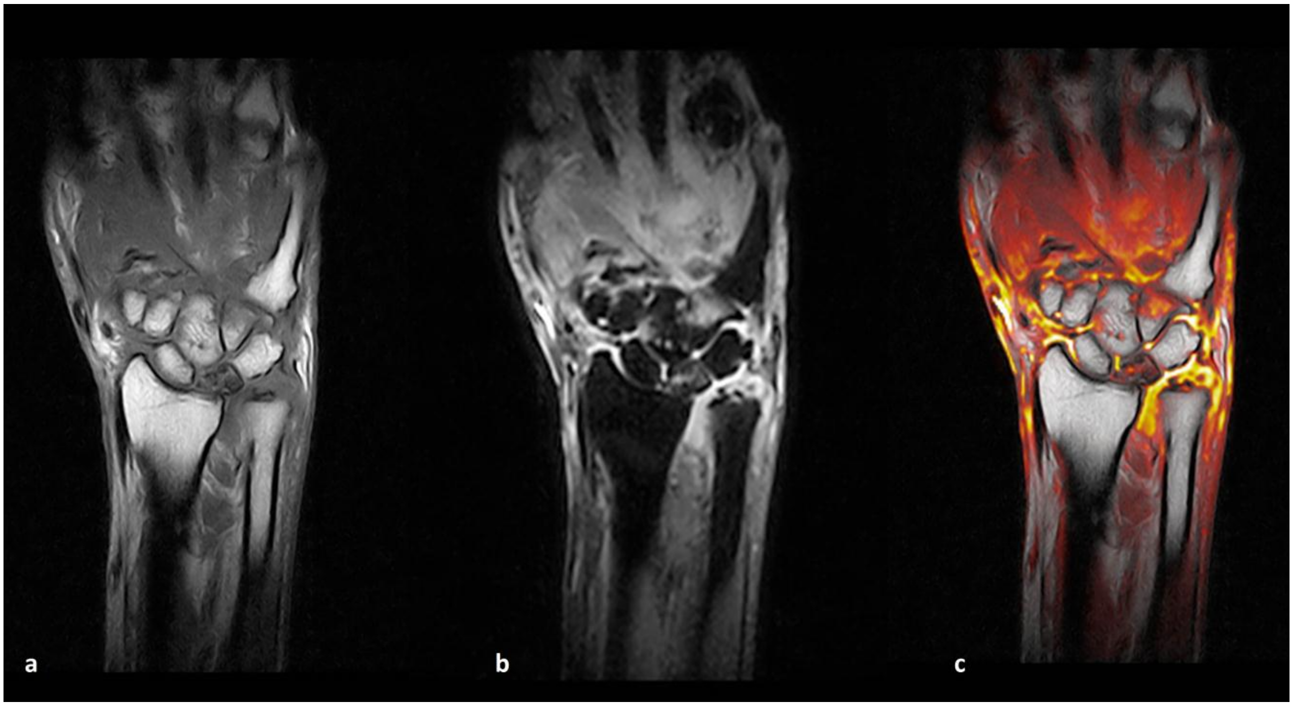

Figure 6. *T1-weighted (a), short tau inversion recovery (STIR) (b) and fusion (c) MR images clearly demonstrate erosions in the carpal bone, and alteration of intensity signal consistent with marrow oedema at the lunate and hamate bones and synovitis at the wrist.*

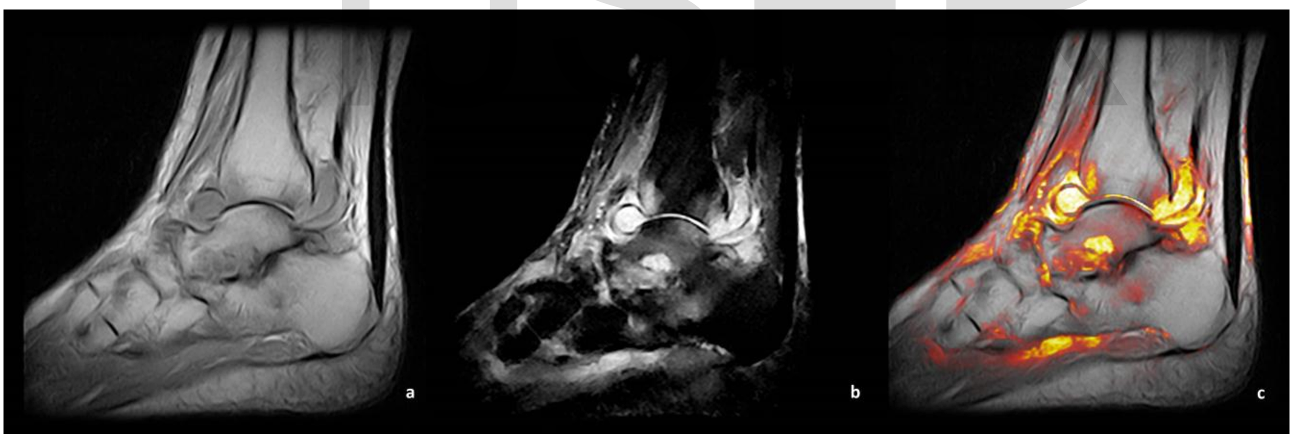

Figure 7. *T1-weighted (a), short tau inversion recovery (STIR) (b) and fusion (c) MR images clearly demonstrate alteration of intensity signal consistent with marrow oedema at the low end of the tibia and astragalus, with synovitis.*

Compared with the utility and costs associated with conventional equipment, OsiriX is distributed free of charge. It runs on commercially available personal computers, so that the overall cost is reasonable. OsiriX is a highly functional DICOM viewer specifically designed for the Mac OS X and its source code is available under Open Source licensing agreement; it can be downloaded at: (http://www.osirix-viewer.com). OsiriX is simple to operate, and images can be easily reconstructed on a commercially available Macintosh computer. It is very easy to use, and allows various high level functionalities with minimal user training. OsiriX foundation developed also a mobile version of OsiriX software for the iPhone, iPod touch and iPad, thus providing a solution for remote preliminary diagnosis and consultation [27]. Even with these portable devices it is possible to zoom, pan, and rotate the acquired images, together with the traditional windowing and levelling options; it is also possible to calibrate distances, to define ROI measurements of area and density signal intensity.

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5 Experimental Results

This section presents experimental results obtained by Osirix-based analysis of CT data in two different rheumatological settings: In the first we evaluated the validity of a computer-assisted manual segmentation (*outlining*) technique to quantify erosion volume on CT scans in patients with RA [9]. In the second, we investigated the utility and the performance of OsiriX software for quantification of disease extent in patients with IPF-SSc [32] and its correlation with physiological impairment [33].

5.1 Computer-assisted manual segmentation to quantify wrist erosion volume using computed tomography scans in rheumatoid arthritis

The optimization of imaging measures is an important strategy for evaluating and monitoring bone damage in RA [1]. Considering that wrist is frequently involved in RA and that anatomical damage at this level has a predictive significance of evolution of the disease, its evaluation assumes an important clinical significance. Although conventional radiography (CR) remains the cornerstone of imaging modalities, CT can be considered the standard reference method for the detection of erosive bone destruction in the early stage of the disease [34]. Current generation of ultrafast CTs allows acquiring high-resolution volumetric data in a few seconds and provides detailed anatomical information. In particular, the introduction of 3D image reconstruction through computer systems, makes the visualization of tiny defects of the wrist a feasible task. High resolution CT systems are fast and produce high spatial resolution images with near isotropic voxels. Therefore, 3D image reconstruction of segmented carpals and the volume measurements of erosions are significantly more accurate [35] (Figure 8)

Figure 8. *Erosions in the wrist of rheumatoid arthritis patient. Wrist visualized by conventional radiograph (A,C,E) end by computed tomography (B,D,F). Bone erosion are clearly evident on CT, but not on the corresponding radiograph.*

The visualization and processing of 3D data require special navigation tools and multidimensional rendering software that are available on high level and 3D rendering workstations that are most accessible in academic and specialized imaging centers. Previously, we developed a semi-automated method for the evaluation of the profile of carpal bones and the subsequent determination of the volume erosion by comparing the images obtained by conventional radiography [9]. Erosions volumes were calculated by a computer-assisted manual segmentation (outlining) technique using *OsiriX* medical imaging software. Each erosion was outlined manually in coronal or axial slice (Figure 9).

The outlining of erosion borders was done using a Bamboo Connect pen tablet system (Wacom Technology Corporation, Vancouver, WA, USA) (Figure 9). We found that the volume measurements of erosions by CT was highly reproducible and closely correlated with the semi-quantitative scores of bone erosions according to the semi-quantitative Outcome Measures in Rheumatology Rheumatoid Arthritis MRI Scoring System (OMERACT-RAMRIS) [36]. This aspect supports the evidence for the semi-quantitative CT measures of erosion as a valid measure to estimate bone destruction in RA.

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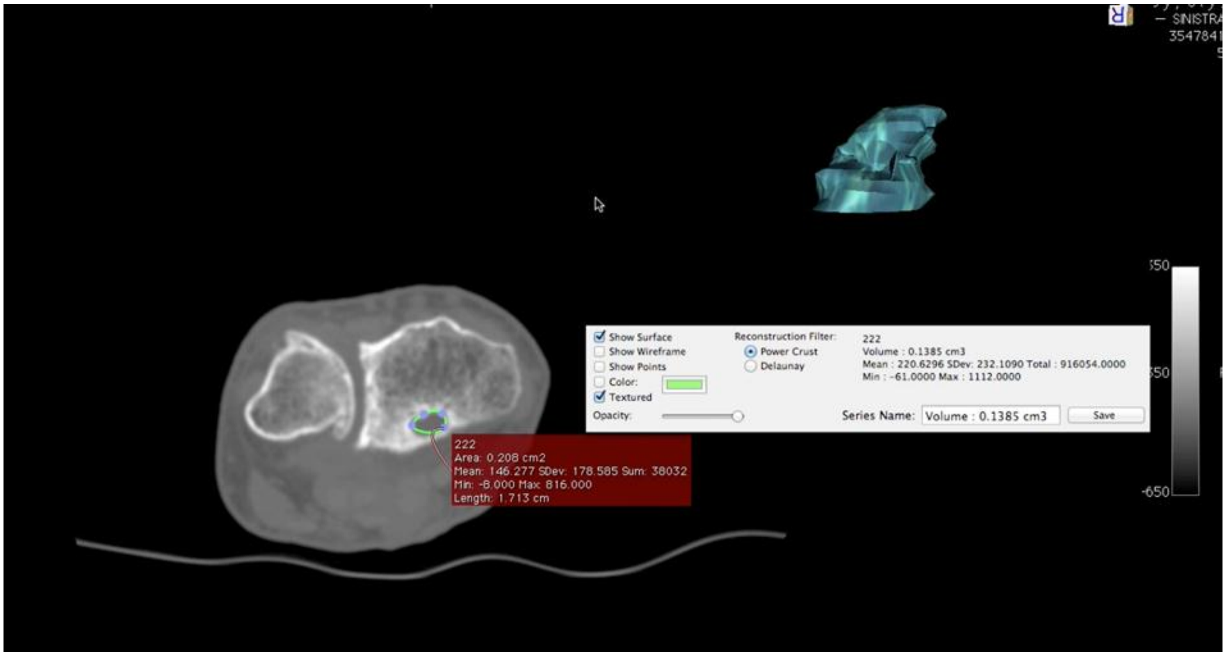

Figure 9. *CT images of a wrist. The erosion volume at the distal radio was obtained after the automatic calculation of the area of the erosion by OsiriX software.*

5.2 Computer-aided quantification of interstitial lung disease from high-resolution computed tomography images in systemic sclerosis

Systemic sclerosis (SSc) is a heterogeneous autoimmune disorder of unknown aetiology that is characterized by musculoskeletal involvement, vascular dysfunction, cutaneous and visceral fibrosis [14]. ILD was reported in up to 70% of patients with SSc and frequently it can be cause of death of these patients [17]. HRCT is currently the most accepted imaging tool for the detection, characterization and treatment monitoring of ILD [15], [16], [17]. The correct interpretation of HRCT findings still often represents a problem for the inexperienced physicians since there is a wide inter-observer variability even among expert radiologists. Therefore, a quantitative, non-invasive and reliable imaging method able to permit an accurate assessment of ILD in SSc is highly desirable. To date, several computerized tools to segment automatically the lung, using HRCT images, have been developed. They include image display (e.g., multiplanar reformations and surface shading for three-dimensional and volume rendering), anatomic image quantitation (e.g., area and volume of airways and lungs) and regional characterization of lung tissue (analysing attenuation, changes in attenuation, and texture patterns in the imaged lung).

They also provide computer-derived measures such as mean lung attenuation (MLA) (representing the average global attenuation value of the pulmonary parenchyma), skewness (representing the extent of asymmetry of histograms) and kurtosis (representing the degree of "peakedness" of the histograms). Additionally, it is possible the acquisition of more sophisticated image analysis including the fractal analysis and the adaptive multiple feature method. With respect the traditional visual interpretation of HRCT lung findings, the automatic computer-based assessment may improve the objectivity, sensitivity, and repeatability of quantitative changes in the lung features [37], [38]. Previously, we showed a high agreement concerning the semi-quantitative HRCT analysis performed by experienced radiologists, and a significant association between the descriptive parameters by both the quantitative OsiriX assessment and the HRCT semi-quantitative analysis [32]. More recently, we investigated the performance of a computer-aided method (CaM) for the quantification of ILD, in seventy-nine patients with SSc, in terms of correlation regarding both the conventional visual reader-based score (CoVR) and the pulmonary function tests (PFTs) findings, feasibility and inter-reader reliability of the CaM [33]. All HRCT images were reconstructed and analysed by OsiriX. The program uses a semi-automated thresholding technique to isolate the lungs from other tissues and structures. For each section, a semi-automatic lung parenchymal segmentation was performed in order to obtain analysis of all images (Figure 10).

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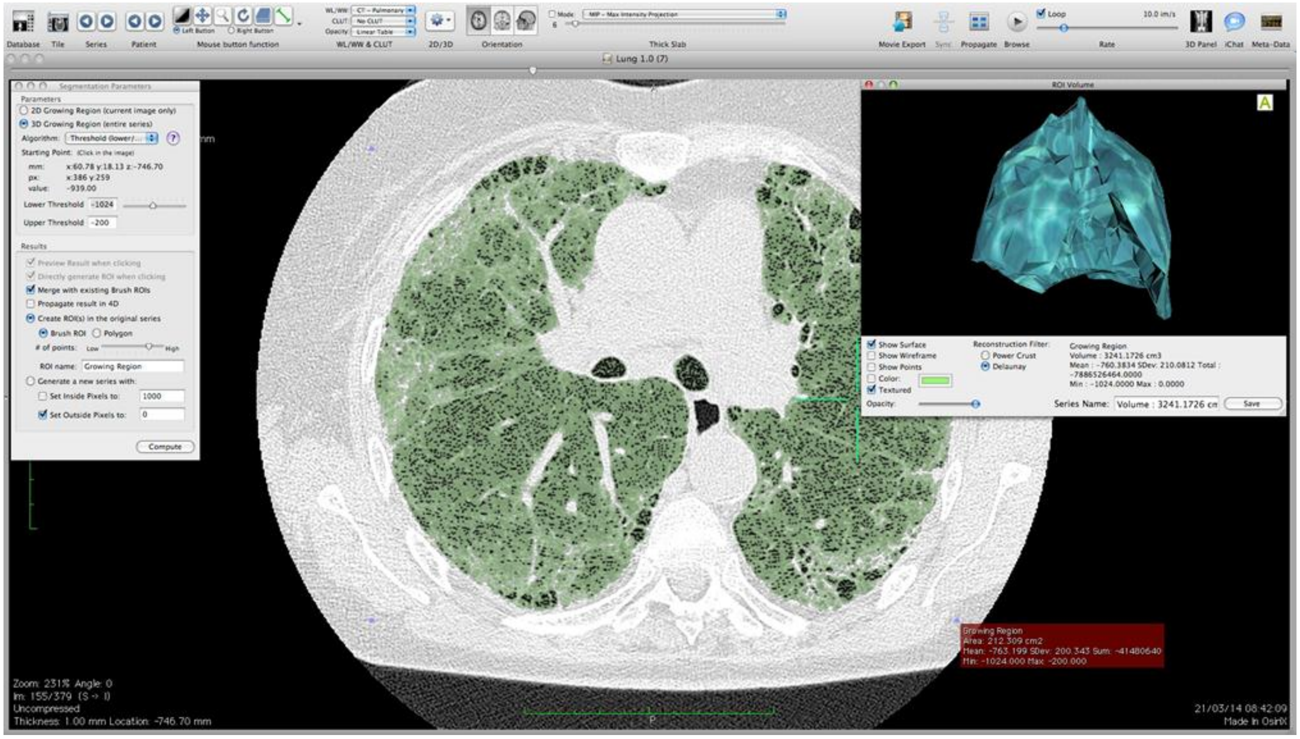

Figure 10. Example of segmentation of lung and representative volumetric reconstruction rendering of lung obtained with the appropriate function in OsiriX.

The results indicate that the CaM analysed by OsiriX provides a good concurrent validity, reliability and feasibility for the assessment of ILD in patients with SSc. Considering the promising advent of user-friendly software tools, this approach may be effectively used in both clinical practice and research setting.

6 Conclusions and Perspectives

Our preliminary observations confirm that the ability to review and manipulate images increases the usability of the information derived from the images. The OsiriX is a highly functional DICOM software, which is cost free and easy to use and offers advanced 3D post-processing tools. With a sophisticated user interface, not only radiologists, but also rheumatologists, can easily manipulate and generate 3D reconstructed images and acquire whole images of 3D anatomical structures. Rheumatologists can master the intuitive control interface within an hour. The software can be installed only on a Mac OS X-based personal computer and this is undoubtedly the main limitation. However, the hardware requirements for the rendering computation are minimal: even a low-end laptop computer can easily perform the rendering process (Figure 11). Taking advantage from the enourmous opportunities offered by Osirix, we can improve teaching activities because it facilitates the achievement of learning objectives.

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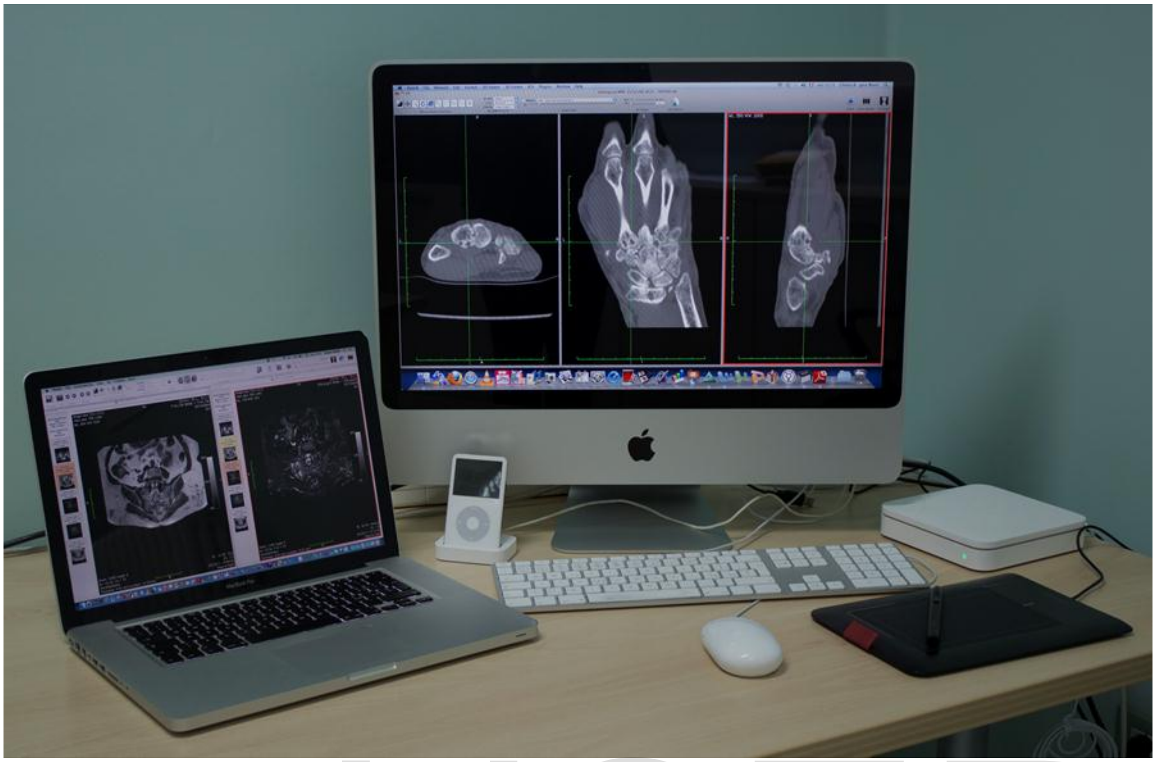

Figure 11. *An example of OsiriX Workstation*

The ever more rapid evolution of OsiriX leads us to believe that in time it will assist ever more effectively rheumatologists in interpreting new multidimensional examinations, providing an attractive and efficient alternative on analysis and image processing, without incurring in excessive costs. It offers a new perspective on musculoskeletal imaging with the necessary tools for exploring in 4D and 5D lung CT and PET/CT examination. It is also a way that leads to an easier communication between rheumatologists and referring radiologists adapting perfectly to the emerging needs of medical community. Imaging is becoming even more prevalent in the diagnostic performance of rheumatologic disease, with the new paradigm of multidimensional image navigation, integrating into the diagnostic process the information from functional and/or molecular imaging.

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Conflict of Interests:

The authors declare that there is no conflict of interests regarding the publication of this paper.

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