Accurate and resource-efficient planning for aortic interventions

Angio-CT post-processing with Mac systems and open source software

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Executive summary

Aortic disease is a common and potentially serious condition; when it involves the thoracic segment or the whole thoraco-abdominal aorta it can be particularly severe. In many cases, thoracic aortic disease can be diagnosed and treated before it becomes dangerous. The most appropriate treatment may be an open surgical operation, or a less-invasive endovascular procedure that involves the use of a stent-graft.

A well-timed diagnosis and accurate planning and sizing can enable surgeons to provide effective treatment. However, in spite of a flawlessly executed operation, important problems may occur after a thoracic or thoraco-abdominal aortic procedure. The most severe complication is spinal cord ischemia, which can cause symptoms as dramatic as paraplegia. Accurate preoperative knowledge of the blood supply to the spinal cord could help reduce the risk of postoperative paraplegia.

New state-of-the-art hardware and imaging software solutions have been recently introduced and are commercially available. OsiriX, a powerful open-source Digital Imaging and Communications in Medicine (DICOM) image viewer, can be downloaded at no charge from its website. It provides the ability to visualize and manipulate multi-modality, multidimensional medical images, including CT. OsiriX runs on off-the-shelf Apple computers, including the powerful Mac Pro multi-core workstation, which is available at a fraction of the cost of dedicated workstations with specialized hardware requirements (graphics card, memory hard drive etc.). Fovia, Inc. has developed High Definition Volume Rendering® software, an OsiriX plug-in that provides superior visualization of vasculature. These technologies enable vascular surgeons to accurately plan aortic procedures in a very cost- and time-effective manner.

Today there is growing evidence that the artery of Adamkiewicz, the principal supplier of blood to the thoraco-lumbar spinal cord, may be visualized through magnetic resonance angiography (MR-A) and computed tomographic angiography (CT-A). These methods, however, rely on post-processing techniques that until recently required costly dedicated workstations and could be very resource-consuming. Nevertheless, surgeons would benefit from an accurate preoperative imaging of the spinal cord blood supply to plan the best possible treatment modality for each patient.

A study was published in the April 2009 issue of the *European Journal of Vascular and Endovascular Surgery*[40] at the San Raffaele Scientific Institute in Milan. In this study 67 CT datasets of patients with severe aortic disease were studied with both standard radiological workstations and OsiriX running on Mac Book Pro laptop computers to detect the artery of Adamkiewicz. The results showed that the analysis performed with OsiriX was not only comparable with those obtained with standard methods but was also consistent with the data obtained from a systematic review of the literature.

While further studies are certainly needed, these initial results are very encouraging. They confirm the value and the accuracy of OsiriX in the preoperative diagnostic workup of patients with aortic disease.

Background

Thoracic aortic disease

Aortic disease is a potentially serious condition, and unfortunately it is not uncommon[1]; when it involves the thoracic segment or the whole thoraco-abdominal aorta it can be particularly severe.[2,3] Arteriosclerotic aneurysms (dilatation of the vessel) are among the most common causes of the disease.

Figure 1: This image is a three-dimensional rendering of the entire aorta obtained with OsiriX software and the Fovia High Definition Volume Rendering® plug-in. We can observe an ascending portion of the aorta, an arch, and a descending portion. From the arch three important branches supply the head and the upper limbs. In the descending portion we can observe a large atherosclerotic aneurysm (arrows). Lower down we can observe branches to the abdominal organs; the kidneys are visualized in red. More distally the aorta bifurcates into two branches (the common iliac arteries) that supply the lower limbs. The white patches on the surface of the aorta denote areas of calcification of the aortic wall, another consequence of arteriosclerosis.

Another important disease is aortic dissection (disruption of the vessel wall with secondary dilatation). If undiagnosed or left untreated, aneurysms and dissections may grow larger and eventually rupture with catastrophic consequences (fatal internal hemorrhage).

Figure 2: Three-dimensional rendering of the aorta obtained with OsiriX software and the Fovia High Definition Volume Rendering® plug-in. In this case, we can observe the wall dissection (arrowheads) that begins between the arch and the descending portion and proceeds spirally all the way down to the artery that supplies the right lower limb. We can also observe significant dilatation of the upper part of the descending aorta (arrows).

Fortunately, in many cases thoracic aortic disease can be diagnosed and treated before it becomes dangerous. The most appropriate treatment may be an open surgical operation,[4-8] or a less invasive endovascular procedure that involves the use of a stent graft.[9-12]

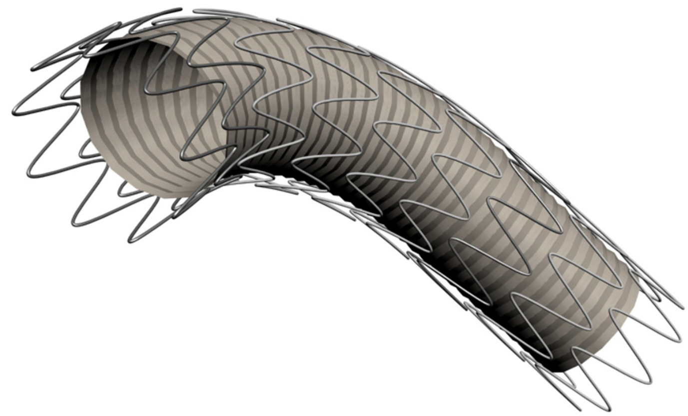

Figure 3: Artist's concept of a stent graft for endovascular treatment of aortic aneurysms. The metal stents are self-expandable and allow the fabric to seal the aneurysm and exclude it from the blood flow.

To plan the best possible treatment modality for each patient, accurate imaging must be obtained preoperatively; most surgeons prefer a high quality CT scan for patients with aortic aneurysms or dissections.

Imaging modalities

Evolution of the CT scanner: from slices to volumes

Many modalities allow us to image the thoracic aorta, each with advantages and drawbacks:

- Chest XR (a valuable basic screening exam)
- Ultrasonography (in particular, trans-thoracic and trans-esophageal echography)
- Digital Subtraction Angiography (implies arterial catheterization, contrast media injection and exposure to ionizing radiation)
- MR-Angiography (no radiation is involved; an intravenous contrast agent may be needed)
- CT-Angiography (exposure to ionizing radiation with intravenous contrast agent injection)

There are several reasons why most surgeons who treat thoracic aortic disease choose CT-Angio as their preferred imaging modality, provided that there aren't specific contra-indications. State-of-the-art multi-detector CT scanners produce excellent imaging. Typically a complete exam to study the thoraco-abdominal aorta consists of 1500-2500 slices (dataset size>1 GB), and some require substantially more. X-ray films or paper prints are obviously inadequate for visualizing thousands of images. Even standard computer-based viewers, and particularly 2D PACS viewing stations, are inadequate since they were not designed to handle large volumes of multi-detector CT data and lack interactive capabilities with the physician reviewing the exam.

To obtain the most from a CT dataset, one must be able to navigate through the scans and manipulate them using formatting techniques to extract the most useful images that will allow an accurate diagnosis.

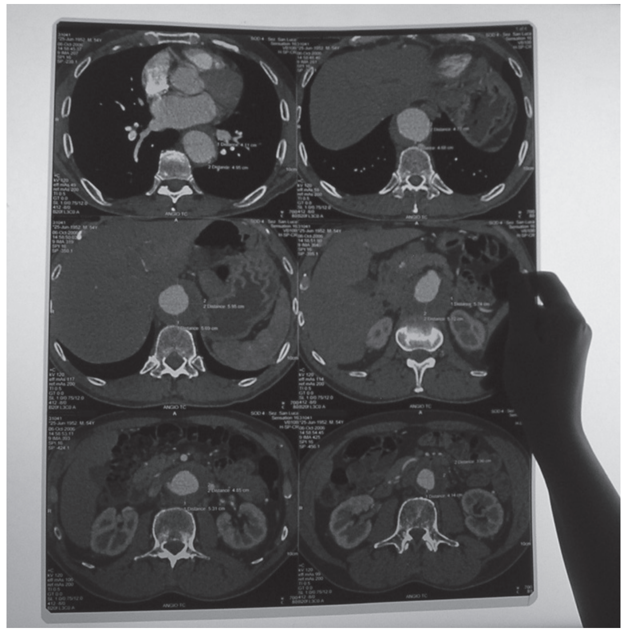

Figure 4: Old CT scanners could produce only images of thick (1 cm) axial sections of the body.

Unlike older CT scanners that could produce only relatively thick axial slices, the newer scanners extract much thinner slices that capture information covering the whole volume of the body part being scanned. With the right tools, the digital information from this volume (the CT dataset) can be displayed in an infinite number of ways.

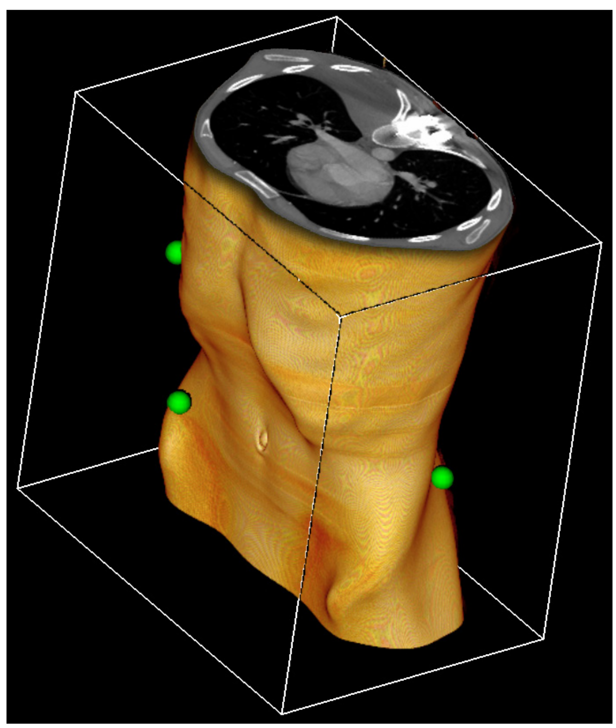

Figure 5: Newer CT scanners can collect information on the whole volume being studied. This dataset, rendered with OsiriX, can be manipulated in many different ways to obtain images that highlight the part of the body that we need to study.

An imaging workstation for surgeons

A powerful, cost-effective alternative

Until recently, reformatting the CT dataset to obtain the images that are really needed to plan procedures was possible only on costly dedicated imaging workstations that are usually located in the radiology department and have to be shared by many specialists, making access to them impractical and inconvenient. In 2004 this situation began to change when Professor Osman Ratib and his coworkers at the University Hospital of Geneva were able to introduce OsiriX software.[13-16]

OsiriX is a dedicated DICOM viewer that can display the output of any of the most current medical imaging modalities. It runs on standard Mac computers.

OsiriX is specifically designed for navigation and visualization of multi-modality and multidimensional images, including CT. It can be downloaded at no charge from the OsiriX website under a GNU software license that allows users to use, modify, and redistribute the software. Users can develop plug-ins to fill specific needs. The active participation of the open-source community assures the rapid evolution and improvement of OsiriX.

As of the beginning of 2009 there were more than 37,000 users of OsiriX, and the number is rapidly growing.[17]

Displaying a CT dataset

How to render an object with three or more dimensions on a flat screen

With the help of OsiriX, we can start working on our CT dataset to obtain the images of the aorta that we need. The classic way to show a CT dataset is axial (transverse) scans.

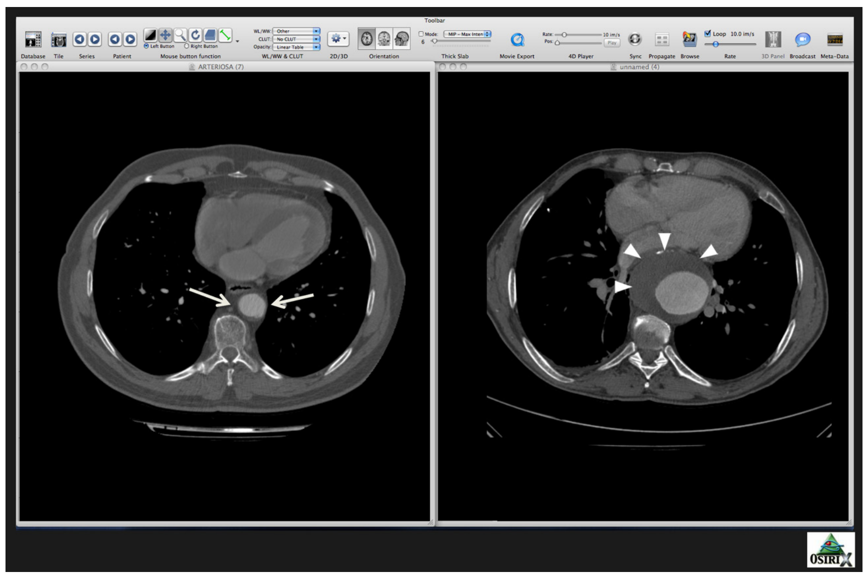

Figure 6: Axial views of aortas, displayed in OsiriX. Left, (arrows) point to a normal aorta; on the right (arrowheads), an aneurysmatic aorta.

But once we understand that the dataset contains the whole volume of the body, it is obvious that the slices can be cut not only in an axial plane but also in a frontal (coronal) or lateral (sagittal) plane. Scans in these three orthogonal planes can be displayed easily and shown in the same window using orthogonal multi-planar reformatting (MPR).

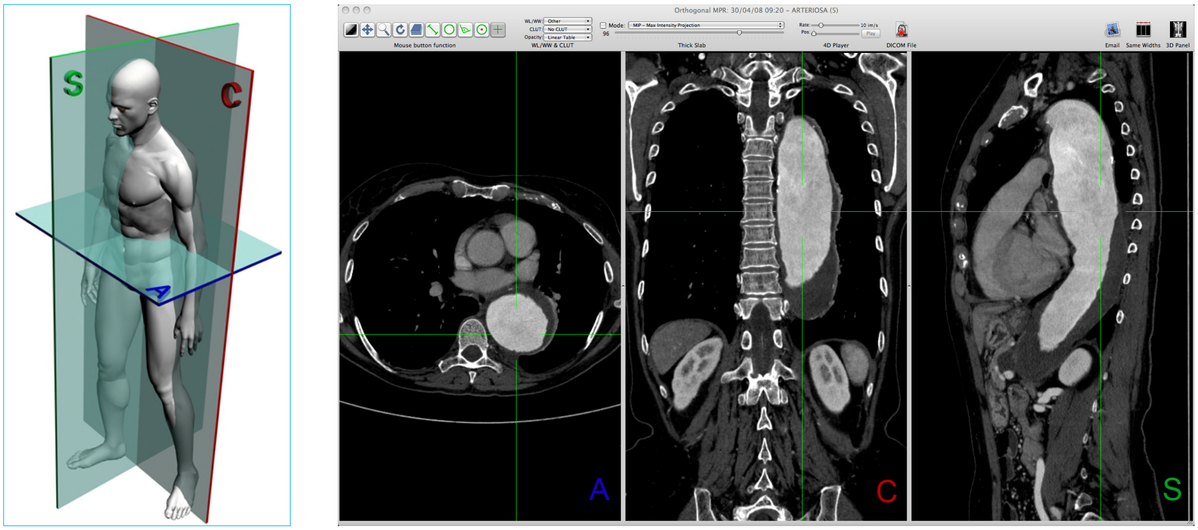

Figure 7: The insert on the left depicts a schematic drawing of the human body with the three orthogonal planes: transverse (axial – blue), frontal (coronal – red), and lateral (sagittal – green). The screen-capture on the right shows how OsiriX can display the three planes simultaneously. A grossly dilated aorta is evident: however, these projections fail to show the entire course of the aorta.

Scrolling these three sets of scans, adjusting window level and width, zooming, and modifying the slice thickness will enable us to gain a great deal of information. Unfortunately, the important structures in our body don't always follow orthogonal planes. The aorta (from the Greek word a-orthos = not straight) takes a twisting path that curves in all directions. An oblique MPR may therefore help us to produce a scan whose angulation matches that of the aorta or the vessel we need to study.

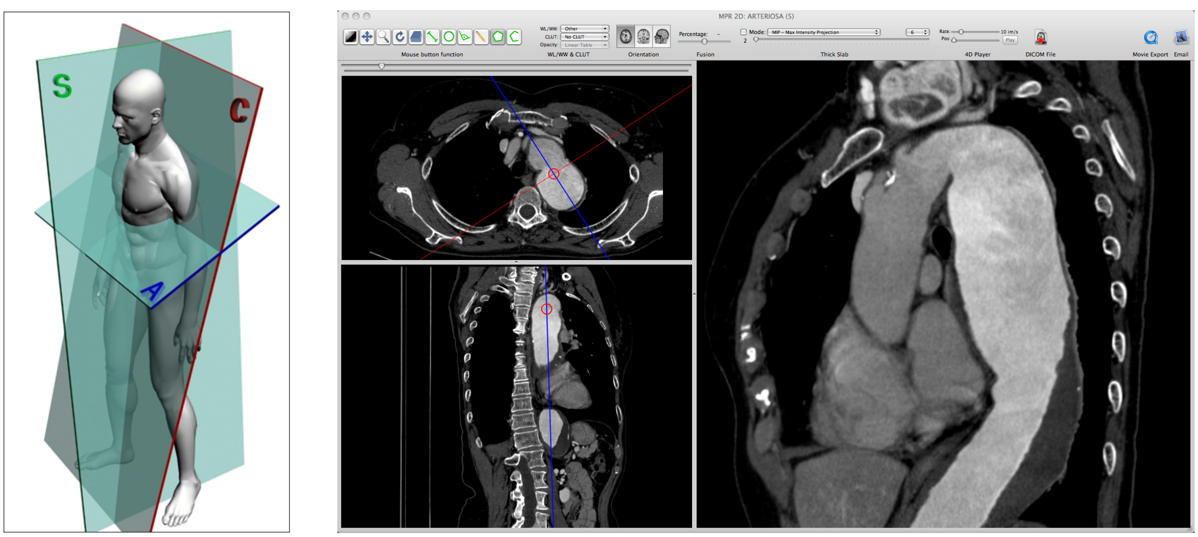

Figure 8: The insert on the left shows how the human body can be crossed by three oblique (non-orthogonal) planes: para-Axial – blue, para-Coronal – red, para-Sagittal – green. The screen-capture on the right obtained with OsiriX displays the three oblique planes simultaneously, and the curved path of the dilated aorta is now evident in the larger image.

Nevertheless if the vessel or structure we are studying is too complicated to be followed even in an oblique MPR we can use a more sophisticated tool within OsiriX: a curved MPR. We can display an orthogonal scan image and hand-draw on it a curving line that follows the course of the structure. OsiriX will produce an image that follows our line to display the structure completely.

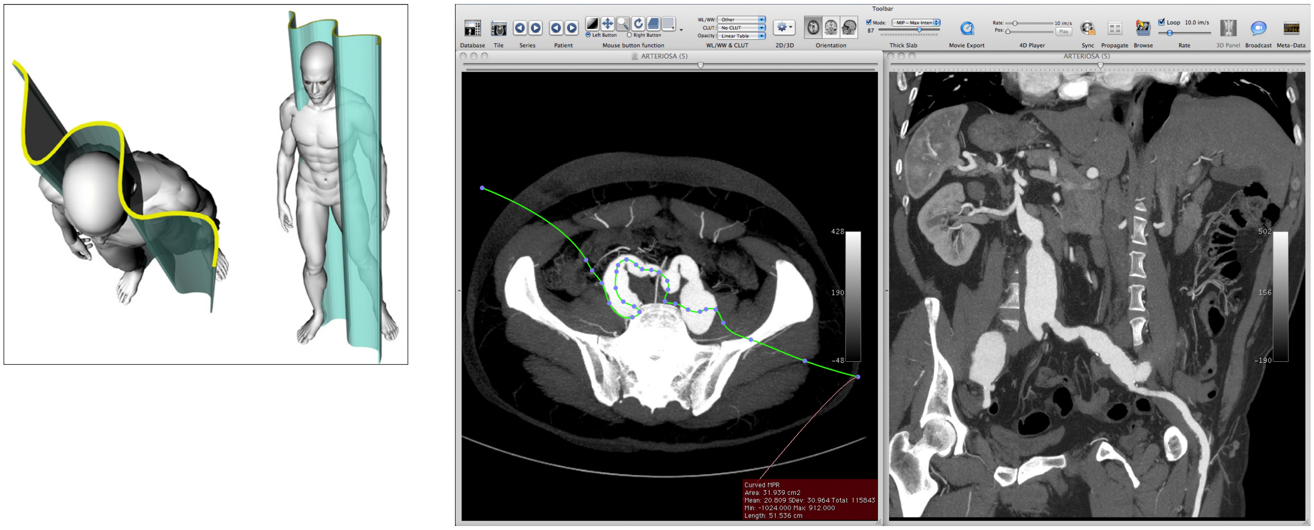

Figure 9: The insert on the left shows how the human body can be sliced in a curved fashion. The curved plane is hand-drawn in green on the axial scan (the OsiriX display on the left). This makes it possible for us to show on the resulting image (OsiriX screen-capture right) the twisting course of the aorta in OsiriX image on the right.

We can go further in viewing the structure in a more realistic three-dimensional way by using 3D rendering tools such as MIP, volume rendering, and surface rendering. (See also Figures 1 and 2.) We can also use color to differentiate structures with different but similar radio-opacity to enhance our diagnostic capability.

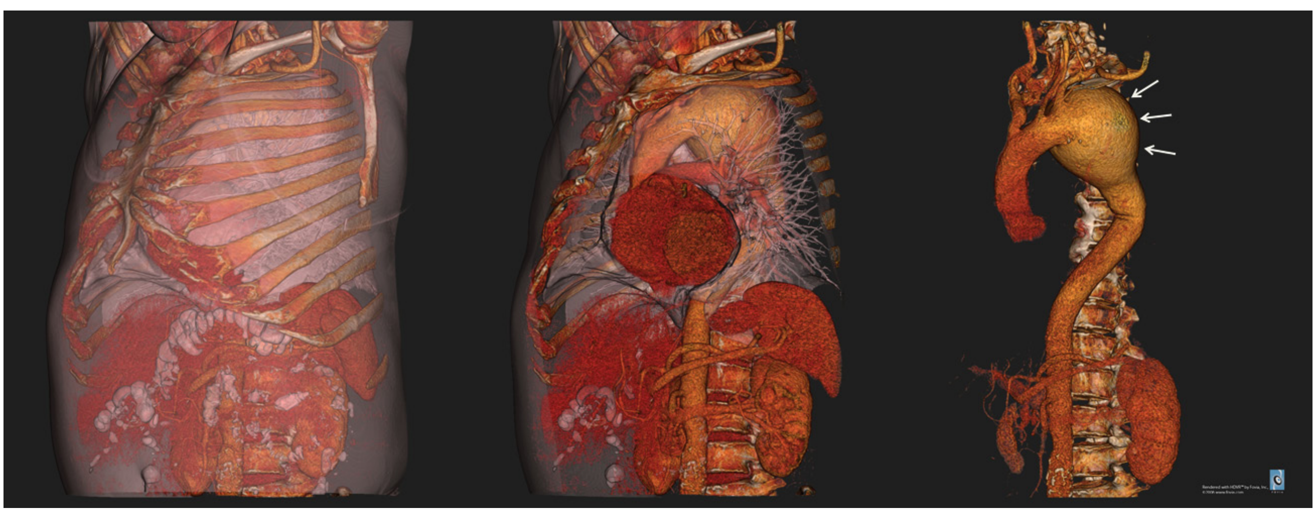

Figure 10: This image obtained with OsiriX and Fovia HDVR™ gives us a pseudo-realistic three-dimensional depiction of the human body highlighting different structures: the ribcage in the left image, the internal organs in the center image and the aorta (with a large thoracic aneurysm—arrows), with vertebral column in the background, in the right image.

Fovia, Inc. has developed High Definition Volume Rendering® (HDVR™) software, an OsiriX plug-in that provides extremely detailed and realistic images of vasculature. Several Fovia HDVR™ vasculature images presented in this paper were obtained on an 8-core Mac Pro computer, with 8GB of memory and a 30-inch Apple Cinema display.

OsiriX also allows us to visualize the 4th dimension: time. The CT scanner is gated or synchronized with the phases of the patient's heartbeat to capture a dynamic motion sequence. Finally, a 5th dimension, function (for example, metabolism) can be captured with PET imaging. The resulting images can fused with a dynamic CT scan sequence to create stunning images. An example is a beating heart and its metabolic activity.

Preoperative planning and sizing

A user-friendly, accurate approach

OsiriX allows vascular surgeons all over the world to accurately plan an aortic procedure by using sophisticated post-processing of their CT datasets in a very convenient and cost/time-effective fashion. Accurate planning is even more important when a stent graft procedure is considered, because precise quantitative measurements are needed in addition to the usual qualitative diagnosis. Diameters, lengths and angles need to be measured very accurately together with the presence of thrombus, calcifications, anomalies, etc.

The importance of precise measurements in the preoperative planning cannot be overemphasized. As the Russian proverb puts it, “Measure twice, cut once.”

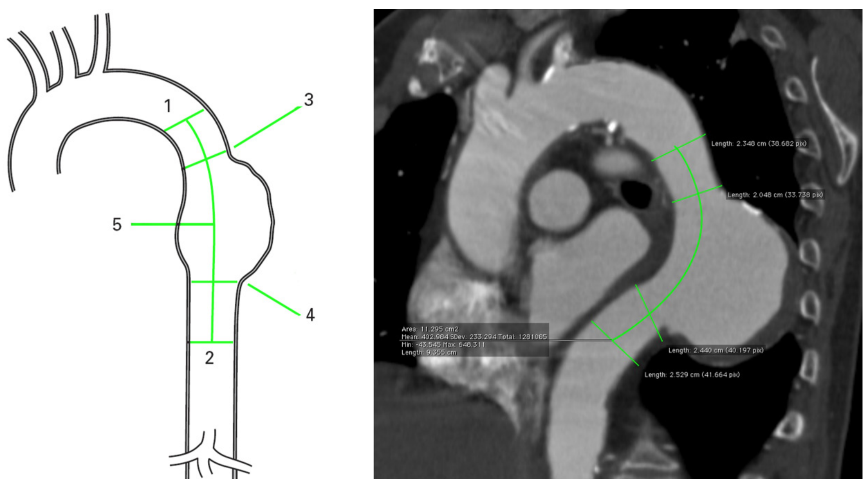

Figure 11: An example of sizing required to plan an endovascular procedure for a thoracic aortic aneurysm. A schematic drawing of the measurements needed (left) and the actual measurements taken on an appropriately reformatted CT scan.

From diagnosis to treatment

The struggle to avoid complications

A timely diagnosis and accurate planning and sizing enable us to offer effective treatment to many patients. However, in spite of a flawlessly executed operation, important problems may occur after thoracic or thoraco-abdominal aortic procedures. The most severe of these is certainly spinal cord ischemia, which can cause symptoms as dramatic as paraplegia.

This terrible complication has many potential causes. Regrettably, in spite of all efforts, it is still often unpredictable. One factor that could help reduce the risk of postoperative paraplegia is accurate preoperative knowledge of the blood supply to the spinal cord.[18-38] This is difficult to obtain because arteries that supply the spinal cord are small (< 1 mm), are surrounded by osseous structures (vertebrae), and vary greatly from patient to patient.

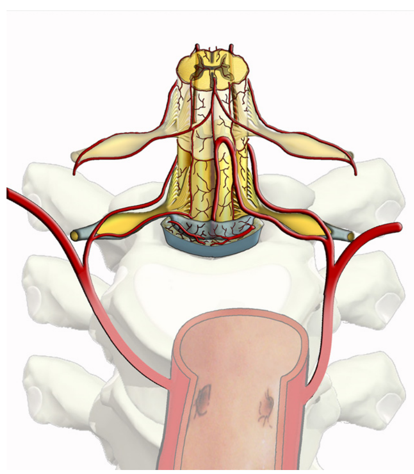

Figure 12: An artist's depiction of the spinal cord blood supply: The aorta is in the foreground and the spinal cord with its arteries is depicted in the background after removal of the vertebrae.

The importance of preoperative knowledge of the location of the Adamkiewicz artery (AKA) before thoracic and thoraco-abdominal aortic surgery was demonstrated by Kieffer and coworkers in the 1980s, by means of selective angiography.[39] The method was complex and invasive, however, and was not widely adopted.

The identification of spinal cord vasculature in patients with aortic disease has been shown to be possible with noninvasive imaging modalities such as MR-Angiography or CT-Angiography since 2000.[26-38] All studies, however, have been performed in highly specialized radiology research institutions (mainly in Japan), and the potential clinical benefit for patients has seemed to be far in the future.

A very recent study that is published in the April 2009 issue of the *European Journal of Vascular and Endovascular Surgery*[40] was performed at the San Raffaele Scientific Institute in Milan. Our Institution is especially active in aortic surgery, teaching and education.

Figure 13: Partial view of the clinical and research facilities at the San Raffaele Scientific Institute in Milan

In this study the CT datasets of 67 patients with severe aortic disease were studied both with standard (and expensive) radiological workstations (Vitrea workstation, Vital Images Inc.) and OsiriX software running on a MacBook Pro laptop computer with an Intel Core-Duo 2.93GHz processor and 4GB of memory to detect the AKA. The results showed that the analysis performed with OsiriX was not only comparable with those obtained with the standard methods but also consistent with the data obtained from a systematic review of the literature.

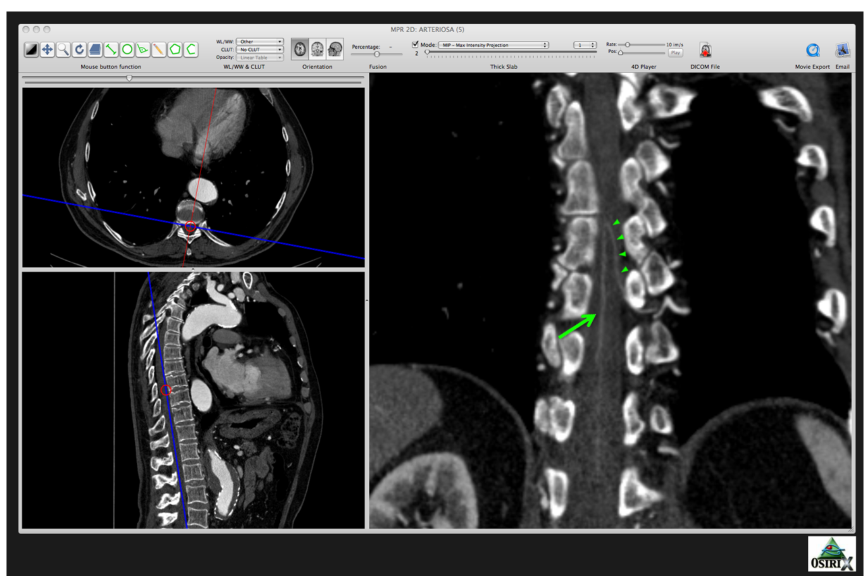

Figure 14: This OsiriX screen-capture displays 2D oblique multi-planar reformatting performed to visualize the spinal cord and the AKA. The anterior spinal artery (arrows) runs longitudinally and is fed by the great radicular artery or AKA (arrowheads) with its characteristic hairpin shape.

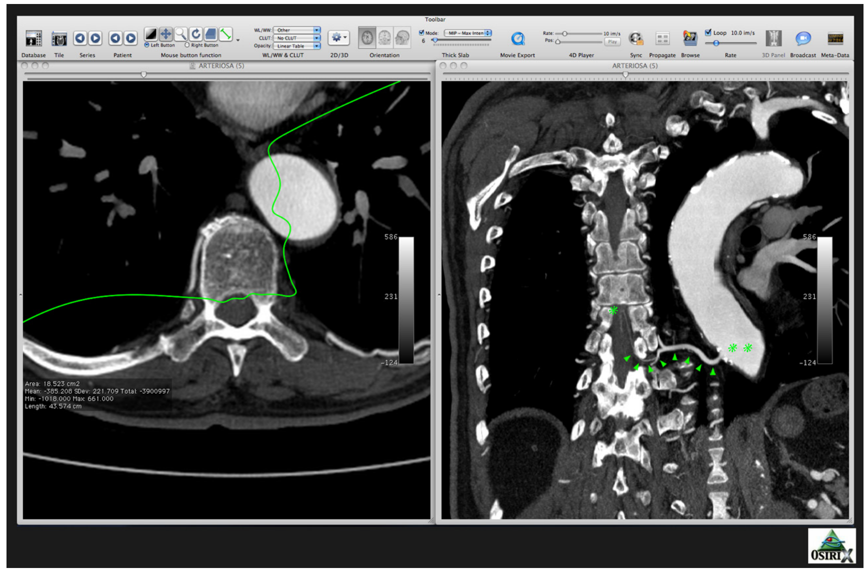

Figure 15: This OsiriX screen-capture displays 2D curved multi-planar reformatting that follows the continuity of the AKA (*) with the aorta (**) through the radiculo-medullary artery and the intercostal artery (arrowheads). Please note that the image on the right is a totally virtual curved plane carved from the CT dataset. Its path is hand-drawn on the axial images (left image, green line).

Though further studies are certainly needed, these initial results are very encouraging because they confirm the value and the accuracy of Mac systems running OsiriX in the preoperative diagnostic analysis of patients with aortic disease.

Follow-up

Imaging medical devices

After a stent graft has been successfully implanted, patients need a follow-up imaging exam to confirm that all is well or to enable the surgeon to correct any potential problems with a well-timed and safe procedure.

The presence of metal parts (which are very radio-opaque) in the endovascular prostheses makes the postoperative scans not only important for the patient's safety but also fascinating to examine. Once again appropriate post-processing of the images is mission-critical for an accurate diagnosis.

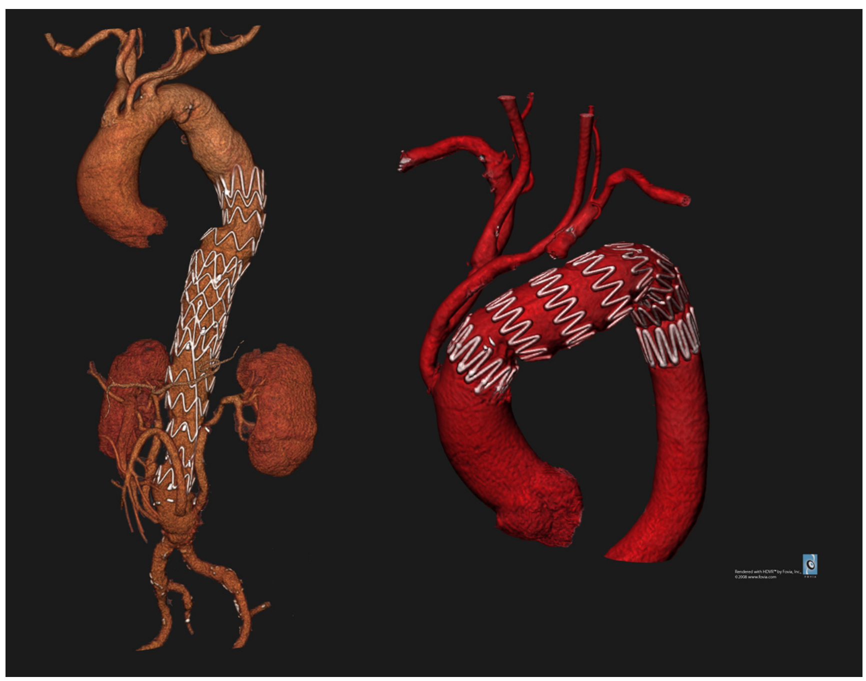

Figure 16: These images, obtained with OsiriX and the Fovia HDVR™ plug-in, show stent grafts placed in the thoraco-abdominal aorta (left) and in the aortic arch (right) as less-invasive treatment for patients with severe aortic aneurysms.

Conclusion

Mac computers running OsiriX software have been shown to be adequate in preoperative planning and sizing for patients with thoracic and thoraco-abdominal aortic diseases. In a study involving CT datasets of 67 patients with severe aortic disease this method has been shown to be non-inferior to expensive standard imaging workstations even in sophisticated tasks such as detecting the artery of Adamkiewicz.

This technology is of great practical utility, because it enables surgeons to perform accurate and refined post-processing tasks on CT datasets in a very resources-conscious fashion. Cost containment in healthcare without loss of efficacy has become vital to medical centers worldwide.

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