REVIEW

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Teaching radiological anatomy

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SUMMARY

Human Anatomy has always been one of the core sciences in medical studies. If anatomical information is fundamental to medical studies, it is indispensable to the training of specialists in diagnostic medical imaging. Diagnostic medical imaging techniques include conventional radiology, ultrasonography, helical or multidetect computed tomography (CT) and magnetic resonance (MR). In this paper, each of these techniques is described in terms of its relevance and usefulness to clinical and anatomical studies. We also describe the different ways in which CT and MR present information: multiplanar reconstruction (MPR), maximum intensity projection (MIP), 3D, volume rendering (VR), and virtual endoscopy. In particular, VR is a very important method for understanding cross-sectional anatomy because it affords a perfect perspective of all body structures on different spatial planes, so the fact that the cross-section can be 3-dimensionally viewed makes it a particularly attractive and illuminating technique. Virtual endoscopy provides images that until very recently were unavailable.

This paper aims to describe the work that has been carried out in recent years since current study plans have been in place. Radiological anatomy is included as part of the content of Human Anatomy. Some of the diagnostic imaging methods are specifically given in-depth attention in an optional subject in the current study plan.

Key words: Human Anatomy – Medical studies – Magnetic resonance – Computed tomography – Ultrasound – Multiplanar reconstruction (MPR) – Maximum intensity projection (MIP) – 3D – Volume rendering (VR)

INTRODUCTION

Human anatomy is one of the basic sciences in medical studies. Since the advent of X-rays to the present day, visualization techniques to image the human body have become an essential tool for diagnosing and treating multiple diseases.

As in days past, modern medicine needs to reach correct diagnoses, establish appropriate treatments, consider prognoses and monitor

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disease development. Anatomical knowledge is a key to all of this.

Teaching radiological anatomy: why?

Imaging methods play an essential and increasing role in modern medicine. Indeed, may be said that the pathological picture is no more than a variation or distortion of the anatomical picture (Fig. 1).

Medical students, physicians in general, and specialists in particular must understand anatomical images to be able to identify pathologic conditions, control the results of their treatments, and monitor the progress of their patients. We regularly find that our doctors have forgotten the anatomy they learned during their Medical School studies and that in general they do not understand anatomical imaging.

Teaching radiological anatomy: to whom?

Students seeking a degree in medicine, medical residents, medical specialists in diagnostic imaging and imaging technicians.

Teaching radiological anatomy: who does it?

The answer is simple: somebody who knows about it.

For years, radiologists have made great efforts to learn, organize and represent the anatomical images that different diagnostic techniques have been providing at what at times has been a dizzying rate.

Radiologists need to learn anatomy and anatomists need to learn anatomical imaging.

The conclusion is clear: the teaching of anatomical imaging must be promoted. Specialist training programs should include anatomy in their schedules, but to do so requires an agreement between Speciality Societies and Universities.

Radiological Anatomy. Imaging Anatomy Methods of Diagnostic Imaging

1. Non sectional: conventional radiology, based on conventional radiology X-rays.
2. Sectional:
   a) ultrasound, employs sound waves
   b) computed tomography (CT), based on computed tomography X-rays
   c) magnetic resonance (MR), uses variations in magnetic fields (Fig. 2)

1. *Non sectional. Conventional radiology*

Despite the fact that this technique uses ionizing radiation, conventional radiology plays a leading role in diagnosis because it is accessible and widely available. The images obtained are the result of the overlapping anatomical structures. Physicians should be familiar with the anatomical and pathological information provided because, along with the patient's clinical history and physical examination, it can be crucial to proper diagnosis. It helps to prevent not only false-positive diagnoses that may lead to a host of complementary tests but also the dreaded false negatives that contribute to significant diagnostic delay (Fig. 3).

Fig. 1. Abdominal CT showing: **(A)** a normal pancreatic region and **(B)** tumour infiltration of pancreatic body and tail by a pancreatic adenocarcinoma.

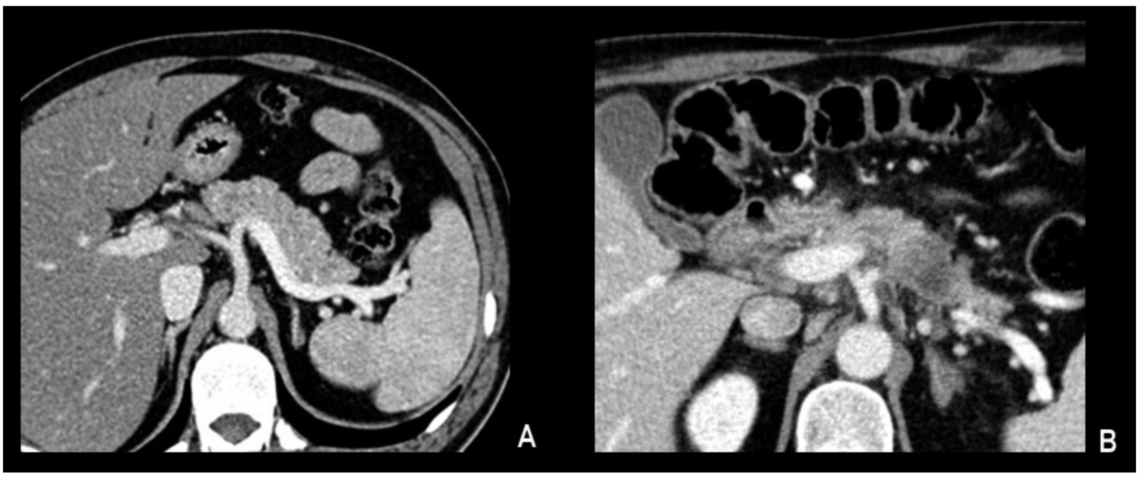


Fig. 2. Imaging methods. **(A)** Anteroposterior radiograph of the orbits, **(B)** axial ultrasound of the eye, **(C)** CT scan of orbits with oblicu-osagittal reconstruction and **(D)** MRI of both orbits on the axial plane.

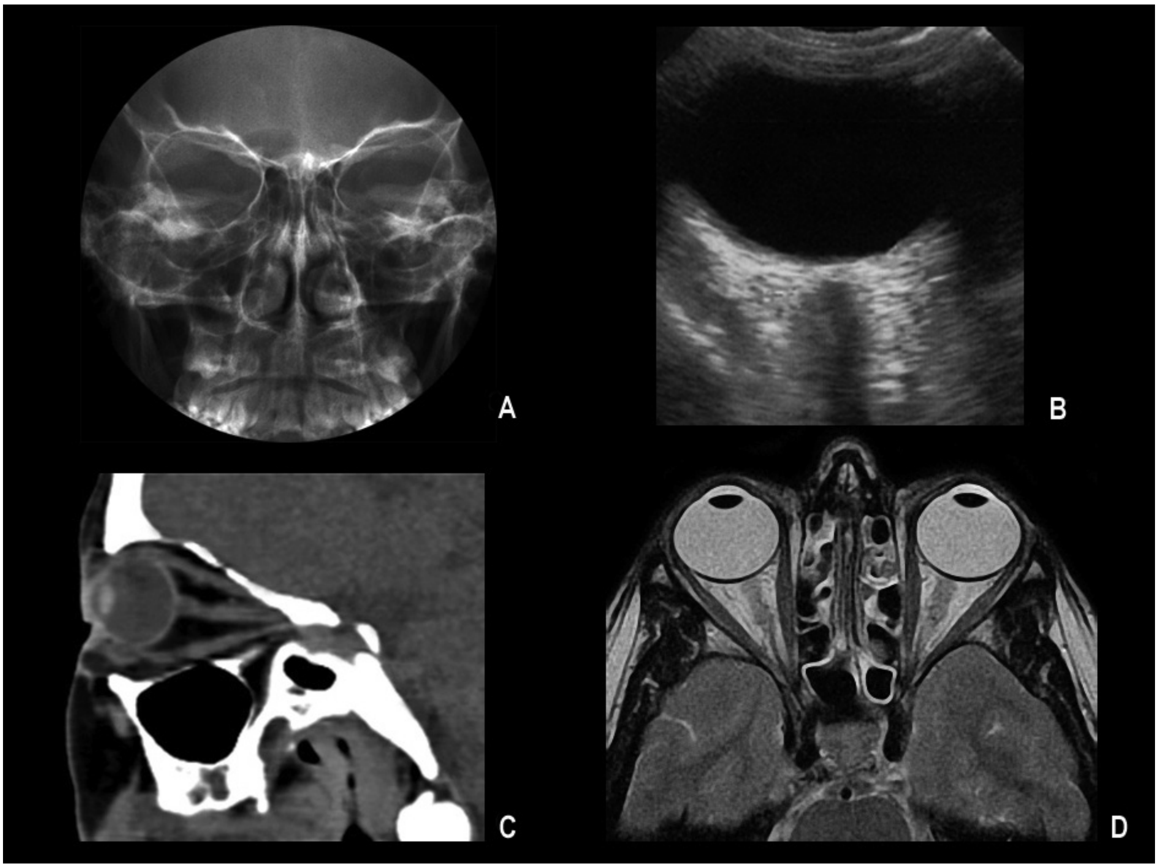
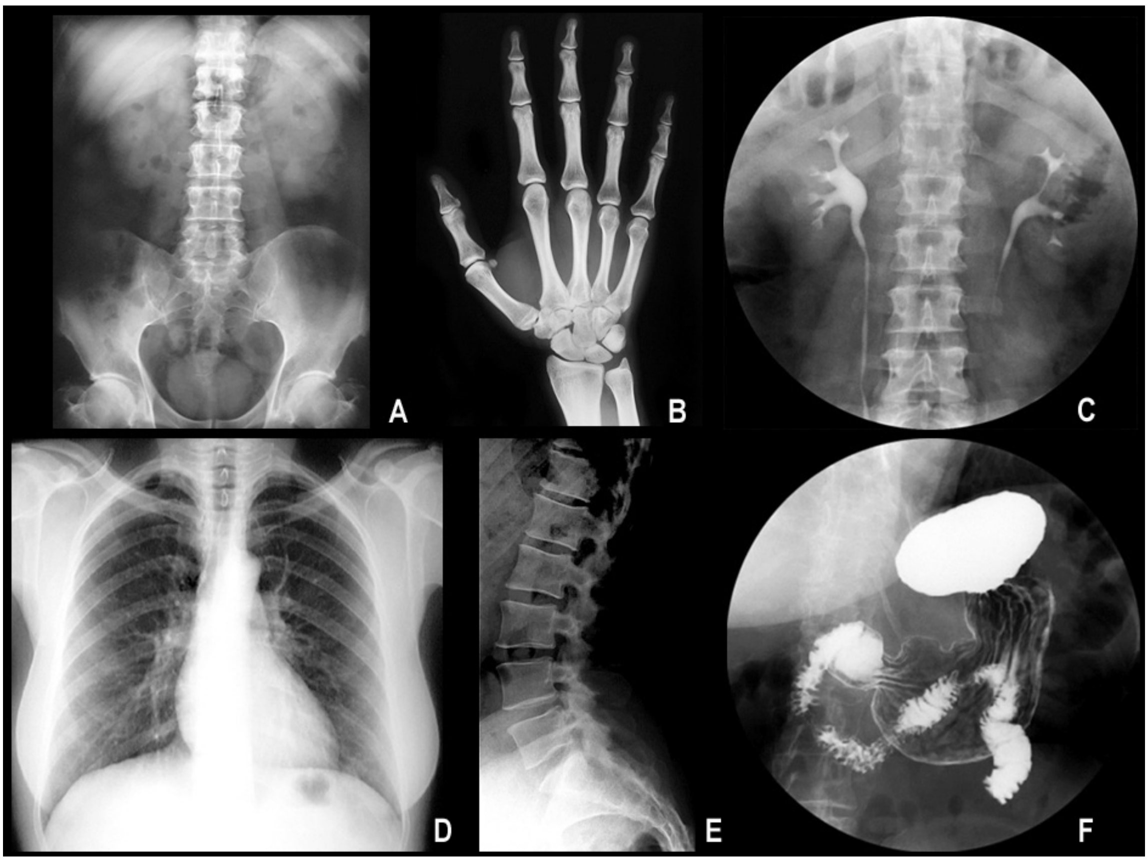


Fig. 3. Conventional Radiology. **(A)** Anteroposterior radiograph of abdomen, **(B)** anteroposterior radiograph of hand, **(C)** elimination urography showing the contrasted pyelocalyceal system of both kidneys, **(D)** posteroanterior chest radiograph, **(E)** X-ray of lumbosacral spine lateral and **(F)** gastroduodenal barium study.



2. *Sectional anatomy*

The remaining three diagnostic methods are all sectional methods that primarily use the axial, coronal or sagittal planes but they can also use any oblique plane that is suitable for presenting the anatomy and pathology (Fig. 4).

Sectional anatomy is the usual method of presenting modern diagnostic methods. It is little known and is spatially difficult to understand. It must be viewed sequentially to prevent mistakes in interpretation and requires significant software support in order to see the images.

a) *Ultrasound*

This sectional method is widely used and is based on sound waves, which means that it has no side effects. It differs from other imaging techniques because it allows dynamic and real-time visualization of anatomical structures. It provides information about an anatomical region through sections of that region, although it does not include all the region's structures in a single section. The resulting image can be difficult to interpret because it is operator-dependent and only the person who created it knows what type of section was made (Fig. 5).

b) *Computed tomography*

This is an imaging technique that provides complete anatomical information of a region of the human body because it images the entire region. As a result, it offers images in axial plane which can subsequently be reformatted into other planes and even turned into three-dimensional images thanks to volumetric data acquisition. The advent of multislice and helical CT has increased its importance as a diagnostic tool, and today it has become indispensable for the diagnosis and follow-up of many diseases.

Because this technique uses ionizing radiation it must be employed with caution. However, multislice technology and new low-radiation techniques have dramatically shortened the scanning time and thus the radiation dose, all of which bodes well for the technique's future.

Iodinated non-ionic contrast media can be administered by a power injector. This allows vessels to be visualized directly and increases the density of organs and tissues, thus allowing them to be better characterized and facilitating diagnosis (Fig. 6)

Fig. 4. Diagnostic Imaging. Source and type of image exploration.

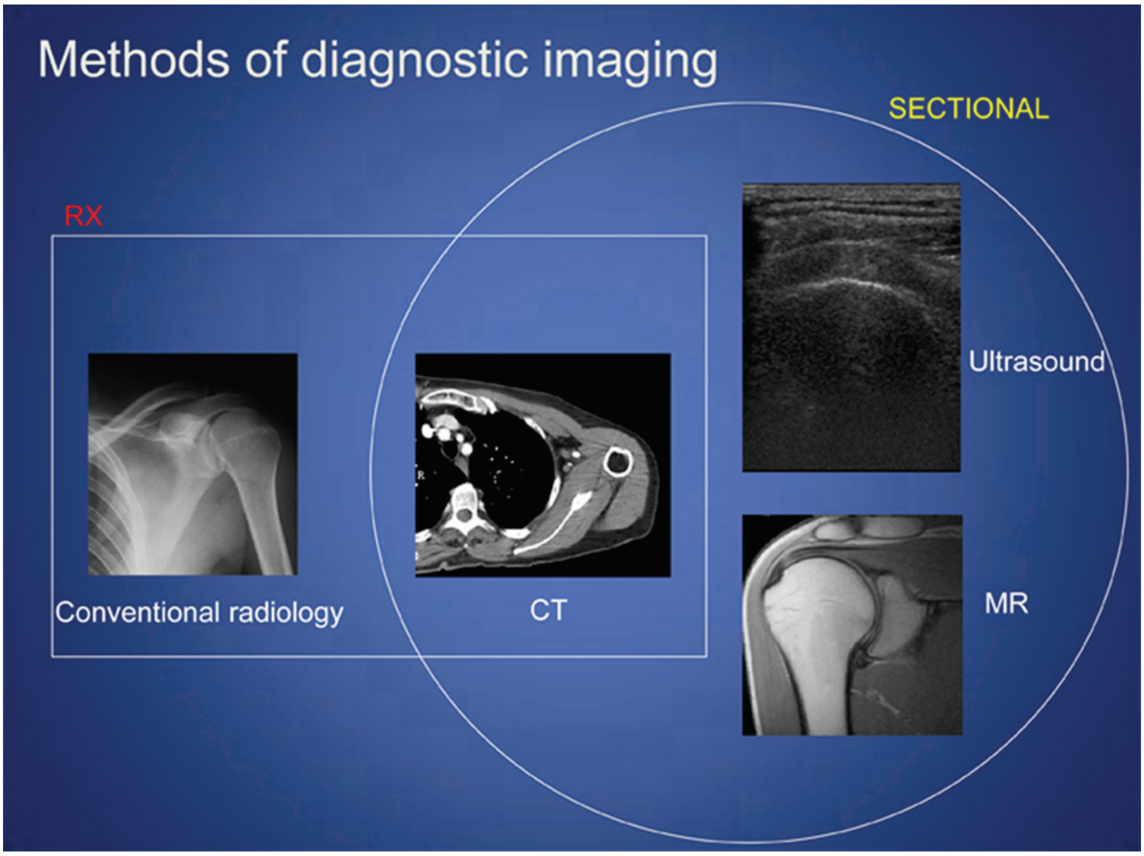


Fig. 5. Ultrasound. (**A**) Liver cut transversely, showing the hepatic veins at the confluence of the inferior vena cava, (**B**) sagittal section of female pelvis showing uterus and bladder, (**C**) sagittal section of a kidney showing corticomedullary differentiation, (**D**) echocardiogram (Doppler colour) showing the four cardiac chambers and the blood flow.

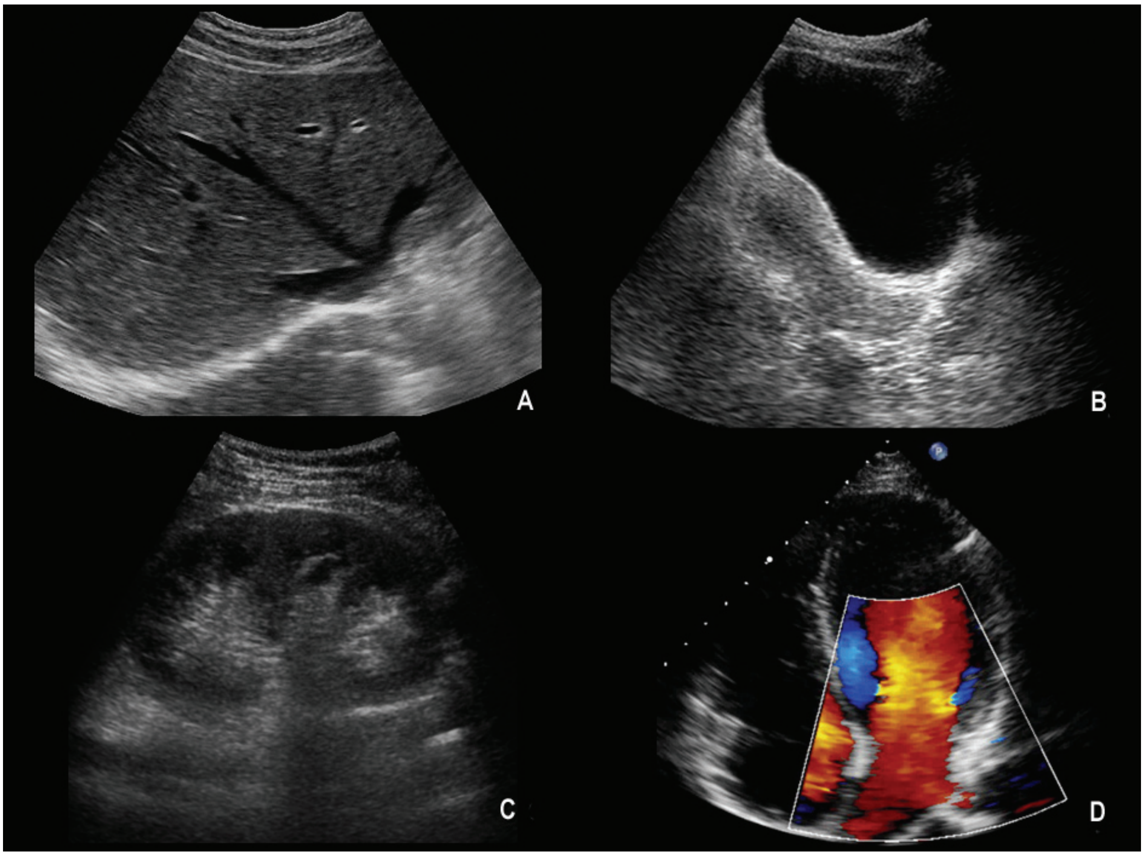
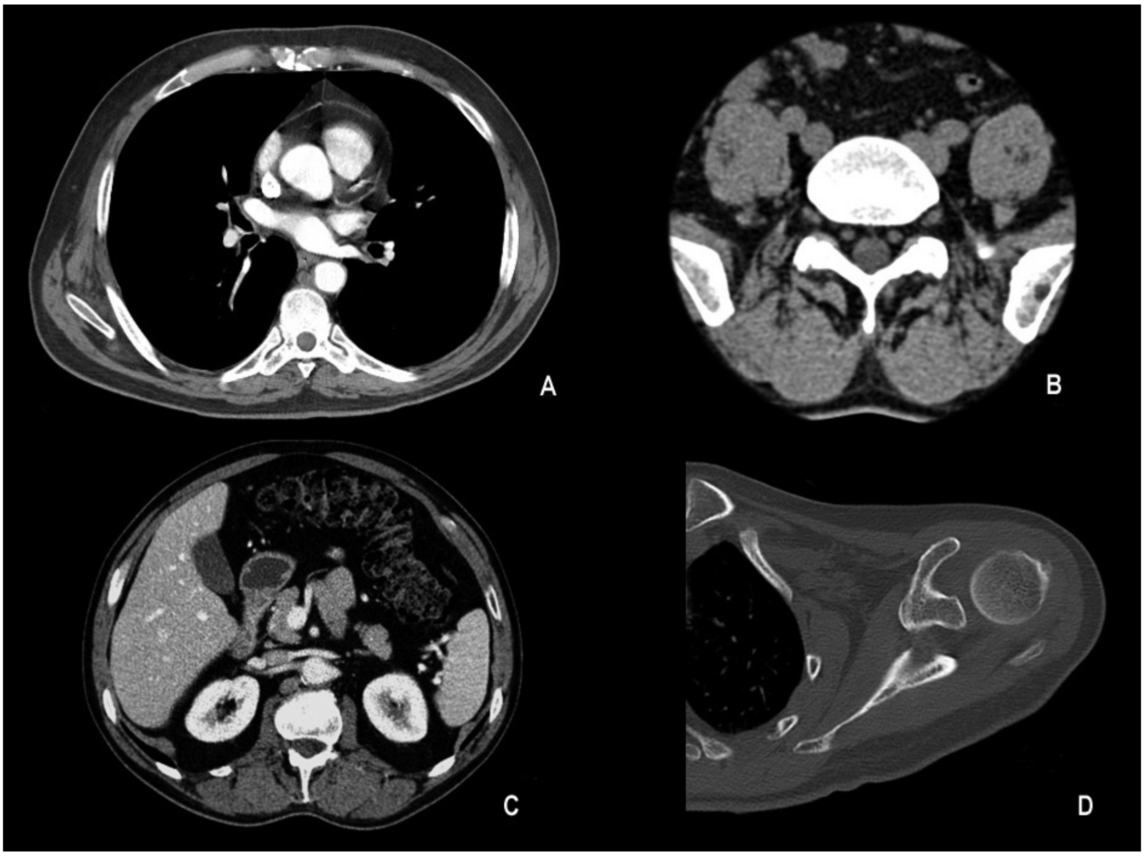


Fig. 6. Computed Tomography. (**A**) Contrasted chest CT: axial section with soft tissue window showing the cardiac base, (**B**) lumbar CT: axial section at the level of conjunction hole with emerging roots, (**C**) contrasted abdominal CT: axial section showing head of the pancreas, mesenteric and renal vessels, (**D**) shoulder CT: axial bone window showing shoulder joint and coracoid process.



c) *Magnetic resonance*

This is a sectional method based on applying radio waves to a magnetic field. It provides an essential image of the central nervous system and musculoskeletal soft tissues. It does not use ionizing radiation so it can be used on children and on pregnant women from the second trimester onwards.

The main drawbacks are longer scan times and higher cost. Prolonged scan times and confined spaces can also cause claustrophobia. Also, given the magnetic field some patients with metal implants or pacemakers cannot be scanned using this technology (Fig. 7).

Image analysis: display and post-processing

The resulting images have changed from an analogic to a digital format and are now integrated into storage systems for analysis as DICOM images (Digital Imaging and Communications in Medicine). This allows images to be shared easily and extensively, because the format is common to all medical computer systems. The usual resolution is 512 x 512 bits.

Image analysis requires:

- *Computers for display*: they usually provide only a vision of the images in the plane they were acquired.
- *Workstations*: they are very powerful computers that use software for processing data and obtaining new images that will facilitate diagnosis and understanding of both anatomy and pathology. They are mainly used when analyzing images from CT and, to a lesser extent, MR.

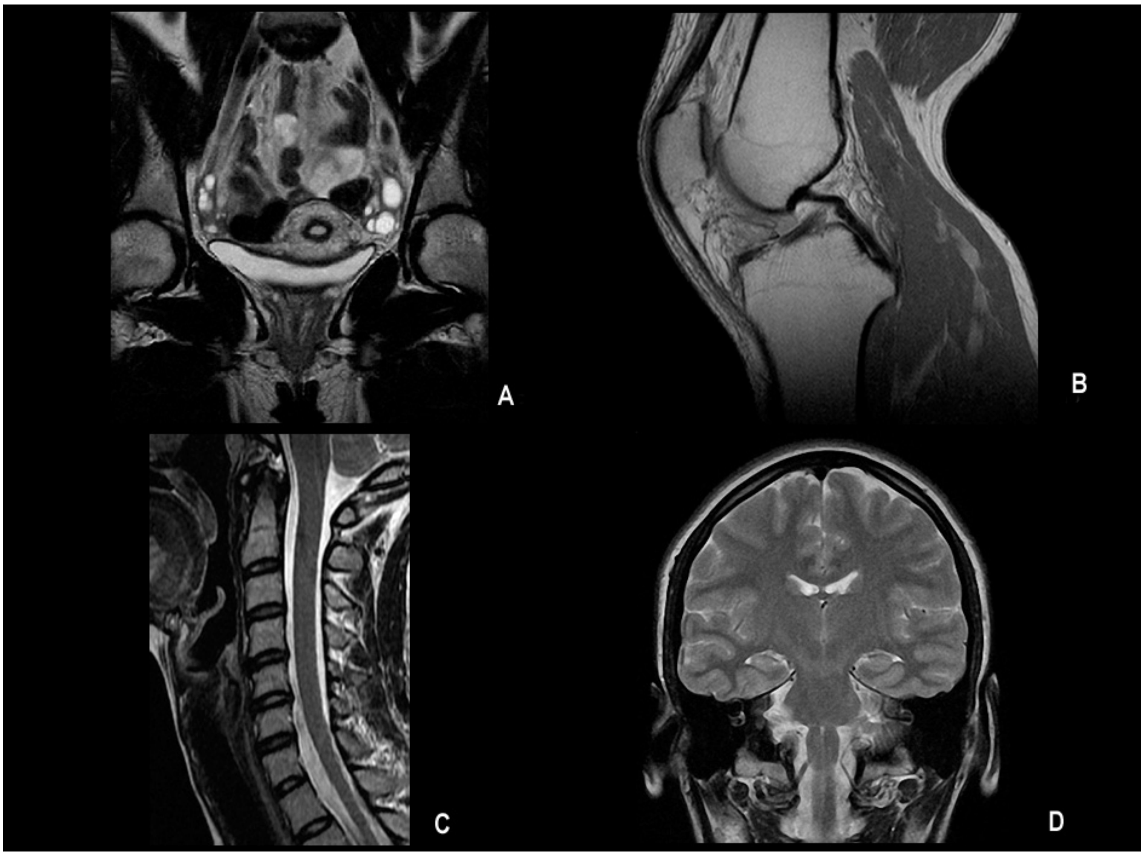
Multiplanar reconstruction (MPR)

These are 2D images reconstructed secondarily from volumetric data obtained during the study. New images can be achieved on any spatial plane (axial, coronal, sagittal or any obliquity). This constitutes significant progress in the field of computed tomography, which is no longer limited to the axial plane (Fig. 8).

Maximum Intensity Projection (MIP)

This is a volume-processing technique. It analyzes all the rows of voxels in any direction and represents them in 2D. It goes through the voxels with maximum opacity. Volume

Fig. 7. MRI. **(A)** Coronal T2-weighted sequence of female pelvis showing uterus, ovaries and bladder, **(B)** sagittal T1 sequence of the knee showing posterior cruciate ligament, **(C)** sagittal T2 sequence showing cervical column and spinal cord, **(D)** coronal T2-weighted sequence at mesencephalic and bulboprotuberance level.



thickness can be chosen and rotated in any direction.

It has two modalities: positive and negative. Positive MIP (maximum intensity projection) in association with contrast media and angio-CT techniques offers a huge advance in the study of vascular disease because it facilitates the study of arterial structures. Negative MIP (minimum intensity projection) gives an excellent overall view of the airways (Fig. 9).

Fig. 8. MPR. **(A)** Cervical CT: coronal reconstruction through the larynx, **(B)** chest CT: coronal curve reconstruction at the chondrosternal region, **(C)** chest CT: sagittal reconstruction of the mediastinum, **(D)** abdominal CT: coronal reconstruction of large vessels.

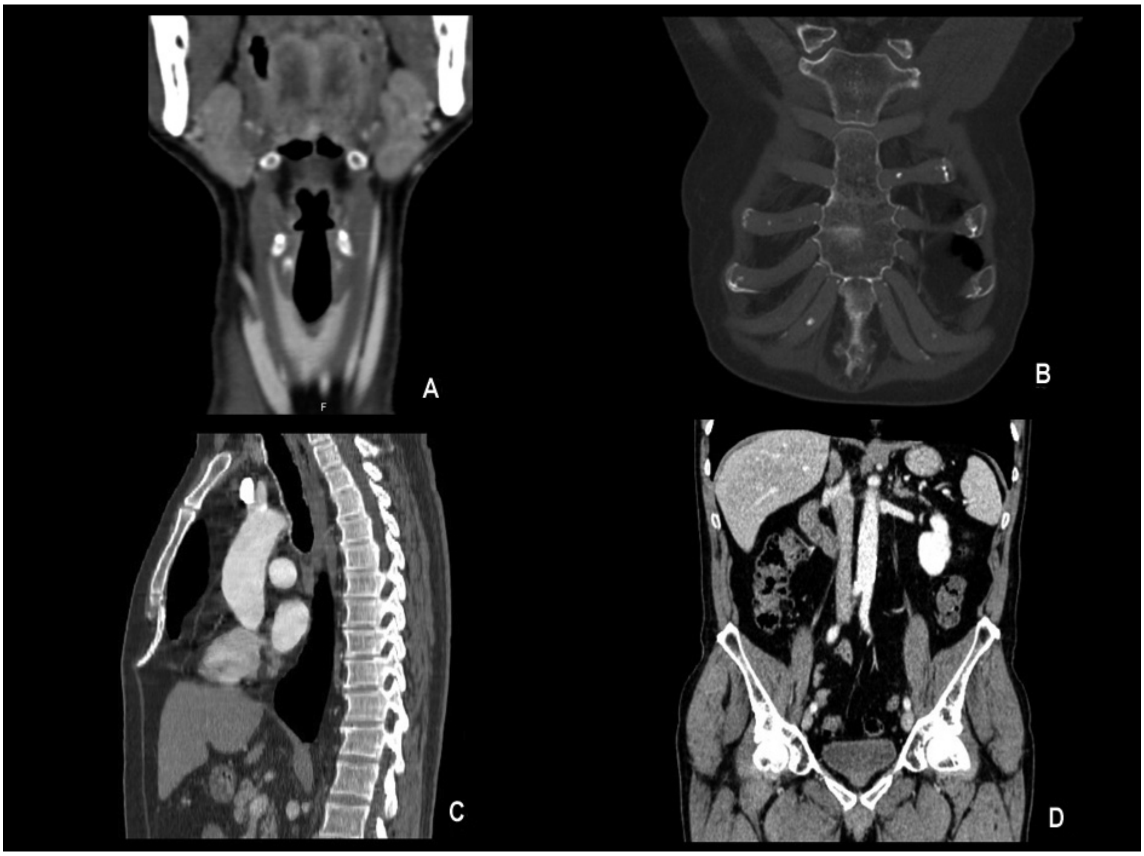


Fig. 9. MIP. **(A)** Aorto-iliac angio-CT: coronal positive MIP reconstruction showing an arteriographic way of aorta and renal arteries by an acquisition performed with intravenous contrast injection, **(B)** chest CT: coronal negative MIP reconstruction showing the overall tracheo-bronchial airway.

Shaded surface rendering (3D SSR)

This technique analyzes and represents the voxels that reach an established threshold of density.

It is a surface representation. The image is interpolated with colours that are similar to the real structures. A theoretical point of lighting is established, so hidden parts are shadowed and the nearest parts are illuminated, providing a three-dimensional image.

This reformation allows good visualization and compression from any perspective of mainly vascular and bone structures and provides spectacular results for understanding complex fractures (Fig. 10).

Volume Rendering (VR)

This term describes techniques that allow structures to be visualized in three dimensions. The volumetric data obtained during the scan can be reconstructed to create a three-dimensional image.

It is currently the most useful and versatile technique and is a complex procedure that combines the 3D surface with MIP.

It uses all the volume data and represents multiple tissues and their relationships. The technique provides good spatial anatomical information and better clinical information than other methods. It gives interpolated colours based on density values. The threshold of representation, opacity or transparency, colour scale, window level, slope and point of enlightenment can be modified (Fig. 11).

In practice, Volume Rendering can be used as an MIP or 3D technique, depending on transparency, or as a multiplanar reconstruction by combining the three-dimensional view with sectional anatomy. The latter mode allows a good understanding of sectional anatomy since it not only displays the different anatomical structures of the section but also represents the three-dimensional structures that will come in the next section. Thus, observer is always well oriented while navigate through sequential planes (Fig. 12).

Fig. 10. 3D. **(A)** Cardiac CT: coronal 3D reconstruction showing the anterior surface of the heart and coronary vessels, **(B)** lumbar spine CT: 3D surface reconstruction showing an oblique and posterior view of the facet joints («Scottish dog «).

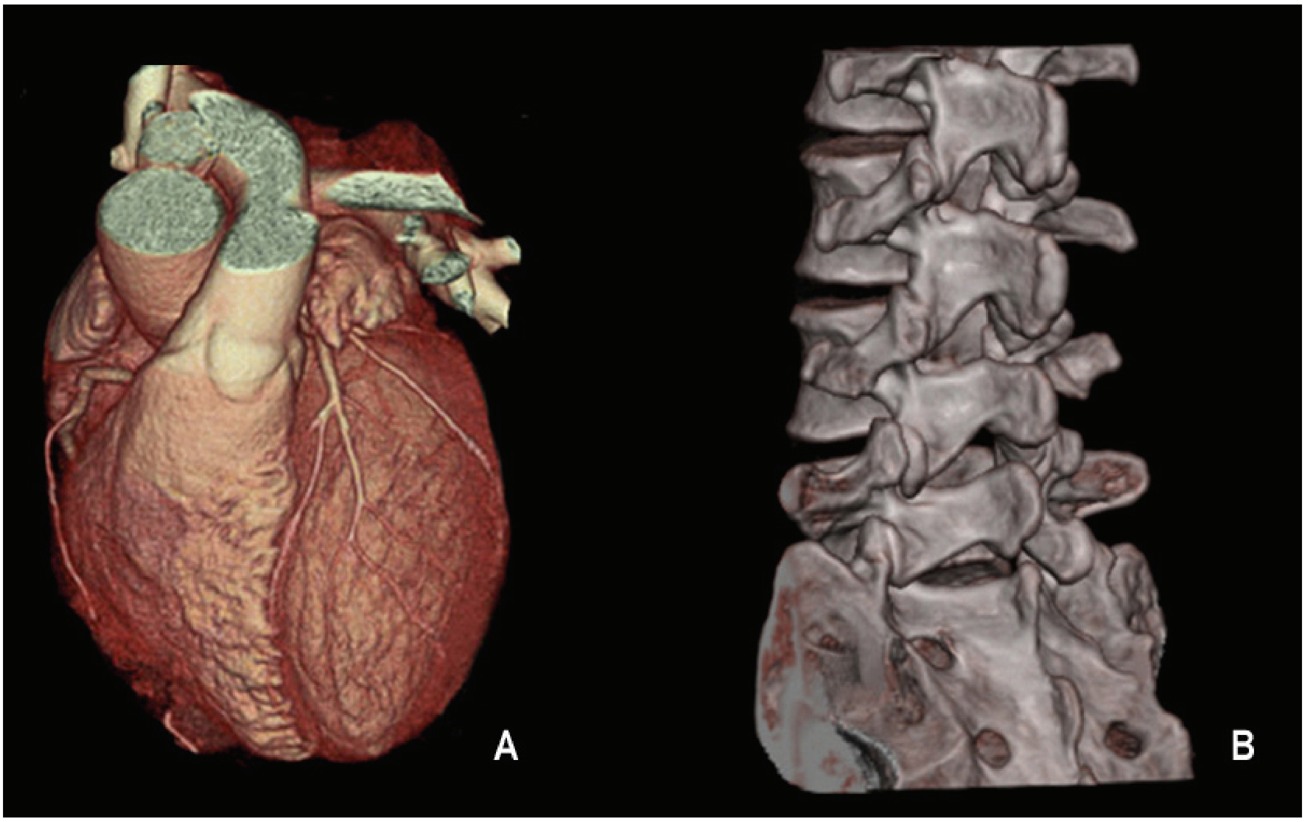


Fig. 11. Volume Rendering. (**A**) Multislice thoraco-abdominal CT: coronal reconstruction showing soft tissue density values of the mediastinum and abdomen, (**B**) coronal reconstruction showing structures with higher density levels (bone and vascular contrasted structures).

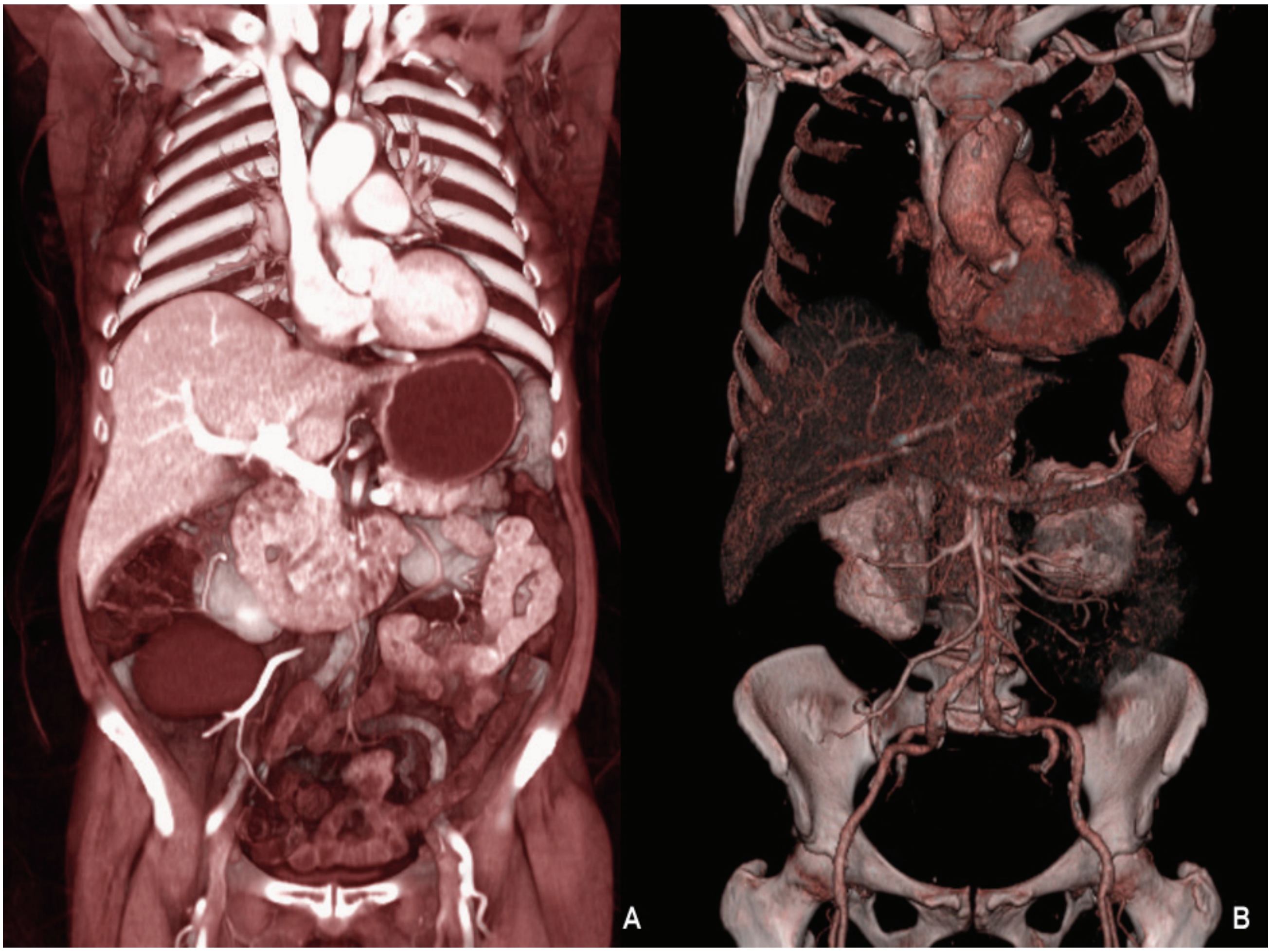


Fig. 12. Volume Rendering. Multislice CT of the heart and great vessels: simultaneous view of MPR coronal and Volume Rendering coronal at the same level. Volume Rendering affords a three-dimensional view of the structures posterior to the section, facilitating the understanding of the section.

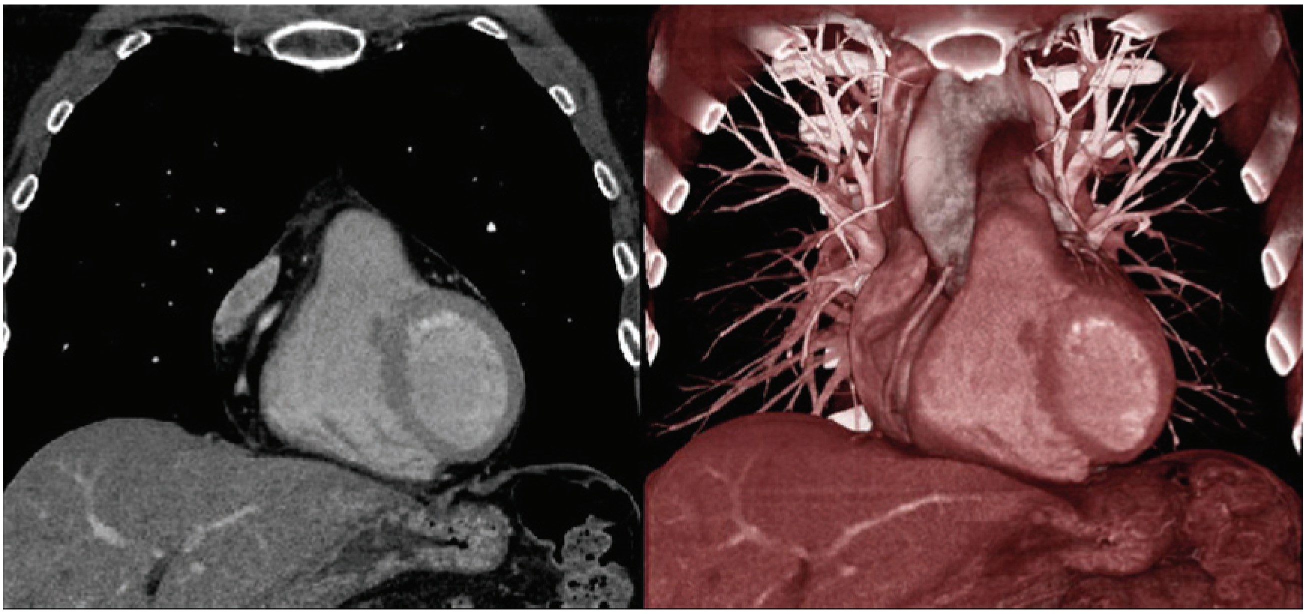
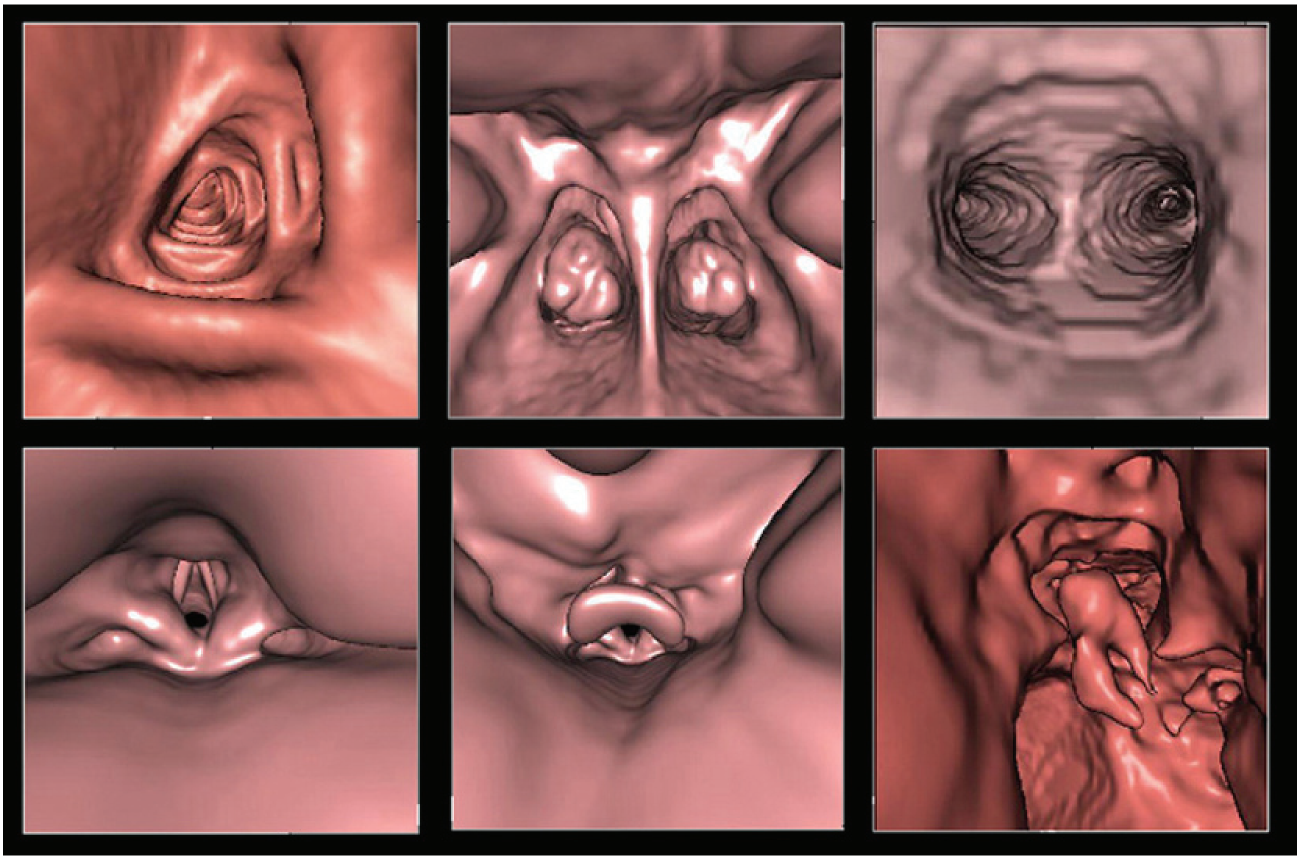


Fig. 13. Virtual Endoscopy. Simulation of endoscopy with 3D technology facilitates inner views of the colon, nostrils, trachea and bronchial bifurcation, larynx and middle ear.



To sum up, Volume Rendering is very educational and provides easily understood anatomical information.

Virtual Endoscopy

This is an advanced three-dimensional technique that allows the visualization of the interior of different structures. It simulates endoluminal endoscopic techniques and provides fascinating insights into vascular, bronchial, laryngeal and gastrointestinal anatomy, among others (Fig. 13).

Conclusion

The images provided by these different methods represent great progress in diagnosing and understanding pathology and planning surgical interventions, and they also play an important role in the teaching of anatomy and congenital malformations (Fig. 14).

It is clear that all methods of diagnostic imaging and the images they provide must become an indispensable part of the teaching of anatomy. This needs to be done in harmony with the other teaching activities of this fine academic discipline.

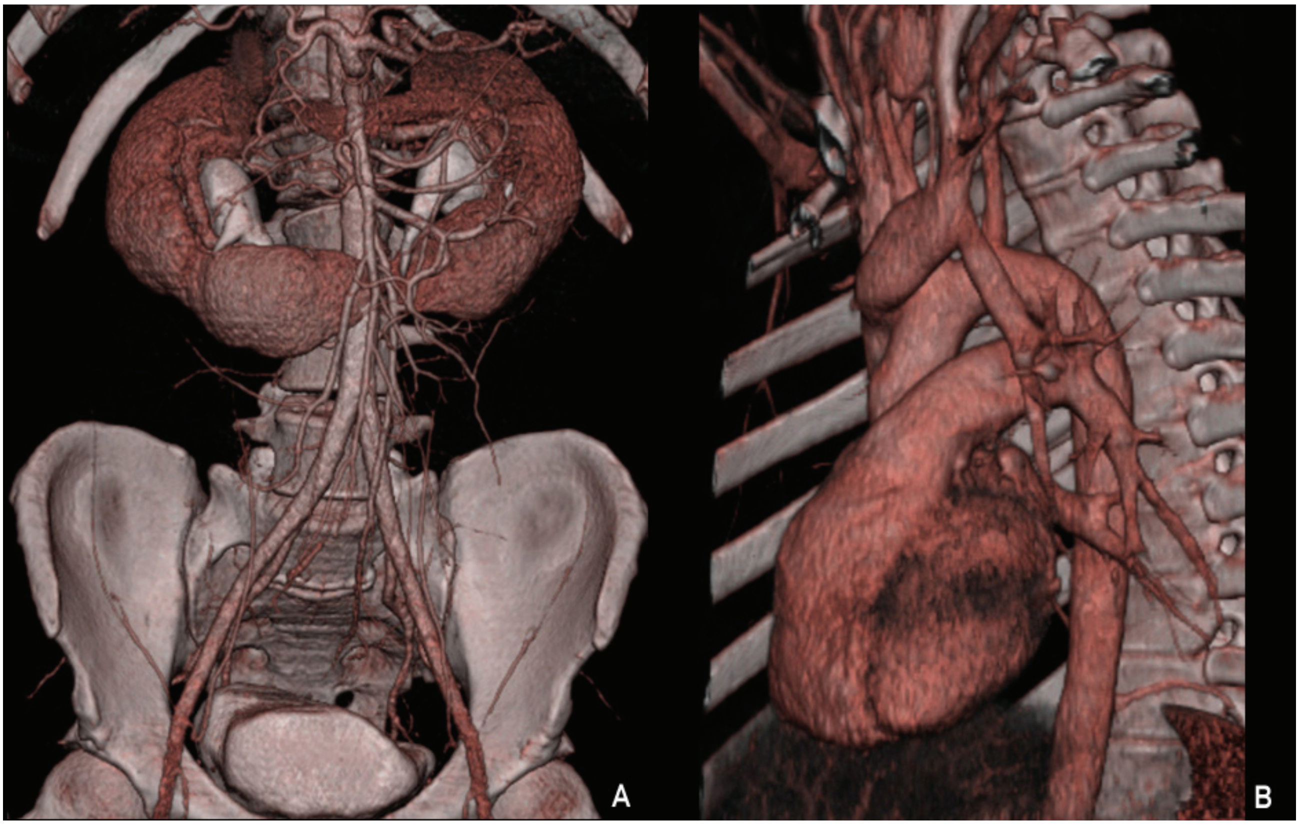
Over the years, this belief has directly influenced our activities at the Rovira i Virgili University. All human anatomy subjects taught during the undergraduate degree incorporate the teaching of radiological anatomy in conjunction with practical sessions at the Joan XXIII University Hospital of Tarragona.

As a result of this experience, with the support of the Rovira I Virgili University and the Spanish Society of Radiology (SERAM) we have published an atlas of sectional anatomy imaging as a learning and consultation tool for students of anatomical imaging.

This anatomical atlas contains 10,200 images that have been labelled according to the anatomical nomenclature and that show the most important elements of each image.

The brief review that is offered here was motivated by our enthusiasm for learning and for being able to teach what we have learned, along with the pleasure of forming a part (albeit small) of the discipline of anatomy.

Fig. 14. Volume Rendering. **(A)** 3D surface reconstruction of a horseshoe kidney provides an easy view of the pyelocalicial systems and vasculature of the area, **(B)** the Volume Rendering reconstruction technique allows a better understanding of this congenital malformation consisting of a partial anomalous venous return (left superior pulmonary vein drains into the left brachio-cephalic vein).



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