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CT Imaging of Hepatic Arteries

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The reason why the water in wells becomes colder in summer is that the earth is then rarefied by the heat, and releases into the air all the heat-particles it happens to have. So, the more the earth is drained of heat, the colder becomes the moisture that is concealed in the ground. On the other hand, when all the earth condenses and contracts and congeals with the cold, then, of course, as it contracts, it squeezes out into the wells whatever heat it holds.
Lucretius, poet (99 B.C.-55 B.C.) Rome

1. Introduction

The knowledge and reliable depiction of celiac trunk vascularization and hepatic arteries is extremely important in several condition like surgery in the hepato-biliary pancreatic area, as well as in interventional radiological treatments[1,2]. In particular, in the setting of liver transplantation a frequently used approach is the split liver from living donors. This kind of procedure is complex and an exact knowledge of the arterial anatomy is necessary to plan the best resection approach and to minimize the risk of mortality[3,4]. Similarly, an accurate depiction of hepatic arterial variants can also help in ensuring a safe operation in treating isolated liver tumors, performing partial hepatectomy.

The patterns of arterial blood supply to the liver are variable. *Nelson et al[5]* reported a typical scheme, in which the liver receives its total inflow from the hepatic branch of the celiac trunk, that occurs in 25-75% of cases (**Figure 1**). In the variant configurations, the liver receives arterial flow through branches coming from the superior mesenteric artery, left gastric artery, abdominal aorta or other visceral branches. Moreover, these vessels may be replaced, representing the primary arterial blood supply to the liver, or accessory, occurring in addition to the normal arterial supply.

Both in the early and in the most recent literature in this subject[6,7,8,9], authors made an effort to compare the several types of variation in order to obtain a single scheme for the most common variants.

Digital Subtraction Angiography (DSA), despite its invasive nature, was regarded as the method of choice for hepatic artery evaluation[10,11] until the introduction of Multi-Detector-Row CT Angiography (MDCTA), which is now considered to be an extremely reliable and non-invasive method in the analysis of hepatic vasculature[12,13]. Modern MDCT scanners acquire their dataset with isotropic sub-millimetric voxels and are capable of visualizing even small vessels like the Adamkiewicz artery[14].

With the introduction of MDCT indications have expanded to include assessment of hepatic arteries by replacing the use of Digital Subtraction Angiography (DSA)[15,16]. Combined with patient- and scanner-adjusted CT data acquisition and contrast medium application strategies, an accurate, retrospective and reliable evaluation of the hepatic artery configuration is possible even in routinely MDCTA exams performed for other indications.

In the analysis of MDCTA, it is possible to use several post-processing methods to visualize the arteries. The most frequently used are Maximum Intensity Projection (MIP), Multi Planar Reconstruction (CPR), Curved Planar Reconstruction (CPR) and Volume Rendering (VR)[17,18,19]. With the more recent workstations, these post-processing images are obtained in real-time, such that the processing time, which was a problem some years ago, is no longer an issue. However, the time taken for the radiologist to visualize datasets using all the different post-processing techniques may be important. For this reason it is important to determine the most reliable post-processing technique(s) for visualizing the vessels.
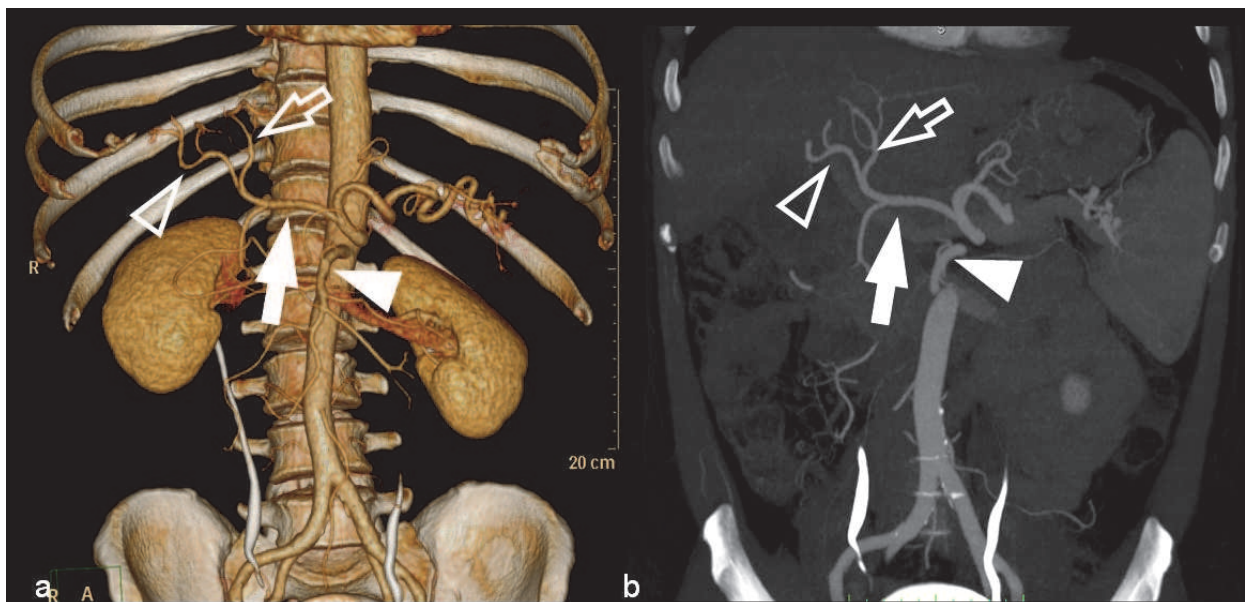

Fig. 1. MDCTA volume rendered (a) and Maximum Intensity Projection (b) images of a Michels type I configuration. In the panel a,b is visible the common hepatic artery (white arrow), the right hepatic artery (open white arrowhead), the left hepatic artery (white open arrow) and the superior mesenteric artery (white arrowhead).

2. Normal anatomy and variants

The anatomy of hepatic artery and its variants, have been extensively described in the literature[9,20,21,22,23] and nowadays the most frequently used is the Michels's classification[9] even if Michel's description is an anatomical classification having nowadays less relevance to modern surgical practice than in the past. Michels described 10 types of configuration for hepatic arteries vasculature, by including the normal anatomy in type 1 and gathering all other types of variants in types 2 -10.

In the conventional anatomy, -**type I** (**Figure 2**) according to Michels classification- the main hepatic artery arises from coeliac artery, gives off the gastroduodenal artery and the proper hepatic artery. The proper hepatic artery continues as the right hepatic artery after giving off the left hepatic artery and then the right hepatic artery splits into its anterior and posterior

branches. The left hepatic artery splits into branches which feed segments II and III. Segment IV is fed by the branch or branches originating from the right, left, or by the proper hepatic artery. The frequency of occurrence of normal hepatic arterial anatomy ranges between 55%-76%.
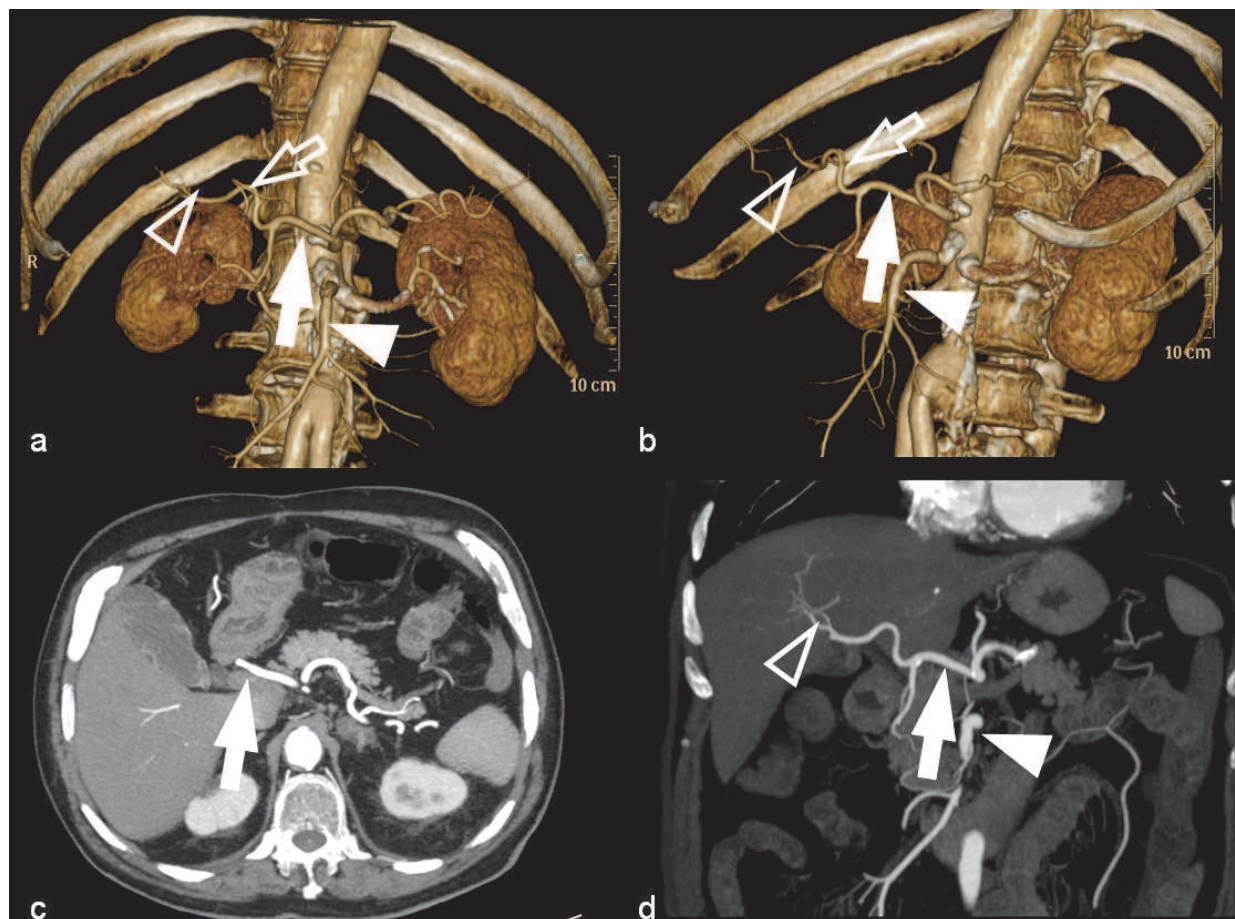

Fig. 2. MDCTA volume rendered (a,b) and Maximum Intensity Projection (c,d) images of a Michels type I configuration. It is visible the common hepatic artery (white arrow), the right hepatic artery (open white arrowhead), the left hepatic artery (white open arrow) and the superior mesenteric artery (white arrowhead).

In the **type II** of Michels variant (replaced left hepatic artery) the left hepatic artery (LHA) originates from the left gastric artery (LGA) (**Figure 3**). The frequency of occurrence of this type of variants is 10%.

In the **type III** of Michels variant (replaced right hepatic artery) the right hepatic artery (RHA) starts from the superior mesenteric artery (SMA) (**Figure 4**) . This case occurs in 11% of the patients.

Type IV of Michels variant identifies a situation where variant II and variant III cohexist: it is a combination of replaced right and replaced left hepatic artery: the RHA originated from SMA and the LHA originated from the GHA. This variant is uncommon and its incidence in population is near 1%.

In the **type V** of Michels variants (accessory left hepatic artery), the left lobe is fed by both the left hepatic artery originating from the proper hepatic artery and the accessory left hepatic artery originating from the LGA; the incidence of this variant is 8%.
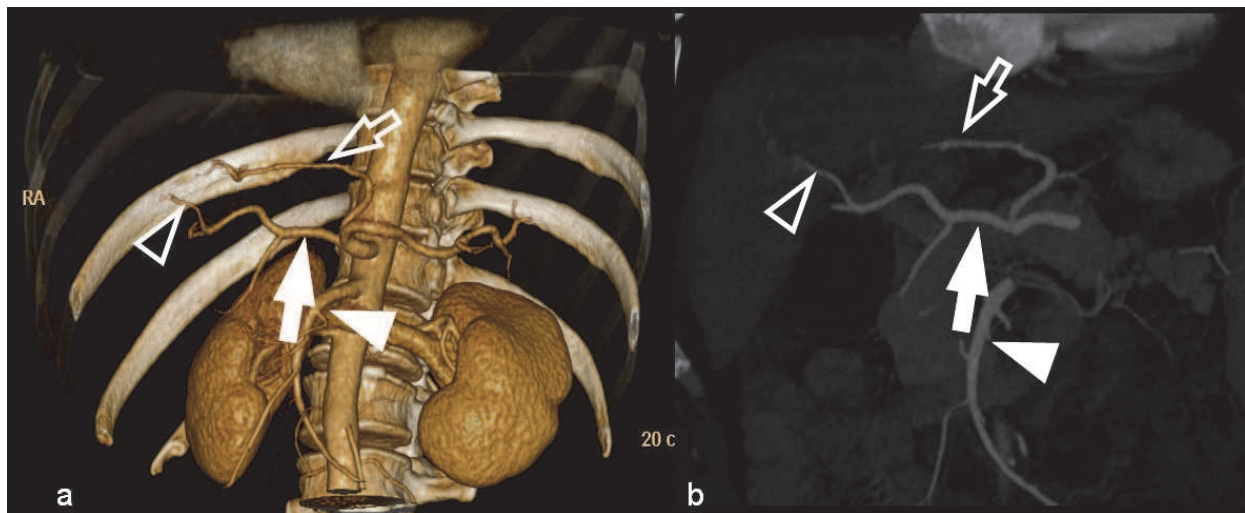
Fig. 3. MDCTA volume rendered (a) and Maximum Intensity Projection (b) images of a Michels type II configuration, where the left hepatic artery origins from the left gastric artery. It is visible the common hepatic artery (white arrow), the right hepatic artery (open white arrowhead), the left hepatic artery (white open arrow) and the superior mesenteric artery (white arrowhead).
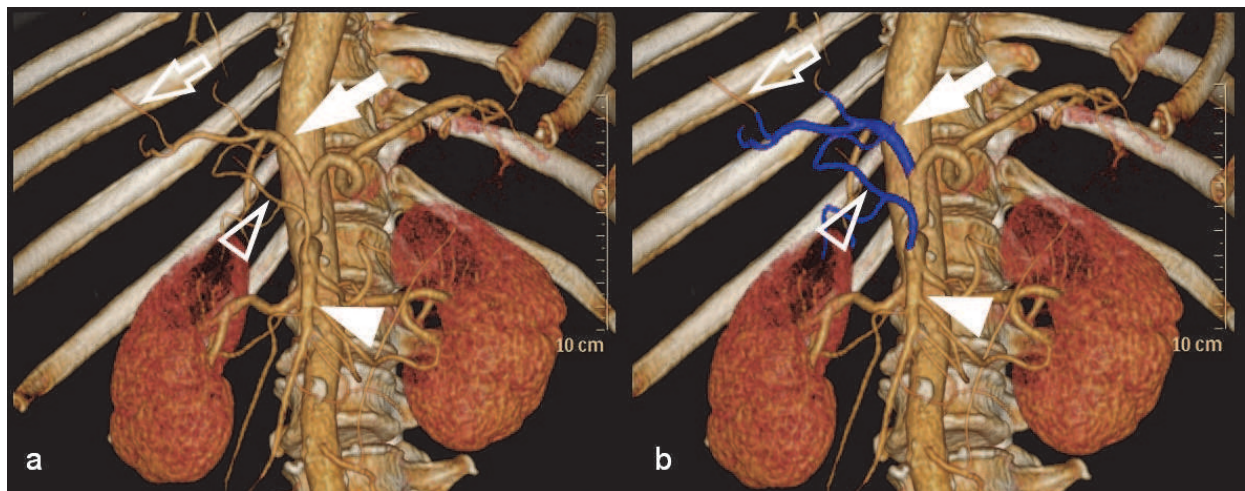

Fig. 4. MDCTA volume rendered (a,b) images of a Michels type III configuration where the right hepatic artery origins from the superior mesenteric artery. It is visible the common hepatic artery (white arrow), the right hepatic artery (open white arrowhead), the left hepatic artery (white open arrow) and the superior mesenteric artery (white arrowhead).

In the **type VI** of Michels variant (accessory right hepatic artery) the right lobe is fed by both the RHA originating from the proper hepatic artery and the accessory RHA deriving from the SMA (incidence 7%).

In the **type VII** of Michels variant, the left lobe is fed by both the left hepatic artery (LHA) originating from the proper hepatic artery and the accessory left hepatic artery originating from the left gastric artery; the right lobe is fed by both the right hepatic artery originating from the proper hepatic artery and the accessory right hepatic artery starting from the superior mesenteric artery; this variant is uncommon with an incidence of 1 %.

In the **type VIII** of Michels variant, the replaced RHA originates from the superior mesenteric artery and the accessory LHA originates from the left gastric artery (VIIIa) or a replaced LHA is accompanied by the presence of accessory RHA (VIIIb); this variant occurs in 2% of our study population.

In the **type IX** of Michels variant the main hepatic artery originates from the superior mesenteric artery (incidence1%) whereas the **type X** of Michels variant shows that the main hepatic artery originates from the left gastric artery (this is an extremely uncommon variant, less that 0.2% of cases).

It is also possible to find other anatomical variants, not included in Michel's classification, as replaced RHA that originates directly from aorta, or the main hepatic artery directly beginning from aorta or from the SMA (**Figure 5**).

Even the anatomy of the artery (or arteries) that feed the segment IV may be of interest, because of their crucial position in the surgical procedures. The arterial supply for segment IV may be quite variable. It is possible to observe single, double and triple supply for segment IV, originating from right, left, and proper hepatic artery. Usually segment IV artery originates form the left hepatic artery in 64-75% of patients and from the right hepatic artery in 25%[24,25,26]. In case of living donor liver transplantation (LDLT) the arterial supply for segment IV, must be carefully preserved to prevent remnant liver failure when the right lobe is removed during the harvest[27].

3. MDCTA technical parameters

MDCTA acquisition parameters as section thickness, increment, pitch, kV and mAs can markedly change according to the employed CT scanner and on the number of available channels; with MDCT scanners at present, up to 256 simultaneous helices are acquired and the system performance has greatly increased. Usually arterial enhancement is provided by the intravenous administration in an antecubital vein of 80-100 (depending of iodine concentration) ml non ionic iodinated contrast material, at an injection speed variable from 3 to 6 mL/sec. We usually use a 5 or 6 mL/sec flow rate.

The contrast material volume should be always defined according to the number of detector-rows of the scanner. *Kamel and colleagues*[28] suggested that the use of high flow rate (5 ml\sec) in the study of hepatic vasculature produces optimal results and we agree with their observations. By using high flow rates it is possible to obtain high e fast opacification of the hepatic arteries.

It is important to remember that the presence of reduced scan time (8 seconds in 64-row scanner to cover 50 cm) requires a reduced volume of contrast material injection. Although aortic CTA studies can be performed with a lower total iodine dose, liver CTA requires a total iodine dose of 45 g in order to produce a correct imaging. Hence, with a 300 mgI/mL concentration, 150 mL is injected at 5 mL/sec, whereas with 370 mgI/mL iodine concentration, it is possible to inject the 45-g iodine dose with a volume of 120 mL injecting it at a rate of 4 mL/sec. We usually used 370 mgI/mL iodine concentration because this determines higher HU hepatic arteries values than the use of 300 mgI/mL iodine concentration.

A contrast material bolus may be followed by a saline bolus in order to reduce streak artefacts due to beam hardening. An antecubital vein is usually chosen, but also other sites may be used: if this situation occurs it is opportune to calculate the delay time again, which indicates delay in seconds between the starting of injection of i.v. contrast material and MDCTA acquisition.

For timing of image acquisition it is necessary to use the bolus tracking technique because it allows customization of scan delay for individuals with reduced cardiac output. In particular, a fixed scanning delay cannot be recommended in patients with cardiovascular disorders: with short acquisition times in fact , it is possible to completely miss the bolus if the delay time is not properly chosen.

For hepatic CTA, bolus-tracking scans that monitor aortic attenuation are acquired every 2 seconds beginning at 10 seconds after start of injection, and imaging is triggered at aortic enhancement of 150 HU. In our experience, the targeted arterial density during CTA of hepatic vasculature, is 300 to 450 HU: with this range values it is possible to obtain optimal post-processing images.

In our Institute CT of hepatic arteries are currently performed with a 16-detector-row scanner and the **arterial phase scans** are performed with the following parameters: a voltage of 120 kV, a tube current of 280-330 mA, collimation 16 x 0.625 mm, field of view of 32–36 cm]: 80–110 mL of a contrast medium were injected into a cubital vein, using a power injector at a flow rate of 5 mL/s and an 18-gauge intravenous catheter in order to obtain a constant iodine delivery rate (2 gI\sec). A bolus tracking technique is used to determine the correct timing of the scan. Dynamic monitoring scanning began 6 seconds after the beginning of the intravenous injection of contrast material. The trigger threshold inside the ROI was set at + 60 HU above the baseline. The delay between the acquisition of each monitoring scan is 1 second. When the threshold was reached, the patient was instructed not to breathe and after an interval of 4 seconds the scan started in the cranio-caudal direction.

4. Post processing techniques

The introduction and widespread availability of 16-section multi-detector row CT technology and, more recently, 64/128/256-section and dual source scanners, has greatly advanced the role of MDCTA in clinical practice. The success of CT angiography depends on a number of critical steps, including the correct timing of data acquisition, the timed delivery of iodinated contrast material and the selection of appropriate scanning parameters. The reconstruction of CT angiographic datasets may result in 1000–5000 images per examination. The large size of the dataset sometimes makes it impractical to extract all the information using standard two-dimensional techniques and makes clear the importance of post-processing techniques. Moreover, post-processing techniques allow to assess the three-dimensional relationship of the arteries to each other or the surrounding organs in a more "surgical view". To obtain high quality post-processed images it is necessary to use data set with thin slice thickness; isotropic voxels provide the best results. Several post-processing techniques may be used to evaluate the hepatic arteries: MPR (Multi Planar reconstruction), CPR (Curved Planar Reconstruction), MIP (Maximum Intensity projection) and VR (Volume Rendering). All of these tools show strengths and pitfalls regarding quantification but it is important to underline that all of them are based upon post processing procedures of the CT data.

Maximum Intensity Projection (MIP) is commonly used as a three-dimensional post-processing method to depict volumetric vascular data sets acquired with Computed Tomography. To produce MIPs, a viewing angle is chosen to define the projection plane, then parallel rays are cast from the projection plane through the stack of reconstructed sections that make up data volume, and the maximum intensity encountered along each ray is placed into the projection plane to create the MIP. It is possible to use different types of

MIP as thin-thick slab MIP or curved MIP. In the Maximum Intensity Projection (MIP) image, only the voxel with highest CT number is displayed depending on the voxel position along the projecting ray40. MIP may generate high quality DSA-like images and it provides an overview of the target vessel but, on the other hand, it shows lower sensitivity in case of dense calcification since it may obscure contrast material in the lumen. MIP allows the visualization of smaller branch vessels with less work than is required for volume rendering and it is widely used in the study of the hepatic vasculature.

Multi-Planar Reconstruction (MPR) is a post-processing technique widely used in the vascular studies. This technique is very simple and, in particular by using near isotropic CT data set, can produce high defined sagittal, coronal and oblique visual plane. MPR creates views in arbitrary plane without loss of information. Multiplanar reformatted images are created starting from the retrospectively reconstructed axial images (deriving from projection data) and resulted image may be oriented in every spatial direction. Moreover, by using 32-256 slice scanner producing isotropic voxels, spatial resolution is similar to the original source images. Usually, the use of MPR in the study of hepatic arteries does not produce acceptable results because of the tortuosity and spatial orientation of hepatic arteries.

Curved Planar Reformation (CPR). CPR is a flexible multi-planar reformatting method that works along the course of the target artery and can be performed using an axial image as a reference to define the course of the desired reformation. This technique has been shown to be useful in displaying both renal arteries and intra-cerebral vessels. In this procedure axial sections are stacked to generate an imaging volume and a reformatting algorithm is applied to the arbitrarily rotated imaging volume. On each image within these contiguous reference images, the course of the target vessel is traced by a series of mouse clicks. Then, along the defined curved line, a single-voxel-thick plane, orthogonal to the reference plane, is extruded through the entire dataset. At the end of the procedure the resulting "curved plane" is flattened and displayed as a 2D, composite sagittal image representing the target vessel. An important issue concerning the use of the CPR is that vascular images depend on the course of the curved plane selected in fact CPR creates images in an arbitrary plane and while the vessel of interest is exquisitely displayed, the neighboring anatomy becomes distorted.

Volume rendering (VR) started to become common in the late 1980s. In the VR CT numbers that make up the image are assigned to be either visible or invisible, to be displayed in varying colours and often to be displayed with varying opacity levels (transparency). VR is an advanced computer intensive rendering algorithm and it incorporates all the CT raw data into a resulting image producing high quality three dimensional pictures. VR always accurately depicts 3D relationships, while MIP may do not. Moreover VR enables a color display, which improves image quality and visualization of hepatic arteries. Unlike MIP, VR does not require slab editing since the bones do not interfere with visualization of the vasculature.

The use of post-processed images play an important role in the interpretation of MDCTA vascular images. MIP is an optimal choice in all situations except in case of vessel tortuosity and when there is not a perfect arterial phase: in fact presence of tortuosity and venous phase may produce superimposition with consequent suboptimal image quality. Superimposition can prevent radiologist from correctly detect and qualify a vessel. VR allows to evaluate vessel tortuosity and it avoid arterial\venous superimposition by depicting 3D relationship. Nowadays, VR and MIP reconstructions are obtained in real-time

and the "time consuming" problem is avoided. Saba et al[29] demonstrated that MIP and VR methods showed optimal inter- and intra-observer agreement and the highest quality scores and therefore should be used preferentially as post-processing techniques to study the hepatic arteries when using MDCTA.

5. Conclusion

MDCTA allows to precisely analyze hepatic arteries configuration. The presence of hepatic arterial variant is a condition with an high prevalence. Arterial patterns should be identified with precision because these are important in the planning and performance of all radiological and surgical procedures in the liver as well as in the upper abdomen.

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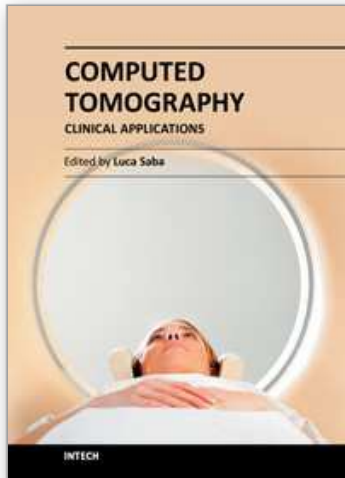
Computed Tomography - Clinical Applications
Edited by Dr. Luca Saba

Computed Tomography (CT), and in particular multi-detector-row computed tomography (MDCT), is a powerful non-invasive imaging tool with a number of advantages over the others non- invasive imaging techniques. CT has evolved into an indispensable imaging method in clinical routine. It was the first method to non-invasively acquire images of the inside of the human body that were not biased by superimposition of distinct anatomical structures. The first generation of CT scanners developed in the 1970s and numerous innovations have improved the utility and application field of the CT, such as the introduction of helical systems that allowed the development of the "volumetric CT" concept. In this book we want to explore the applications of CT from medical imaging to other fields like physics, archeology and computer aided diagnosis. Recently interesting technical, anthropomorphic, forensic and archeological as well as paleontological applications of computed tomography have been developed. These applications further strengthen the method as a generic diagnostic tool for non- destructive material testing and three-dimensional visualization beyond its medical use.

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