Volume CT of Acute Abdomen: Acquisition and Reconstruction Techniques

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Abstract

Along with the development of MDCT, the rapidity of volumic acquisition over the entire abdomen and pelvis has allowed to tailor acquisition protocols to diagnosis indications and etiologic hypotheses of acute abdomen. Furthermore, advances in computer technology (hardware and software) have allowed fast post processing of large volume of data over extended areas using reconstruction algorithms. This chapter is thus aimed at detailing each steps from CT data acquisition to volumetric reconstruction techniques and their practical applications in CT studies of the acute abdomen.

1 Introduction

The development of multidetector computed tomography (MDCT) has revolutionized radiologic explorations, including acute abdomen studies, by introducing real three-dimensional (3D) imaging. For many years, scanner interpretation has been limited to axial examination, of up to 1-cm thick sections. The former MDCTs have allowed to start refining axial sections and developing multiplanar reformation and 3D of variable quality (one may remember ‘stairs’ impairing coronal or sagittal sections in the early 90s). Currently, the acquisition of large volumes in shorter duration, a good spatial resolution in all 3D and the obtention of isotropic voxels constitute a precise databank for different volumetric rendering techniques. Computed hardware and software have progressed over the last few years, allowing faster and

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more ergonomic processing of large volume of data generated by MDCT. Most manufacturers offer consoles that try in integrating these different image processing for routine utilization. However, many radiologists still consider that 3D reconstructions may increase the complexity and interpretation time of a scan examination, which may account for the slow spreading of some of these reconstruction techniques. This chapter is thus aimed at detailing each CT volumetric reconstruction techniques and their practical applications in CT studies of the acute abdomen.

2 CT Acquisition Protocols

2.1 Patient Setting

The patient admission must be reassuring. His level of consciousness permitting, the different steps in CT examination must be clearly explained to him to improve the quality of acquisition, such as avoiding artifacts from kinetic fuzziness related to inopportune movement frequent in algesic patients.

A short and accurate interview must investigate the main contraindications to the use of X-rays (pregnancy) and intravenous iodinated contrast material (allergy, kidney failure, myeloma…). Indeed, in the emergency setting, management may be precipitated and a complete interview may not always be done before admission to the imaging department. If a contraindication arises then, the utility and type of imaging protocol must be discussed with the referring physician, without delaying management of the patient. In some cases, the benefit to risk ratio will lead to perform a scan with injection, despite a theoretical formal contraindication. Knowing whether the patient is treated with certain drugs that require some caution, such as biguanides or beta-blockers may be useful. Biguanide intake must be discontinued the same day and resumed after 48 h, eventually after checking for renal function. Beta-blockers intake should not be discontinued, but it must be known, as it requires increased doses of adrenaline in case of cardiac arrest resuscitation. Fasting may be difficult to observe in emergency conditions and should not delay CT scanning in any cases.

Following the interview, the patient is laid down in dorsal decubitus, with the arms up above the head when possible, to avoid artifacts from beam hardening impairing the reading of hepatic and splenic parenchyma (Delabrousse 2009).

2.2 Acquisition Parameters

A preliminary topogram (scout view) is performed in the anterior and often lateral views. It allows in plotting the anatomic landmarks to set the acquisition boxes at the area to explore. The field of view (FOV) is thus tailored to the patient's outline to allow optimal image reconstruction using a 512×512 scan matrix.

The constants (kV, mAs), preset in the manufacturer acquisition protocols must be sometimes modulated, such as with obese subjects requiring higher energy rays than young and lean subjects.

The collimation may be millimetric, more rarely sub-millimetric, with reconstructions in millimetric axial sections directly available for postprocessing on interpretation console.

2.3 Non-enhanced CT (NECT)

Non-enhanced CT is a fast and simple examination to perform. In non-traumatic acute abdomen, it can be performed in the setting of urolithiasis exploration or when a formal contraindication to iodinated contrast material exists. It can also be performed as the first step of a CT examination with intravenous iodinated contrast material (for example to investigate spontaneous bowel hematomas that are often seen in the setting of underlying coagulopathy (Lane et al. 1997)).

Most of the time, NECT must be performed using a low-dose technique allowing to reduce radiation exposure to the patient. However, the challenge is not to deteriorate the image, with the risk of misdiagnosis due to a decreased signal-to-noise ratio, especially in obese patients. New acquisition algorithms, such as ASIR (Adaptive Statistical Iterative Reconstruction, General Electric Healthcare, Milwaukee, WI, USA) allow in further reduce the doses to 20–80%, while eliminating the noise with no loss of image quality (Kambadakone et al. 2010).

In elderly patients, in whom biliary lithiasis is frequent, the low-dose technique must not be used to help detect low density lithiases within the bile duct.

Table 1 CT acquisition protocols based on the diagnostic hypotheses in non-traumatic acute abdomen

CT techniques	Indications
Low-dose NECT	Acute renal colic
NECT + portal phase	Acute pancreatic and biliary system pathologies
NECT + arterial + portal phases	Acute abdominal pain with coagulopathy (spontaneous bowel hematomas)
Arterial + portal phases (±delayed phase at 3 min)	Abdominal aortic aneurysm rupture
	Acute abdominal hemorrhage
	Mesenteric ischemia
	Renal infarction
Portal Phase alone	Most of the indications:
	Non-specific abdominal pain
	Acute appendicitis
	Diverticulitis
	Bowel obstruction
	Peptic ulcer disease
	…
Portal + delayed phases	Urinary tract diseases (acute pyelonephritis)
	Characterization of a tumor found by chance on portal phase

One recent advance is dual energy technique, notably applied to characterization of urolithiasis: when a calculus is localized on a standard low-dose NECT, a targeted acquisition with dual energy (80/140 kV) is performed over the anatomical area containing the calculus. Post-processing softwares further permit in differentiating calculi based on their composition (uric acid, cystine and calcified stones) more accurately than with simple measurement of their density, which allow the therapy to be adapted (Hidas et al. 2010).

2.4 Intravenous Opacification

In the absence of contraindication to iodinated contrast material and besides renal colic evaluation, the majority of scanners indicated for non-traumatic abdominal pain are performed with intravenous opacification (Table 1). Indeed, opacification allows better evaluation of the vascular lumen, intestinal walls and parenchyma of intraabdominal organ (Urban and Fishman 2000a).

Most often, for example, in case of non-specific abdominal pain, or suspected acute appendicitis or diverticulitis, only one acquisition on portal phase is required to establish a diagnosis or to seek complications (acquisition starting 70 s after injection at a 1.5 mL/kg to 2.5 mL/s rate).

In some cases, especially in case of suspected mesenteric ischemia or intraabdominal hemorrhage (Ernst et al. 2003), an acquisition on arterial phase must be planned. It must be performed using fast intravenous injection (at least 3 mL/s), through a good quality venous line, eventually using contrast media with high iodine concentration (400 mg/mL) (Jaeckle et al. 2008a). The acquisition phase is started 20–30 s after the injection or using a bolus tracking technique.

A delayed acquisition may be performed, either after 10 min in studies of the urinary cavity lumen, or earlier after 3–4 min in studies aiming at

- characterizing a tumor-like lesion found by chance.
- confirm active leaking of intraabdominal bleeding only seen on portal phase (extravasation of contrast material, whose extent varies between acquisition phases).

2.5 Intestinal Lumen Opacification

Numerous protocols, including oral or intravenous intestinal opacification have been described in patients presenting with non-traumatic acute abdomen, in particular for evaluation of suspected acute appendicitis (Johnson et al. 2006; Kaewlai and Nazinitsky 2007; Thoeni and Cello 2006). Some authors even recommend enteroclysis opacification (Gollub 2005). However, recent studies have suggested that oral opacification might not be necessary in acute abdomen (Anderson et al. 2009; Lee et al. 2006b; Mun et al. 2006), as it presents certain risk and disadvantages. Indeed, the patient has to ingest the recommended 800–1,000 mL of contrast material (Pinto Leite et al. 2005). This can be an issue in a patient presenting with abdominal symptoms associated with nausea and vomiting, or in the elderly (with a risk of inhalation). Does performing the opacification justify the need for a nasogastric probe to be placed? The cost of examination and the side effects related to contrast material are increased. Last, the duration of examination is increased, as a 1–2 h time interval is required for the contrast material to reach the cecum, which could seem long in an emergency setting (Huynh et al. 2004).

Colorectal opacification and distension can be obtained by rectal administration of 800–1,000 mL of water or diluted contrast material (Macari and Balthazar 2003; Rao et al. 1997; Urban and Fishman 2000b) for evaluation of suspected acute appendicitis or diverticulitis. This technique is faster than oral opacification (around 15 min). However, it requires a logistic organization and involves non-negligible discomfort to the patient. Furthermore, cecal opacification is inconstant and contraindication exists in patients presenting with neutropenia or with peritoneal or perforation signs (Pinto Leite et al. 2005). It has been shown that one can do without this technique, with no loss of diagnostic efficacy in acute appendicitis (Dearing et al. 2008) and can be reserved for the occasional patient with equivocal findings in acute diverticulitis (Urban and Fishman 2000a).

2.6 Focused CT

In acute abdomen, the interest of only focussing CT acquisition on a part of the abdomen has been investigated in acute appendicitis and is discussed in the corresponding chapter of this book.

3 Thin Slice Review

The first step in scan interpretation is reading axial slices. The advent of multidetector row CT scanners has allowed routine acquisitions of large volume with millimetric and sub-millimetric collimations. However, axial reconstructions of thickness similar to the 5-mm collimation recommended few years ago for single detector row CT scanners are still in use (Johnson et al. 2006; Weltman et al. 2000). Nevertheless, small structures, such as the normal appendix may not be greater than 3 mm in diameter, which requires the use of reconstructed slices of <5 mm thickness for accurate detection (Fig. 1). The value of thin slices has been demonstrated by Johnson et al. (2009b). According to their analysis of 212 scanners with thinner and thinner axial reconstructed slices (5, 3 and 2 mm thick), thinner reconstruction would significantly improve the visualization rate of the appendix (79, 86 and 89%, respectively) and the confidence regarding the presence or absence of signs of acute appendicitis (mean sensitivities were 79.4, 82.4, and 82.4% for 5, 3, and 2 mm, respectively; specificities were 99.2, 98.7, and 98.2%). According to Ketelslegers et al. thin slices improve the detection and characterization of urinary calculi (Ketelslegers and Van Beers 2006). Similarly, it can help in distinguishing small distal ureteral calculi from pelvic phleboliths (Arac et al. 2005). In our department, we have shown the diagnostic value of thin slices in direct visualization of perforation sites in patients with a non-traumatic free pneumoperitoneum (Ghekiere et al. 2007).

Better findings in the use of thinner transversal slices are due to the partial volume effect resulting from the use of thick slices over small structures, in particular when they show not much contrast: the voxels are averaged, which render such structures more challenging to detect.

The two major drawbacks in the use of thinner reconstruction sections are, on one hand, a higher number of images to visualize and on the other hand an increased image noise. To counter the noise without increasing the radiation doses, some advocate reading thin slices with sliding slab ray—sum technique, which is available on many CT workstations (Seo et al. 2009).

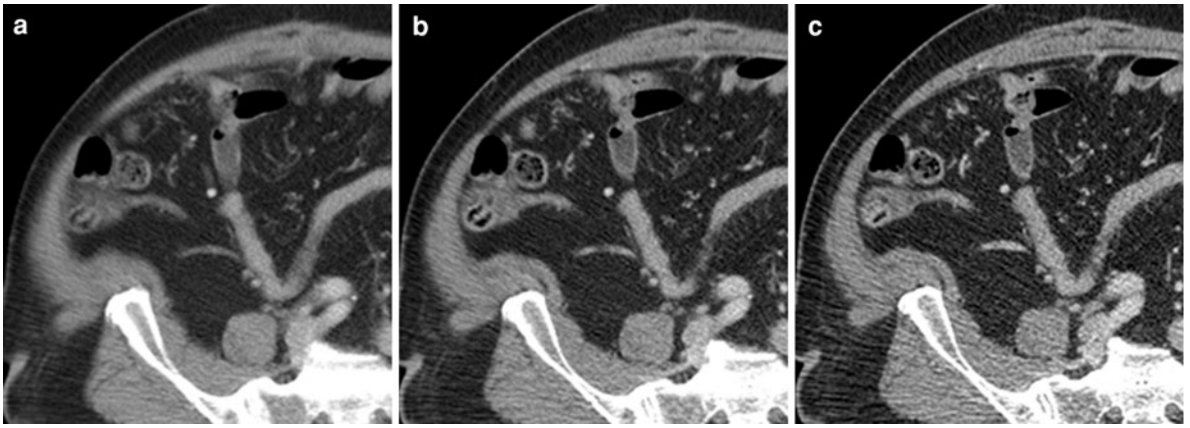

Fig. 1 Value of thin axial sections. Reconstructions in axial sections of decreasing thickness: **a** 10 mm, **b** 3 mm and **c** 1.25 mm, centered on the appendix. Details of the appendiceal wall and vessels are hardly visible in **a** while clearly better seen in **b** and **c**. In contrast, the noise increases from **a** to **c**, while the image is less and less smooth

4 Multiplanar Reformatting

Volume data generated by MDCT scanner can be represented by a cube constituted from sub-elements called voxels (by similarity with 2D image pixels). Isotropy means that voxels are of equal dimensions in all three spatial axes (*x*, *y*, *z*). The 16 and 64 MDCT currently available achieve sub-millimetric isotropic voxels in only one acquisition over the entire abdomen and pelvis. These data may then be analyzed in multi-planar reconstruction (MPR), with a spatial resolution close to that of axial reconstructions. Current consoles enable fast treatment of MPR data, with no waste of time for the physician. Coronal, sagittal or oblique sections can be easily generated (Fig. 2). Of all planes, coronal reconstructions appear as the most useful in evaluation of non-traumatic acute abdominal pain, such as for the diagnosis of a normal appendix (Jan et al. 2005), acute appendicitis, as well as for pitfalls and differential diagnoses of acute appendicitis (Kim et al. 2008; Lee et al. 2006a; Neville and Paulson 2009; Paulson et al. 2005), including in pediatric patients (Kim et al. 2009). Jaffe et al. (2006) have reported similar diagnostic value for coronal reformatted images in small-bowel obstruction. We have shown the added diagnostic value of coronal and sagittal reformations in direct visualization of perforation sites in patients with a non-traumatic-free pneumoperitoneum (Ghekiere et al. 2007).

Curved plane reconstructions (or curved MPR) are a variation of MPR. Instead of using a plane in a standard direction (axial, coronal, sagittal, oblique or double-oblique), the user draws a curve along the course of a structure, such as a vessel. All voxels localized within the plane of the curve are displayed on only one 2D image (the entire vessel is thereby displayed, even if its course is complicated). By changing the viewpoint around the curve initially drawn, one can rotate the curve plane on 360° (and see for example the vessel walls in all directions).

The main applications of curved MPR concern tubular structures, arteries in particular, as well as ureters or bowel (Sun 2006). Some stations include specific applications (such as Advantage Vessel Analysis (AVA), Advantage Workstation Volume Share 4, General Electric Healthcare, Milwaukee, WI, USA) allowing extraction of the lumen of a blood vessel in two clicks and obtention of a curvilinear and 3D image. It is then easy to detect, characterize and even quantify any abnormality of the vascular wall on curved plane reconstructions: beginning and end of a stenosis, percentage of maximal stenosis (in diameter and surface).

In another setting, Nino-Murcia et al. have shown that curved MPR allowed better characterization of dilations of the bile duct and pancreas system, for example by demonstrating the presence of a pancreas divisum responsible of an acute pancreatitis (Nino-Murcia et al. 2001). Other authors also propose to use curved MPR for improved detection of acute appendicitis (Stabile Ianora et al. 2010) or characterization of the site and cause of small-bowel obstruction (Aufort et al. 2005).

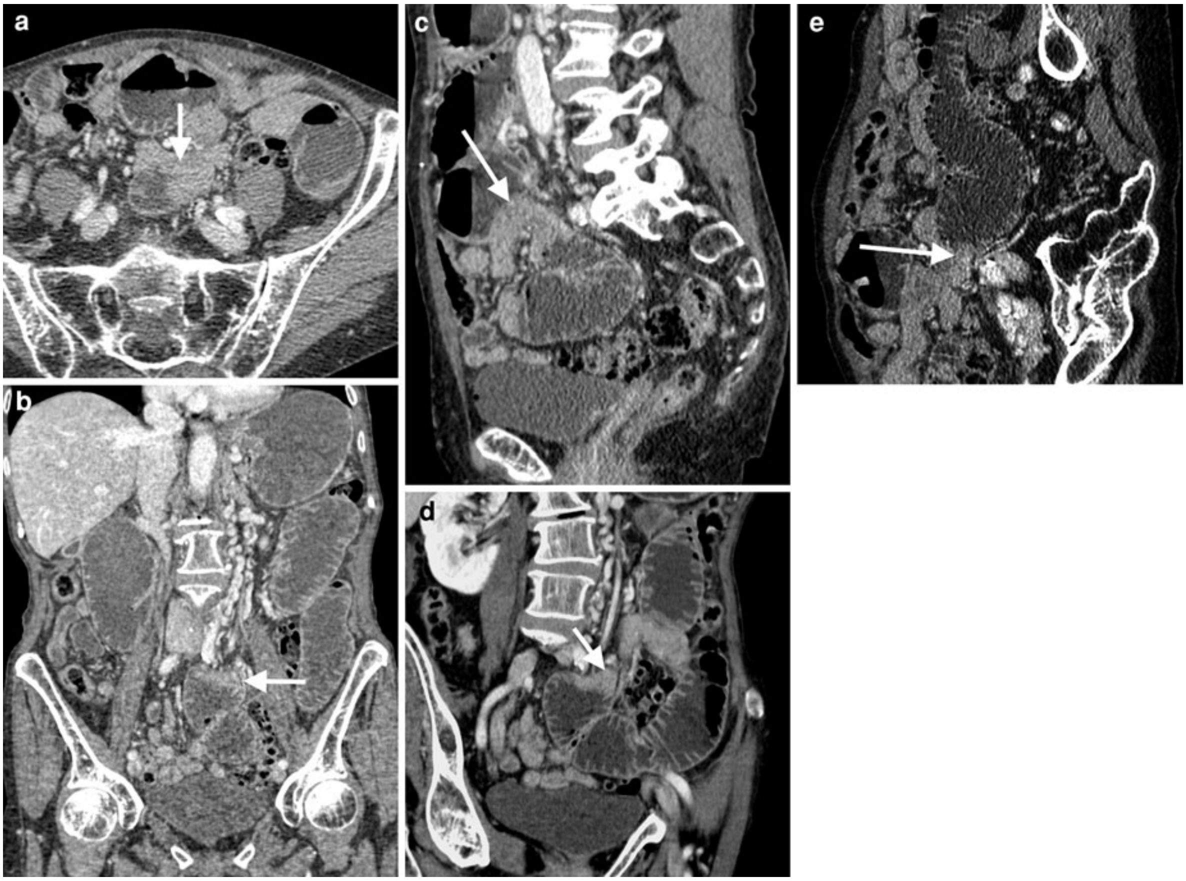

Fig. 2 Value of MPR reconstructions in CT of acute abdomen. Images seen in axial section (**a**), coronal (**b**), sagittal (**c**), oblique (**d**) and curved MPR (**e**) showing the transition area (*white arrow*) of an acute bowel obstruction by a band. Although axial and coronal sections are generally considered as more valuable, sagittal and oblique sections may prove useful, as in this case, whereby the transition level is best seen. Curved MPR images, more time consuming, mostly have iconographic value

Whichever the plane used for MPR, it is also possible to increase the slice thickness by using several types of projection algorithms (Fig. 3) such as average intensity projection (AIP), ray sum, maximum intensity projection (MIP), minimum intensity projection (MinIP) and volume rendering (VR).

5 Average Intensity Projection and Ray Sum

The average intensity projection is a reconstruction algorithm allowing in displaying the average attenuation value of voxels on a given thickness, for any MPR slice in a given plane. This results in a thick slice whose aspect is close to that of the thick axial slices often first reconstructed in most examinations. The usefulness, when compared with thin slices is to reduce the noise and enhance the contrast, while increasing artifacts from partial volume.

Another algorithm, Ray sum, consists in summing up the attenuation value of each voxel projecting on a given plane.

When thin slices are used, the appearance remains close to that of AIP, and would be useful in detecting anomalies of the appendix, for example (Seo et al. 2009). In contrast, the use of Ray sum on larger volumes lead to images close to conventional radiography (Dalrymple et al. 2005), which is expected as radiography produces images by summing up X-rays more or less attenuated through the targeted object. This may be valuable if one wanted to confirm the

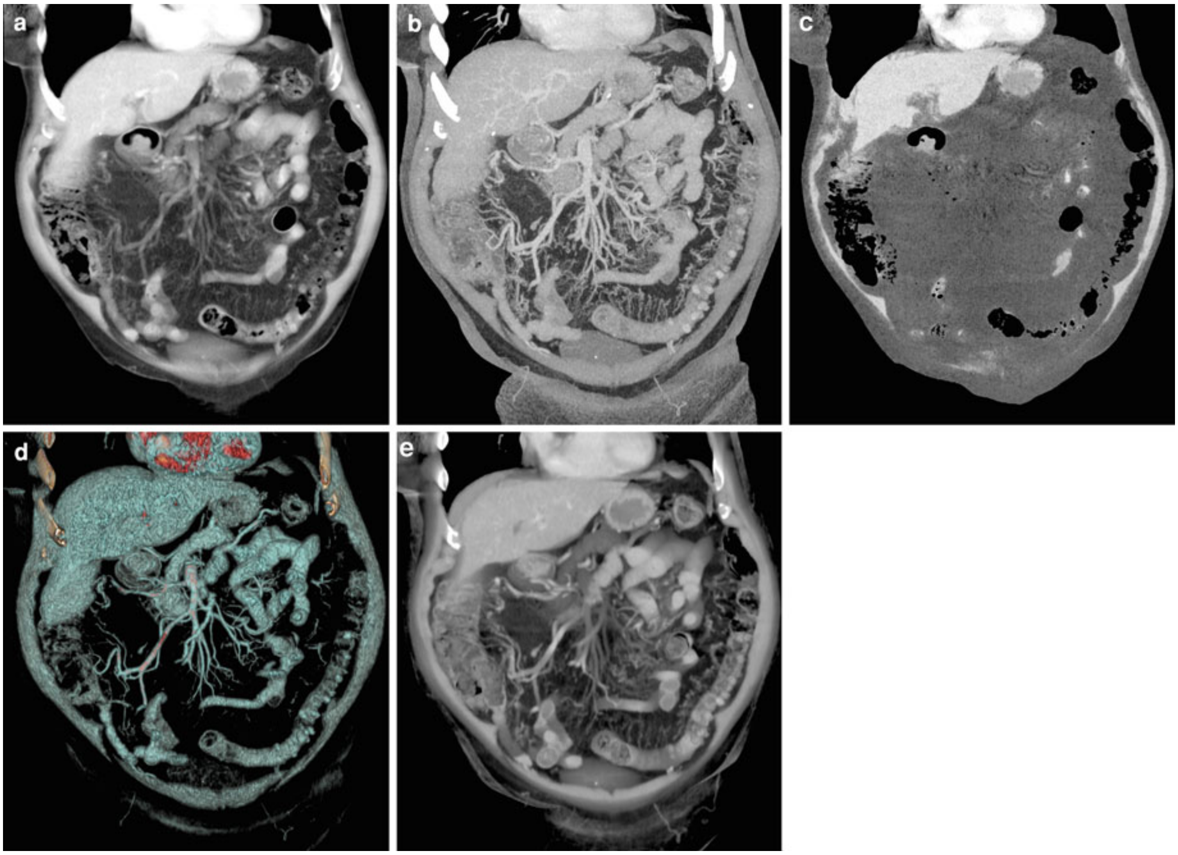

Fig. 3 Thick coronal sections using different reconstruction algorithms: **a** average intensity projection (AIP), **b** MIP, **c** MinIP and volume rendering using two different settings (**d**, **e**). MIP enables better view of dense structures, such as vessels, including smaller ones, such as in the meso (**b**). Structures filled with air better stand out in MinIP (**c**). Anatomical relationships between vessels and adjacent organs are best displayed in VR (**d**, **e**) than in MIP (**c**). In contrast, small vessels are best seen in MIP, with variable results in VR depending on the settings (**d**, **e**)

possibility to locate a calculus on a plain abdominal radiography without the need to actually perform the radiography, before proposing an extracorporeal lithotripsy, in the treatment of a renal colic first diagnosed on MDCT.

6 Maximum Intensity Projection

The MIP algorithm plots a ray perpendicular to the plane studied that crosses continuous slices in this plane. Of all voxels passed through, only the one with the highest density will be displayed. All denser structures in a given volume would be thus displayed on only one 2D image, irrespective of their location within the thickness of this volume (Parrish 2007; Perandini et al. 2010).

MIP is thus by definition tailored to representation of dense objects that strongly differentiate from adjacent tissues of lower density, whether these objects are spontaneously dense, such as lithiasis, calcifications, surgical clips or stercolith, or opacified structures, such as for CT angiography or urography. This algorithm is fast and simple to use. In studies of the urinary tract, coronal MIP allows in fast description of the morphology of the urinary tree, as well as of the location and shape of an eventual calculus before percutaneous treatment (Patel et al. 2009). However, it is in vascular studies that MIP is the most valuable for acute abdominal pathology (Fig. 4), by allowing straightforward and fast mapping of blood vessels (Duran et al. 2009; Wildermuth et al. 2005), both at the artery level in the setting of bleeding or ischemia, and at the vein level in the setting of portal hypertension.

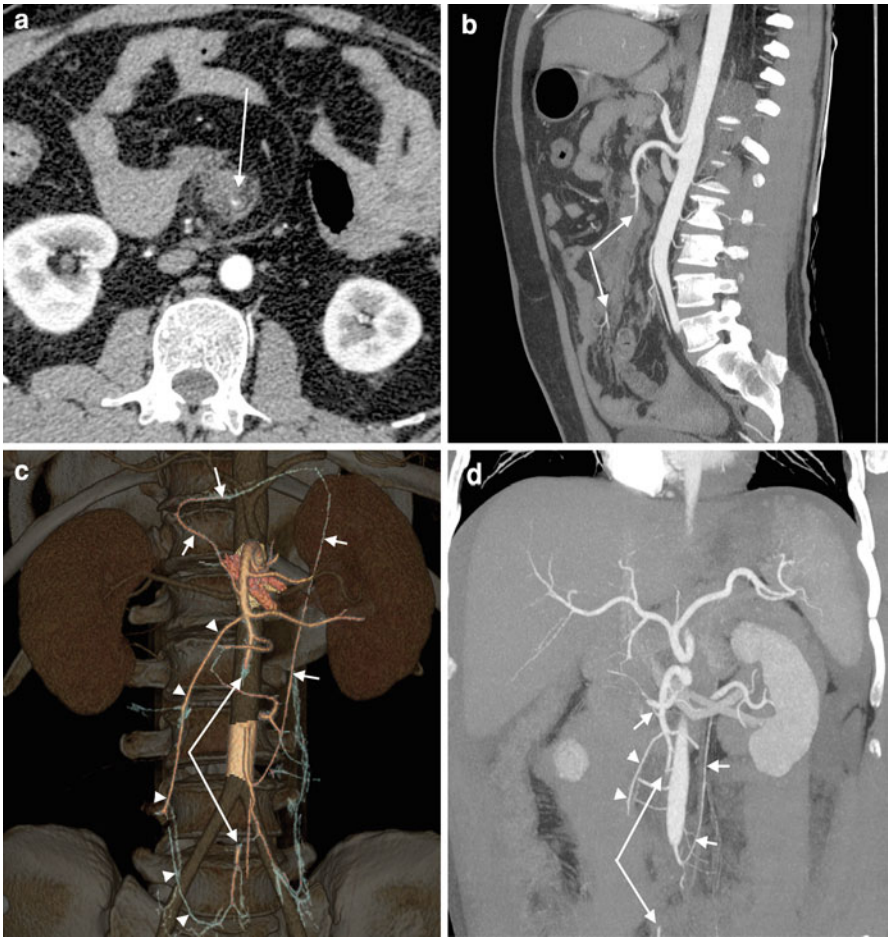

Fig. 4 Traumatic dissection with occlusion of superior mesenteric artery (SMA) (*big arrows*) in axial (**a**) and sagittal oblique thin MIP (**b**) reconstructions. The anastomosis between the SMA proximal and distal segments (*arrowheads*) as well as the Riolan arcade (*little arrows*) are much better depicted on a segmented VR image (**c**) than on a coronal MIP reconstruction (**d**)

Understanding MIP limitations is crucial for proper image interpreting. First of all, the presence of attenuating structures next to blood vessels can impair blood vessel analysis. Attenuating structures, such as bones may be deleted from the volume for better visualization of arteries (with the risk to loose some artery volume if the artery is in contact to the bone), using certain softwares. In case of atheromatous calcifications, studies of the arterial lumen become challenging and an eventual stenosis can prove difficult to depict. To minimize this disadvantages, sliding thin-slab MIP reconstructions may be used which might be more efficient than thicker slices in analysis of vascular lumen (Ertl-Wagner et al. 2006; Kim et al. 2004) and characterization of acute gastrointestinal bleedings (Jaeckle et al. 2008a). Finally, anatomical relationships between displayed structures are not easy to assess due to the absence of shades or 3D landmarks on images (Calhoun et al. 1999; Fishman et al. 2006). This can be partially overcome by generating a series of MIP images, each obtained from a viewpoint different from one to another around the object, thereby creating the illusion of volume rotation, useful in studies of complex vascular structures (Perandini et al. 2010).

MIP is a fast and straightforward technique to use provided that its limitations and how to overcome them are known. MIP is recommended at first intention, especially in studies of the arteries, before to eventually switch to VR as a complementary visualization method.

7 Minimum Intensity Projection

In contrast to MIP, the MinIP algorithm that projects voxels with the lowest density on a 2D image. This allows to preferentially represent hypodense

Fig. 5 Value of MinIP in obstructive pathologies of the bile duct. Axial sections (**a**, **b**) and oblique coronal MinIP (**c**) show a dilation of the intra hepatic biliary ducts (*white asterisk*) upper from an obstruction by a vesicular adenocarcinoma (*black asterisk*)

structures of a given acquisition volume. MinIP is not used commonly, except for representation of the central airways or areas of air trapping within the lungs (emphysema).

In acute abdomen, MinIP may be used to analyze the bile tree and pancreatic duct. Rao et al. (2005) described how they used computed tomography cholangiography in gallbladder carcinoma patients with obstructive jaundice. On thick coronal slabs of the portal vein phase (without the administration of biliary contrast media), they segmented manually the liver and all the visible bile ducts, trying to remove unwanted structures of low attenuation (fat and air) before to apply MinIP algorithm. This method is time consuming (from 15 to 40 min) and does not seem to give more information than 2D images, but it is useful in depicting the 3D anatomy of the biliary system. Therefore, another method, rapid and simple, is to use thin sliding slabs in a coronal or oblique plane, centered on the biliary system, with MinIP algorithm (Kamel et al. 2005) that can depict the site and cause of biliary obstruction (Johnson et al. 2003) (Fig. 5).

8 3D Reconstructions

Several methods allow 3D reconstructions of data generated by a scanner. The former, called shaded surface display (SSD), is progressively replaced by the volume rendering (VR) technique, which offers numerous advantages over SSD, as well as over other techniques including MIP. VR allows to perform quality virtual endoscopy (VE). By segmenting an object or anatomical structure, it is possible to calculate its volume or represent it in its anatomical relationships with the whole acquired volume using the various settings available on most consoles.

8.1 Shaded Surface Display

Shaded Surface Display, also called surface rendering, is a reconstruction algorithm allowing to only represent the surface of an object in 3D. In a first step, the object is segmented: voxels that correspond to the object of interest are selected (see Sect. 8.4. Segmentation). Most often, SSD segmentation is done using a threshold density value: only those values above the threshold are selected, while voxels of inferior value are not. The surface of the object thus defined is then represented in perspective by simulating shadows and light reflection effects using a virtual light source that intensifies the illusion of image relief and depth.

8.2 Volume Rendering

The VR technique is the 3D reconstruction technique that develops the most currently, as it offers wider possibilities over SSD or MIP. This development is possible due to the recent advances in computing power in recent computer hardware. Unlike other techniques that select voxels represented by their densities, all voxels of a same volume will contribute to the VRT image, independently from their densities: the

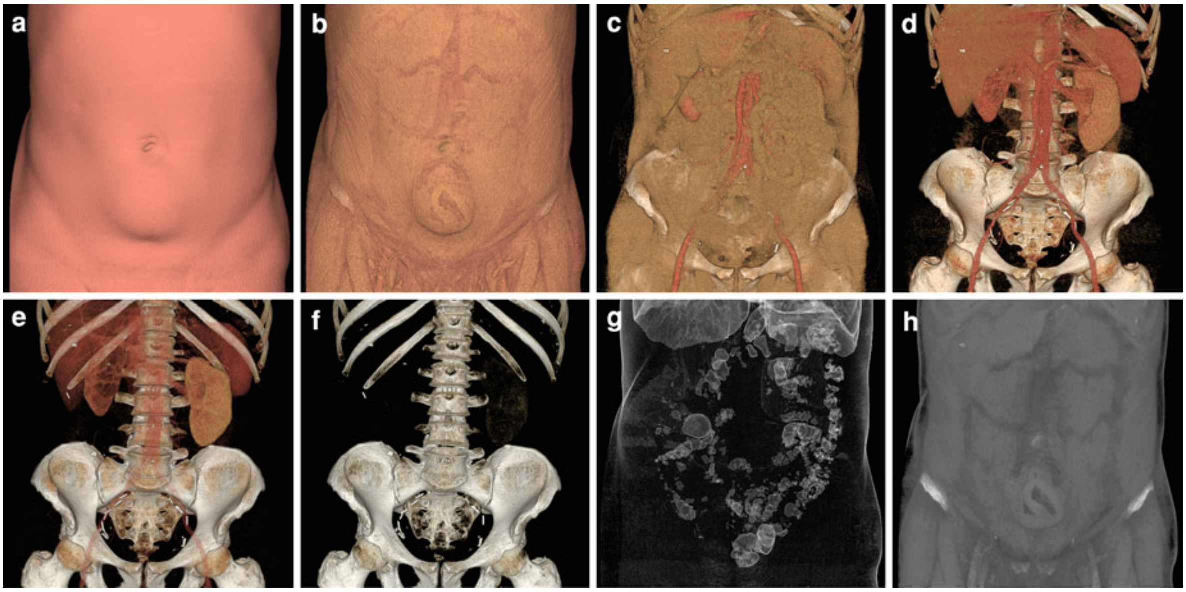

Fig. 6 Volume rendering. Using only one acquisition and by changing the settings thresholds of the voxels shown on the histogram, several images can be obtained showing the different anatomical structures from the skin to the bones (**a**–**f**). Other settings enable better view of the structures filled with air (**g**), of the muscular wall of the abdomen (a sub-umbilical parietal hernia is shown here) (**h**)

entire Hounsfield scale can be represented. This technique assigns a value of opacity ranging from 0% (total transparency) to 100% (total opacity) to each voxel along a virtual line directed in the observer viewpoint. The opacity value as well as the color are selected according to the density of each voxel and using an algorithm set for the type of tissue to be represented. This enables the display of a large variety of tissue structures of variable density in only one volume, from skin to bones (Fig. 6) and this avoids MIP overlays (Fig. 7). Gray scale shading is also used to enhance the 3D effect by adding surface reflections and projected shadows from a computed virtual light source.

8.3 Virtual Endoscopy

Virtual Endoscopy also called perspective volume rendering (pVR), is a special type of volume rendering (VRT), mainly used to make endoscopic views of hollow organs filled with air (paranasal sinuses, pharynx, larynx, bronchial tree, colon) or opacified fluids (arteries, veins, ureters, small-bowel lumen…). The course of a virtual endoscope through the cavity can be simulated ("fly through") and displayed either as successive images visible on a PACS system, or as a video animation (format:".avi"). The most developed indication to date is virtual colonoscopy.

8.4 Segmentation

Segmentation is the operation allowing to select a desired object within a volume, to better visualize it on 3D or to measure its volume (Fig. 8). Tools to help including or excluding the desired object voxels that are more or less accurate, either automated, semi-automated or not, are offered by certain manufacturers.

The simplest and fastest method is to only select within a given volume those voxels whose density ranges between two threshold values. This is easy for high density voxels (bones, calcifications or opacified structures including vessels, urinary or digestive tract) and low density voxels (airways, cutaneous surface). This operation can be automated in certain applications. In contrast, it is more difficult to segment structures of close densities, including internal organs, such as the liver, spleen, nodes, or muscles, using this method.

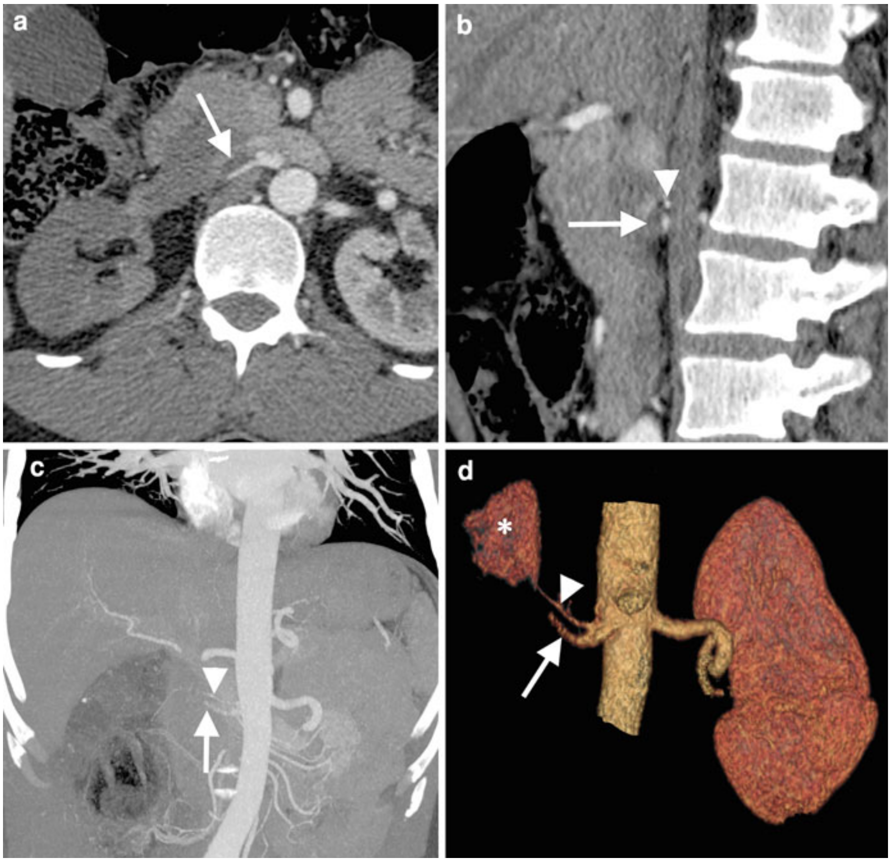

Fig. 7 Value of MIP and VR in acute vascular pathology of the abdomen. Right kidney ischemia over occlusive dissection of the right renal artery (*white arrow*) in axial (**a**) and sagittal (**b**) sections. Oblique coronal section in MIP (**c**) enables fast display of anatomical relationships between the proximal pre-occlusive part of this artery and a superior polar artery (*arrowhead*). VR (**d**) further improves studies of these relationships by avoiding MIP overlays and by visualizing on the same image the superior polar parenchyma, still vascularized (*asterisk*)

Another simple method is to define a region-of-interest (ROI) by plotting a rectangle, ellipse or any other shape centered on the studied object with a virtual scalpel that can be used on 2D MPR images or on 3D images.

The"paintbrush" tool allows in highlighting the object to isolate on 2D images for subsequent 3D reconstruction. The issue is to plot on every slice, which may require extensive work considering the hundreds of images obtained in current examinations. Growing region tools, like the "magic wand", can be also very useful. By setting the wand over a pixel of one of the 2D MPR images and maintaining the left click down, all neighboring pixels of density close to that of the targeted central pixel (within the range of preset thresholds) will be progressively selected, from one to another as an oil stain. Depending on the softwares, the selection of adjacent pixels can be performed on the only 2D image used, on all three planes systematically or even directly on the 3D image. This tool is very useful for fast segmentation of objects of similar densities, such as vascular structures. It can also be used to isolate a plain or intestinal organ or a foreign body. Indeed selected pixels can be easily checked (subtraction tools are also available). The issue is that this technique can become time consuming when the studied object is of complex shape, with different density voxels or when it is in direct contact to other structures of same density (the tool then cannot differentiate voxels of the studied object from voxels of the neighboring organ). Recently developed algorithms associate shape recognition, which renders this technique easier and faster. Segmenting a tumor within an organ, even with close densities is easy.

A very important notion to consider in segmentation is that whatever the technique used, it is imperative to check that the selected volume on 2D MPR images matches to the reality of the studied object. One can indeed miss an important structure, such as a polar artery when segmenting kidney vascularization, or add up voxels that do not belong to the studied object, but to

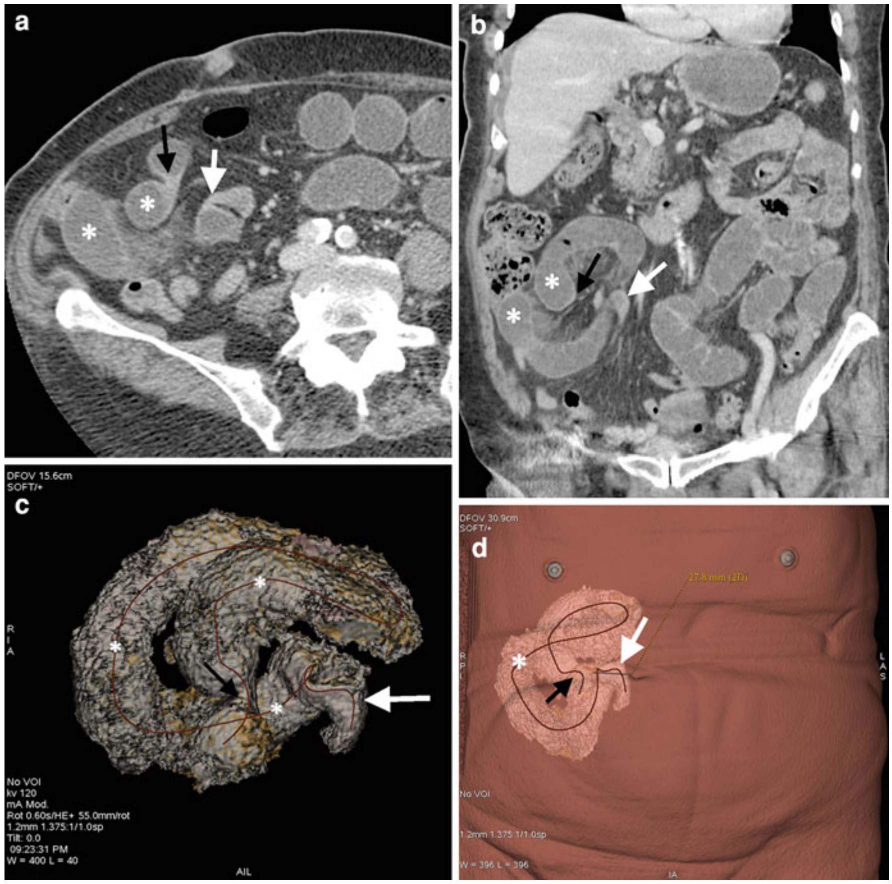

Fig. 8 Value of VR in acute bowel obstruction over band with a volvulated loop. The two beaks (*white* and *black arrows*) of the transition area are seen on axial (**a**) and coronal (**b**) sections as well as on segmentation (**c**) of the volvulated loop (*asterisk*), even without oral contrast administration. The center of digestive lumen is delineated by the *red line*. Entire view of the abdomen with the volvulated loop in transparency allows in mapping the band relative to the umbilicus (**d**)

a neighboring object thereby virtually misrepresenting the targeted object. In any cases, saving the 3D object data in a specific file that can be recorded into a PACS system is necessary. It can eventually allow in further completing the segmentation later on, without losing all the work previously done.

8.5 Utility of 3D in CT of Acute Abdomen

Some of the 3D reconstruction techniques will be useful in CT of acute abdomen (Fig. 9).

SSD is a simple technique that used to have the advantage, few years ago, to reduce the volume of 3D data to compute, as only the surface was represented. Recent advances in calculation power have pushed such limitations. Nevertheless, SSD has numerous disadvantages over VR. The segmentation of a given object using a threshold value is easy when one needs to select structures surrounded by soft tissues of completely different densities, such as bones. It becomes less convenient when the object to depict is surrounded of structures of close density. As an example, it is challenging and even hazardous to study arterial stenosis within a calcified plaque as densities of the calcified plaque and lumen may overlap, and the stenosis may therefore be under- or over-estimated with SSD.

Of note, this technique leads to a loss of information on the density of the represented voxels. When several structures over the segmentation threshold value are lined up in a given direction, only the closer structure to the observer is represented, even if the farther structure has a much more higher CT number. When considering all these limitations, SSD is only scarcely used in abdominal pathology, studies of surface being mostly valuable in osteoarticular trauma. More generally, volume rendering must be preferred to SSD in most if not all applications (Dalrymple et al. 2005).

Numerous publications address the utility of MIP and VR, especially in studies of acute vascular

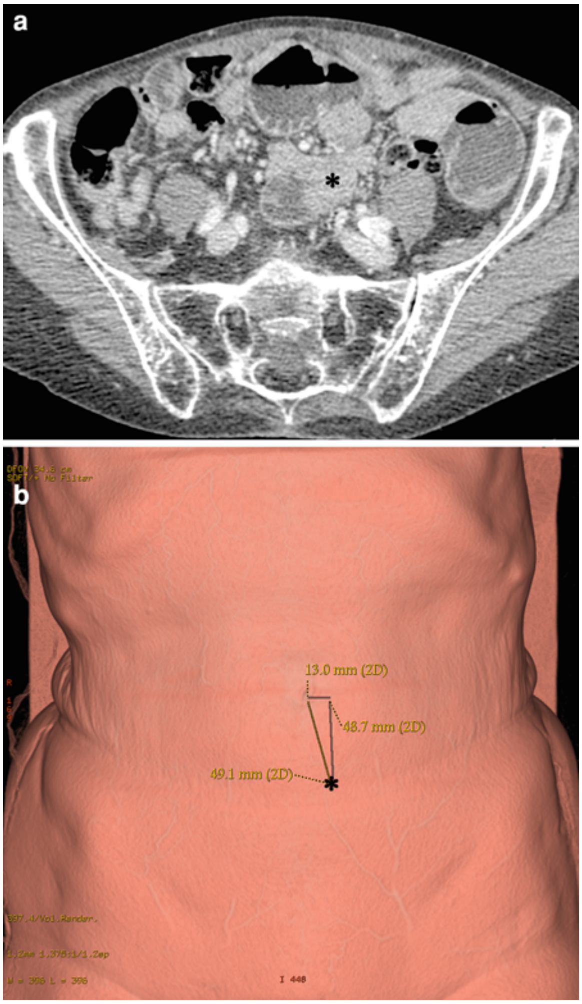

Fig. 9 Mapping of the transition level (*black asterisk*) in bowel acute mechanic obstruction over bands thanks to a cursor set on axial section (**a**) or any other MPR reconstruction. The cursor is then visible in VR (**b**) and allows to locate the band relative to cutaneous landmarks, such as the umbilicus, before surgical management

pathologies of the abdomen (Fig. 6). MIP is of simple use and fast in thick slices in a given plane (axial, coronal, sagittal, and oblique) or in the whole volume. The drawback is that the relationships between arteries and adjacent anatomical structures are much less visualized, with regard to the position of veins, organs, muscles or bones (Fishman et al. 2006). VR enables ranges of color and shadow display helpful in depicting complex 3D structures. Nevertheless, those two techniques are often used concomitantly, and one can switch from one to the other to describe vascular anomalies eventually responsible for mesenteric ischemia (Wildermuth et al. 2005), an acute gastrointestinal bleeding (Jaeckle et al. 2008a, b) or an abdominal aortic aneurysm before and after treatment (Sun 2006).

MIP and VR may also be useful although not necessary, in description of acute abdominal pathologies of intestinal origin, whether they are inflammatory (Crohn's disease), infectious (see Chapter Acute appendicitis) or obstructive pathology (Hong et al. 2006; Johnson et al. 2009a). In intestinal obstruction, 3D techniques actually allow better understanding of anatomical relationships, especially for the course of vessels within some internal herniation (Rezazadeh Azar et al. 2010), or to better localize an area of transition of a mechanic obstruction (Fig. 8). In the last case, density of unopacified loops is similar to that of adjacent organs, which renders proper visualization in VR challenging. Small-bowel opacification by enteroclysis has lead to esthetic results (Candocia and Goldman 2005; Gollub 2005). However, this technique complicates management of abdominal emergencies, especially during shifts, with risks of complications (perforation, enhanced ischemic stress of the intestinal loops, pain…) and impact on diagnosis yet to be evaluated. VR may be used on unenhanced CT examination, allowing better understanding of the organization of a volvulus of the sigmoid or cecum (Aufort et al. 2005) while in the same setting, 3D surfacic VR can be used to depict the distance between an adhesive band and umbilicus before an eventual celioscopic surgery (Fig. 9).

Both VR and MIP are also very much used in urology for better localization and characterization of the location and shape of stones as well as description of the anatomy of the patient's urinary tract before surgical intervention (Patel et al. 2009). VR may also assist in the planning of an intervention: using virtual endoscopy, the surgeon may be prepared to the eventual technical challenges he may actually face.

Lastly, the segmentation of objects within 3D volume, especially in VR, is currently developing. One of the leading applications is measurement of the tumor volume in oncology. In acute abdominal pathology, segmentation enables to, for example, accurately measure the volume of an abscess (Fig. 10), an hematoma or hemoperitoneum. A pathologic organ can also be segmented for better depiction of its

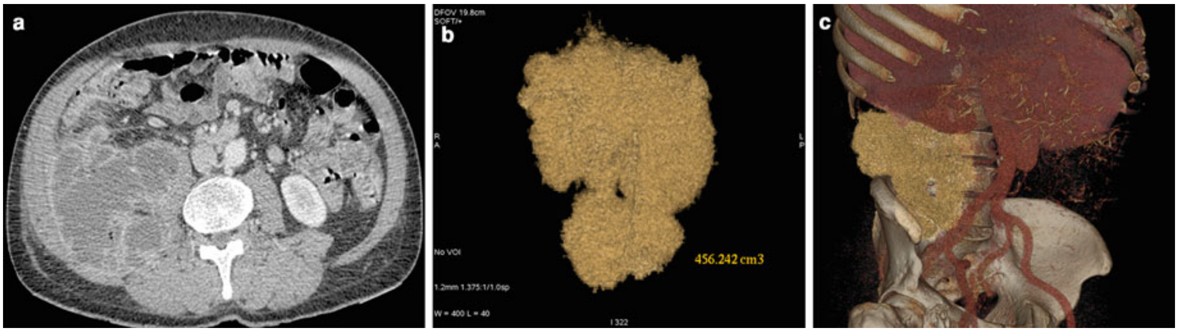

Fig. 10 Large appendicular abscess diffusing within the retroperitoneum on axial section (**a**). Segmentation in VR (*yellow*) allows to measure the volume (**b**) and to depict it relative to adjacent structures (**c**)

position and anatomical relationships with the adjacent structures (Fig. 3). All post-processing consoles may not offer all the tools required for fast 3D segmentation and manufacturers must put some efforts in further improving the ease of use and speed of such a promising technique, although some already have a non-negligible advance over the others.

9 Conclusion

Along with the development of MDCT, the rapidity of volumic acquisition over the entire abdomen and pelvis allow to tailor protocols to diagnosis indications and etiologic hypotheses of non-traumatic acute abdomen. As examinations performed using multiple acquisition phases are facilitated, the use of the lowest effective radiation dose for adequate diagnostic result must be highly considered.

The large volume of data generated by the making of thin sections with isotropic sub-millimetric voxels over extended areas have benefited from advances in computer technology (hardware and software) over the last few years. It is currently simple and fast to use thin sections or MPR in any different plane of interest, with the coronal plane often reported as the most valuable in studies of acute abdomen. Although certain reconstruction algorithms, such as MinIP have limited value, other 3D algorithms, such as MIP or volume rendering have proved useful in vascular pathology. Only recently have MIP and VR started to develop in the studies of intraabdominal organs, notably due to segmentation allowing volume calculations and spatial localization of a particular object. Post-processing techniques will certainly further benefit from computing advances, making them faster and more intuitive in the years to come.

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