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CT study protocol optimization in acute non-traumatic abdominal settings

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Abstract. – Abdominal acute pain is a manifestation of heterogeneous medical conditions, with difficult clinical-laboratory assessment. Multi-detector CT (MDCT) is the gold standard imaging technique for evaluating adult patients with acute abdominal pain. Due to its fast execution and the high spatial resolution, CT is fundamental in the diagnostic and therapeutic work-up of patients with time-dependent pathology that could require surgical treatment, reducing mortality and morbidity. However, the radiological risk connected to the ionizing radiation use should not be underestimated, especially in young patients.

The aim of this study is to identify optimized CT protocols to apply in the management of non-traumatic acute abdomen. In particular, this review is focused on the main emergency settings: acute pancreatitis, small bowel obstruction, acute appendicitis and acute diverticulitis. This survey would not be complete without mentioning Dual-Energy CT (DECT) technique, one of the last frontiers in CT, achieving encouraging results also in acute abdominal conditions.

Key Words:
Non-traumatic acute abdomen, Computed tomography, Optimization protocols, Radiation exposure.

Introduction

Acute non-traumatic abdominal pain is a common cause of access to the emergency department (ED). A purely clinical diagnosis is often impossible due to the wide range of pathologies underlying the acute abdomen. Imaging plays a key role in the diagnostic process and in management of time-dependent pathology that could require surgical treatment.

During diagnostic work-up, plain radiograms are sometimes used as the first approach. Nevertheless, conventional radiology findings are often non-specific and inconclusive, requiring further investigations to confirm what had already been intuited by physicians, with a waste of economic resources and additional radiation exposure[1]. The only case where traditional radiology shows acceptable sensitivity, specificity and accuracy values is represented by small bowel obstruction (SBO). However, also in the setting of SBO, CT is clearly superior, with possibility of identifying transition point, wall ischemia and gastro-intestinal perforations[2-4]. The role of ultrasound (US) as a first-level method in study of patients with abdominal pain is well established. An undisputed benefit of US is the direct interaction with the patient, which, when integrated with semeiotics US signs, allows a rapid clinical evaluation in the emergency setting. Easy execution at bedside, low cost, and lack of ionizing radiation makes US the method of choice in pediatric cases and in pregnant women[5]. US performed by expert hands

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in patients with right upper quadrant (RUQ) pain is crucial in biliary tree pathologies, with an American College of Radiology (ACR) appropriateness score of 8/9[6]. On the other hand, US is strictly operator dependent and could show a lower diagnostic performance in case of poor acoustic window, so as in case of overweight patients[7]. CT is the gold standard imaging technique for evaluating adult patients with acute abdominal pain[8-11]. Due to high sensitivity and specificity, CT is a good method for the evaluation of bowel pathology and retroperitoneal abnormalities[12]. The problem of radiation protection is certainly topical. In Europe, there has been a 23% increase in radiation exposure, largely due to high-dose examinations such as multiphase CT and interventional procedures[13-15]. Overuse of diagnostic imaging may represent a concrete risk to patient health, thus CT protocols should be appropriately planned to reach diagnosis in the shortest possible time, respecting As Low As Reasonably Achievable (ALARA) criteria[16,17]. The aim of this review is to outline the best CT imaging strategies in the management of non-traumatic pathologies associated with acute abdominal pain. This survey would not be complete without mentioning Dual-Energy CT (DECT) technique, one of the last frontiers in CT, achieving encouraging results also in acute abdominal conditions.

Emergency Setting

Acute Pancreatitis

Acute pancreatitis (AP) is one of the most frequent gastrointestinal causes of hospitalization, recording high costs for the health care system because of its possible long-term course (up to 4 weeks)[18]. Accurate diagnosis of AP is defined by at least two of the following features: epigastric pain radiating to the back, amylase and lipase elevation of at least 3 times the normal values and findings typical signs of AP on imaging[19]. Based on the radiological signs underlying pathophysiological mechanism, AP is divided into two distinct subtypes: interstitial edematous pancreatitis (IEP – 85%) and necrotizing pancreatitis (NP – 15%). CT findings of IEP include focal or diffuse glandular enlargement due to inflammatory edema and peri-pancreatic fat stranding and/or haziness. On the other hand, NP demonstrates necrotic collections, which may involve pancreatic parenchyma and/or the peri-pancreatic tissues[20]. While the mortality rate of IEP is around 3%, the NP shows a mortality ranging from 17% to 30%, especially in case of superinfection of necrotic collections, an event that has a strong impact on the prognosis[21-24]. AP grading may vary from a mild form to a severe one. Mild acute AP has self-limited course, without local or systemic complications, whereas a moderately severe form presents transient organ failure (<48 h), with a mortality rate of approximately 2%. Organ failure lasting over 48h or multi organ failure (MOF) identifies severe acute AP, with high mortality rate from 10% to 50%[20]. Moreover, international consensus distinguishes AP clinical course in an early phase (first week from the clinical onset) and a late phase (after first week). During early phase, clinical scores play a major role in AP patient management (e.g., Ranson, APACHE-II, Marshall, BISAP)[25]. International Association of Pancreatology/American Pancreatic Association (IAP/APA) guidelines state that imaging in early phase of AP is indicated in the following circumstances: unclear clinical and biochemical diagnosis, to confirm the clinical hypothesis of severe pancreatitis and in case of clinical worsening despite conservative therapy[26]. While in the early phase of AP the only findings that can be observed at CT examination are edema and glandular enlargement, in the late phase of moderately severe or severe AP local complications such as necrotic collections fully develop and therefore require further imaging investigation[27,28]. The revised Atlanta classification distinguishes pancreatic collections based on their composition and disease course[25]. Acute peri-pancreatic fluid collections (APFCs) are homogenous collections without wall and internal solid components, typically appear during the first 4 weeks of IEP and are mainly located in the lesser sac and in the anterior pararenal space. APFCs are often sterile, they do not require early intervention and tend to self-resolve in about 50% of cases. If they persist for more than 4 weeks, they usually evolve into pseudocysts, which are organized collections with a circumscribed wall (Figure 1). Pseudocyst can encounter local complications such as infections, ruptures and hemorrhages in 50% of cases[12]. Percutaneous CT- guided drainage is the gold standard treatment of complicated pseudocysts, allowing high accuracy both in the detection of lesions and in the definition of anatomical relationships with surrounding vascular structures[29]. Acute necrotic collection (ACNs) of cellular debris without recognizable

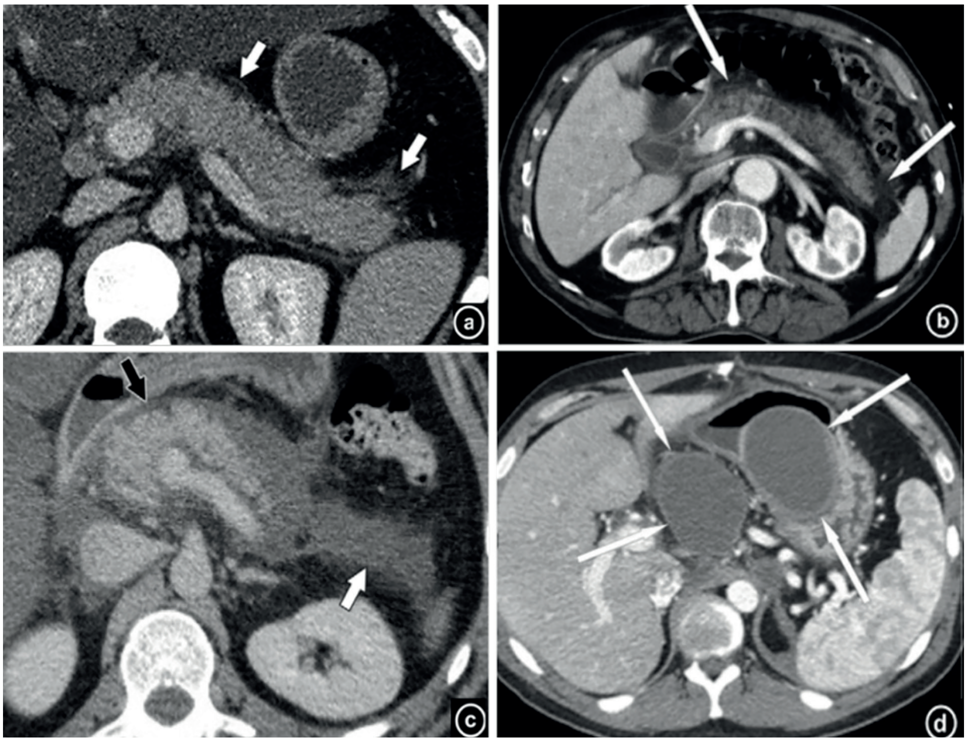

Figure 1. Portal venous phase axial computed tomography images **(a, b, c, d)**. The main signs of IEP are diffuse or focal enlargement of the gland associated with peripancreatic fat stranding (**a, b,** white arrows). Acute peripancreatic fluid collections (APFC) may sometimes develop, typically located in the lesser sac and in the subphrenic recesses (**c,** black and white arrows). When APFCs persist for more than 4 weeks they develop a wall and convert into pancreatic pseudocysts (**d,** white arrows).

wall are observed during the early phase of the necrotizing pancreatitis. After 4 weeks ACNs turn into walled-off necrosis (WON), fluid collections similar to pseudocysts but with partially solid content (Figure 2)[12]. Contrast-enhanced CT (CECT) exhibits high accuracy in identifying extent of pancreatic and peri-pancreatic disease, and potentially life-threatening complications,

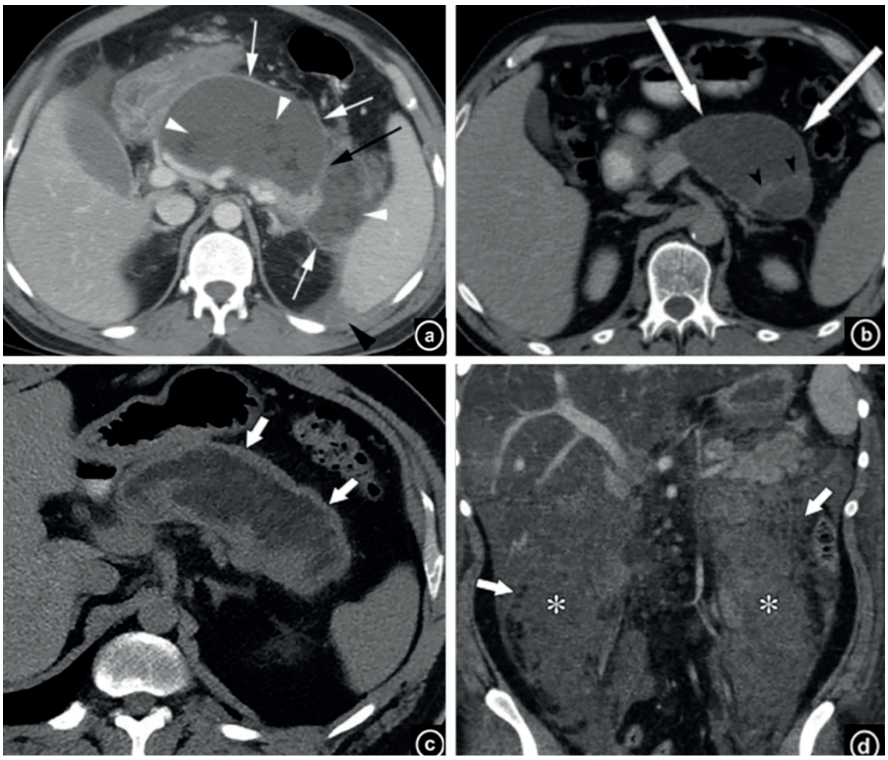

Figure 2. Portal venous phase axial computed tomography images **(a, b)**. Acute necrotic collections (ANC) develop within the first 4 weeks and show a variable amount of partially solid components such as necrotic material and cellular debris (**a, b,** white and black arrows). Unenhanced axial **(c)** and portal venous phase coronal **(d)** computed tomography images. After 4 weeks they show thickened walls and tend to organize in walled-off necrosis (WON) (**c,** white arrows). Air bubbles within necrotic collections along with clinical septic deterioration suggest superinfection (**d,** white arrows).

such as infected necrosis and vascular bleeding[20,30]. Although unenhanced CT (NECT) may detect signs of peri-pancreatic fat stranding and fluid collections, it is not functional in assessing necrosis and therefore adds no value to CECT[27]. CT protocol in AP has two acquisition phases: a late arterial phase (pancreatic phase) on the upper abdomen and a portal venous phase from the top of the diaphragm, including the entire abdomen[12]. Pancreas is well vascularized, the maximum parenchymal enhancement is obtained between 35 and 45 seconds from the injection of a bolus of non-ionic iodinated contrast agent, with a peak at 40 seconds[31]. To optimize the protocol, it is necessary to increase the injection flow rate from 3-5 ml/s using a bolus tracking technique. To achieve good pancreatic enhancement, it is essential to choose a contrast agent with a high iodine concentration, modulating the dose according to patient weight[32,33]. The administration of 50-100 ml of water 20-30 minutes before the acquisition can be helpful in pancreas examinations. A neutral oral contrast agent is preferable to a radiopaque one, which could impair the detection of pathological findings of gastroduodenal region[34,35]. Considering the long-term management of AP, the radiation protection concern should not be underestimated, especially in younger patients[36]. Some authors have questioned the real need for a two-phase protocol. Avanesov et al[37] observed no significant differences between single-portal and dual-phase protocols in the evaluation of AP 72h after clinical diagnosis on 102 examinations sample with a mean effective dose for single-phase of 9 mSv *vs.* 12 mSv in the dual-phase protocol.

However, to evaluate vascular complications such as pseudoaneurysm or acute hemorrhage, arterial phase may still be required[37]. The biphasic approach seems strictly necessary in the assessment of necrotic collections. Balthazar et al [30] has reported that pancreatic necrosis can be suspected when any region of the pancreas demonstrates an attenuation of less than 30 HU during pancreatic arterial phase. However, lack of contrast enhancement may also be related to a decreased blood perfusion, ischemia and parenchymal edema. Noda et al[38] in a subsequent study with biphasic examinations observed that portal venous phase is fundamental in recognizing necrotized area, which can be overestimated in pancreatic arterial phase[38-40]. To reduce radiation exposure, it's possible to use a split-bolus technique recommended by the Royal College of Radiologists in whole body trauma assessment[41]. Split-bolus intravenous contrast medium technique requires only a single scan and can provide multiphase images, with lower radiation dose exposure. A monocentric retrospective study compared the quality of classic multiphase CT images to split-bolus single-phase images by measuring the CT density of the abdominal aorta, portal vein and splenic parenchyma. The only difference recorded was in splenic attenuation, which was higher in split bolus group due to an overlap of arterial enhancement provided from the second bolus administration. Although routine use of a split bolus technique seems reasonable in AP, biphasic approach is still necessary in local complications such as suspected bleeding and characterization of vascular lesions[36]. Thanks to newer generation X-ray tubes, which allow to deliver higher currents (up to 1200 mA), it is possible to consider the application of low dose protocols reducing the KeVs. The diagnostic performance of low-dose protocols has been improved by applying iterative reconstruction (IR) techniques. These algorithms allow to select higher noise levels in the reconstructed images, resulting in a dose reduction[42-45]. However, some authors have pointed out the risk of loss of spatial resolution of low contrast findings by choosing a dose reduction of 25% or more using IR algorithms[46]. During glandular inflammation there is a reduction of the pancreatic parenchyma vascularization due to an impairment of microcirculation, resulting in a lesser iodine contrast medium concentration. Therefore, pathological pancreatic areas may be visible as spots of poor enhancement[47]. Interesting results on the detection of necrotic areas come from the application of the Dual-Energy CT, providing morphologic and functional information. Dual-Energy technology allows to create virtual monoenergetic images (VMI) at a certain value of KeVs, and can quantify the presence of individual elements in a given anatomical district, creating images where a single element can be subtracted or isolated (e.g., iodine maps)[48-50]. VMI and iodine maps have not only showed the ability to discriminate between healthy and inflamed pancreatic parenchyma but have also been shown to better detect necrosis in early stage than conventional images[51]. Recognition of small attenuation necrotic foci impacts on prognostic scores (such as revised Atlanta, CT severity index - CTSI and modified CTSI), allowing identification of patients who may require intensive clinical management. However, it should be considered that these are just preliminary retrospective studies conducted on a small heterogeneous population. Although promising, these results require further investigation, bearing in mind that attenuation thresholds can vary using different monoenergetic KeV values[52].

Small Bowel Obstruction

SBO causes 12-16% of hospital admission for acute abdominal pain, with a mortality range from 2%-8% to 25% when bowel ischemia is present. In the Western World, adhesions are the leading cause of SBO, accounting for 70% of all cases, followed by hernias and malignancies[53-57]. SBO may be partial or complete, depending on reduced or absent intestinal transit. In addition, the occlusion can be defined as simple or strangulated, the latter characterized by ischemic vascular impairment[58]. Physical examination findings and laboratory tests are not specific. The classical radiographic features of SBO are dilated loops (> 3 cm), air-fluid levels and absence of colic air[59-61]. These signs may be easily recognized by a plain radiograph, which is the first indicated exam in SBO (Figure 3). Although this method is widely available, conventional radiology shows a diagnostic failure rate of up to 30% and almost always requires completion with CT assessment[62]. CT multiplanar reconstruction allows to identify with high accuracy transition zones (RTZs), areas of abrupt change of caliber from dilated to collapsed bowel loops which represent pathognomonic obstruction findings (Figure 4)[63]. The strong correlation between RTZs and the anatomical site of occlusion makes them an added value in the preoperative planning of patients requiring surgical treatment[64-68]. On CT scans dilated fluid-filled bowel section assumes a classical "C" or "U" or "coffee bean" configuration with surrounding mesentery suffering. This quickly leads to ischemia and necrosis through pressure on the vascular peduncle or twisting on the mesenteric axis with a volvulus formation (Figure 5)[58,63]. In recent past, CT was performed with oral contrast agent administration, either barium or iodine based. The lack of contrast passing through the narrowing point is a direct sign of complete occlusion. However, distention secondary to fluid retention proximal to the site of the obstruction is sufficient to allow for an accurate study, obviating the drawbacks of using oral contrast such as vomiting and aspiration[69,70]. More importantly, lumen opacification can make it difficult to recognize any wall perfusion abnormalities[58]. Anyway, if it is decided to use an oral contrast agent, it should be chosen carefully. If a perforation is suspected, barium-containing contrast should be avoided, considering the high risk of developing a barium-induced peritonitis[71]. The most used CT protocol requires a wide FOV covering the whole abdomen, with a scan ranging from diaphragmatic domes to the inguinal region in a

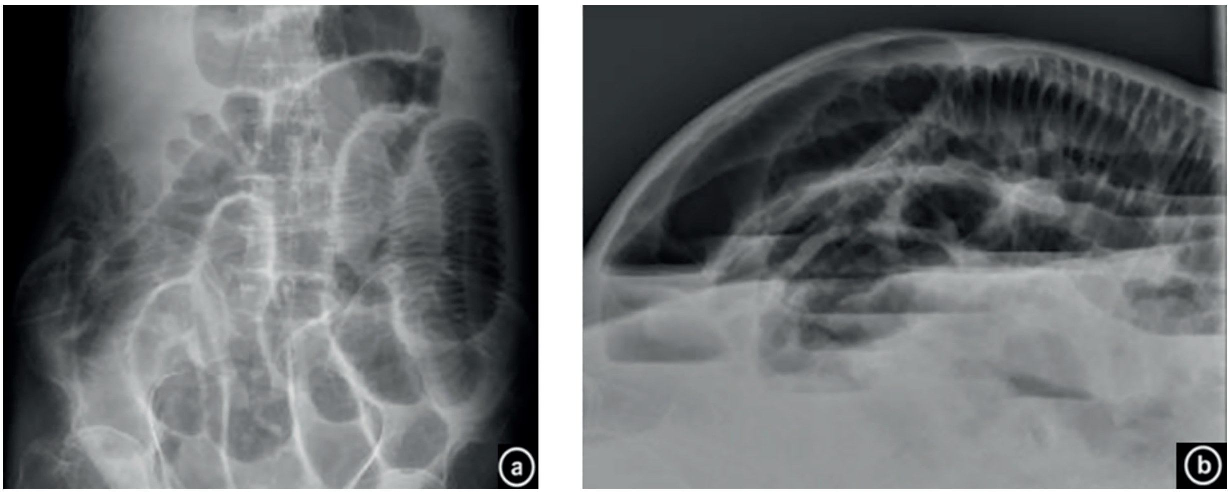

Figure 3. AP plain abdominal radiograph in supine position shows diffuse meteoric overdistension of small bowel loops with thickening of jejunal folds **(a)**. In the LL projection there are multiple air-fluid levels with a "ladder-like" appearance and no free abdominal air **(b)**.

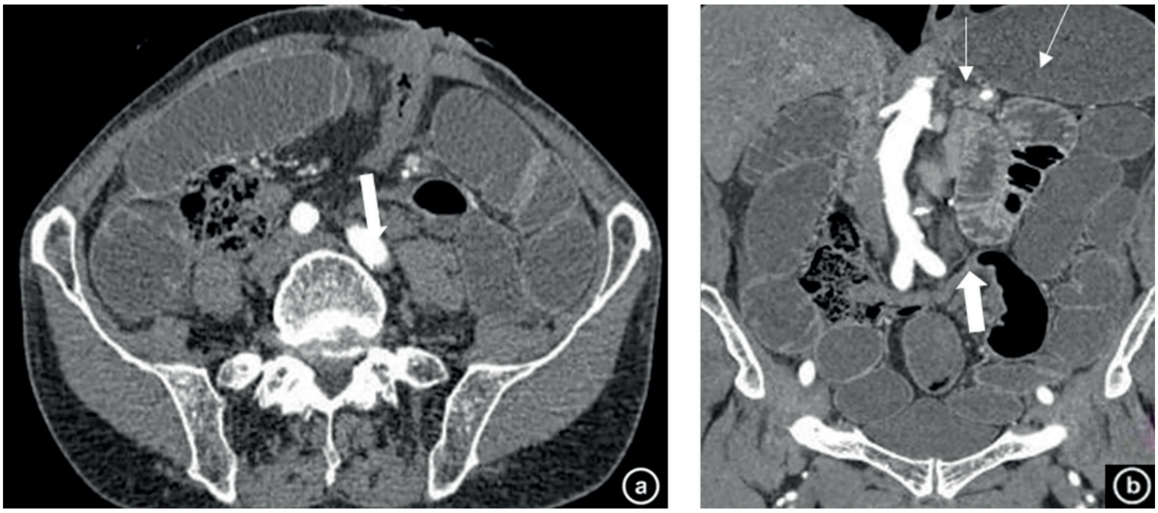

Figure 4. Arterial axial and coronal computed tomography images **(a,b)**. Fluid overdistended small bowel loops with transition zone (RTZ – white arrow), represented by abrupt change of caliber followed by collapsed bowel loops **(a)**. Transition zone can often be better seen in coronal reconstruction together with other signs of small bowel obstruction like thickening of jejunal folds (**b,** little white arrows).

single breath-hold. In patients with acute symptoms, a single portal venous phase acquisition with a scan delay of 65-70 s after initiation of contrast injection (100-150 cc of nonionic iodinated contrast agent) delivered at a flow rate of 2-4 mL/s is sufficient. CECT allows the wall perfusion assessment and vascular engorgement or swirling detection suggestive of a volvulus[72].

A feared complication of SBO is the so-called "strangulated obstruction", which is SBO associated to ischemia[73]. SBO is the only cause of intestinal ischemia that requires immediate surgery, while other forms, could benefit from surgery only in case of transmural bowel necrosis[74]. Although, sensitivity (73%-100%) and specificity (61%-100%) are highly variable in

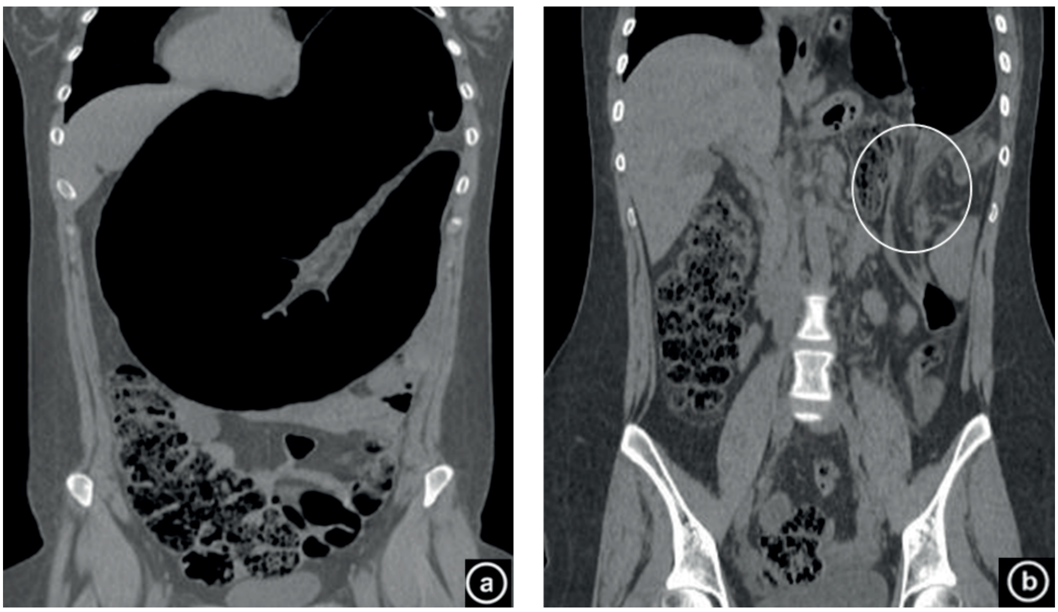

Figure 5. Unenhanced coronal computed tomography images **(a,b)**. Massive meteoric dilation of descendent colon that shows "coffee bean" appearance **(a)** and double transition zones in the coronal plane (**b,** white circle), findings consistent with colic volvulus.

recognizing signs of intestinal ischemia, CECT remains the best technique to predict strangulation[75]. Cox et al [76] retrospectively analyzed CT features of bowel ischemia in patients with surgical bowel obstruction. Presence of bowel wall hypo-enhancement, bowel wall thickening and pneumatosis exhibit high specificity but poor sensitivity in the setting of ischemia. Millet et al [77] identified three complementary signs of strangulation in SBO due to adhesions: reduction of wall enhancement that relates to bowel wall perfusion, diffuse mesentery haziness that reflects venous engorgement and multiple transitional zones associated to closed-loop mechanism. If these three signs are not found on CECT, strangulation can reasonably be ruled out and medical management should be recommended as first line therapy rather than surgical procedure. Comparing data available in literature, it is clear that bowel wall hypo-enhancement is a sign of irreversible bowel ischemia with the highest specificity (94%-100%), increasing the likelihood of bowel ischemia by 11-fold (Figure 6)[72,73,75,77]. Other signs of intestinal ischemia (e.g. segmental bowel wall thickening, wall pneumatosis, mesenteric and portal venous gas, engorged mesenteric vessels, whirl sign) are less sensitive and specific, they may be found in many other pathological conditions and therefore need to be critically analyzed, considering clinical data and other CT findings[63]. Ascites is another confounding factor: although it indicates possible intestinal obstruction[78-81], when it is very abundant as in cirrhotic subjects, it may mask mesenteric edema, an important CT feature of complicated SBO[63]. Particularly, mesenteric edema associated with wall thickening is very suggestive of segmental intestinal ischemia in patients with SBO caused by hernia and adhesions[82]. Probably the reasons for a low sensitivity of CT in recognizing signs of ischemia are due to the lack of unenhanced phase

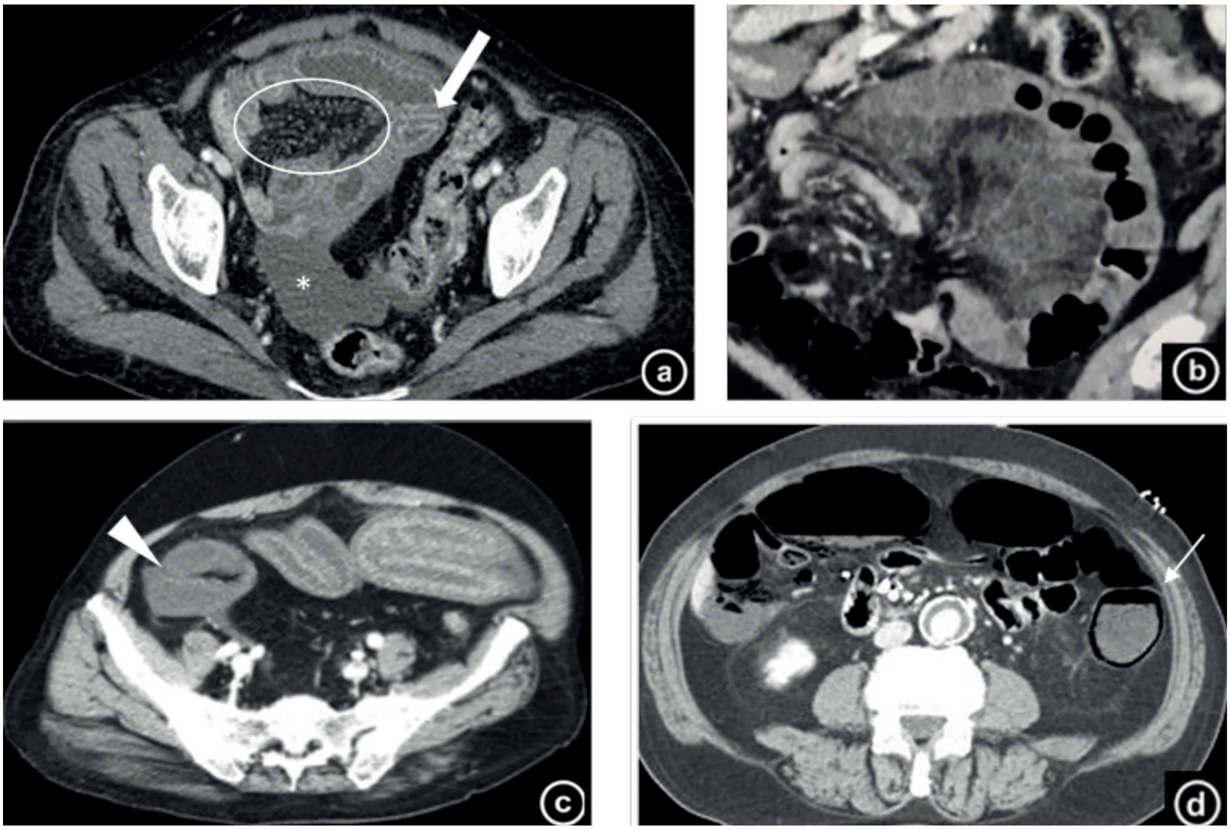

Figure 6. Portal venous phase **(a, b)** and arterial (**c, d)** axial computed tomography images. These images show wall thickening of small bowel loops with target-like enhancement (a, white arrow); other signs can be associated such as ectasia of vasa recta afferent to the involved loops (a, comb sign – white circle), abundant free endoperitoneal fluid (**a,** asterisk) and haziness of the adjacent mesenteric adipose sheath **(b)**. When ischemic hypoperfusion persists, parietal hypoenhancement occurs (**c,** arrowhead) with possible development of wall pneumatosis (**d,** little white arrow).

acquisition and because of the execution of a single venous portal phase, as recommended by the ACR guidelines. These limits can partly be exceeded by Dual-Energy CT, through VMI at low KeV that could extract angiographic information just from the venous portal phase alone. Moreover, iodine maps allow to visualize subtle changes in the intestinal wall, proved to be very effective, not only in the study of gastrointestinal tract neoplasms, but also in the assessment of inflammatory and ischemic pathology[83,84]. Finally, it is possible with Virtual Non-Contrast (VNC) imaging to obtain virtual unenhanced scan, which enables to assess wall bleeding without increasing the exposure radiation dose[85]. However, the VNC imaging diagnostic accuracy may be compromised by artifacts due to an inhomogeneous iodine subtraction. Further optimization of material decomposition algorithms is necessary to obtain pixel attenuation values comparable to true unenhanced images[49].

Acute Appendicitis

Acute appendicitis (AA) is one of the main causes of access to the emergency department, affecting 100 patients every 100.000 inhabitants per year in developed countries[86]. The first diagnostic purpose of imaging is to confirm or rule out the diagnosis of AA, secondly to stratify the risk of patients requiring surgery (Figure 7). Several clinical scores have been proposed in the assessment of patients with AA. The most accredited score is the Alvarado Score, which is based on evaluation of symptoms (nausea, migrating pain), clinical signs (right iliac fossa tenderness/rebound tenderness, body temperature) and laboratory tests (white blood cells count), with a good sensitivity (especially in men) but low specificity[87,88]. Recently, Appendicitis Inflammatory Response (AIR) Score introduces a new biochemical parameter, the C-reactive protein levels, which has been shown to correlate with AA in many studies[89]. AIR Score demonstrated higher specificity (97%) and positive predictive value (88%) than Alvarado Score (76% and 65%, respectively) especially in selecting patients with high probability of AA[89]. The advent of CT reduced the rate of negative appendicectomies (false positive diagnosis) from 26% to 6-10%[90], without an increase of appendiceal perforation due to delayed diagnosis. Both rates represent fundamental measures of quality of care[91]. The extensive CT protocol includes both oral and intravenous contrast administration. Although this protocol provides the most diagnostic value, it is not necessarily the safest for patients. The accuracy of CT in the diagnosis of acute AA is not influenced by use of oral contrast agent. Oral contrast material failed to reach cecum in 18%-30% of patients, thus resulting in longer management time (120 minutes at least) and an increased risk of visceral perforation[92]. Since abdominal gastrointestinal diseases often involve adjacent visceral fat, it's reasonable to assume that visualization of the inflammatory changes would be more readily apparent in pa-

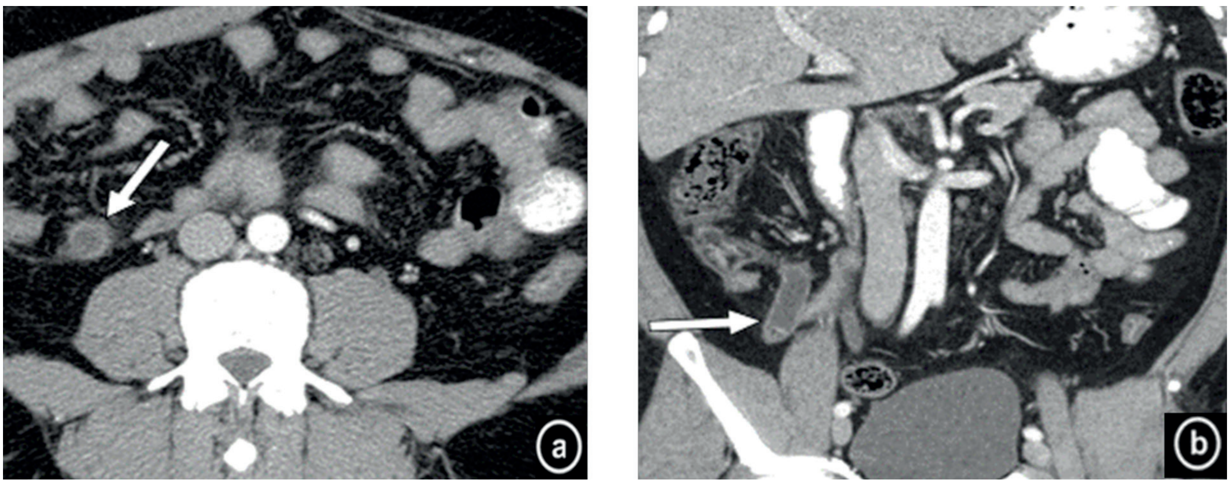

Figure 7. Arterial phase axial computed tomography **(a,b)**. Imaging of an uncomplicated acute appendicitis show an appendix with thickened (> 3 mm) and hyper enhanced wall, increased biparietal diameter (> 7 mm) with alterations of periappendicular fat, mild lumen overdistension and a millimetric coprolite at the distal end (**a, b**, white arrows).

tients with more adipocytes[93]. Therefore, diagnosis of early AA may be challenging in particularly thin patients without enteric oral contrast medium use. Standard-dose intravenous CECT is the most commonly used protocol. Multiphase scans are not indicated because of an excessive radiation dose exposure with little to nonadditional clinical benefit[94,95]. An inappropriate number of CT phases is particularly problematic for pediatric patients and women of reproductive age. Giannitto et al[96], in a cohort of 76 women undergoing abdominal pelvic CT for non-traumatic conditions, observed a mean of 1.2 inappropriate phases for each patient, including those with suspected AA. Excess mean radiation dose to the uterus and ovaries was 38 mSv and 33 mSv per patient, respectively. In literature, no sensitivity improvement was achieved with the combination of both unenhanced and contrast-enhanced sequences, in comparison to CECT alone[97]. According to ACR guidelines, it's appropriate to acquire a portal venous phase scan with 2-3 mL/s intravenous contrast agent injection (non-ionic high iodine concentration), that allows to distinguish bowel inflammation and potentially fatal complications like perforation, peritonitis, abscess or periappendicular collections[98-101]. The CT role without intravenous contrast material is questioned. The main radiological signs of an inflamed appendix (e.g., a diameter of the appendix greater than 8 mm, fatty tissue thickening in the right iliac fossa, endoluminal appendicoliths, a thickening of the cecal wall) could be detected by a simple non-enhanced baseline scan with acceptable sensitivity and specificity, as demonstrated by Hlibczuk et al[101] in a large meta-analysis. The advantages of NECT are evident, combining rapid examination and cost savings with no contrast side-effects (contrast-induced nephropathy, anaphylactic reactions and contrast agent extravasation)[100,101]. Consequently, radiologists may be confident in choosing a single-phase contrast-free CT protocol depending on their own experience. Even though several evidence supports its use, routine use of low-dose CT protocols are still far from being appropriate; one of the main problems may be the concern about low-quality image, leading to incorrect diagnoses. However, low-dose protocols could substantially reduce radiation dose in appendiceal CT study to 2 mSv for adolescents and young adults without impairing clinical diagnosis, which is a cut-off value similar to the worldwide average annual exposure to natural radiation sources[102,103]. Many experiences with low dose protocols are available in literature[104]. Kim et al[105] in a randomized monocentric study compared low-dose CT to a standard dose CT protocol in studying AA. Low-dose CT performance was non inferior to standard-dose CT. However, the patients in the low-dose CT group were more likely to require additional imaging tests, probably due to a lower diagnostic confidence of both physicians and radiologists[105]. These promising data also emerged in a large multicentric study (LOCAT – Low-dose CT for diagnosis of appendicitis in adolescents and young adults) that involved hospitals with different expertise in low-dose CT, overcoming the limitations of the previous monocentric studies[106]. Thanks to the availability of iterative algorithms that can decrease noise, radiologists are encouraged to prefer low dose examinations whenever they can be applied[107-109]. Another method to decrease radiation dose exposure could be abdominal scan range reduction, starting from the first lumbar vertebral body (L1), instead of diaphragmatic domes. Limiting dose to the area of interest could confirm AA diagnosis with a decline of the whole-body effective radiation dose of 39% and an organ dose reduction of more than 90%[110]. Anyway, this protocol is acceptable only when supported by accurate clinical and ultrasonographical patient's assessment[111,112]. Compared to the past when the only therapeutic approach considered in patients with AA was appendicectomy, currently the surgical approach is reserved only for the complicated form of AA (Figure 8, Figure 9)[98,113]. This paradigm-shift coincided with the assumption that CT can distinguish unequivocally complicated forms of AA (e.g., gangrenous or perforated appendix)[86]. However, the diagnostic accuracy of CT is still debated. Some authors suggest that the rate of non-operative treatment (30%/year) of complicated AA can be attributed to the poor diagnostic performance of CT[114]. In a retrospective study Kim et al[115] evaluated the possibility of increasing the diagnostic accuracy of CT in complicated AA by applying 10 CT features extracted from a systematic review of 2018 (contrast enhancement defect of the appendiceal wall, abscess, extraluminal air, intraluminal air, extraluminal appendicolith, intraluminal appendicolith, moderate-to-severe periappendiceal fat stranding, periappendiceal fluid, ileus and ascites)[115]. The simultaneous presence of all 10 CT signs showed

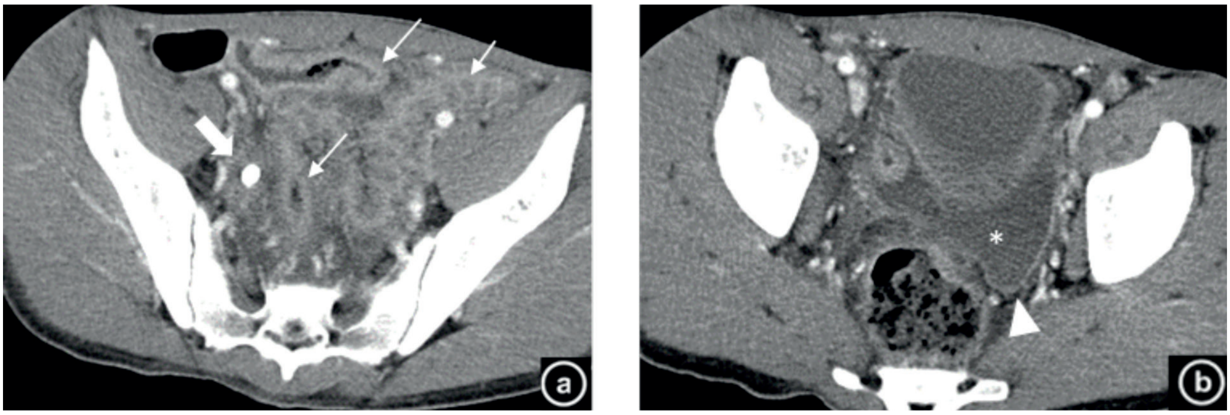

Figure 8. Arterial phase axial computed tomography **(a, b)**. Case of acute appendicitis complicated with peritonitis: CT revealed an inflamed pelvic appendix with an obstructing coprolite at its base (**a,** white arrow) and wall thickening of nearby bowel loops (**a,** little white arrows). Abundant endoperitoneal effusion (**b,** asterisk) and thickening of peritoneal serosa are also noticed (**b,** arrowhead).

a sensitivity of 92% compared to 64% recorded with the evaluation of images based on the experience of the radiologist alone. On the other hand, specificity reached a value of 43% with high rate of false positives, which results in unnecessary surgery in about half of the patients[116]. Dual-Energy-CT may exceed the limits of conventional CT in the identification of complicated AA, improving patient outcome. Elbanna et al [117] applied Dual-Energy CT in case of acute gangrenous appendicitis, finding a high diagnostic performance of 40-keV VMI and iodine overlay imaging reconstructions, with a sensitivity of 100% and specificity of 81.2% and 80.0%, respectively. Moreover, VMI have shown a high accuracy in detecting defects of the appendicular wall enhancement, which had the greatest specificity in differentiation between complicated and non-complicated AA[115]. On the other hand, parameters such as bowel wall thickening, fat stranding and free fluid may seem to be better evaluated in conventional reconstructed images, as low KeV images reduce fat attenuation and do not provide additional information on soft tissue. Dual-Energy CT allows acquisition of both conventional and monoenergetic images, making it a promising tool in the evaluation of appendicular pathology, although further trials are needed to draw definitive conclusions[118].

Acute Diverticulitis

Acute diverticulitis (AD) is a frequent complication of diverticulosis, which commonly affects the left-sided colon, especially sigmoid colon[119].

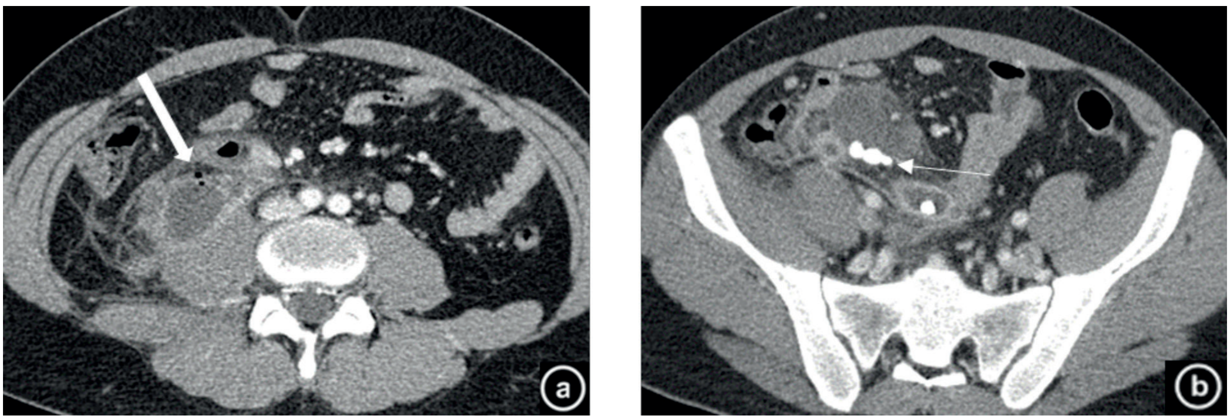

Figure 9. Portal venous phase axial computed tomography **(a, b)**. Acute abdomen with evidence of free air bubbles in the context of a thick-walled fluid collection located in front of the right psoas muscle (**a,** white arrow). In the more caudal scans, it can be appreciated an overdistended appendix with appendicolites inside and outside of the lumen (**b,** little arrow), findings strongly indicative of a perforated acute appendicitis with development of an associated abscess.

Most recent data obtained from endoscopy and CT imaging suggests that the AD lifetime risk in individuals with diverticulosis is approximately 5%, of which 20% will develop a complication (e.g., abscess or perforation)[120]. Upon access to the emergency department, most patients with AD present with left lower quadrant abdominal pain, fever and leukocytosis. However, clinical picture may be more blurred, with a high risk of undiagnosed/misdiagnosed cases. Considering the wide range of differential pathologies, clinical examination alone has a poor positive predictive value without imaging confirmation[121]. The most widely used classification of AD is Hinchey classification. The first version was strictly surgical and had poor CT correspondence. Wasvary et al[122] described a modified version, which is currently in use. Patients with AD are divided into four main categories (I, II, III, IV) and two further subcategories (Ia and Ib), depending on the disease severity (Figure 10). World Society of Emergency Surgery (WSES) AD working group has proposed a classification based on CT findings, which is more feasible in daily clinical practice. AD can be uncomplicated or complicated, depending on whether the extent of disease is limited to the colon wall or not. Specifically, complicated form is divided in four stages with 2 subcategories: 1A with pericolic air bubbles or small amount of pericolic fluid within 5 cm from the inflamed colon segment; 1B and 2A characterized by abscess formation respectively ≤ 4 cm and > 4 cm; 2B if gas is visible more than 5 cm away from the inflamed colon segment; 3 whenever fluid is present without distant free gas; 4 if fluid with distant free gas is

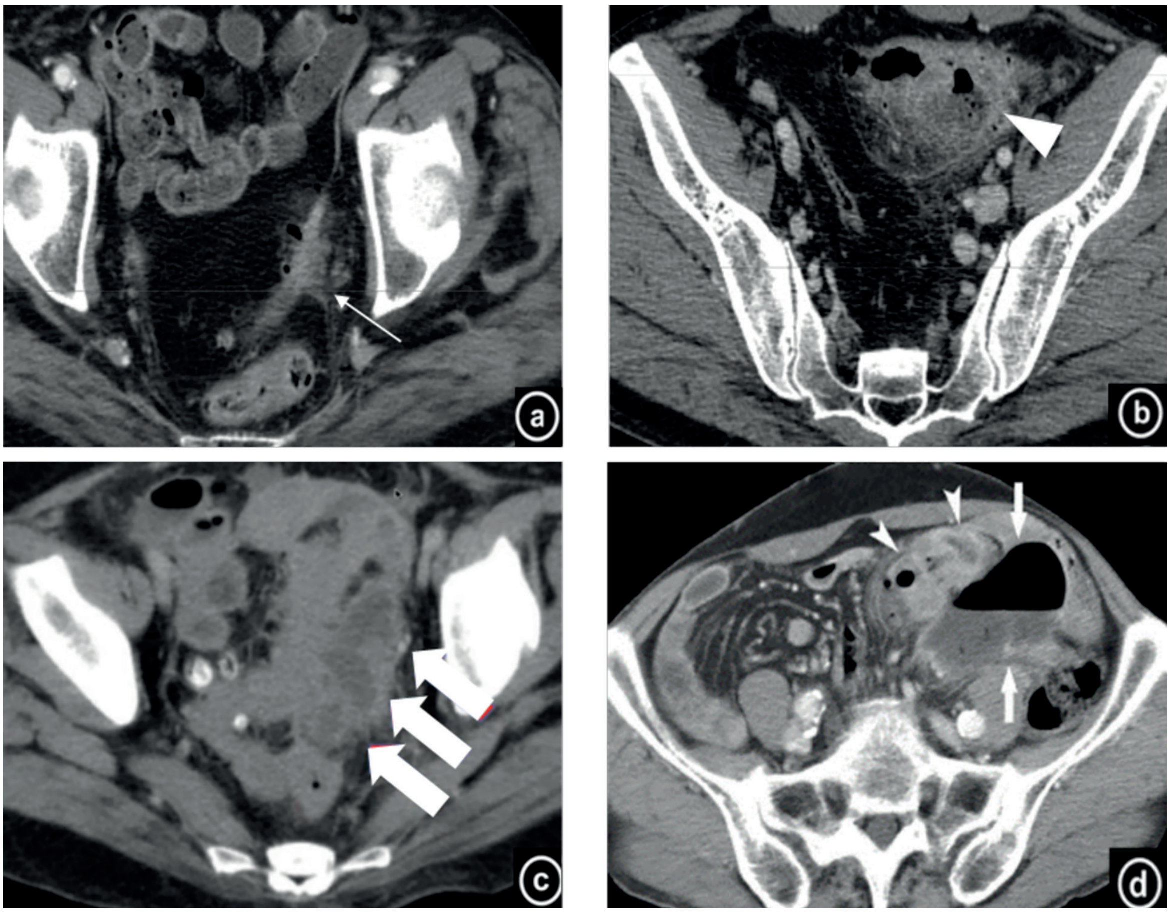

Figure 10. Portal venous phase axial computed tomography **(a, b, c, d)**. Cases of acute diverticulitis: diverticulosis of the sigmoid colon with signs of inflammation due to the presence of phlegmonous thickening of the perivisceral adipose tissue (Hinchey Ia) (**a,** little white arrow). Limited intraparietal abscess collection (< 5 cm) associated with signs of diverticulitis (Hinchey Ib) (**b,** arrowhead). Extensive collection (> 5 cm) in the sigmoid colon wall in a picture of acute diverticulitis (Hinchey II) (**c,** white arrows). Two large pericolic abscesses with air inside, findings indicative of a complicated form of acute diverticulitis with visceral perforation (Hinchey IV) (**d,** arrowheads and white arrows).

evident. Stage 0 corresponds to uncomplicated form with only thickening of the colic wall and increased density of pericolic fat detected on CT scan[123]. CT with intravenous contrast injection is the gold standard in assessment of suspected AD to confirm the diagnosis and estimate the severity of the disease. CT is most useful in doubtful cases and in patients with suspected severe diverticulitis, where a choice among different treatment options should be made[124,125]. Although the arterial phase may seem strictly necessary, a single portal venous phase of the entire abdomen performed after a 70- to 80-s delay, which usually provides excellent visualization of the arterial and venous districts, allows detection of both colon wall abnormalities and vascular complications[126]. In addition, Multiplanar Reconstruction (MPR) is widely used and recommended in the acute abdominal condition evaluation, improving the identification of colic and pericolic abnormalities, especially in case of unusual anatomical location or complications[127]. Low-dose CT techniques allow radiation dose reduction between 75% to 90%, with sensitivity and specificity comparable to those of standard CT[128-131]. Walter et al[132] evaluated the diagnostic performance of low-dose protocols in a population of young adults with suspected AD. Researchers simulated a dose reduction to 75%, 50%, and 25% of the original standard dose tests through synogram synthesis and quantum noise modeling, evaluating the trend in diagnostic accuracy. Despite the progressive deterioration in image quality, diagnostic accuracy and diagnostic confidence were comparable to those of the original dataset, up to 50% of dose reduction[132]. The researchers' position is very clear about oral contrast agent use in AD. As in other non-traumatic abdominal pain conditions, no significant benefit in either diagnosis or assessment of complications is demonstrated in the use of oral contrast agent, compared with intravenous contrast alone[69,133-135]. Furthermore, extraluminal Gastrografin is not a frequent CT finding in gastrointestinal perforations, even in diverticular ones, as observed by Lohrman et al[135] in a small group of patients with surgically and histopathologically proven diverticular perforation[134,135]. However, colon opacification can be useful in differential diagnosis between AD and colon cancer in presence of collapsed bowel loop and mural thickening[136]. Moreover, the addition of oral contrast agent to intravenous contrast injection reduces the possibility of non-targeted catheter placement during intra-abdominal abscesses interventional drainage procedures of[137,138]. Regards to diagnostic accuracy in suspected AD, CT with intravenous contrast injection alone is not inferior even to rectal contrast agent, which is rarely used nowadays[139,140]. The use of rectal contrast material may be limited to suspected perforation or anastomotic leakage after surgery[141].

One possible complication of diverticulitis is diverticular bleeding, which is the main cause of lower gastrointestinal bleeding in the adults[142]. Although CECT allows direct visualization of the contrast extravasation through the bowel wall, areas of active bleeding can be accentuated by Iodine-specific images. Moreover, Dual-Energy techniques help to distinguish between active extravasation of contrast agent and digestive material or foreign bodies[143,144].

Acute abdomen may also be the initial manifestation of an underlying neoplasm. Emergency radiologists should be able to distinguish these clinical settings, which have different clinical and therapeutic work-up. Iodine maps resulted from mural accumulation of intravenous contrast material may be helpful in the detection of colorectal carcinoma and in differentiation from AD. This is an important advantage which may reflect on patients' management, but additional studies are needed to set an appropriate threshold of iodine concentration[145-147].

Conclusions

CT is the most accurate imaging technique for the evaluation of acute non-traumatic abdominal conditions. The most appropriate CT protocol is an essential prerequisite for proper patient management during the diagnostic work-up. The time management is undoubtedly essential in acute pathologies, but patient safety, in terms of radiological exposure, should not be forgotten. Low-dose protocols have demonstrated diagnostic accuracy comparable to standard acquisitions, so radiologists should be confident in choosing techniques that could reduce the radiation burden. Dual energy has certainly implemented the diagnostic potential of conventional CT with promising results in several pathological conditions. Continuing advances in post processing technologies and techniques confirm that in the future there will be an application also in the emergency imaging.

Conflict of Interest

The authors have no conflict of interest to be disclosed. The authors confirm that the article is not under consideration for publication elsewhere. Each author has participated sufficiently to take public responsibility for the manuscript content. .

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