



The Mesenteric Organ: New Anatomical Concepts and an Imaging-based Review on Its Diseases

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The proposal of reclassifying the mesentery as an organ prompts clinicians and radiologists to reappraise their approach to it and to mesenteric diseases (mesenteropathies). Recent updates in mesenteric anatomy and the better comprehension of its structure constitute a basis to push forward the process of disease management and allow the development of less radical (including endoscopic, radiological, and pharmacotherapeutic) treatments. Radiological evaluation currently plays a pivotal role in the noninvasive characterization of abdominal diseases. Mesenteric-based radiological assessments form an essential component in planning radiological interventions and postoperative surveillance programs. The purpose of this article, therefore, is to provide an update on the new anatomical concepts related to the mesentery, also performing an imaging-based review of mesenteric diseases by categorizing them as primary and secondary.

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Introduction

Recent data suggest that the classic model of mesenteric anatomy should be revised. The mesentery is now regarded as continuous, substantive, distinctive, and has essential, as well as specific, functions. These and other properties support that the mesentery may be reclassified as an organ.^{1,2}

The classic concept of mesenteric discontinuity is under discussion: it was previously believed that there were multiple mesenteries (small intestinal, transverse, and sigmoidal). The model held that the mesentery of the ascending and

descending colon region (ie, the right and left mesocolon, respectively) did not occur in adults, instead, these regions of mesentery were described as fusing with the posterior abdominal wall.³ According to this model, persistence of a mesentery associated with the right and left in these regions was considered by many authors as an embryological abnormality, resulting from failure of fusion of the mesentery with parietal peritoneum.^{4,5} These same authors often considered persistence of the ascending and descending mesocolons contributing to the development of pathologies.⁴⁻⁷ However, theories developed to explain right and left mesenteric involution were never widely accepted.¹

Although recent studies involving surgical, cadaveric, and visual datasets demonstrated mesenteric continuity from the duodenojejunal to mesorectal level including the normal presence of right and left mesocolon (Fig. 1),¹ reference texts and research literature continue to describe the classic model as the reference model.^{6,8}

The classic texts consider the mesentery as a discontinuous structure, divided into several segments. However, reference authors have already defended the concept of

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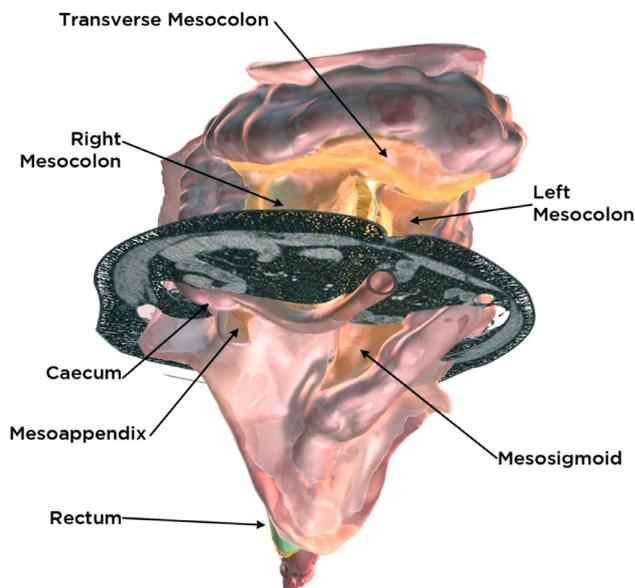


Figure 1 3D model demonstrating mesentery distal to duodenojejunal flexure, viewed from below, with axial CT placed for reference. Online supplemental material available: www.mpgs.ie.

continuity of these mesenteric parts among themselves. Meyers et al conceptualizes the visualization of the abdomen and pelvis as a single space, and that the mesenteries and ligaments of the abdomen and pelvis, and the abdominal and pelvic organs are in continuity and interconnected.³ Renaissance anatomists depicted mesenteric continuity with abdominal digestive organs.⁹ Indeed, Jones Quain (in 1832) described continuity between the small intestinal and right mesocolic regions of the mesentery.¹⁰ Thus, the new concept that the mesentery is a unique structure is the elucidation of something that was already suspect, since the interconnection between the mesenteric segments was already an accepted concept.

Therefore, this paper will focus on the new mesenteric model. We will also briefly summarize and categorize mesenteric diseases.

Current Concepts

Mesentery as an Organ

One of the most accepted definitions is that an organ is an independent part of the body that performs a special function.¹¹ Thus, the new anatomical and functional understanding of the mesentery prompted the suggestion that it should be redesignated as an organ.¹ The criteria proposed in support of this designation included, in brief: its substantive size, its overall continuity, and distinctive functionality.

Mesenteric continuity (leading to substantive size) was confirmed through anatomical, histological, and radiological correlations findings correlation.¹² Among the mesenteric functions already defined, we highlight: (1) *Positioning of intra-abdominal organs*: the mesentery performs a specific and essential role in order to maintain all abdominal

digestive organs in position and in continuity with all other body systems. As a result of the mesenteric attachments (that are the anchorage of mesenteric regions to the posterior abdominal wall), the mesentery and the intestine have a spiral conformation (Fig. 1). This conformation assists in maintaining digestive function, whenever humans adopt an orthostatic position. (2) *Regulation of local and systemic metabolism*: the centrally positioned mesentery is ideally placed to sample environmental signals (derived from the intestine) and coordinate local and systemic homeostatic activities in response. It was recently identified as a major source of systemic C-reactive protein. Mesenteric production of C-reactive protein has been linked to the regulation of glycemic and lipid metabolism. This association provides a molecular linkage between mesenteric-based and systemic metabolic events. In addition, visceral adiposity (of which mesenteric fat is the single largest component) has major effects on systemic inflammatory, coagulopathic, and fibrinolytic systems. Such interactions are of particular importance as increases in visceral (ie, mesenteric) adiposity are linked to development of atherosclerosis, type II diabetes, hypertension, and obesity. (3) *Intra-abdominal organogenesis*: During embryological development, the mesentery contributes to digestive system organogenesis by providing molecular and cellular signals to developing organs. This relationship is encapsulated in the phrase “mesenteric organogenesis” which refers to the development of all abdominal digestive organs within a continuous mesenteric frame.^{2,13}

Anatomy and Radiological Anatomy

Considering the concept of mesenteric continuity, mesenteric anatomy is easier to understand than previously thought. The same applies for structures related to the mesentery, such as Toldt’s fascia, the peritoneum, greater omentum, and peritoneal cavity.

Mesenteric anatomy: As per the current concept, the mesentery is a continuous structure. However, it can be subdivided into regions for didactic purposes, based on the region of intestine with which it is contiguous. It is possible to use mainly vascular markers to aid in the identification of these mesenteric regions (Table 1). Mesenteric regions (Figs. 2 and 3) associated with the small and large intestine include: (1) mesenteric root; (2) small

Table 1 Main Mesenteric Regions and Peritoneal Reflections

Mesenteric Regions	Regions of Peritoneal Reflections
Mesenteric root	Hepatocolic peritoneal reflection
Small bowel mesentery	Splenocolic peritoneal reflection
Ileocolic pedicle territory	Small bowel peritoneal reflection
Right mesocolon	Ileocaecal peritoneal reflection
Transverse mesocolon	Right peritoneal reflection
Left mesocolon	Left peritoneal reflection
Mesosigmoid	Mesosigmoidal peritoneal reflection
Mesorectum	Pararectal peritoneal reflection

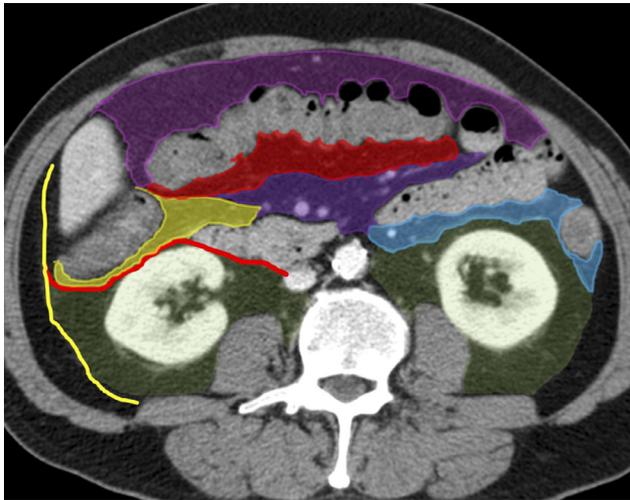


Figure 2 Axial-enhanced CT scan showing an overview of the mesentery with colors for the different regions: small bowel mesentery (purple area), transverse mesocolon (red area), right mesocolon (yellow area), and left mesocolon (blue area). Fascia of Toldt (red line), right lateral peritoneal fold (yellow line), retroperitoneum (orange area), and greater omentum (pink area) are also observed. (Color version of figure is available online.)

bowel mesentery; (3) ileocolic pedicle territory (not shown); (4) right mesocolon; (5) transverse mesocolon; (6) left mesocolon; (7) mesosigmoid; and (8) mesorectum. In an anatomical-radiological review, mesenteric regions could be identified by radiologists in CT studies in the following proportions: ascending mesocolon (75%), descending mesocolon (86%), and sigmoid mesocolon (88%). Flexural mesenteric regions were identifiable in the following proportions: ileocaecal (66%), hepatic flexure (68%), splenic flexure (71%), and rectosigmoid flexure (80%). Toldt's fascia was identifiable in 40% on the right and 54% on the left (Figs. 2 and 3).^{2,12}

Toldt's fascia: Toldt's fascia occurs between the abdominal wall and mesentery, wherever the latter is attached to the posterior abdominal wall. Just as the mesentery is regarded as continuous, so is the fascia as it occupies the potential space between the mesentery and the posterior abdominal wall from the origin of the mesentery to its end.²

The peritoneal reflection: Where the peritoneum of the abdominal wall detaches and is reflected onto an adjacent digestive system organ (including the mesentery). It aids in maintaining the mesentery (and contiguous organs) in position. Wherever an organ is attached to the posterior abdominal wall, the peritoneum of the posterior abdominal wall bridges the space between the organ and the abdominal frame. This region of peritoneum is called the peritoneal reflection. Although the reflection is continuous, zones of it can be arbitrarily named as follows for didactic purposes: hepatocolic peritoneal reflection; splenocolic peritoneal reflection; small bowel peritoneal reflection; ileocaecal peritoneal reflection; right peritoneal reflection; left peritoneal reflection; mesosigmoidal peritoneal reflection; and pararectal peritoneal reflection (Table 1).

Peritoneal cavity: In the past anatomy of the peritoneum and peritoneal cavity was considered complex and confusing. There were several reasons for this. Chief among these was the

concept that there were multiple mesenteries, each attaching along a particular anatomical trajectory. This generated an extremely complex peritoneal landscape. This was described in terms of recesses, fossae, and pouches. Each of these was anatomically outlined by another set of structures called ligaments, folds, membranes, and reflections. Importantly, the spaces, recesses, pouches, and fossae lacked distinctive anatomical boundaries and were highly variable in anatomy. Moreover, many of these conceptual spaces are lost or obliterated during different states. For example, Morrison's pouch is obliterated when occupied by the greater omentum in obese patients. The lateral sigmoidal fossa is lost when the mesosigmoid adheres to the left iliac fossa and the paravesical fossa is lost when the bladder distends.

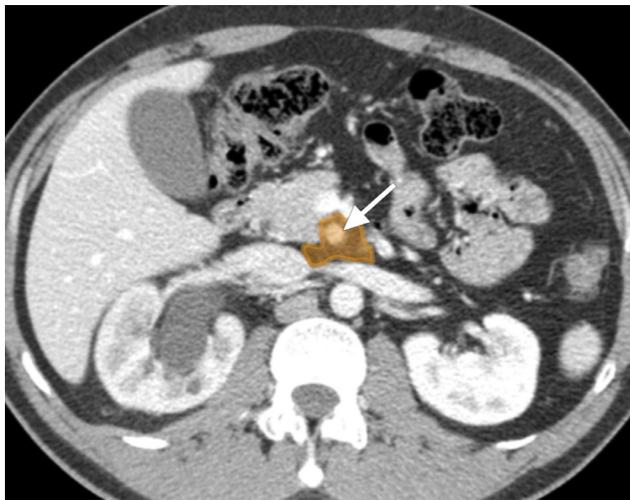
Greater omentum: According to the recent classification, the greater omentum would be a separate structure with an embryological origin similar to the mesentery, covering the transverse mesocolon and serving as a bridge between it and the abdominal wall. During embryological development the greater omentum arises as the anterior portion of the dorsal mesentery. The dorsal mesentery forms a fold. At the lateral aspect of the fold, the spleen develops. Within the front wall of the fold the intestine continues to develop, and between both stomach and spleen the greater omentum arises. It retains this relationship into adulthood when it is draped from the greater curvature of the stomach and covers the upper surface of the transverse mesocolon as well as the small intestine and related region of mesentery.²

Although the anatomy of the mesentery has become simpler to understand, it should not be considered trivial. Anatomy is a foundation science of medicine and is centrally important to diagnosis and treatment of human disease.^{14,15} Current concepts bring a fresh perspective to all mesenteropathies, not only in relation to their aetiology and pathophysiology, but also to their management. This new mesenteric concepts has already prompted related studies with very encouraging results to date.¹³

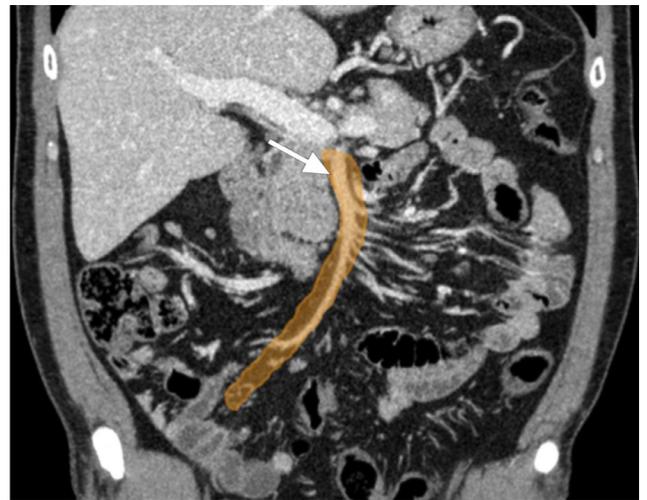
As an important component of the multidisciplinary team, and a key influence in treatment planning, the radiologist must understand the new model of the mesentery and related structures. The radiologist's role involves providing essential information about the nature and stage of mesenteropathies. This process is greatly aided by taking mesenteric continuity into account, and is a key step in disease diagnosis and management.²

Implications of Recent Advancements for Understanding Pathogenesis and Progression of Abdominal Diseases

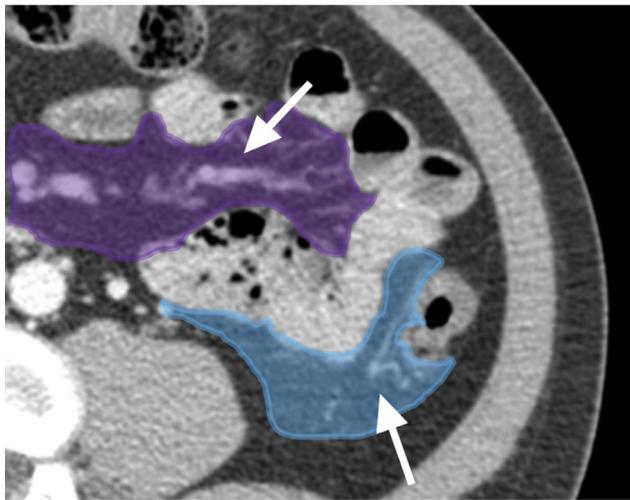
Recent data challenge the classic concept that Crohn's disease arises from the mucosal lining of the intestine and progresses outwardly to involve other intestinal layers. It is possible that Crohn's disease represents a true primary mesenteropathy, that is, a disease that begins in the mesentery. Increasing data strengthen the suggestion that mesenteric adipose inputs are important in the pathobiology of Crohn's disease. For example,



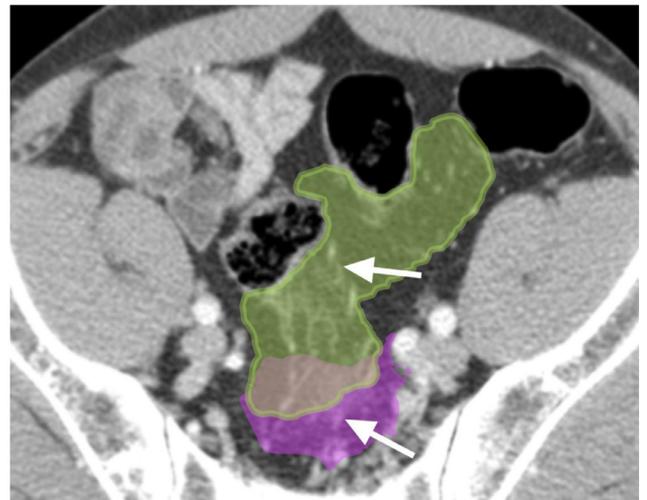
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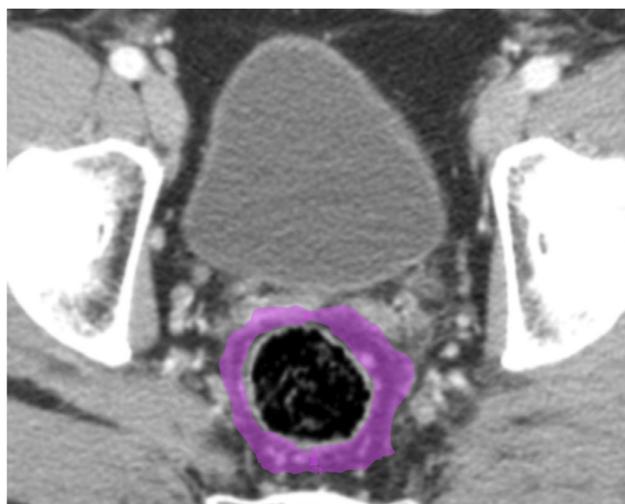
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c



d



e

Figure 3 Contrast-enhanced CT scan showing mesenteric regions. Axial (a) and coronal CT (b): small bowel mesentery has a “mesenteric root” (orange) at the origin of the superior mesenteric artery (SMA); the small bowel mesentery then fans out from the root region (arrows) suspends. Axial CT (c): small bowel mesentery (purple area) and left mesocolon (blue area), with arrows showing vascular markings that help identify these regions. Axial CT (d): mesosigmoid (green) and its confluence with the mesorectum (pink), with arrows showing vascular markings. Axial CT (e): mesorectum (pink). (Color version of figure is available online.)

a direct correlation occurs between the spread of mesenteric fat over the intestinal surface (called fat wrapping or creeping fat) and increased rates of surgical recurrence. An examination of factors associated with increased rates of surgical recurrence demonstrated a stronger association between the extent of fat wrapping (and recurrence) than that which occurred between smoking and recurrence. Reports demonstrate an association between increases in visceral adiposity and the development of postoperative complications in patients undergoing surgery for Crohn's disease. Data are also emerging that suggest a correlation between mesenteric fat, and complications following ileal pouch anal anastomosis.^{2,16-18}

In support of this concept (that mesenteric events drive Crohn's disease) emerging data suggest that if the mesentery is included in resections for Crohn's disease, then surgical recurrence rates are reduced. Radiological and pathological findings support the suggestion that mesenteric inflammatory events precede intestinal manifestations in Crohn's disease.¹⁶ Mesenteric disease manifestations correlate closely with intestinal manifestations.^{16,17} Behr was among the first to propose that extra intestinal factors (the "outside-in hypothesis") were of primary importance in the pathobiology of Crohn's disease.¹⁹

Mesenteric continuity as well as contiguity with adjacent intestine, has major implications for staging of intestinal malignancy. The new anatomical concepts of the mesentery should also change the understanding of the colorectal cancer spread and staging. The idea of lymphatic dissemination within the mesentery is being considered lymphatic dissemination rather than remote metastasis; thus, this change may lead to a revision in TNM staging criteria, which could bring different and perhaps positive results in the treatment and morbimortality of this disease.^{20,21}

Radiological assessment has an essential role in determining the preoperative tumor stage.^{22,23} In order to achieve an appropriate assessment, the radiologist must have a clear understanding of normal and aberrant mesenteric anatomy. It is important that the radiologist be able to interpret the anatomical extent of disease in terms of mesenteric, fascial, and peritoneal landmarks. This in turn aids in determining the level of radicality required during surgery, and the requirement for adjuvant treatment.²⁴

Mesenteropathies

Mesenteropathies (diseases of the mesentery) can be categorized as primary, secondary, or indeterminate. A primary mesenteropathy is defined as one that arises within the mesentery and progresses to involve other organs and systems. A secondary mesenteropathy originates outside the mesentery but progresses to involve the mesentery. Routes of mesenteric involvement include direct, haematological, neurological, and lymphatic invasion. Indeterminate mesenteropathies are conditions for which it is unclear as to whether they arise within or outwith the mesentery. With increasing investigation of abdominal and systemic diseases (in the context of the new model of the mesentery), it is likely their

Table 2 Mesenteropathies

Primary Mesenteropathies	Secondary Mesenteropathies
Internal herniation	Neoplasms
Malrotation	Pseudomyxoma
Volvulus	Lymphomatosis
Vascular	Carcinomatosis
Mesenteric cyst	Sarcomatosis
Hemangiomatosis	Peritoneal GIST
Crohn's disease	Omental cake
Neoplasms	Infectious
Peritoneal malignant mesothelioma	Tuberculosis
Desmoplastic small round cell tumor	Atypical mycobacteriosis
Inflammatory	Actinomycosis infection
Sclerosing mesenteritis	Hydatidosis
IgG4 related sclerosing mesenteritis	
Abdominal cocoon	

GIST, gastrointestinal stromal tumors; IgG4, immunoglobulin G4.

categorization will continue to develop. In this article, we adopted the latest categorization² (Table 2). In the following discussion, we describe the main mesenteropathies and relevant clinical-epidemiological concepts, highlighting the most important radiological findings that may aid in diagnosis.

Primary Mesenteropathies – In General

Internal Hernias

A hernia is defined as the abnormal protrusion of part or all of a viscus through a defect in the wall of the cavity that normally contains the viscus. Mesenteric defects can lead to internal hernias. Since the primary pathogenic abnormality is the mesenteric defect, these can be considered as a primary mesenteropathy.² Nonspecific symptoms are common and include nausea, vomiting, pain, and distension. Diagnosis can be challenging increasing the need for appropriate radiological imaging. Internal hernias related to congenital mesenteric defects include hernias through the foramen of Winslow, as well as the rare intersigmoid and transmesenteric hernias.^{25,26} Para-duodenal (Fig. 4) or para-cecal hernias are also rare and arise due to herniation beneath a reflection of the peritoneum.²⁷ Internal mesenteric-based hernias can also arise during the postoperative period following intestinal resection (if the mesenteric defect has not been closed) or following bariatric intestinal surgery when Peterson's mesenteric space has not been closed off – these types are considered secondary. Radiological features include sac-like appearance of the intestinal loops, clustering of bowel loops in an atypical location, and mesenteric vessel abnormalities (engorgement, crowding, twisting, and stretching of these vessels).^{25,26}

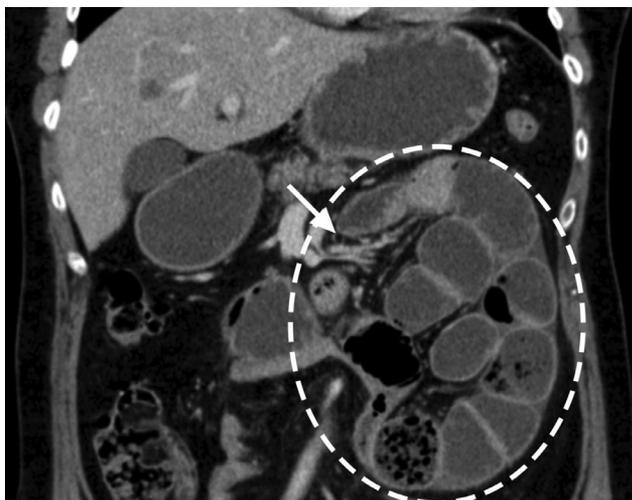


Figure 4 Paraduodenal hernia: Left internal paraduodenal hernia in a 69-year-old woman with diffuse abdominal pain, nausea, and vomiting. Coronal-enhanced CT scan: convergence of mesenteric vessels (arrow) and sac-like appearance (dotted circle).

Malrotation or Nonrotation

Mal- or nonrotation is the best understood when considered in the context of mesenteric continuity. During embryological development, coiling of the mesentery (and by definition the intestine) results in positioning of the right colon and mesentery to the right with the small intestine and mesentery positioned in the middle. Mal or nonrotation occurs when development stops at a point when the right colon and mesocolon are still in a central region of the abdomen, and have yet to progress to the right flank. As a result, the small intestine and mesentery are positioned to the right with the continuous right colon (and mesocolon) located towards the middle. The mesentery has an overall accordion-like conformation. The major issue with mal- or nonrotation is that with failure of the right colon and mesentery to adopt the right-sided position, the mesentery does not attach or anchor normally. Varying degrees of mal- or nonrotation, associated with mesenteric nonattachment occur (Fig. 5). This abnormal conformation is not directly pathogenic and many cases of mal- or nonrotation survive to adulthood when they are identified incidentally. However, failure of the right colon and mesentery to take up a position on the right means they do not attach, and the mesentery is free to rotate around the mesenteric pedicle.

In children, especially in the first year of life, bilious vomiting, abdominal distension, obstruction, or midgut volvulus may occur. Radiological findings in mal- or nonrotation include (1) positioning of the small intestine and mesentery in the right flank, (2) failure of the third part of the duodenum to cross the midline from right to left, (3) vascular displacement of the superior mesenteric vein (SMV) and superior mesenteric artery (SMA) (in most patients SMA and SMV have a vertical relationship or left-right inversion; Fig. 6), and (4) a spiral appearance of mesenteric vasculature that appears to converge on the SMA/SMV at the mesenteric root region.^{2,28,29}

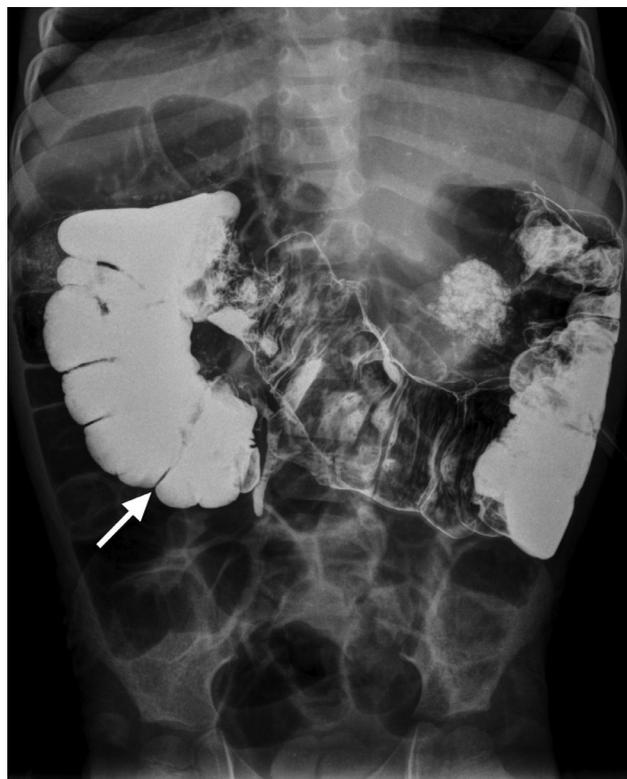


Figure 5 Incomplete mal or nonrotation: Intestinal transit study of a 4-year-old boy presenting with oral malformation and malnutrition. Supine frontal radiograph shows a cecum superomedially displaced (arrow) consistent with mesenteric nonattachment. This finding accompanies variable degrees of malrotation.

Volvulus

Like nonrotation, volvulus is a mesenteropathy characterized by twisting of nonattached mesentery (and hence intestine) around an abnormally narrow zone of mesenteric attachment.² In the past, volvulus was attributed to the “abnormal” persistence of a right and left mesocolon.⁶ Recognition of mesenteric continuity and the universal presence of right and left mesocolon, prompts reappraisal of our understanding of the pathobiology of volvulus. Volvulus arises when mesenteric attachment is inadequate. As a result, the mobile region of mesentery twists around a short region of attachment.^{2,13}

Volvulus is an important cause of bowel obstruction. Acute colonic volvulus accounts for approximately 10%–15% of large bowel obstruction and sigmoid volvulus for approximately 70% of volvulus, occurring mainly in the elderly. Of the cases of volvulus, 25% occur in the cecum. Volvulus of the hepatic or splenic flexures or transverse mesocolon/colon is rare, as these mesenteric regions are normally well attached. Clinical presentation, usually in the elderly, includes insidious symptoms of intestinal obstruction (Fig. 7). Radiological findings that indicate presence of a volvulus include marked distension of large bowel, “bird beak” sign, “whirl” sign, “coffee bean,” and inverted “U” sign (the latter 2 presented exclusively in sigmoid volvulus).^{2,29}



a



b

Figure 6 Complete mal or nonrotation: a. Coronal enhanced CT shows the colon located on the left side of the abdomen (arrow). The small bowel and its associated mesentery are positioned to the right. These are radiological findings seen in complete mal or nonrotation. In malrotation, the third part of the duodenum does not cross the midline from the right side to left. b. Axial enhanced CT shows the SMV (arrow) anterior to the SMA (arrowhead) unlike the normal state, in which the SMV is positioned to the right of the SMA (i.e. left-right inversion).

Mesenteric Ischemia

Mesenteric ischemia is a primary vascular disorder of mesenteric vasculature. There are 3 main causes: mesenteric arterial embolus and thrombus, mesenteric venous thrombus, and nonocclusive mesenteric ischemia.²

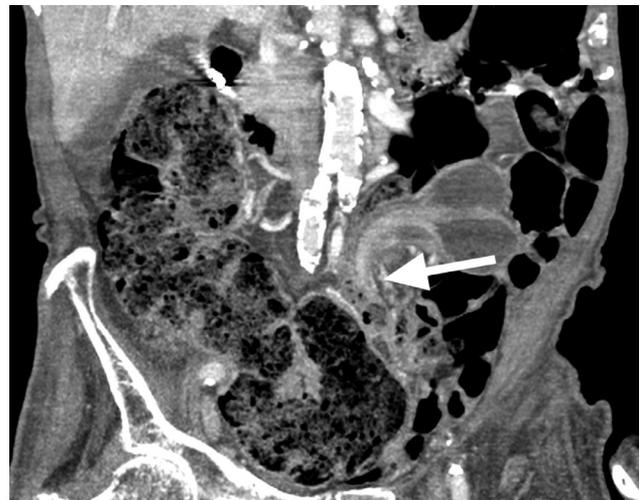


Figure 7 Sigmoid volvulus: Sigmoid volvulus in a 93-year-old man presenting with symptoms of constipation: enhanced-CT (venous phase) with maximum intensity projection (MIP) coronal reconstruction 4 mm demonstrating the point of intestinal occlusion (arrow).

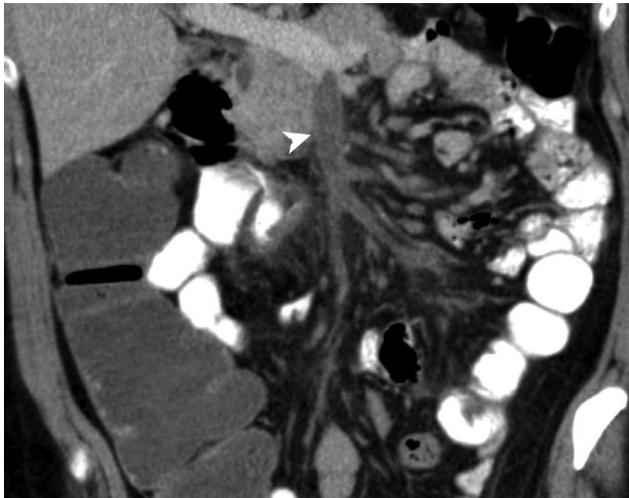
Arterial occlusion accounts for 60%-70% of cases of mesenteric ischemia. It often presents acutely with abdominal pain out of proportion with clinical findings. Progression of ischemia leads to multiple organ dysfunction. Venous occlusion (Fig. 8a and b) accounts for 5%-10% of cases. In these cases, symptoms (including diffuse abdominal pain and distension) are usually vague and worsen in a gradual manner. CT findings vary widely depending on cause and underlying pathophysiology. Arterial defects or SMA size greater than SMV are more often associated with arterial ischemia while venous defects and engorgement are more strongly associated with venous ischemia.³⁰⁻³²

Mesenteric Hematoma

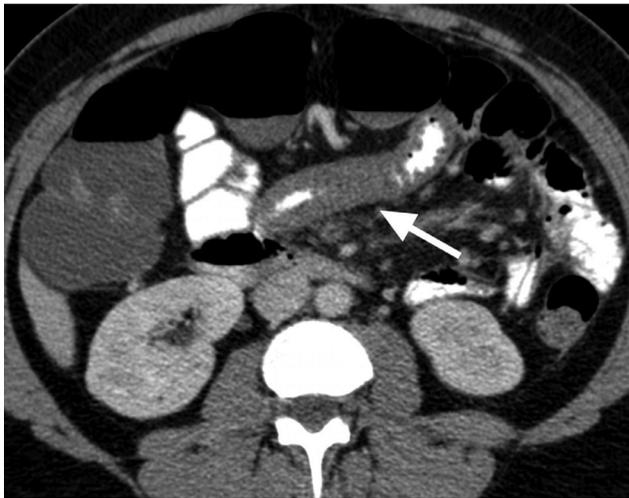
Spontaneous mesenteric haematoma (SMH) (Fig. 9) is a rare form of primary mesenteropathy. In order to diagnose SMH, it is first necessary to rule out other causes of mesenteric haematoma, including trauma, pancreatitis, or gastric ulcer. SMH can arise due to a pseudoaneurysm of the mesenteric vascular plexus. CT and MRI are the preferred diagnostic modalities, and angiography can be performed to confirm diagnosis and enable definitive therapy via embolization.³³

Mesenteric Cyst

Considered a rare primary mesenteropathy (Fig. 10a and b), with an incidence of 0.5-1: 100,000 admissions, mesenteric cysts occur mostly in the small intestinal or right mesocolic regions of the mesentery. The aetiology is unknown; however, mesenteric lymph node disorders may be related. Clinical presentation includes gradual increases in abdominal girth, chronic abdominal pain, or acute onset abdominal pain abdomen secondary to torsion, infection, or hemorrhage into the cyst itself. Imaging demonstrates cystic



a



b

Figure 8 Mesenteric ischemia: Mesenteric ischemia at venous phase and oral contrast-enhanced CT scan: (a) CT with MIP coronal reconstruction 4 mm shows acute SMV thrombosis (arrowhead). (b) Axial CT shows jejunum with wall thickening (arrow). MIP, maximum intensity projection; SMV, superior mesenteric vein.

mesenteric lesions with varying patterns of localization and wall thickness. The close relationship of this lesion with mesentery and exclusion of more prevalent conditions are key to diagnosis. The differential diagnosis is determined by regional anatomy and includes pancreatic pseudocyst, ovarian cyst, urachal cyst, hydrometrocolpos, and peritoneal hydatidosis.^{2,34}

Crohn's Disease

As explained earlier, both aetiology and pathobiology of Crohn's disease continue to be investigated. Increasing data support Crohn's disease being classified as a primary mesenteropathy, triggered by environmental elements.^{2,17} Crohn's disease is more common in northern Europe, North America, and Japan, compared with other geographic regions. It affects

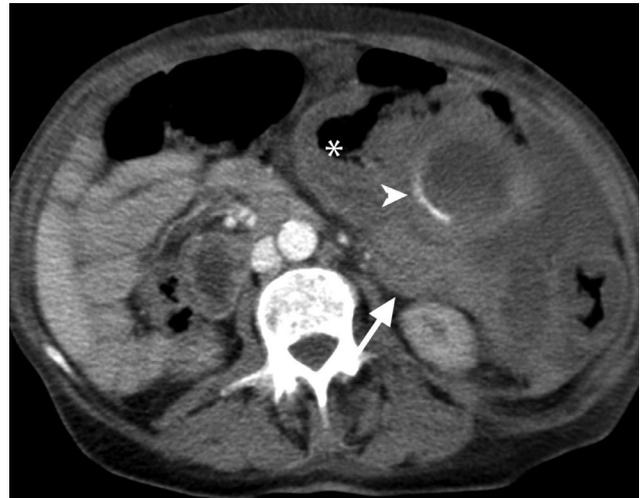


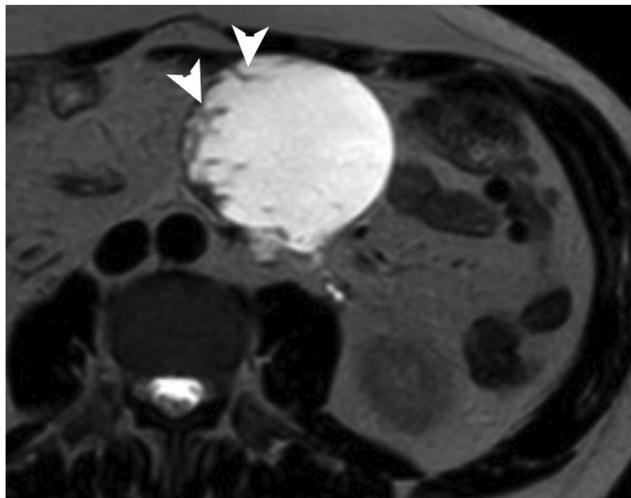
Figure 9 Spontaneous mesenteric haematoma: Axial CT venous phase with administration of oral contrast shows thickening with absent mural enhancement in a segment of transverse colon (*). Transverse colon is compressed by a hematoma (arrows) in the transverse mesocolon and active bleeding is present (arrowheads).

both sexes equally and has a peak incidence between 15 and 25 years of age.

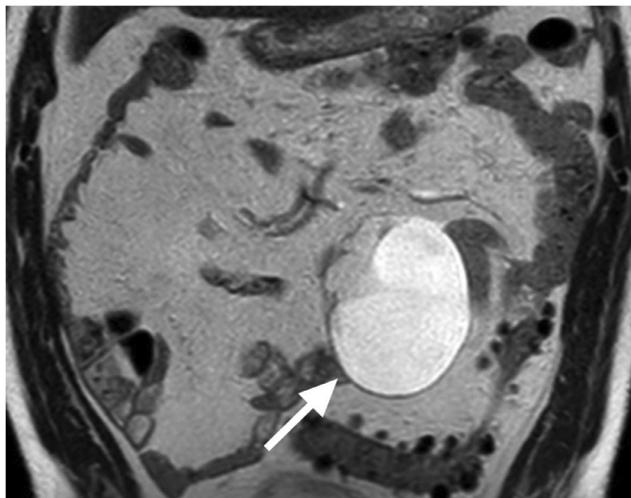
CT and MR enterography are the radiological modalities most often used to assess this disease. Radiological features can be categorized as¹ intestinal (thickened bowel wall with marked contrast enhancement mural stratification), hyperintensity of the bowel wall on MRI T2-weighted images, fibrofatty proliferation, and² mesenteric (pericolonic or perienteric) hypervascularity, known as “comb sign,” and lymph node enlargement. Extramural complications are common and include inflammatory changes, abscess, and fistula formation (Fig. 11a and b).³⁵

Primary Mesenteropathies — Neoplasms

Tumors of the mesentery are not uncommon.^{2,36} They usually arise from mesothelial cells, submesothelial mesenchymal cells, and uncommitted stem cells. However, since the origin of some tumors is poorly defined, some lesions may be difficult to classify. Mesenteric tumors can be classified based on the tissue of origin. Mesothelial tumors include: peritoneal malignant mesothelioma, well-differentiated papillary mesothelioma, multicystic mesothelioma, and adenomatoid tumor. Epithelial tumors include: primary peritoneal serous carcinoma, primary peritoneal serous borderline tumor, smooth muscle tumor, and leiomyomatosis peritonealis. Disseminated and tumors of uncertain origin include: desmoplastic small round cell tumor and solitary fibrous tumor.³⁶ Due to the extension of the theme, we highlight below some of the main primary mesenteric neoplasms



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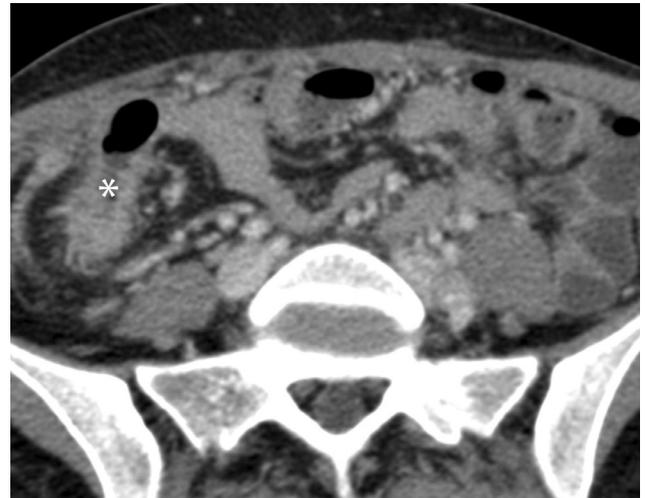


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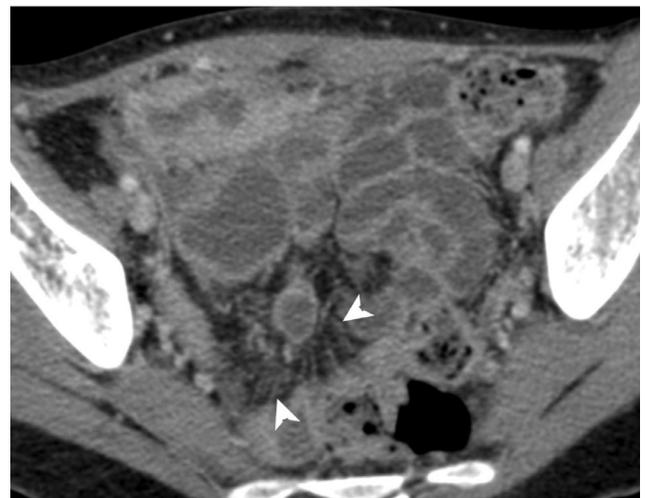
Figure 10 Mesenteric cyst: Homogeneous and nonenhancing cyst in mesentery near the mesenteric root. (a and b) Axial (a) and Coronal (b) T2-weighted MRI show a hyperintense and homogeneous cyst with fine septations (arrowheads in a). (b) Demonstrates its relationship with the small bowel in the coronal plane.

Peritoneal Malignant Mesothelioma

Malignant mesothelioma is a rare neoplasm originating from mesothelial cells or multipotential subserosal mesenchymal cells (which can be found in the pleura, peritoneum, pericardium, or tunica vaginalis of the testis). The peritoneal variant occurs in 6%-10% of malignant mesotheliomas. Mesotheliomas can be classified into 3 subtypes: diffuse malignant mesothelioma, well-differentiated papillary mesothelioma, and multicystic mesothelioma. It may present clinically with abdominal pain, abdominal distention, nausea, anorexia, and weight loss. Imaging findings differ according to subtype. Diffuse peritoneal malignant mesothelioma has 2 possible patterns: disseminated involvement of the peritoneal cavity and focal intraperitoneal masses (Fig. 12). Multicystic mesothelioma subtype presents as a multiseptated lesion that may have anatomical association with the uterus or ovaries. Finally, well-differentiated papillary mesothelioma subtype



a



b

Figure 11 Crohn's disease: (a and b) Axial CT venous phase shows (a) concentric parietal thickening of the ileal loops (*) with thickening of the mesofascial planes and vascular engorgement of the adjacent mesentery (b) (comb sign - arrowheads).

has few reported cases and therefore definitive imaging patterns have not been elucidated.³⁶

Desmoplastic Small Round Cell Tumor

This tumor is a rare primary mesenteric neoplasm of uncertain histological origin, occurring mainly in male adolescent and young adults. It is characterized by the presence of small, round, blue cells on histological evaluation. Radiological findings (Fig. 13) include peritoneal thickening, nodules, and heterogeneous mass lesions, often associated with punctate calcifications. It may also present as a single mass.³⁶

Hemangiomas

Vascular malformation or hemangiomas syndromes can be classified as primary mesenteropathies when arising in the



Figure 12 Diffuse peritoneal malignant mesothelioma: Axial non-enhanced CT shows fluid distributed throughout the abdominal cavity (*). Punctate nodular calcifications are apparent (arrowhead).

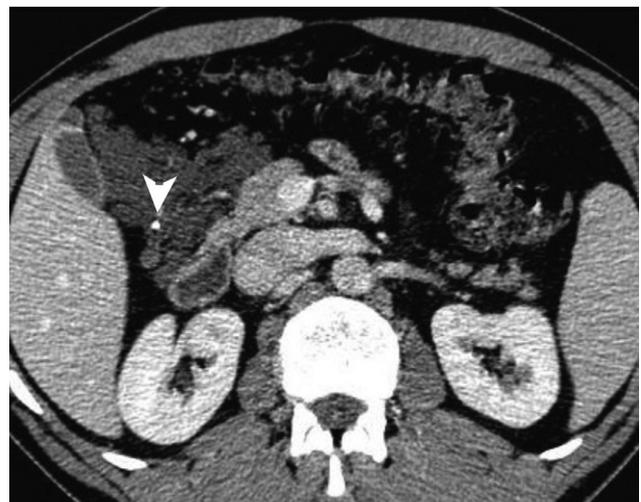


Figure 13 Desmoplastic small round cell tumor at enhanced CT with coronal reconstruction. There are multiple solid masses with heterogeneous enhancement (arrowheads) and malignant ascites (*).

mesentery. Hemangiomas are considered benign neoplasms characterized by abnormal proliferation of blood vessels and mesenchymal tissue.³⁷ They may be congenital or appear soon after birth and grow simultaneously to viscera.³⁸ Vascular malformations are congenital and similar to hemangiomas; they are composed of abnormal vascular channels lined with a single layer of dysplastic endothelium. They are named after the vascular element they most closely resemble: capillary, venous, and lymphatic malformations. When large or numerous, the term hemangiomas is applied. On unenhanced CT, hemangiomas (Fig. 14a and b) may appear as an ill-defined mass of similar attenuation to



a



b

Figure 14 Hemangiomas: (a) Enhanced CT with coronal reconstruction demonstrating an ill-defined mass of similar attenuation to muscle (arrow). (b) Axial-enhanced CT shows the same mass with a phlebolith (arrowhead).

muscle. CT may also show the presence of associated phleboliths.^{37,39}

Primary Mesenteropathies — Inflammatory Group

Primary inflammatory mesenteropathies include sclerosing mesenteritis (SM), IgG4-related SM,² and sclerosing encapsulating peritonitis (also known as abdominal cocoon).

SM — Mesenteric Panniculitis

SM is an uncommon pathology caused by chronic and idiopathic inflammation of mesenteric adipose tissue. It has 3 developmental stages. The first stage, mesenteric lipodystrophy, involves degeneration of mesenteric fat and is usually

asymptomatic. The second stage, mesenteric panniculitis (Fig. 15a), involves inflammatory changes, lymphatic distension, and early fibrosis. It may lead to vague abdominal symptoms. The third stage, known as retractile mesenteritis, is marked by pronounced fibrosis and foreshortening of the mesentery. It may present with abdominal pain or symptoms related to intestinal obstruction. There may also be symptoms related to intestinal ischemia.

Radiological findings differ according to stage: early stage SM manifests as a subtle increased attenuation in the mesentery. The latter can progress to manifest radiologically as a soft tissue mass. Fibrotic changes are pronounced in final stages. SM appears to preferentially involve the mesenteric root region (where the upper region of mesentery narrows and continues distally as the lower region of the mesentery).

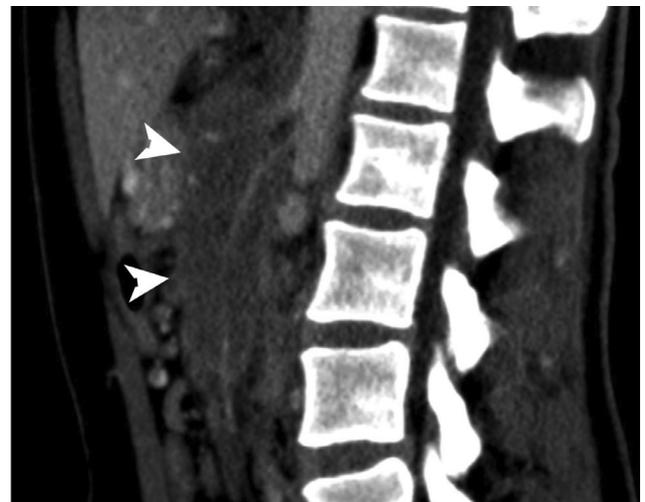
Given that the SMV and SMA are located here, it frequently manifests as a “fat halo” – the fat ring sign – around these vessels. This radiological sign is useful in differentiating it from other inflammatory or neoplastic disorders of the mesentery.^{2,40,41}

SM – IgG4 Related

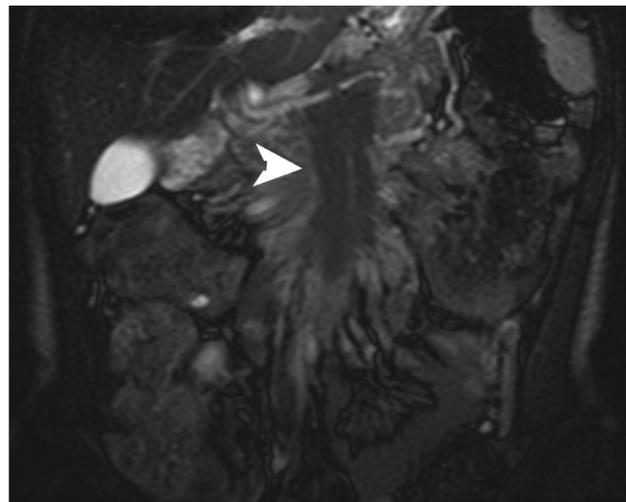
IgG4-related disease (IgG4-RD) is an inflammatory and fibrosing disease of unknown etiology. SM is one of many manifestations of IgG4-RD. This relationship is important as it reflects the fact that many apparently systemic conditions secondarily affect the mesentery. Findings at radiological investigation are nonspecific, with similar features to those seen in SM (Fig. 15b and c). Histopathological findings are



a



b



c

Figure 15 Sclerosing mesenteritis: (a) Stage 2 sclerosing mesenteritis; axial nonenhanced CT shows subtle increased attenuation within the mesentery (arrowheads). (b and c) IgG4-related sclerosing mesenteritis presented in its final stage, also known as retractile mesenteritis. (b) Sagittal-enhanced CT and (c) Coronal T2-weighted MRI shows findings suggestive of fibrosis (ie, infiltrative, heterogeneous, and enhancing tissue with retractable effect involving mesenteric root (arrows)).

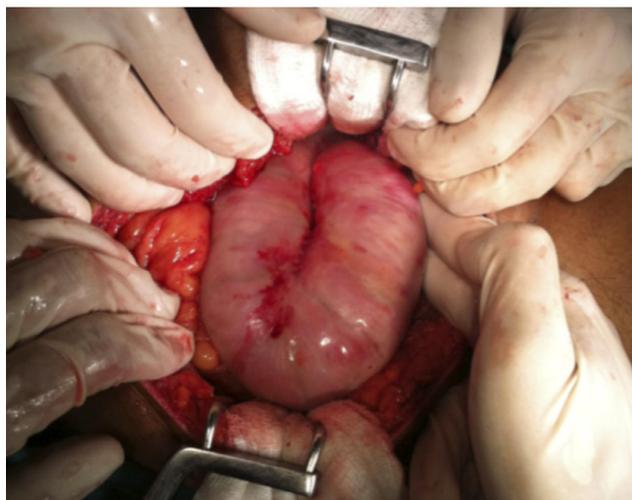
distinct, however, and are characterized by lympho-plasmacytic infiltrate and storiform fibrosis. IgG4-RD is usually responsive to corticosteroid therapy.^{2,41,42}

Abdominal Cocoon

Abdominal cocoon syndrome (also known as sclerosing encapsulating peritonitis) can be primary or secondary. The secondary form arises from multiple previous surgeries, peritoneal dialysis, tuberculosis, sarcoidosis, or generalized peritonitis. The primary form is idiopathic and can be considered a primary mesenteropathy arising from the mesothelial lining of the mesentery. At surgery, loops of small intestine are wrapped in a thickened layer of neoperitoneum that is contiguous with the surface of the mesentery. Radiological features reflect this arrangement and include the presence of a thin membrane that does not enhance, and



a



b

Figure 16 Abdominal cocoon: gastric and duodenal distention due to obstruction in the level of duodenojejunal flexure. (a) Axial-enhanced CT shows a cluster of jejunal intestinal loops surrounded by a thin membrane, creating a cocoon-like appearance (arrows). (b) Intraoperative findings.

involving a “conglomerate” of intestinal loops not unlike that observed in internal herniation (Fig. 16a and b).^{43,44}

Secondary Mesenteropathies

A secondary mesenteropathy originates outside the mesentery, but as the disease progresses, the mesentery becomes involved (either through direct spread from a contiguous organ) or via alternative routes of spread.² We focus here on secondary neoplastic and infectious mesenteropathies. However, secondary mesenteropathies are not limited to these categories. Secondary mesenteropathies are currently under investigation and it is possible that many diseases may be added to this classification in the near future.

Secondary Neoplasms

Lymphomatosis, Carcinomatosis and Sarcomatosis

Lymphomatosis, carcinomatosis, and sarcomatosis are neoplastic conditions that secondarily affect the mesentery and present with overlapping characteristics. However, the pathogenic origin and particular characteristics may be useful in differentiating these conditions. For example, in carcinomatosis, peritoneal and omental dissemination, marked ascites, and lymphadenopathy around the neoplastic origin are common features. Primary tumor sites include the ovary, colon, and stomach. In lymphomatosis, omental caking with homogeneous bulky masses are common. Often, this is accompanied by diffusely distributed enlarged lymph nodes. Sarcomatosis may present as a bulky hypervascular and heterogeneous mass. There may be hemoperitoneum, but lymph node enlargement is rarely observed.⁴⁵

Lymphomatosis

Peritoneal lymphomatosis, defined as the intraperitoneal spread of lymphoma, is a rare manifestation of non-Hodgkin lymphoma. Radiological findings include bulky homogeneous masses, peritoneal thickening, and diffuse lymphadenopathy (Fig. 17a and b). The peritoneum and mesentery may be diffusely infiltrated. The presence of small omental nodules with delicate infiltration of omental fat creates a characteristic “smudged” appearance. Mesenteric infiltration often follows a stellate distribution on imaging.⁴⁵

Carcinomatosis

Carcinomatosis arises from intraperitoneal dissemination (called seeding) of a nonperitoneal tumor. The most common radiographic findings (Fig. 18), ascites (free or loculated), greater omentum involvement (“omental cake”), invasion of the mesentery, increased mesenteric fat density, mesenteric mass or nodules, and tumor implants in the peritoneal serous membrane. The differential diagnosis includes other primary and secondary mesenteric malignancies, as well as infections with mesenteric involvement.⁴⁶



a



b

Figure 17 Lymphomatosis: (a) Axial-enhanced CT shows a bulky homogeneous intraperitoneal mass (arrow), associated with free fluid. (b) Axial-enhanced CT shows another type of lymphomatous appearance, with prominent straightened vessels secondary to lymphomatous infiltration of the mesentery causing a “stellate appearance” (arrowheads). There is also homogeneous soft tissue in the greater omentum, known as omental-caking (*).

Sarcomatosis

Sarcomatosis often accompanies development of intra-abdominal sarcomas. The most common of these connective tissue tumors are gastrointestinal stromal tumors (GISTs), liposarcomas, and leiomyosarcomas. Intra-abdominal sarcoma may arise due to metastatic spread from extremity sarcoma. Sarcomas are usually spherical with considerable deformation of contiguous structures (Fig. 19a and b). They are often hypervascular and ascites is not an associated feature.⁴⁷ There are numerous reports of sarcomas of the mesentery. They present considerable challenges in terms of diagnosis and treatment and have a high risk of local recurrence following surgical excision.



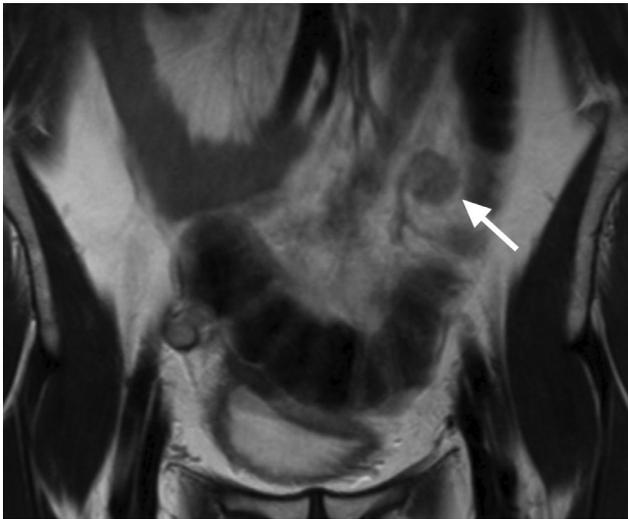
Figure 18 Carcinomatosis: Sagittal-enhanced CT shows peritoneal thickening (arrowhead) and marked ascites (*).

Pseudomyxoma

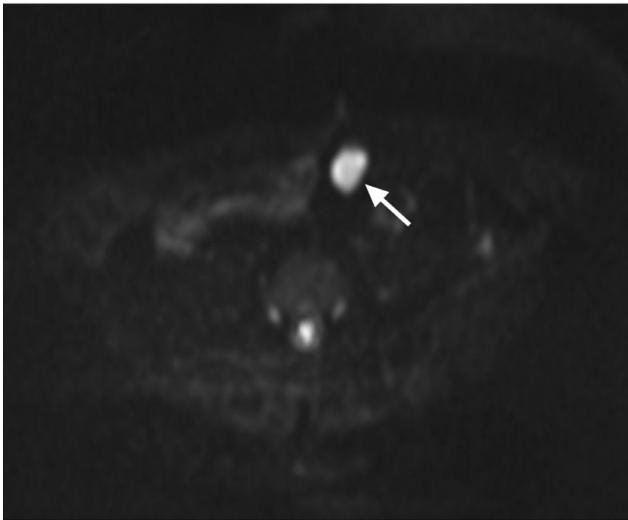
Classical pseudomyxoma peritonei arises from low-grade mucinous carcinomas that mainly originate in the appendix or ovaries. The primary lesion penetrates or ruptures into the peritoneal cavity where mucinous secretions continue to accumulate, leading to “jelly belly.” Patients present with a profound increase in abdominal girth and associated weight loss. Ultrasound identifies echogenic ascites, suggesting a gelatinous consistency. Mucinous ascites usually has a low attenuation in CT. Scalloping (Fig. 20) of the visceral (including mesenteric) surface is an important feature that refers to indentations in surface mesothelium and helps differentiate pseudomyxoma peritonei from simple ascites.⁴⁸

Peritoneal gastrointestinal stromal tumor (GIST)

GIST is the group of smooth muscle mesenchymal tumors with variable malignant potential. Metastases from GIST commonly occur to the liver and peritoneal cavity via hematogenous spread and peritoneal seeding (ie, the so-called “Peritoneal GIST”; Fig. 21). Clinical findings vary depending on the location and tumor size. Gastric, small bowel, and colonic lesions often present with bleeding, but may also be associated with abdominal pain, nausea, and vomiting. Peritoneal GIST is most often seen in large masses that are often necrotic with heterogeneous enhancement and less commonly present with diffuse hypervascular omental and peritoneal caking. Necrosis within the masses may lead to fistulization and, owing to tumor hypervascularization, may present with gastrointestinal bleeding and hemoperitoneum. In some cases of



a



b

Figure 19 Peritoneal sarcomatosis: 38-year-old female presenting with peritoneal sarcomatosis. (a and b) Coronal T2-weighted MRI (a) and axial diffusion weighted imaging (DWI) (b) demonstrating nodular peritoneal implants from sarcoma (arrows).

intense peritoneal dissemination, the primary site of GIST cannot be identified.^{47,49,50}

Secondary Mesenteropathies — Infectious

Many infectious disorders secondarily affect the mesentery. In this section, we highlight some important secondary mesenteropathies arising due to infection.

Tuberculosis

Tuberculosis is responsible for about 1.7 million deaths annually. The incidence is increasing due in part to HIV infection and use of immunosuppressive drugs. Peritoneal tuberculosis is the most common presentation of abdominal

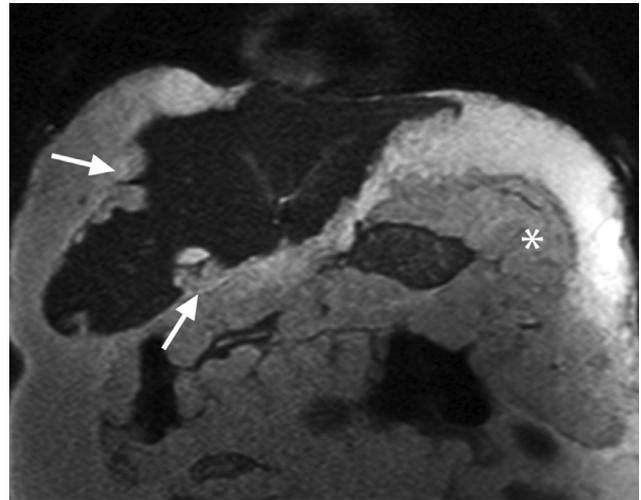


Figure 20 Pseudomyxoma peritonei: Coronal T2-weighted MRI showing hyperintense cystic implants along the surfaces of the liver (arrows) – presence of scalloping of the visceral surfaces- and at the small and large bowel mesentery (*).

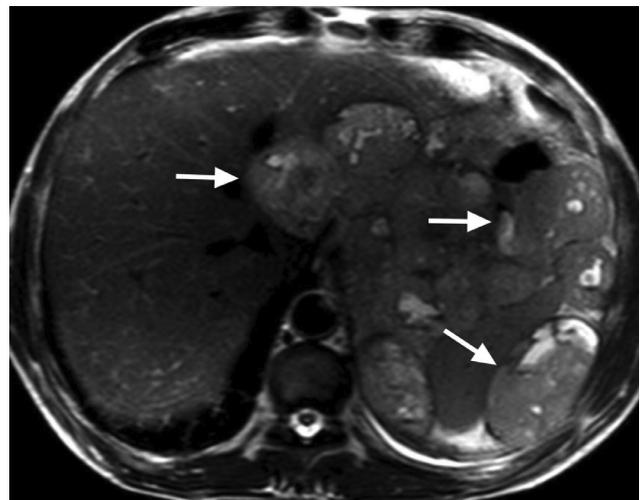
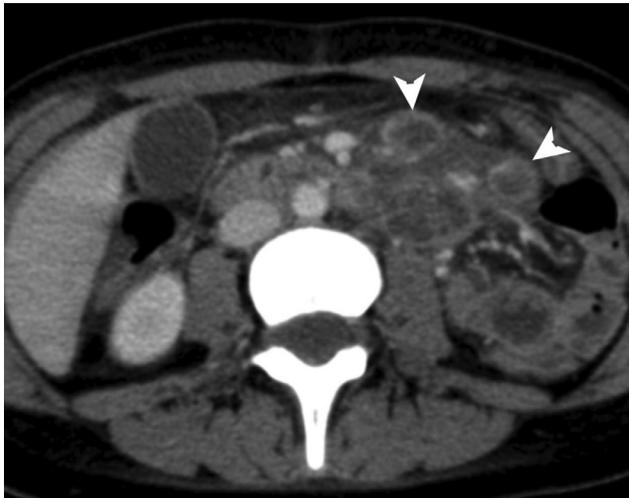
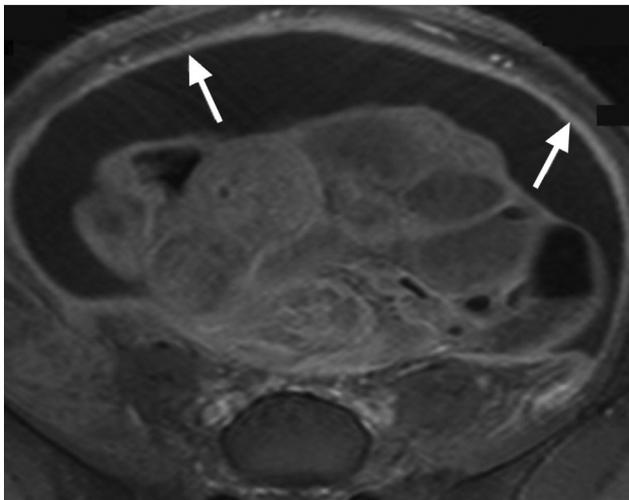


Figure 21 Peritoneal GIST: Axial T2-weighted MRI demonstrating multiple nodular and heterogeneous peritoneal implants (arrows) arising from a gastric GIST.

tuberculosis and may involve the peritoneum, mesentery, and omentum. It is classically classified into 3 types (Fig. 22a and b): dry, wet, and fibrous. The dry type manifests mainly with peritoneal and mesenteric thickening secondary to the presence of caseous nodules, lymph node enlargement, and fibrinous adhesions. The wet type is characterized by free or loculated ascites that may be associated with smooth peritoneal thickening. Finally, the fibrous type is highly varied in appearance as it often resembles peritoneal carcinomatosis. It is usually characterized by presence of intestinal thickening, as well as with formation of matted regions of mesentery and loops of intestine (not unlike that which can arise in Crohn's disease). Some imaging characteristics that may help in this diagnosis include smooth peritoneal thickening with marked enhancement after intravenous contrast injection and



a



b

Figure 22 Tuberculosis: A 20-year-old woman presenting with the dry type of mesenteric tuberculosis (a) Axial-enhanced CT venous phase shows multiple enlarged lymph nodes with central necrosis (arrowheads). Wet-type mesenteric tuberculosis: (b) Axial T2-weighted MRI in a 27-year-old woman showing wet-type tuberculosis with substantial ascites and diffuse, smooth, and regular peritoneal thickening (arrows).

mesenteric lymph node enlargement with areas of central necrosis.⁵¹

Atypical Mycobacteriosis

Mycobacterium avium-intracellulare complex consists of 2 species of acid-fast mycobacteria: *Mycobacterium avium* and *Mycobacterium intracellulare*. Collectively, they are referred to as MACs. MAC-related infections usually arise in immunocompromised hosts. In the developed world, extra-pulmonary MAC infection is one of the most frequent opportunistic infections to develop in patients with acquired immunodeficiency syndrome. Clinical presentation may include weight loss, abdominal pain, vomiting, fever, night sweats, malabsorption, and diarrhoea. Barium studies may reveal



Figure 23 Mycobacteriosis: Axial-enhanced CT (venous phase) from a 28-year-old man with AIDS-related abdominal mycobacteriosis. Image demonstrates involvement of mesenteric lymph nodes with central necrosis (arrowheads) and small bowel diffusely thickened (arrows).

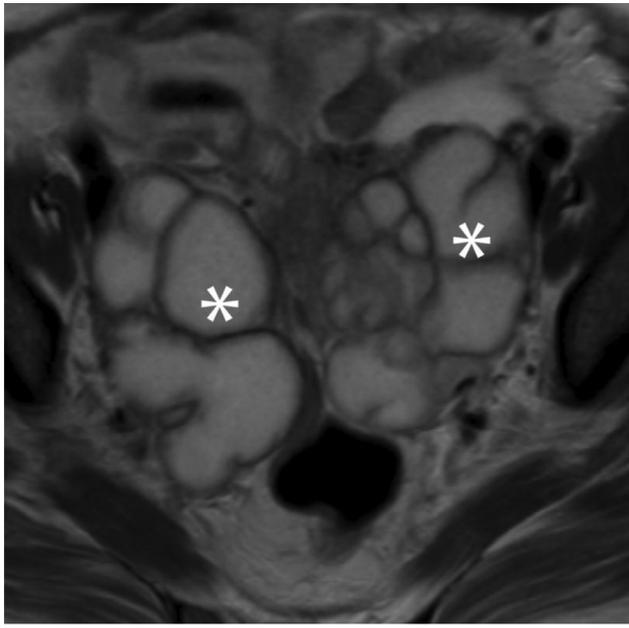
diffusely thickened small bowel with irregular mucosal folds and nodularities. At CT, the small bowel may appear segmentally or diffusely thickened with mucosal hyperenhancement. Mesenteric nodes are often enlarged and increased in number. In MAC-infections, mesenteric nodes are usually smaller than those observed in tuberculosis; however, similar to tuberculous involvement, there may be lymph nodes with central necrosis (Fig. 23).⁵²

Actinomycosis Infection

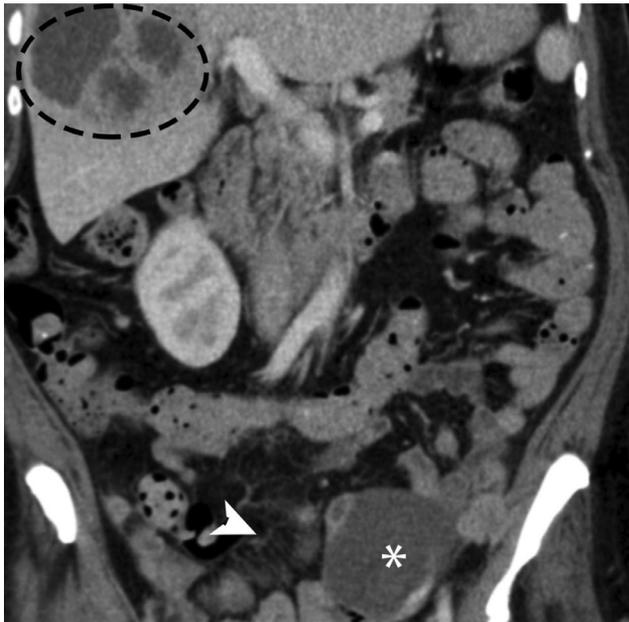
Mesenteric dissemination of actinomycosis is associated with intra-uterine device usage. It is also described following perforation of abdominal viscera by inflammatory or neoplastic disease, surgery, or trauma. Abdominopelvic actinomycosis infection accounts for 20% of all manifestations of this condition. Symptoms include lower abdominal pain, cachexia, fever, and may be accompanied by leukocytosis on laboratory investigations. Disease progression often leads to tubo-ovarian abscess formation. Intra-abdominal dissemination (Fig. 24a and b) is usually via direct spread along mesenteric and peritoneal surfaces with resultant formation of abscesses, sinus tracts, and fistulas. Hematogenous spread is also possible. The usual CT findings include a large mass (adjacent to the involved bowel) that is predominantly cystic but may be solid with marked contrast enhancement.^{53,54}

Hydatidosis

Hydatid disease is a worldwide zoonosis caused by *Echinococcus granulosus* and *Echinococcus multilocularis*. Peritoneal hydatidosis is usually secondary to liver disease, occurring in approximately 13% of cases, and is usually only detected when the cysts are large enough to produce symptoms. Clinical presentation is variable and is dependent on the location of the disease. In the liver, the site most affected by the disease is the



a



b

Figure 24 Actinomycosis: (a) Axial T2-weighted MRI from a young female with bilateral tubo-ovarian abscesses (and intra-abdominal spread) after IUD use. (*). (b) Coronal-enhanced CT (venous phase) shows abdominal spread of actinomycosis. There is a hepatic abscess (dotted circle), a pelvic abscess, (*) and increased density of adjacent mesentery (arrowhead).

right lobe. Image findings depend on stage of disease: unilocular cyst, containing daughter vesicles, containing daughter cysts, partially calcified, or completely calcified (dead). Abdominal and pelvic hydatid cysts arise from primary liver cysts (Fig. 25). Peritoneal surfaces provide an excellent bed for implantation and growth of these secondary cysts. Cysts may be multiple and located anywhere in the peritoneal cavity. At

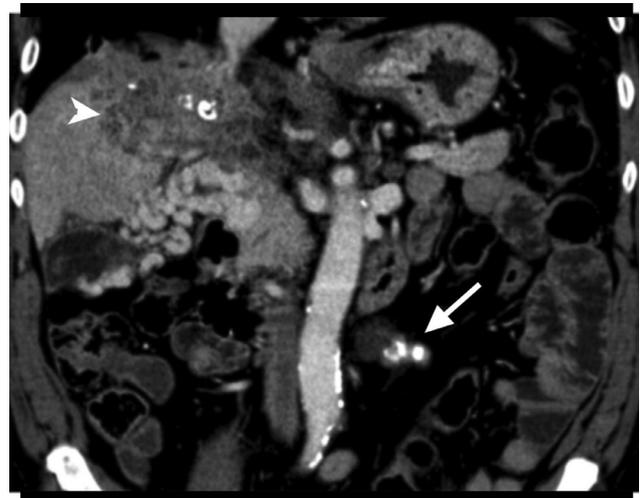


Figure 25 Hydatidosis: A 68-year-old man from an indigenous village with nonspecific symptoms. Coronal-enhanced CT venous phase shows calcified hepatic cysts (arrowhead) and abdominal cysts with parietal calcifications (arrow).

imaging, findings are similar to those found in hepatic disease. Peritoneal hydatid disease may grow and occupy the entire peritoneal cavity, simulating a multiloculated mass. Cyst fluid usually has water attenuation. Hydatid disease may have wall or internal septa. The cyst wall typically has high attenuation with unenhanced CT, even without associated calcification. Detachment of the laminated membrane from the pericyst can be visualized as linear areas of increased attenuation within the cyst. Daughter vesicles manifest as round structures located peripherally within the mother cyst.⁵⁵

Conclusion

The mesentery gained a new approach based on anatomical and physiological properties. Recent advancements in our understanding of mesenteric anatomy demonstrate that abdominal digestive organs are linked across a continuous mesentery and this anatomical organization is held in position (in part) by a peritoneal covering.

The clarification of mesenteric anatomy prompts a reorientation of its approach. In keeping with this advancement, many abdominal diseases can be categorized as primarily arising within the mesentery or secondarily progressing to involve the mesentery, with major implications for the diagnosis, treatment, and surveillance of these.

Recognition of mesenteric continuity and its possibility of acknowledgment as a new organ, leads to a novel radiological approach of the abdomen in general. With a mesenteric-based approach, the radiologist can systematically generate a composite anatomical picture of the abdomen that accurately correlates with findings in normal and diseased states. The mesenteric-based approach can greatly support the diagnosis and treatment of many abdominal disorders and is a major knowledge of abdominal radiology.

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