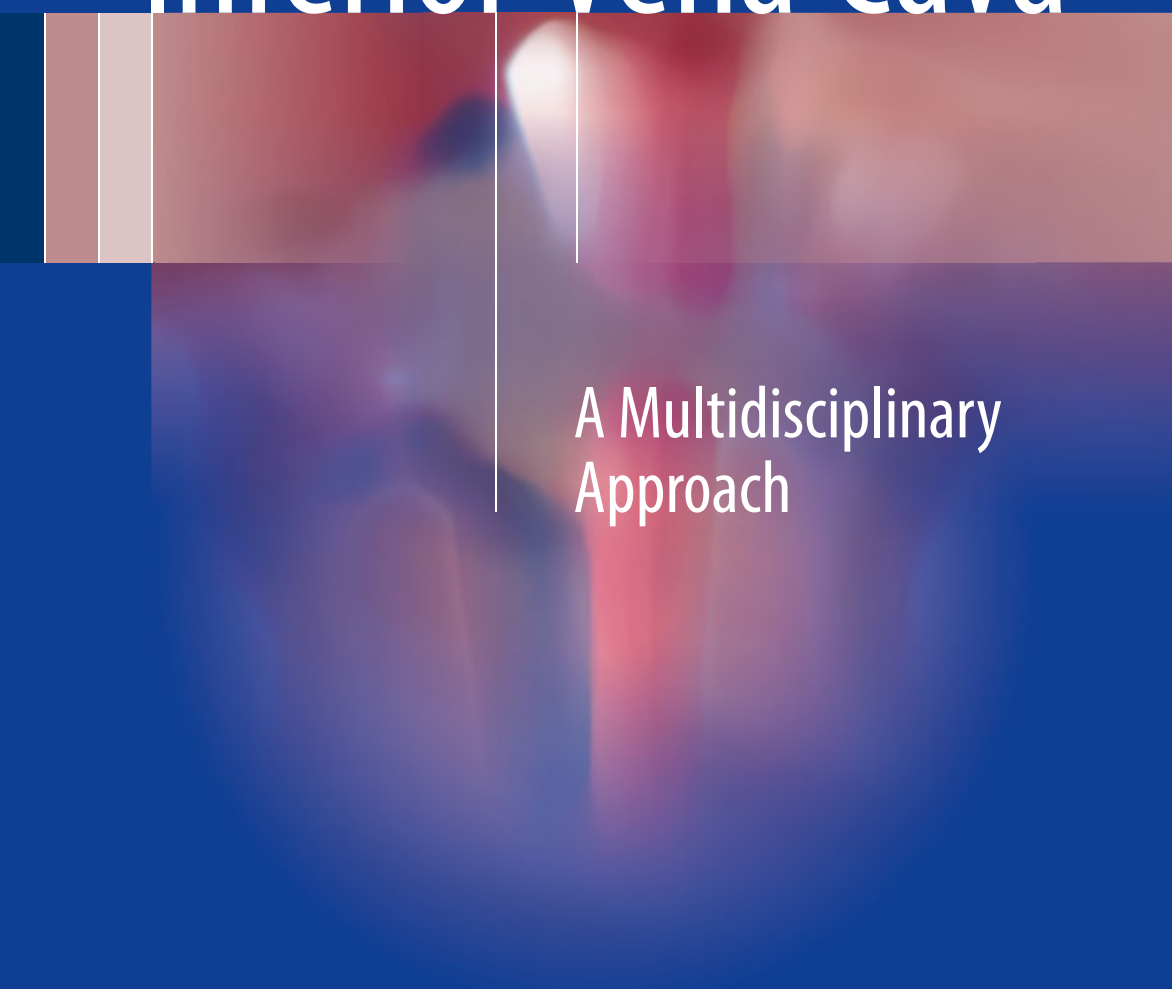
Daniel Azoulay · Chetana Lim
Chady Salloum *Editors*

Surgery of the Inferior Vena Cava

A Multidisciplinary Approach



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Editors

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In Memoriam

This book is dedicated in memory of Tom Starzl who passed away March 04 2017. He will remain our Hero.

Daniel Azoulay

Foreword by Thomas E. Starzl

When Professor Daniel Azoulay requested me to write a Foreword for his book on inferior vena cava (IVC) surgery, I responded that "… I have never seen a book dealing primarily (or solely) with the inferior vena cava (IVC). In my opinion, one is justified. If I read your email correctly, that is what you seem to have accomplished …" His answer was "You are right: there is no book in English devoted exclusively to the inferior vena cava (IVC)… There is one in French, now more than 25 years old, edited by Edouard Kieffer, consisting of presentations at a special meeting of vascular surgeons."

After seeing the list of distinguished chapter authors, I concluded that this book would have a bright future. However, the quality of such multiauthor texts is ultimately dependent on the editor, here Daniel Azoulay. I first met him in 1989 while visiting his mentor Henri Bismuth in Villejuif, France. As a trained thoracic surgeon, Azoulay's activities were at first limited to the resection of lung metastases. Ten years later, he arrived in Pittsburgh with Professor Bismuth to present their seminal experience with split liver transplantation. Our next rendezvous was in October 2008 when we had dinner together at the 20th year liver transplant celebration of The Royal Free Hospital in London. His transition to "liver surgeon" was now complete.

By then, Azoulay's achievements were sufficient to make him a prime candidate for the then vacant position of leader of the Pittsburgh Transplantation Institute. Instead, he stayed in France where he ultimately became the Departmental Chief of two University surgical units at the Henri-Mondor Hospital complex in the Paris suburb of Creteil. Over the years, and while taking on an increasingly heavy load of academic duties, he has personally performed more than 1500 liver resections and an equivalent number of liver transplantations while participating in the care of more than 5000 patients in each category. Observations from this experience have been recorded in more than 650 publications that have been cited nearly 13,000 times (Institute for Scientific Information [ISI], Philadelphia).

All of the experience has involved the IVC in one way or the other, uniquely qualifying him as both contributor to and editor of this book. This book addresses almost all current topics of the IVC, ranging from surgical anatomy, IVC anomalies, imaging and radiological assessment, control of hemodynamics during surgery,

invasion of every type of malignancy into IVC, use of vena cava filters, and the contributions each to the other, of liver transplantation and nontransplant hepatic surgery. This text will be of interest to surgeons (hepatobiliary, vascular, and digestive) and urologists, as well as radiologists and anesthesiologists. I recommend reading it thoroughly and referring to it if problems with IVC are encountered or anticipated.

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Foreword by Eduardo Barroso

My friendship with Daniel Azoulay goes back to his journey at Paul Brousse as one of Henri Bismuth's brightest surgeons. When he requested me to write a small Foreword for this book, I was flattered as I consider him an outstanding innovating surgeon.

The new paradigm of precision surgery summarizes the basic needs for the correct practice of the so-called subspecialties of abdominal surgery. Of these basic needs, I cannot emphasize enough the absolute importance of a multidisciplinary approach and the creation of true referral centers.

The revolutionary idea of moving towards a super-specialization in abdominal surgery becomes now brilliantly apparent in this book dedicated exclusively to the surgery of the inferior vena cava (IVC).

After carefully reading this work, the need of a true multidisciplinary approach becomes evident. This includes the diagnostic and staging phases, imaging with several stages of sophistication, the role of oncology in the definition of a global therapeutic strategy and, of course, the surgical procedure, and the fundamental role of surgeons and anesthesiologists.

As this work is dedicated to surgery of the IVC and not only the diseases of the vena cava, it is no wonder that there is a significant predominance of diseases of other organs and systems, which despite not having origin in the IVC, will demand more or less complex surgical approaches to this vein. This culminates, most of the times, with the need of extensive venous resections associated with surgical procedures in other abdominal organs.

The level of difficulty of the approach to the IVC is not the same from its origin up to the renal veins, in its course above the renal veins to the diaphragm, and especially in its retrohepatic course. Above the liver and up to the right atrium, its approach and eventual resection may be the most complex.

The primary leiomyosarcoma of the IVC is the only intrinsic disease of the vena cava addressed by the authors. The difficulty in its resection will depend on its location. This is also true for the approach of the retroperitoneal tumors, which may invade the IVC on several levels.

The tumors of the right kidney with extensive tumoral thrombosis, sometimes up to the right atrium, are easily approachable with the collaboration of urologists and hepatic surgeons, especially surgeons with expertise in transplantation. Obviously only transplant surgeons can perform surgery of the IVC in association to liver

resection or to transplantation whether in cadaveric donor (classic or piggyback) or living donor.

The authors also approach the state of the art regarding IVC filters in the prevention of pulmonary embolism.

I believe it was not the authors' intention to support the creation of a new subspecialty related to the surgery of the IVC. This work emphasizes the need of a multidisciplinary approach involving other specialties in the diagnosis and staging of diseases that might involve surgical resections of the IVC. In this setting, experienced radiologists, along with a wide variety of imaging methods, are pivotal. Oncologists will help define, along with the use of new drugs, the survival benefit of such a radical strategy.

The authors recognize another multidisciplinary concept, which is the collaboration between surgeons, with important expertise in several areas of abdominal surgery, and anesthesiologists used to the management of IVC clamping and the eventual last resort need of extra-corporeal bypass.

As the majority of IVC surgery is performed in the segments above the renal veins, hepatobiliary and transplant surgeons have a clear advantage when dealing with these cases.

Daniel Azoulay, by being editor and author of this work, and the quality of the people he chose to co-work with him, guarantee this book to be very useful for the majority of abdominal general surgeons, as they must clearly know their competences and limitations when treating their patients.

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Foreword by Masatoshi Makuuchi

Combined resection of the liver and inferior vena cava (IVC) for hepatic malignancy has traditionally been considered a contraindication to resection for advanced tumors of the liver because the surgical risks are high and the long-term prognosis is poor.

IVC runs through the liver and is circumferentially surrounded by the liver except on its posterior aspect. I always explain to my students that when we liken IVC to women's body, the liver is a bra and the ligament is a bra hook. Its dissection from the liver requires a high degree of skill and extensive training. Even today, after 36 years of experience of hepatectomy, I still feel some tension every time I try to separate the IVC from the liver or the tumor.

The joint part of IVC and three major hepatic veins carries risk of serious hemorrhage in liver resection. Control of blood loss is the fundamental and most crucial for safe operation.

IVC control is processed by dissection and taping of the inferior and middle right hepatic veins, ligation and division of the IVC ligament, and dissection and taping of right hepatic vein and middle and left hepatic venous trunk from left side after division of the ductus Arantius. After these processing steps, the liver is divided under the intermittent occlusion, the IVC is treated by the Pringle maneuver, clamping diagonally at the cranial side of the renal vein at the lower part of the liver, then clamping the upper part of the inferior vena cava. By this way, the liver and IVC are completely blocked and bloodless area is created. All preparations are made for safe surgery.

By these ways, the tumor with the liver and the invaded IVC wall is removed. The defect of IVC is sutured directly or replaced by the autovenous wall or cryopreserved vein, which should prepared before division of the IVC wall.

Daniel Azoulay is an outstanding surgeon and is worthy for a "right-hand man" of Henri Bismuth. After the age of 30, he spent most of his time in the Hepato-Biliary Center at the Paul Brousse Hospital in Villejuif – an innovative, dedicated liver disease center headed by Henri Bismuth. This remarkable book reflects the experience in hepatic and biliary surgery compiled at the Center over nearly a quarter of a century.

This book addresses almost all current topics in IVC surgery ranging from surgical anatomy, imaging and radiological assessment, control of hemodynamics during surgery, invasion of every type of malignancy into IVC, juxtahepatic vena cava,

liver transplantation, and vena cava filter. The authors and editors should be congratulated for gathering a wealth of knowledge in this book that updates the state-of-the-art surgery.

It will be of a great interest to surgeons (hepatobiliary, vascular, and digestive) and urologists, as well as radiologists and anesthesiologists. I would like to recommend reading it thoroughly and referring to it each time they encounter a problem of IVC.

As such, the nightmare of IVC will soon be over.

Masatoshi Makuuchi, MD, PhD, FACS (Hon)
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Imaging and Radiological Assessment of the Inferior Vena Cava

1

M. Chiaradia, F. Legou, J. Arfi-Rouche, V. Tacher, H. Kobeiter, F. Pigneur, A. Rahmouni, and A. Luciani

1.1 Introduction

The inferior vena cava (IVC) is the main vein of the human body, formed by the confluence of the left and right common iliac veins. It ascends in the retroperitoneum to the right of the aorta and exits the abdomen through the diaphragmatic hiatus to join the right atrium. It drains the left and right renal veins, the lumbar veins, the right adrenal vein, the right gonadal vein, and the hepatic veins. The azygos venous system connects to the IVC (directly or through the renal veins). The IVC has four segments: the hepatic, suprarenal, renal, and infrarenal segments [1].

Formation of the IVC is the result of anastomoses and regression of embryonic veins including the vitelline vein and paired posterior cardinal, supracardinal, and subcardinal veins. The hepatic segment is composed of the vitelline vein, the suprarenal segment is composed of a segment of the right subcardinal vein, and the renal segment is formed by the anastomosis between the right subcardinal and the right supracardinal veins; a part of the supracardinal vein constitutes the infrarenal segment [2].

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Knowledge of the IVC disease is primordial before surgery to avoid serious complications. This chapter will focus on the imaging techniques, the main diagnostic features, and the interventional radiology of IVC disease.

1.2 IVC Imaging Techniques

Different imaging techniques are available for IVC assessment—ultrasound (US), multi-detector computed tomography (MDCT), and magnetic resonance imaging (MRI)—and conventional venography can also be used [3].

1.2.1 Conventional Venography

Conventional venography is the historical gold standard for IVC imaging. The main limitation of this modality is its invasiveness and the use of a high quantity of iodine contrast agent. It is performed using a pigtail catheter positioned just below the common iliac vein confluence. It has been replaced by noninvasive imaging techniques, MDCT and MRI. The advantages of conventional venography are multiple: good spatial resolution, the possibility to analyze the flow, and collateral pathway visualization.

1.2.2 Ultrasound

Evaluation of the IVC with ultrasound is widely available. The suprarenal portion of the IVC, especially the retro-hepatic portion, is most of the time perfectly analyzed. The main advantage of US exploration is the possibility to combine Doppler assessment, which provides an estimate of the direction and speed of the blood flow within the IVC. However, the infrarenal portion of the IVC is imperfectly seen because of bowel gas interposition and depth of the IVC in the abdomen especially in obese patients. Furthermore, vessel reconstructions are not possible on US. CT and MR imaging are hence usually required for staging and surgical treatment planning.

1.2.3 Multi-Detector Computed Tomography (MDCT)

Imaging of the IVC is most of the time performed on MDCT because of its availability. Routine abdominal CT protocol includes venous portal phase (60–70 s of delay). IVC evaluation is limited by flow artifacts arising from non-opacification from common iliac veins and admixture from renal veins. Infrarenal IVC analysis is not optimal in this case. Uniform enhancement is obtained on late venous phase (70–90 s of delay) [3, 4]. This additional sequence however increases radiation exposure for patients. Contrast injection is performed via an antecubital vein at a rate of at least 3 mL/s as much as possible.

CT scanner allows good spatial and contrast resolution. Vessel reconstructions in multiplanar reformation are available and include maximum intensity projection (MIP) and volume rendering (VR). The optimal protocol should include non-contrast injection scan in order to depict spontaneous high-attenuation abnormality (thrombus) or chronic calcifications (chronic venous occlusion) and a delayed venous phase described above.

1.2.4 Magnetic Resonance Imaging (MRI)

IVC exploration can be performed with MRI, with no X-ray exposure. Furthermore, the exploration can be made with or without contrast injection. MRI is particularly interesting in IVC thrombus evaluation. MRI availability and cost limit the use of this imaging technique on a routine basis. Anatomic sequences in two planes are generally acquired (axial and coronal T2), followed by flow sequences. Balanced steady-state free sequences are key sequences (True FISP, Siemens; FIESTA, GE; Balanced FFE, Philips) that improve flowing proton signal, which appear bright, allowing vessel analysis [5].

Thick-sliced two-dimensional time-of-flight (2D TOF) imaging, which is MRI flow sequence without contrast injection, provides useful diagnostic information especially for IVC thrombosis [6, 7]. Signal from protons in flowing blood is visible, whereas protons from background tissues display no signal [6].

Three-dimensional breath-hold T1-weighted MR imaging after dynamic contrast administration (fast low angle shot sequence) in coronal planes allows both arterial and venous analysis. Maximum intensity projection reformation can be used to further improve anatomical description of abnormalities.

1.2.5 PET-CT

PET-CT is an interesting imaging modality in oncology setting, providing anatomical and metabolic information. Fluorine-18 fluorodeoxyglucose (18 F-FDG) PET-CT is commonly used in cancer staging (disease). It can also be used to detect avid fluorodeoxyglucose thrombus, reflecting malignant thrombus. FDG uptake increases in actively dividing cells like inflammatory cells or malignant cells. FDG uptake in thrombus may reflect septic or malignant thrombus and can help final diagnosis [8–10]. In addition, PET-CT can monitor treatment response using SUV variation over time. A fully diagnostic CT can also be combined with PET-CT imaging.

1.3 Main Imaging Diagnostic Feature

Recognition of IVC abnormalities is essential. IVC abnormalities are multiple, including congenital anomalies, neoplasms, and other postsurgical features.

Table 1.1 IVC obstruction etiologies

Intrinsic
Thrombosis Stenosis (ex: congenital membranes) Tumor: primary, invasion from adjacent organ/retroperitoneum Iatrogenic (central catheter placement, cava filter)
Extrinsic
Compression by retroperitoneal mass (lymph nodes, retroperitoneal fibrosis, tumor, aortic aneurysm) Enlarged liver Pregnant uterus Surgical ligation, clip

1.3.1 IVC Obstruction

IVC obstruction concerns in 90 % of cases of the infrarenal segment. Its causes are multiple (Table 1.1). The most common etiology is thrombosis arising from common iliac vein thrombus. Predisposing conditions are frequent (coagulopathy, cancer, sepsis, immobility, dehydration, etc.). Isolated IVC thrombus can occur after liver transplantation due to stenosis of caval anastomoses or filter cava placement. Primary tumors are rare. Leiomyosarcoma is the most common malignant primary tumor. Surgical resectability depends on the location of the tumor. Extension from adjacent organs (renal cancer, adrenal carcinoma, pheochromocytoma, liver cancer) or retroperitoneum (retroperitoneal fibrosis) is more common and radiologist should be careful in these cases.

Diagnostic imaging is easy as soon as acquisition time is correct. The key imaging is based on the detection of a filling defect within the IVC. However, filling defect in IVC can result from multiple causes including flow-related artifacts, bland thrombus, benign thrombus, or malignant thrombus [11, 12]. Acute thrombus (<1 week) classically appears as intraluminal hyperdensities within the IVC on CT prior to contrast injection, with homogeneous signal intensity on MR, whereas non-acute thrombus can remain undetected on CT prior to injection, with heterogeneous signal intensity on MRI [13]. Acute and non-acute thrombi usually show filling defect on both CT and MRI after contrast injection.

1.3.1.1 Artifactual Filling Defect and Bland Thrombus

Artifactual filling defects are due to incomplete filling of IVC by contrast agents. This is usually caused by flow of enhanced blood from renal veins mixed with non-opacified blood returning from lower limbs [11]. Delayed images as described above may ease the final diagnosis (Fig. 1.1).

Bland thrombus is the most common thrombus of IVC. It often extends from pelvic and lower extremity deep vein thrombosis. There is no enhancement of this thrombus after contrast injection (Fig. 1.2). Patients with IVC thrombosis are at high risk of pulmonary embolism. This thrombus can be idiopathic, the consequence of hypercoagulable state or induced by venous stasis (immobility, external compression).

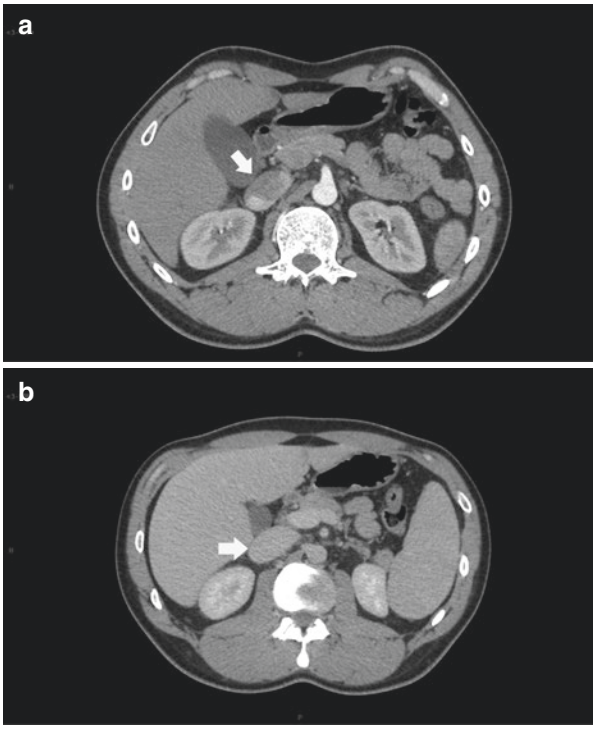

Fig. 1.1 Inferior vena cava artifactual filling defect (*arrow*) (axial CT) on early venous phase (**a**) with homogenization on late venous phase (*arrow*) (**b**)

1.3.1.2 Benign Tumor Invasion Within the IVC

Benign tumor invasion within the IVC is rare and may be secondary to the vascular extension of renal angiomyolipoma [14], leiomyomatosis [11], or adrenal pheochromocytoma [15]. The appearance is close to that of malignant tumor invasion.

1.3.1.3 Malignant Tumor Invasion Within the IVC

Primary and secondary tumor can extend within the IVC. Both often share similar imaging features, characterized by a contiguous adjacent mass, expansion within the lumen vessel and thrombus enhancement after contrast injection [11]. However, neoplastic IVC invasion and bland thrombus induced by neoplastic hypercoagulability state can coexist. If an adjacent mass is not found, IVC-enhancing mass may correspond to primary sarcoma. Extension of thrombus must be perfectly described by radiologist because it affects surgical procedure. Supradiaphragmatic extension must be carefully searched. In this case, IVC resection and cardiopulmonary bypass are required, increasing morbidity and mortality [11, 16].

Primary IVC tumors are rare, and leiomyosarcoma is the most common primary tumor (<1 % of all malignancies) (Fig. 1.3). Differentiation of primary leiomyosarcoma arising from IVC to leiomyosarcoma arising from retroperitoneal space is

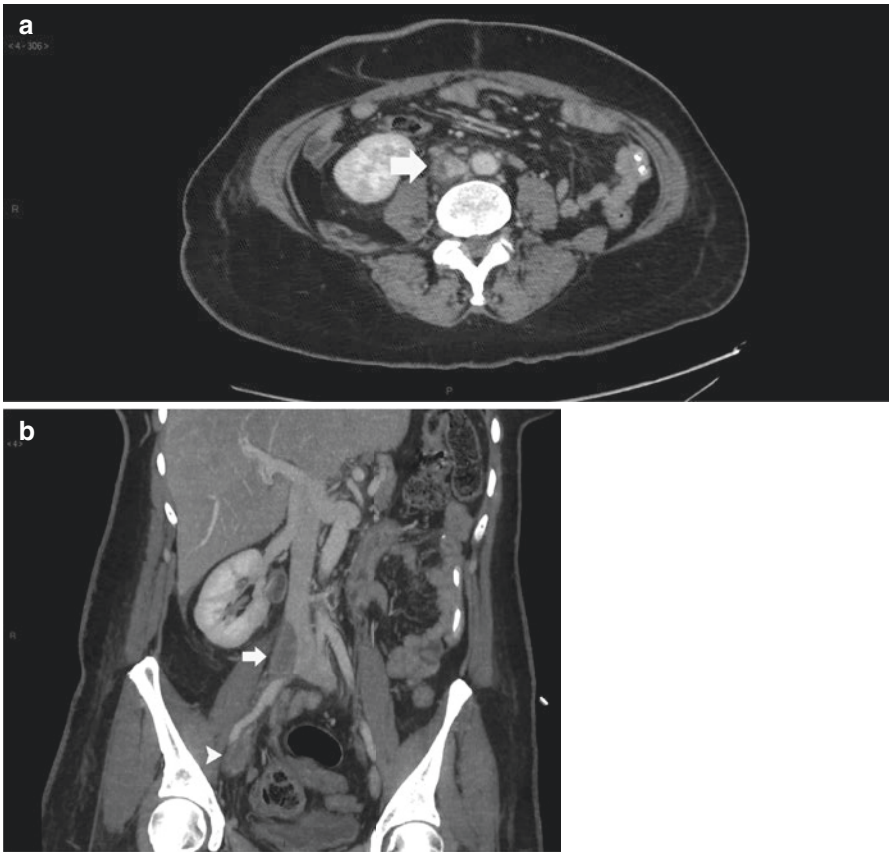

Fig. 1.2 A 55-year-old patient with right common iliac vein thrombus (*arrowhead*) extending in the inferior vena cava (*arrow*) on axial (**a**) and coronal CT (**b**)

crucial since surgical treatment differs. Complete surgical resection is the only curative treatment. Cavoplasty or stent graft is required [17]. Distinction between these two entities on imaging is challenging because both masses are predominantly extra-luminal and are supposed to arise from smooth retroperitoneal muscle than from IVC. Some authors have suggested that tumors could be considered as primary IVC leiomyosarcoma if a segment of IVC needs to be resected during surgery. When this tumor is infrarenal and collateral vessels are well developed, IVC ligation is possible. In case of insufficient collateral vessels, edemas of lower limbs are frequent. In this case and in case of suprarenal disease, cavoplasty or stent graft is preferred. Distinction of primary IVC leiomyosarcoma on imaging allows surgery planning with vascular surgeon. The key diagnosis of IVC leiomyosarcoma is the imperceptible cava lumen (75 % of cases in [18]). A positive embedded sign has also been described. Compression of IVC by retroperitoneal mass (negative embedded sign) suggests a non-cava origin.

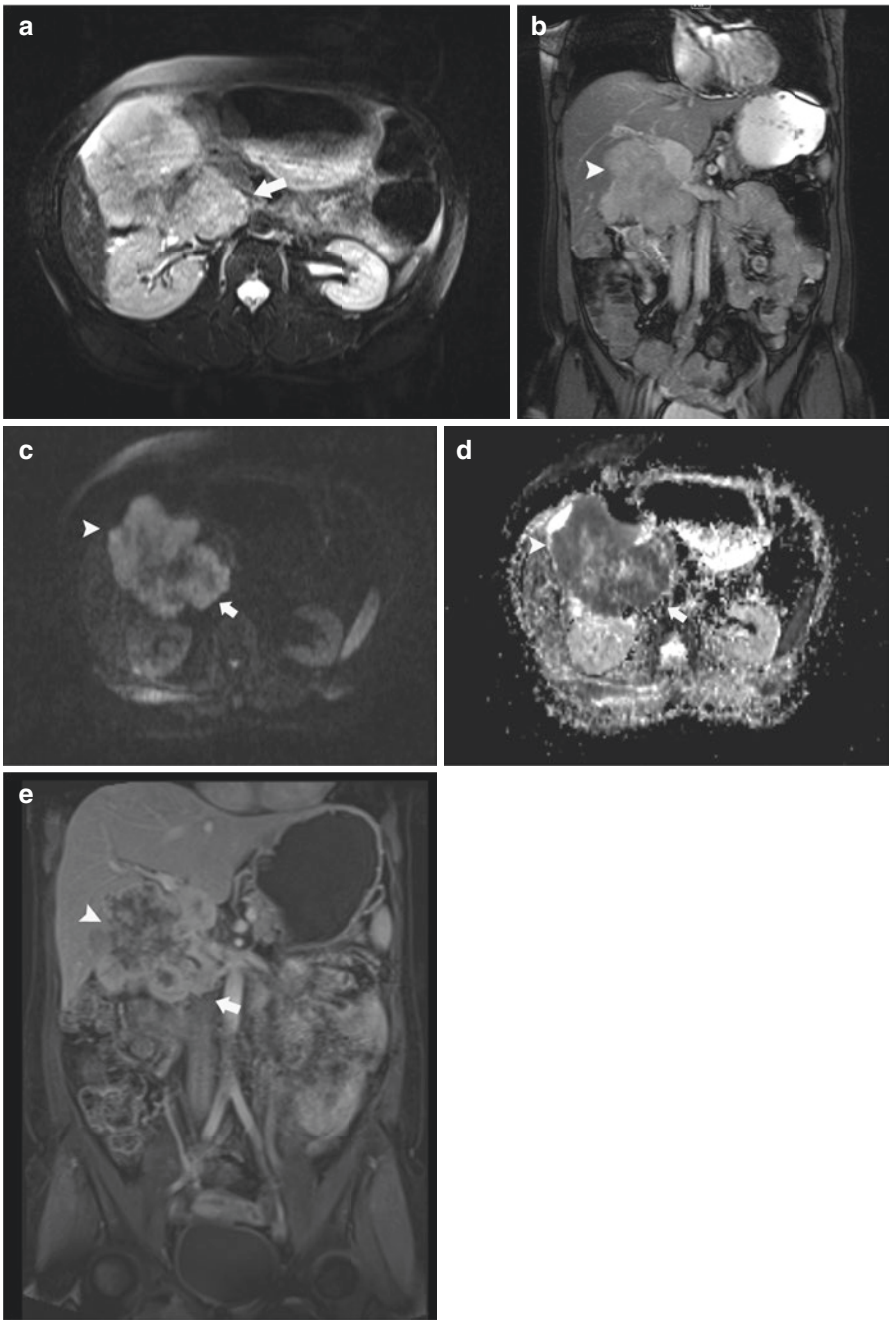

Fig. 1.3 A 58-year-old patient with an inferior vena cava leiomyosarcoma. Axial and coronal T2 (**a**, **b**), axial diffusion (**c**), apparent diffusion coefficient (**d**), and coronal contrast-enhanced T1-weighted MR images (**e**) show an inferior vena cava leiomyosarcoma (*arrow*) with liver invasion (*arrowhead*)