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Color Doppler ultrasonography of the abdominal aorta

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Abstract Alterations of the abdominal aorta are relatively common, particularly in older people. Technological advances in the fields of ultrasonography, computed tomography, angiography, and magnetic resonance imaging have greatly increased the imaging options for the assessment of these lesions. Because it can be done rapidly and is also non-invasive, ultrasonography plays a major role in the exploration of the abdominal aorta, from its emergence from the diaphragm to its bifurcation. It is indicated for the diagnosis and follow-up of various aortic diseases, especially aneurysms. It can be used to define the shape, size, and location of these lesions, the absence or presence of thrombi and their characteristics. It is also useful for monitoring the evolution of the lesion and for postoperative follow-up. However, its value is limited in surgical planning and in emergency situations.

Sommario La patologia dell'aorta addominale è relativamente frequente, in particolare nelle persone di età avanzata. Le innovazioni tecnologiche introdotte nel campo dell'ecografia, della tomografia computerizzata, dell'angiografia e della risonanza magnetica, hanno ampliato notevolmente il ventaglio di opzioni dell'imaging vascolare. In particolare l'ecografia ha un ruolo di primaria importanza per la possibilità di valutare l'aorta addominale dall'emergenza diaframmatica fino alla biforcazione, per la rapidità di esecuzione e la non invasività. Risulta pertanto indicata per la diagnosi e il follow-up delle varie malattie, in particolare degli aneurismi, dei quali può definire forma, dimensioni, topografia, assenza o presenza di trombi e loro caratteristiche, così come nel monitoraggio e nel follow-up post-operatorio. I limiti dell'indagine sono rappresentati dalla pianificazione dell'intervento chirurgico e dalle situazioni di emergenza.

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Introduction

Technological innovations in the field of ultrasound, computed tomography, angiography, and magnetic resonance imaging (MRI) have expanded the options for vascular imaging and modified diagnostic protocols in terms of the available technologies, diagnostic problems, and treatment solutions that involve the use of radiological methods to guide and monitor interventional procedures [1,2].

Ultrasonography is the first-line imaging study for the diagnosis and the postoperative evaluation and follow-up of patients with diseases of the abdominal great vessels [3].

The combination of velocimetry with ultrasound and color methods (color Doppler ultrasound) substantially increased the possibilities for ultrasound in the diagnosis of disorders involving the deep vessels. It stimulated the acquisition of functional data, which were often unobtainable with other methods, and significantly increased the space occupied by ultrasound methods in diagnostic imaging [4,5].

Anatomy

The abdominal portion of the aorta lies between the inferior border of the twelfth thoracic vertebra and fourth lumbar vertebrae; at this level, the aorta divides into the right and left common iliac arteries and the middle sacral artery, which continues downwards and vertically.

The aorta lies in the retroperitoneal space, in front of the bodies of the lumbar vertebrae.

Anteriorly, it is overlain by the body of the pancreas, the third portion of the duodenum, the root of the mesentery, and the left renal vein. On the right, lies the inferior vena cava; on the left, the left pillar of the diaphragm and the duodenojejunal flexure [6].

The aorta gives rise to the inferior phrenic arteries, the celiac trunk, the superior mesenteric artery, the middle adrenal arteries, the renal and gonadal arteries, and the inferior mesenteric artery (Fig. 1A).

The inferior phrenic arteries are the first two branches of the abdominal aorta. They originate from the lateral walls of the aorta and ascend to the diaphragm, which they vascularize. They supply the superior adrenal arteries.

The celiac trunk arises from the anterior wall of the abdominal aorta at some point between the body of twelfth thoracic vertebra and the disc lying between the first and second lumbar vertebrae, approximately 1.5 cm below the diaphragm. It runs forward, and after 2—3 cm, it divides into the left gastric artery, the common hepatic artery, and the splenic artery.

The large-caliber hepatic artery runs toward the hepatic hilum; after giving rise to the gastroduodenal artery, it continues as the proper hepatic artery. At the level of the hilum, it divides into the two branches, right and left, that supply blood to the liver. Within the hepatoduodenal ligament, the hepatic artery is located anteriorly on the left, the bile duct anteriorly on the right, and the portal vein is in the posterior compartment. These three structures, which make up the hepatic pedicle, form the anterior pillar of the foramen of Winslow. The hepatic artery also gives rise to the cystic artery (which originates from the right branch of the hepatic artery and proceeds to the gallbladder); the right gastric artery (which runs along the lesser gastric curvature and anastomoses with the left gastric artery); and the gastroduodenal artery. The latter artery originates behind the first portion of the duodenum and then divides into two branches. The first is the right gastroepiploic artery, which rises along the greater curvature of the stomach and anastomoses with the left gastroepiploic artery (a branch of the splenic artery). The second branch is the superior pancreaticoduodenal artery, which descends along the medial margin of the second portion of the duodenum and anastomoses with the inferior pancreaticoduodenal artery (a branch of the superior mesenteric artery).

On the left, the left gastric artery ascends, runs along the lesser curvature of the stomach within the hepatogastric ligament, and anastomoses with the right hepatic artery.

The splenic artery is the largest branch of the celiac trunk. It runs toward the spleen, with a winding course, along the upper margin of the pancreas. At the hilum of the spleen, it divides into several branches that penetrate the organ and supply any accessory spleens.

The superior mesenteric artery originates from the anterior wall of the abdominal aorta at level of the D12-L1 intervertebral space, about 1 cm caudal to the emergence of the celiac trunk. It descends behind the pancreas, between the head and the neck, and then emerges between the lower edge of the pancreas and duodenum. Passing in front of the latter, it penetrates the mesentery and curves toward the right iliac fossa. It supplies part of the duodenum, the remaining portions of the small intestine, and part of the large intestine. Its collaterals include the inferior pancreaticoduodenal artery, which merges with the superior pancreaticoduodenal artery and supplies blood to the head of the pancreas and the duodenum; the jejunal and ileal arteries (10—15 branches that vascularize the bowel loops, except those of the last section); the middle colic artery; the right colic artery (which reaches the ascending colon); and the ileocolic artery, which runs to the left iliac fossa. Caudal to the origin of the latter artery, the superior mesenteric branches into smaller-caliber vessels that supply the cecum and the last ileal loops (Fig. 1B) [7].

The middle adrenal arteries originate from the lateral walls of the aorta at the level of the superior mesenteric artery and proceed to the adrenals.

The renal arteries originate from the lateral walls of the aorta below the superior mesenteric artery at the level of the first lumbar vertebra. These two large branches run horizontally to the hila of the two kidneys. Here, each divides into 3—4 branches, which penetrate into the renal pelvis. The right renal artery measures 5—6 cm. It runs posterior to the right renal vein, the inferior vena cava, the head of the pancreas, and the descending portion of duodenum. The left renal artery is about 3—4 cm long. It runs behind the left renal vein, the body of the pancreas, and the splenic vein [8].

The gonadal arteries are the arteries that supply the testes in the male and the ovaries in women [9].

The inferior mesenteric artery originates from the anterior wall of the aorta at the level of the intervertebral disc L3—L4. It proceeds downward toward the left, crossing over the common iliac vessels. It enters the root of the mesosigmoid and reaches the upper end of the rectum as the superior hemorrhoidal artery.

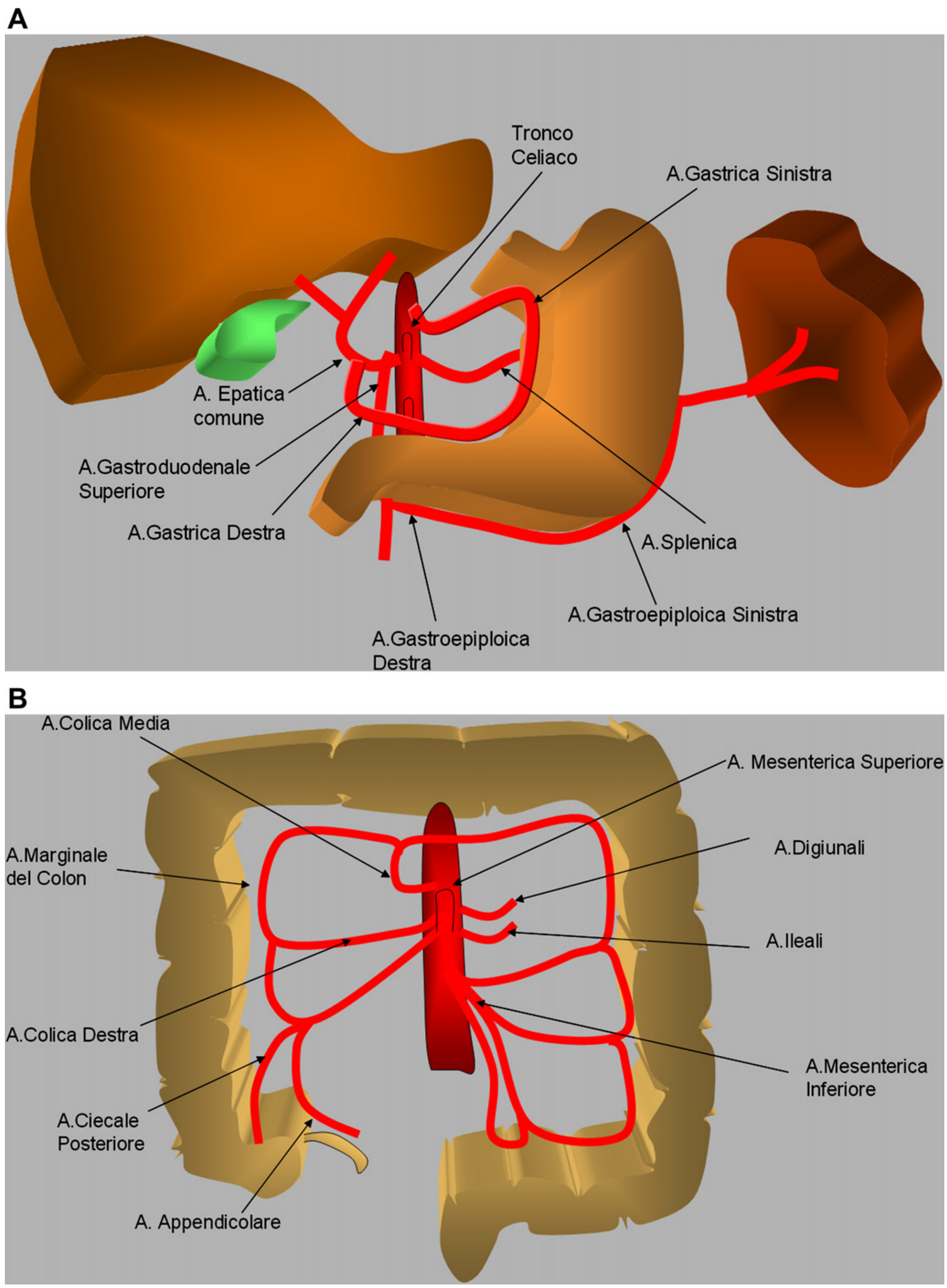

Fig. 1 A. The figure shows the vessels that arise from the upper stretch of the abdominal aorta (the celiac trunk) and their branches. B. The superior mesenteric artery and the inferior mesenteric artery branches into smaller-caliber vessels that supply the bowel loops.

Pathological anatomy

Atherosclerosis

Atherosclerosis is characterized by the formation of atheromata, which are raised, fibroadipose plaques that develop within the intimal layer of the artery or within the innermost layers of the tunica media [10].

With time and progression of the disease, the fibrous component prevails, giving the plaque a pearly appearance. Some atheromata undergo calcification or ulceration, and mural thrombi can form over complicated and uncomplicated atheromata. As a result, the vessel wall becomes deformed and rigid, and the luminal narrowing severely impairs blood flow to the organs.

Focal lesions weaken the arterial wall and predispose them to the aneurysmal dilatation and rupture.

Atherosclerotic aneurysms are most common in the abdominal aorta. They are rarely seen in patients younger than 50 years. They can be saccular, fusiform, or cylindrical.

The cause is usually atheroma expansion in the tunica media, which destroys the musculoelastic support of the wall.

The symptoms of an abdominal aortic aneurysm are related to complications, which include rupture with massive hemorrhage into the peritoneal cavity or retroperitoneal tissues; compression of nearby organs; occlusion of adjacent vessels; and embolism secondary to mural thrombi. Aneurysms can also be manifested by an abdominal mass suggestive of malignancy.

The size of the aneurysm has important clinical implications. Those with diameters less than 6 cm are less likely to rupture, whereas diameters greater than 7 cm are frequently associated with rupture, which can be fatal.

Steno-occlusive disorders

The most common causes of obstruction is atherosclerosis, which affects individuals who are middle-aged or elderly and results in partial or total occlusions, the latter caused by single or multiple atheromata. The occlusion is generally located at the opening of the aorta or in the first two centimeters of the vessel or at the level of its main bifurcation, and it is often associated with poststenotic dilatation.

Less common causes include fibromuscular hyperplasia, which involves the more distal segments of the arteries (particularly the renal arteries) and is often detectable in more than one area; arteritis, which may be accompanied by other immunological diseases; and extrinsic compression of the celiac trunk by the arcuate ligament of the diaphragm.

Thanks to the rich network of anastomoses between the three main systems of this district, an obstruction that has developed slowly will be compensated for to some extent by the development of collateral circulation.

This explains why the obstruction of two of the main trunks may not be associated with any appreciable clinical symptoms or, indeed, even in the presence of symptoms, the occlusion of all three major arteries. On the other hand, stenosis of a single arterial trunk is sometimes associated with typical postprandial abdominal symptoms.

Symptoms may persist even after the hemodynamic situation has been surgically corrected, and in some cases the clinical picture may regress spontaneously over time, even if the arterial obstruction has not been eliminated.

Clear-cut systematization is difficult because there are so many different circulatory situations, each accompanied by various clinical presentations.

Acute mesenteric ischemia is associated with high mortality rate. The arterial stenosis is often misdiagnosed, especially when the characteristics of the abdominal pain are not clearly explained, and the condition may lead to bowel infarction before to the correct diagnosis is made.

Apart from arterial thrombosis, embolism, and vasculitis, acute ischemia can also be caused by the simultaneous development of portal hypertension or thrombosis of the superior mesenteric vein.

Because early clinical diagnosis of celiac-mesenteric ischemia is so difficult, imaging studies play a crucial role in these cases.

Alterations in the course of the vessel

Over the years, the aorta often becomes more tortuous, particularly in women and in individuals with hypertension. As a result, the vessel tends to cross the midline, coming into close contact with and sometimes partially compressing the inferior vena cava.

Alterations in size

Decreases in size are fairly rare. They are typically seen in coarctation of the thoracic aorta. Aortic dilatation is much more common. It sometimes involves the full length of the vessel, including the thoracic segment, and is associated with marked lengthening of the artery, a situation referred to as dolichoectasia of the aorta.

Abdominal aortic aneurysms are among the most clinically significant forms of dilatation. They are predominantly atherosclerotic in nature, and their frequency peaks around the age of 70 years.

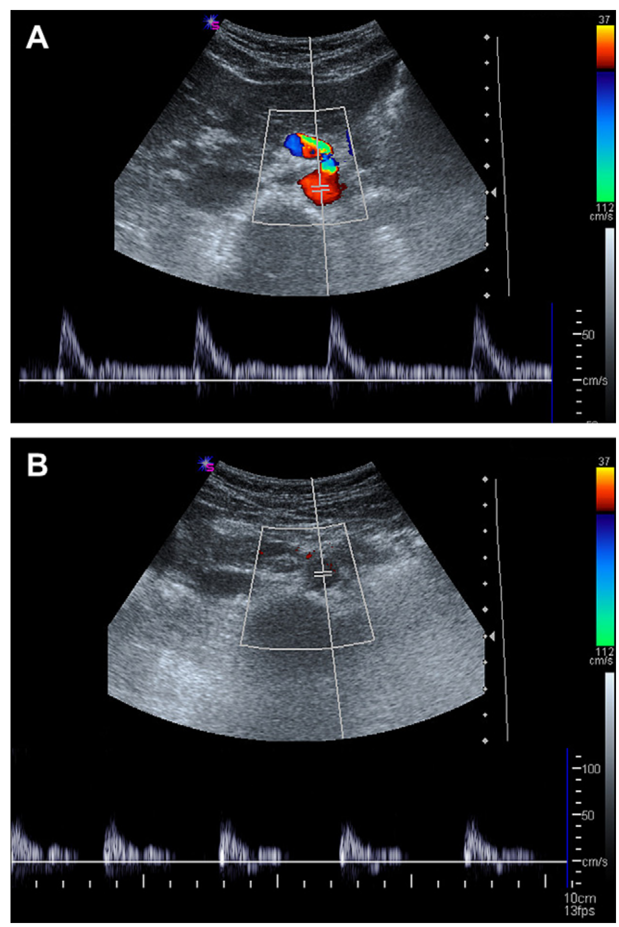

Fig. 2 The Doppler waveform of the abdominal aorta varies depending on whether flow is cranially or below the renal arteries: in the former case, there is an appreciable diastolic component, as occurs in areas with low resistance (A); downstream there is no diastolic component, and the trace is characterized by a small inverted wave (districts with high resistance) (B).

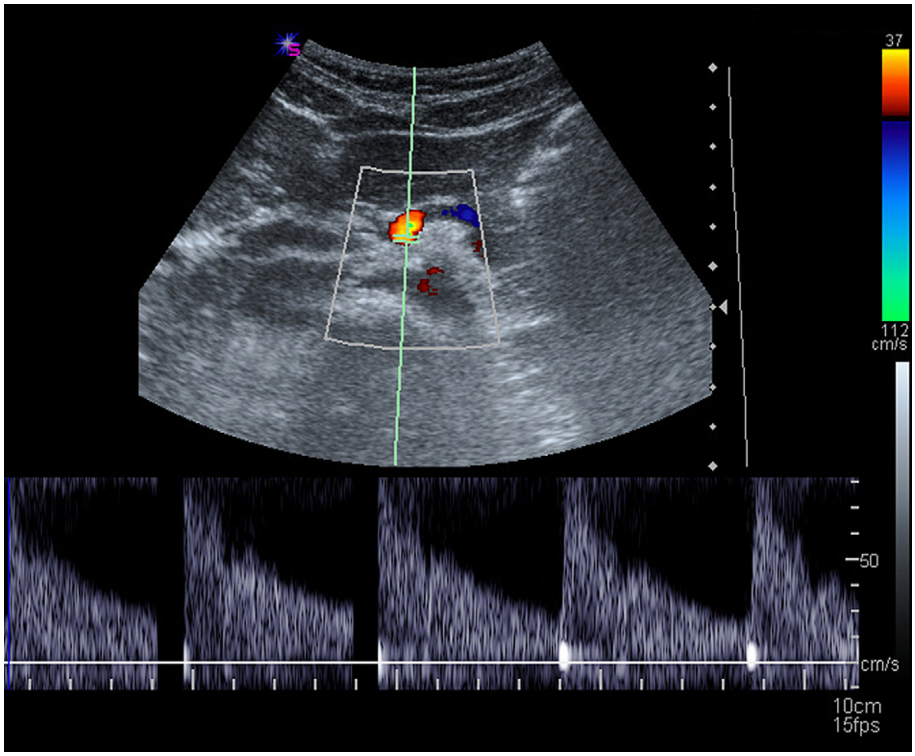

Fig. 3 The Doppler tracing of the celiac trunk is characterized by large diastolic component.

In most cases, they arise downstream from the emergence of the renal arteries and the aorta's intersection with the left renal vein, which surrounds the anterior wall of the aorta and prevents its dilatation. In fact, aneurysms involving both the supra- and infrarenal segments of the aorta often have an hourglass appearance due to the local expansion-opposing effects of the left renal vein.

The aneurysm sac usually contains thrombotic formations and atheromata, which can substantially reduce the patency of the lumen.

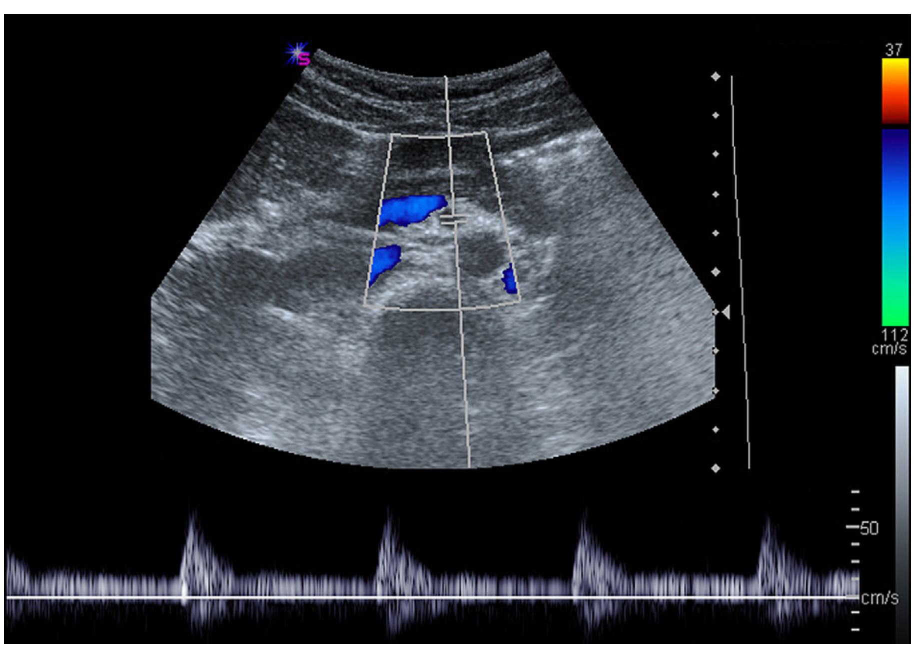

Fig. 4 The Doppler tracing of the superior mesenteric artery varies depending on whether or not the patient is fasting. There is an appreciable diastolic component, which, along with the systolic peak, increases after a meal when the area supplied by the vessel is characterized by an increased demand for blood.

Inflammatory aneurysms are characterized by the infiltration of inflammatory cells and by proliferation of granulation tissue around the adventitia. This inflammatory tissue is located outside the anterior and lateral walls of the vessel; the posterior wall is typically spared. Sometimes the inflammatory tissue extends from the periaortic area into the retroperitoneum, incorporating the structures found there, such as the vena cava, the ureters, and the renal veins.

An ischemic aneurysm is caused by circumscribed ischemia of the aortic wall caused by thrombosis of the vasa vasorum. It is manifested by a pseudodiverticular lesion on the anterior wall of the aorta. Although these formations are usually small, they carry a high risk of rupture because the thickness of the wall that surrounds them is reduced.

Dissecting aneurysms involve the tunica media of the aorta and are generally preceded by cystic medionecrosis. Through lesions in the intima, blood thrusts its way into the wall of the vessel, usually between the outer and middle thirds of the tunica media, forming an intramural hematoma. The hematoma extends distally, dissecting the wall, and sometimes involving the proximal segments of the branches. Distal progression can cause rupture of the adventitia with extravasation of blood or a second rupture of the intima, through which the blood is returned to the general circulation.

Treatment of abdominal aortic aneurysms

An aneurysm is a localized, permanent dilatation of an artery caused by structural alteration of the vessel wall.

At the level of the abdominal aorta (which has a normal diameter of 12—20 mm), a maximum transverse diameter of 25 mm may be considered pathological. The abdominal segment is the portion most frequently affected by the aneurysm (70% of all cases).

The etiology is multifactorial, but a predominant role is played by atherosclerosis. The incidence is 6 to 9 times higher in males than in females, and there is a strong correlation with smoking and poorly controlled hypertension.

Aneurysmal disease is invariably progressive, which means that the diameter of the dilatation tends to increase with time, and this inevitably leads to vessel rupture. This event is a surgical emergency owing to the severe bleeding it causes. Aneurysm rupture has been demonstrated to be the most frequent cause of death in patients with these lesions. The risk of rupture is directly proportional to the diameter of the lesion, although rupture can also occur with small aneurysms.

For this reason, although when patients are asymptomatic (as they are in most cases), surgical repair is generally recommended to avoid rupture. The risk associated with surgical repair is much higher if the operation is performed as an emergency procedure after rupture, and this justifies the use of surgery in a patient in apparently good health.

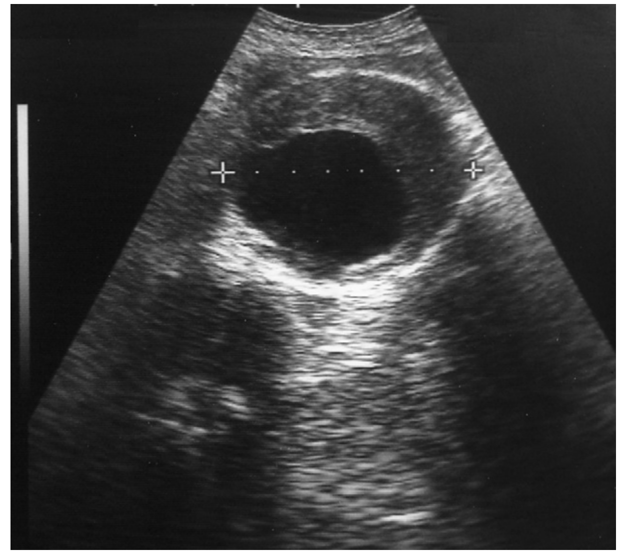

Fig. 6 The figure shows an atherosclerotic aneurysma.

Fig. 5 Atheromata are the commonest alteration observed in the abdominal aorta, but unlike those found in other vessels, these of the aorta rarely give rise to steno-occlusive phenomena.

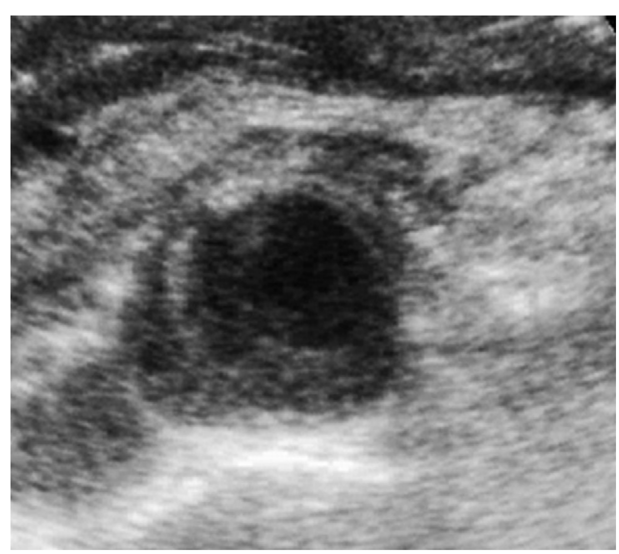

Fig. 7 Atherosclerosis is characterized by the formation of the atheromata, which are raised, fibroadipose plaques that develop within the intimal layer of the artery or within the tunica media.

There is currently no medical treatment capable of curing or even limiting the progression of this disease: surgery is the only option.

According to current practice guidelines, an abdominal aortic aneurysm with a maximum transverse diameter greater than 45 mm is an indication for surgery. For smaller aneurysms, the surgical risk is considered statistically higher than the expected risk of rupture within a year. Therefore, surgery is usually not justified in these cases. Possible exceptions are rapidly growing lesions (those presenting an increase in diameter greater than 5 mm in the last 6 months) and asymmetric "blister" lesions, which are usually an indication of high wall vulnerability.

Currently, the surgeon has two options: conventional open surgery and angiographically guided transarterial stent placement.

Open surgery involves an abdominal, often transperitoneal, incision, which allows exposure of the retroperitoneal organs. The dilated segment is replaced with a prosthesis made of Dacron®, a synthetic material with elastic properties resembling those of the arterial wall.

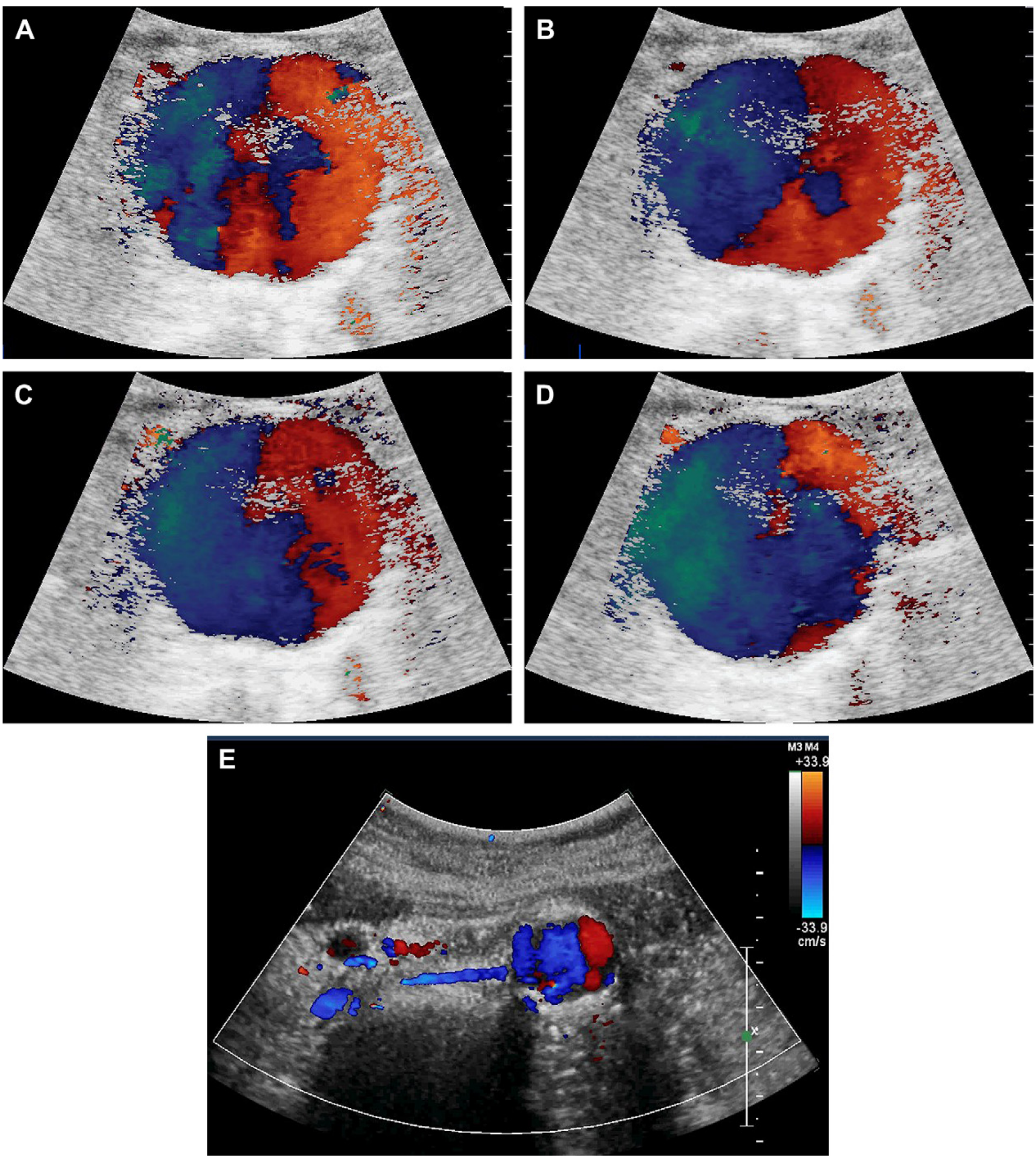

Fig. 8 On Color Doppler, the aneurysm is characterized by swirling flow with decreased linear velocity. The figures show the Color Doppler flow of an abdominal aortic aneurysm (A, B, C, D, E).

This is a standardized technique, which produces excellent long-term results. The patient is usually discharged within 6—8 days. Apart from a reasonable period of convalescence, no further care is needed after discharge. The mortality rate associated with elective procedures of this type is currently quite low (around 2—3%).

The procedure is naturally quite invasive and can be associated with major complications at the cardiac (surgical stress), respiratory (bed rest, transient disuse of the accessory muscles of respiration), and renal (possible clamping of the aorta above the emergence of the renal vessels, possible reinsertion of the renal vessels) levels. Anesthesiological difficulties can also arise in patients with major comorbidities, those with previous abdominal surgery, and those with severe obesity ("hostile abdomen").

The endovascular technique involves the transarterial insertion and release of a woven prosthesis mounted on a self-expandable stent. The prosthesis is inserted via a peripheral arterial access (e.g., the femoral artery) and positioned under fluoroscopic guidance. This approach does not eliminate the aneurysmal lesion, but it is functionally excluded from the circulation.

Excellent mid-term results have been obtained with this technique. Mortality is comparable to that observed with traditional surgery, but there is a significant reduction in morbidity. It may, therefore, be used to treat high-risk patients or those who would be excluded from open surgery.

The disadvantages are related to difficulties involved in effective positioning of the stent. Several conditions must be fulfilled to ensure firm anchorage of the stent: the vessel access (femoral or iliac) must not be excessively tortuous and the aneurysmal neck should be sufficiently long, not tapered, non-calcified, with no thrombus covering the walls to ensure firm anchorage.

Complications may arise as a result of technical failure or the presence of endoleaks, which leave the aneurysmal chamber exposed to the pressure of blood flow. Moreover, the procedure requires the use of iodinated contrast agents, which are highly nephrotoxic and may be associated with alterations in renal function ranging from transient postoperative decreases to ARF. Patients with CRF are particularly vulnerable to this type of damage. The size of the prosthesis must be selected with care, and it must be carefully positioned to avoid interference with the emergence of the renal and internal iliac arteries. No data is available on the long-term performance of these prostheses, and therefore many surgeons are hesitant to use them in young patients.

Color Doppler sonography

The abdominal aorta can be explored from its emergence from the diaphragm to the bifurcation, but it is not always easy to visualize owing to its depth and the presence of overlying hollow viscera.

For the study of the abdominal aorta, low-frequency transducers are used. The patient's position is varied (supine, lying on the left side with support, etc.) to achieve the best acoustic window [11].

In B-mode, the vessel appears anechoic with hyperechoic walls [12]. The Doppler waveform varies depending

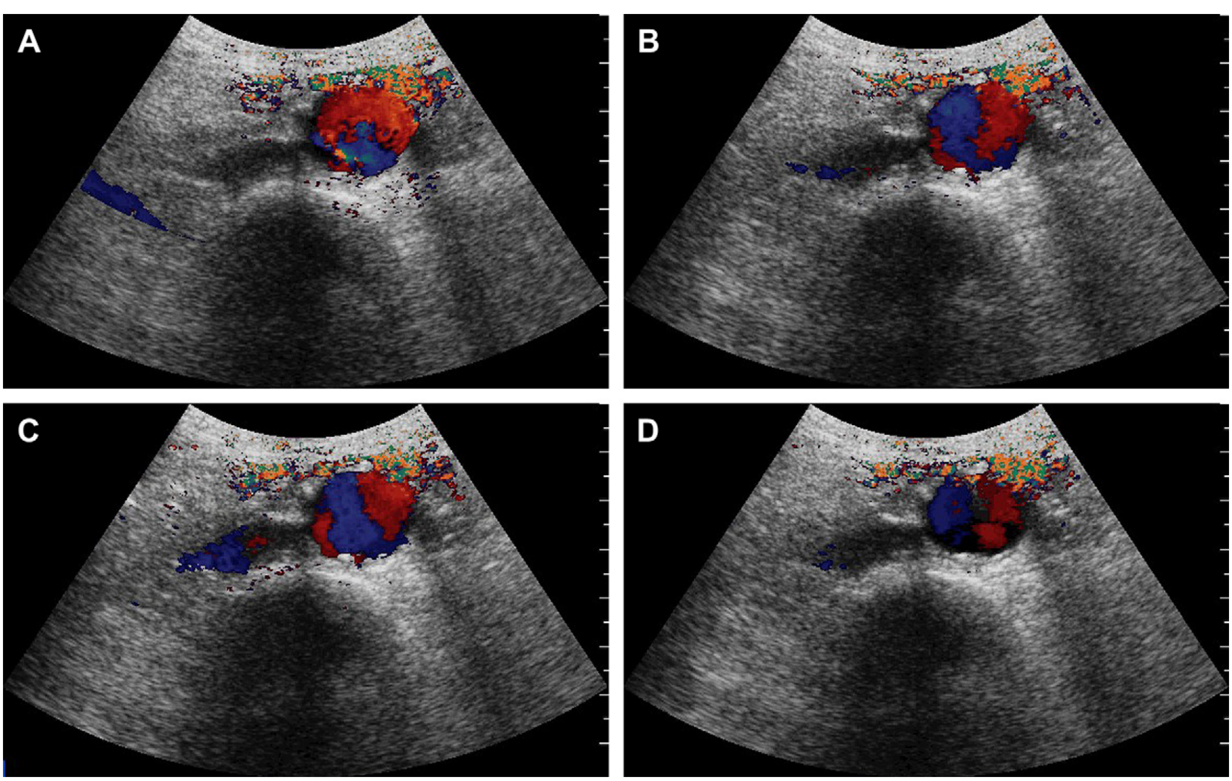

Fig. 9 On Color Doppler, the aneurysm is characterized by swirling flow with decreased linear velocity. The figures show the Color Doppler flow of an iliac artery aneurysm (A, B, C, D).

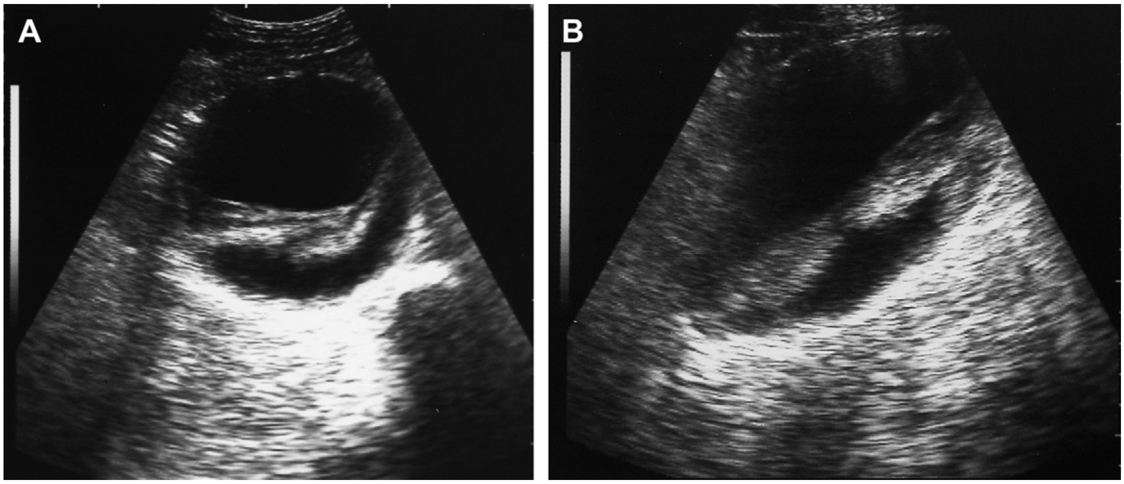

Fig. 10 Ultrasound can be used to assess the presence of parietal thrombi and their echostructural characteristics. A shows the transversal view of an aneurismal dilatation with parietal thrombi; B shows the longitudinal view of the same vessel.

on whether flow is sample cranially or below the renal arteries: in the former case, there is an appreciable diastolic component, as occurs in areas with low resistance (Fig. 2A); downstream there is no diastolic component, and the trace is characterized by a small inverted wave (districts with high resistance) (Fig. 2B) [13,14].

Before dividing into the iliac arteries, the abdominal aorta gives rise to the celiac tripod, the superior mesenteric artery, the renal arteries, and the inferior mesenteric artery.

As for the celiac trunk, the hepatic and splenic arteries can always be discerned, while the left gastric and

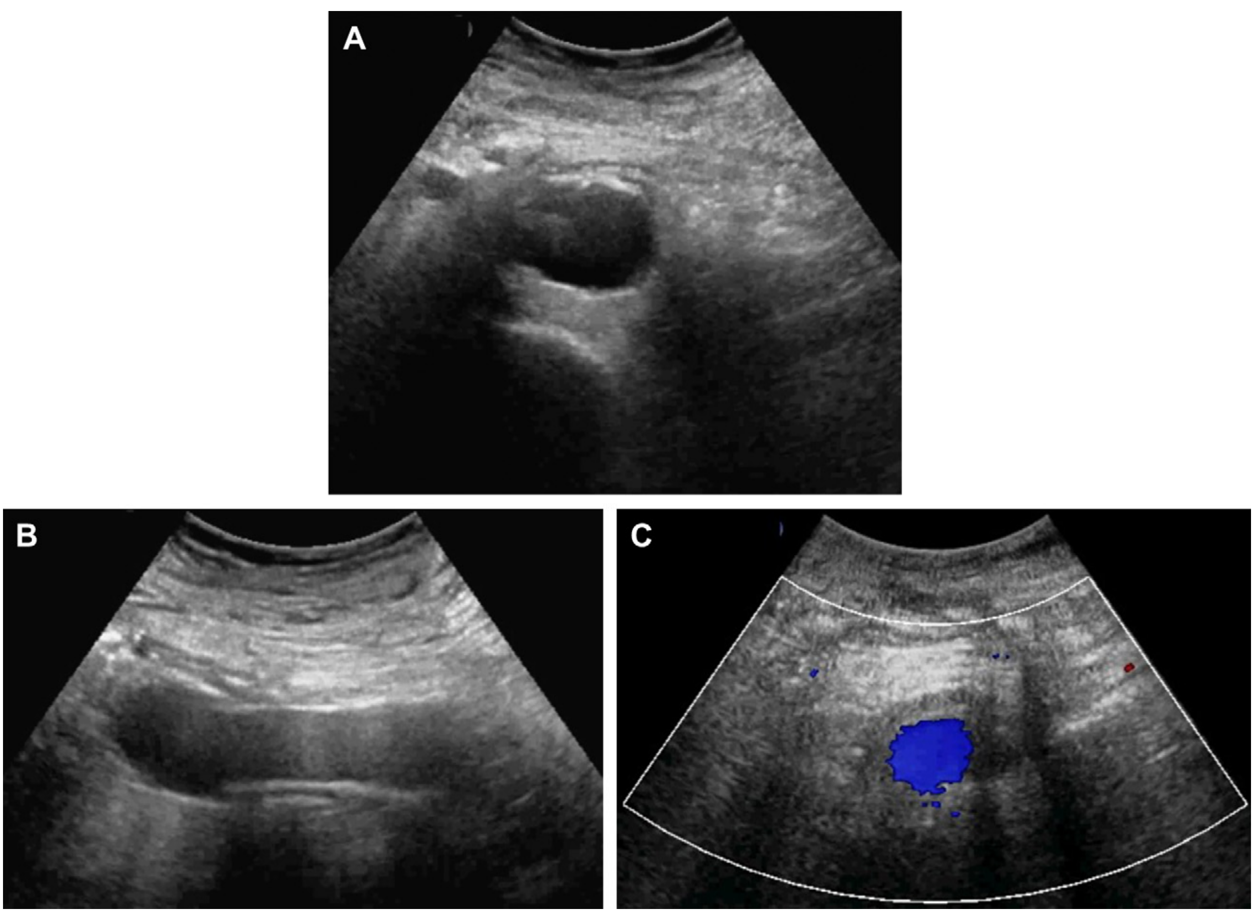

Fig. 11 In the post-surgical phase, ultrasound can be used to monitor the diameter of the prosthesis and to detect stenosis and occlusions. Trasversal view (A, C); longitudinal view (B).

gastroduodenal arteries are seen only sporadically. The Doppler tracing of the celiac trunk is characterized by large diastolic component (districts with low resistance) (Fig. 3) [15].

The superior mesenteric artery can always be visualized on ultrasound. It arises just below the celiac axis/trunk, and the Doppler tracing varies depending on whether or not the patient is fasting. There is an appreciable diastolic component, which, along with the systolic peak, increases after a meal when the area supplied by the vessel is characterized by an increased demand for blood (Fig. 4) [16].

The proximal segments of the renal arteries are evaluated with the patient in the supine position. The right lateral decubitus position is used to examine the left renal artery through the acoustic window provided by the kidney. The left lateral decubitus is used to explore the right renal artery (located posterior to the vein). The trace is characterized by an early systolic peak followed by a second systolic peak—higher or lower than the first—and a moderate diastolic component [8].

The inferior mesenteric artery arises from the left anterolateral wall of the abdominal aorta, just below the origin of renal arteries. Owing to its small size, it is not always easy to identify. The Doppler tracing is characterized by a high systolic peak with little or no diastolic component.

Atheromata are the commonest alteration observed in the abdominal aorta, but unlike those found in other vessels, those of the aorta rarely give rise to steno-occlusive phenomena (Figs. 5—7). On the other hand, they are often the cause of aneurysm formation.

Ultrasonography is used to confirm a clinically suspected aneurysm and to determine its size. The transverse diameter is easy to measure; determining the length is often more complicated. The location of the aneurysm is also of major importance, in particularly its position with respect to the kidneys (Fig. 8)—supra- and infrarenal aneurysms require different surgical procedures—and its relation to the left renal vein [12].

Ultrasound can also be used to assess the presence or absence of thrombi, their echostructural characteristics, and any signs of dissection (Fig. 10) [17].

On Color Doppler, the aneurysm is characterized by swirling flow with decreased linear velocity (Figs. 8 and 9) [18].

Ultrasound can also reveal aortic dissections and distinguish the true and false lumens (Fig. 10), but bleeding is generally assessable with this modality [19,20].

In the post-surgical phase, ultrasound can be used to monitor the diameter of the prosthesis (Fig. 11) and to detect stenosis and occlusions. As in the pre-operative phase, bleeding is generally not assessable. The suspicion of periprosthetic infection is raised by the presence of hypoechoic formations surrounding the stent, but their presence must be confirmed by CT and MRI [21,22].

Conclusions

Atheromata are the commonest alteration observed in the abdominal aorta, but unlike those found in other vessels, those of the aorta rarely give rise to steno-occlusive phenomena. On the other hand, they are often the cause of aneurysm formation.

Ultrasonography plays a fundamental role in the diagnosis of abdominal aortic aneurysms, which are often discovered incidentally, and it is the method of choice for the follow-up of these lesions.

It can confirm a clinical suspicion of aneurysm and determine the size.

Ultrasound usually provides very accurate measurements of the axial diameter of the aneurysm, unless the involved segment is particularly tortuous, in which case the caliber may be overestimated. This obstacle can be overcome with MRI, which can be used to visualize the entire vessel (if necessary with a coronal scan).

The length of the aneurysm is often more difficult to determine.

The location of the aneurysm of major importance, in particular whether it is supra- or infrarenal since these situations require different surgical procedures, and its relationship with the left renal vein.

On color Doppler, aneurysms present with swirling flow and decreased linear flow velocities.

Ultrasound can also disclose the presence of thrombosis and aortic dissection, and in the latter case it can distinguish the true and false lumens.

Periaortic blood collections can occasionally be identified with ultrasound, but it is not reliable for the diagnosis of fissures or rupture of an aneurysm. If these complications are suspected, CT should be performed.

Finally, sonography is helpful for monitoring the diameter of stents and for identifying stenosis and occlusions; it may also reveal findings suggestive of periprosthetic infection.

Conflict of interest statement

The authors have no conflict of interest.

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