INVITED PICTORIAL ESSAY

Hepatic involvement in hereditary hemorrhagic telangiectasia: CT findings

M. Memeo,[1] A. A. Stabile Ianora,[1] A. Scardapane,[1] P. Buonamico,[2] C. Sabbà,[2] G. Angelelli[1]

[1]Department of Radiology, University Hospital–Policlinico of Bari, Piazza Giulio Cesare 11, 70124 Bari, Italy
[2]Department of Emergency Medicine, HHT Centre, University Hospital–Policlinico of Bari, Piazza Giulio Cesare 11, 70124 Bari, Italy

Abstract

Hereditary hemorrhagic telangiectasia (HHT), also known as Rendu-Osler-Weber disease, is an autosomal-dominant vascular disease characterized by mucocutaneous or visceral angiodysplastic lesions (telangiectases and arteriovenous malformations) that may be widely distributed throughout the cardiovascular system. The recognition of mucocutaneous telangiectases, the occurrence of spontaneous and recurrent episodes of epistaxis, the presence of visceral involvement, and a family history of this disease are the clinical criteria that allow diagnosis. In comparison with skin, lungs, gastrointestinal tract, and brain involvement, hepatic involvement defined by clinical criteria alone has long been considered uncommon. Our experience with a large group of HHT patients, even those asymptomatic for liver involvement, demonstrates that it is more frequent than reported and is characterized by the presence of intrahepatic shunts, disseminated intraparenchymal telangiectases, and other vascular lesions. Congestive cardiac failure, portal hypertension, portosystemic encephalopathy, cholangitis, and atypical cirrhosis have been reported as possible serious complications related to this condition. Thus, a correct diagnosis is important, and diagnostic imaging has a fundamental role in detecting alterations involving the liver. The possibilities to perform a multiphasic study and to provide high-quality multiplanar and angiographic reconstructions, gives multidetector row helical computed tomography the ability to detect and characterize the complex anatomopathologic alterations typical of this disease.

Key words: Hereditary hemorrhagic telangiectasia—Multidetector row computed tomography—Liver—Vascular alterations—Intrahepatic shunts—Reconstructions

Correspondence to: M. Memeo; *email:* doc.mauri@libero.it

Hereditary hemorrhagic telangiectasia (HHT), also known as Rendu-Osler-Weber disease, is a vascular disease with hereditary autosomal-dominant transmission that occurs with an estimated frequency of 10 to 20 per 100,000 individuals [1, 2]. Its typical manifestations are mucocutaneous or visceral angiodysplastic lesions (telangiectases and arteriovenous malformations) that may be widely distributed throughout the cardiovascular system.

The diagnosis of HHT is essentially based on a combination of clinical findings: the recognition of mucocutaneous telangiectases, the occurrence of spontaneous and recurrent episodes of epistaxis, the presence of visceral involvement, and a family history of this disease [3–5]. At present its pathogenesis is not clear, but it may be a result of genetic mutations that interfere with angiogenesis and its control mechanisms [6–11].

The organs most frequently involved are the skin, lungs, gastrointestinal tract, and brain [6]; hepatic involvement, almost always defined by clinical criteria, has been considered uncommon, and its prevalence has ranged from 8% to 31% in different studies [3, 12, 13]. In our experience, performed as a retrospective study in a large group of HHT patients, even those with limited clinical symptoms for hepatic involvement, hepatic involvement has proved to be more frequent than reported, likely due to the higher general sensitivity of the imaging method we used in detecting hepatic alterations compared with those used in the past and with clinical findings alone.

The presence of intrahepatic shunts, disseminated intraparenchymal telangiectases, and other vascular lesions are the typical findings of hepatic involvement [13, 14]. Although patients with liver involvement are generally asymptomatic, congestive cardiac failure, portal hypertension, portosystemic encephalopathy, cholangitis, and atypical cirrhosis have been reported [12, 13, 15–18], so a correct diagnosis is important for the follow-up of symptomatic and asymptomatic patients.
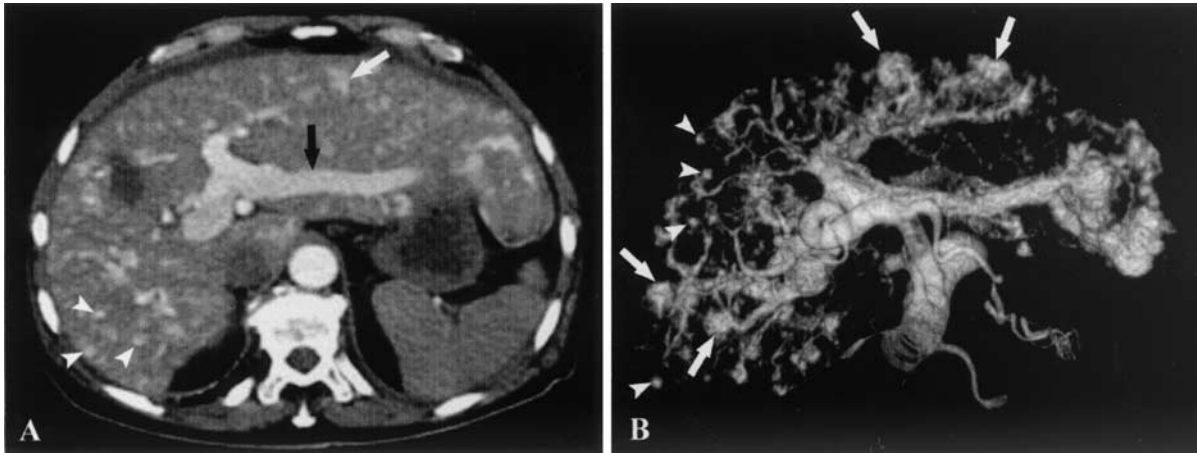
Fig. 1. A 66-year-old man with a history of epistaxis and a positive family history for HHT. (**A**) Contrast-enhanced axial CT and (**B**) volume-rendered three-dimensional image in the early arterial phase show simultaneous opacification of arterial and portal vessels (*black arrow*) consisting of arterioportal shunting and some large confluent vascular masses (*white arrows*). Some small, vascular lesions considered telangiectases are also labeled (*arrowheads*).

Diagnostic imaging has a fundamental role in the identification of hepatic vascular alterations. Ultrasonography, especially in association with color Doppler, is the usual method for screening patients with HHT and suspected liver involvement [7, 15, 16, 19] because it is readily available, noninvasive, cost effective, and able to demonstrate intraparenchymal shunts and other vascular malformations, and it can provide qualitative and quantitative analyses of the arterial, venous, and portal flows [20].

Angiography previously was the most useful imaging method for the assessment of vascular abnormalities [21–23], but is currently seems to be indicated only in selected cases for hemodynamic measurements in symptomatic patients or for pre-transplantation workup.

The possibility of performing angiographic reconstructions provided by magnetic resonance imaging (MRI) and helical computed tomography (hCT) have caused them to take on an important role in identifying and characterizing lesions involving hepatic vascular structures.

MRI performed with dynamic and angiographic sequences (angio-MRI) provides information similar to that obtained with CT in the study of hepatic disorders [7, 13, 24–26].

Helical CT, in particular the multidetector row hCT scanners that can scan three to 10 times faster than can single-detector row hCT, allows a complete multiphasic study of the hepatic vascular system. Compared with traditional hCT, multidetector row hCT also improves the quality of multiplanar reformatting (MPR) and angiographic (maximum intensity projection, MIP; and volume rendering, VR) reconstructions and increases the diagnostic accuracy of this imaging method because it produces thinner section collimation [27].

In this pictorial essay we review our experience with multidetector row hCT and reconstruction software in the evaluation of liver involvement in a large group of HHT patients. The imaging findings obtained with this current hCT technique are shown, and the probable pathologic–radiologic correlations are discussed.

Technique

All studies discussed in this review were performed with a multiphasic technique consisting of a double arterial phase (arterial and arteriolar phases) and a portal venous phase. This type of liver study protocol has been proposed for the assessment of hypervascular hepatocellular carcinoma (HCC) [28–30], although discordant results have been obtained. Instead, the advantage of supplying a clear temporal separation among the arterial, arteriolar, and venous phases, with different enhancing patterns of parenchyma, arteries, portal, and hepatic veins, may help to detect hypervascular alterations other than HCC, such as shunts or arterial anomalies, thus reducing the risk of misdiagnosis [31].

All the examinations were performed on a four-row multidetector hCT (MX 8000, Marconi Medical System, Cleveland, OH, USA) and carried out with the following parameters: slice collimation, 2.5 mm; pitch, 1.25; increment, 0.6 mm; rotation time, 0.5 s; 120 kVp; and 250 mAs. Multiphasic CT scans were performed with the patients in supine position, through the region of clinical interest, beginning from the hepatic dome (location determined by the scout digital radiograph) and proceeding in a caudal direction to the lower margin of the kidneys. Nonionic contrast medium (Ultravist 370, Schering, Berlin, Germany) was injected into the cubital vein through a 16- to 18-gauge needle by an automatic injector (MK-IV, Medrad, Pittsburgh, PA, USA) by using the following parameters: volume, 1.5 mL/kg body weight with a maximal amount of 150 mL; flow rate, 4 mL/s. The scanning time delay was deter-
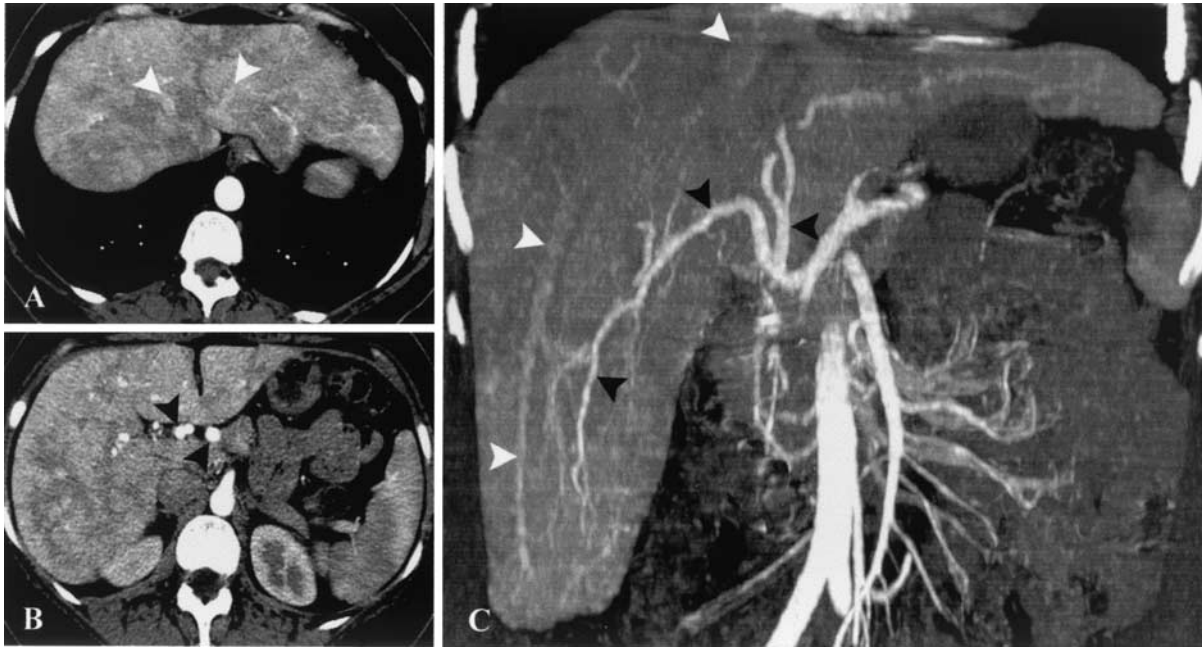
Fig. 2. A 46-year-old woman with recurrent episodes of epistaxis, mucocutaneous telangiectases, and a positive family history for HHT. **A, B** Contrast-enhanced axial CT images in the early arterial phase show early venous drainage with simultaneous evidence of hepatic veins (*white arrowheads*) and hepatic artery (*black arrowheads*) due to the presence of arteriosystemic shunting. The liver parenchyma is heterogeneous. **C** Three-dimensional MIP coronal reconstructed image better depicts the enhancement of the hepatic arteries (*black arrowheads*) and hepatic veins (*white arrowheads*). The hepatic veins have normal dimensions.

mined with a test bolus (20 mL at 4 mL/s) of contrast medium followed by a series of single-level CT scans at low dose (120 KVp, 10 mA).

The region of interest (10–20 mm^2) was placed over the abdominal aorta below the celiac trunk origin, and scans were acquired every second for 10 to 40 s. The time to peak aortic enhancement was used to determine the scanning delay for the first arterial phase images. The average scanning delay for the early arterial phase (arterial) was 20 s, and that for the late arterial phase (arteriolar or parenchymal), performed after an interscan delay of 5 s for table movement, was 35 s. The portal venous phase was performed 20 s after the end of the second arterial phase. The complete CT scan lasted no longer than 10 min in all cases.

For multiplanar and angiographic rendering, CT data sets were transferred over the Ethernet to a Kayak XU800 workstation (Hewlett Packard, Palo Alto, CA, USA) running VITREA 2.6 reconstruction software (Vital Images, Minneapolis, MN, USA). The application programs used for hepatic involvement assessment were MPR, three-dimensional MIP, and VR, which allowed manipulation of the data set to obtain multiplanar (axial, coronal, and sagittal) and angiographic reconstructions.

Intrahepatic shunts

The presence of intraparenchymal shunts is the most frequent finding associated with HHT disease. Three types of intrahepatic shunts between the major vessels of the liver are possible [32]: arterioportal (hepatic artery to portal vein), arteriosystemic (hepatic artery to hepatic vein), and portosystemic venous (portal vein to hepatic vein or vena cava). Visualization of these shunts on cross-sectional imaging was unusual, but the introduction of dynamic hCT, particularly in association with a multiphasic study protocol, makes their identification easier than in previous decades.

Arterioportal shunts

Intrahepatic arterioportal shunts consist of abnormal communications between the hepatic arteries and the portal veins. Although these shunts may occur in benign hepatic neoplasms or be the consequence of trauma or biopsy procedures, they are typically associated with cirrhosis and HCC in relation to the tendency for these neoplasms to grow in the portal veins [32]. In HHT they represent a congenital vascular malformation and the most common type of shunting isolated or in association with arteriosystemic shunts.

The multiphasic hCT findings of arterioportal shunting are indirect and include the early and prolonged enhancements of the portal vessels during the early arterial phase (Fig. 1). This phase is essential for diagnosing this type of shunt. In normal conditions, during the early arterial phase, the portal veins are not completely filled by the contrast medium, so they are not enhanced or only slightly hyperat-
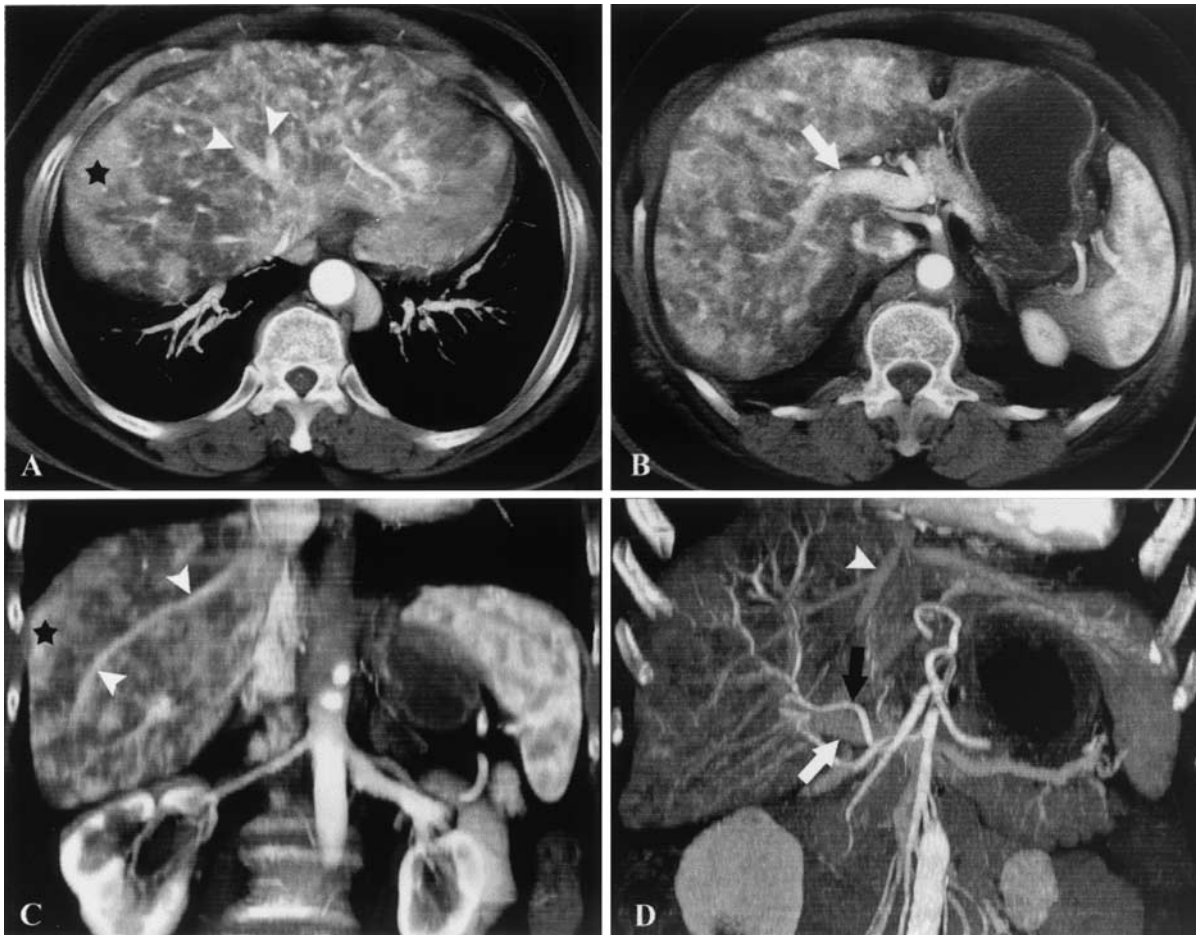
Fig. 3. A 64-year-old woman with epistaxis and a positive family history for HHT. (**A, B**) Volume-rendered three-dimensional axial and **C** coronal reconstructed images during the early arterial phase show an extremely heterogeneous liver parenchyma with peripheral THADs (*star*). The simultaneous visualization of the hepatic veins (*white arrowheads*), portal vein (*white arrow*), and hepatic artery (*black arrow*), better evident in the (**D**) coronal MPR reformatted image, is a sign of arteriosystemic and arterioportal intraparenchymal shunts.

tenuating. In the late arterial phase, the hepatic parenchyma, portal veins, and sometimes hepatic veins begin to be well enhanced, and this enhancement does not allow definite detection of this kind of hepatic vascular alterations. Like other nontumoral arterioportal shunts, this kind of shunts are typically subcapsular or peripheral and may be associated with focal, increased attenuation, wedge-shaped defects with early portal venous filling [33]. The presence of these areas of perfusion disorder often may be the only sign associated with the intraparenchymal arterioportal shunts.

The hepatic arteries are often enlarged, presumably due to the increased blood flow necessary to compensate for the reduction of hepatopetal portal flow and the decreased peripheral resistance. A dilated portal vein (diameter > 13 mm), often associated with collateral vessels and splenomegaly (longitudinal spleen diameter > 130 mm), is a common finding in HHT patients with arterioportal shunts and is related to the high-pressure blood flow that comes from the hepatic artery filling the portal veins. In the presence of these shunts, these are CT findings of a certain portal hypertension condition. In our experience, an enlarged portal vein also may be evident in patients with arteriosystemic shunts isolated or in association with arterioportal shunts; in this case, only a direct measure of the hepatic wedge pressure could ascertain the presence of portal hypertension. Therefore, in HHT patients, a dilated portal vein without other clinical or instrumental findings should not be interpreted as a definite sign of portal hypertension. However, intrahepatic arterioportal shunts in HHT infrequently may cause a life-threatening portal hypertension that requires emergency surgical or endovascular treatment [32].

Arteriosystemic shunts

These types of shunts, consisting of abnormal communications between hepatic arteries and hepatic veins, are considered rare and typically associated with benign and malignant liver neoplasms [32]. Isolated shunts or more often in asso-
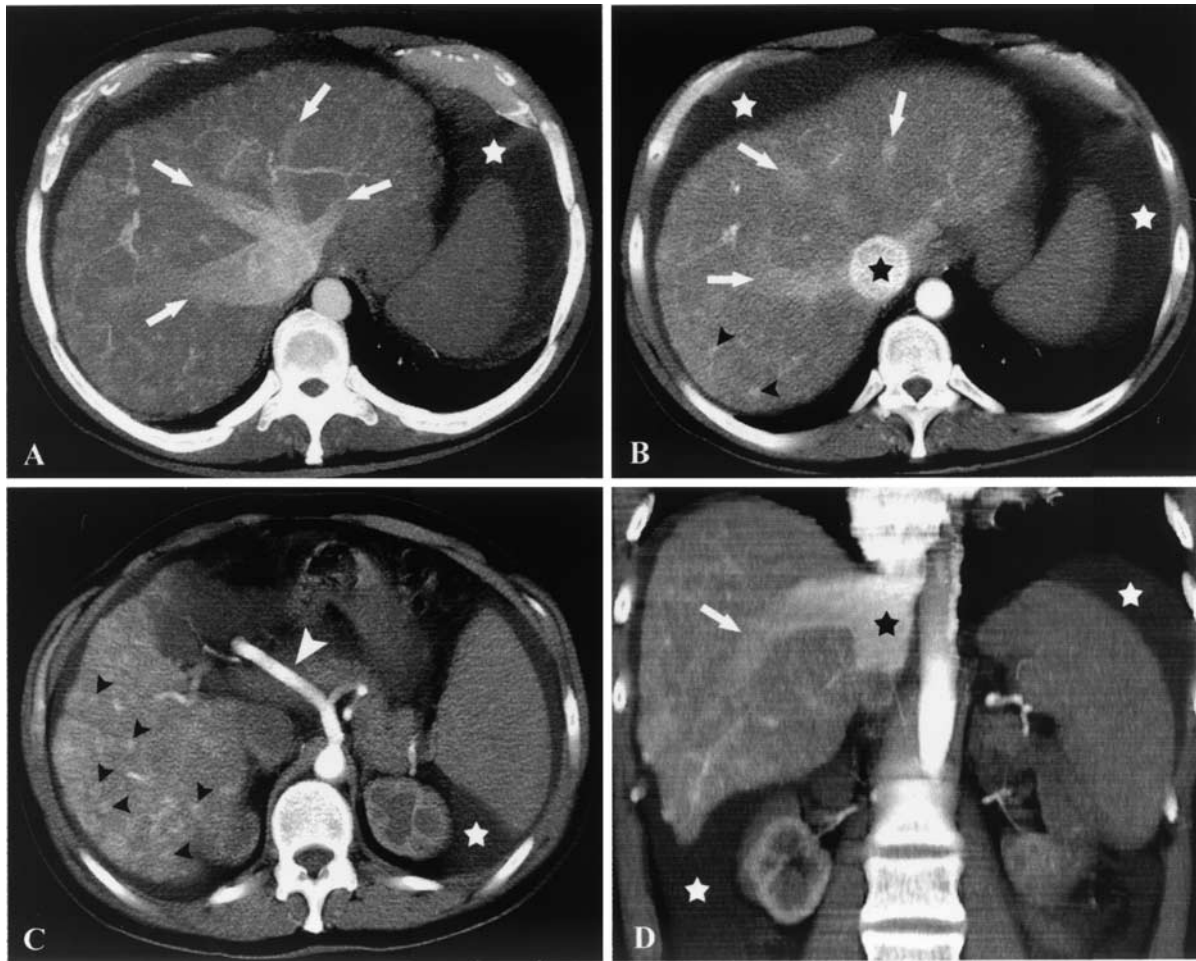
Fig. 4. A 38-year-old man with a history of recurrent epistaxis and congestive heart failure. (**A–C**) Axial three-dimensional MIP reconstructed images at different levels and (**D**) coronal three-dimensional MIP during the early arterial phase show simultaneous opacification of the hepatic artery (*white arrowhead*) and the hepatic veins (*arrows*) consisting of arteriosystemic shunts. Note the enlarged hepatic veins and inferior vena cava (*black stars*) and the perihepatic and perisplenic ascitic effusions (*white stars*). Some small telangiectases are also labeled (*black arrowheads*).

ciation with arterioportal shunts are a frequent finding in the liver parenchyma of HHT patients. Even in this case, their hCT visualization with a multiphasic study is an indirect finding and consists in the early enhancement of one or more than one hepatic veins during the early arterial phase. Usually, during a multiphasic study, hepatic veins become evident in the late phases: in accordance with contrast medium dynamics, the hepatic veins begin to be filled by contrast medium during the late arterial phase, become slightly hyperattenuating, and are completely filled by contrast medium and, hence, strongly enhanced only in the portal-venous phase. The simultaneous opacification of the hepatic artery and the hepatic veins during the early arterial phase is an indirect sign of early venous drainage related to arteriosystemic shunting (Figs. 2, 3). The early filled hepatic vein involved by the shunt may be enlarged.

A high-output cardiac failure attributed to the intrahepatic left-to-right shunt due to arteriosystemic venous shunts is a possible severe complication. In these patients, the CT finding of early visualization of hepatic veins and the inferior vena cava due to shunts also may be referred to the reflux of contrast-enhanced blood from the right atrium into the inferior vena cava and hepatic veins, which often may be enlarged (Fig. 4). These findings often are associated with other signs of passive hepatic congestion such as heterogeneous enhancement (reticulated-mosaic pattern) during the arterial phases and increase of the liver dimensions, including the left and caudate lobes. Ascites and splenomegaly, sometimes visible in these cases, are to be related to the stasis and not to a portal hypertension condition: the portal vein usually is not dilated and collateral vessels are not evident. In such cases with advanced symptoms, the thera-
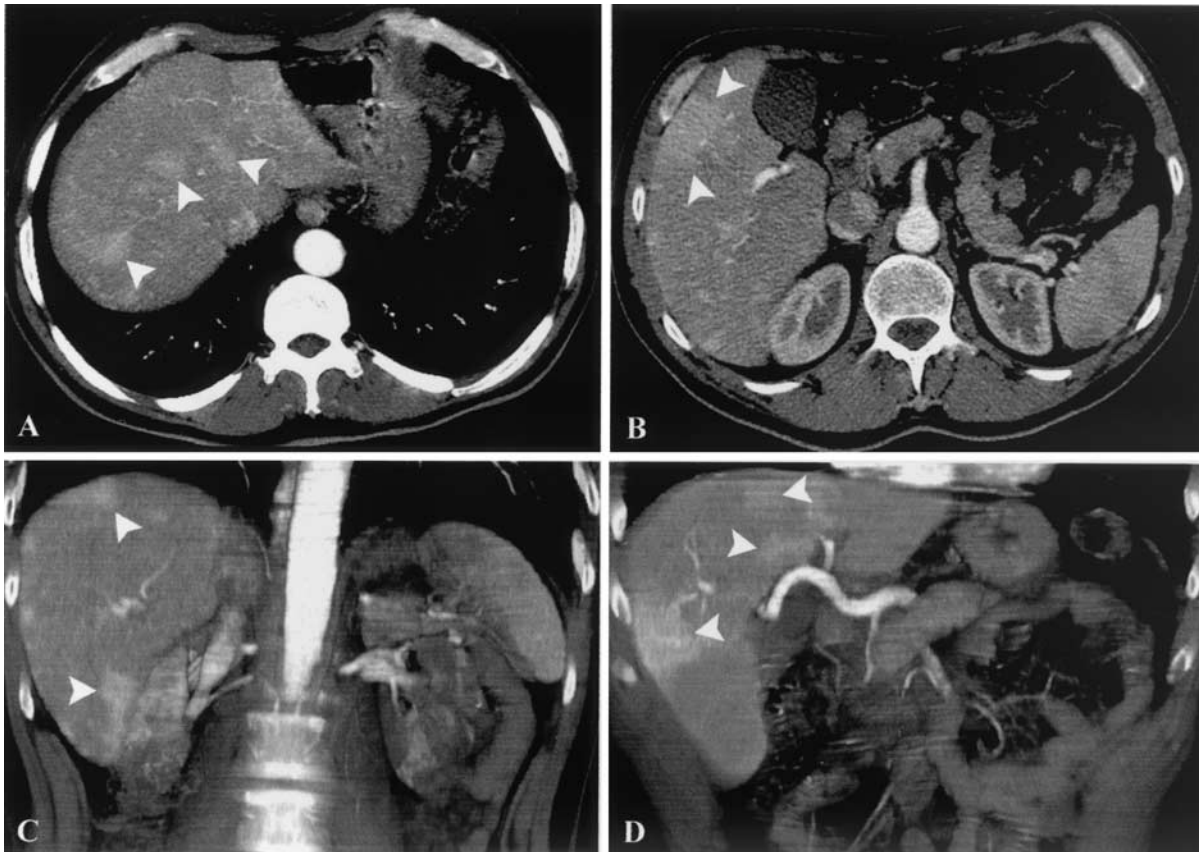
Fig. 5. A 67-year-old man with mucocutaneous telangiectases and rare episodes of epistaxis. **A, B** Contrast-enhanced axial CT scans at different levels in the late arterial phase show multiple high-attenuation areas (*white arrowheads*) with rounded or irregular margins depicting THADs. **C, D** Volume-rendered three-dimensional coronal reformatted images in the same arterial phase show the triangular shape and localization in the parenchymal hepatic periphery of these THADs areas.
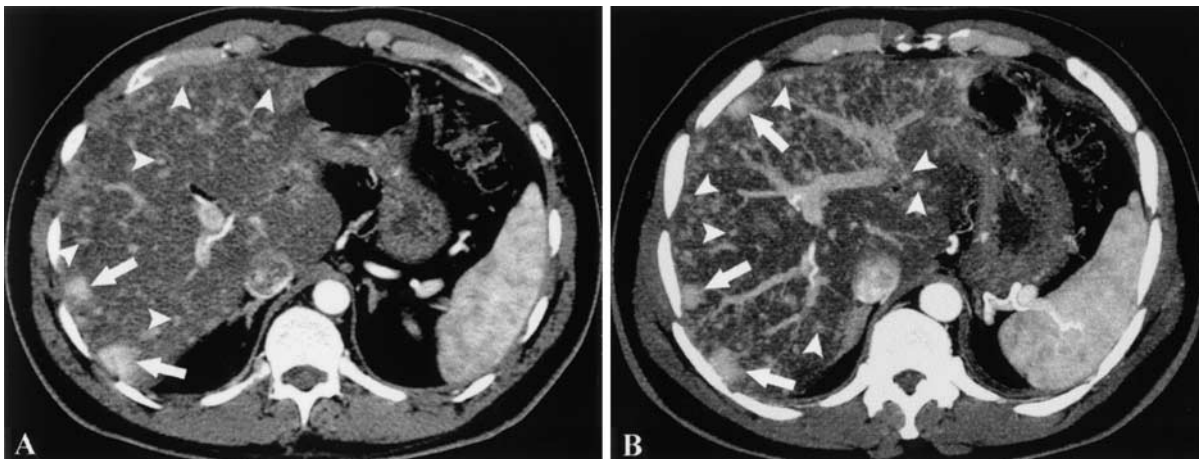

Fig. 6. A 45-year-old man with recurrent epistaxis, a positive family history of HHT, and pulmonary arteriovenous malformations. (**A**) Contrast-enhanced axial CT scan and (**B**) three-dimensional MIP axial reconstructed image during the late arterial phase show heterogeneous liver parenchyma due to the presence of several small, rounded vascular lesions (*arrowheads*) consisting of telangiectases and of some LCVMs in the parenchymal periphery (*arrows*).
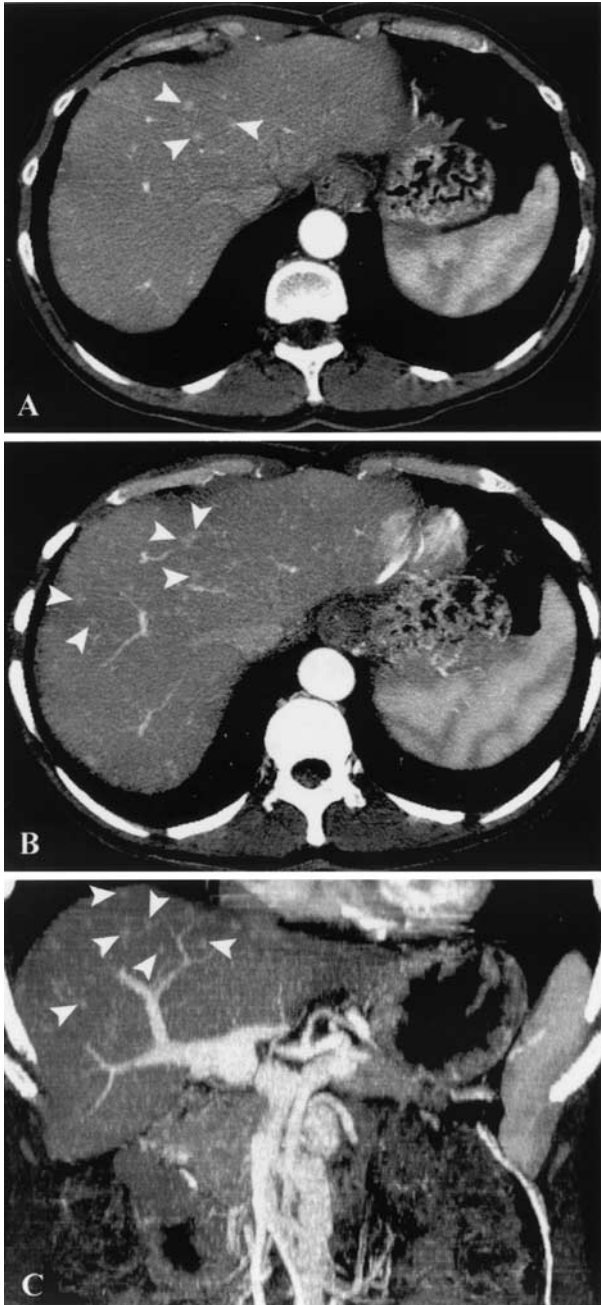
Fig. 7. A 42-year-old woman with several mucocutaneous telangiectases, epistaxis, and a positive family history of HHT. **A** Contrast-enhanced axial CT during the early arterial phase. Some small telangiectases are visible in the liver parenchyma (*arrowheads*). (**B**) Axial and (**C**) coronal three-dimensional MIP reconstructed images. The same vascular lesions are better evident and many others are recognizable (*arrowheads*).

peutic role of hepatic arterial embolization has been proposed [23, 34] but is controversial because of its unpredictable results and association with a high risk of fatal hepatic necrosis [35–37]; thus, liver transplantation remains the only therapeutic possibility [14, 38–40].

Portosystemic shunts

These type of shunts are usually found in patients with cirrhosis in relation to the increased portal venous pressure that causes the development of a myriad of extra- and intrahepatic portosystemic anastomoses to divert some portal venous blood directly into the systemic venous circulation [41]. The extrahepatic portosystemic collateral pathways are multiple and well known because they are always associated to a portal hypertension condition, whereas intrahepatic anomalous communications between portal veins and systemic veins are typically identified incidentally as part of the workup for cirrhosis or, less commonly, after a patient's condition has been diagnosed as hepatic encephalopathy [42, 43]. Only few cases of intrahepatic spontaneous portosystemic shunts have been reported in the literature and are rarely seen in HHT patients [17, 44]. Four different morphologic types have been described [42]: the most common type consists of a large vessel connecting the right portal vein to the inferior vena cava; the second type is a shunting between peripheral branches of portal and hepatic veins in one hepatic segment; the third type consists of an aneurysmal peripheral connection between portal and hepatic veins; and the fourth type has multiple communications between peripheral portal and hepatic veins diffusely in both lobes.

The angiographic and sonographic findings of these types of shunts recently have been well described [45, 46], but portosystemic venous shunts may be difficult to detect with hepatic angiography in patients with predominant arteriosystemic shunts. In these patients, high-pressure arterial flow from the hepatic artery via arteriovenous shunts is present in hepatic veins, and pulsed or color Doppler examination may be helpful to detect small arterioportal shunts and proximally located portosystemic shunts [46]. CT diagnosis remains difficult, probably due to the impossibility, even with a multiphasic liver study, to clearly separate a "portal" from a "venous" phase and "early" arterial from "late" arterial from portal-venous phase. Thus, the only CT finding is direct evidence during the portal-venous phase of dilated portal veins communicating with a large systemic or hepatic vein. Sometimes the communication is seen as dilated paraumbilical veins with an intrahepatic course [47].

We do not have cases of direct visualization of a communication between these two vascular channels, but their presence always must be sought, especially before embolization treatment in symptomatic patients. In presence of this type of shunt, the liver is supplied by blood from the hepatic artery alone because much of the portal blood flow enters the hepatic veins directly through these shunts. In this case, portal blood flow to the liver will be inadequate after hepatic artery embolization, and life-threatening liver infarction will occur [46].

Perfusion disorders

Intraparenchymal perfusion disorders such as transient hepatic attenuation differences (THADs) represent the epiphe-
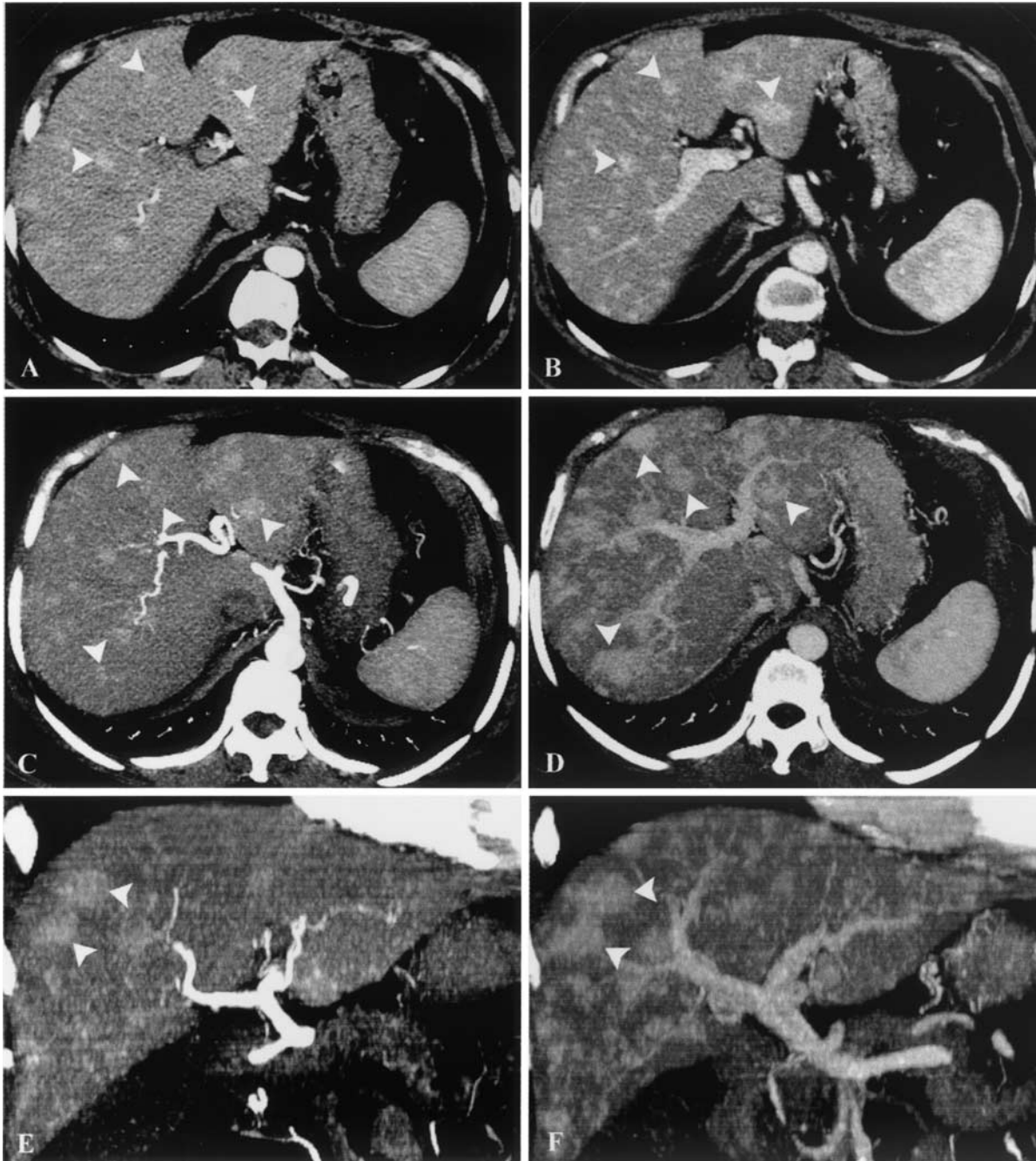
Fig. 8. A 62-year-old woman with a positive family history of HHT and several mucocutaneous telangiectases. *Early arterial phase:* (**A**) contrast-enhanced axial CT image, (**C**) three-dimensional MIP axial image at the same level, and (**E**) coronal reconstructed image. Some rounded lesions consisting of LCVMs are visible (*arrowheads*). *Late arterial phase:* (**B**) contrast-enhanced axial CT scan at the same level as **A**, (**D**) three-dimensional MIP axial image, and (**F**) coronal reconstructed image. The vascular lesions seen in the early arterial phase are more evident (*arrowheads*), but the portal vessels are enhanced and other vascular structures are evident. Note that the MIP images better depict these vascular lesions. Several telangiectases are also evident.

nomenon of alterations of the dual hepatic vascular system (70–75% portal vein, 25–30% hepatic artery), and their most common cause is low portal inflow due to obstruction (e.g., thrombosis of a portal vessel) in forms not associated with focal lesions and due to compression in those with associated focal lesions, even though some malignancies and abscesses can induce thrombosis. In HHT patients, this phenomenon is frequently associated with the presence of arterioportal shunts, reflecting the blood flow alteration induced by the shunt, and its evidence should be interpreted as another

indirect sign of the presence of these types of shunts. Indeed, the presence of shunts determines a diversion of the portal flow by a higher-pressure arterial flow, thereby creating a relatively low portal inflow that induces a compensatory preferential redistribution of arterial flow to a hepatic lobe or segment that therefore appears enhanced [18, 48]. Thus, in THADs related to arterioportal shunting, there is no portal block but a mixing of arterial and venous blood. These hepatic perfusion disorders appear during the arterial phases as high-attenuation parenchymal areas that become isoattenuating on portal-phase images. Such areas of transient enhancement are usually peripheral and wedge shaped with straight margins and of lobar, segmental, or subsegmental distribution [49], but sometimes they display globular or pseudo-globular morphology: the axial section of a conical shape may appear round or oval (Fig. 5) [50, 51]. Hence, they are not distinguishable from small HCC foci and in these cases differential diagnostic problems may arise.

Vascular lesions

The disorders of angiogenesis control mechanisms typical of HHT may explain the occurrence of other lesion-like vascular abnormalities in the liver parenchyma: telangiectases and large confluent vascular masses (LCVMs).

We consider as parenchymal hepatic telangiectases the rounded, strongly enhanced lesions with a diameter smaller than 10 mm and a predominantly peripheral arrangement. These vascular ectasias are, perhaps, analogous to those found on the nose, skin, and in the gastrointestinal tract and appear as round formations, with a diameter of 5 to 7 mm, which form relations with vascular branches having their same attenuation (Figs. 1, 4, 6). These small vascular spots also are better recognizable in the reconstructed MPR and MIP images that enhance the difference in density between hepatic parenchyma and vascular structures (Fig. 7).

The term *LCVMs*, not mentioned before in the literature, has been introduced by us to describe the aspect and likely underlying formation process of the lesions with a diameter larger than 10 mm. In our experience, they appear as large vascular pools characterized by early and persistent enhancement during the arterial phases after contrast medium injection (Figs. 1, 6). Presumably they are large areas of multiple telangiectases that coalesce or large shunts that are directly visible. Sometimes LCVMs represent THADs with globular or pseudo-globular morphology or capillary hemangiomas.

The number and size of these vascular lesions increase in the late arterial phase, but their differentiation from vascular branches is easier during the first arterial phase because of lesser enhancement of the portal and hepatic veins and of the hepatic parenchyma (Fig. 8).

Conclusions

The assessment of hepatic involvement in HHT patients is important from the clinical point of view because the pres-

ence of any vascular alterations has a higher frequency than reported and, even if usually asymptomatic, may induce serious complications. Diagnosis of the pathology is based on clinical and historical data, and diagnostic imaging has a fundamental role in detecting the disorders involving the different anatomic regions. The possibility to perform a multiphasic study of the liver and to provide high-quality multiplanar and angiographic reconstructions gives multidetector row hCT the ability to detect and characterize the complex anatomopathologic alterations typical of this disease.

References

1. Dakeishi M, Shioya T, Wada Y, et al. (2002) Genetic epidemiology of hereditary hemorrhagic telangiectasia in a local community in the northern part of Japan. Hum Mutat 19:140–148
2. Kjeldsen AD, Vase P, Green A (1999) Hereditary hemorrhagic telangiectasia, HHT. A population based study of prevalence and mortality in Danish HHT patients. J Intern Med 245:31–41
3. Plauchu H, de Chadarevian JP, Bideau A, Robert JM (1989) Age-related clinical profile of hereditary hemorrhagic telangiectasia in an epidemiologically recruited population. Am J Med Genet 32:291–297
4. Shovlin CL, Guttmacher AE, Buscarini E, et al. (2000) Diagnostic criteria for hereditary hemorrhagic telangiectasia (Rendu-Osler-Weber syndrome). Am J Med Genet 91:66–67
5. Marchuk DA, Guttmacher AE, Penner JA, Ganguly P (1998) Report on the workshop on hereditary hemorrhagic telangiectasia, July 10–11, 1997. Am J Med Genet 76:269–273
6. Guttmacher AE, Marchuk DA, White RI Jr. (1995) Hereditary hemorrhagic telangiectasia. N Engl J Med 333:918–924
7. Buscarini E, Buscarini L, Civardi G, et al. (1994) Hepatic vascular malformations in hereditary hemorrhagic telangiectasia: imaging findings. AJR 163:1105–1110
8. McAllister KA, Grogg KM, Johnson DW, et al. (1994) Endoglin, a TGF-beta binding protein of endothelial cells, is the gene for hereditary haemorrhagic telangiectasia type 1. Nat Genet 8:345–351
9. Berg JN, Gallione CJ, Stenzel TT, et al. (1997) The activin receptor-like kinase 1 gene: genomic structure and mutations in hereditary hemorrhagic telangiectasia type 2. Am J Hum Genet 61:60–67
10. Johnson DW, Berg JN, Baldwin MA, et al. (1996) Mutations in the activin receptor-like kinase 1 gene in hereditary hemorrhagic telangiectasia type 2. Nat Genet 13:189–195
11. Shovlin CL, Letarte M (1999) Hereditary haemorrhagic telangiectasia and pulmonary arteriovenous malformations: issues in clinical management and review of pathogenic mechanisms. Thorax 54:714–729
12. Reilly PJ, Nostrant TT (1984) Clinical manifestations of hereditary hemorrhagic telangiectasia. Am J Gastroenterol 79:363–367
13. Bernard G, Mion F, Henry L, et al. (1993) Hepatic involvement in hereditary hemorrhagic telangiectasia: clinical, radiological and hemodynamic studies of 11 cases. Gastroenterology 105:482–487
14. Garcia-Tsao G, Korzenik JR, Young L, et al. (2000) Liver disease in patient with hereditary hemorrhagic telangiectasia. N Engl J Med 343:931–936
15. Cloogman HM, Di Capo RD (1984) Hereditary hemorrhagic telangiectasia: sonographic findings in the liver. Radiology 150:521–522
16. Ralls PW, Johnson MB, Radin DR, et al. (1992) Hereditary hemorrhagic telangiectasia: findings in the liver with color Doppler sonography. AJR 159:59–61
17. Naganuma H, Ishida H, Niizawa M, et al. (1995) Hepatic involvement in Osler-Weber-Rendu disease: findings on pulsed and color Doppler sonography. AJR 165:1421–1425
18. Quiroga S, Sebastia C, Pallisa E, et al. (2001) Improved diagnosis of hepatic perfusion disorders: value of hepatic arterial phase imaging during helical CT. Radiographics 21:65–81
19. Vilgrain V, Menu Y, Nahum H (1991) Doppler sonography in Osler-Weber-Rendu disease. AJR 157:413–414
20. Bodner G, Peer S, Karner M, et al. (2002) Nontumorous vascular malformations in the liver. Color Doppler ultrasonographic findings. J Ultrasound Med 21:187–197

21. Nyman U (1977) Angiography in hereditary hemorrhagic telangiectasia. Acta Radiol Diagn (Stockh) 18:581–592
22. Thomas ML, Carty H (1974) Hereditary hemorrhagic telangiectasia of the liver demonstrated angiographically. Acta Radiol Diagn (Stockh) 15:433–438
23. Chavan A, Galanski M, Wagner S, et al. (1998) Hereditary hemorrhagic telangiectasia: effective protocol for embolization of hepatic vascular malformations—experience in five patients. Radiology 209:735–739
24. Varma DG, Schoenberger SG, Kumra A, et al. (1989) Osler-Weber-Rendu disease: MR findings in the liver. J Comput Assist Tomogr 13:134–135
25. Manfredi R, De Gaetano AM, Natale L (1993) Non-invasive integrated imaging of Rendu-Osler disease with hepatic involvement. Radiol Med (Torino) 86:922–925
26. Bonomo L, Carriero A, Maggialetti A (2001) Storia di una metodica. In: Bonomo L, Carriero A, Maggialetti A (eds) Angiografia con risonanza magnetica—circolo periferico, 1st ed. Idelson-Gnocchi, Naples, Italy, pp 3–15
27. Rydberg G, Buckwalter KA, Caldemeyer KS, et al. (2000) Multisection CT: scanning techniques and clinical application. Radiographics 20:1787–1806
28. Murakami T, Kim T, Takamura M, et al. (2001) Hypervascular hepatocellular carcinoma: detection with double arterial phase multi-detector row helical CT. Radiology 218:763–767
29. Kim T, Murakami T, Hori M, et al. (2002) Small hypervascular hepatocellular carcinoma revealed by double arterial phase CT performed with single breath-hold scanning and automatic bolus tracking. AJR 178:899–904
30. Ichikawa T, Kitamura T, Nakajima H, et al. (2002) Hypervascular hepatocellular carcinoma: can double arterial-phase imaging with multidetector CT improve tumor depiction in the cirrhotic liver?. AJR 179:751–758
31. Murakami T, Kim T, Takahashi S, Nakamura H (2002) Hepatocellular carcinoma: multidetector row helical CT. Abdom Imaging 27:139–146
32. Lane MJ, Jeffrey RB, Katz DS (2000) Spontaneous intrahepatic vascular shunts. AJR 174:125–131
33. Kim TK, Choi BI, Han JK, et al. (1998) Nontumorous arterioportal shunt mimicking hypervascular tumor in cirrhotic liver: two-phase spiral CT findings. Radiology 208:597–603
34. Caselitz M, Wagner S, Chavan A, et al. (1998) Clinical outcome of transfemoral embolization in patients with arteriovenous malformation of the liver in hereditary haemorrhagic telangiectasia (Weber-Rendu-Osler disease). Gut 42:123–126
35. Jackson JE (1999) Hepatic vascular malformations in hereditary hemorrhagic telangiectasia: treatment with embolization. Radiology 213:927–928
36. Miller FJ, Whiting JH Jr., Korzenik JR, White RI (1999) Caution with use of hepatic embolization in the treatment of hereditary hemorrhagic telangiectasia. Drs Chavan and colleagues respond. Radiology 213:928–930
37. Whiting JH Jr., Korzenik JR, Miller FJ, et al. (2000) Fatal outcome after embolotherapy for hepatic arteriovenous malformation of the liver in two patients with hereditary hemorrhagic telangiectasia. J Vasc Interv Radiol 11:855–858
38. Bauer T, Britton P, Lomas D, et al. (1995) Liver transplantation for hepatic arteriovenous malformation in hereditary hemorrhagic telangiectasia. J Hepatol 22:586–590
39. Boillot O, Bianco F, Viale JP, et al. (1999) Liver transplantation resolves the hyperdynamic circulation in hereditary hemorrhagic telangiectasia with hepatic involvement. Gastroenterology 116:187–192
40. Pfitzmann R, Heise M, Langrehr JM, et al. (2001) Liver transplantation for treatment of intrahepatic Osler's disease: first experiences. Transplantation 72:237–241
41. Ito K, Higuchi M, Kada T, et al. (1997) CT of acquired abnormalities of the portal venous system. Radiographics 17:897–917
42. Park JH, Cha SH, Han JK, Han MC (1990) Intrahepatic portosystemic venous shunt. AJR 155:527–528
43. Mori H, Hayashi K, Fukuda T, et al. (1987) Intrahepatic portosystemic venous shunt: occurrence in patients with and without liver cirrhosis. AJR 149:711–714
44. Michaeli D, Ben-Bassat I, Miller HI, Deutsch V (1968) Hepatic telangiectases and portosystemic encephalopathy in Osler-Weber-Rendu disease. Gastroenterology 54:929–932
45. Matsuo M, Kanematsu M, Kato H, et al. (2001) Osler-Weber-Rendu disease: visualizing portovenous shunting with three-dimensional sonography. AJR 176:919–920
46. Hashimoto M, Tate E, Nishii T, et al. (2003) Angiography of hepatic vascular malformations associated with hereditary hemorrhagic telangiectasia. Cardiovasc Intervent Radiol 26:177–180
47. Itai Y, Kurosaki Y, Saida Y, et al. (1994) CT and MRI in detection of intrahepatic portosystemic shunts in patients with liver cirrhosis. J Comput Assist Tomogr 18:768–773
48. Oliver JH III, Baron RL (1996) Helical biphasic contrast-enhanced CT of the liver: technique, indications, interpretation, and pitfalls. Radiology 201:1–14
49. Chen WP, Chen JH, Hwang JI, et al. (1999) Spectrum of transient hepatic attenuation differences in biphasic helical CT. AJR 172:419–424
50. Colagrande S, Centi N, Carmignani L, et al. (2003) Meaning and etiopathogenesis of sectorial transient hepatic attenuation differences (THAD). Radiol Med 105:180–187
51. Itai Y, Matsui O (1997) Blood flow and liver imaging. Radiology 202:306–314