Radioembolization: Identifying and Managing Anatomic Variants

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Abstract

Radioembolization treatment carries the risk of non-target embolization as well as of incomplete treatment. The distribution of microspheres reflects the arterial vascular territory subtended by the injected arteries. Thus, it is important to recognize anatomic variants in hepatic arterial anatomy. These variants include congenital accessory and replaced arteries supplying portions of the liver and the tumors within, as well as parasitized non-hepatic arteries recruited to supply arterial blood to intrahepatic tumors. Several different strategies allow more safe and complete radioembolization preparation and treatment in the presence of these variants. Consolidation or redistribution of flow may be performed to simplify or to increase the safety of microsphere administration. Likewise, parasitized extrahepatic vessels may be embolized to restore intrahepatic flow to tumors, thus, limiting risk for non-target embolization and increasing completeness of treatment. Both scenarios require close attention to tumor blood supply and recognition of arterial variants.

1 Normal, Variant, and Parasitized Extrahepatic Arterial Supply to the Liver

Standard hepatic arterial anatomy and its variants were described by Michels based on his study of 200 cadavers (Michels 1966). He defined ten configurations of hepatic arterial variants. Of these, the most common was a trifurcation of the celiac artery into the splenic, left gastric artery (LGA), and common hepatic arteries (CHA). The CHA bifurcated into the proper hepatic (PHA) and gastroduodenal arteries (GDA). The PHA in turn bifurcated into a right hepatic artery (RHA) and left hepatic artery (LHA). A segment IV artery that arose off the RHA was termed a

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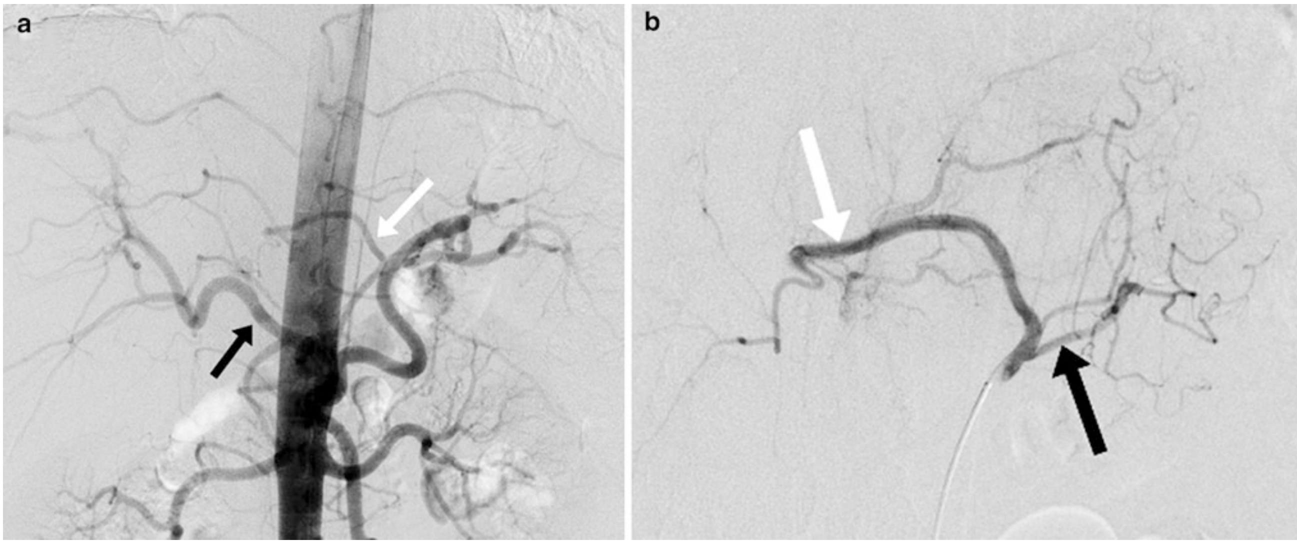

Fig. 1 53-year-old male with small bowel adenocarcinoma metastatic to the liver undergoing radioembolization preparatory angiogram. **a** Aortogram showed a replaced left hepatic artery (*white arrow*) arising off the left gastric. Note the lack of any arteries feeding the left hepatic lobe arising from the proper hepatic artery (*black arrow*), **b** Selective angiogram of the gastrohepatic trunk confirmed the replaced left hepatic artery (*white arrow*) sharing a common origin as the left gastric artery (*black arrow*). This represents a Michels Type II configuration of hepatic arterial anatomy and is the most common variant

Table 1 Michels classification of variant hepatic arterial anatomy

Michels type	Description	Incidence[a] (%)
I	Standard anatomy with right hepatic, middle hepatic, and left hepatic arising from the celiac axis	55
II	Replaced left hepatic from left gastric artery	11
III	Replaced right hepatic from superior mesenteric artery	10
IV	Replaced right hepatic from superior mesenteric artery; replaced left hepatic from the left gastric artery; middle hepatic from celiac artery	1
V	Accessory left hepatic from left gastric artery	8
VI	Accessory right hepatic from superior mesenteric artery	7
VII	Accessory right hepatic from superior mesenteric artery; accessory left hepatic from left gastric artery	1
VIII	Combination of replaced right hepatic with accessory left hepatic OR accessory right hepatic with replaced left hepatic	2
IX	Common hepatic from superior mesenteric artery	2.5
X	Common hepatic from the left gastric artery	<1

[a] Denotes incidence in Michels' study of 200 cadavers

middle hepatic artery, or segment IV could originate from the LHA. Although this configuration was called "standard" or "normal," it was only found in 55 % of subjects. Other common variants included a replaced left hepatic artery (rLHA) arising from the left gastric artery seen in 11 % of patients (Fig. 1), a replaced right hepatic artery (rRHA) arising from the superior mesenteric artery (SMA) seen in 10 % of patients, and an accessory left hepatic artery (aLHA) arising from the LGA seen in 8 % of patients. Table 1 shows a complete list of anatomic variants according to the Michels classifications.

A study evaluating 600 patients that had undergone angiography showed a similar distribution of patients with variant hepatic arterial anatomy (Covey et al. 2002). Standard anatomy was seen in 61.3 % of patients. The most common variant was an aLHA arising from the LGA in 10.7 % of patients, and an rRHA from the SMA in 8.7 % of patients. In addition, several other variants were present that were not mentioned in Michels' study, including an origin of the CHA directly from the aorta, and a "double hepatic" artery where one or both of the left and right hepatic arteries arose directly from the aorta or from the celiac artery. These

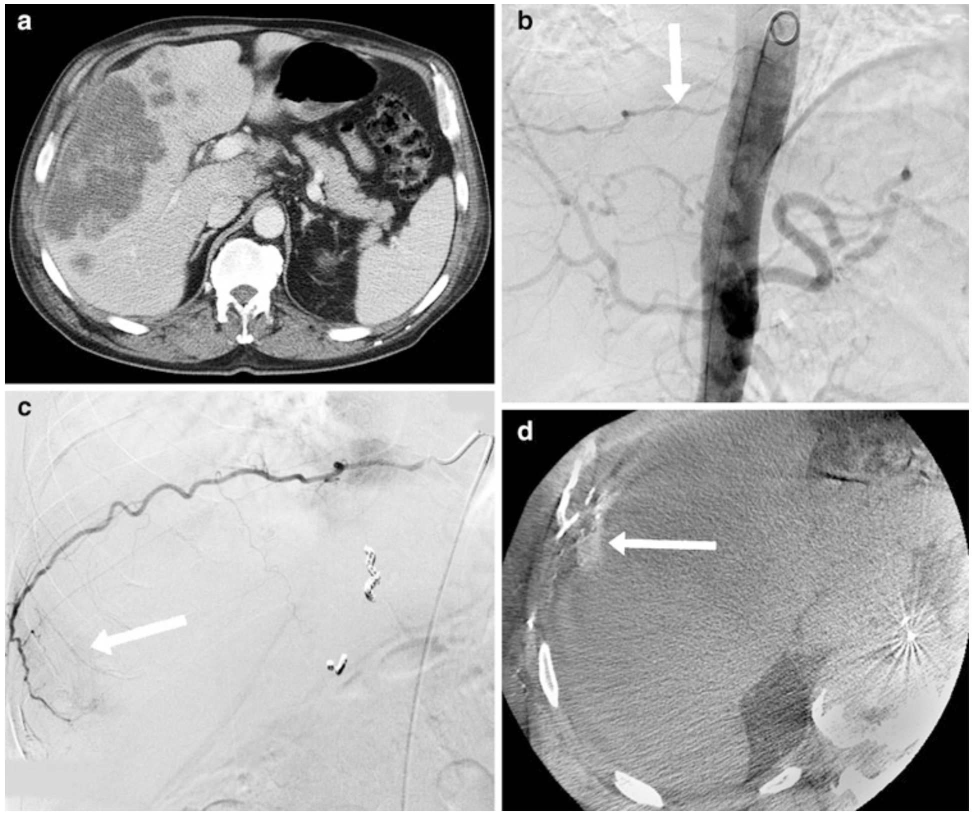

Fig. 2 63-year-old male with cholangiocarcinoma undergoing radioembolization preparatory angiogram. **a** Pre-procedure CT scan showed a large tumor along the anterolateral margin of the right lobe of the liver, **b** Aortogram showed a hypertrophied right T9 intercostal artery (*white arrow*), **c** Selective angiography of T9 showed tumor blush (*white arrow*), **d** CACT on selective injection of the right T9 intercostal artery confirmed tumor enhancement (*white arrow*). To deliver radioactive microspheres to this territory, the parasitized intercostal artery was pre-emptively bland embolized with large particles to re-establish intrahepatic perfusion from the hepatic artery

two studies demonstrate the wide variability that can occur with variant hepatic arterial anatomy.

The perihilar plexus includes arteries that provide a communicating arcade between the right and left hepatic arteries (Tohma et al. 2005). This arcade connects the segment IV branch or the main LHA with the main or anterior trunk of the RHA. Intrahepatic communications between segments also exist, and provide collateral flow when branch hepatic arteries are occluded or compromised. These interlobar and intersegmental communicating branches were described several decades ago during studies of patients after hepatic arterial ligation for trauma or tumor treatment. Proximal interruption of any major hepatic artery, such as the RHA or LHA, results in near immediate filling via cross collaterals of the occluded branch (Charnsangavej et al. 1982; Mays and Wheeler 1974). This property was successfully exploited over 30 years ago in consolidation of flow for intra-arterial chemotherapy (Chuang and Wallace 1980). Familiarity with and evaluation of these arcades are important in expanding options concerning catheter placement for radioembolization.

Michels also recognized the importance of extrahepatic blood supply to the liver. He categorized 16 different routes, apart from the hepatic arterial variants, from which blood could supply parts of the liver (Michels 1966). The extrahepatic branches described included inferior phrenic, internal mammary, and intercostal arteries (Fig. 2). Other studies have shown that tumors near the surface of the liver are more likely to recruit extrahepatic blood supply, which become particularly evident when there has been compromise of normal intrahepatic arteries, for instance, from intra-arterial therapies (Seki et al. 1998). Parasitized extrahepatic arteries frequently supply tumors at the bare area of the liver, even prior to any treatment, and are a cause of recurrence after chemoembolization of intrahepatic supplying branches (Miyayama et al. 2010). Therefore, these potential routes require close attention and appropriate recognition in the evaluation of radioembolization patients, since unmanaged they can lead to incomplete treatment and recurrence after treatment.

Special attention should be paid to several suspect vessels that are the most common parasitized extrahepatic arterial sources of tumor supply, which can be found in about 18 % of untreated patients. The most common is the right inferior phrenic artery, which one study found to be the supply in almost half of all patients where an extrahepatic source was found (Chung et al. 2006). The same study found that greater omental arteries were the extrahepatic source in 15.6 % of cases, with cystic, adrenal, and intercostal arteries accounting for 5.4–8.8 % each. Much less frequent were left and right gastric, right and left internal mammary, renal or renal capsular, superior mesenteric, left inferior phrenic, and pancreaticoduodenal arteries.

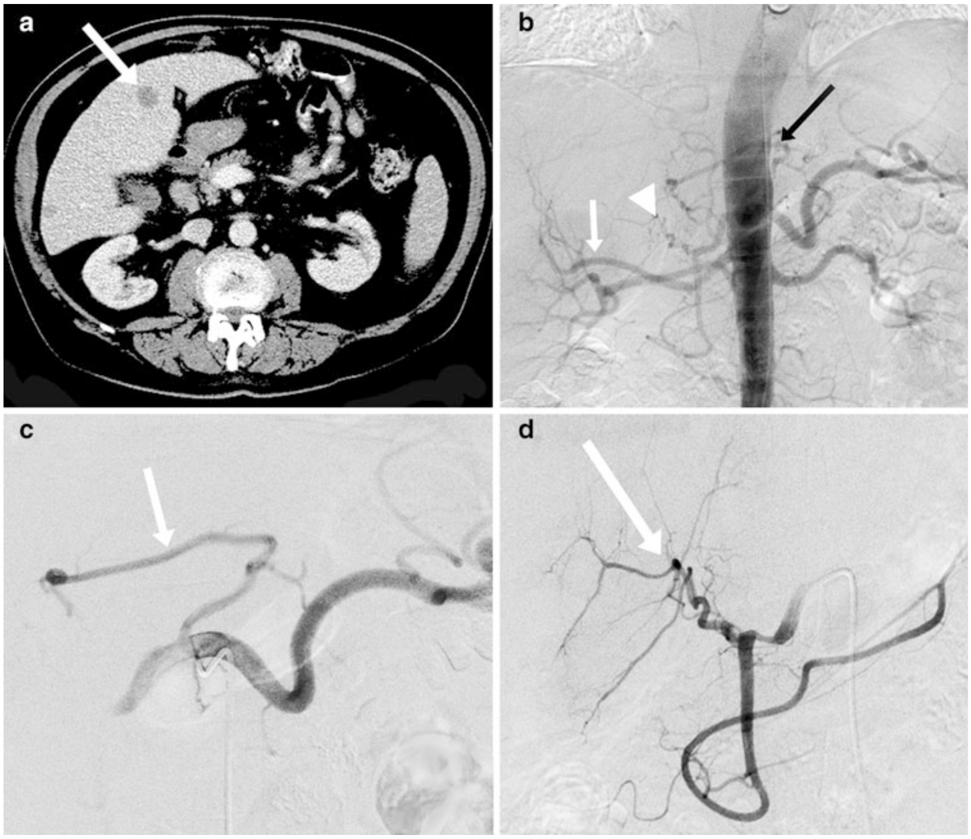

Fig. 3 74-year-old male with rectal cancer metastatic to the liver undergoing radioembolization preparatory angiogram. **a** Pre-procedure CT scan showed bilobar metastases including in segment 4 (*white arrow*), **b** Aortogram showed a replaced right hepatic artery (*white arrow*), accessory left hepatic artery (*black arrow*), and a segment 4 artery arising off the proper hepatic artery (*white arrowhead*), **c** Selective angiography of the celiac artery confirmed the accessory left hepatic artery (*white arrow*), **d** Common hepatic arteriogram better demonstrated the segment 4 artery arising off the proper hepatic artery (*white arrow*). In this instance, embolization of the segment 4 artery could be performed to consolidate flow to the replaced right and left hepatic arteries in order to reduce the number of treatment sites

For optimum treatment–complete treatment of all intrahepatic tumors and avoidance of intra and extrahepatic nontarget embolization-hepatic arterial variants, and parasitized extrahepatic vessels need to be addressed during planning of radioembolization.

2 Redistribution and Consolidation of Hepatic Arterial Flow

2.1 Redistribution

Intrahepatic collateral vessels can supply arterial flow to tumors across segments or lobes. Selective embolization of intrahepatic branches to redistribute intrahepatic flow patterns to the tumors has been shown to be effective and safe (Karunanithy et al. 2011; Bilbao et al. 2010). During evaluation of intrahepatic arterial tumor supply, multiple feeding vessels may be identified, often in close proximity to hepatico-enteric or hepatico-splanchnic vessels. Although, pre-emptive coil embolization of the hepatico-enteric vessels imparts a high degree of safety, some vessels may be too small or angulated to allow this skeletonization. Embolizing one or more intrahepatic feeding branches can reduce the number of sites of administration of radioactive microspheres, and can facilitate administration distal to recognized hepatico-enteric vessels. For instance, a disadvantageous segment IV artery with small ductal artery branches can be coil embolized so that arterial supply to that segment is taken over by branches of the LHA or RHA or both (Fig. 3). Alternatively, coil embolization of a segment VIII artery supplying the lateral edge of a left lobe tumor can reduce treatment to only the LHA, sparing the remainder of the right lobe.

In a study of 24 patients, 11 of whom had Michels Type I anatomy, single photon emission computed tomography (SPECT) combined with computed tomography (CT) performed after administration of technetium macroaggregated albumin (^{99m}TC-MAA) showed uptake in the redistributed areas in all 11 Michels Type I patients (Bilbao et al. 2010). Branches embolized include segment IV, segment VIII, and LHA. In a separate study, 11 patients underwent

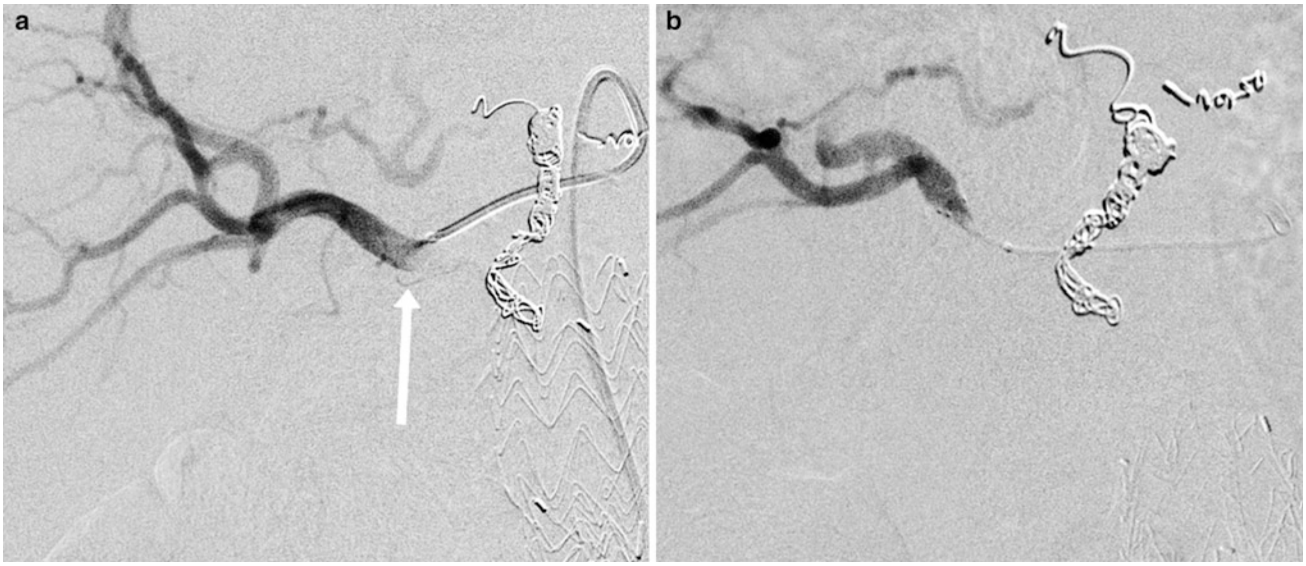

Fig. 4 69-year-old male with colorectal cancer metastatic to the liver undergoing radioembolization treatment. **a** Angiography of a replaced right hepatic artery arising from the SMA revealed small proximal branches supplying duodenum (*white arrow*), **b** Because of the multiplicity, small sizes, and acute angulations, the arteries could not be coil embolized and a reflux protection device (Surefire Medical Inc., Westminster, CO) was used to reduce the risk of radioembolic bead delivery to the bowel. A great deal of biological variability is found in the enteric branching patterns of replaced and accessory right hepatic arteries

embolization of the anterior division RHA, RHA, segment IV, or LHA to redistribute flow for administration of radioactive microspheres (Karunanithy et al. 2011). Post-treatment PET showed a statistically significant decrease in standardized uptake values (SUV). These studies demonstrate that embolization of intrahepatic branches from either the left lobe or right lobe can successfully redistribute flow to simplify and increase the safety of treatment. It is important to note that both studies performed embolization with coils only. More distal embolization using particles would lodge in the tumor at the arteriolar level (Lee et al. 2008). This could theoretically prevent radioactive microspheres from reaching the tumor.

2.2 Consolidation

A similar technique for management of variant hepatic arteries can be used. The goal of consolidation is to create a simpler and safer arterial anatomy for the administration of radioactive microspheres. Since many variant hepatic arteries arise off of branches that also supply the gastrointestinal tract, non-target radioembolization is an increased risk (Riaz et al. 2009). For instance, administration in the rLHA or aLHA originating from the LGA can result in reflux into esophageal and gastric branches just proximal to the course of the variant artery in the fissure of the ligamentum venosum. Likewise, the rRHA or aRHA frequently gives off small branches to the duodenum, and arises from the main SMA, which supplies nearly the entire bowel (Fig. 4). One early study on radioembolization safety consolidated variant hepatic arteries with resultant reconstitution of flow by intrahepatic collaterals and is important because it demonstrated that consolidation is able to limit toxicity, although treatment efficacy was not fully assessed (Andrews et al. 1994). Consolidation by coil embolization of variant or redundant arteries provides a way to achieve distribution of microspheres to the targeted tumors while minimizing non-target deposition complication risk to the patient.

In evaluating for any evidence of variant anatomy, all prior cross-sectional imaging, either contrast enhanced computed tomography (CT) or magnetic resonance (MR) imaging, should be closely studied. Thin-section arterial phase breath-held imaging is the most useful, if available, and coronal and sagittal reformatted images may help to confirm existence, origin, and course of variant vessels. Identified anatomic variants should be compared to the intrahepatic tumor distribution to predict dominant arterial supply to the targeted regions. Scrutiny of cross-sectional imaging will guide and possibly even expedite the preparatory angiography prior to radioembolization treatment.

During preparatory phase angiography, abdominal aortography is performed with injection of contrast medium at up to 15 cc/sec for 30 cc with the flush catheter at the level of mid to lower thorax (T7–T9) to identify variant hepatic and parasitized extrahepatic arteries, including those too small to be detected by CT or MRI, and to establish a baseline for future comparison. Next, all arteries of interest including normal and variant and parasitized vessels should

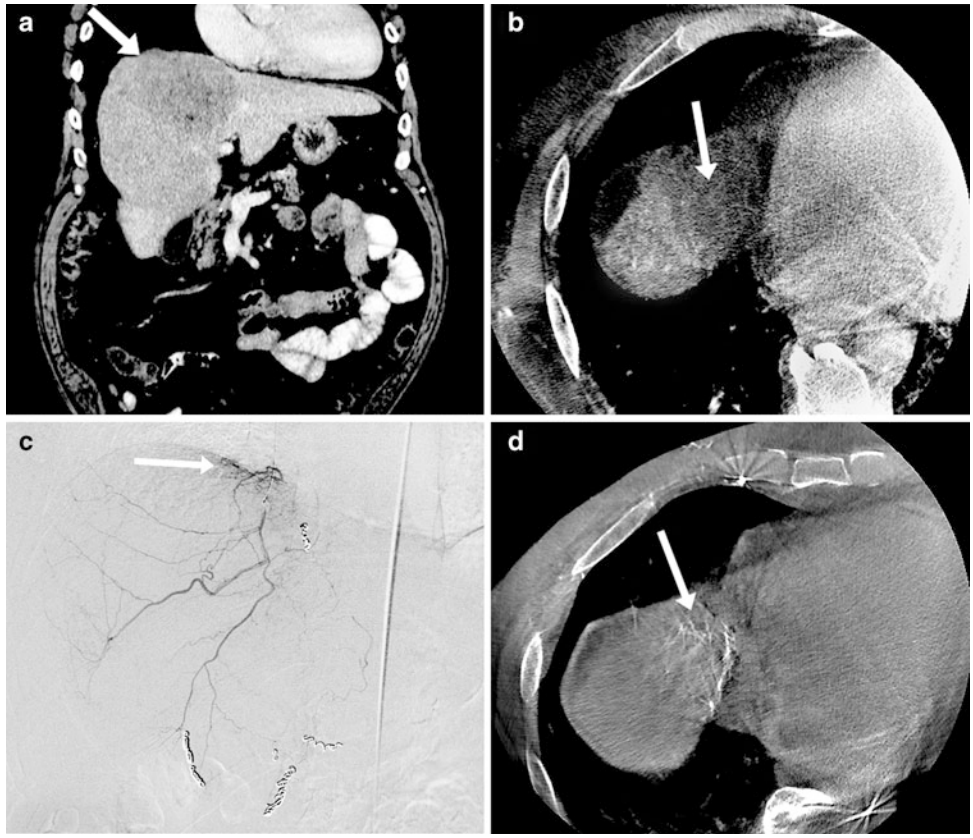

Fig. 5 65-year-old male with hepatocellular carcinoma undergoing radioembolization preparatory angiogram. **a** Pre-procedure coronal reconstruction of venous phase CT scan showed a large tumor abutting the dome of the liver (*white arrow*), **b** CACT on injection of the common hepatic artery after skeletonization showed an area of unenhanced liver (*white arrow*) at the dome, **c** Selective angiography of the right internal mammary artery confirmed supply of a small portion of the tumor at the dome (*white arrow*), fed by a pericardiophrenic branch, **d** CACT of the right internal mammary artery showed enhancement of the previously unenhanced liver (*white arrow*). Because of the area of unenhanced liver, a search was made for extrahepatic arterial supply and the right internal mammary artery was identified as the parasitized vessel. This branch was bland embolized to re-establish intrahepatic perfusion to this area

undergo catheter selection and selective digital subtraction angiography (DSA). When available, C-arm cone beam CT (CACT) should also be performed for volumetric definition of subtended arterial territory. If no variant or parasitized arteries are identified, DSA and CACT should be performed while injecting contrast medium into the PHA or CHA. If any territories and especially if any tumors within the liver do not enhance, the search for additional arterial inflow should be renewed (Fig. 5). Selective catheterization and injection of the mesenteric vessels are performed as needed to confirm anatomy of the SMA, CHA, PHA, GDA, LHA, and RHA. Because of the high incidence of hepatofugal branches arising from the LHA, including the RGA, accessory LGA, left inferior phrenic artery, and falciform artery, some authors recommend power-injected angiography of each LHA (Lewandowski et al. 2007).

Once the anatomy is defined, skeletonization of the hepatic artery (elimination of hepatico-enteric or hepatico-splanchnic anastomoses) has become the standard of care (Lewandowski et al. 2007). In some cases, skeletonization of variant arteries may prove to be the safest and most effective option. For instance, coil embolization of gastro-esophageal branches of an LGA may allow for safe administration into an rLHA when the other hepatic arterial inflow routes are even higher in risk. In other cases, high risk variant hepatic arteries may undergo coil embolization to consolidate the hepatic artery inflow into simpler or safer anatomy (Fig. 6). CACT and DSA should be performed through selective injection of the variant hepatic arteries to identify the hepatic territory and any tumors supplied. The variant hepatic artery may be embolized with 0.018″ or 0.035″ coils, or with a vascular plug if large enough in size (Fig. 7). Because of the pre-existing communicating arcades, the remaining hepatic arterial inflow routes will assume the arterial supply to the tumors. In cases, where there is doubt regarding the adequacy of the communicating arcades, for instance in the post-resection or post-ablation liver, a test balloon-occlusion can be performed from an additional arterial access site.

In certain cases, the variant hepatic artery provides the dominant supply to the tumor(s). Coil embolization of the variant artery may introduce too much uncertainty and dependence on intrahepatic arcades for adequate delivery of microspheres to the tumors. In these situations, the conventional hepatic artery may be embolized instead. The intrahepatic arcades are arterial and thus without valves, so flow may course in either direction. As a result, the supply is consolidated to the variant hepatic artery, and administration of radioactive microspheres only needs to be performed here. The safety of this approach depends on being able to skeletonize the variant artery adequately.

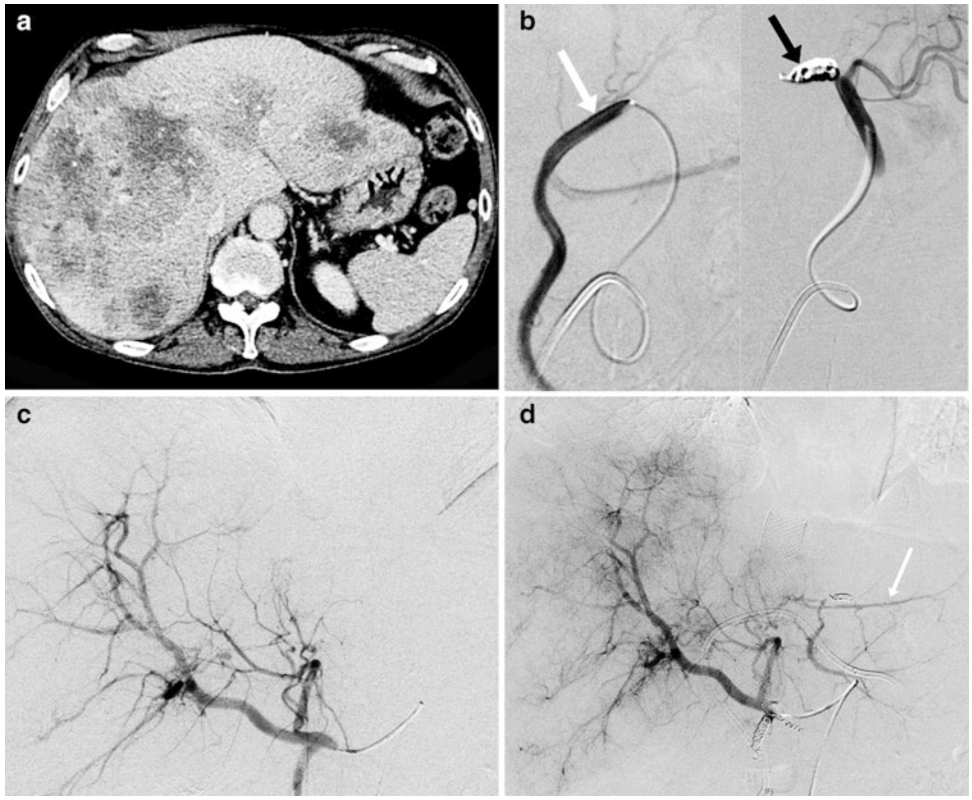

Fig. 6 62-year-old male with colonic adenocarcinoma metastatic to the liver undergoing radioembolization preparatory angiogram. **a** Pre-procedure CT scan showed large tumor burden in both the right and left lobe, **b** Angiography demonstrated a replaced left hepatic artery off the left gastric artery (*white arrow*), which was coil embolized (*black arrow*), **c** Selective angiography of the common hepatic artery prior to left hepatic embolization showed a segment 4 branch and right hepatic without a left hepatic artery, **d** Angiogram of the common hepatic artery after embolization of the replaced left hepatic showed filling of the left lobe through intrahepatic anastomoses with the segment 4 branch. This simplified treatment and increased patient safety by eliminating an additional treatment from the replaced left hepatic

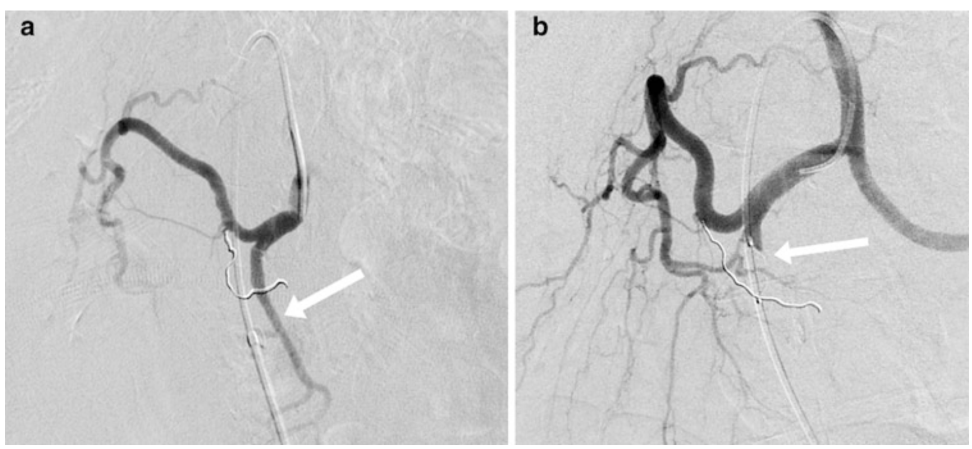

Fig. 7 72-year-old female with metastatic oropharyngeal squamous cell cancer to the liver undergoing radioembolization preparatory angiogram. **a** Common hepatic artery angiogram after coil embolization of the RGA showed a patent gastroduodenal artery requiring embolization for treatment of the left lobe (*white arrow*). This patient had a replaced right hepatic artery, **b** Embolization of the GDA was performed using an Amplatzer 4 (St. Jude Medical, St. Paul, MN) vascular plug (*white arrow*)

Once consolidative embolization is completed, repeated DSA and CACT should be performed with injection of contrast medium at the planned site of microsphere administration to confirm arterial perfusion of territories previously supplied by the embolized branches (Fig. 8). Discordance can sometimes be observed with slower or weaker contrast enhancement because collateral channels may need time to mature, and such observations should be factored into scheduling of subsequent microsphere administration (Abdelmaksoud et al. 2011). Contrast medium molecules are approximately 4–5 orders of magnitude smaller than radioactive microspheres, so the ability of contrast medium to traverse intrahepatic collateral networks does not guarantee the ready passage of microspheres. As another confirmatory test, ^{99m}Tc-MAA ranging in size from 10 to 100 microns is injected at the intended site of microsphere administration and SPECT is performed to model future intrahepatic distribution of microspheres, as well as to calculate the lung shunt fraction according to previously described methods (Lewandowski et al. 2007).

Immediately prior to administration of microspheres, DSA and CACT should be repeated to confirm complete

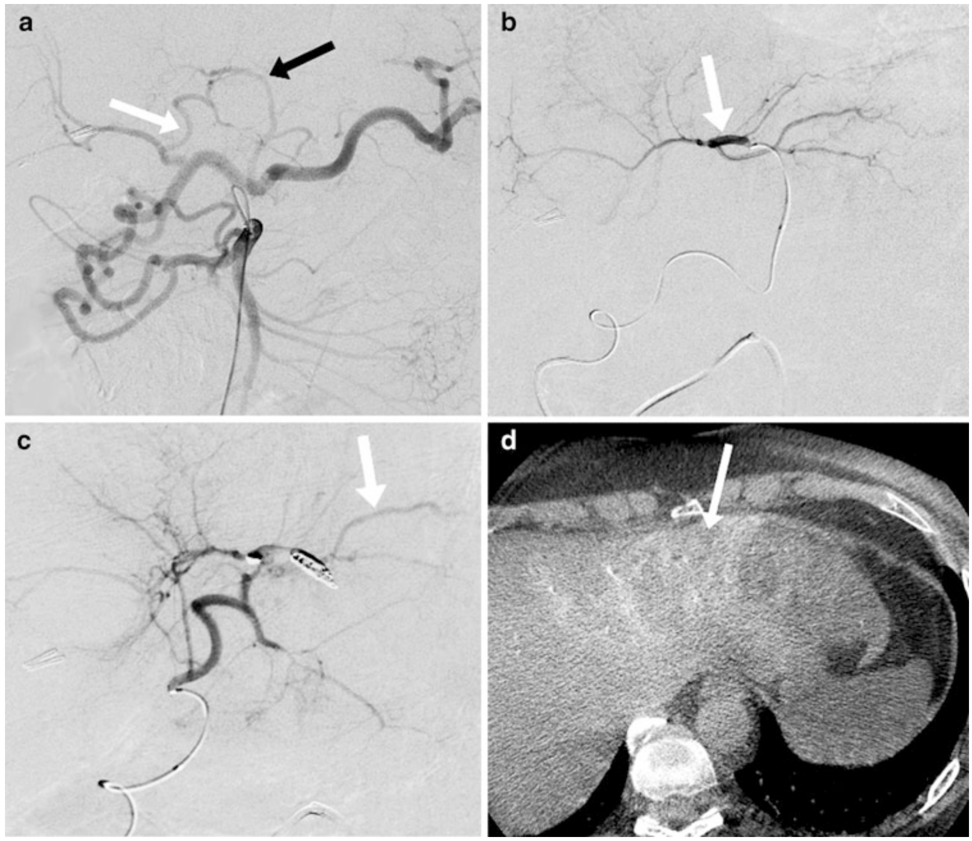

Fig. 8 55-year-old female with gallbladder adenocarcinoma metastatic to the liver undergoing radioembolization preparatory angiogram. **a** Superior mesenteric artery angiogram showed cross-filling of the celiac artery with a left hepatic artery supplying segment 3 (*white arrow*) and an accessory left hepatic artery from the left gastric artery supplying segment 2 (*black arrow*). The patient had a celiac artery occlusion, **b** Accessory left hepatic artery angiogram showed segment 2 and segment 4a supply (*white arrow*), **c** After coil embolization of the aLHA, angiogram through the left hepatic artery showed reconstitution of the segment 2 and 4a branches (*white arrow*), **d** CACT performed on injection of the left hepatic after embolization of the aLHA showed enhancement of all of segments 2 and 4a

perfusion of targeted territories and tumors after redistribution or consolidation. Tumors and regions that do not have adequate perfusion from the intended site of administration may be eligible for additional consolidative embolization. However, redistributive and consolidative embolizations are not reversible.

Consolidation is not indicated in all patients with variant hepatic arterial anatomy. Redistribution and consolidation should only be performed if coil embolization of branch hepatic arteries results in fewer sites of administration, improves the selectivity or completeness of treatment, and/or reduces the risk of non-target radioactive microsphere administration. This most commonly involves patients with diffuse and multifocal disease, which typically requires treatment of the whole liver. The alternative is placement of multiple microcatheters, but this can be time consuming, requires setup of multiple vials, may increase the risk of spill or misadministration, increases radioactive waste, and may increase the complication risk to the patient. In the largest published series, only 59 % of patients with variant hepatic arterial anatomy were expected to benefit, and thus underwent consolidation (Abdelmaksoud et al. 2011). For instance, patients that did not require consolidation had segments supplied by variant anatomy free of tumor or had a solitary tumor fed by a single variant hepatic artery. The same study showed a 95.5 % success rate of adequate delivery of microspheres to consolidated regions previously supplied by variant arteries in patients who responded to radioembolization.

3 Extrahepatic Arterial Anatomy: Identification and Treatment

Parasitized extrahepatic arteries can be found in approximately 17 % of all patients undergoing initial chemoembolization (Chung et al. 2006) and 17 % of patients undergoing radioembolization (Abdelmaksoud et al. 2011). With both of these treatment options, failure to address parasitized extrahepatic vessels results in under treatment of tumors and residual disease (Kim et al. 2005). There is copious literature describing safe and effective chemoembolization delivered through parasitized extrahepatic arteries (Chung et al. 1998; Kim et al. 2007; Miyayama et al. 2001; Park et al. 2003), but the safety of administration of radioactive microspheres in these vessels has not been shown and in many cases would be expected to carry a very high risk. These vessels, though, can be addressed in a similar manner as with variant arteries, relying on intrahepatic collateral channels to assume hepatic arterial supply to tumors.

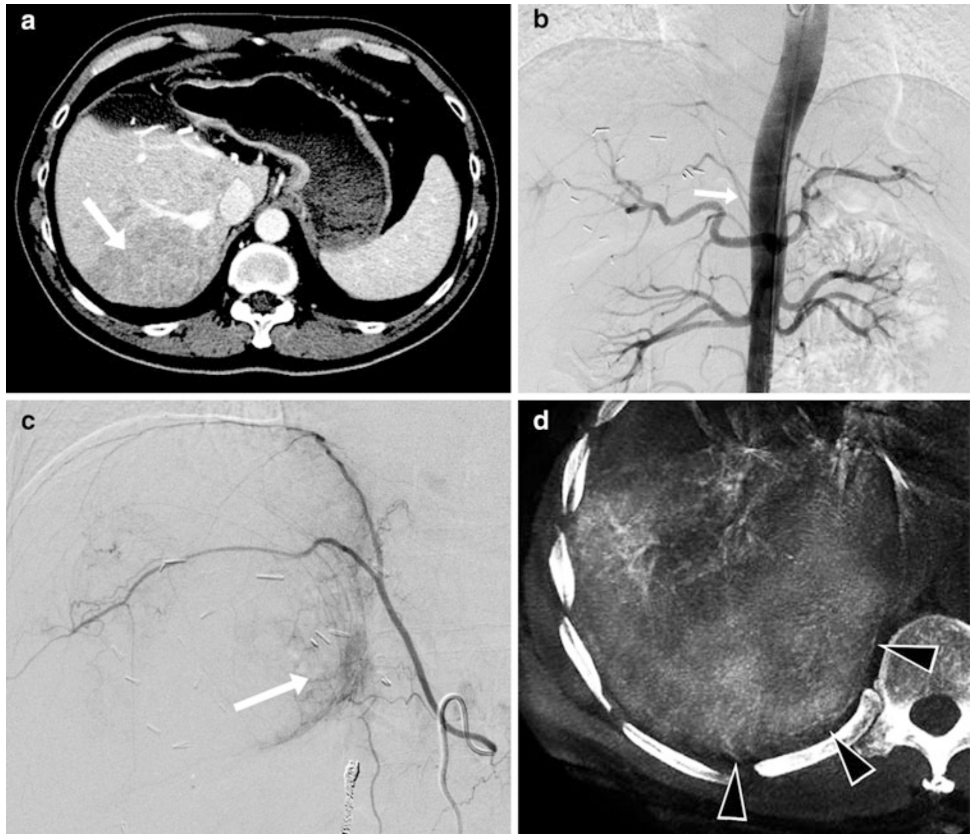

Fig. 9 46-year-old male with hepatocellular carcinoma undergoing radioembolization preparatory angiogram. **a** Pre-procedure CT showed a large mass in the posterior right hepatic lobe involving the bare area of the liver, **b** Aortogram showed a hypertrophied right inferior phrenic artery (*white arrow*), **c** Selective angiography of the right inferior phrenic artery showed tumor blush (*white arrow*), **d** CACT performed on injection of the common hepatic artery after large particle embolization of the right inferior phrenic artery showed enhancement of the entirety of the tumor (*black arrowheads*)

Parasitized extrahepatic arteries should be carefully screened on all diagnostic cross-sectional CT or MR imaging. Factors that should raise suspicion include tumor size over 5 cm, (Chung et al. 2006) tumors in contact with the bare area of the liver, (Miyayama et al. 2010) right border of the liver, or inferior border of the liver, and superficial tumors (Fig. 9) (Seki et al. 1998). Other risk factors include any prior therapies that may compromise the normal hepatic architecture, including surgical ligation of the hepatic artery, (Charnsangavej et al. 1982; Koehler et al. 1975) chemoembolization, (Chung et al. 2006) and prior hepatic arterial infusion pump placement (Seki et al. 1998). Again, thin-section arterial phase breath-held images yield the most useful information.

Angiography is again initiated with abdominal aortography with flush injection of the mid to lower thoracic aorta to identify any hypertrophied extrahepatic vessels which could supply tumor. The flush catheter is positioned cranially to opacify the intercostal arteries from T8 to T11, the most commonly affected levels. For tumors located anteriorly in the left lobe, additional thoracic angiography may need to be performed to interrogate the internal mammary arteries. In equivocal cases, DSA and CACT may be performed with injection of contrast medium into the CHA or PHA to search for areas of the liver that do not enhance and are thus suspicious for supply from parasitized extrahepatic vessels.

If parasitized extrahepatic arteries are identified, they may be embolized using larger particles, generally the largest that can pass through the catheter or microcatheter being used. This may be as small as 300–500 μm spherical embolics or as large as a slurry of 2 mm gelatin sponge cubes. In general, the largest particles that can fit through the catheter should be used to achieve the goal of elimination of parasitized supply while still allowing the tumor capillary bed to fill via intrahepatic collateral channels. Occlusion of parasitized vessels at the capillary level by smaller particles might have some therapeutic effect from ischemia, but would prevent distribution of radioactive microspheres to these areas, which would be expected to yield a superior outcome. Once stasis is achieved with large particles, coil embolization may be performed for more permanence if desired. Early in our experience, we observed that coil embolization alone of the parasitized vessels is not sufficient to effect intrahepatic flow redistribution, since recruitment of additional parasitized extrahepatic arteries frequently occurred (Abdelmaksoud et al. 2011). For instance, coil embolization of a parasitized intercostal artery usually resulted in immediate recruitment

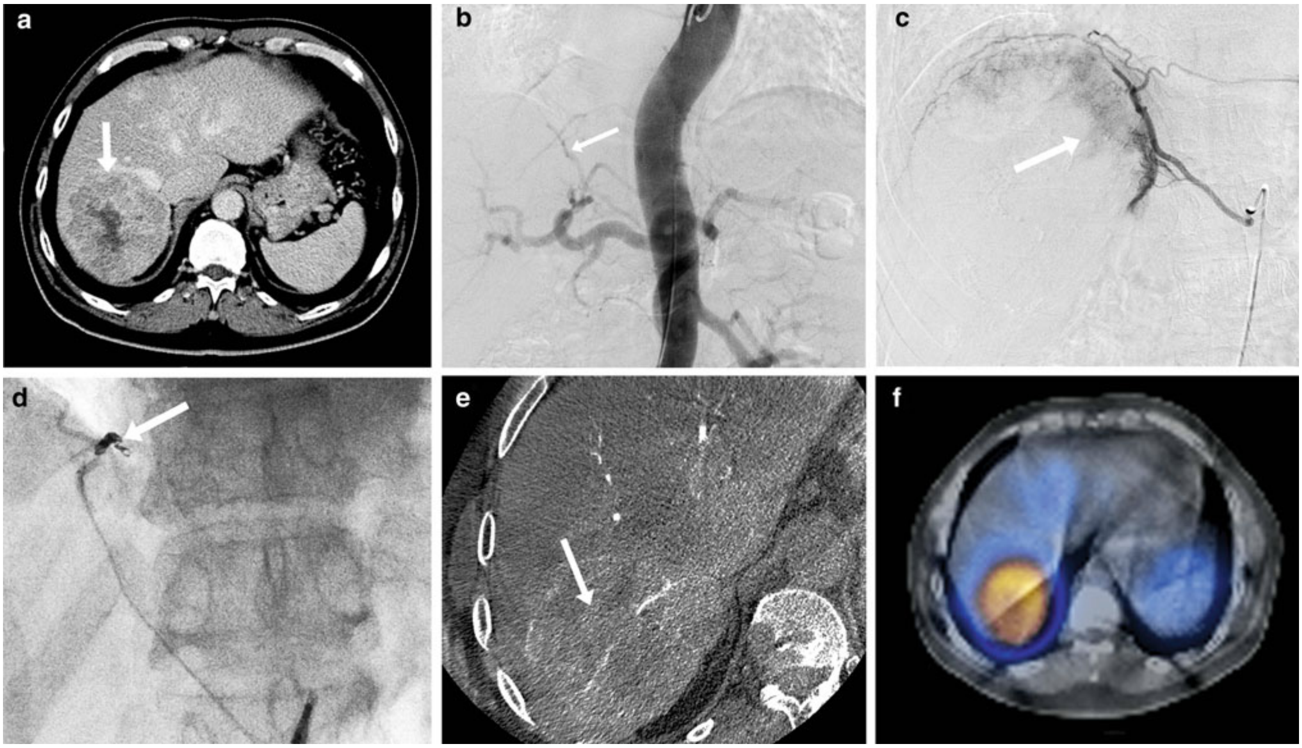

Fig. 10 57-year-old male with pancreatic neuroendocrine tumor metastatic to the liver undergoing radioembolization preparatory angiogram. **a** Pre-procedure CT scan showed a large metastasis in posterior right lobe of the liver (*white arrow*), **b** Aortogram showed a hypertrophied right inferior phrenic artery (*white arrow*), **c** Selective angiography of the right inferior phrenic artery showed tumor blush and the left inferior phrenic artery (*white arrow*), **d** The left inferior phrenic artery was coil embolized (*white arrow*) to allow particle occlusion of the parasitized right inferior phrenic artery, **e** CACT on injection of the common hepatic artery showed enhancement of the entire tumor (*white arrow*), **f** Fused ^{99m}Tc-MAA SPECT/CT confirms complete tumor coverage

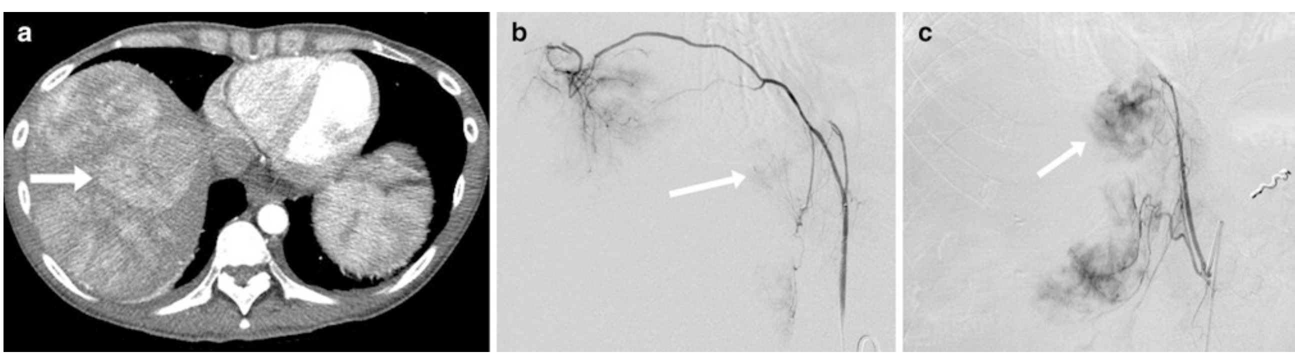

Fig. 11 39-year-old male with metastatic neuroendocrine tumor to the liver undergoing radioembolization. **a** Pre-procedure CT showed several large masses in the right hepatic lobe (*white arrow*), **b** Selective angiography of the right inferior phrenic artery showed tumor blush (*white arrow*). The patient underwent large particle embolization of the right inferior phrenic artery to stasis and subsequent radioembolization of the left lobe, **c** The patient returned 1 month later for treatment of the right lobe and had new parasitized branches off the right inferior phrenic artery to the bare area (*white arrow*), although the dome area of parasitization remained occluded

of the intercostal arteries immediately adjacent, rather than recruitment of intrahepatic collateral supply.

If numerous side branches of a trunk are parasitized, the parent vessel distal to the origin of the parasitized branches can be coil embolized first. The side branches can then be embolized with particles without concern for non-target embolization and ischemia in the distal parent vessel (Fig. 10). Once near stasis is achieved, the parent vessel may be coil embolized proximally as well. For instance, if numerous small pancreaticoduodenal arteries are parasitized, including some too small to select with a microcatheter, the right gastroepiploic artery may be first coil embolized. The pancreaticoduodenal arteries can then be embolized with particles from the proximal GDA, without significant risk of non-target embolization of the stomach. Coil embolization alone of the GDA without particle embolization could result in additional recruitment of parasitized flow via the supraduodenal and inferior pancreaticoduodenal arteries.

Upon particle embolization of the parasitized vessel, repeated DSA and CACT should be performed on the CHA or PHA to confirm that intrahepatic reperfusion of the tumor has occurred. Similar to simulation after redistributive or consolidative embolization, scintigraphy and SPECT after ^{99m}Tc-MAA injection should be performed for additional confirmation of intrahepatic reperfusion (Fig. 10).

Since tumors that have previously parasitized extrahepatic blood flow are likely to be at persistent, increased tendency to recruit additional vessels, repeat abdominal aortography should be performed to assess for development of new parasitized extrahepatic arteries at the time of radioactive microsphere administration (Fig. 11). In addition, contrast enhanced DSA and CACT with injection of contrast medium at the intended site of microsphere administration should be performed to confirm complete tumor coverage via an intrahepatic route. When additional parasitized extrahepatic vessels are found, they can be managed in the same way as during the preparatory angiogram.

As with chemoembolization, failure to address parasitized extrahepatic vessels can result in under treatment of tumors, but unlike chemoembolization, administration of radioactive microspheres into the intercostal, phrenic, internal mammary, omental, pancreaticoduodenal, adrenal, and colic arteries could be expected to cause substantial toxicity (Kim et al. 2005). Pre-emptive embolization of these parasitized vessels to re-establish intrahepatic supply is an effective alternative. 94.1 % of patients with parasitized extrahepatic arteries who were treated by particle and coil embolization to redistribute intrahepatic flow and had evaluable disease on imaging follow-up showed uniform partial response or stable disease. The tumors previously supplied by parasitized extrahepatic vessels responded equivalently to those supplied by native hepatic arteries, suggesting that the intrahepatic collateral vessels were capable of carrying microspheres to the targeted tumors. No patients showed evidence of non-target radioembolization (Abdelmaksoud et al. 2011).

4 Conclusion

Variant hepatic arterial anatomy and parasitized extrahepatic arteries can provide challenges for adequate treatment of intrahepatic tumors by radioembolization. Application of redistribution and consolidation techniques to simplify and to increase safety of treatment can be an effective way to manage these situations. Coil embolization of accessory vessels and particle embolization of parasitized extrahepatic arteries can be employed to redistribute tumor perfusion to be solely from easy to treat intrahepatic branches. Use of these strategies can help to maximize complete radioactive microsphere distribution to the entirety of the tumors, and to minimize the risk of accidental extrahepatic deposition.

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