Radioembolization with yttrium-90 microspheres work up: Practical approach and literature review


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Abstract  Radioembolization (RE) is a selective internal radiotherapy technique in which yttrium-90 blended microspheres are infused through the hepatic arteries. It is based on the fact that primary and secondary hepatic tumors are vascularized mostly by arterial blood flow whereas healthy hepatocytes obtain their blood supply mostly from the portal network. This enables high radiation doses to be delivered, sparing the surrounding non-malignant liver parenchyma. Most of the complications are caused by unexpected particles passing into the gastrointestinal tract through branches originating from the main hepatic arterial supply. Knowledge of this hepatic arterial network and of its variations and the technical considerations this raises are required in preparation for treatment. This work describes the specific anatomical features and techniques for this anatomy through recent literature illustrated by cases from our own experience.

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Abbreviations: CA, Celiac axis; SMA, Superior mesenteric artery; HA, Hepatic artery; CHA, Common hepatic artery; GDA, Gastroduodenal artery; APDA, Anterosuperior pancreaticoduodenal arcade; MHA, Main hepatic artery; RGA, Right gastric artery; LGA, Left gastric artery; CA, Cystic artery; FA, Falciform ligament artery; RHA, Right hepatic artery; aLHA, Left hepatic artery; PA, Phrenic artery; aLHA, Accessory left hepatic artery; aRHA, Accessory right hepatic artery; SDA, Supraduodenal artery; RE, Radioembolization; 90Y, Yttrium-90; AMA, Albumin macroaggregates; CT, Computed tomography; HCC, Hepatocellular carcinoma; MIP, Maximum Intensity Projection; TACE, Transcatheter arterial chemomobilization; CT, Computed tomography; rLHA, Replaced left hepatic artery; rRHA, Replaced right hepatic artery.

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Introduction

Hepatic radioembolization is a recent oncological interventional radiology technique reported for the first time in 1988 [1], and used to treat hepatocellular carcinoma and liver metastases. This technique involves administering glass or resin microspheres loaded with yttrium-90 through a catheter into the artery or arteries supplying target lesions. Yttrium-90 is a beta emitter with a half-life of 64.053 hours and disintegrates into zirconium-90, which is stable. The average penetration of the irradiation is 2.5 mm, reaching a maximum of 10 mm. By coming closer to the target lesions very high doses can therefore be delivered, reducing the toxicity to the adjacent liver parenchyma, unlike external radiotherapy [2]. Both the treatment itself and its success are governed by several stages:

• CT and MR for arterial mapping and to assess the hepatic lesions;
• arteriography, the purposes of which are to occlude the various arteries in the hepatic pedicle which run outside of the liver in order to reduce extrahepatic diffusion of the microspheres as the extent of embolization varies between groups and depending on the substances used for treatment [3–6]; to occlude accessory arteries supplying the liver, attempting to achieve arterial supply only from the hepatic artery or its variants. The use of computed tomography reconstruction mode, available on some angiography tables, or cone-beam CT is, in the opinion of some authors, a valuable aid to this stage [3,5,7,8];
• technetium 99 scintigraphy, which is used to quantify the hepatopulmonary shunt and confirm that no extrahepatic uptake is present.

Because of the risk of radiation damage, these factors may contraindicate treatment in some cases.

This report describes each stage from our own experience and from the literature, with particular attention to the technical points which need to be understood. Each artery is described in succession, explaining its anatomy, how to recognize it on computed tomography and how to manage it in the preoperative phase.

In some cases, occlusion of some arteries is a real technical challenge and we describe from our own experience the different technical options available, some of which are inspired from interventional neuroradiology techniques.

Extrahepatic branches of the hepatic pedicle

Gastroduodenal artery

The common hepatic artery (CHA) divides into the main hepatic artery (MHA) and the gastroduodenal artery (GDA). The GDA runs along the posterior aspect of the first part of the duodenum, giving rise to the anterosuperior pancreati-coduodenal artery, next to the upper part of the pancreas and divides into the inferior pancreaticoduodenal artery and the gastro-epiploic artery, running to the inferior edge of the duodenum. There are many anatomical variants, some of which may impact on the procedure. These include the origin of a cystic artery ([Fig. 1b] and right gastric or right hepatic artery (single or accessory).

This artery is always present and it can be easily identified both on CT and on arteriography ([Fig. 1].

Reflux of yttrium-90 (90Y) loaded spheres into the GDA carries a risk of pancreatitis (ischemic or radiation-induced) and gastroduodenal ulceration, explaining why most authors agree that it should be occluded [3,9–13]. The risk of reflux is increased if the GDA arises distally from the MHA (and particularly if it arises from a trifurcation of the MHA into right and left branches of the hepatic artery and GDA) [3,5]. When the decision is made to occlude this artery, it should be occluded as proximally as possible as branches supplying extrahepatic regions commonly arise very early ([Fig. 1b]). Possible collateral branches should also be looked for and occluded [2,11] (Figs. 2 and 3).

Occlusion of this artery is debatable in two situations:

• in the presence of retrograde flow (hepatopetic), a situation usually seen in tight stenoses or obstruction of the celiac axis (CA), occluding the artery, is of no benefit and may even be potentially harmful in this situation [14–16];
Radioembolization as a means to achieve occlusion and improve the clinical outcomes of patients with HCC, particularly in those with large tumors that are not amenable to surgical resection. Techniques such as transcatheter arterial chemoembolization (TACE) have been widely used, but recent advancements have led to the development of radioembolization procedures, which involve the selective administration of high doses of radiation to the tumors via microspheres or radioactive beads.

Figure 2. Occlusion of the gastroduodenal artery in a 50-year-old male patient. The gastroduodenal artery (arrowhead) and adjacent collateral artery (arrow) is seen (a). Coil occlusion and immediate recanalization distal to the packing (double arrow) by the development of a collateral branch (arrow) (b) requiring its occlusion (c). Note that the right gastric artery can be seen (white arrow).

- if the decision is made to carry out distal selective injection, the risk of reflux into the artery is then very low [2]. This approach is favored by several authors who recommend injecting as distally as possible, fractionating the dose if necessary, and thereby avoiding occlusion of the GDA and reducing the development of collaterals [6,13].

The GDA is generally straightforward to catheterize with a microguide-assisted microcatheter.

Technical tips
The GDA is usually occluded by coiling (hydrocoils or metal coils) (Fig. 2c) [17]. As the packing remains mobile for as long as thrombus does not form, the risk of migration may remain when the artery is wide in diameter and therefore requires a large number of coils (up to 8 in our experience). This risk can be reduced by the anchoring technique which involves deploying the start of the first coil in a collateral branch and finishing deployment in the gastroduodenal artery which acts as a support for the subsequent coils (Fig. 4).

Some authors consider that the use of a single hydrocoil of appropriate dimension can achieve occlusion and reduce costs [17] in the same way as plug occlusion [12] (Fig. 5).

The angiogenesis occasionally promoted by occlusion of the GDA may lead to the development of potentially dangerous uncatherizable collaterals, which raises the question of permanent occlusion. Transient occlusion with a Hyperform remodeling balloon (Covidien) is another technique which has been recently described without complication [18].

The use of microcatheters such as the Antireflux SureFire Infusion System may help to avoid occlusion when it is possible to administer spheres distally to arteries supplying extrahepatic territories [19].

Practical considerations
Occlusion of the GDA is recommended by most authors, particularly when it arises distal to the MHA.

It is, however, debatable or even harmful if retrograde flow is present.

Figure 3. Occlusion of a branch of the gastroduodenal artery by the superior mesenteric artery; a: arteriography of the common hepatic artery and occlusion of the gastroduodenal artery (arrowhead). Distal anastomoses seen between the gastroduodenal artery and a pancreaticoduodenal arcade supplied by a branch arising from the right branch of the hepatic artery (black arrows); b: failed anterograde catheterization because of the narrow diameter and stenosis in the main hepatic artery. Catheterization of the arcade (arrows) was then performed retrogradely through the superior mesenteric artery, enabling it to be occluded (c). Note the cystic artery (white arrow) and hepatic arterial supply originating from one of its branches (white arrowhead).
Figure 4. Opacification of the celiac axis showing the gastroduodenal artery (arrowhead) and anterosuperior pancreaticoduodenal arcade (arrow) (a). An initial coil is anchored (arrow) in the anterosuperior pancreaticoduodenal artery (b) allowing the subsequent coils to be deployed without migration of the packing (arrowhead) (c). Complete and proximal occlusion of the gastroduodenal artery confirmed on final control (d). Note the initial occlusion of the right gastric artery (double arrow) (b).

Right gastric artery (formerly called the pyloric artery)

Together with the left gastric artery (LGA), the right gastric artery (RGA) forms the anastomotic arcade for the lesser curvature of the stomach which they vascularize together with the pylorus. This is found routinely in published arteriography findings [20]. It arises usually from the MHA (45–57%) or the left branch of the HA (23%) and occasionally from the GDA (3–12%), the CHA (2–7–5%) or the right branch of the HA (4%) [20,21].

It is usually identifiable on a pretreatment scan (Fig. 6). If the flow is sufficient, it can be seen on proximal arteriography by its characteristic curvature (Figs. 2c and 7).

Figure 5. Opacification of a large gastroduodenal artery (a), plug occlusion (deployment in b) followed by a check confirming that it is completely occluded (c). Note the large arterioportal fistula (double arrow).
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The complications of diffusion of microspheres into the RGA range from transient upper epigastric pain, which can be easily relieved by standard analgesics and gastric antisecretory agents, to antpyloric ulcers which are often large and not well relieved by oral treatments as they are located in the serosa and subserosa and usually require surgery (Fig. 8) [22–24]. These different complications have been reported frequently in the literature with a prevalence of 1 to 45% depending on the series. In the American centers, which have the greatest experience, the incidence is between 2.9 and 4.8% [24], although the actual incidence is difficult to assess as occlusion of the GDA, LGA and RGA is often at the discretion of the surgeons, as is investigating for possible retrodudodenal and supraduodenal arteries [25,26].

Despite the fact that occlusion of this artery is questioned by some authors [6], it remains recommended by the great majority of groups [2,3,10,21,27,28].

The presence and/or development of accessory RGAs (usually from the distal branches of the left branch of the HA) explain why some gastroduodenal ulcers develop despite occlusion of the RGA [29]. 

Figure 6. Axial (a) and coronal (b) MIP CT reconstructions. Left branch of the hepatic artery (arrowhead) and right gastric artery (arrow).

Figure 7. Opacification of the common hepatic artery (a) revealing a large right gastric artery originating from the main hepatic artery (small arrows) catheterized secondarily (b) then occluded (c) in a patient who had previously undergone left hepatectomy as shown by the surgical clips (arrowhead). Note the full arcade of the lesser curvature, extending to the left gastric artery (arrow) (b).

Figure 8. Technetium 99 scintigraphy after work up. Overlapping uptake onto the anterior aspect of the antpyloric region, suggesting extrahepatic diffusion of the spheres.

Technical tips

Catheterization of the RGA is difficult because of its narrow diameter, occasionally tight proximal angle (Figs. 6 and 7) and many anatomical variants. Multiplanar CT reconstructions are a valuable aid in some cases to identify its angle (RAO, LAO) in order to define an appropriate view to work in, facilitating catheterization during arteriography (Fig. 9).

Microcatheter (2.1/1.7 or 2.3/2.8 French)—microguides (0.014 in) couples are usually required. The artery is then occluded with 1.5 or 2 mm diameter coils. It is important to ensure that its most proximal part is occluded because of the presence of early dividing branches. Some authors recommend extensive occlusion to reduce recruitment of accessory branches [29].

Figure 9. Oblique MIP coronal CT reconstruction (a) showing the right gastric artery (arrow) and identifying a kink facilitating catheterization during arteriography (b).

Figure 10. Selective catheterization of the left gastric artery (arrow) (a and b) extending to the origin of the right gastric artery (double arrow) (c) enabling it to be occluded proximally with coils (d).
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As catheterization is difficult, it is essential that the guide catheter is stable. Depending on the anatomical configuration of the celiac axis and the diameter of the MHA, a conventional catheter does not always provide sufficient support and advancing the catheter increases the risk of reactive arterial spasm. In this case a more stable catheter is highly recommended.

If direct catheterization is difficult, retrograde catheterization through the LGA is occasionally possible (in up to 89% of cases) [31] (Fig. 10). Because of the winding path of the LGA and its length and fragility (particularly when it gives rise to an aLHA), catheterization is difficult and occasionally impossible if plexiform anastomoses are present [21]. Similarly to the anterograde approach, it is important to reach the ostium of the RGA in order not to miss some proximal branches.

If both anterograde and retrograde approaches fail, one alternative is to achieve transient occlusion with a remodeling balloon. ⁹⁰Y is then injected distally [18] (Fig. 11).

One recent described technique may also facilitate occlusion of the artery when its particularly narrow diameter does not allow a microcatheter to pass. This involves using a detachable hydrocoil as a microguide [32].

Practical considerations
Most authors recommend that this artery be occluded.
Several technical options are available to occlude it if its anatomy does not allow conventional catheterization.

Figure 11. Opacification of the left branch of the hepatic artery (arrowhead) and a narrow right gastric artery (arrows) recognizable by its characteristic shape (a and b). As this could not be catheterized, a remodeling balloon was inflated at its ostium (arrowhead) (c). Infusion of ⁹⁰Y distally with a microcatheter (arrow) with no risk of reflux into the right gastric artery. Distal end of the balloon microguide (double arrow).

Figure 12. Oblique MIP CT reconstruction identifying the cystic artery (arrow) originating from the gastroduodenal artery (arrowheads) and its two dividing branches (smaller arrows) (same patient as in Fig. 1b).
Cystic artery (CA)

The cystic artery is responsible for the main vascularization of the gallbladder and is the primary arterial supply to the extrahepatic biliary tree [33]. It divides early into two branches which run to the gallbladder, one superficial peritoneal branch and the second deep parietal branch. It gives rise to the right branch of the HA in 63.9% of people, the CHA (26.9%), the left branch of the HA (5.5%), the GDA (2.6%), the superior pancreaticoduodenal arcade (0.3%) and the SMA (0.8%) [34]. If it arises from the right branch of the HA, its origin is often distal, close to the bifurcation between the anterior segmental (segments V and VIII) and posterior segmental (segments VI and VII) branches. An accessory CA is present in 2 to 25% of people [34–36]. Secondary arterial supplies are common, arising mostly from perforating branches from the liver parenchyma and the GDA.

It is recognizable by its Y shape and can be identified on CT and arteriography in most patients (Figs. 1b, 3a and 12).

Gallbladder complications due to diffusion of $^{90}$Y particles into the CA are rare, and the great majority of patients do not develop any gallbladder complications. If they do occur, they mostly involve transient postprandial right hypochondrial pain, although up to 23% of cases are complicated by radiation-induced cholecystitis in some series [37,38].

Several groups report that clinical symptoms resolve with medical treatment [37,38]. Prophylactic antibiotics with fluoroquinolones was used routinely by some groups when the right lobe of the liver is being treated or more generally when clinical symptoms are present, although there is no statistical evidence that these are effective [39]. It is not uncommon after RE treatment to see gallbladder abnormalities on imaging, which appear as a thickening or even a defect of the gallbladder wall. These abnormalities are not specific and should not incorrectly suggest radiation-induced cholecystitis, which is primarily a clinical diagnosis [39,40].

The approach to the CA is controversial. Some authors recommend that it be occluded whereas others believe that the risk of ischemic cholecystitis is too great if it is.

The operator is then faced with several possible situations and options. He/she should assess the risks of:
- radiation-induced cholecystitis following proximal administration to the CA;
- suboptimal diffusion of spheres in distal injection;
- ischemic cholecystitis if the artery is occluded.

Several types of CA occlusion are reported in the literature, the most common of which are the use of Spongol coils or inducing spasm with the microguide. Some authors prefer temporary occlusion with Spongol [37,38]. The induced spasms technique is less predictable, causing transient incomplete, unquantifiable stenosis and carrying a risk of complications (dissection or perforation) [37].

If gallbladder uptake is present, some authors are less inclined to occlude a large diameter CA in order to reduce the risk of ischemic cholecystitis than when the diameter is narrow, suggesting that collateral arterial supply constitutes a significant component (from the liver parenchyma or GDA) which reduces this risk of ischemia [3,39]. As such, occlusion of the CA carries less risk of ischemia when the GDA
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is occluded very proximally, enabling gallbladder arterial supply from its perforating branches [3,4].

Generally in the literature, most radiological gallbladder abnormalities are asymptomatic and very few cases have required surgery [37,39,40].

The existence of parasitic arterial supply to the tumor from the CA is a specific point which may result in hyper-selective occlusion of the branches of the CA to the tumor before injecting yttrium spheres [41] (Fig. 3d).

No cases of post-RE cholecystitis occurred in our series and the CA was seen on most of the angiographies. Significant scintigraphy uptake was found in two patients: temporary occlusion with a remodeling balloon was performed in one case and the spheres were released distally in the second case (Fig. 12). This type of temporary occlusion by a remodeling balloon is a transient solution which is safe but expensive and has been very little assessed/perform in published reports [18]. Only one permanent occlusion of a CA arising from the proximal part of the GDA with coils was considered necessary (Fig. 1b).

Practical considerations
Wherever possible, preference should be given to low rate administration of spheres distally in the CA.
If occlusion of the CA is necessary, very proximal occlusion of the GDA is recommended.
Occlusion with resorbable gelatin appears to be a simple and effective method associated with few ischemic complications.
Temporary occlusion with a remodeling balloon is an attractive but not well assessed possibility (Fig. 13).
Radiological and clinical findings are often inconsistent and the clinical features should take priority in selecting any treatment options.
If cholecystectomy is being considered, this should be deferred wherever possible to more than two weeks after yttrium treatment in order to reduce irradiation to the operator.

Falciform ligament artery
The falciform artery (FA) was described for the first time in 1753 and originates from the distal branches of the LHA or MHA. It therefore usually arises from arteries supplying segments IV (68%), III, and the common trunk segments II and III. Occasionally, it has been reported to arise from the right branch of the HA or the CA [20]. It runs in the falciform ligament alongside the para-umbilical vein and then spreads out around the umbilicus and communicates with the distal branches of the superior and inferior epigastric arteries [7,42].

It is recognizable by its “L” shape and cranio-caudal path along the anterior abdominal wall. It is usually not seen on imaging (Fig. 14).

Anatomical series describe it in almost 70% of patients but it is only found in 10% of arteriography series, predominantly in prospective (25–50%) compared to retrospective (2%) studies because of its distal origin and narrow diameter (0.7 mm) which requires a sufficiently high flow rate to be infused into the left branch of the HA, ideally in a RAO view, when it is better seen in the capillary and venous phases [43,44]. It is far more important and its diameter is increased after laparotomy or stenosis/occlusion of the left branch of the HA [44]. It is also better seen on selective hepatic arteriography with helicoidal acquisitions [7].

Radioembolization complications due to spheres passing into the FA are rare, mild and usually transient. The most common presentation is abdominal pain or an epigastric skin rash which lasts from a few hours to a few weeks [45]. These generally resolve spontaneously or with analgesia [43]. A few cases of skin necrosis have, however, been described following hepatic chemoembolization procedures [45–47].
The 99Tc scintigram must be examined carefully as any uptake in the abdominal wall due to spheres spreading into the FA is usually low and may require multiplanar reconstructions in a SPECT CT examination [48].

Although some authors recommend that this artery be looked for routinely and embolized prophylactically [3,45], the low incidence of complications and their usually mild nature are such that other authors only do this if it is visible on standard arteriography. This approach is very reasonable as symptoms almost never develop even if uptake is seen on scintigraphy [43]. On the other hand, some groups recommend that it be occluded if uptake is seen [3,49].
The FA can be occluded by selective microcatheterization and introducing microcoils (0.018). As it is less than a millimeter in diameter and arises distally, this procedure is difficult and occasionally unproductive [42,49].

Practical considerations
The consequences of diffusion of yttrium spheres into the FA are rare and mild.
To find it, a specific angiography protocol is often required.
Operators do not need to be concerned about this artery if it is not seen on standard radiography or if no abdominal wall uptake is seen on scintigraphy.
SPECT CT images should be read carefully and on multiplanar reconstructions, as uptake from spheres passing into the FA is low.
Knowledge of the existence of this artery and the possible complications allow any painful abdominal symptoms which develop following the procedure to be recognized and understood.

Retroduodenal, supraduodenal and retroportal arteries
The supraduodenal artery (SDA) supplies the horizontal portion of the first segment of the duodenum. It is reported in almost 93% of surgical series [35] and has many variations. It arises mostly from the GDA (27%), CHA and MHA (20%) and from left (20%) and right (13%) of the HA [35,50]. It is associated with similar complications to the RGA, which is a reason for identifying and, where appropriate, occluding it [3,9,27]. It may be responsible for parasitic arterial supply to the tumor [51]. Some authors describe occluding the artery with biological glue [52].
The anterosuperior pancreatoduodenal artery (ASPD) (formerly the retroduodenal artery) supplies the duodenal bulb and the uncinate process of the pancreas. The origin of this artery also varies and is usually from the proximal part.
of the GDA but it may also arise from the CHA or MHA (15%) and requires particular attention [50,53].

The retroportal artery arises from the proximal portions of the CA (41%) or SMA (58%).

It contributes to the anastomotic arterial supply to the extrahepatic biliary tract [33,54] and communicates with the posterosuperior pancreaticoduodenal artery (type I) or the right branch of the HA (type II).

These arteries are rarely seen individually as they are secondary and of narrow diameter. When they are visible and identified, however, embolization may be required [3].

When they are not easy to catheterize, temporary occlusion of the CHA with a remodeling balloon redistributes local hemodynamics, reversing the flow in the GDA and therefore the flow in these small arteries and avoiding adverse effects due to particle introduction [18,55].

**Extrahepatic arterial supplies to the tumor**

The existence of extrahepatic arterial supply to neoplastic liver lesions and particularly hepatocellular carcinoma (HCC) is well documented in the literature and affects 17 to 30.8% of liver tumors [50,51,56–58]. These afferent supplies raise several problems. Failing to take account of such an artery in RE by administering the spheres through the main hepatic pedicle carries a risk of only partial treatment, potentially missing the volume of tumor supplied by these branches and subsequently promoting future arterial changes to the benefit of these accessory branches. Conversely, infusing 90Y through these branches, which are often narrow, requires occasionally difficult catheterization, anatomical knowledge of potentially dangerous anastomoses and fragmentation of the doses to be administered to volumes of liver which are complicated to assess and atypical. The injection must be administered at a low flow rate and appropriate to the diameter of the supplying artery.

Several factors predisposing to recruitment and development of these branches have been identified. These include a previous history of chemoembolization, occlusion of the main arterial pedicle and also the size of tumor volume (63% of tumors over 6 cm), exophytic tumors, those located in the infracapsular area and contact with the *area nuda* [50,56,58].

Three main options can then be considered:
- administering the spheres through these arteries;
- occluding them and therefore achieving a single hepatic pedicle;
- not considering them if their vascular supply appears to be negligible.

Although many hepatic embolization and chemoembolization procedures through these different arteries are reported in the literature (internal thoracic, phrenic, colonic and renal arteries, etc.) [51], few similar procedures have been described for RE. Occlusion of these arteries can produce a single hepatic pedicle by opening intrahepatic shunts, restoring vascularization to territories which have been occluded by branches of the PHA. The viability of these anastomoses for RE procedures has been demonstrated by several authors based on the arteriographic vascular changes after arterial occlusion, the distribution of MAA uptake in pretreatment scintigraphy and achieving tumor response in these revascularized territories [58–61].

We will only describe the problems experienced when an inferior phrenic artery is present, as the other arteries are significantly less common.

**Inferior phrenic artery**

The right and left inferior phrenic arteries (PA) arise usually from the celiac axis and the abdominal aorta (40 and 38% for the right PA respectively) although they also arise from the renal arteries, the LGA and the CHA [62]. They may arise separately or through a common trunk, then dividing into ascending and descending branches and may give rise to vascularizing branches, vascularizing the inferior vena cava, adrenal glands, inferior esophagus or give rise to accessory gastric and splenic branches. Communications with the internal thoracic, intercostal, muscular, phrenic and pericardial arterial systems are also seen and transpleural communications have been described, usually in patients suffering from chronic lung diseases. Their phrenic and adrenal arterial supplies are constant findings [51,62].

![Figure 15. Axial (a) and oblique coronal (b) reconstructions of an arterial phase abdominal CT. Right phrenic artery (arrows) running closely to a lesion in segment II (arrowhead).](image-url)
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The common origin of the 17 to 30% of cases of extrahepatic arterial supply to HCC tumors is the right PA (up to 50%) [41,50,51,56,57]. This proportion appears to be increased if an aLHA is present [11] and after chemoembolization, as a result of arterial redistribution (up to 83%) [41]. A significant size of tumor contact with the diaphragm and being located in segment VII are factors in which this artery is almost always involved [57]. Its involvement should also be strongly suspected when the tumor blush is not present on arteriography. It is therefore a problem frequently encountered during RE procedures and this artery should therefore be identified routinely before treatment [2,3,35,63].

It is often increased in diameter when it is responsible for arterial supply to the tumor and can then be identified on a pretreatment CT [57,62] (Fig. 15). It can usually not be seen on arteriography following a conventional injection into the celiac axis or MCA because its origin is extremely proximal. It should therefore be looked for on aortography (right-sided or "pigtail" catheter) or by direct catheterization after identifying its origin on a section image (Fig. 16).

Its narrow diameter origin and path represent common obstacles to catheterizing the artery, particularly when it arises from the proximal superior portion of the CA. "Shepherd stick" or "Simmons" catheters are used most commonly and some people describe using "homemade" catheters, equipped with a lateral orifice [64].

Some groups describe administering spheres through the PA after a detailed analysis of arterial supply as being both achievable and useful and avoiding occlusion of the PA. The configurations required to make this procedure safe are only, however, met in a small number of patients [51], and the identification and occlusion of many anastomotic branches required is sometimes complex and laborious.

Redirection of anterograde hepatic flow is an option described by Abdelmaksoud et al. [58]. This has been validated angiographically and scintigraphically and requires distal occlusion of the PA, distal to its extrahepatic branches, prior to administration of microspheres. This option has the advantage of a conventional infusion of spheres into the hepatic pedicle.

Practical points

The PA is the most common extrahepatic arterial supply for HCC.

In situ administration may cause various and potentially serious complications due to many extrahepatic afferent vessels.

Opening of intrahepatic shunts as a result of occluding the PA and administering spheres through the main hepatic pedicle is a more straightforward option and less likely to cause extrahepatic complications.

Other extrahepatic arteries

The same applies to all of the other extrahepatic arteries (omental, adrenal, intercostal, cystic, internal thoracic, renal, colonic and lumbar, etc.). Most of these are usually very narrow in diameter and for the most part have insignificant impact on the RE.

Significant anatomic variants

Right hepatic artery (RHA)

Depending on whether the embryonic hepatic arteries persist, several variants in the origin of the right branch of the hepatic artery are seen. The most common is an RHA (origin of the SMA) (10 to 12% of cases) [20,65]. This artery can coexist with the right branch of the HA (it is then called an accessory RHA) or be the only artery in 3% of cases (replaced RHA) [66]. Very rarely, the right branch of the HA arises from the pancreaticoduodenal arcades, the GDA (3.6%), CA (1.2%) or a phrenic artery [20,35,50].

It is important to identify these variants. This is done easily on computer tomography images and involves looking for an often proximal branch of the SMA running to the liver.

Two options are described in the literature, administration of spheres through the accessory RHA (aRHA) or replaced RHA (rRHA), or occluding the artery. The first option requires calculating the distal hepatic volume and fractionating doses, as the territory involved may include one or more liver segments. The arteriography—CT couple
LGA.

**Practical points**

Pretreatment examination for a variant of the origin of the right branch of the HA should be performed routinely.

Administration of spheres through the main hepatic pedicle after its distal occlusion is straightforward to perform and carries few complications.

**Left hepatic artery (aLHA)**

These anatomical variants can similarly involve the left branch of the hepatic artery. The most common is the origin of the left branch of the hepatic artery from the LGA. This artery may be the only feeding artery of the left hepatic lobe (replaced LHA) or coexist with the left hepatic branch (accessory LHA). The prevalence of these arteries range from 3.8 to 10% and from 8 to 10.7% respectively [65] (Fig. 17).

The left branch of the HA can also arise either as a single artery or as an accessory from the GDA (1.2%) [20]. When present, the small accessory LHA (aLHA) usually vascularizes segments II and III of the liver and, less frequently, segment IV [3]. These arteries should also be looked for.

These variants can usually be easily identified on the pretreatment CT. The gastrohepatic trunk is usually seen in the fissure of the venous ligament.

It may be possible to identify an aLHA or a replaced LHA (rLHA) indirectly by CT combined with arteriography when incomplete left parenchymography indicates the existence of an external arterial supply.

This artery is fragile and readily spasms. Catheterization may be difficult and requires Simmons catheters [2,21] (Fig. 18).

The existence of an aLHA or rLHA raises several problems, most similar to those produced by variants of the origin of the right branch of the HA. Identification of possible extrahepatic branches is an additional difficulty. Branches supplying the diaphragm, esophagus or stomach carry a risk of extrahepatic complications when spheres are infused through
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This hepatic arteries usually arise from the proximal horizontal portion of the aLHA and making the procedure occasionally difficult, particularly as catheterizing the LGA may be complicated and unstable. An indirect sign of the presence of these extrahepatic branches is the opacification of a left gastric vein, providing venous return from part of the stomach and inferior esophagus.

In exactly the same way, the option of occluding and infusing spheres through the main hepatic pedicle would appear more straightforward and carry less risk of extrahepatic complications.

Some authors have maximized this approach by creating a single hepatic pedicle going as far as occluding an hepatic artery (usually the left branch) and administering the spheres through the right branch of the HA with homogeneous distribution of uptake throughout the whole liver [59–61]. This option would appear to simplify all the procedures.

**Tips and tricks**

It is essential to look for an accessory or a replaced LHA. This is seen easily in the fissure of the venous ligament when present. It must be catheterized cautiously as the trunk readily spasms.

Spheres may be administered through this artery but carries risks of complications due to the presence of branches supplying extrahepatic tissue, which should be identified and occluded first.

Occluding these arteries redistributes the intrahepatic arterial flow by opening anastomoses and creating a single hepatic pedicle and allows the spheres to be administered through the main hepatic pedicle. This option has been successfully confirmed in several studies [59–61].

Retrograde opacification of this artery or reestablishing the fistula hepatic parenchymography on the final review confirms the intrahepatic arterial redistribution.

It is recommended that a Simmons catheter is used for catheterization for better stability.

**Other variants involving the main arteries**

Many other variants of the origin of the HA and RHA are described in the literature, the main ones being the presence of a double hepatic artery, hepatic arteries arising directly from the CA or the aorta, and a GDA arising from the aorta or the SMA. These variants are very rare (<2%) [20,65], and are usually recognizable on the pretreatment scan. They do not require any specific technical approach.

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Figure 18. Another patient with an accessory left hepatic artery (arrow). Left gastric artery (small arrows) (a). Attempted catheterization of the accessory left hepatic artery complicated by dissection of the left gastric artery at its origin (b). Insertion of two stents (arrow) recanalizing this artery (double arrow) and occluding the accessory left hepatic artery (arrow) (c). Note the presence of embolic material in the right gastric artery (coils) and gastroduodenal artery (plug).
Conclusion

The preparatory phase for hepatic radioembolization procedures is a key stage and relies on good knowledge of the hepatic vascular anatomy and its subtleties.

Disclosure of interest

The authors declare that they have no conflicts of interest concerning this article.

References


