Diagnostic and Interventional Imaging (2015) **96**, 57—64

ORIGINAL ARTICLE / *Cardiovascular imaging*

Preoperative portal vein embolization with a combination of trisacryl microspheres, gelfoam and coils

J. Cazejust*, B. Bessoud, M. Le Bail, Y. Menu

Radiology Department, Saint-Antoine Hospital, 184, rue du Faubourg-Saint-Antoine, 75012 Paris, France

KEYWORDS
Portal vein embolization;
Contralateral approach;
Liver tumor;
Embolic agents

Abstract
Purpose: To evaluate the safety and efficiency of preoperative portal vein embolization (PVE) with a combination of trisacryl microspheres, gelfoam and coils for inducing lobar hypertrophy in hepatobiliary malignancy patients.
Materials and methods: PVE was performed by a percutaneous left approach in 63 patients with hepatic malignancy (hepatocarcinoma = 38, colorectal metastasis = 14, cholangiocarcinoma = 11). The indication of PVE and surgery was evaluated by hepatic tumor board take into consideration to the tumor extension and the hepatic volume on initial and post-embolization CT-scans. The total functional liver volume (TELV) and future liver remnant (FLR) volume were measured before and 24 ± 5 days after PVE to assess FLR, TELV and FLR/TELV ratios. Efficiency evaluation was based on FLR increase, the ability to perform the hepatectomy and the hepatic function after surgery. Safety evaluation was determined by clinical and biological follow-up after embolization and surgery.
Results: PVE was successful in all the patients. The mean FLR volume increases by $57 \pm 56\%$ after embolization ($449 \pm 180\,cm^3$ to $663 \pm 254 cm^3$) ($P < 0.0001$). The FLR/TELV ratio increases by 11% after PVE ($25 \pm 8\%$ to $36 \pm 12\%$). Three minors' complications were registered without impact on surgery, and four patients developed portal hypertension. Forty-nine patients underwent hepatectomy; none of them developed liver failure. Surgery was not performed in 14 patients due to tumor progression ($n = 9$), inadequate hypertrophy of FLR ($n = 1$) and portal hypertension ($n = 4$).
Conclusion: Preoperative PVE with a combination of trisacryl microspheres, gelfoam and coils is a safe and effective method for inducing contralateral hypertrophy before right hepatectomy in patients with advanced hepatobiliary malignancy.

* Corresponding author.
E-mail address: julien.cazejust@sat.aphp.fr (J. Cazejust).

2211-5684/$ — see front matter
http://dx.doi.org/10.1016/j.diii.2013.07.004

Major hepatectomy (resection of four or more liver segments) is associated with increased morbidity and mortality mainly due to liver insufficiency. Portal vein embolization (PVE) is intended to obtain hypertrophy of future liver remnant to minimize the risk of postoperative liver failure.

PVE is a well-established procedure, but it is extremely variable from one center to another, probably because there is no consensus in the literature on which embolic agent induces the greatest degree of liver hypertrophy after PVE [1]. Many embolic agents have been used in the literature, such as n-butyl cyanoacrylate (NCBA), microparticles, coils, alcohol, nitinol plugs [2]. At the beginning of the study, no clinical study had demonstrated an advantage of one embolic agent compared to the others. However, a very recent retrospective study [3] seems to demonstrate that the use NCBA could induce a better hypertrophy than using microparticles plus coils.

Although it is a common practice in many institutions to use a combination of particulates and coils to perform the embolization, PVE using a combination of trisacryl microspheres, gelfoam and coils has never been described in the literature.

Our objective was to analyze the outcomes of PVE before right hepatectomy, in terms of liver hypertrophy, resection rates, and complications after embolization with a combination of trisacryl microspheres, gelfoam and coils.

Material and methods

Patients

A retrospective monocentric study was performed, including all patients undergoing PVE for liver malignancy who required right hepatectomy, between February 2009 and January 2013. Our local ethics committee approved the retrospective analysis of the data, and all patients gave their written informed consent for the procedure. The indications of right hepatectomy or extended hepatectomy and presurgery embolization were elaborated through a case-by-case discussion at the weekly meeting of the multidisciplinary hepatobiliary tumor board (including hepatologists, oncologists, liver surgeons and interventional radiologists).

Pre-embolization CT was performed to determine the extent of hepatobiliary disease, the presence or absence of extra-hepatic disease and/or distant metastasis, the portal vein and hepatic artery permeability, the presence or absence of portal vein variants, and biliary obstruction.

The portal vein embolization was suggested according to the hepatic volumetry and underlying hepatic disease [1]. In case of healthy liver, the Future Liver Remnant (FLR) should be at least 25% of the total liver volume; whereas in case of liver cirrhosis, the FLR must be at least 40% of liver volume. For patients undergoing previous chemotherapy, the FLR should be at least 30% of liver volume [1]. For three patients, although the volume of FLR was over 25%, on a non-cirrhotic liver, the portal vein embolization had been performed anyway. The portal vein embolization was determined for these three patients because the tumor was a hilar cholangiocarcinoma, with dilatation of intrahepatic bile ducts that can lead to a poorer liver regeneration after unprepared surgery.

We did not take into account the complexity of the resection in calculating the necessary percentage of functional liver volume.

Exclusion criteria were as follows: unresectable tumor (arterial invasion, bilobar disease, stage IV hilar cholangiocarcinoma), metastatic disease (extra-hepatic or lymphadenopathy), portal vein occlusion and/or renal failure.

Endoscopic ($n = 2$) or percutaneous ($n = 7$) biliary drainage was performed in patients with biliary obstruction at least 1 week before PVE, associated with short intravenous antibiotic therapy (ceftriaxone and metronidazole antibiotics) immediately before the procedure and during the next 2 days.

Portal vein embolization

Embolization was performed under general anesthesia by one of the three vascular and interventional radiology faculty members. For the percutaneous approach in our institution, we use a platelet count greater than 50,000/mL and Prothrombin Time greater than 50%, as recommended in the literature [1]. Otherwise, patients were transfused with appropriate factors.

The portal venous system was accessed percutaneously under sonographic and fluoroscopic guidance using a contralateral approach.

A 22-gauge Chiba needle (Neff Percutaneous Access Set®; Cook, Bloomington, Indiana, USA) was introduced into a distal portal vein and then, thanks a 5-F vascular sheath used to facilitate subsequent catheter exchanges.

Flush portography was performed with a 5-F catheter (Cook, Europe; Bjaeverskov, Denmark) or a 5-F cobra-shaped catheter (Cobra®; Terumo, Tokyo, Japan) in the main portal vein (Fig. 1). Anteroposterior, right and left anterior oblique projections, were obtained as needed to delineate the portal vein anatomy.

Selective right anterior and posterior portal vein injections were performed. In each branch, trisacryl microspheres (Embosphere®; Biosphere Medical, Roissy, France) ranging from 300 to 1200 microns were administered in a stepwise fashion: smaller particles were used first to occlude the distal branches, and larger particles were used subsequently to occlude the more proximal branches. The larger particles were not used until the forward portal blood flow was substantially reduced. Additional embolization with gelatin sponge particles (Gelitaspon®; Gelita Medical BV, Amsterdam, the Netherlands) was performed until near-complete stasis was achieved. Then, 0.035-inch coils (Tornado® or Nester® or both, Cook Medical, Bloomington, Indiana, USA) were placed within the proximal right anterior and posterior portal veins branches or the right portal vein (if long enough) to further reduce the portal inflow that could lead to recanalization. If a right hepatectomy extended to the segment IV was planned, the same procedure was performed to occlude segment IV of the liver.

A final portogram was obtained with the flush catheter positioned in the main portal vein to assess the completeness of the embolization (Fig. 2).

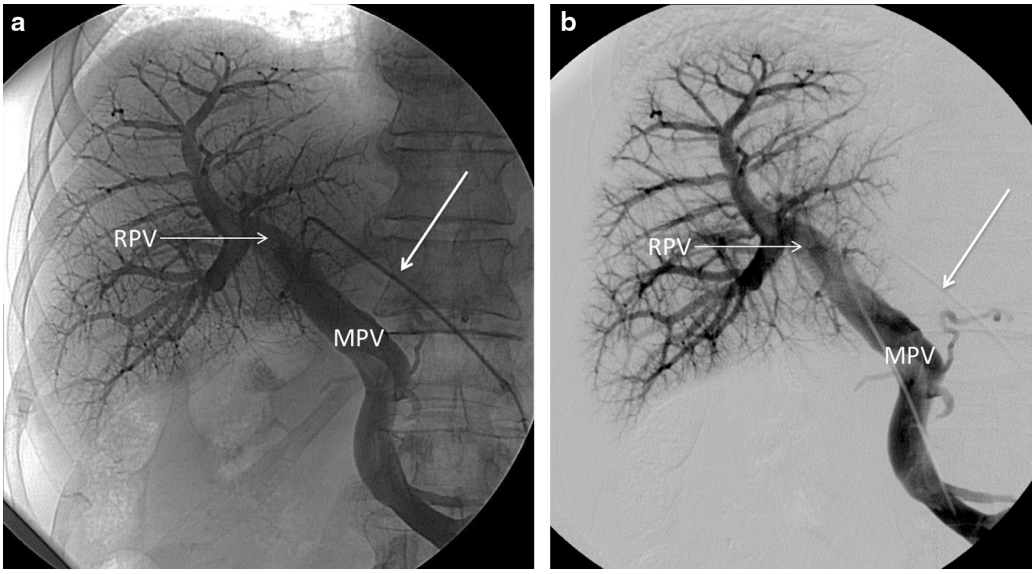

Figure 1. Initial portography in a patient with hepatocellular carcinoma in the right liver lobe: a: native image; b: digital substraction image. White arrow: 5-F catheter in the main portal vein; MPV: main portal vein; RPV: right portal vein.

At the end of the procedure, the catheter was removed under manual compression during 5 minutes, without any tract embolization.

No patient had clinical or radiological evidence of pre-existing portal hypertension; therefore, portal vein pressure was not measured.

Clinical evaluation

PVE was performed during a short hospitalization in the surgery department. No medication was systematically administered after the procedure. Clinical and biological evaluation depicted post-embolization syndrome, liver failure or catheter related complications. All patients were inpatients and stayed in the hospital for at least one night. Patients were discharged when they were found to be in a clinically stable condition by surgical and interventional radiology staff.

The outcomes were assessed by recording all complications according to the Society of Interventional Radiology Standards of Practice Committee Classification of Complications by Outcome [4] after PVE during the hospitalization and at the preoperative consultation within the few days after the post-embolization CT. Post-embolization pain was graded with a numerical scale ranging from 1 to 10.

Technical success rate was defined as the successful occlusion of the branch of the right portal vein after PVE.

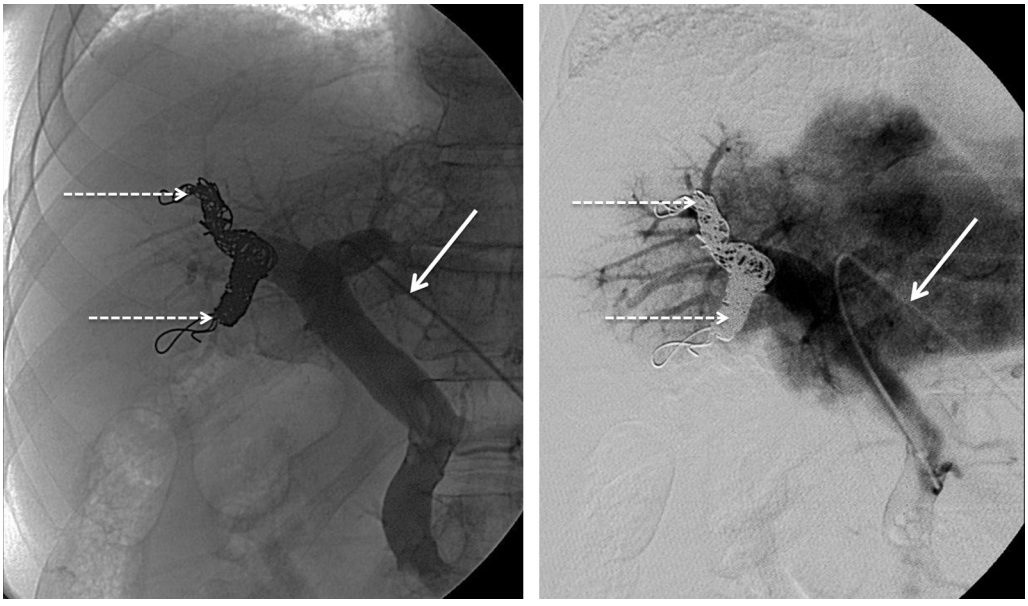

Figure 2. Final portography, showing coils in the different branches of the right portal vein (dashed arrows), no vascularization of the right liver lobe but a patency of the branches of the left portal vein. White arrow: 5-F catheter in the main portal vein for the final control.

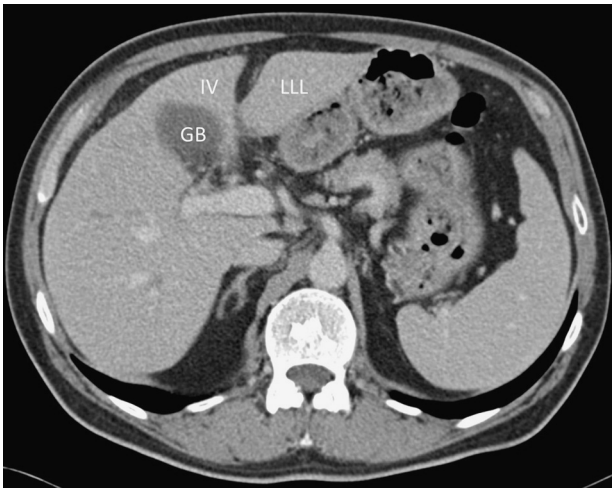

Figure 3. Axial portal venous phase CT in a 65-year-old man, with hepatocellular carcinoma developed on alcoholic cirrhosis obtained 22 days before the portal vein embolization. IV, I and LLL correspond to segment IV, I and the left liver lobe respectively, GB corresponds to the gallbladder.

Clinical success was defined as the operability rate, post-PVE and post-surgery complications and hepatic insufficiency.

Assessment of hypertrophy

A CT-scan of the abdomen and pelvis was repeated before and approximately 3 weeks after PVE to evaluate tumor progression and to perform volumetric measurements.

The CT-scan protocol used to define precisely the liver segments was a triple phase CT (one acquisition without contrast media injection, and two contrasts enhanced acquisitions at arterial phase, obtained 35 seconds after injection and portal venous phase obtained 90 seconds after injection). All measurements were obtained on the portal venous phase, to delineate more precisely the hepatic veins.

Volumetric measurements were performed by a single radiologist, using the semi-automatic ADW 4.5 GE software on 3 mm-thick slices. These measurements included: total liver volume, tumor volume, segment IV volume, segment I volume, and segments II and III volume. Total functional liver volume (TLV) was defined as the total liver volume minus the tumor volume. In addition, FLR volume was calculated. Depending on the patient and tumor extension, the volume of the FLR was calculated as the sum of segments II and III volumes ± segments I and/or IV volumes. Finally, the ratio between the FLR and the TLV was calculated. Hypertrophy rates were calculated as follow: (FLR post-embolization—FLR pre-embolization)/(Total liver volume—Tumor volume), as previously described in the literature [5].

The selection of patients for surgical treatment was based on the evaluation of disease extent, volumetric CT analysis [6], and the FLR measurements performed immediately before surgery (Figs. 3 and 4).

Tumor progression was defined as the detection of extrahepatic metastasis, left hepatic tumor or an increase of preexisting tumor that contraindicate surgery (vascular invasion).

To assess the efficacy of PVE, FLR volumes were compared before and after embolization. The mean absolute FLR volumes (in cm^3) and FLR/TLV ratios were calculated before and after embolization to determine the degree of hypertrophy.

Statistical analysis

All data were expressed as means ± standard deviations (SD). The Mann—Whitney test and the Fisher exact test were used to compare continuous and categorical variables, respectively. The rates of hepatic resection were analyzed, and the Fisher exact test was used to determine if the differences were statistically significant ($P < 0.05$). Spearman's rank coefficient was used to calculate the correlation between two continuous variables. The Wilcoxon signed-rank test was used for matched comparisons. Statistical significance was set at a P-value < 0.05. All analyses were performed with SAS v.9.2 (Sas Institute Inc., Cary, North Carolina, USA).

Results

Study population

From February 2009 to January 2013, 31 patients (52 men and 11 women) were considered for right hepatectomy after PVE for hepatobiliary malignancy.

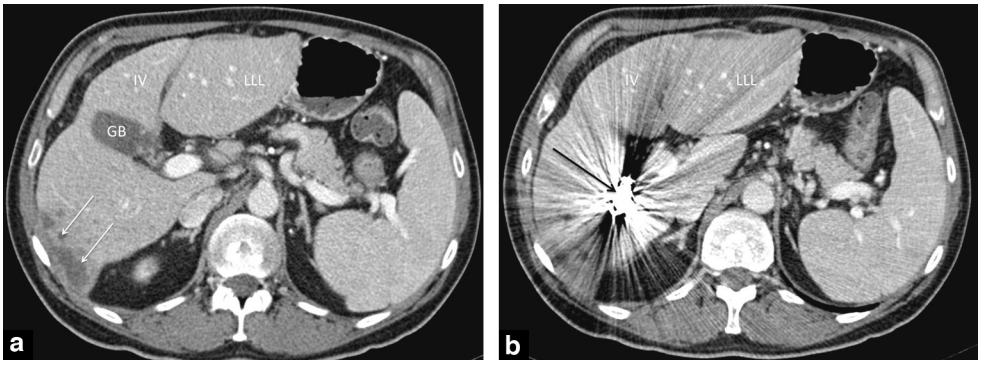

Figure 4. Axial portal venous phase CT obtained 23 days after portal vein embolization. IV, I, LLL and GB correspond to segment IV, I, the left liver lobe and the gallbladder respectively. Image (a) is obtained at the same plane as Fig. 3. White arrows (a) correspond to distal infarcts in the sub capsular part of the right liver lobe. Black arrow (b) corresponds to post-portal vein embolization coils.

Table 1 Patients demographics.

Sex (M/F)	52/11
Age (years, mean, range)	63 [38—80]
Tumor type (*n*/%)	
HCC	(38/60)
Cholangiocarcinoma	(11/18)
Metastasis	(14/22)
Vials of microparticles (mean, SD)	8.9 ± 1.8
Coils (mean, SD)	14.1 ± 4.2
Resection rate (*n*/%)	49/78%
Resection rate according to tumor type	
HCC	(30/38)
Cholangiocarcinoma	(4/11)
Metastasis	(2/14)

M: men; F: female; *n*: number; SD: standard deviation.

The mean age was 63 years old (ranging from 38 to 80 years). All patients had advanced hepatobiliary malignancies (hepatocellular carcinoma in 38 patients, cholangiocarcinoma in 11 patients and liver metastasis from colorectal cancer in 14 patients) and required right hepatectomy. The diagnosis of malignancy was either a biopsy-proven malignant neoplasia ($n = 29$) or typical imaging findings on multi-detector CT and/or magnetic resonance imaging ($n = 34$). The demographical and histological parameters were reported in Table 1.

Among the 38 patients with hepatocellular carcinoma, 37 had liver cirrhosis (all patients were classified as Child—Pugh class A). The cause of cirrhosis was viral hepatitis B ($n = 9$), viral hepatitis C ($n = 11$), alcoholism ($n = 8$), viral hepatitis C and alcoholism ($n = 5$), non-alcoholic steatohepatitis ($n = 3$), or hemochromatosis ($n = 1$). The three patients with liver metastases received prior chemotherapy (Folfox).

Concerning the embolic agents (Table 1), we used a mean number of 8.9 ± 1.8 vials of particles ranging from 300 to 1200 μm which correspond to a volume of 15.3 ± 3.1 mL of particles; and, at most, one entire gelfoam pad cut per patient. A mean of 14.1 ± 4.2 coils were used to obtain the right portal vein branches occlusion. The amount of contrast media used for the procedure was 467 ± 113 mL.

Clinical evaluation

Puncture of the distal part of the segment III portal branch was performed in all cases, and technical success rate of PVE was 100%, achieving a complete occlusion of all right portal vein branches.

No patient developed post-embolization syndrome, grade 3 or 4 pain after PVE or progressive liver failure after PVE or surgery. No patient required a specific medication after embolization. No subcapsular hematoma or thrombosis was found at the site of the left branch puncture of the left portal branch on the post-embolization volumetric CT-scan.

The median length of hospital stay was 2 days (ranging from 1 to 4 days) for PVE.

Table 2 Volumetric measurements before and after portal vein embolization.

	Before PVE	After PVE
TLV (cm^3: mean, SD)	1.825 ± 91	1.934 ± 83
FLR (cm^3: mean, SD)	449 ± 180	663 ± 254
FLR/TLV (%)	25 ± 8	36 ± 12
Hypertrophy of FLR (%)		57 ± 56
Increase of the FLR/TLV ratio (%)		11 ± 7

TLV: total liver volume; FLR: future liver remnant; SD: standard deviation; PVE: portal vein embolization.

Complications of PVE

Seven complications occurred as a result of PVE, though none was directly related to the particular embolic agent used. Three patients developed minors complications and four portal hypertension that contraindicate surgery.

Four patients developed signs of portal hypertension on follow-up CT imaging, and two of them had measurements of portal pressure via transjugular approach to confirm CT-scan findings. These patients were not operated on because of the portal hypertension.

One patient developed an intrahepatic portovenous shunt on the side of portal venous puncture, between the distal part of the left hepatic vein and the distal part of the segment III portal branch. This shunt was stable according to the Doppler and multi-detector CT performed during follow-up examination, even after right hepatectomy.

Two patients had one coil displacement, in the left portal vein. The coils were then removed with a 10-mm Amplatz GooseNeck® Snare Kit (EV3, White Bear Lake, Minnesota, USA). Intra-portal IV anticoagulant therapy was injected. The left portal branch patency was confirmed by final portography, US-Doppler examination of 24 hours and on pre- and post-hepatectomy CT-scans.

Assessment of hypertrophy

All post-embolization volumetric CT-scans were performed from 14 to 35 days (mean of 24 days ± 6 days) after PVE. The mean TLVs were 1.825 ± 91 cm^3 before and 1.934 ± 83 cm^3 after PVE. The mean absolute FLR volumes were 449 ± 180 before and 663 ± 254 cm^3 after PVE. The mean absolute FLR volume increased by 57% ± 56% ($P < 0.0001$). Volumetric data are reported in Table 2.

The pre-embolization FLR/TLV ratio was 25% ± 8%, and the post-embolization FLR/TLV ratio was 36% ± 12%. The mean increase in the FLR/TLV ratio after PVE was 11% ± 7% ($P < 0.0001$).

There was no significant difference in FLR hypertrophy according to age ($P = 0.53$), sex ($P = 0.28$), tumor type ($P = 0.32$) or liver cirrhosis ($P = 0.13$).

The degree of hypertrophy negatively correlated with the initial FLR volume ($r = -0.37$; $P = 0.024$).

Resection rate and outcome

Of the 63 patients who underwent PVE, 49 (78%) underwent successful right hepatectomy four to 7 weeks after PVE. No

death was recorded up to 2 months after surgery, and no case of postoperative liver failure was recorded.

Fourteen patients (22%) did not undergo resection because of tumor progression ($n = 9$), inadequate hypertrophy ($n = 1$) or portal hypertension ($n = 4$).

For 13 patients, although the percentage of theoretical FLR needed was not obtained, the right hepatectomy was performed anyway.

Eight of them (with a healthy liver) had a future liver remnant of 20 to 23% (theoretical value recommended is 25% or more). Six of them (with a cirrhotic liver) had a future liver remnant of 35 to 39% (theoretical value recommended is 40% or more).

Discussion

Despite the decrease in postoperative complications after liver resection over the past 10 years, insufficient hepatic functional reserve, suggested by a small FLR volume after major liver resection, is still considered a risky situation.

Major hepatectomy (i.e., resection of four or more liver segments) is associated with increased morbidity and mortality. The increase in mortality has been reported as high as 0.5 to 4% in patients with a healthy liver [7] and from 4 to 12% in patients with a cirrhotic liver [8,9]. Postoperative complications are mainly due to liver failure.

Therefore, by hypertrophying the FLR, the safety and tolerance of major liver resections might be improved. Based on this hypothesis, PVE has been proposed to increase the size of the FLR after major hepatectomy, thus reducing the risk of postoperative liver insufficiency. PVE consists of preoperatively embolizing portal branches of the segments that will be resected. PVE has been used in patients with or without chronic liver disease, and with diseases such as cholangiocarcinoma, hepatocellular carcinoma and liver metastases [8].

PVE is a well-established procedure, but it is extremely variable from one center to another, probably because there is no official recommendation for using a specific embolic agent [1]. No monocentric, comparative study has examined which embolic agent would provide better hypertrophy, but according to the recent literature, n-butyl cyanoacrylate (NCBA) and trisacryl microspheres appear to be the two most commonly used embolic agents [10]. However, gelfoam [11], coils [12], alcohol [13], and nitinol plugs [14,15] alone or in combination [16—20] have also been used as embolic agents, but seem less efficient because of recanalization of the portal vein and/or low hypertrophy of the FLR. Moreover, the rate of hypertrophy after PVE depends on the pre-embolization FLR volume more than any other factor, as described previously [12]. Since 1990 PVE was proposed as a mean to prepare the patient and liver for extended resection [21], refined indications, techniques and embolization materials have contributed to improve the outcomes of the procedure and the subsequent extended hepatic resection.

To summarize our results, we performed successfully 31 left percutaneous transhepatic PVE approach, with the use of a mean number of 8.9 ± 1.8 vials of particles, plus particles of gelfoam pad cut and a mean of 14.1 ± 4.2 coils. No patient developed post-embolization syndrome and the mean hospital stay was 2 days. Four complications (3 minor and one portal hypertension) occurred as a result of PVE. The mean absolute FLR volume increased by $57\% \pm 56\%$ and the mean increase in the FLR/TLV ratio after PVE was $11\% \pm 7\%$. Of the 63 patients who underwent PVE, 49 underwent successful right hepatectomy, without death up to 2 months after surgery, and no case of postoperative liver failure. Fifteen patients had a limited hypertrophy of FLR, but only one had not been operated on.

There is no clear rationale for the use of three embolic agents. However, this could be a more reproducible procedure, since we use systematically at least a vial of each particle size (300—500; 500—700; 700—900 and 900—1200 μm) in the different embolized portal branches. Moreover, at the end of procedure, slowing the flow in the right portal branch may cause a reflux of embolization material in the future liver remnant. The use of gelfoam at the end of procedure could minimize this risk, since gelfoam is an absorbable agent. Finally, although we did not conduct a study of cost, the use of Gelfoam has allowed us to use less trisacryl microspheres, which are more expensive than gelfoam.

Our PVE procedure consisted in all cases of a transhepatic contralateral approach, whereas ipsilateral or contralateral approaches were described in the literature. We used this technique because it seemed easier for us to catheterize the anterior and posterior right portal branches. Moreover, the contralateral approach allows us to better control the release of coils starting distally in the right portal vessels, to perform a final portography and to use it as a good tool to measure intra-portal pressure before and after portal vein embolization if needed.

PVE is indicated based on preoperative CT measurements [6] of the FLR and its ratio with either the theoretical TLV or by a direct measurement of the functional liver volume. According to the literature, the FLR/TLV ratio should be at least equal to 25% in a healthy liver, equal to 30% after chemotherapy and equal to 40% in a cirrhotic liver [19,22—27].

Three-dimensional volumetric CT-scan is the method of choice for assessing TLV and FLR [28—30]. The average time period between PVE and post-embolization volumetric CT-scan should be approximately 3 to 4 weeks [31], as in our study (mean of 26 days, ranging from 16 to 32 days).

Our results suggest that hypertrophy after PVE is inversely correlated with the initial FLR volume, even in a cirrhotic liver ($r = -0.37$; $P = 0.024$). These results confirm those of a recent study by de Baere et al. [12] on PVE in patients with malignant disease and a non-cirrhotic liver.

Our PVE procedure consisted of a transhepatic contralateral approach and the use of a combination of three embolization agents, which are already used separately, but not in combination, to the best of our knowledge. Although this study is not a randomized trial focused on comparing different agents of embolization, the hypertrophy resulting from the PVE technique used was comparable to that found in series reported in the literature using other techniques. Moreover, no case of liver failure, severe pain or post-embolization syndrome was observed with this technique, which indicates that it did not result in a higher rate of complications than other techniques described in the literature.

There are several limitations to our study in addition to the small number of patients and its retrospective design. The diseases studied were varied: hepatocellular carcinoma (in all but one developed on liver cirrhosis), cholangiocarcinoma (the liver was most often healthy) and liver metastases in patients who have had chemotherapy (which can affect the liver and its potential ability to regenerate). Moreover, in case of liver cirrhosis, the causes of cirrhosis were heterogeneous.

For fourteen patients, although the percentage of theoretical FLR needed was not obtained, the right hepatectomy was performed anyway. Surgeons argued that surgery was the only curative treatment available for these patients. Four of them (with a healthy liver) had a future liver remnant of 20 to 23% (theoretical value recommended is 25% or more). Three of them (with a cirrhotic liver) had a future liver remnant of 35 to 39% (theoretical value recommended is 40% or more).

Although the combined use of microparticles and gelfoam could allow us to use less of microparticles (higher cost), we have not been able to make cost study, which would probably be important to make in these economical difficult periods.

Our study shows similar results to those in the literature obtained with other agents of embolization in terms of hypertrophy of the future liver remnant, but it is not a comparative study. These results are to be compared to the Madoff at al. ones [23], using spherical particles (from 100 to 700 μm) and coils, with a mean FLR increase of 69% and mean FLR/TELV of 9.7%. In this study about 44 patients, three patients had an inadequate hypertrophy and the overall resection rate was 71%. In a recent systematic review of PVE before liver resection including 44 articles [2] the hypertrophy rate of the FLR was 24 to 26% with the use of PVA + coils while the mean increase of the FRL volume was 37.9 ± 0.1% (20.5—69.4%).

A recent retrospective study [3] comparing the results of PVE using two PVE procedures showed that the use of NBCA (20 patients) seems more effective than the use of spherical 100—300 μm microparticles and coils (14 patients). These results are to be compared to an experimental study in a pig model, which have demonstrated an advantage of NCBA over three other embolic agents [16].

It would be interesting to conduct a prospective, randomized study to compare the rates of hypertrophy using several methods of embolization, the length of this procedure and the cost.

Conclusion

In conclusion, our results suggest that PVE using the combination of three different embolic agents (trisacryl microspheres, gelfoam and coils) is a safe, well-tolerated and effective method for inducing contralateral hypertrophy before right hepatectomy in patients with advanced hepatobiliary malignancies.

Disclosure of interest

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

References

[1] Denys A, Bize P, Demartines N, Deschamps F, De Baere T. Quality improvement for portal vein embolization. Cardiovasc Intervent Radiol 2010;33:452—6.

[2] Van Lienden KP, van den Esschert JW, de Graaf W, Bipat S, Lameris JS, van Gulik TM, et al. Portal vein embolization before liver resection: a systematic review. Cardiovasc Intervent Radiol 2013;36:25—34.

[3] Guiu B, Bize P, Gunthern D, Demartines N, Halkic N, Denys A. Portal vein embolizaion before right hepatectomy: improved results using n-butyl cyanoacrylate compared to microparticles plus coils. Cardiovasc Intervent Radiol 2013 [Epub ahead of print] http://www.ncbi.nlm.nih.gov/pubmed/23361117

[4] Omary RA, Bettmann MA, Cardella JF, Bakal CW, Schwartzberg MS, Sacks D, et al. Quality improvement guidelines for the reporting and archiving of interventional radiology procedures. J Vasc Interv Radiol 2002;13:879—81.

[5] de Baere T, Roche A, Elias D, Lasser P, Lagrange C, Bousson V. Preoperative portal vein embolization for extension of hepatectomy indications. Hepatology 1996;24:1386—91.

[6] Soyer P, Roche A, Elias D, Levesque M. Hepatic metastases from colorectal cancer: influence of hepatic volumetric analysis on surgical decision-making. Radiology 1992;184:695—7.

[7] Nordlinger B, Peschaud F, Malafosse R. Resection of liver metastases from colorectal cancer-how can we improve results? Colorectal Dis 2003;5:515—7.

[8] Farges O, Belghiti J, Kianmanesh R, Regimbeau JM, Santoro R, Vilgrain V, et al. Portal vein embolization before right hepatectomy: prospective clinical trial. Ann Surg 2003;237:208—17.

[9] Fong Y, Fortner J, Sun RL, Brennan MF, Blumgart LH. Clinical score for predicting recurrence after hepatic resection for metastatic colorectal cancer: analysis of 1001 consecutive cases. Ann Surg 1999;230:309—18 [discussion p. 318—321].

[10] Denys A, Prior J, Bize P, Duran R, De Baere T, Halkic N, et al. Portal vein embolization: what do we know? Cardiovasc Intervent Radiol 2012;35:999—1008.

[11] de Baere T, Roche A, Vavasseur D, Therasse E, Indushekar S, Elias D, et al. Portal vein embolization: utility for inducing left hepatic lobe hypertrophy before surgery. Radiology 1993;188:73—7.

[12] de Baere T, Teriitehau C, Deschamps F, Catherine L, Rao P, Hakime A, et al. Predictive factors for hypertrophy of the future remnant liver after selective portal vein embolization. Ann Surg Oncol 2010;17:2081—9.

[13] Ogasawara K, Uchino J, Une Y, Fujioka Y. Selective portal vein embolization with absolute ethanol induces hepatic hypertrophy and makes more extensive hepatectomy possible. Hepatology 1996;23:338—45.

[14] Bent CL, Low D, Matson MB, Renfrew I, Fotheringham T. Portal vein embolization using a nitinol plug (Amplatzer vascular plug) in combination with histoacryl glue and iodinized oil: adequate hypertrophy with a reduced risk of nontarget embolization. Cardiovasc Intervent Radiol 2009;32:471—7.

[15] Kalenderian AC, Chabrot P, Buc E, Cassagnes L, Ravel A, Pezet D, et al. Preoperative portal vein embolization with Amplatzer(®) vascular plugs (AVP): a review of 17 cases. J Radiol 2011;92:899—908.

[16] de Baere T, Denys A, Paradis V. Comparison of four embolic materials for portal vein embolization: experimental study in pigs. Eur Radiol 2009;19:1435—42.

[17] Denys A, Lacombe C, Schneider F, Madoff DC, Doenz F, Qanadli SD, et al. Portal vein embolization with N-butyl cyanoacrylate before partial hepatectomy in patients with hepatocellular carcinoma and underlying cirrhosis or advanced fibrosis. J Vasc Interv Radiol 2005;16:1667—74.

[18] Madoff DC, Abdalla EK, Vauthey JN. Portal vein embolization in preparation for major hepatic resection: evolution of a new standard of care. J Vasc Interv Radiol 2005;16:779—90.
[19] Madoff DC, Hicks ME, Abdalla EK, Morris JS, Vauthey JN. Portal vein embolization with polyvinyl alcohol particles and coils in preparation for major liver resection for hepatobiliary malignancy: safety and effectiveness: study in 26 patients. Radiology 2003;227:251—60.
[20] Madoff DC, Hicks ME, Vauthey JN, Charnsangavej C, Morello Jr FA, Ahrar K, et al. Transhepatic portal vein embolization: anatomy, indications, and technical considerations. Radiographics 2002;22:1063—76.
[21] Makuuchi M, Thai BL, Takayasu K, Takayama T, Kosuge T, Gunvén P, et al. Preoperative portal embolization to increase safety of major hepatectomy for hilar bile duct carcinoma: a preliminary report. Surgery 1990;107:521—7.
[22] Ferrero A, Viganò L, Polastri R, Muratore A, Eminefendic H, Regge D, et al. Postoperative liver dysfunction and future remnant liver: where is the limit? Results of a prospective study. World J Surg 2007;31:1643—51.
[23] Madoff DC, Abdalla EK, Gupta S, Wu TT, Morris JS, Denys A, et al. Transhepatic ipsilateral right portal vein embolization extended to segment IV: improving hypertrophy and resection outcomes with spherical particles and coils. J Vasc Interv Radiol 2005;16:215—25.
[24] Azoulay D, Castaing D, Krissat J, Smail A, Hargreaves GM, Lemoine A, et al. Percutaneous portal vein embolization increases the feasibility and safety of major liver resection for hepatocellular carcinoma in injured liver. Ann Surg 2000;232:665—72.
[25] Kubota K, Makuuchi M, Kusaka K, Kobayashi T, Miki K, Hasegawa K, et al. Measurement of liver volume and hepatic functional reserve as a guide to decision-making in resectional surgery for hepatic tumors. Hepatology 1997;26:1176—81.
[26] Capussotti L, Muratore A, Baracchi F, Lelong B, Ferrero A, Regge D, et al. Portal vein ligation as an efficient method of increasing the future liver remnant volume in the surgical treatment of colorectal metastases. Arch Surg 2008;143:978—82.
[27] Abulkhir A, Limongelli P, Healey AJ, Damrah O, Tait P, Jackson J, et al. Preoperative portal vein embolization for major liver resection: a meta-analysis. Ann Surg 2008;247:49—57.
[28] Shirabe K, Shimada M, Gion T, Hasegawa H, Takenaka K, Utsunomiya T, et al. Postoperative liver failure after major hepatic resection for hepatocellular carcinoma in the modern era with special reference to remnant liver volume. J Am Coll Surg 1999;188:304—9.
[29] Urata K, Kawasaki S, Matsunami H, Hashikura Y, Ikegami T, Ishizone S, et al. Calculation of child and adult standard liver volume for liver transplantation. Hepatology 1995;21:1317—21.
[30] Vauthey JN, Chaoui A, Do KA, Bilimoria MM, Fenstermacher MJ, Charnsangavej C, et al. Standardized measurement of the future liver remnant prior to extended liver resection: methodology and clinical associations. Surgery 2000;127:512—9.
[31] Ribero D, Chun YS, Vauthey JN. Standardized liver volumetry for portal vein embolization. Semin Intervent Radiol 2008;25:104—9.