

CIRSE Standards of Practice on Portal Vein Embolization and Double Vein Embolization/Liver Venous Deprivation.

Title: CIRSE Standards of Practice on Portal Vein Embolization and Double Vein Embolization/Liver Venous Deprivation.

Publication year: 2024

Journal: Cardiovascular and interventional radiology

Authors: Interventional Radiology Unit, Curry Cabral Hospital, Unidade Local de Saúde São José; Centro Clínico Académico de Lisboa, SAMS Hospital, Lisbon, Portugal. tiagobilhim@hotmail.com.

Society: CIRSE

Origin country: International

Target countries: International

DOI: 10.1007/s00270-024-03743-8

PMID: 38884781

Source: <https://pubmed.ncbi.nlm.nih.gov/38884781/>

pmc Cardiovasc Intervent Radiol Cardiovasc Intervent Radiol 365 springeropen 8003538
Cardiovascular and Interventional Radiology 0174-1551 1432-086X pmc-is-collection-domain yes
pmc-collection-title Springer PMC11303578 PMC11303578.1 11303578 11303578 38884781
10.1007/s00270-024-03743-8 3743 1 Cirse Standards of Practice Guidelines CIRSE Standards of
Practice on Portal Vein Embolization and Double Vein Embolization/Liver Venous Deprivation
<http://orcid.org/0000-0003-3044-8474> Bilhim Tiago tiagobilhim@hotmail.com 1
<http://orcid.org/0000-0002-8819-6209> Böning Georg 2 Guiu Boris 3
<http://orcid.org/0000-0002-1222-850X> Luz José Hugo 4 <http://orcid.org/0000-0002-2275-7384>
Denys Alban 5 1 <https://ror.org/0353kya20> grid.413362.1 0000 0000 9647 1835 Interventional
Radiology Unit, Curry Cabral Hospital, Unidade Local de Saúde São José; Centro Clínico
Académico de Lisboa, SAMS Hospital, Lisbon, Portugal 2 grid.6363.0 0000 0001 2218 4662
Department of Radiology, Charité – Universitätsmedizin Berlin, corporate member of Freie
Universität Berlin and Humboldt-Universität zu Berlin, Augustenburger Platz 1, 13353 Berlin,
Germany 3 <https://ror.org/00mthsf17> grid.157868.5 0000 0000 9961 060X Department of
Radiology, St-Eloi University Hospital, Montpellier, France 4 grid.419166.d Department of
Interventional Radiology, Brazilian National Cancer Institute (INCA), Rio de Janeiro, Brazil 5
grid.9851.5 0000 0001 2165 4204 Department of Radiology and Interventional Radiology, Centre
Hospitalier Universitaire Vaudois CHUV, University of Lausanne, Lausanne, Switzerland 17 6 2024
2024 47 8 468309 1025 1036 18 12 2023 20 4 2024 17 06 2024 08 08 2024 28 08 2024 © The
Author(s) 2024 2024 <https://creativecommons.org/licenses/by/4.0/> Open Access This article is
licensed under a Creative Commons Attribution 4.0 International License, which permits use,
sharing, adaptation, distribution and reproduction in any medium or format, as long as you give
appropriate credit to the original author(s) and the source, provide a link to the Creative Commons
licence, and indicate if changes were made. The images or other third party material in this article
are included in the article's Creative Commons licence, unless indicated otherwise in a credit line to
the material. If material is not included in the article's Creative Commons licence and your intended
use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain
permission directly from the copyright holder. To view a copy of this licence, visit
<http://creativecommons.org/licenses/by/4.0/> . This CIRSE Standards of Practice document is aimed
at interventional radiologists and provides best practices for performing liver regeneration therapies
prior to major hepatectomies, including portal vein embolization, double vein embolization and liver
venous deprivation. It has been developed by an expert writing group under the guidance of the
CIRSE Standards of Practice Committee. It encompasses all clinical and technical details required
to perform liver regeneration therapies, revising the indications, contra-indications, outcome
measures assessed, technique and expected outcomes.

Open access funding provided by FCT|FCCN (b-on).

The CIRSE Standards of Practice (SOP) Committee established a writing group which was tasked with producing up-to-date recommendations for performing portal vein embolization (PVE), with or without hepatic vein embolization (HVE). CIRSE SOP documents are not clinical practice guidelines or systematic reviews of the literature. CIRSE SOP documents are not intended to impose a standard of clinical patient care but recommend a reasonable approach to and best practices for performing PVE, with or without HVE. Institutions should regularly review their internal procedures for development and improvement, taking into account international guidance, local resources and regular internal morbidity and mortality reviews.

The writing group, which was established by the CIRSE SOP Committee, consisted of 5 clinicians with internationally recognised expertise in PVE. The current document updates the 2010 CIRSE SOP on PVE [1]. A summary of definitions and key recommendations on PVE, sequential PVE followed by HVE, double vein embolization (DVE or bi-embolization or PVE/HVE) and liver venous deprivation (LVD) can be found in Table 1 . The writing group reviewed existing literature on PVE/HVE/DVE/LVD, performing a pragmatic evidence search using PubMed to select relevant publications in the English language and involving human subjects, preferably published from 2010 (last SOP document) to date. The final recommendations were formulated through consensus. Table 1 Definitions and key recommendations from the working group on portal vein embolization (PVE), sequential PVE followed by hepatic vein embolization (HVE), double-vein embolization (DVE) or bi-embolization and liver venous deprivation (LVD)

PVE Portal vein embolization; DVE Double-vein embolization; LVD Liver venous deprivation; FLR Future liver remnant; NBCA n -butyl cyanoacrylate; PHLF Post-hepatectomy liver failure

Liver resection is considered the standard of care curative option in patients with secondary or primary liver tumours. Liver surgery for liver tumours is split between liver-sparing surgery, where tumours are resected with oncological margins (tumourectomy), and anatomical resection where the segment or lobe bearing the tumour is resected entirely. Anatomical liver resection is considered a major resection when more than three segments are resected in one surgery [2]. Despite refinements in surgical techniques and improvement in patient preparation and critical care, major hepatectomy still carries a significant risk of morbidity and mortality mainly due to post-hepatectomy liver failure (PHLF).

Reported incidence of PHLF varies widely between 1.2% and 32% due to variations in patient population and procedures, but also due to the lack of a universally accepted definition of PHLF [3]. The International Study Group of Liver Surgery (ISGLS) redefined PHLF based on bilirubin and international normalized ratio (INR) values measured at day 5 or thereafter and proposed a severity grading system [3]. Risk factors for PHLF are related to the volume of future liver remnant (FLR) [4], and also to the underlying liver status such as post-chemotherapy liver injury [5 , 6] or chronic liver disease such as cirrhosis [7] or chronic cholestasis [8]. Recently, in complement to the FLR volume, FLR function appeared as an important factor associated with PHLF [9 , 10]. To identify patients with insufficient liver function in the FLR, new nuclear medicine investigations have been developed such as mebrofenin scintigraphy [8 , 9] allowing quantification of liver function.

Strategies to increase the FLR volume preoperatively have been developed over the years, allowing more patients to undergo successful surgical resection. The first is PVE, which consists of embolizing the portal branches of the future resected liver (i.e. usually right liver portal branches) 3–5 weeks before hepatectomy [11]. This method has a very low morbidity and is well tolerated [12] and carries a high success rate. However, in 15–20% of patients after PVE, the planned hepatectomy cannot be performed either due to tumour progression or due to insufficient hypertrophy [13]. There is a surgical equivalent technique which is portal vein ligation that can sometimes be used, especially when tumourectomies are to be performed on the FLR. With this surgery, one of the portal vein branches is ligated and can also be embolized with ethanol. Another option is to perform ablation of the FLR tumours and PVE at the same time. To reduce the risk of

tumour progression, by decreasing the delay between liver preparation and resection, an aggressive surgical approach has been developed associating right portal vein ligation and liver partition—so called ALPPS (associating liver partition and portal vein ligation for staged hepatectomy) one week before hepatectomy [14]. Despite initial enthusiasm due to very rapid FLR hypertrophy, concerns were raised due to the high morbidity and mortality rates seen with this surgical strategy [15]. One possible explanation for these disappointing results is the fact that despite a rapid volumetric gain, the function of the FLR does not necessarily mirror the volumetric gain and may even decrease [16]. Preoperative FLR functional evaluation has been advised after studies assessing ALPPS series revealing that volumetric gain might not be followed by functional gain [16]. After ALPPS first-stage, liver functional gain was only half of the volumetric gain, explaining the high rate of morbidity and mortality following this regenerative surgical approach [16]. One other strategy has been explored in patients with insufficient liver volume gain four weeks after PVE, by adding HVE. This strategy, called sequential PVE followed by HVE, has shown to add further liver regeneration [17]. A major drawback of this approach is the delay between each procedure increasing the risk of liver or extrahepatic tumour progression. A delay of four weeks is necessary to assess liver volumetric gain after PVE followed by another four weeks after additional HVE [17 – 19]. In this context, the concept of combining PVE and HVE in the same procedure appeared recently under different descriptions in the literature such as LVD and DVE (i.e. bi-embolization) [20 , 21]. The theoretical benefit is to accelerate and induce more hypertrophy than PVE alone and to reduce the risk of absent or insufficient hypertrophy. After PVE, portal vein collaterals between the FLR and the embolized liver develop and compromise FLR hypertrophy. Embolizing ipsilateral hepatic and portal vein branches with ALPPS or LVD/DVE will block the development of these portal vein collaterals between the FLR and the embolized liver. This will optimize flow and minimize hepatotrophic factor washout from the FLR, enhancing hypertrophy [14 – 21].

Indications for these liver regeneration techniques are based on liver volume assessment by computed tomography (CT). All surgical groups agree that a FLR/TLV (total liver volume) ratio below 20% is an indication for a liver regeneration technique such as PVE, DVE, LVD or ALPPS. Debates about the use of either the functional liver volume measured by CT or the estimated total liver volume based on body surface area are still unresolved [22 , 23]. Both methods can be used, but they carry some discrepancies in 5% of patients [24], potentially leading to decision errors regarding PVE indication. Of course, estimating the liver volume by CT does not estimate the function and regenerative capacity of FLR after resection. Many groups also consider the liver function estimated either by mebrofenin scintigraphy-CT or by MRI using hepato-specific contrast agent. These two imaging techniques can estimate hepatocyte function by quantitative imaging [8 , 25 , 26]. PVE/DVE/LVD can be proposed in patients bearing colorectal (or other less frequent) liver metastases, but also before major hepatectomy for hepatocellular carcinoma, or intrahepatic cholangiocarcinoma or hilar type (Klatskin) cholangiocarcinoma [27 , 28]. The threshold of FLR/TLV ratio for PVE or DVE/LVD is different among these different groups and varies between 20% (colorectal metastases), 30% (colorectal metastases with post-chemotherapy liver injury) and 40% (hepatocellular carcinoma with underlying liver cirrhosis and Klatskin tumours) [27]. The suggested thresholds for resections are shown in Table 2 . There are no absolute contra-indications for PVE or DVE/LVD if the patient is considered eligible for major hepatectomy. For patients with Klatskin tumours and obstructive jaundice, most centres recommend biliary drainage before liver regeneration treatments and bilirubin levels < 5–10 $\mu\text{mol/L}$, even though simultaneous biliary drainage and PVE has been shown to be safe and effective [28]. Table 2 Definitions and recommended outcome measures assessed after liver hypertrophy techniques

PHLF Post-hepatectomy liver failure; ISGLS International study group of liver surgery; FLR Future liver remnant; TLV Total liver volume; NBCA n -Butyl cyanoacrylate; DH Degree of hypertrophy; PVE Portal vein embolization; LVD Liver venous deprivation; KGR Kinetic growth rate; FLRabH FLR absolute hypertrophy; BSA Body surface area; ICG Indocyanine green; MRI Magnetic resonance imaging

The decision for liver regeneration therapies should be made in multidisciplinary team meetings (MDT) of surgeons, hepatologists, oncologists, and interventional radiologists with respect to the individual patient's performance status, tumour resectability and vascular invasion, FLR volume and function, type of tumour and underlying liver disease. Informed consent should be obtained 24 h ahead of treatment. In addition to routine laboratory parameters, particularly for coagulation and bilirubin, pre-surgical work-up (within the month preceding intervention) should include CT/MRI-based liver volume analysis (FLR/TLV/FLR ratio) and ideally should also include functional liver assessment. If additional ablations are planned within the FLR, the corresponding volumes must be considered in the calculation.

As biliary obstruction can impair liver regeneration and hypertrophy, the biliary tree of the FLR should be drained before PVE/DVE/LVD when bilirubin levels $> 2 \mu\text{mol/L}$ (threshold for a safe major hepatectomy) [28]. For patients with hepatocellular carcinoma with underlying liver cirrhosis, transarterial chemoembolization may be performed 3–4 weeks before PVE/DVE/LVD, enhancing the regeneration of the FLR [29 , 30]. The CIRSE SOP on Peri-operative Anticoagulation Management During Interventional Radiology Procedures should be followed for PVE/DVE/LVD [31]. There are guidelines for prophylactic antibiotic therapy in interventional radiology in general but not for PVE/DVE/LVD in particular; therefore, decisions should be made on a case-by-case basis considering individual risk factors (prior biliary manipulation or infection), the patient's history and the therapeutic strategy including combinations of vascular/non-vascular interventions [32].

After skin disinfection and local anaesthesia, PVE is usually performed via ultrasound-guided percutaneous transhepatic portal vein access using a 21–22G needle and 0.018-inch guide wire included in dedicated tri-axial micropuncture kits (with a metallic stiffening cannula, a dilator, and a 10–20 cm long 4–6 Fr. sheath) [1 , 11 , 12]. Alternative routes include transileocolic and transsplenic approaches. The transileocolic technique necessitates a mini-laparotomy and can also be part of a two-stage surgical resection. The transhepatic route allows for the procedure to be conducted via either ipsilateral or contralateral puncture. The advantages of ipsilateral (i.e. right access for right PVE) access are: no damage to the FLR, ability to gain access to segment IV portal venous branches and reduced risk of radiation exposure to the operator's hand. Its drawbacks include the need for reversed catheters that are used for PVE and for the completion portography, with longer and more complex procedures. The contralateral approach may induce damage to the FLR and poses more radiation exposure to the operator, but it provides more direct access to the target portal vein branches [1 , 11 , 12]. Catheters used are usually 4–5 Fr. reversed catheters for ipsilateral approach and 4–5 Fr. angled-tip catheters for contralateral approach. When the embolic agent used is n-butyl cyanoacrylate (NBCA), it is recommended to perform the embolization with 2.4–3.0 Fr. microcatheters. NBCA can adhere to the interior of catheters and migrate to untargeted portal vein branches. Thus, using super selective catheterization with microcatheters reduces the risk of untargeted embolization to portal vein branches of the FLR.

After gaining access to the portal system, 2D (20 ml of contrast medium; 10 ml/s contrast injection; right anterior oblique view of 25°) or 3D portography (35 ml of 1:1 or 3:2 iodine contrast to saline mixture; 5 ml/s contrast injection; with 2 s X-ray delay and 5 s acquisition/rotation time; volume of contrast adjusted to acquisition/rotation time) is recommended to assess the portal anatomy. With ipsilateral approaches, the portography should be performed with reversed catheters and selective embolization of portal vein branches can be performed via the same catheter when particles and coils are used. However, microcatheters should be used for embolization with NBCA. The same reversed catheter can be used for the completion portography. With contralateral approaches the same angled-tip catheter can be used for portography and embolization but a different catheter should be used for completion portography, when NBCA is used. Embolization of segment IV portal venous branches, although technically challenging, is safe in experienced hands and can improve hypertrophy and extend resectability [33] at the expense of a technically challenging procedure (4–6 branches usually supply segment IV). Cone-beam CT or angio-CT technologies with 3D road-mapping and microcatheters are therefore recommended.

Embolic materials used for PVE [34] include absolute ethanol [35 – 37], polyvinyl alcohol (PVA), gelatin sponge, fibrin glue, NBCA mixed with lipiodol [38], polidocanol-foam, or hybrid combinations of these agents with coils [39] or vascular plugs [40 , 41]. Several studies showed a benefit of NBCA over PVA [42] and microparticles + coils [43 – 45] in terms of FLR hypertrophy, with similar complication rates. For particles, 200–1000 µm particles (spherical or non-spherical) are recommended followed by 8 mm–16 mm diameter coils placed in the portal vein branch being embolized, through 4–5 Fr. catheters. Plugs used are usually 8–18 mm in diameter (10–20% oversizing) and will require larger (6–8 Fr.) sheaths for deployment. NBCA/lipiodol dilutions of 1/4–1/8 are recommended and care must be taken to flush all catheters with dextrose 5% and to avoid saline. Continuous injection of glue or a sandwich technique (injection of small amounts of NBCA interspaced with dextrose flushing) are based on operator preference.

The LVD technique was originally outlined as a fully transhepatic procedure [20]. Hepatic veins (HVs)—right, optional accessory right, and possibly middle (extended LVD)—are initially accessed with ultrasound guidance using a 21–22 G Chiba needle and a 0.018-inch wire, along with a micropuncture set. PVE is performed after wire/sheath access to the HVs. A 6–10 Fr. sheath is placed in each HV to deploy a vascular plug, positioning its distal end about 15 mm proximal to its junction with the vena cava. The plug positioning is crucial, so that surgical HV ligation with a stapler is not compromised during the planned hepatectomy. The vascular plug should be oversized by around 40% to prevent migration, and its accurate placement can be confirmed with ultrasound. Veno-venous collaterals quickly develop after proximal occlusion by the vascular plug, which is the reason why glue at a lower dilution (1/3–1/5) has been proposed to occlude not only distal venous branches but also these collaterals. These collaterals pose a challenge as they may lead to untargeted NBCA embolization to the lungs. This is one of the reasons why some centres prefer DVE over LVD. All transhepatic accesses can be embolized with glue, gelfoam or coils. The same LVD technique can be performed via a transjugular or transfemoral approach, with a micro-catheter in parallel to the vascular plug, to inject glue. The critical step is to prepare the glue and iodized oil mixture prior to plug deployment and to start injecting the mixture immediately behind the plug due to the quick expansion of these collaterals when outflow is blocked. Since, the middle HV drains approximately 2/3 of the right paramedian sector, the tolerance of LVD led to a proposal to extend LVD (extended LVD) embolizing not only the right (and accessory right HV when present) but also the middle HV using the exact same technique [46].

The notion of DVE or bi-embolization has been introduced but is specific to deploying only vascular plugs ± coils in the HVs via transjugular or transhepatic access [21]. This method may leave distal collaterals open, which can bypass the vascular plug within minutes. Thus, multiple vascular plugs ± coils should be used to occlude the whole HV. LVD embolizes both proximal (via vascular plug) and distal venous branches (via NBCA), as well as potential collaterals. The use of multiple vascular plugs placed all along the HVs and their tributaries can be considered instead of vascular plug + glue [47]. No data are currently available on the most optimal technique. PVE should be performed prior to DVE or LVD to allow better glue penetration into portal vein branches and reduce the risk of contralateral non-target glue reflux [48].

PVE/DVE/LVD can be performed in an outpatient setting; however, a short (1-day) inpatient stay is usually preferred. According to the CIRSE SOP on Analgesia and Sedation for Interventional Radiology in Adults, accurate evaluation, monitoring and documentation of patient care is important to minimise the risk of adverse events [49]. Procedural medication and monitoring of the patient should be delivered by a team member other than the specialist performing the procedure [49]. PVE/DVE/LVD can be performed using only pain medication without sedation in most cases. Nevertheless, sedation or general anaesthesia is also possible and might be required when NBCA is used as it induces more inflammation and pain when compared to PVA and coils. Whenever deeper levels of sedation are required, anaesthetists should be involved [49]. Follow-up imaging to assess hypertrophy of the FLR should ideally be performed using the same modality as before the procedure and timed to coincide with the planned surgery, ideally 14–28 days after the intervention. The time from PVE/DVE/LVD to planned hepatectomy varies between teams and clinical scenarios ranging from 2–4 weeks in non-cirrhotics to 2–3 months in cirrhotics [11 – 21]. Asthenia may

develop after LVD, thus routine multivitamin and phosphorus supplementation may be considered, which may also enhance FLR hypertrophy [20 , 21 , 46 , 47].

Technical and clinical success after PVE (complete occlusion of all planned portal branches and enough FLR regeneration for the intended hepatectomy, respectively) is very high, and should be expected to be above 98% and 90%, respectively [34 , 38]. Common reasons for technical failure are inability to access the portal system (blocked needle pathway due to liver tumour burden or altered portal anatomy caused by the tumour mass or unexpected thrombosis of the portal system) or incomplete embolization of the portal vein branches (missed portal vein branch during PVE) [44 , 50]. Lack of the expected FLR regeneration after a technically successful performed PVE, measured by the degree of hypertrophy (DH) and kinetic growth rate (KGR), has been associated with a significantly higher incidence of PHLF [51 , 52], and should be interpreted as an alert sign of a poor background liver function and reserve.

One of the most feared complications after PVE is that it may preclude the awaited liver surgery. A systematic review revealed that in 0.4% of cases, patients will not proceed to the planned hepatectomy due to major complications (severe cholangitis, large abscesses and sepsis, and portal venous or mesentericoportal venous thrombosis) [34]. As with other hepatic percutaneous procedures, complications after PVE may arise due to the transhepatic access, such as subcapsular haematoma, haemoperitoneum, pneumothorax, haemobilia, arteriovenous shunts, pseudoaneurysm, cholangitis and sepsis. Other complications such as post-embolization syndrome, non-target embolization, portal vein thrombosis and transient liver failure may also occur. The complication threshold for PVE should be expected to be 2.5% [53]. Mortality after PVE is rare and has been scarcely reported. In a meta-analysis consisting of 1088 patients, the overall morbidity rate for PVE was 2.2% without mortality [53]. In a single-institution large cohort of 146 patients, the thirty-day mortality was 0.7% [38]. Mortality rate after PVE should be expected to be maximum of 0.1% [34].

It has been suggested that PVE might lead to tumour progression and worse oncological outcomes in patients submitted to liver surgery [54 , 55]. The arterial buffer phenomenon (increase of liver arterial perfusion after portal vein occlusion) [56] and the release of hypertrophic factors involved in the regeneration process may stimulate tumour growth. Nevertheless, larger studies, including a systematic review with meta-analysis, showed no adverse effect in the local liver tumour progression, nor in the overall survival of patients treated with liver surgery, with versus without prior PVE [57].

Regenerative results of PVE have been extensively reported. Commonly reported hypertrophy outcome parameters are FLR absolute hypertrophy, DH and KGR. FLR absolute hypertrophy is related to the FLR growth in relation to its initial volume. DH shows the increase in the FLR ratio after PVE. KGR is a dynamic outcome measurement, a time-lapse of the regenerative process. It is calculated by dividing DH by the waiting time after PVE, usually in weeks. KGR shows how fast the regenerative process takes place. $KGR \geq 2$ has been directly correlated with the absence of PHLF and lower mortality after major hepatectomies [51]. Highly relevant clinical outcomes such as PHLF, peri-operative transfusion requirements, operative times, and complication rates after hepatectomies in patients submitted to liver regeneration therapies have been reported (Table 3). Patients who develop PHLF show longer intensive care and hospital stays and more postoperative complications (infectious; bile leaks; bleeding) [58 , 59]. PHLF developed in 10% and 9% of the patients for the group submitted to major hepatectomies with and without PVE, respectively [59]. The five-year overall survival was similar between these two groups, being 38.2% and 37.9% for patients with and without PVE, respectively [59]. Table 3 Expected outcomes after portal vein embolization (PVE), sequential portal vein embolization followed by hepatic vein embolization (HVE), double vein embolization (DVE) and liver venous deprivation (LVD)

PVE Portal vein embolization; DVE Double-vein embolization; LVD Liver venous deprivation; eLVD Extended LVD; NR Not reported; FLR Future liver remnant; Clinical success defined as achieving the intended FLR volume and ratio for hepatic resection; PHLF Post-hepatectomy liver failure; DH

Degree of hypertrophy; KGR Kinetic growth rate; FLRabh FLR absolute hypertrophy

a Different criteria for PHLF were used among studies (50–50 criteria [68], ISGLS criteria [69])

b Clinical failure for this procedure was reported in cirrhotic cohorts

c only reported for LVD and not for eLVD

d After three weeks [61]/53.4% at seven days for eLVD [46]

After PVE, > 70% of patients undergo the planned liver surgery, and this threshold should be considered acceptable [34 , 44 , 59]. Nevertheless, 20–30% of patients submitted to PVE will not go through the planned hepatectomy, the main reason being disease progression in the waiting period after PVE. Another reason for not performing the planned liver resection is insufficient growth after PVE in 5–10% of patients [34 , 44 , 59].

In 2021 two systematic reviews and one randomized trial evaluated the effect of different embolic materials in liver regeneration after PVE, showing the superiority of NBCA over PVA plus coils [44 , 45 , 58]; the beneficial increment in liver regeneration when segment IV embolization was performed; and the non-influence of neo-adjuvant systemic chemotherapy on PVE regenerative results [44]. In the aforementioned RCT [44], PHLF was 13% for the NBCA group and 27% for the PVA plus coils group ($p = 0.27$).

Different strategies have been proposed to overcome the potential insufficient regeneration after PVE, including sequential HVE after PVE [17], LVD [20], DVE [21] and ALPPS [14]. Sequential HVE has been shown to increase the volume of the FLR after insufficient PVE. The threshold of 5–10% increase in the FLR absolute growth should be expected 2 weeks after hepatic vein embolization in patients already submitted to PVE [17 – 19]. Interestingly, although sequential hepatic vein embolization is very well tolerated and complication rates are similar to PVE, reports of middle hepatic embolization erroneously recognized and embolized as the right hepatic vein have been reported from different groups [17 , 60].

Up to now there were only small retrospective cohorts and systematic reviews comparing the regenerative results of PVE and LVD. The latter technique seems to promote superior regenerative results. One study [47] reported superior KGR and FLR absolute hypertrophy for LVD when compared to PVE. Another study found superior volumetric and functional FLR gain when using LVD compared to PVE [61]. FLR functional gain after LVD was obtained earlier than volumetric hypertrophy [62]. These findings suggest that the planned hepatectomy might be performed (1 or 2 weeks) earlier after LVD when compared to PVE [61 , 62]. Interestingly, in these studies, KGR results (1.4%/week) and FLR volume increase (14–19%) for PVE were unusually low, maybe explaining the LVD superiority. Negative studies comparing PVE and LVD have also been reported. A prospective cohort of 14 patients submitted to LVD compared by matched analysis to PVE showed no FLR hypertrophy superiority for LVD before major hepatectomies [63]. Strong evidence about the indications, technique, complications, hypertrophy results and clinical outcomes of LVD and eLVD (extended LVD) as well as DVE will soon be available through ongoing multicentre clinical trials [64 , 65]. DVE and LVD have shown similar safety and hypertrophy results, but direct comparative trials are lacking [61 , 66 , 67].

A summary of the working group recommendations can be found in Table 4 and Fig. 1 . Table 4
Summary of working group recommendations

MDT Multidisciplinary team meeting; FLR Future liver remnant; PVE Portal vein embolization;
NBCA n -Butyl cyanoacrylate; LVD Liver venous deprivation; DVE Double-vein embolization

Flowchart of patient assessment prior to major hepatectomy. ICG, Indocyanine green; PVE, Portal vein embolization; ALPPS, Associating liver partition and portal vein ligation for staged hepatectomy; LVD, Liver venous deprivation; DVE, Double-vein embolization; HVE, Hepatic vein embolization

Associating liver partition and portal vein ligation for staged hepatectomy

Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Open access funding provided by FCT|FCCN (b-on). None.

Tiago Bilhim is a paid consultant for Merit Medical and has received speaker fees for Philips Medical, Cook Medical, and Terumo and is a stock holder for EmbolX. Boris Guiu is a consultant for Roche, Astra Zeneca, BMS, Boston Scientific, Guerbet, Terumo, and Canon Medical. All other authors declare that they have no conflict of interest.

All authors had control of the publication.