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AIM AND SCOPE

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EDITORS FOR THIS ISSUE

Abdominal cross-sectional imaging of the associating liver partition and portal vein ligation for staged hepatectomy procedure

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Abstract

Associating liver partition and portal vein ligation for staged hepatectomy (ALPPS) is a recently introduced technique aimed to perform two-stage hepatectomy in patients with a variety of primary or secondary neoplastic lesions. ALPSS is based on a preliminary liver resection associated with ligation of the portal branch directed to the diseased hemiliver (DH), followed by hepatectomy after an interval of time in which the future liver remnant (FLR) hypertrophied adequately (partly because of preserved arterialization of the DH). Multidetector computed tomography (MDCT) and magnetic resonance imaging (MRI) play a pivotal role in patients' selection and FLR assessment before and after the procedure, as well as in monitoring early and late complications, as we aim to review in this paper. Moreover, we illustrate main abdominal MDCT and MRI findings related to ALPPS.

Key words: Hepatectomy; Computed tomography; Magnetic resonance imaging; Associating liver partition and portal vein ligation for staged hepatectomy; Liver surgery

Core tip: Associating liver partition and portal vein ligation for staged hepatectomy (ALPPS) is a variant

of two-stage hepatectomy aimed to obtain rapid hypertrophy of the future liver remnant. Given its recent introduction, there are still controversies on indications and safety issues. Cross-sectional imaging by means of multidetector computed tomography (MDCT) and magnetic resonance imaging (MRI) play a key role in the multidisciplinary process of patients' selection and postoperative management. This review aims to emphasize such a role and illustrate main abdominal ALPPS-related findings on MDCT or MRI.

INTRODUCTION

Resection is the only treatment proven to achieve long-term survival in patients with primary hepatic malignancies or selected liver metastases[1,2]. Over the last years, advances in surgical techniques, systemic chemotherapy and intensive care improved the outcome of liver resection, leading to wider criteria for operability compared to the past[3]. However, adequate future liver remnant (FLR) (*i.e.*, the liver remnant planned to be left *in situ*) is still a critical factor in selecting patients when extended hepatectomy is required, given the need to minimize the risk of postoperative liver failure[4,5]. FLR should be at least 25%-30% of the liver volume in patients with normal preoperative liver function, 30% in chronic liver disease, and 40% in the setting of chemotherapy-related injury or cirrhosis[6,7]. Borderline FLR volumes pose the dilemma of whether attempting radical surgery *vs* performing palliative treatments[7].

In the 2000s, two-stage hepatectomy after preoperative percutaneous portal vein embolization (PVE) or portal vein ligation (PVL) has been proposed as a strategy to resect primarily inoperable tumors after having increased the FLR[8,9]. This approach combines the technical advantages of two-stage hepatectomy (*i.e.*, wedge resections of lesions in the FLR in the case of bilobar tumors) with the compensatory hypertrophy of the FLR induced by PVE or PVL performed at the time of first surgery[10]. The mechanism with which PVE and PVL lead to hypertrophic FLR is complex, involving both the diversion of portal blood flow and release of growth factors[7]. Since hypertrophy usually takes at least 4 wk to be completed, this technique shows high failure rate because of insufficient FLR growth and/or tumor progression during the interval of time between the two stages[11,12].

Associating liver partition and portal vein ligation for staged hepatectomy (ALPPS) is a two-stage hepatectomy

procedure introduced in September 2007 by Schnitzbauer *et al*[13] to obtained more rapid and larger increase of the FLR volume compared to conventional staged hepatectomy (40%-80% within 6-9 d *vs* 8%-27% within up to 60 d, respectively)[4,6,7,13-15]. The key technical point in ALPPS is the preservation of hepatic artery blood flow to the diseased hemiliver (DH) at the time of first surgical stage. Preserved arterialization leads the DH to act as a vital auxiliary liver and assist the growth of FLR through metabolic and synthetic functions[16,17]. ALPPS achieves a high rate of tumor complete resection (83%)[18], given the successful rate of adequate FLR growth (78%-91%)[19]. Additionally, the reduced interval of time between surgical steps translates into lower tumor progression rate, less adhesions during second surgery, faster patients recovery and prompter starting of adjuvant chemotherapy[4,15,20,21].

ALPPS is becoming increasingly popular in patients candidate to extended hepatectomy. To our knowledge, though imaging plays a key-role in planning the procedure and monitoring the results of both surgical stages, radiological findings related to ALPSS have been poorly reported. In this review, we aimed to summarize the current role for multidetector computed tomography (MDCT) and magnetic resonance imaging (MRI) in the procedure, which enable detailed view of pre- and postoperative anatomy, as well as prompt and reliable identification of complications. We also illustrated main cross-sectional imaging findings related to ALPPS, with special emphasis on normal aspects.

ALPSS: INDICATIONS AND TECHNIQUE

Indications

There is controversy on which lesions should be treated with ALPPS[6], given initially reported high mortality rates (up to 22% in some series)[22]. It should be kept in mind that ALPPS is an "extrema ratio" procedure to be proposed after careful, multidisciplinary patient selection[6,23,24]. Morbidity and mortality amount up to 14% and 6.6% in experienced centers applying strict selection criteria[10,25-27]. Best results have been obtained in patients with bilobar metastases from colorectal cancer with predictable radical resection, absence of extrahepatic disease and partial or complete response to chemotherapy[2]. Other treatable lesions include hepatocellular carcinoma, cholangiocarcinoma (intrahepatic or hilar), gallbladder carcinoma, and metastases from breast cancer or neuroendocrine tumors[7,25,26]. However, higher postoperative mortality was reported for non-colorectal liver metastases[7]. ALPPS can be also offered as first-line treatment or salvage-therapy after failed PVE[20,25,28-32].

Contraindications to ALPPS include unresectable lesions in the FLR, unresectable extrahepatic metastases, infiltration of the retrohepatic avascular space, severe portal hypertension, high anesthesiology risk, medical contraindications to major hepatectomy, impossibility to achieve negative margins, and unresectable primary
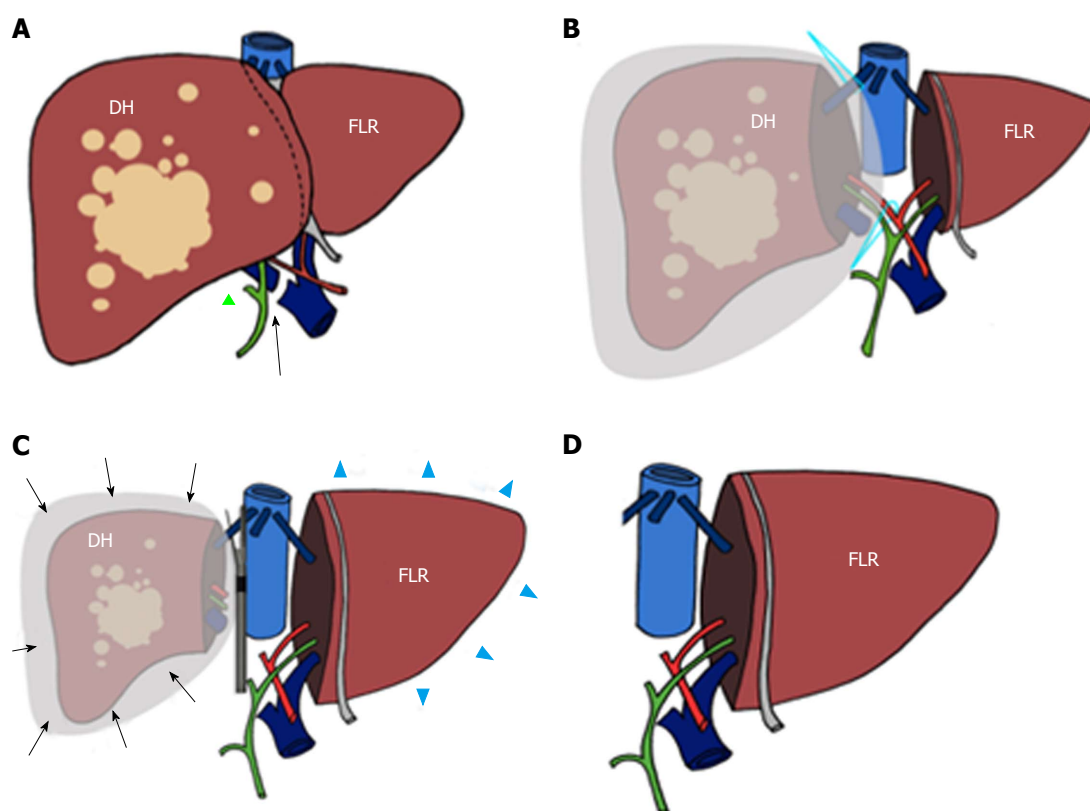
Figure 1 Scheme of trisectionectomy associating liver partition and portal vein ligation procedure. During surgical stage 1 the right portal vein is sectioned and sutured (arrow in A) after performing cholecystectomy (green triangle in A). Subsequently, the diseased hemiliver (DH) is sectioned from the future liver remnant (FLR) and wrapped with a bag (B). At the time of surgical stage 2 (C), hypertrophy of the (FLR) (blue arrowheads in D) and atrophy of the DH (arrows) have been obtained. Associating liver partition and portal vein ligation for staged hepatectomy procedure is then completed by removing the DH (D).

tumor in extrahepatic locations[26]. ALPPS is not reccomended in patients with advanced liver cirrhosis, because liver regeneration in the context of chronic liver disease is less predictable[7,33]. On the other hand, some Authors attempted ALPPS in selected cirrhotic patients[34].

Technique

Elective indication to ALPPS is right trisectionectomy[7], in which FLR and DH consist of Couinaud segments 2-3 *vs* 4-8 (Figures 1 and 2), respectively. Other technical approaches include right hepatectomy (leaving a segments 2-4 FLR), left hepatectomy (leaving segments 5-8 FLR), central hepatectomy (segments 4, 5 and 8 FLR) or monosegmental ALPPS[35-37].

ALPSS includes two consecutive surgical stages (stage 1 and stage 2). During stage 1, the portal branch directed to the DH side is sectioned and sutured in order to divert the portal flow to the FLR. Hepatectomy is subsequently performed to separate the FLR from DH completely (complete ALPPS) or partially (partial ALPPS)[32,38]. If affected by metastases, the FLR is cleaned up by wedge resections and/or intraoperative radiofrequency ablation[17,26]. At the end of the procedure, DH is left in situ, often after having enveloped it into a hermetic bag made of plastic or a biodegradable type- I acellular collagen membrane[39]. The rationale for using the bag is to avoid adhesions and obtain an easier removal of DH on surgical stage 2,

as well as better drainage or identification of collections (Figures 1 and 2)[7]. The purpose of stage 1 is to induce hypertrophy of the FLR (in which arterial and portal vascular supply is preserved) and atrophy of the DH (in which arterial supply alone is preserved). Cholecystectomy is also performed[40]. In the case of perihilar cholangiocarcinoma, biliary continuity is obtained by performing Roux-en-Y bilioenteric anastomosis[26]. After stage 1 completion, two drains are placed along the transection line and within the plastic bag, respectively.

Stage 2 is scheduled 7-14 d from stage 1[2]. Hepatectomy is completed by removing atrophic DH after transecting the serving hepatic artery, hepatic duct and hepatic veins (*e.g.*, right hepatic and middle hepatic veins in the case of right trisectionectomy, or right hepatic vein only in the case of right hepatectomy).

IMAGING TECHNIQUES

First-line imaging after both surgical stages 1 and 2 is represented by ultrasonography (US) with Color-Doppler examination. In our experience, US permits a "quick-and-dirty" evaluation at patient's bedside to screen for gross complications (*e.g.*, collections) and assess the patency of FLR portal vein, hepatic artery branches and hepatic vein. However, early postoperative US is limited by lack of patients' collaboration and reduced acoustic
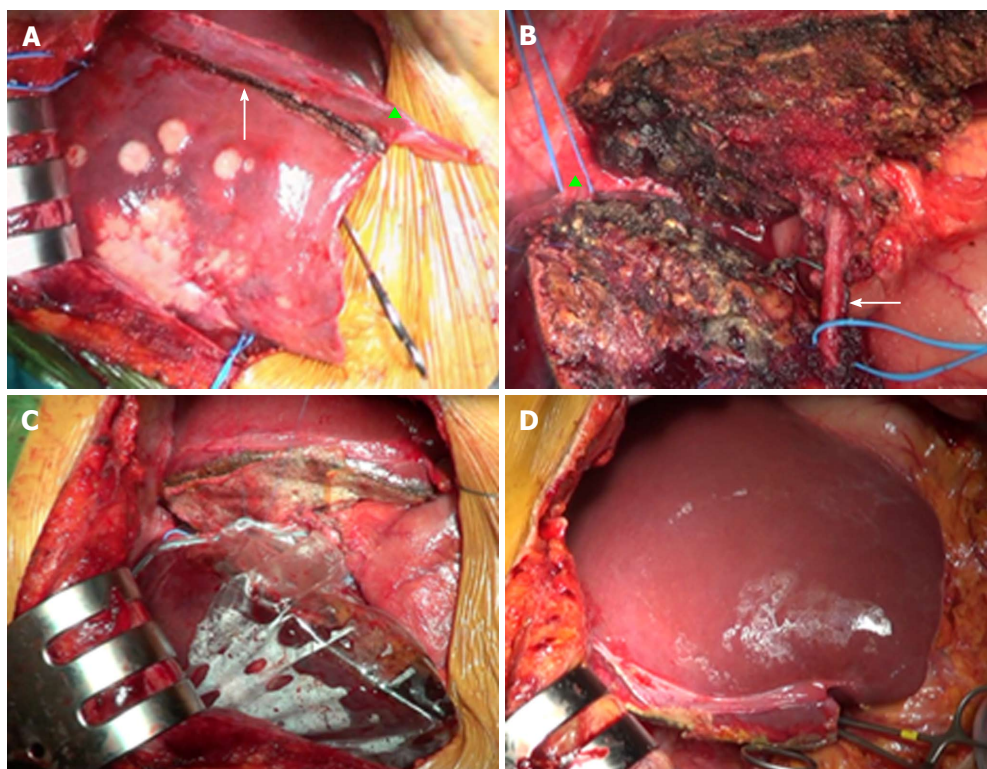
Figure 2 Surgical overview of the associating liver partition and portal vein ligation for staged hepatectomy procedure. A: Intraoperative findings during stage 1, with evidence of resection line (arrow) on the right side of ligamentum falciforme (green triangle); B: Resected liver with right hepatic vein (green triangle) and right hepatic artery (arrow) encircled by a vessel loop to simplify their identification during stage 2; C: After transection, diseased hemiliver is enveloped with a plastic bag; D: Pronounced hypertrophy of future liver remnant during intraoperative stage 2.

windows because of bowel gas and surgical dressing material[41]. Furthermore, US lacks panoramicity, *i.e.*, the capability to represent a section or a 3D reconstruction of the entire liver within a single image. Consequently, though this technique is useful in initial diagnosis of liver abnormalities, it has no direct role in selecting patients for ALPPS (*e.g.*, by assessing the number of lesions in the FLR or estimating its volume). Thus, cross-sectional imaging with MDCT and/or MRI is mandatory in the preoperative patients' selection, in evaluating postoperative increase in FLR volume and in assessing complications.

Because of wide panoramicity, fast acquisition time and lesser costs, MDCT should be regarded as the cross-sectional modality of choice to image patients before and after ALPPS. Our institutional protocol is summarized in Table 1. Fast acquisition makes MDCT feasible in less collaborating patients, with the possibility to extend the examination to the thorax and/or the lower abdomen if needed. Moreover, the multiphasic MDCT protocol has the advantage of providing all-in-one evaluation of liver neoplasms (in terms of both tumor burden and characterization), extrahepatic disease or complications, and the status of arterial, portal and venous structures for the purpose of preoperative planning and complications assessment. Multiplanar reformations and 3D reconstruction are of help in interpreting images and communicating imaging results to referring clinicians.

Given limited availability and longer acquisition

times, MRI should be reserved to inconclusive MDCT cases, especially in the preoperative phase, *i.e.*, when there is less risk of image quality degradation because of reduced patients' collaboration. Similarly to other liver applications[41-44], MRI should be performed with 1.5 Tesla or 3.0 Tesla magnets, equipped with highly performing gradients and multi-element surface coils (preferably 8-16 elements) implementing parallel imaging. Our MRI protocol is illustrated in Table 2.

Hepatobiliary contrast agents such as gadoxetic acid and/or gadobenate dimeglumine improve the detection and characterization of focal liver lesions by representing the vascularity and the presence/absence of hepatocellular contrast uptake at one time[45,46]. When liver metastases are the cause for ALPPS, preoperative MRI with diffusion-weighted imaging and hepatobiliary contrast agents should be regarded as the method of choice for detailed identification of small lesions potentially affecting ALPPS feasibility or FLR cleaning up[47]. Furthermore, hepatobiliary contrast agents are of help in assessing tumor relapse after surgery.

Magnetic resonance cholangiopancreatography (MRCP) should be used preoperatively to evaluate whether biliary tree anatomic variants are at risk of increasing surgical difficulty, or to assign the Bismuth category of cholangiocarcinoma extension[48]. In the postoperative phases, this technique can be of help in assessing the content of fluid collections (fluid *vs* hemorrhagic) or early and late biliary complications. In

Table 1 Institutional multiphasic multidetector computed tomography protocol for evaluating associating liver partition and portal vein ligation for staged hepatectomy patients before and after surgery (LightSpeed HD, General Electrics, Milwaukee, United States)

Scan phase (timing from contrast injection)	Scal lenght	Scanning parameters	Rationale in the preoperative phase	Rationale in the postoperative phases
Unenhanced	Upper abdomen	KVp 120 mA modulated between 200-450 Tube rotation 0.6 s Pitch 0.984 Noise index 16.10 Collimation 1.25 mm (0.625 for the angiographic phase) Image reconstruction thickness 1.25 mm	Identifying potential confounders in image interpretation (*e.g.*, lesion's or vascular calcifications). Measuring baseline attenuation of target lesions (*e.g.*, fat-containing HCC) or in diffuse liver disease (*e.g.*, steatosis) This phase is not required if recent prior imaging is available.	Identifying potential confounders in image interpretation (*e.g.*, surgical clips). Measuring the attenuation of intra-abdominal collections (biloma *vs* hematoma) This phase in not mandatory in repeated follow-up examinations
Angiographic phase (20)	Upper abdomen		Assessing the patency and anatomic variants of the hepatic artery and its branches, both on source images and MIP reconstructions	Assessing the sources of suspicious active postoperative bleeding
Delayed arterial (35-40 s)	Upper abdomen		Assessing hypervascular focal liver lesions (malignant and benign ones)	Assessing the patency of the hepatic artery and its branches. Identifying the recurrence of hypervascular tumors in the delayed post-operative period
Venous (70 s)	Whole abdomen		Assessing lesions' enhancement pattern for the purpose of identification/characterization. Assessing the patency and anatomic variants of the portal trunk and intrahepatic branches, both on source images and MIP reconstructions. Identifying additional abdominal findings potentially contraindicating ALPPS. Assessing for signs of chronic liver disease (including splenomegaly, venous collaterals and ascites)	Assessing the portal status (absence of flow in the ligated portal branch and patency of the FLR branch). Assessing successful tumor cleaning up in the FLR before surgical stage 2. Ruling out thrombosis of the portal braches, hepatic veins and inferior vena cava. Identifying tumor relapse
Delayed (3-5 min)	Upper or whole abdomen, depending on findings on previous scans		Assessing lesions' enhancement pattern for the purpose of identification/characterization. Identifying additional findings potentially contraindicating ALPSS (*e.g.*, peritoneal carcinosis). This phase is not mandatory	Assessing venous bleeding. This phase in not mandatory

MIP: Maximum intensity projection; FLR: Future liver remnant; ALPPS: Associating liver partition and portal vein ligation for staged hepatectomy; HCC: Hepatocellular carcinoma.

particular, 3D T1-weighted MRCP acquired in the delayed phase after gadoxetic acid administration is useful in confirming clinical suspicion of biliary leakage (*e.g.*, persisting postoperative fluid collections associated with clinical sign of biliary sepsis) by showing active contrast extravasation[44]. The presence of endobag after surgical stage 1 can avoid gadoxetic acid-based MRCP, since bile leakage can be actively monitored through the internal surgical drainage.

ROLE FOR IMAGING

Preoperative imaging

Preoperative findings are essential to understand whether ALPPS is feasible or not based on tumor burden, liver status and presence of ancillary findings with potential surgical significance. There are five main goals of cross-sectional imaging in this setting.

The first task for imaging is accurate detection and characterization of liver lesions. Radiologists should carefully report the number, size, and location of individual lesions, as well as their relationship with surgically relevant anatomic structures, including the hepatic artery, main portal branches, hepatic veins, and first- to second-order biliary branches (Figure 3). This will help the surgeon to establish lesions resectability and the risk for intraoperative complications (*e.g.*, lesions close to the retrohepatic course of inferior vena cava, a region at higher risk of intra-operative bleeding). Second, imaging aims to evaluate the status of liver parenchyma, looking for signs of cirrhosis, cholestasis, steatosis or any other pathologic change attributable to the effects of lesions, diffuse liver disease or chemotherapy. Liver status may influence operability, regardless of the FLR volume (see below). Third, it is crucial to identify vascular and biliary anatomy variants of potential surgical significance (*e.g.*, aberrant and/or accessory branches)[49]. Fourth, any extrahepatic finding potentially affecting the feasibility of ALPPS should be

Table 2 Institutional magnetic resonance imaging protocol with *i.v.* administration gadoxetic acid (0.025 mmol/kg at an injection rate of 1 mL/s) for evaluating associating liver partition and portal vein ligation for staged hepatectomy patients before and after surgery

Sequence	Weightening	Acquisition plane	Technical clues	Rationale in the preoperative phase	Rationale in the postoperative phase
Half fourier acquisition single-shot turbo spin echo/ single shot fast spin echo	T2	Coronal, transverse	-	Ruling out signs of chronic liver disease, including splenomegaly and/or ascites. Detection of parenchymal low signal intensity in iron accumulation	Detection of perihepatic/ abdominal collection and/or ascites
GE in-phase/out of-phase	T1	Transverse	Dual echo, breath hold sequence with slice thickness 6 mm	Characterization of fat-containing lesions. Detection of signal intensity patterns of liver steatosis or hemochromatosis	Evaluation of the postoperative status of liver parenchyma. Characterization of tumor recurrence
MRCP	T2	Radial coronal acquisition (2D) or oblique coronal (3D)	2D and/or 3D technique	Evaluation of anatomic variants complicating or contraindicating surgery. Assessing the Bismuth category of hilar cholangiocarcinoma	Assessment of biliary strictures (site, extent) and biliary dilation upstream
Dynamic study with fat saturated 3D GE	T1	Transverse	Thin slice thickness (3 mm). Baseline acquisition followed by early arterial, late arterial, venous and delayed phases	Detection and characterization of liver lesions	Detection and characterization of parenchymal abnormalities, including tumor recurrence
Single-shot echoplanar imaging	Diffusion	Transverse	b values 50 and 400 and 800 s/mm^2 (1.5T) or 50 and 800 and 1200 s/mm^2 (3.0T). Nominal acquisition time about 3 min (1.5T) and 4 min (3T)	Detection and characterization of smaller lesions (< 1 cm in size)	Detection of parenchymal/ periportal edema. Detection and characterization of smaller lesions (< 1 cm in size)
Fat saturated Turbo spin echo	T2	Transverse	Respiratory triggered, with slice thickness 6 mm. Nominal acquisition time 1.50 min	Detection and characterization of liver lesions.	Detection of parenchymal/ periportal edema. Detection and characterization of liver lesions. Assessment of collections
GE in-phase/out of-phase	T1	Transverse	Same sequence as (2), acquired in the hepatobiliary phase (15-20 min after contrast injection)	Detection and characterization of liver lesions	Detection and characterization of liver abnormalities
Fat saturated 3D GE	T1	Transverse	Same sequence as (4), with modified flip angle (35°) to increase lesion-to-parenchyma conspicuity. Acquired in the hepatobiliary phase		
Contrast-enhanced MRCP	T1	Oblique coronal	Thin-slice (1 mm) fat saturated 3D fast low angle shot (FLASH) sequence acquired	Functional evaluation of biliary obstruction (if present)	Detection of active bile leakage. Functional assessment of bile duct strictures and patency of bilioenteric anastomosis

GE: Gradient echo; MRCP: Magnetic resonance cholangiopancreatography.

evaluated, including large, inoperable primary cancer on other sites, as well as portal hypertension (including splenomegaly and venous collaterals).

The final key step in preoperative imaging is liver volumetry (LV) of the FLR and the whole liver. FLR volume should be calculated by excluding major vessels and FLLs, in order to obtain a reasonable estimate of final viable liver tissue supporting liver function. FLR should be no lower than 25%-30% of preoperative liver volume in patients with normal liver function, and no lower than 40% in patients with underlying chronic liver disease or liver dysfunction (including the effects of chemotherapy)[7,23,50-52]. Many dedicated liver volumetry software are currently available, most times implemented in the picture archive and communication systems used for routine image analysis. In our Institution, abdominal radiologists perform LV together with liver surgeons, with the objective of reliable volumes definition according to
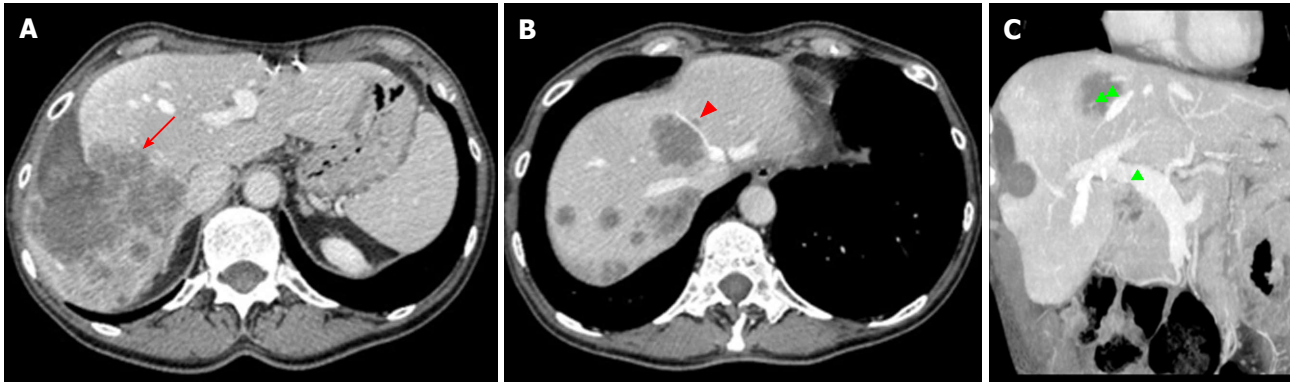
Figure 3 Radiologists should carefully report the number, size, and location of individual lesions, as well as their relationship with surgically relevant anatomic structures, including the hepatic artery, main portal branches, hepatic veins, and first- to second-order biliary branches. A: Preoperative assessment with computed tomography in a 64 male years old patient showing colorectal metastases on the right hepatic lobe (red arrow). Right trisectionectomy associating liver partition and portal vein ligation for staged hepatectomy was planned; B: One small satellite lesion was found on the left side of the middle hepatic vein (arrowhead), indicating the need for future liver remnant clean-up during stage 1; C: No vascular involvement was shown, as exemplified by patent main portal trunk and intrahepatic branches (green triangle), except for infiltration of the middle hepatic vein (double green triangle). Based on this finding, a wide free margin between the line of resection and the middle hepatic vein was obtained.
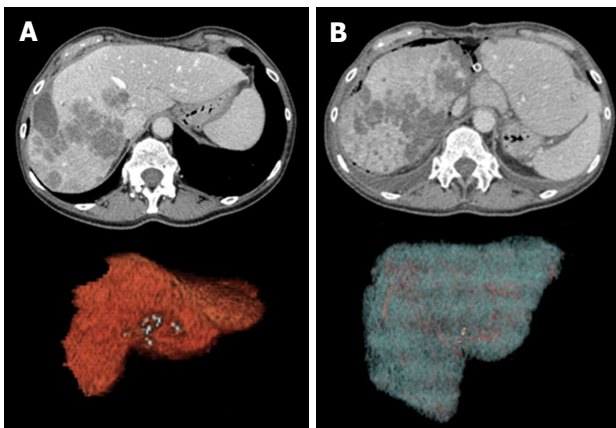

Figure 4 Evolution of the future liver remnant (liver segments 2 + 3) before (A) and after stage 1 surgery (B). Future liver remnant remnant almost doubled in volume (from 280 cm^3 to 468 cm^3), showing clear enlargement on 2D images and volume rendering reconstructions.

the intended lines of resection.

Imaging after surgical stage 1

Goals: In uncomplicated patients, post-stage 1 imaging is performed at the time adequate FLR hypertrophy is expectedly achieved (about 6-9 d from surgery)[7]. Cross-sectional imaging is mandatory to calculate the increase in volume of the FLR using LV (Figure 4), to confirm tumor-free status of the FLR, and to verify the expected changes in the DH (atrophy and persistent portal devascularization).

In the case of US and/or clinical suspicion, MDCT or MRI must be anticipated to guarantee early assessment and intervention. Cross-sectional imaging is also of help in ruling-out surgical complications or insufficient FLR volume as a cause for postoperative liver failure.

Normal findings: Normal hypertrophic FLR is represented in Figure 4. Enlargement can be easily appreciated

on transverse and reformatted 2D images, though precise estimation should be always performed on 3D reconstructions obtained with LV. The magnitude of expected FLR increase ranges between 61% and 93% compared to the baseline volume[50]. In our center, a minimum increase of 40% is needed for completing the procedure. It is of paramount importance to distinguish between true parenchymal hypertrophy and liver enlargement from postoperative liver edema or congestion. Measurement of Hounsfield units (HU) on MDCT can be of help in the distinction, since edematous parenchyma shows significantly lower attenuation compared to unaffected liver[20]. In rare cases in which doubts persist, MRI can be of help in differential diagnosis by showing parenchymal and/or prominent periportal edema.

FLR and DH are often surrounded by a thin rim of free fluid, which is usually more prominent around the DH when the endobag is on site. Of note, thin walls make the endobag usually not directly visible on images. Small air bubbles are frequently mixed within the perihepatic fluid, sometimes at a larger extent along the line of hepatectomy (Figure 5). It is crucial not to misdiagnose this normal finding with an infected collection, which is usually larger, lenticular or round in shape and sometimes well-encapsulated on contrast-enhanced images. Mild periportal edema is commonly present as a thin hypodense (on MDCT) or hyperintense (on T2-weighted MRI images) halo surrounding the intrahepatic portal branches.

Except for the portal branches of the DH, the vascular supply to the liver is preserved, with the hepatic artery for the DH appearing slightly hypertrophic compared to the baseline examination to compensate for portal occlusion. No biliary dilation should be observed, in both the DH and FLR.

Main complications: Postoperative complications of ALPPS include bleeding, bile leakage, fluid or bile collections,
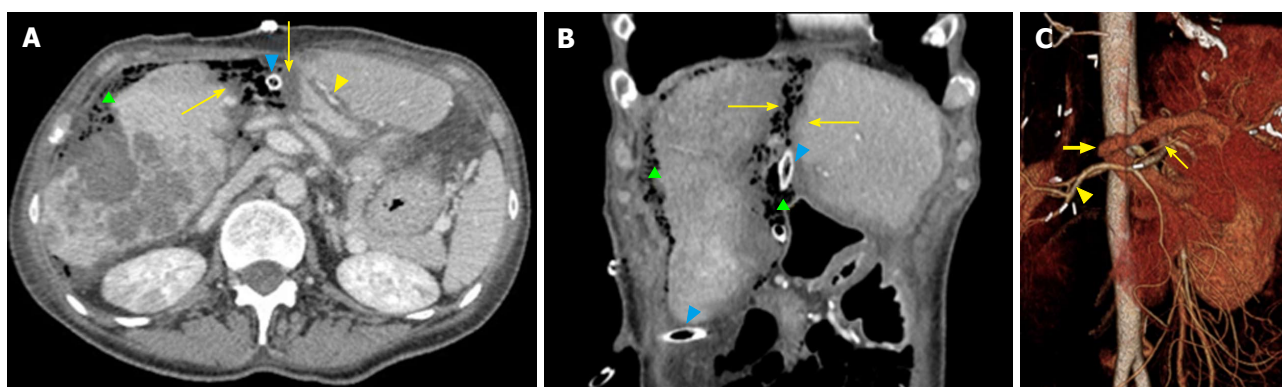
Figure 5 Normal findings on computed tomography after stage 1 surgery on transverse (A) and coronally-reformatted images (B), as well as volume rendering 3D reconstruction (C) (right trisectionectomy associating liver partition and portal vein ligation for staged hepatectomy). A thin rim of free fluid with air bubbles is visible along the surface of diseased hemiliver (right liver lobe), suggesting its accumulation within the plastic bag (green triangle on A and B). A similar finding can be appreciated along the line of transection. Mild periportal edema (yellow arrowhead in A), thin hypodense bands along the edges of surgical resection (arrows on both A and B) and drains (blue arrowheads) are visible. Main right portal branch was ligated and transected (thick arrow in C). Hepatic artery branches are patent (C), including right hepatic artery, which shows mild hypertophy (arrowhead), and left hepatic artery (thin arrow).
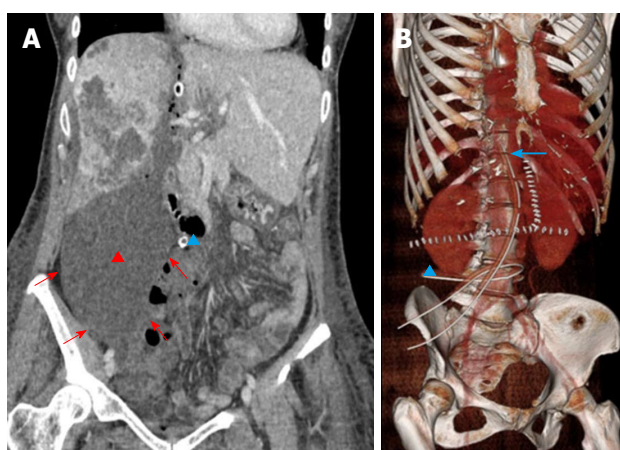

Figure 6 Biloma in a 49-year-old female patient who underwent associating liver partition and portal vein ligation for staged hepatectomy because of peripheral cholangiocarcinoma of the right liver lobe. A: Computed tomography was performed because of bile flowing from the right drainage (blue triangle). The examination confirmed a large fluid collection beneath the DH (red triangle), which distended the plastic bag (red arrows). Biloma was removed with the DH during stage 2 surgery, resolving the biliary leakage originating from right transection surface; B: Normal position of the two drains on volume rendering reconstruction. Left drain has a vertical course along the line of transection up to the inferior margin of the diaphragm (arrow). Right drain has an horizontal course beneath DH (triangle), with its his placed within the plastic bag, in order to drain collections. DH: Diseased hemiliver.

biliary fistula, cholangitis, portal vein thrombosis (PVT), hepatic vein and hepatic arterial thrombosis, hepatic dysfunction, liver failure, persistent postoperative ascites, pleural effusion, prolonged ileus, coagulation disorders, cardiovascular, respiratory, and renal system dysfunction, encephalopathy and infection[5,53]. Clinical presentation is often challenging, since patient's signs and symptoms tend to be non-specific. They include fever, abdominal pain, jaundice, ascites, pleural effusion, abnormal liver tests and bleeding or bile within the drains[54]. Post-hepatectomy liver failure has been specifically defined according to so called 50-50 criteria (prothrombin time < 50% and total serum bilirubin > 50 mmol/L on postoperative day

5 or after)[55]. Imaging is recommended in symptomatic patients to rule-out vascular, biliary or parenchymal causes. The most common ALPPS complications encountered on abdominal cross-sectional imaging are collections, hemorrhage and vascular thrombosis.

Collections are represented by hematoma (up to 50% of cases), biloma (25%) and infected collections (25%)[56]. Collections tend to origin from the resection surfaces, *i.e.*, (assuming right trisectionectomy) in the subphrenic space if originating from the FLR, and within the endobag if originating from DH. Small bilomas and/or transient hematomas are common during the first postoperative days, being rapidly reabsorbed or showing no tendency to increase. On the contrary, collections with large size or increasing in volume over a few days should be regarded as pathological (Figure 6). Bilomas are virtually indistinguishable from serous collections on MDCT, since they present homogeneous fluid content (< 30 HU) without contrast-enhancement. Active biliary leakage can be shown on gadoxetic acid-enhanced MRCP because of contrast extravasation from bile ducts or liver surface into the collection[57,58]. Early diagnosis of biliary leakage is important to prevent biliary sepsis. In this case, stage 2 might be anticipated before the FLR is sufficiently hypertrophied, even if at risk of subsequent insufficient liver function. Hematomas usually show more heterogeneous content than bilomas, with mixed internal areas of low and high attenuation (> 30 HU) on MDCT reflecting the presence of fibrin septa and clots. On MRI, bilomas appears as fluid collections with hypointensity on T1-weighted images and hyperintensity on T2-weightd images, whereas hematomas show typical hyperintensity on T1-weighted fat suppressed images. Treatment options for collections include drainage under sonographic or MDCT guidance, as well as surgical toilette in more extensive cases[3,59]. Infected collections typically show small air bubbles from anaerobic bacteria, and may be surrounded by thickened contrast-enhancing walls of peripheral inflammatory tissue.
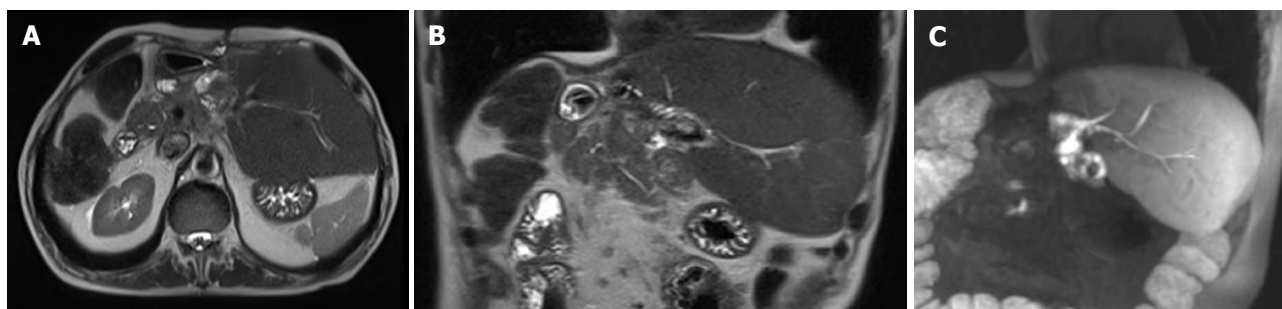
Figure 7 Bilioenteric anastomosis between the jejuneum and biliary branches for hepatic segments 2-3 after right trisectionectomy associating liver partition and portal vein ligation for staged hepatectomy performed for hilar colangiocarcinoma showing. A, B: Magnetic resonance imaging single-shot turbo spin echo T2 weighted images acquired on transverse (A) and coronal planes (B) show absence of biliary dilatation; C: This finding was confirmed on thick maximum intensity projection coronally-reformatted image acquired on the hepatobiliary phase after gadoxetic acid administration, demonstrating regular flow of hyperintense bile.

Postoperative hemorrhage generally arises within 48 h from intervention, commonly originating from the resection margins (*e.g.*, because of an arterial branch truncation or congestion of the hepatic vein due to stenosis or ligation), incomplete intraoperative hemostasis or dehiscence of vascular sutures[3]. MDCT with angiographic phase should be promptly performed to identify the site of bleeding and guide embolization or surgery.

The most threatening vascular complication after stage 1 is portal thrombosis. This rare condition may affect the portal trunk and/or the FLR branch, thus affecting the hypertrophy process. Not surprisingly, patients showing extensive PVT are at high risk of liver failure and death[7,26,28]. Color Doppler US has a primary role in detecting thrombosis. Similarly to other postoperative scenarios[41], thrombosis manifests with absent flow, with our without direct demonstration of an intraluminal echogenic thrombus on B-mode. Although no specific data on ALPPS have been reported, to our knowledge, contrast-enhanced US is supposedly of help in confirming absent contrast arrival in thrombotic vessels[41]. Post-contrast MDCT and/or MRI acquired on venous and delayed phases are useful to confirm color Doppler findings, as well as to map the extent of thrombosis (portal trunk and/or FLR main branch and/or intrahepatic branches) and the degree of occlusion (partial or complete filling defects). Contrast enhancement of vascular walls is an additional findings of thrombosis, likely representing contrast engorgement within dilated vasa vasorum[60,61]. Partial thrombosis may benefit from medical therapy, whereas complete thrombosis requires thrombolysis.

Imaging after surgical stage 2
Goals: Early cross-sectional imaging is usually not required in the case of an uncomplicated clinical course. Chest X-ray and abdominal US with color Doppler interrogation of major vessels are usually sufficient to monitor the patient in the first weeks after the intervention. MDCT and/or MRI should be ordered in the case of suspicious complications and/or inconclusive findings on US. On the contrary, cross-sectional imaging has a major role in the delayed postoperative period, mainly in assessing tumor recurrence and/or late complications with or without prior US.

Recommended imaging follow-up includes US and MDCT or MRI scan after 3 and 6-12 mo from surgery, respectively[54]. However, there is no definite schedule for imaging controls, which should be tailored to patients according to the type and extent of the operated tumor, concomitant chemotherapy and history of major complications after surgical stage 1 and/or 2. MRI is reserved to cases of suspicious biliary complications or for characterizing ambiguous CT findings.

Normal findings: Asymptomatic, small amounts of intra-abdominal air or small fluid collections are common findings in the postoperative phase. Air is usually reabsorbed early, whereas collections can persist up to two months after surgery[56]. Another frequent finding is represented by a hypoattenuating linear band adjacent to liver raw surface (about 30%-50% of cases), which has been related to the effects of parenchymal devascularization or bile/blood accumulation[56]. No vascular or biliary abnormalities should be found (Figure 7).

Of note, transitory splenic enlargement is commonly encountered within 6 mo from hepatectomy. The degree of splenomegaly is generally proportional to the volume of liver resection, with average increase in splenic volume of about 40% compared to the preoperative period[62-64].

Main complications: Complications after stage 2 may be classified into early and late, depending on the onset from surgery. Early complications occur within a few weeks from stage 2, and manifest with a clinical and radiological spectrum similar to that following stage 1 surgery. Thus, hematomas/bilomas (Figure 8), bleeding, vascular thrombosis and pleural effusion represent main expected findings, presenting as described above. Late complications are stage 2 specific, and tend to occur from 3 to about 6 mo after this surgical step. The most frequent and relevant ones are tumor recurrence and biliary complications. The treatment of late complications may be challenging, especially if further surgery is
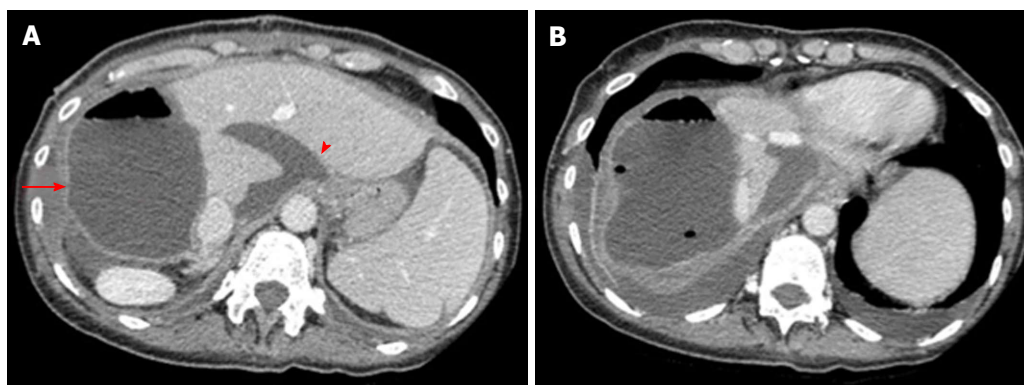
Figure 8 Intrabdominal collection 9 d after stage 2 surgery in a 49-year-old female patient with fever and altered liver function tests. A: Large, encapsulated collection with fluid-air level was shown after diseased hemiliver removal, with mild parietal enhancement (arrow). Part of the collection surrounded liver segment I (arrow head); B: Bilateral pleural effusion coexisted.
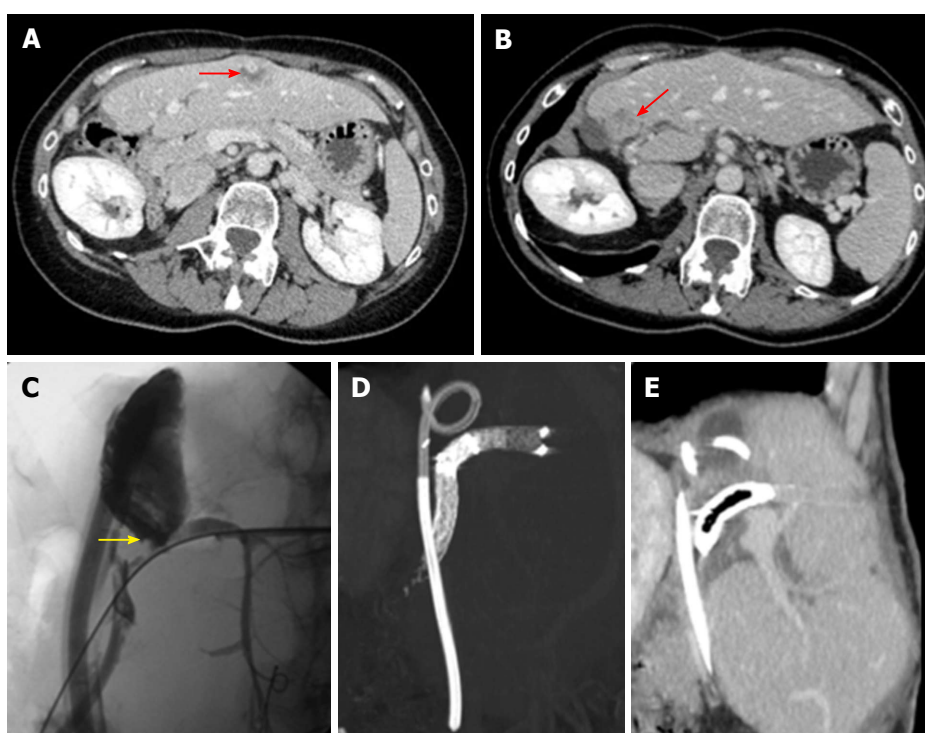

Figure 9 Recurrence appears with multidetector computed tomography and/or magnetic resonance imaging signs of the original tumor, though recurrence can manifest with pleomorphic, nonspecific appearance in our experience. A, B: Multifocal recurrent cholangiocarcinoma presenting 16 mo after right trisectionectomy associating liver partition and portal vein ligation for staged hepatectomy. Lesions showed atypical persistently hypovascular appearance on dynamic contrast-enhanced multidetector computed tomography; C-E: Wedge resection of recurrences was complicated by biliary leakage, as shown on percutaneous transhepatic cholangiography (arrow in C), treated by positioning a drainage within the biloma and a biliary stent graft, as shown on maximum intensity projection reconstruction in D and oblique sagittal reformation in E.

needed. Indeed, additional interventions may in turn increase the risk of morbidity (Figure 9).

The International ALPSS registry[27] reported disease-free survival of 73% and 59% at 1 and 2 years after ALPSS, respectively, with median survival of 14 mo. Recurrence appears with MDCT and/or MRI signs of the original tumor, though recurrence can manifest with pleomorphic, nonspecific appearance in our experience (Figure 9). Suspicious solid lesions should be regarded as tumor recurrence, regardless of the fact they mimic preoperative lesions or not.

Late biliary complications include stricture and fistula. Because of the recent introduction of ALPSS, it is difficult to quantify the prevalence of these complications, which are generally rare in experienced centers. Strictures are multifactorial in origin, having been related to mechanical stress from FLR enlargement and rotation, as well as to iatrogenic causes (inaccurately placed clips, injury, periductal bile leakage and ischemia due to injured FLR hepatic artery)[65,66].

MRCP is the elective tool to assess the site of obstruction, which appears as a focal zone of absent signal on fluid-

Table 3 Overview of normal and abnormal findings after surgical stages 1 and 2

| Postoperative phase | Goals of ALPPS | Normal findings | | Abnormal findings |
		Findings not to be confused with pathological aspects		prompting intervention
After surgical stage 1	Hypertrophic FLR (≥ 40% of baseline preoperative volume)	Thin rim of free fluid around both FLR and DH		Large, persisting collections (hematoma, bilomas, infected collections)
		Air bubbles within the perihepatic fluid, especially on the hepatectomy line		Bleeding
				Biliary dilation
		Mild periportal edema		Bile leakage/fistula
		Hypertrophy of hepatic artery for the DH		Portal vein thrombosis
After surgical stage 2	Uncomplicated appearance of the FLR (*e.g.*, no relapsing focal liver lesions)	Thin rim of free fluid around FLR		Early complications
		Air bubbles		see surgical stage 1
		Hypoattenuating linear band adjacent to liver raw surface		Late complications (3-6 mo)
				Biliary stricture
		Rotation of hypertrophic FLR		Biliary fistula
		Transitory splenomegaly		Tumor recurrence

ALPPS: Associated liver partition and portal vein ligation for staged hepatectomy; FLR: Future liver remnant; DH: Diseased hemiliver.

sensitive images, as well as the degree of proximal biliary dilation[42]. Strictures of the bilioenteric anastomosis should be evaluated with gadoxetic acid-based MRCP, which shows lack of contrast flow from the biliary tree to the anastomotic bowel loop[65,67]. This technique is of help also in identifying the site of bile extravasation when chronic biliary fistula is suspected. Similarly to other clinical scenarios[42], MRCP is electively ordered in patients with low pre-test probability of biliary complications, since a negative result is reliable enough to avoid invasive procedures of direct cholangiography. On the other hand, MRCP is effective also in patients with high pre-test probability of disease, since it provides a panoramic and detailed representation of pathological findings, *i.e.*, an accurate road-map for planning the most appropriate interventional approach. Most bilomas and strictures are treated with endoscopic sphincterotomy and balloon dilation followed by endoprothesis placement.

An overall view of normal postoperative findings and complications after both surgical stages 1 and 2 is provided in Table 3.

CONCLUSION

ALPSS is an increasingly popular two-stage hepatectomy technique associated with portal ligation aimed to obtain rapid and adequate FLR hypertrophy, thus extending operability in patients with massive primary or secondary neoplastic liver involvement.

Cross-sectional imaging, especially MDCT, plays a key role in planning ALPPS procedure and monitoring different surgical stages. In particular, MDCT is the main instrument to provide liver volumetry, which is of special importance in assessing technique feasibility and assessing variation in volume of the FLR between surgical stages. MDCT also confirm a clinical or sonographic suspicion of complications, including collections, bilomas, hematomas, post-surgical bleeding, PVT, and tumor recurrence. MRI should be used as a problem-solving tool in both preoperative and postoperative phases, whereas MRCP has an elective role in assessing biliary complications.

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