Comparison of Liver Venous Deprivation and Portal Vein Embolization for Future Liver Remnant Hypertrophy: A Single-Center Retrospective Study

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Abstract

Aim: This study aimed to compare the safety, feasibility, and efficacy of liver venous deprivation (LVD) and portal vein embolization (PVE) in inducing future liver remnant (FLR) hypertrophy prior to major hepatectomy.

Method: In this retrospective single-center study, 38 patients who underwent PVE (n=29) or LVD (n=9) between June 2020 and January 2025 were analyzed. Patients were selected based on small FLR volume requiring preoperative hypertrophy induction. Pre- and post-procedural liver volumetric measurements were performed using contrast-enhanced CT, and standardized FLR (sFLR) percentages were calculated. Clinical outcomes, including postoperative complications and mortality, were also evaluated.

Results: Among 38 patients, 21 (15 PVE and 6 LVD) proceeded to surgery. Although pre-procedural sFLR percentages were similar between groups (19.5±2.0% for PVE vs. 19.9±2.6% for LVD; p=0.806), post-procedural sFLR percentages were significantly higher in the LVD group (33.4±5.1% vs. 24.5±5.1%, p=0.012). The mean degree of standardized FLR hypertrophy, expressed as an absolute percentage point increase was significantly greater in the LVD group (13.5% vs. 5%, p=0.009), and the percentage FLR increase was higher (68.6±20.7% vs. 24.7±15.6%, p=0.006). No significant differences were observed in postoperative complication rates (16.6% vs. 20%, p=0.601) or mortality (16.7% vs. 13.3%, p=0.847).

Conclusion: LVD demonstrated superior FLR hypertrophy compared to PVE while maintaining a comparable safety profile. LVD may offer an effective alternative for patients with small baseline FLR

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ETHICAL STATEMENT: Before the start of the research, a written decision No: 2025-90 was taken from the Ethics Committee of University of Health Sciences, Basaksehir Cam and Sakura City Hospital. Ethics committee was taken on 08.04.2025.

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volumes at high risk of insufficient liver regeneration. Further prospective studies are warranted to confirm these findings and define the optimal clinical indications for LVD.

Keywords: Portal vein embolization, liver venous deprivation, future liver remnant, hepatic hypertrophy, major hepatectomy, interventional radiology.

Gelecekteki Karaciğer Rezidüsü Hipertrofisi için Karaciğer Venöz Deprivasyonu ile Portal Ven Embolizasyonunun Karşılaştırılması: Tek Merkezli Retrospektif Bir Çalışma

Öz

Amaç: Bu çalışma, major hepatektomi öncesinde gelecekteki karaciğer rezidüsü (FLR) hipertrofisini indüklemek amacıyla uygulanan karaciğer venöz deprivasyonu (LVD) ile portal ven embolizasyonunun (PVE) güvenlilik, uygulanabilirlik ve etkinlik açısından karşılaştırılmasını amaçlamaktadır.

Yöntem: Bu retrospektif, tek merkezli çalışmada, Haziran 2020 ile Ocak 2025 tarihleri arasında PVE (n=29) veya LVD (n=9) uygulanan toplam 38 hasta analiz edilmiştir. Hastalar, preoperatif hipertrofi indüksiyonu gerektiren düşük FLR hacmi temel alınarak seçilmiştir. İşlem öncesi ve sonrası karaciğer volumetrik ölçümleri kontrastlı BT ile yapılmış ve standartlaştırılmış FLR (sFLR) yüzdeleri hesaplanmıştır. Postoperatif komplikasyonlar ve mortalite dahil olmak üzere klinik sonuçlar da değerlendirilmiştir.

Bulgular: Toplam 38 hastanın 21'i (15 PVE ve 6 LVD) cerrahiye yönlendirilmiştir. İşlem öncesi sFLR yüzdeleri gruplar arasında benzer bulunmuştur (PVE için %19,5 ± 2,0; LVD için %19,9 ± 2,6; p=0,806). Ancak işlem sonrası sFLR yüzdesi LVD grubunda anlamlı derecede daha yüksek saptanmıştır (%33,4 ± 5,1'e karşı %24,5 ± 5,1; p=0,012). Ortalama FLR hipertrofi oranı LVD grubunda belirgin şekilde daha fazlaydı (%13,5'e karşı %5; p=0,009) ve FLR yüzdesel artışı da daha yüksekti (%68,6 ± 20,7'e karşı %24,7 ± 15,6; p=0,006). Postoperatif komplikasyon oranları (%16,6'ya karşı %20; p=0,601) ve mortalite (%16,7'ye karşı %13,3; p=0,847) açısından anlamlı fark saptanmadı.

Sonuç: LVD, PVE'ye kıyasla daha üstün FLR hipertrofisi sağlarken benzer bir güvenlik profili sunmuştur. LVD, düşük başlangıç FLR hacmine sahip ve yetersiz karaciğer rejenerasyonu riski yüksek olan hastalar için etkili bir alternatif olabilir. Bu bulguların doğrulanması ve LVD'nin optimal klinik endikasyonlarının belirlenmesi için ileriye dönük çalışmalara ihtiyaç vardır.

Anahtar Sözcükler: Portal ven embolizasyonu, karaciğer venöz deprivasyonu, gelecekteki karaciğer rezidüsü, hepatik hipertrofi, major hepatektomi, girişimsel radyoloji.

Introduction

Major hepatectomy remains a critical intervention for patients with advanced hepatobiliary malignancies, yet its success hinges on ensuring adequate future liver remnant (FLR) volume and function to prevent postoperative liver failure[1,2]. Portal vein embolization (PVE) has long been the standard preoperative strategy to induce FLR hypertrophy by redirecting portal flow to the non-embolized liver[3,4]. However, PVE alone does not always achieve sufficient hypertrophy, particularly in patients with compromised liver function or small baseline FLR[5,6]. To address this limitation, novel approaches such as hepatic vein embolization (HVE) have emerged to augment FLR regeneration by modulating both inflow and outflow dynamics[7,8].

The concept of combining PVE and HVE was first explored by Hwang et al.[7], who demonstrated that sequential right HVE after PVE induced incremental FLR hypertrophy by exacerbating ischemic injury in the embolized lobe. While effective, this two-stage approach prolonged the preoperative period and carried risks of interval tumor progression. Building on this foundation, Guiu et al.[9,10] introduced the liver venous deprivation (LVD) technique, which simultaneously embolizes the portal and hepatic veins during a single procedure. Their pioneering work revealed that LVD not only accelerated FLR volume increase but also induced significant histological changes,

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including sinusoidal dilatation and hepatocyte atrophy in the embolized lobe, correlating with enhanced regenerative capacity[9].

In this study, we aimed to compare the feasibility, safety, and regenerative potential of PVE alone versus the simultaneous combined approach of portal and hepatic vein embolization known as LVD, evaluating their effects on volumetric growth and clinical outcomes.

Material and Methods

Patient Selection

This retrospective, single-center study included patients who underwent PVE and/or HVE between June 2020 and January 2025 as a preparatory step for major hepatic resection. The study was approved by the institutional ethics committee(Ethical approval number: 2025-90), and written informed consent was obtained from all patients prior to the procedures.

Inclusion Criteria:

- Patients undergoing major liver resection (right/left hepatectomy or extended hepatectomy).
- Patients with a small FLR (<25% of total liver volume) in non-cirrhotic patients or <40% in cirrhotic patients**.**
- Patients who underwent pre- and post-procedure CT-based liver volumetric measurements.
- Patients with primary or metastatic liver malignancies scheduled for major liver resection (right/left hepatectomy or extended hepatectomy).
- No evidence of significant extrahepatic disease precluding curative resection.

Exclusion Criteria:

- Patients without pre-procedural volumetric liver data.
- Those who had previous liver surgery affecting volumetric analysis.
- Patients with portal vein thrombosis or hepatic venous outflow obstruction before embolization.
- Patients with unresectable tumors or contraindications to major hepatectomy.

PVE Procedure

In our study, all PVE procedures were performed under mild to moderate sedation following appropriate sterile field preparation and local anesthesia (10 mL of 1% prilocaine). Embolization procedures were carried out using a percutaneous transhepatic approach under ultrasound and fluoroscopic guidance. The choice between an ipsilateral or contralateral portal vein approach was determined based on the patient's vascular anatomy and tumor localization.

During the procedure, acoustic set-assisted access was used to puncture the target portal vein segment, and a 5F introducer sheath was placed. After the sheath placement, an

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initial portography was performed using a 5F Simmons 1 catheter (Cordis, Cardinal Health, United States) to evaluate vascular anatomy, confirm adequate contrast opacification of the target branches, and assess potential collateral circulation. Once the branches to be embolized were identified, a 2.7F microcatheter (Progreat, Terumo, Tokyo, Japan) was advanced into the target portal vein branches to perform controlled embolization. N-butyl cyanoacrylate (NBCA) mixed with lipiodol was the primary embolic agent used for PVE. To ensure controlled embolization and optimal penetration into distal segmental branches, NBCA was diluted with lipiodol at a 12.5% concentration.

The embolization process was continued until complete occlusion of the target portal vein branches was achieved. Following embolization, a control portography and Cone Beam CT (CBCT) imaging were obtained to confirm procedural success and to rule out non-target embolization. The access site was sealed using NBCA-lipiodol or coils to minimize the risk of bleeding and portal vein thrombosis (Figure 1-2).

All procedures were performed by experienced interventional radiologists, and any potential complications, including portal vein thrombosis, non-target embolization, and segmental infarction, were meticulously documented.

Figure 1(a, b). Axial contrast-enhanced CT images obtained before **(a)** and after **(b)** portal vein embolization (PVE), **(c)** Segmentation of the future liver remnant (FLR) (highlighted in green) on the pre-procedural CT image shown in **(a)**, **(d)** Segmentation of the FLR (highlighted in green) on the post-procedural CT image shown in **(b).**

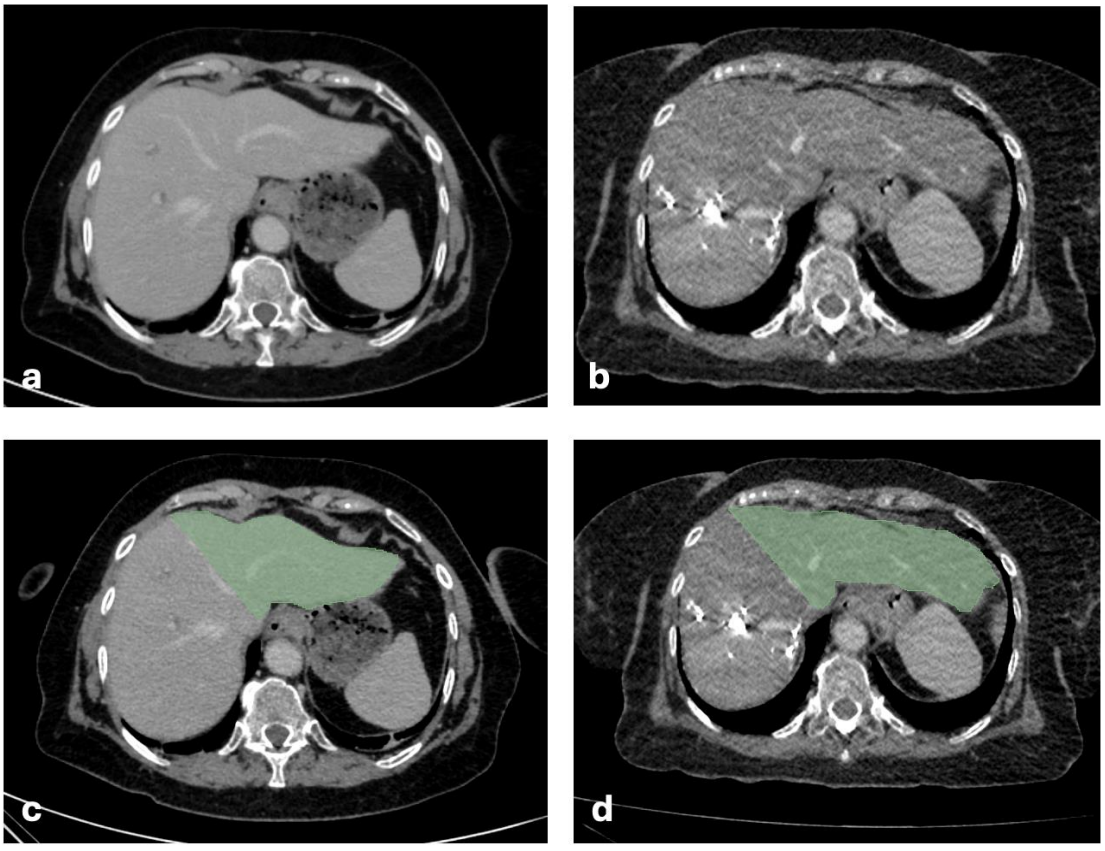

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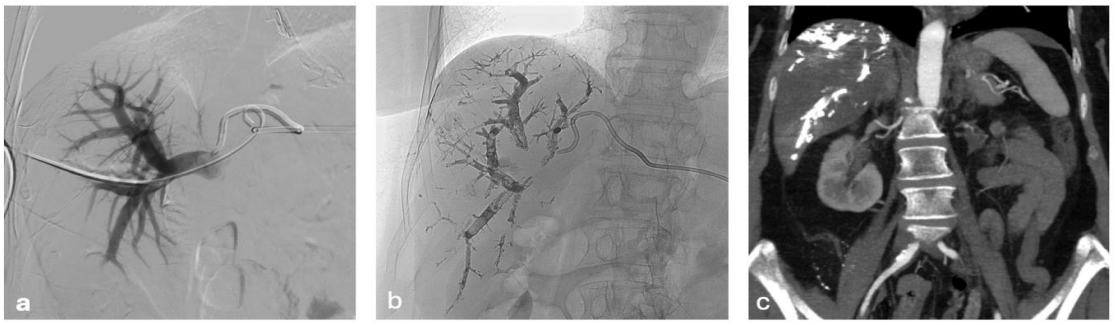
Figure 2(a). Angiographic image obtained from the right main portal vein following percutaneous transhepatic puncture, **(b)** Non-subtracted fluoroscopic image showing embolization of the right portal vein branches after portal vein embolization (PVE), **(c)** Coronal contrast-enhanced CT image obtained post-procedure, demonstrating NBCA-lipiodol opacities within the right portal vein branches.



HVE Procedure

In all cases, LVD was performed as a single-stage procedure, with simultaneous embolization of the portal and hepatic veins during the same session. HVE was performed to enhance the hypertrophy of the FLR by preventing venous outflow from the embolized liver segments. In our study, the procedure was conducted using either a transjugular or percutaneous transhepatic approach, depending on the patient's vascular anatomy and procedural feasibility.

For the transjugular approach, a 9F long sheath was inserted into the inferior vena cava (IVC) via jugular vein puncture. Alternatively, in the percutaneous transhepatic approach, direct access to the right or middle hepatic vein was obtained, and a 9F introducer sheath was placed. The target hepatic vein(s) (right, middle, or accessory hepatic vein) were selectively catheterized under fluoroscopic guidance using a 5F catheter.

For embolization, an Amplatzer vascular plug was deployed within the hepatic vein at the predetermined location. In some cases, additional coil embolization was performed to enhance the effectiveness of venous occlusion. The embolization site was carefully selected to ensure that the deployed device remained 10 mm proximal to the IVC-HV junction, preventing unintended migration or incomplete occlusion.

Pre- and post-embolization venography was performed to confirm the correct positioning of the embolic material and to assess for any residual venous drainage or collateral formation. The procedure was considered successful upon complete occlusion of the hepatic vein, thereby inducing hepatic congestion in the embolized lobe and accelerating compensatory hypertrophy in the future liver remnant. Post-procedural follow-up included monitoring for potential complications, such as hepatic congestion, ischemic injury, or non-target embolization (Figure 3).

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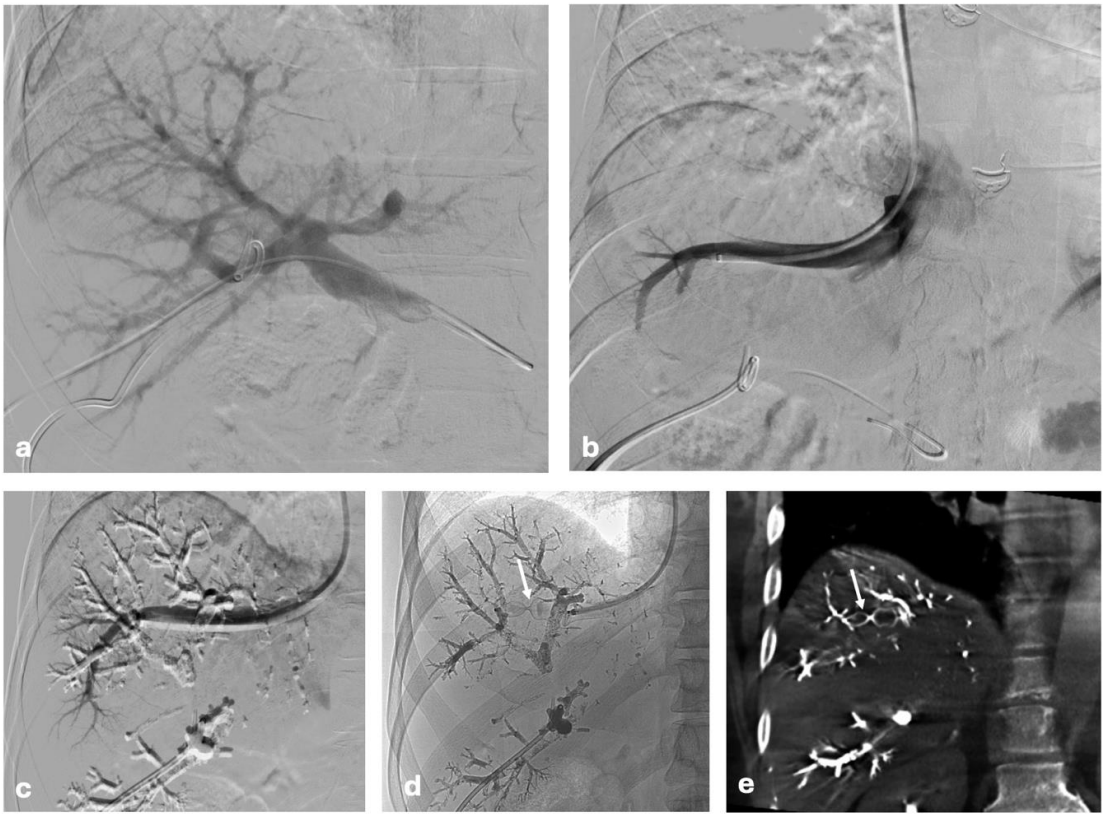
Figure 3(a). Angiographic image obtained from the main portal vein following percutaneous transhepatic puncture, **(b)** Following right jugular vein access, fluoroscopic image showing catheterization of the right hepatic vein before embolization, **(c)** Portal venogram demonstrating successful embolization of the right portal vein branches with NBCA-lipiodol mixture, **(d)** Fluoroscopic image showing occlusion of the right hepatic vein with an Amplatzer vascular plug (white arrow), **(e)** Coronal Cone Beam CT (CBCT) image obtained after liver venous deprivation (LVD), showing NBCA-lipiodol opacities in the right portal vein branches and Amplatzer vascular plug in the right hepatic vein (whitearrow).



CT Volume Measurement

Liver volumetric measurements were performed using 3D Slicer software (version 5.8.1), a validated open-source tool for medical image segmentation and quantitative analysis. Volumetric assessment was based on contrast-enhanced abdominal CT scans acquired in the portal venous phase, with 5-mm slice thickness axial images used for segmentation.

The segmentation process involved manual and semi-automated selection of the liver parenchyma, ensuring precise delineation of the FLR and excluded non-hepatic structures. The following volumetric parameters were calculated with Figure 4[4,11–13].

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Figure 4. Calculations

$$BSA = \sqrt{\frac{Height\ (cm) \times Weight\ (kg)}{3600}}$$

$$TELV = -794.41 + (1267.28 \times BSA)$$

$$sFLR = \frac{FLR\ Volume}{TELV}$$

$$\%FLR\ Increase = \frac{FLR\ Post-PVE/HVE - FLR\ Pre-PVE}{FLR\ Pre-PVE} \times 100$$

All volumetric measurements were reviewed and approved by an experienced interventional radiologist. The liver segmentation process was carried out using threshold-based selection, region-growing algorithms, and manual refinements, ensuring accurate volumetric assessment.

Statistical Analysis

Statistical analyses were performed using IBM SPSS Statistics software (version 23.0; IBM Corp., Armonk, NY). Continuous variables (e.g., age, BMI, FLR volumes, %FLR increase) were expressed as mean ± standard deviation (SD) and compared using independent samples t-tests, as normality assumptions were confirmed via the Shapiro-Wilk test ($p>0.05$). Categorical variables (e.g., gender, tumor type, complications, mortality) were analyzed using Fisher's exact test or Pearson's chi-squared test, depending on expected cell frequencies.

Results

Patient Demographics And Clinical Characteristics

In total, 38 patients were included in the study: 29 underwent PVE, and 9 underwent LVD. Among patients who underwent LVD, surgical resection could not be performed in two cases due to tumor progression and in one case due to insufficient FLR hypertrophy. In the PVE group, 9 patients were excluded from surgical resection due to tumor progression, 3 due to insufficient FLR hypertrophy, 1 due to the development of acute renal failure, and 1 due to the patient's refusal to undergo surgery after embolization.

Ultimately, 21 patients who successfully underwent surgery 15 following PVE and 6 following LVD were included in the final analysis.

Demographic and clinical characteristics are summarized in Table 1. No significant differences were observed between the groups in terms of age (52.6±11.4 vs. 59.2±17.5 years, $p=0.464$), gender distribution (male: 60% vs. 66.7%, $p=0.715$), or BMI (25.2±1.3 kg/m², vs. 24.8±1.1 kg/m², $p=0.545$). Cholangiocarcinoma was the predominant tumor type in both groups (66.7% in PVE vs. 83.3% in LVD, $p=0.328$). The interval between embolization and surgery was comparable (56.3±34.5 vs. 45.2±10.5 days, $p=0.272$). Postoperative complications occurred in 20% of patients who underwent PVE and 16.6% of those who underwent LVD ($p=0.601$), with no significant differences in hospital stay (19.9±7.6 vs. 20.8±3.6 days, $p=0.732$) or mortality rates (13.3% vs. 16.7%, $p=0.847$).

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However, follow-up duration was significantly shorter in the LVD group (9.2±9.4 vs. 23.9±17.3 months, p=0.031).

Table 1. Patient demographic and clinical characteristics

Variable	**PVE (n = 15)**	**LVD (n = 6)**	**p**
Age (years, mean ± SD)	52.6±11.4	59.2±17.5	0.464
Gender, n (%)			0.715
- Male	9 (60%)	4 (66.7%)	
- Female	6 (40%)	2 (33.3%)	
BMI (kg/m², mean ± SD)	25.2±1.3	24.8±1.1	0.545
Tumor Type, n (%)			0.328
- Cholangiocarcinoma	10 (66.7%)	5 (83.3%)	
- Hepatocellular Carcinoma	3 (20%)	0 (0%)	
- Hemangioendothelioma	1 (6.7%)	0 (0%)	
- Colon Cancer Metastasis	1 (6.7%)	1 (16.7%)	
VE-Surgery Interval (days, mean ± SD)	56.3±34.5	45.2±10.5	0.272
Postoperative Complications, n (%)	3 (20%)	1 (16.6%)	0.601
Hospital Stay (days, mean ± SD)	19.9±7.6	20.8±3.6	0.732
Follow-up Duration (months, mean ± SD)	23.9±17.3	9.2±9.4	**0.031**
Mortality, n (%)	2 (13.3%)	1 (16.7%)	0.847

Abbrevations; PVE: portal venous embolization, LVD: liver venous deprivation, BMI: body mass index, VE: venous embolization, SD: Standard Deviation

Volumetric Outcomes

Volumetric parameters are detailed in Table 2. The total estimated liver volume (TELV) was significantly lower in the LVD group (1536.6±300.1 mL vs. 2144.5±422.5 mL, p=0.006). Similarly, baseline FLR volume was significantly smaller in the LVD group (300.4±35.5 mL vs. 412.4±57.0 mL, p=0.001). Post-embolization FLR volumes were comparable between groups (501.2±20.2 mL vs. 510.3±63.2 mL, p=0.622). Baseline sFLR percentages were similar between groups (19.9±2.6% vs. 19.5±2.0%, p=0.806), whereas post-procedural sFLR was significantly higher in the LVD group (33.4±5.1% vs. 24.5±5.1%, p=0.012). Notably, the mean degree of hypertrophy was significantly greater in the LVD group (13.5% vs. 5%, p=0.009), as was the percentage FLR increase (68.6±20.7% vs. 24.7±15.6%, p=0.006).

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Table 2. Volumetric Outcomes of PVE vs. LVD

Parameter	PVE (n = 15)	LVD (n = 6)	p
TELV (ml, mean ± SD)	2144.5 ± 422.5	1536.6 ± 300.1	**0.006**
FLR Pre VE (ml, mean ± SD)	412.4 ± 57.0	300.4 ± 35.5	**0.001**
FLR Post VE (ml, mean ± SD)	510.3 ± 63.2	501.2 ± 20.2	0.622
sFLR Pre VE (%)	19.5 ± 2.0	19.9 ± 2.6	0.806
sFLR Post VE (%)	24.5 ± 5.1	33.4 ± 5.1	**0.012**
Mean degree of hypertrophy(%)	5	13.5	**0.009**
%FLR Increase (mean ± SD)	24.7 ± 15.6	68.6 ± 20.7	**0.006**

Abbrevations; PVE: portal venous embolization, LVD: liver venous deprivation, TELV: total estimated liver volume, FLR: future liver remnant, sFLR: standardized future liver remnant, VE: venous embolization, SD: Standard Deviation

Safety And Follow-Up

Both groups demonstrated comparable safety profiles, with no significant differences in procedural complications or mortality. Hepatic congestion or ischemic injury specific to LVD was not observed in patients who underwent LVD.

These findings suggest that LVD induces more robust FLR hypertrophy compared to PVE alone, particularly in patients with smaller baseline FLR volumes, while maintaining a comparable safety profile.

Discussion

Our study highlights the significant advantages of LVD compared to PVE alone, particularly regarding FLR hypertrophy, resectability, and safety profiles. Consistent with prior reports, our results showed that LVD induced more robust FLR hypertrophy compared to conventional PVE. Specifically, we observed a mean percentage FLR increase of 68.6±20.7% in the LVD group versus 24.7±15.6% in the PVE group (p=0.006). This dramatic hypertrophy with LVD is consistent with findings in the emerging literature. The pioneer study by Guiu et al. first described “LVD” showing that adding hepatic vein occlusion to PVE produced rapid and substantial FLR growth (from 28.2% to 40.9% of total liver volume within 3 weeks)[9]. Subsequent comparative studies have confirmed that LVD yields a higher degree of hypertrophy than PVE. In the multicenter DRAGON collaborative analysis, the median FLR increase after LVD was 59% vs 48% with PVE (p=0.020)[14]. Similarly, a recent systematic review and meta-analysis found LVD associated with significantly larger post-embolization FLR volumes and faster kinetic growth rates[15].

This superior hypertrophy directly translates into improved resectability: in DRAGON, 90% of patients were able to undergo curative resection after LVD, compared to 68% after PVE (p=0.007)[14]. Shindoh et al. demonstrated that even among patients with extremely low baseline FLR, PVE enabled eventual resection in approximately 72% of cases, while 28% of patients failed to proceed to surgery due to insufficient liver regeneration[2]. In this study, surgical resection could not be performed in 33% of patients who underwent LVD and 48% of patients who underwent PVE due to tumor progression,

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acute renal failure, insufficient FLR hypertrophy, or the patient's refusal to undergo surgery.

One critical advantage of LVD identified in this cohort and corroborated by literature is the accelerated hypertrophy kinetics, which potentially reduces the interval between embolization and surgery. This rapid hypertrophic response minimizes the risk of tumor progression that often prevents surgical intervention after PVE alone[2]. Schnitzbauer et al. emphasized the clinical importance of rapid hypertrophy, particularly in aggressive hepatobiliary malignancies, where delays may preclude curative intent resection[16].

Regarding procedural safety, our findings underscore the comparable risk profiles of LVD and PVE, with no significant differences in complications or mortality rates observed between groups. This aligns with existing literature documenting the favorable safety profile of PVE and suggesting LVD does not significantly increase procedural morbidity[1,17]. Notably, hepatic congestion or ischemic injury specific to hepatic vein embolization was absent in our series, mirroring findings reported in recent large-scale studies[9,14,18].

Although pre-procedural FLR volumes were similar between patients who underwent LVD and those who underwent PVE, post-procedural sFLR percentages were significantly higher in the LVD group (33.4±5.1% vs. 24.5±5.1%, p=0.012). This finding suggests that LVD can achieve greater hypertrophy compared to PVE alone, potentially reducing the risk of insufficient liver regeneration and surgical dropout. Similar results have been reported in recent systematic reviews, supporting the superiority of LVD in inducing more robust FLR hypertrophy[18].

The primary limitation of this study is the small sample size, particularly in the LVD group, which significantly reduced statistical power and hindered the detection of potentially meaningful differences. Second, heterogeneity in tumor types may have confounded outcomes. The predominance of cholangiocarcinoma in the PVE+HVE group and the absence of HCC cases limit the generalizability of results, as liver regeneration dynamics may differ across tumor subtypes. The retrospective design introduced additional constraints, including incomplete or non-standardized data collection. Key variables such as ASA classification and preoperative chemotherapy details were not consistently recorded, potentially biasing the interpretation of outcomes. Additionally, the absence of hepatocellular carcinoma (HCC) cases in the LVD group and their presence in 20% of the PVE group may have influenced hypertrophy outcomes, as liver regeneration capacity differs across tumor types. This imbalance should be considered when interpreting volumetric comparisons.

In conclusion, study demonstrates that LVD is a feasible and safe alternative to PVE, offering superior FLR hypertrophy, especially in patients with smaller baseline FLR volumes. The significantly greater percentage increase in FLR volume and higher standardized FLR achieved with LVD suggest that this technique may enhance resectability and improve surgical candidacy in patients at risk for insufficient liver regeneration following PVE alone. Importantly, LVD was not associated with increased procedural complications or mortality, supporting its safety profile. Although limited by a small sample size and retrospective design, studies findings contribute to the growing body of evidence supporting LVD as a more effective strategy for preoperative liver

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hypertrophy. Further large-scale prospective studies are warranted to validate these results and establish standardized indications for LVD in hepatic surgery candidates.

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