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Splenic Artery Ligation: Effects on Portal Flow and Hypersplenism in Living Donor Liver Transplantation

Authors' Contribution:
Study Design A
Data Collection B
Statistical Analysis C
Data Interpretation D
Manuscript Preparation E
Literature Search F
Funds Collection G

ABCDEF 1 Sinan Efe Yazici
ABCDEF 1 Ahmet Atasever
EF 2 Yildiray Yuzer

1 Department of Liver Transplantation, Faculty of Medicine, Demiroğlu Bilim University, Istanbul, Türkiye
2 Department of Liver Transplantation, Florence Nightingale Hospital Liver Transplantation Center, Istanbul, Türkiye

Corresponding Author: Ahmet Atasever, e-mail: drahmetatasever@gmail.com
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Background: Living donor liver transplantation (LDLT) has been shown to be safe in the curative treatment of liver cirrhosis. Portal flow modulation techniques, such as splenic artery ligation (SAL), have been used to avoid complications like small-for-size syndrome (SFSS). However, the effects of SAL on portal flow, splenic function, and hematologic outcomes remain underexplored.

Material/Methods: This retrospective study analyzed 60 LDLT recipients treated at a single center from January 2023 to December 2024. Thirty patients underwent SAL (SAL+) while 30 did not undergo SAL (SAL-). Data on demographic and clinical characteristics, portal flow dynamics, spleen volume, hematologic parameters, and postoperative complications were collected and analyzed using IBM SPSS 20.0. Statistical significance was set at $P<0.05$.

Results: SAL significantly reduced portal flow from 3148±989 mL/min to 1949±830 mL/min ($P<0.001$), optimizing the portal flow/graft weight ratio. SAL also decreased splenic volume by 21% and alleviated thrombocytopenia, with postoperative platelet counts increasing 3.8-fold compared to preoperative levels ($P<0.001$). There were fewer complications in the SAL+ group, with significant reductions in biliary complications and improved graft function. No severe ischemic splenic changes or thromboembolic events were observed in the SAL+ group.

Conclusions: SAL is an effective strategy for portal flow modulation in LDLT, significantly reducing portal flow to optimal levels and improving hematologic outcomes. By preserving splenic function and minimizing complications, SAL is a safe and beneficial approach to managing SFSS and improving graft performance in LDLT patients.

Keywords: Liver Transplantation • Living Donors • Portal System • Spleen • Splenic Artery • Thrombocytopenia

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Introduction

Living donor liver transplantation (LDLT) has been shown to be safe in the curative treatment of liver cirrhosis and has many advantages over cadaveric liver transplantation [1]. The development of living donor liver transplantation in transplant surgery has led to a revival of interest in hepatic hemodynamics. Portal hypertension can persist after liver transplantation, especially in partial liver transplant recipients. A successful LDLT operation depends on adequate volume of the transplanted liver graft and an appropriate balance of portal vein inflow and hepatic vein outflow [2].

When the liver graft is too small to meet the metabolic needs of the recipient, the recipient may have small-for-size syndrome (SFSS). SFSS is clinically manifested by impaired coagulation, cholestasis, and ascites, resulting in septic complications and lower graft survival [3,4]. The basic pathophysiology of this syndrome is that the graft receives portal overflow, resulting in sinusoidal congestion and hemorrhage [5]. As a secondary effect of portal overflow, arterial vasoconstriction leads to ischemic damage. Portal flow modulation improves graft function by increasing arterial flow [6].

SFSS typically occurs when the graft volume is less than 0.8% of the graft-recipient weight ratio (GRWR) [7]. For these grafts, an optimal portal vein flow (PVF) of 250 mL/min/100 g is recommended [8]. Several methods have been attempted to avoid SFSS. These include splenic artery ligation (SAL), splenectomy, and the diversion of portal venous blood through mesocaval, portocaval, or inferior mesenteric shunts [9,10].

In chronic liver diseases, splenomegaly and hypersplenism may develop following the onset of portal hypertension [11]. Thrombocytopenia is a common hematological disorder in patients with chronic liver disease, with the severity of liver disease being the most significant factor. The pathophysiology of thrombocytopenia in chronic liver disease has been shown to be associated with the hypersplenism hypothesis, in which portal hypertension leads to accumulation and sequestration of all blood cellular elements, particularly platelets, in the enlarged and congested spleen.

The aim of this study was to investigate both the effects of portal flow modulation and the recovery process of hematological disorders such as hypersplenism and thrombocytopenia in patients undergoing splenic artery ligation following liver transplantation. These findings may provide an important clinical guideline for the management of hematological complications after liver transplantation and contribute to a better understanding of the postoperative effects of surgical interventions.

Material and Methods

This retrospective study was conducted at Demiroğlu Bilim University Florence Nightingale Hospital Liver Transplantation Center between January 2023 and December 2024.

Ethical Considerations

The study was approved by the institutional ethics committee, and informed consent was obtained from all participants. The study followed the principles outlined in the Declaration of Helsinki.

Participants

A total of 60 liver transplant recipients were included in the study – 30 patients underwent splenic artery ligation and 30 patients in the control group did not undergo splenic artery ligation.

Inclusion and Exclusion Criteria

Inclusion Criteria

Patients Surviving for 1 Month: Only patients who survived for at least 1 month after transplantation were included in the study, ensuring adequate follow-up for evaluating early-term outcomes.

Adults (≥18 years): The study was limited to adult patients aged 18 years or older to ensure homogeneity in the sample population with respect to organ function and response to surgery.

Living Donors with Right Lobe Donation: Only living donors who donated the anatomical right lobe of the liver were included in the study, as this anatomical approach is the one most commonly used for liver transplantation at our center.

Exclusion Criteria

Thrombocytopenia Requiring Platelet Transfusion: Patients who required platelet transfusions due to thrombocytopenia during the perioperative and early postoperative (30 days) period were excluded, as this could confound the assessment of organ function and the impact of splenic artery ligation.

Splenic Vein Thrombosis: Patients diagnosed with thrombosis of the splenic vein were excluded from the study, as this condition can alter portal flow dynamics and interfere with assessment of the effects of splenic artery ligation.

Collateral Ligations or Shunt Procedures: Patients who underwent collateral ligation or shunt procedures to modulate blood flow were excluded, as these interventions could significantly alter the

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normal vascular dynamics and confound the evaluation of the effects of splenic artery ligation on portal flow and organ function.

Splenectomy: Patients who had undergone splenectomy were excluded from the study, as removal of the spleen could lead to altered vascular dynamics and confound the assessment of the effects of splenic artery ligation.

Somatostatin Infusion: Patients who received somatostatin infusion were excluded, as this treatment could influence portal hemodynamics and interfere with the assessment of the effects of splenic artery ligation.

Demographic and Clinical Data

The demographic and clinical characteristics of the patients, including sex, age, and etiology of liver cirrhosis, were evaluated. Additionally, the Model for End-Stage Liver Disease sodium (MELD-Na) score and Child-Pugh score were used to determine the severity of liver disease. Intraoperative variables, including intraoperative bleeding volume, need for blood transfusion, and graft weight measured at surgery, were recorded. The GRWR was calculated to evaluate the adequacy of the graft weight relative to the recipient. In the first 30 days complications were monitored and recorded to assess the outcomes of the procedure. Intraoperative findings were recorded, including intraoperative bleeding measured in milliliters (mL). The need for blood transfusion was also documented, with the number of units transfused being recorded for each patient.

Laboratory Data

Patients' platelet values immediately before surgery as well as their platelet levels during the first month after surgery were recorded. In addition, amylase values were recorded on the first postoperative day as part of routine monitoring. Platelet and amylase values were obtained from the hospital's electronic health record system. Platelet values are reported in $\times 10^9$/L and amylase values are reported in U/L.

Radiological Findings

Cross-Sectional Imaging

All recipients underwent preoperative contrast-enhanced computed tomography (CT) to visualize the portal system. In the arterial phase of the CT, the presence of splenic artery aneurysms was specifically evaluated. The spleen volumes were calculated using Myrian® 2.7.1 software, an advanced imaging application designed for organ segmentation. The volumetric analysis was performed using the venous phase of the contrast-enhanced CT scans, which offers optimal visualization of the splenic parenchyma for accurate measurements.

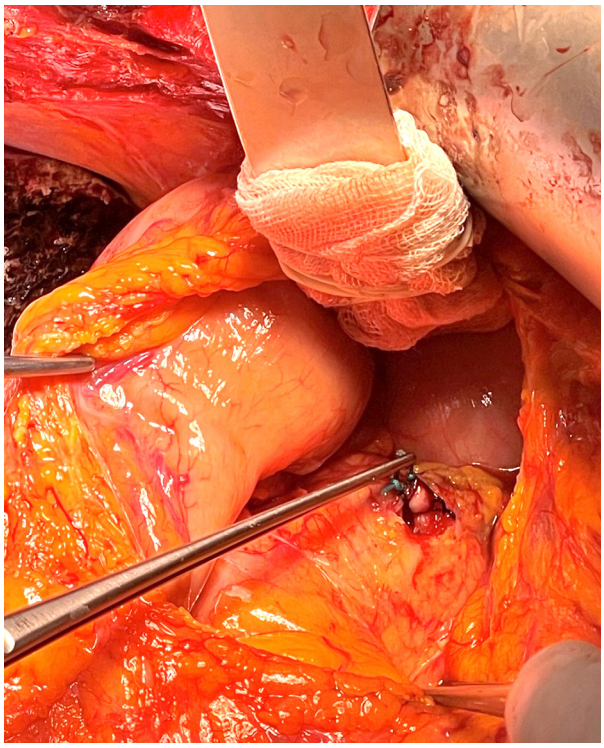

Figure 1. Intraoperative image of splenic artery ligation.

Postoperatively, a follow-up CT scan was performed at 1 month as part of the routine follow-up protocol. During this scan, the healthy spleen and the ischemic area were measured to assess the effects of the surgical procedure and any potential complications related to splenic perfusion.

Ultrasound Imaging

Intraoperatively, portal flow was assessed using Doppler ultrasonography. Portal flow measurements were taken before and after ligation of the splenic artery to evaluate the effects of the procedure on portal circulation. The changes in portal flow were compared, and the results were analyzed to determine how the ligation influenced portal dynamics. The ratio of portal flow to liver graft weight was calculated and analyzed.

Decision to Perform Splenic Artery Ligation and Surgical Technique

The ligation decision was made according to the presence of aneurysm in the splenic artery, and the portal flow-to-graft weight ratio.

The gastrocolic ligament was opened. The splenic artery was dissected over the pancreas. Depending on the density of collaterals in the region, the splenic artery was ligated with thick, non-absorbable material from 2 separate points from the safe dissection area (**Figure 1**).

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Complications

Complications were categorized into 4 groups: bleeding, portal vein thrombosis (PVT), biliary complications, and "none." Bleeding complications included significant hemorrhage requiring re-exploration or further surgical intervention. PVT was defined as any occlusion or thrombus formation in the portal vein detected during or after the transplant procedure. Biliary complications encompassed issues such as bile leaks, strictures, or obstruction that required surgical, endoscopic, or percutaneous intervention. Patients who did not experience any of these complications were categorized as "none".

Statistical Analyses

The data were analyzed using IBM SPSS 20.0 software. Descriptive statistics are presented as frequencies (n, %) for categorical variables, and as mean±standard deviation or median (Q1-Q3) for continuous variables. The normality assumption was tested using the Kolmogorov-Smirnov test. In cases where the assumptions for parametric tests were not met, the differences between independent groups were analyzed using the Mann-Whitney U test. When parametric test assumptions were satisfied, differences between means were analyzed using the independent-samples *t* test and paired-samples *t* test. A significance level of 0.05 was considered statistically significant.

Results

A total of 60 patients were included in the study – 30 in the splenic artery ligation (SAL +) group and 30 in the no splenic artery ligation group (SAL -). The sex distribution in the entire cohort was 20 females (33.3%) and 40 males (66.7%). The median age of the patients was 56 years (IQR: 43-62), and no significant age difference was observed between the groups ($P>0.05$). The etiology of liver disease in the study cohort was diverse. The 2 most common causes of liver cirrhosis were non-alcoholic steatohepatitis (NASH) (n: 16, 27%) and viral hepatitis (n: 16, 27%). Other causes were ethanol-induced liver cirrhosis, Budd-Chiari syndrome, echinococcus alveolaris, glycogen storage disease, cryptogenic liver cirrhosis, autoimmune hepatitis-induced liver cirrhosis, primary biliary cirrhosis, secondary biliary cirrhosis, primary sclerosing cholangitis, and Wilson's disease.

The MELD-Na scores of the total patient cohort ranged from 9 to 20, with a median of 14 (IQR: 10-20), indicating moderate liver disease severity. In terms of Child-Pugh classification, 30% of patients were classified as Child-Pugh A, 53.3% as Child-Pugh B, and 16.7% as Child-Pugh C. There was no significant difference in either the MELD-Na or Child-Pugh scores between the SAL (+) and SAL (-) groups ($P>0.05$), suggesting similar liver disease severity and function across both groups. In this study, 6 patients (10%) had a splenic artery aneurysm, all in the SAL (+) group. Demographic and clinical data are summarized in **Table 1**.

GRWR was comparable between the groups, with a mean value of 1.08±0.19 in the SAL (+) group and 1.13±0.24 in the SAL (-) group ($P>0.05$). Intraoperative blood loss was 1000 (IQR: 500-1500) mL in the SAL (+) group and 950 (IQR: 500-1500) mL in the SAL (-) group, showing no statistically significant difference ($P>0.05$). Transfusion requirements were also similar, with the SAL (+) group requiring 3.5 (IQR: 2-6) units of blood and the SAL (-) group requiring 4 (IQR: 2-7) units ($P>0.05$). These findings indicate similar intraoperative characteristics between the 2 groups, excluding portal flow measurements. Portal flow was 1771±550 mL/min in the SAL (-) group and 3148±989 mL/min in the SAL (+) group, with this difference being statistically significant ($P<0.001$). The intraoperative data are summarized in **Table 2**.

Biochemical and radiological data are summarized in **Table 3**. Preoperative platelet counts were significantly lower in the SAL (+) group compared to the SAL (-) group ($P<0.001$). Similarly, peak platelet counts were also significantly different between the groups ($P<0.05$). Peak platelet values were reached on postoperative day 17 in the SAL (+) group and on postoperative day 16 in the SAL (-) group. The peak platelet count was 3.8 times higher than the preoperative platelet count in the SAL (+) group and 2.05 times higher in the SAL (-) group, with a statistically significant difference between the groups ($P<0.001$). The first 30-day postoperative course of the platelet levels in both groups and the fold increase compared to the preoperative platelet levels are presented in **Figures 2 and 3**. Amylase levels, however, were comparable, showing no significant difference ($P>0.05$).

Preoperative spleen volumes were significantly larger in the SAL (+) group than in the SAL (-) group ($P<0.001$). Postoperative spleen volumes showed a significant decrease in both groups, with a significant difference observed between the SAL (+) and SAL (-) groups ($P<0.001$). Partial splenic ischemia was observed in 18 patients in the SAL (+) group. The median ischemic spleen volume was 5.51% (IQR: 2.1-18.2) of total spleen volume. These findings show key biochemical and radiological differences between the groups.

In the SAL (+) group, more patients experienced no complications compared to the SAL (-) group. Biliary complications were more frequent in the SAL (-) group, while bleeding complication requiring re-exploration and portal vein thrombosis occurred only in the SAL (+) group. Data on complications are summarized in **Table 4**.

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Table 1. Demographic and clinical sata.

Characteristic	SAL (+) Group (n: 30)	SAL (-) Group (n: 30)	Total (n: 60)
Sex			
Male	11 (36.7%)	9 (30%)	20 (33.3%)
Female	19 (63.3%)	21 (70%)	40 (66.7%)
Age (years) (median, IQR)	56 (43-62)	57 (50-63)	56 (45-62)
Etiology n (%)			
Non-alcoholic steatohepatitis	7 (23.3%)	9 (30%)	16 (26.7%)
Viral hepatitis	6 (20%)	10 (33.3%)	16 (26.7%)
Cryptogenic cirrhosis	4 (13.3%)	0 (0%)	4 (6.7%)
Alcoholic cirrhosis	3 (10%)	3 (10%)	6 (10%)
Wilson	3 (10%)	0 (0%)	3 (5%)
Autoimmune	1 (3.3%)	1 (3.3%)	2 (3.3%)
Others	6 (20%)	7 (23.3%)	13 (21.6%)
MELD-Na Score (median, IQR)	14 (10-20)	11 (9-16)	14 (10, 20)
Child-Pugh Score n (%)			
Child-Pugh A	6 (33.3%)	12 (66.7%)	18 (30%)
Child-Pugh B	18 (60%)	14 (43.8%)	32 (53.3%)
Child-Pugh C	6 (20%)	4 (40%)	10 (16.7%)
Presence of splenic artery aneurysm	6 (20%)	0 (0%)	6 (10%)

Table 2. Intraoperative data.

Variable	SAL (+) Group (n: 30)	SAL (-) Group (n: 30)	*P* value
Graft-recipient weight ratio (GRWR)	1.08±0.19	1.13±0.24	>0.05
Portal flow (mL/min)	3148±989	1771±550	**<0.001**
Intraoperative blood loss (mL) (median, IQR)	1000 (500-1500)	950 (500-1500)	>0.05
Transfusion requirement (units) (median, IQR)	3.5 (2-6)	4 (2-7)	>0.05

Portal flow decreased significantly following splenic artery ligation, from 3147.7±989.1 mL/min before ligation to 1949.2±829.8 mL/min after ligation (P<0.001). Similarly, the portal flow/graft weight ratio showed a significant reduction, from 3.97±1.43 before ligation to 2.45±1.12 after ligation (P<0.001). Pre- and post-ligation data for the SAL (+) are summarized in **Table 5**. After splenic artery ligation, portal flow decreased by 37.1±6.3% (**Figure 4**). These findings indicate a substantial modulation of portal hemodynamics achieved through splenic artery ligation.

Discussion

In living donor liver transplantation, it is thought that excessive portal flow following perfusion leads to sinusoidal congestion and hemorrhage, forming the fundamental mechanism of small-for-size graft syndrome (SFSS) [5]. There are numerous studies suggesting that the damage caused by portal overflow to the liver can be mitigated through portal modulation, potentially improving graft functions [12]. In our study, the reason for focusing on portal flow rather than portal pressure in

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Table 3. Biochemical and radiological data.

Variable	SAL (+) Group	SAL (-) Group	*P* value
Preoperative platelet count (×10⁹/L) (median, IQR)	59 (41-77)	149 (111-218)	**<0.001**
Peak platelet count (×10⁹/L) (median, IQR)	230±115	301±135	**<0.005**
Peak platelet day (postoperative day)	17 (16-18)	16 (15-21)	>0.05
Peak platelet count/preoperative platelet count (×10⁹/L)	3.80	2.05	**<0.001**
Amylase (U/L)	58±38	66±31	>0.05
Spleen volume (preoperative, cm³)	883±393	443±220	**<0.001**
Spleen volume (postoperative, cm³)	699±337	428±232	**<0.001**
Ischemic spleen volume (cm³) (18 patients SAL (+) Group)	105±193 (5.51%)	0	–

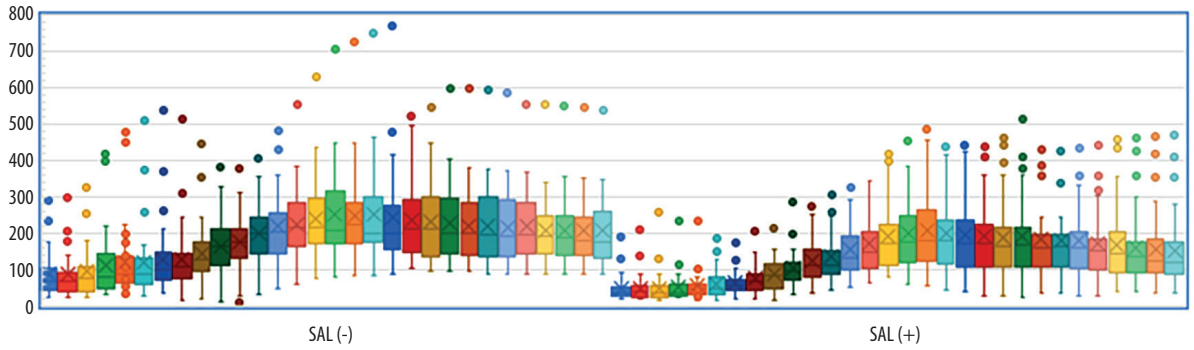

Figure 2. Postoperative platelet values for the first 30 days.

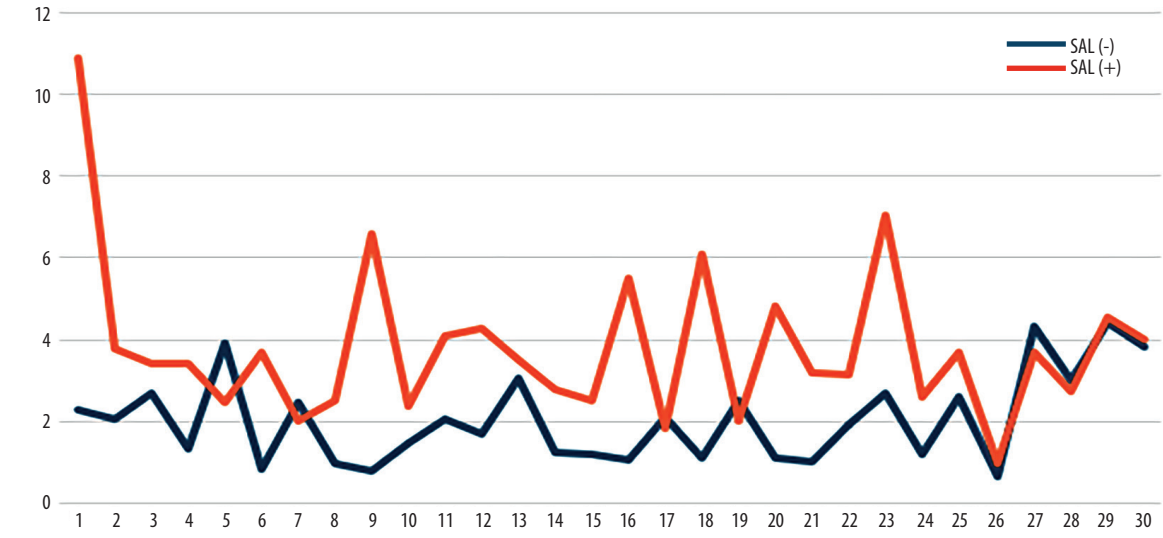

Figure 3. Postoperative peak platelet value/preoperative peak platelet value for the first 30 days.

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Table 4. Complications.

Complication	SAL (+) Group	SAL (-) Group
No complications	20 (66.7%)	12 (40%)
Biliary complications	8 (26.7%)	18 (60%)
Bleeding	1 (3.3%)	0
Portal vein thrombosis (PVT)	1 (3.3%)	0

Table 5. Pre- and post-splenic artery ligation data.

Complication	Pre-ligation	Post-ligation	*P* value
Portal flow (mL/min)	3148±989	1949±830	**<0.001**
Portal flow/graft weight ratio	3.97±1.43	2.45±1.12	**<0.001**

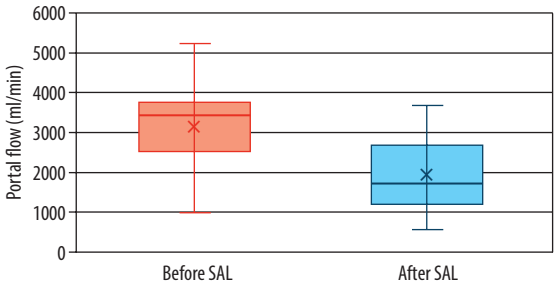

Figure 4. Portal flow before and after SAL.

portal flow modulation is that portal pressure is influenced by central venous pressure [13].

Portal venous flow below 250 mL/min/100 g is associated with poor graft outcomes [8,14]. In our study, a PVF of 100-250 ml/min/100 g was considered optimal. SAL was performed in patients with PVF above this level. We analyzed the effect of splenic artery ligation on the PVF/graft weight ratio in liver transplant recipients. In particular, the mean portal flow rate was approximately 4 times the graft weight before splenic artery ligation and decreased to less than 2.5 times after splenic artery ligation, showing that portal flow rate was reduced to optimal limits to avoid the adverse effects of portal overflow on the liver graft.

It has been reported in the literature that there can be a decrease in portal venous flow after splenic artery ligation [15], and Su et al showed that splenic artery ligation decreased portal blood flow by 14.3% [16].

In our study, a 37% decrease in portal venous flow was observed in patients who underwent splenic artery ligation after the procedure. The 37% reduction in our study is slightly higher than the values in previous studies. This difference may be due to differences in patient selection, surgical technique, measurement methods, timing, patient population characteristics, or clinical protocols. In conclusion, our study suggests that SAL can help preserve the short- and possibly long-term functional integrity of the graft by significantly reducing excess portal flow in living donor liver transplants.

Many methods can be used in portal modulation, including splenectomy [17], splenic artery embolization [18], splenic artery ligation [19], porto-systemic shunts [20], and somatostatin [21].

The exclusion of patients on somatostatin aimed to eliminate potential confounding factors for the effect of splenic artery ligation in our study.

When considering options to reduce portal vein blood flow, there is substantial evidence showing splenic artery ligation is preferable to splenectomy [22]. Samimi et al demonstrated significantly higher patient mortality in liver transplant recipients undergoing concomitant splenectomy, mainly as a result of early and late septic complications [23]. Ito et al reported that splenectomy was associated with longer operative time, greater blood loss, and a higher risk of venous thrombosis and infection [24]. Splenectomy weakens the defense against encapsulated bacteria and increases the risk of serious and life-threatening infections, especially in immunocompromised patients [25].

In our study, there was no significant difference in blood loss and transfusion needs between the groups with and without splenic artery ligation. There was no significant difference in the incidence of venous thrombosis. Serious bacterial infections were not observed. This situation is especially critical for patients receiving immunosuppressive therapy after liver transplantation. Our results suggest that splenic artery ligation

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provides significant advantages in clinical management by preserving splenic integrity and function in the liver transplant patients. It has been reported in the literature that thromboembolic complications can occur due to excessive platelet increase, which is frequently seen after splenectomy, and that this situation may require antithrombotic treatment and should be followed closely [16].

In our study, although there was a significant difference between the postoperative peak platelet values of the patients with and without SAL in favor of the SAL group, the postoperative 1-month platelet values remained within normal limits and thromboembolic complications due to excessive platelet increase were not significantly detected, thus reducing the need for long-term anticoagulant use. This result suggests that splenic artery ligation is also advantageous in terms of preserving the long-term hematologic balance of the patients.

Although splenic artery embolization is an effective method to reduce portal flow of small grafts after liver transplantation [18], ischemic complications of splenic artery embolization, such as splenic infarction, have also been reported in the literature [26]. In our series, only a small splenic area (5.51%) was ischemic in 18 patients with SAL and there was no significant splenic infarction. This shows that the spleen can be protected from ischemic changes by providing adequate perfusion through additional vascular sources such as short gastric, gastroepiploic, and omental vessels, and that ischemic complications after embolization can be minimized. Splenomegaly causes sequestration of blood products in the splenic sinusoids and the literature suggests an association between splenomegaly and resultant cytopenias [27].

The present study show that SAL significantly improves splenic volume and platelet values in living donor liver transplant patients. First, the percentage change in splenic volume in the group that underwent SAL showed a significantly more pronounced decrease than in the group that did not undergo SAL. This finding suggests that SAL alleviates splenic sequestration due to hypersplenism by significantly reducing splenic volume. Secondly, the positive effect of SAL on platelet values was also clearly demonstrated. The ratio of postoperative peak platelet values to preoperative values was significantly higher in patients who underwent SAL compared to the group without SAL. This increase indicates that hematologic complications related to hypersplenism such as thrombocytopenia can be effectively controlled by SAL. This improvement may be explained by decreased sequestration due to decreased splenic volume and increased circulating effective platelet count.

Taken together, these 2 statistical findings suggest that SAL modulates portal hemodynamics and normalizes hematologic balance by improving signs of hypersplenism to a clinically relevant extent. Compared to alternative methods such as splenectomy and splenic artery embolization, splenic artery ligation is an approach that minimizes the risk of ischemia, maintains immunological protection, supports hematologic balance in the long term, and reduces potential complications.

This study has several limitations. First, this is a retrospective study with a small sample size at a single center. Second, the effect of low portal venous outflow was not analyzed. Third, patients with shunts were not included. Future larger, multicenter, prospective studies may more comprehensively confirm these multifaceted benefits of splenic artery ligation.

Conclusions

SAL in LDLT significantly reduces the risk of damage to the graft from portal overflow. SAL also was shown to significantly reduce splenic volume, alleviate sequestration due to splenomegaly, and improve thrombocytopenia, with significant improvements in platelet count. SAL as an effective method that not only optimizes portal flow but also promotes hematologic balance, improving graft function and patient outcomes.

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Declaration of Figures' Authenticity

All figures submitted have been created by the authors who confirm that the images are original with no duplication and have not been previously published in whole or in part.

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