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Distribution of Splenic Arterial Flow and Segmental Spleen Volume for Partial Splenic Arterial Embolization

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Introduction: The spleen is a lymphatic organ that manages immune surveillance of the blood, produces blood cells, and helps filter the blood, remove old blood cells, and fight infection. The normal splenic weight is approximately 65-265 g. This study evaluated spleen volume and segmental volume.
Methods: 121 patients who underwent enhanced CT at our center were analyzed. The spleen was divided into upper, middle, and lower segments according to arterial flow area, and the volume of each segment was measured. Patients were classified into two groups as those with and without liver cirrhosis, and differences in the distribution of the segments in these groups was evaluated.
Results: The mean upper, middle, and lower spleen segmental volume ratios were 35.4%, 37.0%, and 27.6%, respectively. In the liver cirrhosis group, the segmental splenic volume ratios for the upper, middle, and lower segments were 34.5%, 38.5%, and 28.0%, respectively, indicating that these ratios remain similar regardless of liver cirrhosis status.
Conclusion: The present findings on segmental spleen volume are useful for estimating infarction volume in cases of partial splenic arterial embolization. (J Nippon Med Sch 2024; 91: 83–87)

Key words: spleen, segmental volume, LC

Introduction

The spleen is a lymphatic organ that is primarily responsible for immune surveillance of the blood[1]. The spleen is organized to filter out pathogens and abnormal cells in the blood and facilitate low-probability interactions between antigen-presenting cells and cognate lymphocytes[2]. The spleen is located posterolaterally, in the left upper abdominal cavity. All splenic vessels, lymphatics, and nerves enter and leave the organ through the hilum, which is located centrally on the medial surface. The splenic artery is a branch from the celiac artery, and splenic arterial branches are end arteries that do not intercommunicate; consequently, occlusion leads to infarction[3]. The normal weight of the spleen is approximately 65-265 g[4]. Splenomegaly and hypersplenism are common in patients with cirrhosis but are not directly related, as patients with normal-sized spleens may have hypersplenism, and some with large spleens do not[5]. In this study, we focused on splenic volume and segmental volume, as there is little research on segmental splenic volume. We divided the spleen into 3 segments and calculated the volume of each segment. These data may contribute to predicting splenic infarction volume in partial splenic artery embolization (PSE).

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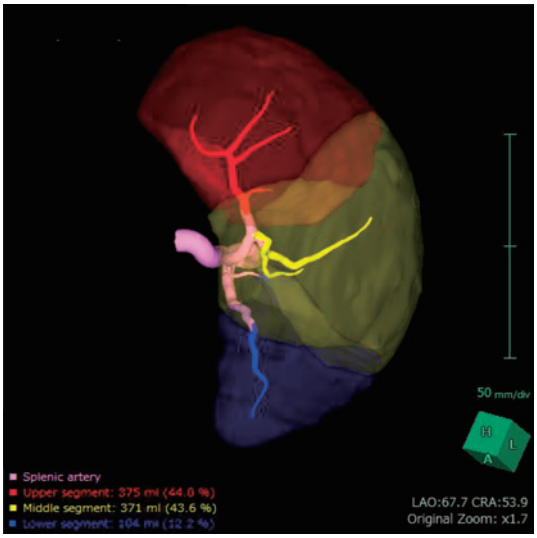

Fig. 1 Segmental splenic volume, as determined by the Synapse Vincent analyzer

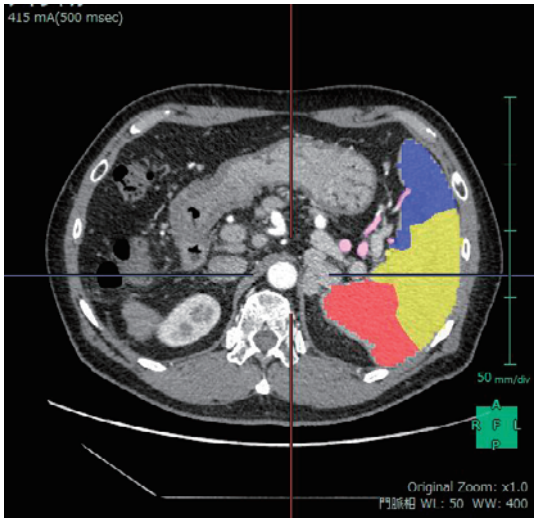

Fig. 2 Segmental splenic volume, as determined by the Synapse Vincent analyzer

Materials and Methods

Forty-four consecutive patients underwent PSE between 2014 and 2022, and 77 consecutive patients underwent surgery in our center for hepatobiliary and pancreatic disease between 2019 and 2021. Data from 121 patients who underwent enhanced CT at our centers were analyzed. The spleen was divided into upper, middle, and lower segments, in accordance with arterial flow area, and the volume of each segment was measured. The average spleen weight for a healthy Japanese adult is 62.8 g ±41.5 g for males and 80.7 g±51.8 g for females[6]. We defined splenomegaly as a splenic volume over 200 mL. The diagnostic criteria for liver cirrhosis were pathological findings of liver cirrhosis or CT images showing an irregular liver surface and splenomegaly and swelling of the left lobe of the liver and atrophy of the right lobe of the liver.

This was a retrospective cohort study. We obtained informed consent from all patients studied. Data collection and analysis were performed in accordance with the relevant institutional guidelines and the ethical standards of the Declaration of Helsinki. We obtained ethical approval from the ethics committee of Nippon Medical School Hospital (No. B-2021-459). Consent forms were signed by the patients before the start of the study.

Measurement of Segmental Spleen Volumes

In all cases, no spleen treatment, such as PSE, was performed. Total and segmental spleen volumes were measured with a Synapse Vincent analyzer (Fujifilm Medical Co., Tokyo, Japan)[7]. For measurement, delayed-phase images reconstructed at 5-mm intervals were used. After importing pre- and post-PSE images into the analyzer, the splenic artery and regions of noninfarcted and infarcted spleen parenchyma were selected manually, and a region of interest was designated in each slice. We selected the branch of the splenic artery at the splenic hilum and defined the supply area of the inferior polar artery[8] as the lower segment. We also defined the area of the superior polar artery and superior splenic artery[8] as the upper segment. The remaining area was defined as the middle segment. We calculated the volume of each segment by using the analyzer (**Fig. 1, 2**).

Evaluation Factors

We evaluated age, sex, and laboratory findings for serum total bilirubin (T-bil), prothrombin time (PT%), and platelets (Plts).

Statistical Analysis

Statistical analysis was performed using the statistical software package SPSS, version 16.0 (Chicago, IL, USA). Categorical variables were compared with the χ^2 test or Fisher's exact test. A P value of less than 0.05 was considered to indicate statistical significance.

Results

The clinical characteristics of the study participants are shown in **Table 1**. Seventy-four patients had liver tumors, including hepatocellular carcinoma, intrahepatic cholangiocarcinoma, hilar cholangiocarcinoma, and metastatic liver tumors. The mean upper, middle, and lower segmental volume ratios were 35.4%, 37.0%, and 27.6%, respectively. The mean spleen volume was 358 mL. After determining that 77 (55.4%) patients had liver cirrhosis, the patients were divided into those with liver cirrhosis

Table 1 Clinicopathological characteristics of the patients

Age (years)		67.7
Sex	M/F	83/38
Splenic volume (mL)		358
	Upper segment (mL/%)	121/35.4
	Middle segment (mL/%)	130/37.0
	Lower segment (mL/%)	105/27.6
Liver cirrhosis	+/−	67/54
Splenomegaly (>200 mL)	+/−	69/52
Platelet ($\times 10^4$/mL)		14.1
T-bil (mg/dL)		1.08
PT (%)		87.0
BMI		23.4

Table 2 Clinicopathological findings in patients with and without liver cirrhosis

	Liver cirrhosis (N=67)	No liver cirrhosis (N=54)	p-value
Splenic volume (mL)	496	143	0.001
Upper Segment (mL)	167	52.3	0.001
Middle Segment (mL)	182	50.9	0.001
Lower Segment (mL)	145	38.9	0.001
Splenic volume ratio			
Upper Segment (%)	34.5	36.7	0.364
Middle Segment (%)	38.5	35.0	0.103
Lower Segment (%)	28.0	27.8	0.510
Platelet ($\times 10^4$/mL)	9.1	20.8	0.001
PT (%)	72.6	105	0.001
T-bil (mg/dL)	1.2	0.9	0.102
BMI	24.3	22.3	0.010

and those without liver cirrhosis or splenomegaly (**Table 2**). There were 67 liver cirrhosis cases. The cause of liver cirrhosis was hepatitis B virus (HBV) in 5 cases, hepatitis C virus (HCV) in 19 cases, alcohol misuse in 21 cases, and nonalcoholic steatohepatitis (NASH) in 11 cases. There were 3 cases of primary biliary cirrhosis (PBC), 1 case of autoimmune hepatitis (AIH) and idiopathic portal hypertension (IPH), and 6 cases of unknown cause. In the cirrhosis group, total spleen volume and the volumes of the 3 segments were significantly larger than the respective values for the non-liver cirrhosis group. However, the segmental splenic volume ratios of the upper, middle, and lower segments were 34.5%, 38.5%, and 28.0%, respectively, indicating that the ratios for the 3 segments were similar in liver cirrhosis. Next, these patients were divided into a splenomegaly group and non-splenomegaly group (**Table 3**). There were significantly more liver cirrhosis and Child B patients in the splenomegaly group than in the non-splenomegaly group. In addition, platelet count and total bilirubin level were significantly lower in the splenomegaly group.

Discussion

This study examined the segmental volume of the spleen. First, we measured splenic volume and segmental volume in 121 patients. Several studies have reported separating the spleen into lobes and segments on the basis of its arterial supply[9]. However, the splenic artery exhibits multiple variations[9]. Some reports advocate splenic segmental classification based on the origin of the splenic arterial branch. However, others have considered the many variations of the branches. We classified the splenic segments as upper, segment, and lower segments and calculated segmental splenic volume ratios. Next, we determined the difference in segmental volume ratios in patients with and without liver cirrhosis and found that the volumes of the 3 segments were similar in these groups. Splenomegaly is a frequent finding in patients with liver disease, especially in those with cirrhosis and portal hypertension[10]. Portal hemodynamics are probably impor-

Table 3 Clinicopathological findings in patients with and without splenomegaly

	Splenomegaly (N=69)	No splenomegaly (N=52)	p-value
Age	67.3	68.3	0.621
Sex (male/female)	50/18	32/20	0.162
LC (+/−)	55/14	12/40	0.001
Child-Pugh classification			
A/B	43/26	51/1	0.001
Platelet ($\times 10^4$/mL)	9.14	20.1	0.001
PT (%)	75.2	102	0.001
T-bil (mg/dL)	1.25	0.73	0.003
BMI	24.5	21.8	0.001

tant in splenomegaly, but the interrelation is complex[11].

In this study, we investigated the segmental volume of the spleen. A sufficient increase in platelet count at 1 year after PSE was achieved with a splenic infarction ratio of 64.3%[12]. Recently, we reported that achieving a splenic infarction ratio of 63% doubled platelet count (article under review). These findings suggest that embolizing the lower and middle segments of the spleen can achieve a 63% splenic infarction ratio. Moreover, we suggest calculating the pretreatment segmental volume of the spleen by CT volumetry and determining the splenic infarction ratio preoperatively.

In this study, we revealed that the volume ratios of the 3 spleen segments were similar in liver cirrhosis. Liver cirrhosis combined with hypersplenism will lead to blood flow redistribution[13]. Portal hypertension is also a cause of splenomegaly. Nathan et al. reported that increased splenic arterial inflow is associated with increased splenic venous outflow and that decreased splenic venous flow is associated with decreased splenic arterial flow. Large arteriovenous anastomoses are present in the human spleen in cirrhosis, and these result in splenomegaly[14]. These findings likely explain why the volumes of the 3 segments of the spleen grow equally in liver cirrhosis. We report that in splenomegaly, the spleen enlarges uniformly regardless of the location, and that when PSE is performed, therapeutic effects can be obtained by embolizing a certain proportion, regardless of the severity of splenomegaly.

Our study had limitations. First, because it was a retrospective study at a single center, patient selection bias is a concern. Second, the Synapse Vincent analyzer is not suitable for measurement of micro-arteries, as collateral arteries and veins are sometimes observed. The sample size was comparatively small; thus, multicenter studies are required in order to confirm our findings.

Conclusion

This is the first report to evaluate segmental splenic volume. The findings will assist in predicting splenic infarction volume in PSE.

Availability of data and materials: The datasets used and analyzed in the current study are available from the corresponding author on reasonable request.

Author contributions: Junji Ueda and Hiroshi Yoshida designed the study and wrote the report. Yasuhiro Mamada, Nobuhiko Taniai, Masato Yoshioka, Akira Matsushita, Satoshi Mizutani, Youichi Kawano, Tetsuya Shimizu, Tomohiro Kanda, Hideyuki Takata, Hiroyasu Furuki, Yuto Aoki, Mampei Kawashima, Toshiyuki Irie, Takashi Ohno, and Takahiro Haruna summarized the clinical data. All authors read and approved the final manuscript.

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