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• CLINICAL RESEARCH •

Percentage of peak-to-peak pulsatility of portal blood flow can predict right-sided congestive heart failure

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Abstract

AIM: To study the change of portal blood flow for the prediction of the status of right-sided heart failure by using non-invasive way.

METHODS: We studied 20 patients with rheumatic and atherosclerotic heart diseases. All the patients had constant systemic blood pressure and body weight 1 week prior to the study. Cardiac index (CI), left ventricular end-diastolic pressure (LVEDP), mean aortic pressure (AOP), pulmonary wedge pressure (PWP), mean pulmonary arterial pressure (PAP), mean right atrial pressure (RAP), right ventricular end-diastolic pressure (RVEDP) were recorded during cardiac catheterization. Ten patients with RAP <10 mmHg were classified as Group 1. The remaining 10 patients with RAP ⩾10 mmHg were classified as Group 2. Portal blood velocity profiles were studied using an ultrasonic Doppler within 12 h after cardiac catheterization.

RESULTS: CI, AOP, and LVEDP had no difference between two groups. Patients in Group 1 had normal PWP (14.6±7.3 mmHg), PAP (25.0±8.2 mmHg), RAP (4.7±2.4 mmHg), and RVEDP (6.4±2.7 mmHg). Patients in Group 2 had increased PWP (29.9±9.3 mmHg), PAP (46.3±13.2 mmHg), RAP (17.5±5.7 mmHg), and RVEDP (18.3±5.6 mmHg) (P<0.001). Mean values of maximum portal blood velocity (Vmax), mean portal blood velocity (Vmean), cross-sectional area (Area) and portal blood flow volume (PBF) had no difference between 2 groups. All the patients in Group 1 had a continuous antegrade portal flow with a mean percentage of peak-to-peak pulsatility (PP) 27.0±8.9 % (range: 17-40 %). All the patients in Group 2 had pulsatile portal flow with a mean PP 86.6±45.6 (range: 43-194 %). One patient had a transient stagnant and three patients had a transient hepatofugal portal flow, which occurred mainly during the ventricular systole. Vmax, Vmean and PBF had a positive correlation with CO (P<0.001) but not with AOP, LVEDP, PWP, PAP, RAP, and RVEDP. PP showed a good correlation (P<0.001) with PWP, PAP, RAP, and RVEDP but not with CI, AOP, and LVEDP. All the patients with PP >40 % had a right-sided heart failure with a RAP=10 mmHg.

CONCLUSION: The measurement of PP change is a simple and non-invasive way to identify patients with right heart failure.

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INTRODUCTION

Hepatic artery and portal vein contribute to the hepatic blood inflow. In cirrhotic patients, oral nitroglycerin can reduce portal blood flow due to systemic hypotension[1-4]. Congestive heart failure, systemic hypotension and the use of hypotensive agents can decrease cardiac output. The reduced cardiac out put and systemic hypotension can decrease the portal inflow volume. Marked reduction of hepatic inflow may cause ischemic hepatitis. Patients with cardiopulmonary diseases may develop ischemic hepatitis with abnormal serum ALT levels[5,6].

On the other hand, right-sided congestive heart failure can result in the increase of pressure in inferior vena cava and hepatic veins[6,7]. The liver in passive "backward" congestion status can develop hepatomegaly and synchronous pulsation, and the liver histology shows engorged and dilated terminal hepatic veins, atrophy of hepatocytes and eventually cardiac cirrhosis. The high pressure of the hepatic veins can transmit through the liver to result in post-sinusoidal portal hypertension and cardiac ascites. The diameter of portal vein has been proved to correlate with right atrial pressure[8]. Thus, right-sided heart failure can affect portal vein flow patterns.

The role of heart function in portal blood flow remains uncertain. Therefore, we studied the changes of portal blood flow in patients with different degree of right-sided heart failure using non-invasive ultrasonic Dopper[5,8-11].

MATERIALS AND METHODS

We studied the portal blood velocity profiles in 20 patients (9 males, 11 females, mean age: 49±16 years) who underwent cardiac and/or Swan-Ganz catheterizations for cardiovascular disorders (16 rheumatic heart disease cases, 4 atherosclerotic heart disease cases) to compare the portal profiles of 20 healthy volunteers. Although all the patients took medications affecting the hemodynamics such as isosorbide dinitrate and furosemide, their systemic blood pressure and body weight were constant for at least 1 week prior to the study. Patients with fever, infection, and shock were excluded. All the patients had no past history of liver disease, alcoholism or other metabolic disorders such as chronic renal failure or diabetes mellitus. None underwent transfusion or under cardiac inotropic agents. All the patients had an abdominal sonographic examination excluding chronic liver disease or splenomegaly. Patients with severe dyspnea were excluded if they were not able to remain on supine position for the study of ultrasonic Doppler.

Cardiac profiles including cardiac index (CI), left ventricular end-diastolic pressure (LVEDP), mean aortic pressure (AOP), pulmonary wedge pressure (PW), mean pulmonary arterial

pressure (PAP), mean right atrial pressure (RAP), right ventricular end-diastolic pressure (RVEDP) were recorded during the cardiac and Swan-Ganz catheterizations. Ten patients with PAP <10 mmHg (range: 1-7 mmHg) without right heart failure were classified as Group 1. The other 10 patients with right heart failure and RAP=10 mmHg (range: 10-28 mmHg) were classified as Group 2.

We studied the portal profiles using an ultrasonic Doppler composed of a real-time mechanical sector scanner and a 3.5 mHz pulsed Doppler flowmeter (Aloka Echo Camera Model SSD-650, Tokyo) within 12 h after cardiac catheterization. After more than 8 h fasting, portal profiles were measured in supine position for more than 30 min. Portal blood flow was measured from the main portal vein with the patient in expiratory apnea. We located the cursor in the main portal vein at a site just entering or immediately after entering the liver and opened the gate of cursor as wide as possible to include the inner diameter of the main portal vein. We corrected the flow angle formed by the directions of ultrasonic beam and the portal blood flow below 55 degree to minimize the variation caused by the angle of insonation. The Doppler signal could be viewed on the screen and heard through a build-in speaker. Portal blood flow was measured by the same physician to avoid inter-observer variations[12].

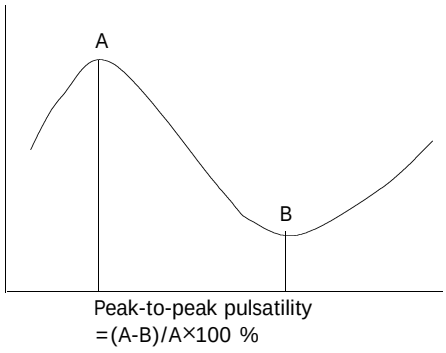

Figure 1 Mean portal blood velocity (Vmean) was calculated (cm/s) by the equation of "Vmean=0.57×maximum portal blood velocity (Vmax)".

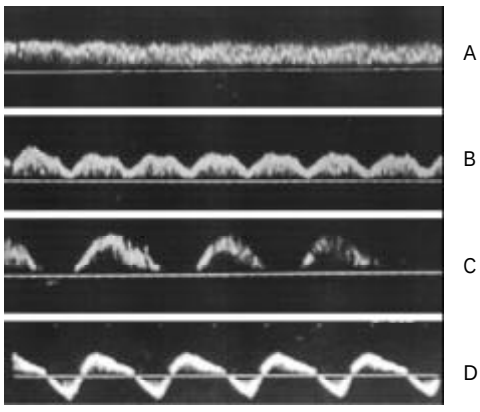

Figure 2 Representative waveform of portal blood flow from patients with normal (A; PP: 17 %), transiently reduced (B; PP: 60 %), stagnant (C; PP: 100 %) or retrograde (D; PP: 194 %) portal blood flow.

For each measurement, at least 3 reproducible patterns were made to calculate the mean maximum portal blood velocity (Vmax) over a period of 4 seconds to ensure the measurement accuracy. Mean portal blood velocity (Vmean) was calculated (cm/s) by the equation of "Vmean=0.57×Vmax" as described by Moriyasu *et al* (Figure 1)[13]. Cross-sectional area (Area) was also recorded (cm^2) at the site of main portal vein where portal blood velocity was measured. The direction of portal blood velocity, antegrade or retrograde, was also measured. Positive signal above the zero velocity indicated the flow toward the transducer and vice versa. Portal blood flow volume (PBF) was obtained (ml/min) by the equation "PBF=Area×Vmean ×60"[12,13]. The percentage of peak-to-peak pulsatility (PP) was calculated by the equation of PP=(maximum-minimum)/maximum frequency shift (Figure 1)[5,10,12]. The waveforms were classified as continuous (PP=40 %; Figure 2A), decreased (PP 41-99 %; Figure 2B), stagnant (PP=100 %; Figure 2C), and retrograde (PP >100 %; Figure 2D).

The study protocol was reviewed and approved by the Institutional Review Committee under the guidelines of the 1975 Declaration of Helsinki. Statistical analysis was performed using Student's *t*-test and linear regression as appropriate.

RESULTS

The clinical and biochemical data are shown in Table 1. All the controls had normal blood chemistries. All the patients had normal serum bilirubin, and prothrombin time. The mean serum albumin levels were lower in Group 1 (3.9±0.7 g/dL, $P<0.02$) and Group 2 (3.7±0.5 g/dL, $P<0.01$) than Controls. The serum ALT levels were all less than two times of the upper normal limit. Group 2 patients (35±20 IU/L) had a higher mean serum ALT activity than that of the controls (24±6 IU/L, $P<0.05$) but not statistically different from that of Group 1 (23±8 IU/L). Group 2 (59±29 IU/L) had a higher mean AST level than those of Group 1 (31±11 IU/L, $P=0.004$) and controls (21±6 IU/L, $P<0.001$). The higher serum AST activities, were supposed to be related to ischemic hepatitis. The other clinical and biochemical data between Group 1 and 2 showed no statistical difference.

Table 1 Clinical and biochemical data of patients with congestive heart failure ($\bar{x}\pm s$)

	Control	Group 1	Group 2
Gender (M/F)	10/10	4/6	5/5
Age (y)	46±12	50±13	47±19
Total protein (g/dL)	7.5±0.6	7.1±0.8	6.9±1.1
Albumin (g/dL)	4.3±0.2	3.9±0.7	3.7±0.5
Total serum bilirubin (mg/dL)	0.9±0.4	1.3±0.8	1.4±0.8
AST (IU/L)	21±6	31±11	59±29
ALT (IU/L)	24±6	23±8	35±20
Prolonged prothrombin time (s)	-	1.1±0.9	1.4±0.8

The CI [3.0±1.4 L/(min· m^2); range: 2.3-8.6 L/(min· m^2) *vs* 2.4±0.5 L/(min· m^2); range: 2.8-4.2 L/(min· m^2)], AOP (87.8±11.7 mmHg; range: 65-100 mmHg *vs* 87.6±16.5 mmHg; range: 65-115 mmHg), and LVEDP (12.2±9.3 mmHg; range: 4-40 mmHg *vs* 22.8±13.0 mmHg; range: 10-40 mmHg) were not statistically different between Group 1 and 2 (Table 2). All the Group 1 patients had normal PWP (mean: 14.6±7.3 mmHg; range: 5-40 mmHg), PAP (mean: 25.0±8.2 mmHg; range: 16-48 mmHg), RAP (mean: 4.7±2.4 mmHg; range: 1-10 mmHg), and RVEDP (mean: 6.4±2.7 mmHg; range: 4-14 mmHg). All the group 2 patients had abnormally higher PWP (mean: 29.9±9.3 mmHg; range: 13-38 mmHg), PAP (mean: 46.3±13.2 mmHg; range: 25-65 mmHg), RAP (mean: 17.5±5.7 mmHg; range: 12-28 mmHg), and RVEDP (mean: 18.3±5.6 mmHg; range: 9-26 mmHg) than those of Group 1 patients ($P<0.001$).

Table 2 Cardiac profiles in patients with congestive heart failure [$\bar{x}\pm s$, (n)]

	Group 1	Group2
CI [L/(min· m²)]	3.0±1.4 (6)	2.4±0.5 (7)
AOP (mmHg)	87.8±11.7 (9)	87.6±16.5 (8)
LVEDP (mmHg)	12.2±9.3(10)	22.8±13.0(9)
PWP (mmHg)	14.6±7.3(9)	29.9±9.3[a] (9)
PAP (mmHg)	25.0±8.2(10)	46.3±13.2[a] (9)
RAP (mmHg)	4.7±2.4(10)	17.5±5.7[a] (10)
RVEDP (mmHg)	6.4±2.7(10)	18.3±5.6[a] (10)

[a]P<0.001 *vs* group 1.

The mean values of Vmax (24.5±4.9 cm/s; range: 17-33 cm/s *vs* 21.5±6.1 cm/s; range: 16-33 cm/s), Vmean (14.0±2.9 cm/s; range: 9.7-18.8 cm/s *vs*12.3±3.5 cm/s; range: 8.6-13.7 mmHg), area (0.80±0.17 cm²; range: 0.64-1.13 cm² *vs* 0.94±0.18 cm²; range: 0.79-1.33 cm²) and PBF (678±239 ml/min; range: 373-1120 ml/min *vs* 684±191 ml/min; range: 432-922 ml/min) between Group 1 and 2 did not show any statistical difference (Table 3). All the 10 patients in Group 1 had a continuous antegrade portal flow with a mean PP 27.0±8.9 % (range: 17-40 %). The mean PP of the remaining 10 patients in Group 2 was 86.6±45.6 % (range: 43-194 %); all the patients had a pulsatile portal blood flow with PP >40 %. 6, 1 and 3 patients had transiently reduced, stagnant, and hepatofugal portal blood flow, respectively. The transiently reduced, stagnant and retrograde flow occurred mainly immediately after the corresponding ventricular systole. Different from earlier reports, we have observed that the decreased or reversed portal blood flow did not occur during ventricular systole in 3 patients with ventricular premature depolarizations or atrial fibrillation (Figure 3).

Table 3 Portal profiles in patients with congestive heart failure ($\bar{x}\pm s$)

	Control (n=20)	Group1 (n=10)	Group2 (n=10)
Vmax (cm/s)	20.1±3.1	24.5±4.9	21.5±6.1
Vmean (cm/s)	11.2±1.9	14.0±2.9	12.3±3.5
Area (cm²)	1.01±0.20	0.80±0.17	0.94±0.18
PBF (ml/min)	685±136	678±239	684±191
PP (%)	23.3±6.3	27.0±8.9	86.6±45.6[a]

[a]P<0.001 *vs* control and group 1.

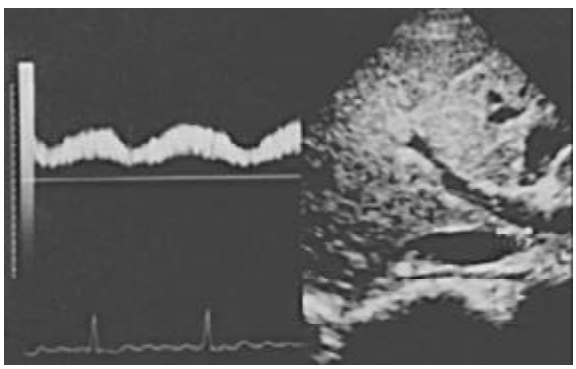

Figure 3 Occurrence of reduced portal blood flow immediately after ventricular systole.

By using linear correlation, Vmax, Vmean and PBF had a positive correlation with CI (P<0.001) but not with AOP, LVEDP, PWP, PAP, RAP, and RVEDP. PP showed a good correlation with PWP, PAP, RAP, and RVEDP (P<0.001) but did not show any correlation with CI, AOP, and LVEDP. PP had no correlation with Vmax, Vmean and PBF.

DISCUSSION

In the present study, all the 10 patients with RA=10 mmHg had a PP>40 %. On the contrary, all the patients with RAP <10 mmHg had a PP 40 % or less. It suggested these patients developed transiently reduced, stagnant or hepatofugal portal blood flow. 4 (36 %) of the patients with RAP=10 mmHg had a retrograde portal blood flow with a PP >100 %. Therefore, the portal blood flow can be retrograde during severe right heart failure[13]. Furthermore, RAP, PWP and RVEDP have a good correlation with PP. Thus, the waveforms of portal blood flow correlate well with right heart function[14]. Therefore, the measurement of PP change is a simple and non-invasive way to identify patients with right heart failure[9,15].

In the present study, AOP did not correlate with PP and "estimated" PBF[12,13,16]. Actually, all the patients had preserved AOP and only 1 patient whose AOP was 2.3 L/(min· m²) with RAP< 10 mmHg had AOP less than 2.6 L/(min· m²). Thus, right heart failure rather than reduced CI is responsible for PP changes[5,17-19]. Furthermore, "estimated" portal inflow showed no difference between patients with high and low RAP. Since the portal inflow can be transiently reduced, stagnant or hepatofugal during severe right heart failure, the "actual" portal inflow volume should be lower than the "estimated" volume[20]. As a consequence, the "estimated" volume does not represent the "actual" portal inflow volume. Hence, the correlation among "actual" PBF, AOP and RAP warrants further study.

Portal blood flow contributes to 90 % of blood flow and 50 % of oxygen supply of the liver. Therefore, portal inflow plays an important role in the delivery of oxygen to the liver[16]. It has been well known that cirrhosis with portal hypertension can result in reduced PP[16,21,22]. However, the volume of portal inflow varies due to the occurrence of collaterals or the presence of portal hypertension. In alcoholic cirrhosis, oral nitroglycerin can cause systemic hypotension to reduce portal inflow[1-4,22,23]. In the present study, all the patients did not experience systemic hypotension. Therefore, their transiently reduced, stagnant or hepatofugal portal blood flow was not likely to be related to systemic hypotension[15,24].

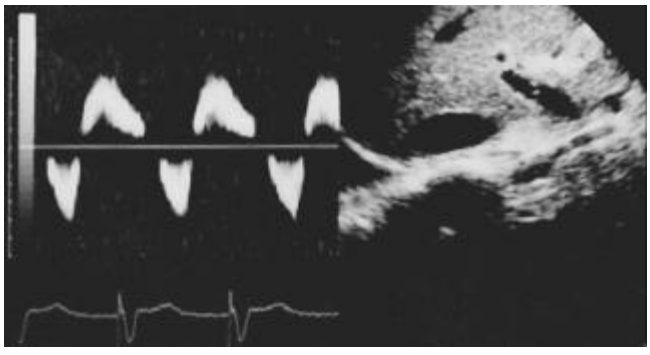

Figure 4 The occurrence of transient hepatofugal portal blood flow immediately after ventricular systole.

In the present study, the occurrence of transiently reduced (Figure 3), stagnant or hepatofugal (Figure 4) portal blood flow was immediately after ventricular systole[14,24,25]. The increased PP in those patients with RAP=10 mmHg suggests that the portal inflow is transiently reduced immediately after ventricular systole. The occurrence of transiently stagnant or hepatofugal portal blood flow may impair the delivery of

oxygen to the liver. It is well known that left heart failure and systemic hypotension can decrease hepatic inflow to cause ischemic hepatitis with a higher AST level[15,26]. However, it is not uncommon that some patients with heart failure have both abnormally higher serum ALT and LDH levels even without systemic hypotension clinically[5,6,24]. Thus, the occurrence of transiently reduced, stagnant or hepatofugal portal blood flow may in part explain the relatively higher AST levels in those patients with RAP=10 mmHg than those <10 mmHg.

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