Analysis of Acute and Chronic Heart Failure in View of Hepatic Oxygen
Supply-Demand Relationship Using Hepatic Venous Oxygen Saturation

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The adequacy of hepatic circulation in terms of oxygen supply-demand
relation was assessed by measuring hepatic venous oxygen saturation (Shvo₂)
in patients. Among those with congenital cardiac lesions (n = 11), Shvo₂
during the early postoperative period was markedly low as less than 20% in
Fontan operation group (n = 5) with subsequent clinical findings of acute
hepatic dysfunction. Significant correlations were found between Shvo₂
values early after surgery and subsequent peak values in serum hepatic
enzymes. Serum total bilirubin and prothrombin time started to deteriorate
when Shvo₂ became below 30%. Cardiac index, hepatic perfusion pressure
and mixed venous oxygen saturation showed positive linear correlations with
Shvo₂, and central venous pressure (CVP) with an inverse relation. In chronic
valvular disease (n = 28), those with NYHA class IV patients showed lower
Shvo₂ (average: 47.4%) at cardiac catheterization than the others (class-I;
66.4%, class-II; 63.9%, p < 0.05). These results indicate that Shvo₂ monitoring
appears to be useful to assess the hepatic perfusion in terms of oxygen
supply-demand relation in acute and chronic heart failure, and Shvo₂ of 30%
seems to be a critical level.

Heart failure, acute as well as chronic, combined with systemic venous congestion
and low cardiac output may develop hepatic dysfunction and failure. Hepatic failure following
acute myocardial infarction or open heart surgery has been well described1-3 and its
etiology has been postulated as hepatic hypoperfusion from shock or hepatic congestion
resulting in hepatic tissue hypoxia4,5. Chronic liver dysfunction is also one of the major complications in chronic heart failure with combined valvular disease6,7. However, there has been little clinical investigation in this subject, particularly of hepatic perfusion in view of oxygen supply-demand relationship8. Because the hepatic venous oxygen saturation (Shvo₂) may represent the oxygen supply-demand relation in liver, we have introduced Shvo₂ monitoring in patients after Fontan-type operation (atriopulmonary connection)9,10 where acute right heart failure is likely to occur with elevated central venous pressure and low cardiac output11. Shvo₂ may also be useful in assessing the patients with chronic valvular disease where hepatic congestion is likely to occur. Therefore, in this study, we analyzed the Shvo₂ in patients with acute heart failure after open heart surgery for complex congenital anomalies and also in patients with chronic valvular disease.

Key words:
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Fig. 1. Relationships between mean Shvo₂ (mShvo₂) and peak values in liver functions of logGOT, logGPT and total bilirubin. For prothrombin time, the lowest value was used. In total bilirubin and prothrombin time, significant linear relations were seen in the range of mShvo₂ below 30%.

MATERIALS AND METHODS

I: Analysis in Congenital Heart Disease (Group-1)

Group-1A: Analysis at early post-open heart surgery

In 11 patients with congenital heart disease mainly of complex lesions, an Shvo₂ monitoring catheter was placed directly to the hepatic vein at the end of open heart surgery. The ages of patients ranged from 2 to 11 years with average of 6 years; the cardiac defects were single ventricle in 3, pulmonary atresia with intact ventricular septum in 2, tetralogy of Fallot in 3, transposition of the great arteries in 2 and atrial septal defect in 1. The operative procedures were modified Fontan-type operation in 5 and other intracardiac repair in the remaining 6 patients. The catheter was placed for 2–4 days postoperatively and blood gas analysis was made for hepatic venous blood every 4–6 hours. Cardiac index, arterial pressure, central venous pressure (CVP), arterial oxygen saturation were also measured. As the liver function, serum glutamic-oxaloacetic transaminase (GOT), glutamic-pyruvic transaminase (GPT), total bilirubin (TB), and prothrombin time (PT) were measured during the first 2 postoperative weeks, and the maximum value for each parameter (minimum for PT) was used as the index of acute liver dysfunction.

Group-1B: Analysis in chronic state after Fontan-type operation

In 7 patients with Fontan operation (2 patients were added to 5 patients of Group-1-A), postoperative cardiac catheterization was performed at 1–17 months (average 5.6 months). The clinical and hemodynamic results were analyzed in relation to the Shvo₂ analysis.

II: Analysis in patients with acquired valvular heart disease (Group-2)

At the routine cardiac catheterizations for valvular heart disease, hepatic venous blood sampling was performed and Shvo₂ was analyzed. The subjects were 28 patients ranging in age from 32 to 70 years with average of 47 years. The main lesion was mitral stenosis in 8, mitral insufficiency in 11, post-mitral valve replacement in 3, and aortic valve disease in 6 patients. Clinical and hemodynamic results were compared with Shvo₂.

Statistical analysis: The correlation coefficient was obtained by linear regression analysis and

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significance was determined when p value was less than 0.05. For multiple comparisons, Newman-Keuls analysis was used.

RESULTS

Group 1-A: The ShvO₂ during the first 4 days after Fontan-type surgery was found to be as low as 20%. In order to compare the data between patients, mean value of ShvO₂ (mShvO₂) for the 24 hours around the lowest point was used. The mShvO₂ was from 5 to 16% in Fontan-type operation, 20–23% in transposition repair, 40 to 80% in the others. In those with Fontan-type repair, all developed acute liver dysfunction with elevation of GOT and GPT over 1,000 U/L. However, no death resulted from this complication.

Early postoperative liver function expressed by the maximum values in each parameter in each patient during the first 2 weeks were analyzed in relation to mShvO₂. There were significant inverse linear correlations between mShvO₂ and logGPT, and between mShvO₂ and logGOT (GOT: r = -0.86, p < 0.001; GPT: r = -0.84, p < 0.002). There was an inverse correlation between mShvO₂ and TB (r = -0.92, p < 0.001) and a positive correlation with PT (r = 0.85, p < 0.02) (Fig. 1). For TB and PT, the above described linear relations to mShvO₂ were observed in the range of mShvO₂ below 30%.

Those with Fontan type operation showed cardiac index (CI) ranging from 1.4 to 3.2 l/min/m² (average of 2.3) and central venous pressure (CVP) from 14 to 20 mmHg (average 18.5) during the same period where mShvO₂ was obtained. These patients had relatively low CI and high CVP compared to the remaining patients. Between mShvO₂ and each hemodynamic parameter, expressed by the mean value during the first 48 hours postoperatively, there were significant positive correlations in CI, in hepatic perfusion pressure (HPP, mean arterial pressure minus CVP), in SvO₂ (mixed venous oxygen saturation), and inverse correlation in CVP (Fig. 2). In the relationship between mShvO₂ and SvO₂, there was no correlation in the range of SvO₂ below 70%.

Group 1-B: As the hemodynamic parameters, CI ranged from 1.7 to 3.8 l/min/m² (average; 2.5 ± 0.79, mean ± SD), CVP from 8 to 17 mmHg (13.0 ± 3.3), SvO₂ from 53 to 66% (61.5 ± 5.7). ShvO₂ ranged from 3.2 to 75.4% with average of 34.5 ± 25.0%. Between these hemodynamic parameters and ShvO₂, there was a linear correlation with CI (r = 0.41, p < 0.005) and no significant correlations to the remaining parameters were seen.

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Group-2: As the New York Heart Association functional class (NYHA), 5 belonged to class I, 4 to class II, 11 to class III, and 8 to class IV. Shvo2 was significantly lower (p < 0.05) in those of NYHA-IV (47.4 \pm 12.1\%, mean \pm SD) compared to those of class-I (66.4 \pm 8.2\%) and class-III (63.3 \pm 9.2\%).

Between Shvo2 and hemodynamic parameters, significant correlations were found in Shvo2 (r = 0.431, p < 0.05) and HPP (r = 0.406, p < 0.05). Between CI and Shvo2, there was a weak positive correlation (r = 0.319, 0.05 < p < 0.1). No significant relation was found between Shvo2 and CVP. NYHA class-IV showed higher value of TB as 2.0 \pm 1.0 mg/dl compared to the others (I: 0.8 \pm 0.4, II: 1.0 \pm 0.5, III: 1.0 \pm 0.4 mg/dl).

DISCUSSION

1) Fontan-type operation and acute hepatic dysfunction

In this study, acute liver dysfunction with significant release of the related enzymes had a very high incidence among patients with Fontan-type operation. After this type of operation, it is likely to see low cardiac output and elevated CVP from its hemodynamic principle as the right ventricular bypass procedure. A similar situation with low cardiac output and acute elevation of serum liver enzymes after open heart surgery for congenital lesion has been reported. The late development of liver cirrhosis after Fontan-type operation may also be related to these hemodynamic characteristics. In these situations, particularly of Fontan-type operation, we have previously described a marked decrease in Shvo2 in the early postoperative period. The fall in Shvo2 as low as below 20\% may indicate the possible derangement in oxygen supply-demand relationship in the liver. The positive relationship between the degree of liver dysfunction and Shvo2 shown in this study may indicate the presence of acute tissue hypoxia in the liver which can be detected by Shvo2.

2) Relation between hemodynamic parameters and Shvo2 in acute postoperative stage

The mean value of Shvo2 during the first to second postoperative day showed positive correlations to CI and HPP and an inverse correlation to CVP, indicating that the hepatic perfusion in terms of oxygen supply-demand may directly depend on cardiac output and arterial pressure and the inversely affected by CVP. On the other hand, Svo2 can be considered as an alternative for this purpose because hepatic perfusion may relate to the systemic circulation. If that is the case hepatic venous sampling may not have a role in assessing hepatic perfusion. However, considering the relationship between Svo2 and Shvo2, the linear correlation was only seen when Shvo2 was above 70\%. This may suggest that the Svo2 alone can not predict the hepatic perfusion in terms of the oxygen supply-demand relationship under critical conditions. Total bilirubin and prothrombin time also started to deteriorate when Shvo2 went below 30\%. Shvo2 of 30\% may be regarded as a critical level of hepatic perfusion. From the previous experimental studies of hepatic oxygen consumption and related perfusion in animals, the liver appears to be protected from hypoxia by lowering venous oxygen content to a great extent, but the critical level of oxygen supply has not been elucidated. Because this method can not be used in all patients, further studies are required for technical modification.

It may be controversial whether the results obtained in this study are applicable to other situations or are specific to those patients with Fontan-type operation. However, our analyses included other type of patients. In addition, 2 patients with transposition of the great arteries or related lesions had mild to moderate falls in Shvo2 and development of liver injuries. Therefore, the relationship of the Shvo2 to the other parameters observed here may occur in other situations with low cardiac output and high CVP.

3) The value of measuring Shvo2 in chronic heart failure

In this study, Shvo2 was analyzed in patients with chronic heart failure in two groups, those after Fontan-type operation in mid-term follow-up and those with chronic valvular disease. In the former group, the Shvo2 had a correlation only with cardiac index. CVP itself had no direct relation, but this may have resulted from the situation where the CVP was basically elevated in these patients with Fontan-type operation. The result suggests that those with Fontan-type operation with elevated CVP and low cardiac output appear to have depressed hepatic perfusion in late after surgery with chronic compromised conditions.

In chronic valvular disease, those with NYHA class IV had relatively low Shvo2 in this study.
This suggests that those with chronic heart failure with valvular disease and possible tricuspid valve regurgitation are likely to have low cardiac output with hepatic congestion resulting in depressed hepatic perfusion. However, Shvo₂ itself had linear correlations to Svvo₂ and hepatic perfusion pressure, and less correlation to the cardiac index. Therefore, it has a limitation to analyze the Shvo₂ simply with reference to the other cardiac parameters in this situation, and a further study is required to elucidate the implication of Shvo₂ in chronic state of heart failure.

Summary: 1) In patients after repair for congenital cardiac lesions, markedly low Shvo₂ below 30% under low cardiac output and elevated CVP appears to indicate the presence of impairment in hepatic oxygen supply-demand relation developing liver injuries. 2) In patients with chronic valvular disease, the grade of heart failure may be assessed by Shvo₂ as well. 3) Shvo₂ measurement in acute as well as chronic heart failure may have a role in assessing systemic and hepatic circulatory conditions.

REFERENCES