RELATION BETWEEN MIXED VENOUS BLOOD OXYGEN SATURATION AND CARDIAC PUMPING FUNCTION AT THE ACUTE PHASE OF MYOCARDIAL INFARCTION

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In this study, we monitored changes in the mixed venous blood oxygen saturation (SVO₂) level of 45 patients with acute myocardial infarction and compared these results to the traditional parameters. The SVO₂ level was found to correlate well with the clinical course of patients and their hemodynamic conditions.

The mean SVO₂ level of the group having congestive heart failure (53.3 ± 8.4%) was found to be statistically lower than those without (69.8 ± 5.6). Furthermore, patients whose SVO₂ level was lower than 60% were found to be at greater risk for heart failure and a very high mortality rate. Patients were classified into four subsets according to Forrester’s hemodynamic classification; their SVO₂ levels were 70.7 ± 4.1% (I: 23 cases), 54.7 ± 6.9% (II: 8 cases), 55.8 ± 9.4% (III: 10 cases), and 47.0 ± 8.0 (IV: 4 cases), respectively.

A reverse relationship between pulmonary capillary wedge pressure and SVO₂ having a correlation coefficient of r = -0.64 was observed, and a logarithmic curvilinear relation between cardiac index ~ SVO₂, stroke volume index ~ SVO₂, and left ventricular stroke work index ~ SVO₂ was also evident. When the decrease in the SVO₂ level was more than 5%, it always showed a significant decrease in the cardiac index.

This study suggested that continuous monitoring of the SVO₂ level revealed simultaneous changes in the hemodynamic state, which lead to the assistance and aid for treating patients with critical conditions of acute myocardial infarction. In such circumstances, it was noted that the SVO₂ level should be maintained above 60% in order to stabilize the hemodynamic state.

In recent years, treatment for arrhythmias has improved due to the significant developments in the monitoring systems of the coronary care units (CCU), development of anti-arrhythmic drugs, and installation techniques of the pacemaker. However, therapies dealing with the decrease of the cardiac pumping function due to heart failure and cardiac shock still need improvement. Measuring the cardiac output (CO) by heart dilution and pressures of the pulmonary capillary wedge pressure (PCW) have been used clinically, but unfortunately these methods can not promptly reflect the dynamic changes in the

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Fig. 1. The relation between the $\text{SvO}_2$ values measured from the apparatus of Opticath in vivo and from the gas analyzer of ABL2-RADIOMETER.

Fig. 2. The mean values and standard deviations of $\text{SvO}_2$ for the group that had symptoms of congestive heart failure (CHF+) and the group that did not (CHF-), when admitted.

$y = 1.01x - 0.45$
$r = 0.97$
$p < 0.001$
$n = 170$

satisfaction ($\text{SvO}_2$) reveals the balance of oxygen that is required and supplied in vivo, and is a good indicator of the oxygen metabolism that occurs in the respiratory and metabolic systems.

Thus, we decided to continuously monitor the changes in the $\text{SvO}_2$ level of those patients with acute myocardial infarction (AMI), and compare them to the traditional parameters.

**SUBJECTS**

The subjects in this study consisted of 45 patients with AMI that were hospitalized in the CCU of the Iwate Medical University Hospital. Out of these patients, 31 were men with a mean age of $64.4 \pm 10.5$ y.o. and 14 were women being $67.6 \pm 14.5$ y.o.. Locations of the infarction included the anterior (18 cases), broad anterior (9 cases), inferior (12 cases, among which 5 were accompanied with right ventricular infarction), subendocardial (5 cases), and high posterior regions (1 case). None of them were complicated by respiratory diseases or anemia.

All subjects were divided into 2 groups according to Killip's classification\(^1\) of congestive heart failure, class I (25 cases), class II (9 cases), class III (8 cases), class IV (3 cases). Twenty cases had congestive heart failure (Killip class II, III, and IV, CHF+) and 25 cases did not (Killip

Fig. 3. The means and standard deviations of $S\text{vO}_2$, CI, and PCW for the groups CHF+ and CHF−.

Fig. 4. The means and standard deviations of $S\text{vO}_2$ for the subsets of Forrester’s classification.

class I, CHF−). Furthermore, all subjects were divided into 4 subsets according to Forrester’s classification: subset I (23 cases), subset II (8 cases), subset III (10 cases) and subset IV (4 cases). Between these groups and subsets, the relationships were studied in terms of the level of $S\text{vO}_2$ and other parameters of dynamic circulatory function during the acute phase of myocardial infarction (i.e. the first 5 days after manifestation of the disease).

METHODS

The apparatus used in this study was the SHAW Catheter Oximetry System made by the OXIMETRIX Company. It is a system with the ability to measure cardiac output by heart dilution using the traditional Swan-Ganz catheter. In addition to measuring the cardiac output, it provides continuous measurement of the $S\text{vO}_2$ level using the spectro-photometric method.

Levels of $S\text{vO}_2$ samples taken from the pulmonary artery were determined with the blood gas analyzer (% $S\text{vO}_2$ blood samples in-vitro) and compared to the system (% $S\text{vO}_2$ fiberoptic in-vivo) (Fig. 1). The calculated regression equations were close to the line of identity showing a high correlation coefficient between them. Thus, the values measured by this apparatus were considered reliable.

When patients were admitted to the CCU, the Opticath Fiberoptic Catheter was inserted into the central vein through the subclavicular vein and the tip set at the pulmonary artery. Through this catheter, the PCW, CO, and heart rate (HR) were measured. While these measurements were being taken, the $S\text{vO}_2$ level was also continuously being monitored. Furthermore, at the same time, the arterial blood oxygen saturation ($S\text{vO}_2$) was measured from the femoral artery with the blood gas analyzer.

Cardiac index (CI), stroke volume index (SVI), left ventricular stroke work index (LWSWI), Oxygen Consumption (VO$_2$), and Arterial-Venous Oxygen Content Difference (A-VO$_2$ diff.) were calculated using the following
Fig. 5. The means and standard deviations of $\mathrm{SvO}_2$ for the groups divided by CI above or below 2.2 L/min/m$^2$ and by 18 mmHg PCW.

Fig. 6. The means and standard deviations of CI and PCW for the 2 groups divided according to the values of $\mathrm{SvO}_2$ higher or lower than 60%.

The formulae are:

- CI = $\frac{CO}{BSA}$
- SVI = CI / HR
- LVSWI = SVI x (mean atrial blood pressure - PCW) x 0.0136
- $\text{A-VO}_2\text{diff.} = \text{Hemoglobin} \times 1.34 \times (\text{SaO}_2 - \text{SvO}_2)$
- $\text{VO}_2 = CO \times \text{A-VO}_2\text{diff.}$

RESULTS

1. Effects of congestive heart failure.

Figure 2 shows the values of the $\mathrm{SvO}_2$ level (mean ± standard deviation) for each group.

accompanied with or without congestive heart failure (CHF+ and CHF−). The CHF− group had a $S\bar{v}O_2$ level of 69.8 ± 5.6% and CHF+ group 53.2 ± 8.4%, indicating the former to be statistically higher than that of the latter ($p < 0.001$). Among ten of the non-survivors, 9 belonged to the CHF+ group and only one to the CHF− group (the symbol ⋄ representing the survivors and ▲ the patients who died within one month). There were 9 non-survivors with a $S\bar{v}O_2$ level under 60% and only one case above 60%. The latter had repeated anginal attacks and exhibited
symptoms of congestive heart failure after admission. Though an emergent aorto-coronary bypass operation was performed, the patient died of a cardiac pumping dysfunction.

The mean values of CI and PCW (Fig. 3) were 2.99 ± 1.00 L/min/m² and 9.6 ± 4.2 mmHg for the CHF− group and 2.29 ± 0.75 L/min/m² and 19.5 ± 7.0 mmHg for the CHF+ group, respectively. Both indicating a statistical significance between the 2 groups (p < 0.01).

2. Comparison among the subsets of Forrester's classification.

The symbol ○ represents the survivors without CHF, △ the non-survivors without CHF, ● the

survivors with CHF, and ▲ the patients who died within one month. The mean values and standard deviations of the $S\overline{V}O_2$ level for each subset of Forrester's classification (Fig. 4) were 70.7 ± 4.1% (subset I), 54.7 ± 6.9% (II), 55.8 ± 9.4% (III) and 47.0 ± 8.0% (IV). Subset I had the highest value and statistical significance was found between this subset and the others ($p < 0.01$ for I ~ II, I ~ III and $p < 0.001$ for I ~ IV). All cases were categorized into 2 groups based on

$Y = -0.15X + 14.7$
$r = -0.83$ $p < 0.001$
$n = 335$

Fig. 11. The relationship of $S\overline{V}O_2$ and A-VO$_2$ diff.

$Y = -0.62X + 238.7$
$r = -0.11$
$n = 335$

Fig. 12. The relationship of $S\overline{V}O_2$ and VO$_2$.

a lower (14 cases) or higher (31 cases) CI value of 2.2 L/min/m$^2$ (Fig. 5). The mean value of $S\overline{V}O_2$ in the former group was 53.3 ± 9.6% and lower in the latter 66.6 ± 8.6% ($p < 0.01$). The same study was also done for PCW, and it showed the value of the $S\overline{V}O_2$ level to be 52.2 ± 7.9% in the group having PCW above 18 mmHg (12 cases), and 66.2 ± 9.2% for the group that was below 18 mmHg (33 cases).

3. The $S\overline{V}O_2$ level was measured at the time
of admission and the patients were divided into 2 groups, 24 cases whose $\text{SvO}_2$ level was higher than 60% and 16 cases whose $\text{SvO}_2$ level was lower than 60% (Fig. 2 and 4). Those under 60% were found to have cardiac pump dysfunction, and 9 of them died (56%) during hospitalization. Figure 6 reveals the mean values and standard deviations of the $\text{SvO}_2$ level, CI, and PCW for these 2 groups. Values of the $\text{SvO}_2$ level and CI ($69.4 \pm 4.6\%$, $3.01 \pm 0.94 \text{L/min/m}^2$) were higher for the former group ($\text{SvO}_2$ level was higher than 60%) than those of the latter (49.8 ± 6.4%, $2.10 \pm 0.69 \text{L/min/m}^2$ with $p < 0.01$). A PCW of $11.2 \pm 5.2 \text{mmHg}$ for the former group and $19.2 \pm 8.3 \text{mmHg}$ for the latter showed a statistical difference of $p < 0.01$.

4. There were 335 measurements in all of the PCW, CI, SVI, LVSWI, A-VO$_2$ diff., VO$_2$, and SvO$_2$ while measuring the CO during the acute phase of myocardial infarction in all of the 45 patients. Twelve patients of the CHF+ group changed to CHF−, seven CHF+ patients remained the same, and four died during this time.

(a) Relationship between PCW and SvO$_2$

A linear equation $Y = -0.8X + 73.8$ could be drawn (Fig. 7) with a correlation coefficient of $-0.64$ ($p < 0.01$). In other words, whenever there was an increase in PCW, the value of SvO$_2$ tended to decrease.

(b) Relationship between CI and SvO$_2$

The CI and SvO$_2$ value had a positive logarithmic curvilinear relationship ($Y = 53.8 \log X + 42.7$) with a correlation coefficient of 0.68 (Fig. 8). This implied that the degree of change in the level of SvO$_2$ due to CI was greater when the value of CI was smaller, and lesser when CI was larger.

(c) Relationship between SVI and SvO$_2$

The equation for the relationship between SVI and SvO$_2$ was $Y = 47.7 \log X + 6.6$ and the correlation coefficient was 0.70 (Fig. 9). Since this was also a logarithmic equation, the degree of variation of SvO$_2$ due to SVI was the same as that due to CI.

(d) Relationship between LVSWI and SvO$_2$

Figure 10 shows a logarithmic curvilinear relationship between LVSWI and SvO$_2$ ($Y = 36.2 \log X + 9.8$, $r = 0.77$). As mentioned in section (b) and (c), a similar variation in the level of the SvO$_2$ tended to be affected by LVSWI.

(e) Relationship between SvO$_2$ and A-VO$_2$ diff.

Figure 11 shows the relationship between SvO$_2$ and A-VO$_2$ diff.. This relationship is represented by the negative regression line $y = -0.15X + 14.7$ ($r = -0.83$, $p < 0.001$). In other words, the SvO$_2$ level was found to increase as A-VO$_2$ diff. decreased.

(f) Relationship between SvO$_2$ and VO$_2$

Figure 12 shows the relationship between the

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level of $\text{SvO}_2$ and $\text{VO}_2$. There was no significant correlation coefficient in regards to the relationship between the level of $\text{SvO}_2$ and $\text{VO}_2$.

5. Whenever the value of the $\text{SvO}_2$ level either increased or decreased beyond 5% during the continuous monitoring, parameters for the dynamic circulation were measured. There were 134 measurements in all, and a linear relationship ($Y = 0.062X - 0.29, \ r = 0.77$) was found between the variations in the $\text{SvO}_2$ level and CI when the variation of the $\text{SvO}_2$ level was beyond 5% (Fig. 13).

**DISCUSSION**

Values of the $\text{SvO}_2$ level relate to the balance of oxygen that is required and supplied in vivo, and the degree of variation was found to be greatly affected by respiratory function and the metabolic system. If the function of gas exchange in the lungs remained intact and no significant changes in the concentration of hemoglobin occurred, the $\text{SvO}_2$ level was found to be a good indicator of cardiac pump function during the acute phase of myocardial infarction. Wyler and Adachi proved this in their experiments, and other reports also emphasized the importance of this. In our study, of those patients with acute heart failure, repeated angina attacks were the main symptom in the acute phase of myocardial infarction, accompanied by the worsening of other dynamic circulatory parameters. The level of $\text{SvO}_2$ decreased during short-period attacks, and this corresponded to the decrease of cardiac pump function. On the other hand, the $\text{SvO}_2$ level increased whenever the symptoms improved. Thus, continuous monitoring of the $\text{SvO}_2$ level proved to be a good indicator for understanding the status of cardiac pump function.

Since it is thought that changes in the cardiac function are significant during the acute phase of myocardial infarction, this study compared the cardiac pump function with the dynamic circulatory parameters and levels of $\text{SvO}_2$ through the use of a continuous monitoring method on 45 patients.

After dividing all the subjects into 2 groups according to Killip’s classification of congestive heart failure and comparing the $\text{SvO}_2$ levels between them, it was noted that the group with CHF (CHF+) had a significantly low value (Fig. 2). As for the parameters of dynamic circulation, CI was significantly low (Fig. 3), and PCW was high in the CHF+ group. Nine out of 10 non-survivors, within a month after admission, were in the CHF+ group, and 8 of them had $\text{SvO}_2$ levels of below 60%. Only one patient with a right ventricular infarction died without symptoms of heart failure (CHF−) and had a $\text{SvO}_2$ level of 52%. In other words, when the patients were diagnosed as having congestive heart failure, they tended to present a low $\text{SvO}_2$ level along with a deterioration in hemodynamics. It was noticed that many of those cases having a $\text{SvO}_2$ level of 60% or lower, were accompanied by congestive heart failure as well as a high mortality rate. In accord with our findings, Baele and colleagues also reported that the $\text{SvO}_2$ level should be kept at 60% or greater, since cardiac pump function tended to deteriorate at levels below 60%.

Among four of the subsets divided by Forrester’s classification, subset I had the highest $\text{SvO}_2$ level (Fig. 4). It was also found that the mean value of the $\text{SvO}_2$ level was higher for those patients whose CI was greater than 2.2 L/min/m², and the mean value of the $\text{SvO}_2$ level for those patients whose PCW was lower than 18 mmHg was found to be higher than those whose PCW was higher (Fig. 5). This is to say, in the acute phase of AMI the $\text{SvO}_2$ level was found to decrease as hemodynamics deteriorated, and that hemodynamics, in turn, were found to deteriorate when the $\text{SvO}_2$ level was decreased.

All the parameters of the dynamic circulation (PCW, CI, SVI, LVSWI, A-VO₂diff., and VO₂) were compared with the $\text{SvO}_2$ level. It showed that PCW had a reverse relationship with the $\text{SvO}_2$ level, having a correlation coefficient of −0.64 (Fig. 7). If PCW became higher, the $\text{SvO}_2$ level became lower. When necrosis of the left ventricular muscle in the acute phase occurred, the cardiac contractive power and compliance decreased, and it was for this reason that the diastolic pressure tended to increase. In this condition, the cardiac preload became greater and change in the $\text{SvO}_2$ level became evident.

On the other hand, CI and $\text{SvO}_2$ had a positive logarithmic curvilinear relationship (Fig. 8). A greater variation in the $\text{SvO}_2$ level occurred when CI became lower. Therefore, if the cardiac output became smaller than a specific level, the tissue oxygen uptake required per unit became greater (when there was no blood supply for the tissues in the muscle). Thus, even a slight change in the amount of blood supply resulted in a large

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change in tissue oxygen uptake, which in turn resulted in a greater variation in the SvO₂ level.

The SvO₂ level had a reverse relationship with the A-VO₂diff, having a correlation coefficient of −0.83 (Fig. 11), but there was no significant correlation coefficient between the relationship of the level of SvO₂ and VO₂ (Fig. 12). In the acute phase of AMI, the SvO₂ level was an important factor in relation to the values of A-VO₂diff. However, the SvO₂ level was not influenced by VO₂.

It was not surprising that similar relations took place between CI ~ SvO₂, SVI ~ SvO₂ and LVSWI ~ SvO₂. Assuming that the limitation of the clinical pulmonary congestion is 18 mmHg for PCW and the limit of peripheral hypoperfusion is 2.2 L/min/m² for CI according to Forrester’s report, the values of the SvO₂ level obtained from the equations of these 2 curves (Figs. 8 and 9) were 60% and 62%, respectively. It would mean that a condition of sufficient cardiac pump function was maintained and the oxygen supply to the tissues was also sufficient enough when the level of SvO₂ was higher than 60 ~ 62%. Hence, the SvO₂ level must be kept above 60% during monitoring.

During the first 5 days following AMI, the cardiac output was measured several times when the SvO₂ level showed a 5% deviation from the previous value during continuous monitoring. As demonstrated in Fig. 12, the SvO₂ level and CI had a linear relationship with the equation being Y = 0.062X − 0.29 and a correlation coefficient of r = 0.77. Thus, a 5% deviation during continuous monitoring was thought to be a landmark indicating the beginning of a decrease in cardiac output.

CONCLUSION

This study suggested that continuous monitoring of the SvO₂ level showed simultaneous changes in the hemodynamic state, which led to the help and assistance of treating patients with critical conditions of acute myocardial infarction. In cases where the SvO₂ level was below 60% or had more than a 5% deviation from the previous value, it was considered that cardiac pump failure might have been taking place.

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