Hemodynamics in Mothers and Infants during Labor based on Plethysmography

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Introduction

Birth, marriage and death are said to be three major events of life. Delivery serves as the base for continuation of human beings. The biological and sociological importance of delivery cannot be overemphasized. Delivery is an issue familiar with every mankind. So far as hemodynamics during delivery are concerned, particularly in the cardiopulmonary function during the second-stage intense labor pains, worldwide obstetricians have been preoccupied for centuries with a view that cardiac output and blood pressure increase during this period, without casting any doubt on the view. This is a serious error. No appropriately conducted experiment endorsed the validity of this view. Conversely, the truth is that cardiac output decreases markedly during intense labor pains and blood pressure also falls substantially. This is evident by measuring the pulse rate of women during labor: The pulse rate is quite lower than usual in these women. This is explained in detail by Valsalva maneuver and Starling's law. Plethysmography (PTG) can illustrate the whole course of these changes in a concrete, continuous and evident manner.

As examples of similar situation, we may cite inability to breathe during urination or the appearance of dizziness or blackout caused by intense straining in the case of severe constipation. These symptoms are attributable to a decrease in cerebral blood flow due to straining. The decrease in cerebral blood flow is due to a fall in blood pressure because cerebral blood flow depends on blood pressure. This fall in blood pressure is an outcome of reduction in cardiac output caused by straining (Valsalva maneuver). A similar mechanism or view underlies the discussions made in this paper.

The frequency of labor under anesthesia (painless labor) is extremely lower in Japan than Western countries. The frequency is as lower as 2-3% in Japan, while it is much higher in France (over 90%) and USA and UK (about 60%). The plethysmographic finding during natural delivery reflected heavy loads and stress on the cardiopulmonary function of the mother and the baby. Vasodilatation of pregnant women can be explained by the theorem of Poiseuille, and vascular contraction seen in
puerperae and newborns can be explained by the rule of Ohm.

PTG findings and Discussion

Although interpretation of pulse waves is often considered as difficult, it is simple if you can understand the meaning of several representative wave patterns. The upper column of Fig. 1 is a normal wave pattern of a young individual. In young individuals, myocardial contractility is high and vascular resistance is low. For this reason, the pulse wave of young individuals ascends sharply, reaching a peak soon. A characteristic of young individuals lies in that the crest time (CT), i.e. the time span from lowest blood pressure (S) to the peak pressure (P), is short. As aortic sclerosis advances during

Fig. 1 Aging-related change of normal wave into sclerotic wave
The upper column shows normal waves. During the course of aging, progression of aortic sclerosis makes the peak (P) of the normal wave more roundish. This is a transitional form (between normal wave and sclerotic wave) and called compound wave. As aortic sclerosis further advances, the ascending of the pulse wave becomes sharp but the latter part of this wave depicts an upward convex curve due to increase in the tensile resistance as it approaches the peak, shown in the lower column. As a result, CT is prolonged, and T wave disappears. Notch (C) is marked. This is sclerotic wave, a pattern typical of aortic sclerosis. A pulse wave, similar to the one mentioned above, is sometimes seen even in healthy young individuals due to functional vascular contraction. Distinction between the two is difficult.
the course of aging, the tensile resistance of the aorta becomes higher, and the pulse wave reaches a peak while depicting an upward convex curve, resulting in prolonged CT. The lower column of Fig. 1 shows sclerotic wave, a typical pulse wave of a patient with aortic sclerosis.

Fig. 2 shows a representative abnormal pulse wave. The dilated wave indicates that the blood vessel is dilated. This abnormal
wave pattern is often seen in pregnant women. The pulse waves of pregnant women can be roughly divided into normal and dilated waves. During pregnancy, progesterone of a placental origin increases sharply, resulting in elevation of basal body temperature and dilatation of blood vessels. Sclerotic wave is typical of aortic sclerosis. Anacrotic wave is considered as a pattern suggesting latent heart failure but it is sometimes seen also in healthy young individuals. The delta contracted wave reflects the spread of atherosclerosis to peripheral arterioles. These abnormal patterns can also appear during functional vascular contraction due to low temperature, tension, smoking, etc. even in young individuals. However, functional abnormal patterns return to normal patterns if the precipitating factor is erased. The abnormal wave patterns mentioned above appear frequently in puerperae, with the frequency being about 60% for the total of three abnormal patterns. Vasodilation during pregnancy suddenly changes into vascular contraction and tension in about 10 minutes after the start of puerperium. Furthermore, since these three abnormal patterns are often seen in the cases of hypertension of pregnancy (toxemia of pregnancy), they are of high diagnostic value. Furthermore, although autonomic imbalance as a condition characterized by mixture of normal and abnormal wave patterns, mixed wave patterns were seen in all 10 women with climacteric disturbance who received a group health checkup. This result suggests that pulse wave is an important parameter also in the diagnosis of climacteric disturbance.

Plateau wave means a flat pulse with reduced amplitude. Amplitude reduction in plethysmographs indicates reduced cardiac output, first of all. This wave pattern, which is the most dangerous and important one clinically seen in the patients with severe conditions such as hemorrhagic shock and in critical conditions, inevitably appears during delivery.

Case 1; (Fig. 3a) A 32 year old, 1-para. Figures in the upper, middle, and lower column indicate digital plethysmographs during the first phase of delivery. The uterine cervical opening had dilated to a level equivalent to 4 finger widths, but the level of pain and strain was moderate, and rupture of membrane had not occurred. The pulse wave during the intermittent labor period showed a dilated wave (upper) and its amplitude was normal same as that seen during pregnancy. As contraction began, the amplitude decreased sharply (middle and lower column), reaching a plateau. The plateau wave remained to be seen during strain and its amplitude increased soon after strain ended.

The course of change in pulse wave, seen in this case, appeared mysterious. At a glance, it resembled the course known for patients at shock or critically ill conditions. Theoretically, contraction of the uterus should be elevate the pulse amplitude because it induces return of uterine blood into the maternal body and elevates cardiac output. According to currently established theory, cardiac output and blood pressure increase during labor. In practice, however, the pulse wave indicated a totally reverse change. Later, we learned through more detailed analysis of the data that the plateau wave seen in this case corresponded to phase 2 and 3 of Valsalva maneuver during which cardiac output and blood pressure decreased, and that the pulse amplitude increased during phase 4 (overshoot). We
were greatly perplexed without knowing such maneuver, when we first saw the plethysmographic records of this case.

In the pulse wave in expulsive pain in the same woman (Fig. 3-b, bottom), the pulse amplitude decreased as the pain became stronger, showing an almost complete plateau wave. It is considered as a reason that the woman might clench her fist to endure the pain.

Fig. 4 is a recording in a 22 year old non-pregnant woman. Digital plethysmography, conducted with the finger stretched, showed a pulse wave with normal shape and amplitude. However, when the hand was slightly gripped, amplitude decreased. Tighter grip resulted in a complete plateau wave.

An earlobe transducer was prepared by Fukuda Denshi Co., Ltd. The earlobe was expected to remain absolutely still. However although the pulse waves at the finger tip were normal, the pulse waves recorded at the earlobe of the same individual ware
mostly abnormal (Fig. 5), resembling those of patients with atherosclerosis or hypertension. Because atherosclerosis is unlikely to advance more rapidly in the earlobe arteries than in the finger tip arteries, the abnormal pulse waves at the earlobe seemed to be attributable to vascular contraction.

Following this finding, we measured the earlobe and finger tip temperature of 26 young non-pregnant women and found that the earlobe temperature (35.3±0.8 ℃) was significantly lower than the finger tip temperature (36.0±0.9 ℃) (p<0.001). Vascular contraction was thus endorsed.

Reduction in earlobe pulse wave amplitude will not be clinically useful as an indicator unless it occurs immediately after a decrease in cardiac output. Therefore, we examined a 68 year old male with atrial fibrillation. In this case (Fig. 6) R-R interval on electrocardiogram was totally irregular. When observed in more detail, the pulse wave amplitude and size became greater as the TQ interval, i.e. the duration of diastole, became longer. Pulse wave became smaller
as TQ interval became shorter. Thus a close correlation was noted between TQ interval and pulse wave amplitude \((r=0.811)\). This is consistent with the Starling's law that cardiac output increases as diastole becomes longer and decreases as diastole becomes shorter. Earlobe pulse wave was thus shown to be useful as an indicator.

Figure 6  Correlation between preceding R-R interval and pulse amplitude (68-year-old man with atrial fibrillation)

Figure 7  Case 2 (bearing-down pains associated with crowning) (earlobe plethysmography)

Case 2; (Fig. 7) A 26 year old woman, 1-para. Bearing-down pains at the time of crowning of fetal head. Earlobe pulse wave recorded while the woman was suffering from the most intense pains and in an unruly state. The first portion of the upper column indicates the waves during transition from the intermittent phase to
the contraction phase. The pulse amplitude was normal during the intermittent period. Contraction began and the midwife guided the woman saying: “Breathe in and breathe out. Breathe in again” and gave her the third advice “Breathe strong and hold your breath. Hold out!” Then, the woman began straining, resulting in rapid reduction of the pulse amplitude and appearance of a plateau wave. When you try to palpate parturient’s pulse during this period, it becomes weaker rapidly from the normal level. This reflects transition of phase 1 into phase 2 of Valsalva maneuver. Furthermore, because of the bodily movement of the woman, noise appeared in lead II ECG, making its interpretation difficult. As strain continued, the pulse wave became almost completely flat as shown in the second, third and fourth columns, and considerable tachycardia was noted. At that time, the pulse was very weak, occasionally unable to palpate. At a glance, the woman’s pulse wave resembled that of the patients in severe hemorrhagic shock or moribund condition. ECG could not be recorded at all.

First and second columns in Fig. 8 correspond to pulse waves immediately before delivery. They are completely flat waves. Tachycardia was noted, and ECG was rich in noise. The downward arrow in the third column is the wave recorded at the time of birth. Pulse and ECG returned normal in a few seconds after birth.

The downward arrow in the second column in Fig. 9 corresponds to 50 seconds after birth. At that time, then newborn was crying. Pulse wave and ECG were returning normal. The downward arrow in the fourth column corresponds to the time of placental delivery. A large slow pulse wave was recorded. This is explained
by "autotransfusion", i.e., return of large amounts of blood from uterus unto maternal circulation due to rapid contraction of the uterus after placental delivery. The woman followed an uneventful course. A similar course was also followed by other 5 cases of normal delivery.

Fig. 10-a shows the experimental Valsalva maneuver, according to the textbook written by Friedberg CK. If the man breathes deeply followed by breath holding and application of 40 mmHg abdominal pressure, blood pressure rises. This is phase 1. Then, blood pressure decreases rapidly. This is phase 2. If breathing is resumed in 15 seconds, blood pressure showed a sharp temporary reduction. This is 3. Blood pressure then rises. This is phase 4 (overshoot). Overshoot is palpable by checking the pulse of the woman during labor. The pulse, which was very weak during strain, becomes strong soon after breathing is resumed, and its increase is evidently palpable. This change is quite impressive and even moving. Fig. 10-b is a schematic representation reproduced from Flessas and Spodick et al. (1980). In phase 2 and 3, blood pressure showed reduction, accompanied by reduction in cardiac output and stroke volume. Left ventricular volume is also smaller. Flessas and Spodick stated that Valsalva maneuver is, in essence, aimed at elevating the intrathoracic pressure to a degree sufficient to cause a sharp decrease in blood flow through the right half of the
heart system during a certain period. Fig. 10-c illustrates a differential pulse wave (velocity pulse wave) reproduced from Chirife and Spodick et al. (1972)\(^9\). This wave is easy to check because records with stable baseline can be obtained thanks to shorting of the time constant. It is therefore advisable to use differential pulse waves for...
experiments. If the paper speed is set low, changes are easier to detect, simultaneously allowing saving of the record paper. It is advisable to set the time constant at 0.01 sec and paper speed at 1mm/sec for differential pulse wave recording.

The author recently placed a question to a specialist in sports medicine; “How about hemodynamics during intense straining such as weight lifting?” The answer was: “Hemodynamics cannot be measured during such activity. Measurement is possible immediately before and after the activity.” This suggests that there is no means allowing accurate extracorporeal measurement of hemodynamics during strain other than pulse wave measurement.

Reports on cardiac output during labor are summarized in Table 1-a (first phase of delivery)\(^\text{10}\) and Table 1-b (second phase of delivery)\(^\text{11}\). During both first and second phases, cardiac output increased during the contraction, according to many reports. However, Winner and Romney

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Table 1-a  Hemodynamics of a uterine contraction (first stage of labor) (Ueland and Hansen, 1969)

<table>
<thead>
<tr>
<th>Investigators</th>
<th>Maternal posture</th>
<th>Analgesia</th>
<th>Anesthesia</th>
<th>Cardiac output</th>
<th>Heart rate</th>
<th>Stroke volume</th>
<th>Blood pressure (mmHg)</th>
<th>Pulse pressure (mmHg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hendricks 1958</td>
<td>Not given</td>
<td>Demerolchlorpromazin</td>
<td>None</td>
<td>+ 30.9</td>
<td>− 12</td>
<td>+ 17</td>
<td>+ 10</td>
<td>+ 5</td>
</tr>
<tr>
<td>Adams and Alexander 1958</td>
<td>Not given</td>
<td>Seconal 180mg.</td>
<td>Demerol 100mg.</td>
<td>+ 19.7</td>
<td>+ 14</td>
<td>− 6</td>
<td>+ 9.5</td>
<td>+ 7.9</td>
</tr>
<tr>
<td>Winner and Romney 1966</td>
<td>Not given</td>
<td>Scopolamine 0.4mg.</td>
<td>None</td>
<td>+ 1.4</td>
<td>+6 to 29 beats per minute</td>
<td>Probably minus</td>
<td>+ 30.2</td>
<td>+ 16.4</td>
</tr>
<tr>
<td>Ueland and Hansen 1968</td>
<td>Supine*</td>
<td>None</td>
<td>None</td>
<td>+ 24.8</td>
<td>+ 24.8</td>
<td>+ 33.1</td>
<td>+ 14.8</td>
<td>+ 13.5</td>
</tr>
<tr>
<td>Ueland and Hansen 1968</td>
<td>Side*</td>
<td>None</td>
<td>None</td>
<td>+ 7.6</td>
<td>+ 7.6</td>
<td>+ 7.4</td>
<td>+ 9.8</td>
<td>+ 11.9</td>
</tr>
</tbody>
</table>

Same Patients studied in both positions.

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Table 1-b  Hemodynamic changes during labor and delivery by various investigators (Niswonger and Langmade: 1970)

<table>
<thead>
<tr>
<th>Investigator</th>
<th>Method</th>
<th>Analgesia</th>
<th>Anesthesia</th>
<th>No. of case</th>
<th>Pre or early</th>
<th>Late</th>
<th>Increase</th>
<th>%</th>
<th>Late labor</th>
<th>Post-delivery</th>
<th>Increase</th>
<th>%</th>
<th>Preanesthesia</th>
<th>Delivery increase</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Hendricks and Quilligan (1956)</td>
<td>Pulse pressure</td>
<td>Mild to moderate</td>
<td>Some form of conduction analgesia</td>
<td>74</td>
<td>3.9</td>
<td>4.32</td>
<td>1.13</td>
<td>35</td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>2. Adams and Alexander (1958)</td>
<td>Dye dilution (Evan’s blue)</td>
<td>Seconal</td>
<td>Demerol</td>
<td>Not reported</td>
<td>19</td>
<td></td>
<td>7.1</td>
<td>8.4</td>
<td>1.3</td>
<td>18</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. Winner and Romney (1966)</td>
<td>Dye dilution Indocyanine</td>
<td>Demerol</td>
<td>Scopolamine</td>
<td>N2O-O2 pudendal</td>
<td>5</td>
<td></td>
<td>No change</td>
<td>No change</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>5. Zimmerman (1950)</td>
<td>Intracardiac catheterization</td>
<td>Spinal</td>
<td></td>
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<td></td>
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Many reports showed that maternal cardiac output increases both during the contraction and at the time of delivery. However, Winner and Romney (1966) suggested the possibility of decrease in cardiac output during these periods. According to Winner and Romney, bearing-down effort leads to essentially powerful Valsalva maneuver.
(1966) reported that the stroke volume at first phase is probably minus and the output at second phase showed no change. These investigations clearly stated that intense labor pains are sometimes accompanied by marked reduction of cardiac output\textsuperscript{12}

In past reports, dye dilution method was often employed for testing. Fich's direct method was also used occasionally. These methods are the most accurate ones for measurement of cardiac output also at present. However, since cardiac output is a very delicate parameter and an error by several percent is inevitable even when this parameter is measured during absolute rest, the value of cardiac output during the contraction is not reliable.

Fig. 11-a illustrates the right ventricular pressure during strain in the presence of expulsive labor pains reported Winner and Romney\textsuperscript{12}. Right ventricular pressure, which is usually several mmHg, has risen
to 100mmHg or higher. Right ventricular pressure reflects intrathoracic pressure. If the intrathoracic pressure rises, blood cannot enter the heart from the superior or inferior vena cava, resulting in damming back. Because the volume of blood entering the heart is equal to the volume of blood leaving the heart, a sharp reduction in the volume of blood entering the heart will lead to a sharp reduction in cardiac output and blood pressure. This experiment provides direct and adequate evidence for the view that intense labor pains reduce cardiac output and blood pressure markedly. Fig. 11-b shows the reduction in mean blood pressure and elevation in right ventricular pressure observed in phase 2 and 3 of experimental Valsalva maneuver attempted by the same investigators. They reported that experimental Valsalva maneuver essentially has no difference from Valsalva maneuver during strain in the contraction.

Fig. 11-c pertains to Valsalva maneuver in the contraction during second phase of delivery, reported by Ueland and Hansen\(^1\). The upper column of this figure indicates arterial pressure and the lower column shows central venous pressure. They erroneously made a conclusion from the upper column of this figure, saying that blood pressure rises during straining in delivery. If the figure is viewed carefully, we note initial four-phase changes associated with experimental Valsalva maneuver, followed by irregular episodes of hypertension and hypotension probably reflecting intermittent breathing made by the woman during straining. The marked elevation in central venous pressure, i.e. right atrial pressure in the lower column, resembles the “damming back” condition shown in Fig. 11-a, although the investigators overlooked it.

![Fig. 12 Schematic representation of circulation during bearing-down pains.]

During the intermittent phase, uterine muscles are filled with blood. As contraction begins, uterine blood is shifted to the maternal circulation. Due to the Valsalva maneuver associated with strain, the intrathoracic pressure rises, resulting in discontinuation of blood flow through the superior and inferior vena cava. As a result, blood return to the right atrium and cardiac output decrease. Aortic transmural pressure decreases simultaneously. Meanwhile, a decrease in maternal cardiac output and uterine muscle tensioning reduce the flow of blood from uterine arteries to the uterus. As a result, placental blood flow decreases, and if this decrease is large, fetal distress due to suffocation may arise.

Fig. 12 is a schematic representation prepared by the author. Hemodynamics during intermittent labor at second phase of delivery differ little from those during pregnancy. However, during the contraction period, uterine muscles contract, causing obstruction of the uterine arteries and thus discontinuation of blood flow. As a result, placental blood flow decreases, causing stress on fetal brain. At the same time, the maternal cardiac output decreases substantially, leading to a decrease in blood supply to the placenta and another stress to the fetus.

In this connection, it is noteworthy that
Hashimoto (1967) independently published a report demonstrating mother-baby hemodynamics during delivery totally identical to those reported by Winner and Romney and Mikami et al. Hashimoto, however, did not refer to the association of such findings with Valsalva maneuver.

**Conclusion**

Although both women presented in this paper were multipara, the stress on the heart and lung of these women and their babies during natural delivery seem to be excessively serious and merciless if we analyze our plethysmographic findings and the results of the experiment conducted by Winner and Romney. In this connection, Akio Yosano, a Japanese female poet, stated: "Pain during delivery causes limitless anger of a women at her husband. However, this anger is erased by seeing the delivered baby and by the sense of gratitude to her husband who has brought the baby to the mother."

Our common sense as humans dictates that forcing women to endure an avoidable and unnecessary pain is an ethical problem rather than an issue of whether or not a physician attending the woman selects delivery under anesthesia. Delivery under anesthesia should be applied to all cases.

Although interpretation of pulse waves is considered to be difficult, physicians specializing in obstetrics and gynecology and anesthesiologists involved in obstetric care should adopt and utilize plethysmography because there is no other means of continuous extracorporeal monitoring with satisfactory accuracy. The Ptolemaic theory still prevails in the field of obstetrics and gynecology. However, it is not rational to avoid utilization of plethysmography just because it is difficult to interpret, and physicians involved in obstetrics and gynecology should return to the heliocentric theory as soon as possible, ending the conventional story (way of doing) in the 21st century medicine.

Otherwise, our descendants in the near future will blame physicians involved in obstetrics and gynecology and obstetric anesthesiology for their negligence and lack of the sense of responsibility.

**References**

10) Ueland K and Hansen JM: Maternal cardio-

