EFFECT OF POSTURAL CHANGES ON THE PHYSIOLOGICAL FUNCTION IN MAN

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The hemodynamic responses and metabolic changes were examined in 13 healthy male students on the passive tilting from recumbency to 60°, 75° and 90° or vice versa, respectively. Abrupt increase of heart rate was observed by cardiotachograph on each of postural change. The average per cent increase in heart rate was about 50% as compared with that of recumbent, however, no significant difference was observed among each angle. Systolic pressure fell 15 mm Hg on tilting, but diastolic pressure remained at about the same level.

Urinary output of catecholamine, particularly of noradrenaline, increased markedly. The increased noradrenaline excretion may be attributed to the vasoconstriction, which was inferred from the reduction of amplitude in volume pulse in the big toe and from the fall in skin temperature. The rise of rectal temperature on tilting from recumbency to tilt position may be attributed to both the decrease of heat loss through vasoconstriction and the increase of heat production.

On tilting urine volume and urinary output of sodium and chloride decreased, while little change was observed in potassium excretion.

The studies on the changes of physiological functions accompanied with maintaining the prolonged standing or with changing the posture from recumbency to standing or vice versa, have raised attention not only in academic interest, but also in practical significance in the daily life, in connection with the posture at work.

Many reports have been dealt with the hemodynamic responses, such as of heart rate, blood pressure, and peripheral circulation, in postural change. Matsuda et al reported the instantaneous alteration of heart rate following the change of posture using the cardiotachograph. However, their paper was not referred to the circulatory change following the prolonged tilting.

There was a report by Winslow et al, who had predicted the peripheral vasoconstriction from the reduction of skin temperature observed in maintaining the erect posture. The present paper concerns with the cardiovascular response followed by prolonged tilting as well as immediate after the postural change using a cardiotacho-
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... graph and photoelectric plethysmograph. It is also referred to the possible change in urinary output of catecholamines and plasma unesterified fatty acid (UFA) during varying posture.

As for the energy metabolism, the body tilting accompanies an increased heat production and a decreased heat loss due to the peripheral vasoconstriction, and consequently the accumulation of heat would be resulted in the core. Thus, the heat balance was also examined.

**EXPERIMENTALS**

The subjects tested were 13 male students between 21 to 26 years of age. The tests were carried out on the fasting state in an air conditioned room with 25°C and with 55% relative humidity. Subjects were tilted passively on tilt board supported at the longitudinal midpoint. The board was operated manually within 20 seconds in every tilts. Heart rate was recorded by cardiotachograph, amplitude of pulse wave was measured by photoelectric plethysmograph in a right big toe. Temperatures were measured in the rectum, forehead, upper breast, abdomen, lower arm, dorsum of hand, finger, thigh, lower leg, big toe and ear with thermistors. Urinary catecholamines, adrenaline and noradrenaline, were estimated fluorimetrically. Sodium and potassium concentrations in urine were measured by flame photometry and chloride with the method described by Schales and Schales, creatinine by Folin's method, UFA determination by Barreto's method after extraction with Dole's method.

Tilting tests were performed in two independent series. In one series of test (Experiment A) the subjects were preadapted to the ambient temperature (25°C) in recumbency for 30 minutes, then were tilted from horizontal to the head-up reclining position in order 60°, 75° and 90°, or vice versa, for 20 minutes each, inserted with 20 minutes of recumbency among each degree of tilting.

In the second series (Experiment B), after voiding the urine at 9.00 a.m. the subjects were kept in bed untill 10.00 a.m. and were put on a tilting board for following 90 minutes, then tilted to a given angle for 90 minutes, followed by 90 minutes recumbency thereafter. The tilt angles were 60°, 75° and 90° respectively as in Experiment A and in this case the tilting test was restricted only once a day. At the end of each period urine sample was collected for the determination of catecholamines, urinary electrolytes and creatinine. After urine specimen was obtained, 50 to 150 ml of tap water were given. Blood specimen for plasma UFA was withdrawn from antecubital vein at regular intervals throughout the experiments.

**RESULTS**

*Heart Rate, Blood Pressure and Volume Pulse:*

The responses of heart rate, blood pressure and volume pulse in 8 subjects in Experiment A are illustrated in Fig. 1. The average heart rate rose to nearly...
maximum level (about 100 beats per minute) within about 60 seconds and maintained this level throughout every tilt period. The pulse rate in each reclining position was significantly higher than that of the recumbency and the per cent increase was 50% for 75°, 45% for 90° and 40% for 60°. On changing from tilted position to recumbency, the heart rate fell promptly to the recumbency level.

Fig. 2 shows an example of the cardiotachogram and also indicates the heart rate in this case counted from the cardiotachogram in every 10 seconds. In this example, the heart rate is about 60 per minute in a recumbency and began to rise immediately after tilting started and attained already to a maximum level, about 90 beats per minute, at the end of tilting operation. In the tilting position the pulse pressure maintained a reduced value compared with that in recumbency, it is due to the decreased systolic pressure and the increased diastolic pressure. The average decrease in systolic pressure was about 15 mm Hg.
Fig. 2. An example of cardiotachogram during tilting. upper: cardiotachogram in initial phase of postural change from recumbent to 60°, middle: the heart rate counted from cardiotachogram in every 10 seconds, lower: the amplitude of volume pulse.

Fig. 3. The changes in heart rate, blood pressure and volume pulse during prolonged tilting (Experiment B).
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The amplitude of volume pulse in the big toe diminished and may suggest the peripheral vasoconstriction following the tilting (Fig. 1 and 2).

In the experiment B the heart rate increased rapidly immediately after the changing posture from recumbency to reclining, as observed in Experiment A. However, in this case of prolonged tilting, it increased gradually after initial rise. The pulse pressure maintained the same level during the prolonged tilting (Fig. 3).

Skin and Rectal Temperatures:

An example of skin temperature fluctuation following the change of body posture is shown in Fig. 4 (Experiment A). Generally said the skin temperatures dropped after tilting in the regions such as ear, thigh, dorsum of hand, forehead, on the contrary that of foot raised. A consistent lowering in mean skin temperature was
found, though the individual variation was observed in the lowering rate of skin temperature. The fall in the mean skin temperature ranged between 0.05°C and 0.20°C after 20 minute tilting, and its decrement tended to increase with greater angles of tilting. On the other hand, gradual and progressive increase was observed in rectal temperature ranged from 0.14°C to 0.26°C.
Urinary Excretion of Catecholamines:

Tilting of healthy subjects from recumbency to 60°, 75° and 90° induced a rise in average noradrenaline excretion from the preceding recumbency values of 15.5, 17.9 and 16.2 mµg/min to 33.1, 32.9 and 42.7 mµg/min, respectively. The difference between recumbency and tilting values was highly significant (p<0.01), but no significant difference was found among values in these tilt angles (Fig. 6). As for the adrenaline output, it tended to increase during tilting but when comparing the recumbency values with that of tilting, no significant differences could be observed.

Plasma UFA:

The changes in plasma UFA concentration in 7 subjects are illustrated in Fig. 7. There is a tendency to rise above control levels, however, in the case of 90° tilting the increase in UFA was not marked. With return to recumbency position plasma UFA tended to decrease.

Urinary Electrolytes Excretion:

The tilting from horizontal position resulted in a sharp decline of sodium output accompanied with the equimolecular decrease of chloride and with reduced urinary volume (Fig. 8). While the potassium was excreted at the constant rate independent of the posture. The per cent decrease of sodium was 70% for 75°, 65% for 60° and 55% for 90° respectively, if recumbency values were taken as standard.

Fig. 8. The effects of tilting upon the urinary output of electrolytes and urinary volume.
Many reports\textsuperscript{5,8,19} referred to the instantaneous alterations in heart rate following change in posture. The cause for this alteration may be explained as follows: on the tilting the venous return from lower extremities to heart is decreased by the gravity\textsuperscript{20}. Due to this decrease in venous return and following drop in internal pressure of vena cava inf., the receptors in the wall of vena are stimulated, which in turn resulted in tachycardia by McDowall reflex. Both the aortic and carotid sinus reflex also participate to increase the heart rate.

Turner \textit{et al}\textsuperscript{4} observed the blood stagnation in lower extremities on tilting using the leg plethysmography. Vasoconstriction may be resulted to minimize the pooling of blood in the lower extremities. As described above, the shortening of amplitude in volume pulse and decreased skin temperature are strongly suggestive the vasoconstriction. As the result of this vasoconstriction, the increased endogenous production of noradrenaline was expected as Euler \textit{et al}\textsuperscript{21} reported previously. In every tilt, their findings were confirmed.

The reason for gradual increase of heart rate during the prolonged tilting is still obscure, but it may be partially attributed due to the gradual stagnation of blood in lower parts of body.

The hemodynamic adaptation to an abrupt change in body posture was established
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in almost all of the subjects, but two cases of syncope were observed in the course of the experiment (Fig. 9). The syncope was accompanied with the bradycardia, the reduction of blood pressure, dizziness and sweating. The cause of fainting is obscure, but it would be related to the circulatory failure in maintaining the adequate arterial blood supply to brain, due to the vasodilatation in the splanchnic bed as well as in the skeletal muscle.

Subsequently, the energy metabolism and heat balance in postural change will be discussed, in connection with the increased rectal temperature. The energy consumption on tilting were increased in 7% for 60°, 13% for 75°, 23% for 90°, as compared with that of resting value. Though the rectal temperature tended to increase with greater angles of tilting, statistically significant correlation between the rectal temperature rise and the oxygen consumption was not found. This fact indicates that the increase of rectal temperature are not attributed simply to the increased oxygen consumption. Thus, it is expected that the decreased heat loss, due to the skin temperature reduction, should be one of the factors resulting the rectal temperature rise. The relationship between heat production and heat loss is showed in next formula:

\[ M + \Delta H = R + C + E, \]

where \( M \): heat production, \( R, C \) and \( E \): heat loss by radiation, conduction and convection, and evaporation respectively, \( \Delta H \): heat debt. Assuming that the heat production equals the heat loss, \( \Delta H \) equals zero. Thus, \( \Delta H \) is defined equals to \( H_0 - H_1 \), in which \( H_0 \) and \( H_1 \) are the amounts of body heat in the standardized and arbitrary experimental conditions respectively.

The amount of body heat is calculated in the following equation:

\[ H = 0.83 \times \text{body weight} \times \frac{(2T_r + T_s)}{3}, \]

where 0.83 is the specific heat of body, \( T_r \) and \( T_s \) represent the rectal and mean skin temperature respectively. From above equation, net heat loss was calculated and plotted against the rectal temperature rise in Experiment A (Fig. 10). The line, which

\[ y = -0.230x + 0.170 \quad (r = -0.614, \ p < 0.01) \]

\[ \text{increment of heat loss} \quad \text{Cal/m}^2/\text{min} \]

Fig. 10. The relationship between the decrement of net heat loss and the rectal temperature rise.
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is fitted to the decrement of net heat loss \((X)\) against the rectal temperature rise \((Y)\), is indicated in the following equation:

\[
Y = -0.230X + 0.170 \quad (r = -0.614, n=25, p<0.01)
\]

From above consideration, it is deduced that the cause of rectal temperature rise on tilting would be attributed to the increased oxygen consumption as well as the decreased heat loss, due to the vasoconstriction.

The marked increase in catecholamine excretion on tilting, particularly in noradrenaline, was described by von Euler\(^{22}\) and Sundin\(^{23}\). They reported that the rise of the urinary output of noradrenaline was most marked in case of 75° tilting, and that smaller but still significant increase was also observed at 25° and 50° tilting. In our experiments, in which the tilting angles of 60°, 75° and 90° were chosen, a significant increase in urinary noradrenaline excretion was observed in every angle, however, insignificant differences among these three angles. The data support the concept that noradrenaline is released from the sympathetic nerve ending and play an important role in hemodynamic adaptation on abrupt change in posture.

Plasma UFA increased on tilting but not so remarkable as reported by Hamlin et al\(^{24}\) and the increase would be attributed to the effect of fasting rather than the action of adrenaline.

Camp et al\(^{25}\) and Thomas\(^{26}\) have stated that a decrease in renal excretion of sodium was observed after tilting. This was also true in our experiment B. Several possibilities are suggested to explain the cause of this decreased sodium excretion: 1) the increased reabsorption of sodium in renal tubules, 2) a vasoconstrictor substance, like adrenaline or noradrenaline, appears in blood and causes a relative ischemia of renal glomerulus and results in diminished glomerular filtration rate, 3) the diminished sodium washing-out accompanied with a decrease in renal excretion of water. By means of ultrasonic flowmeter, Franklin et al\(^{27}\) demonstrated that renal blood flow remained stable in the tilted dog and denied the second possibility. Fairly constant creatinine excretion during tilting in our experiment may support the Franklin’s view, since the creatinine is not subjected to renal reabsorption. Moreover, the washing-out effect is not reasonable to explain the decreased excretion of sodium, in considering the fact reported by Camp et al\(^{28}\), that drinking of saline solution before tilting caused a decreased sodium excretion, while the urinary volume maintained constant. Therefore, the first possibility may be predicted as a primary cause of the decreased sodium excretion. It has been proved that aldosterone has an influence upon the renal tubules and increases renal reabsorption of sodium. Muller and co-workers\(^{29}\) reported that aldosterone output was higher in ambulant subjects than in those who remained bed. However, aldosterone acts to prevent the water reabsorption and promotes the hypotonic urine production. Therefore, it is very hard to explain the oliguria on tilting only by the increased aldosterone secretion.

On the other hand, it is anatomically proved that the sympathetic nerves distribute
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abundantly around the renal tubule cells, and to say that the sympathetic nerve stimulation caused the increased sodium reabsorption. Therefore, the decreased sodium excretion on tilting might be related to functional alteration of sympathetic nervous system, as it was deduced from vasoconstriction in another parts of body.

However, in order to clarify the mechanisms controlling the electrolytes and water excretion following postural change, it requires further experiments, including the researches of hormonal (ADS, aldosterone etc.) and renal functions.

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REFERENCES