Research Article

Evaluation of cardiorespiratory changes during various phases of menstrual cycle in young women before and soon after exercise

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Abstract

Background: Menstruation involves a cyclic expulsion of sanguinous fluid and a sloughing of uterine wall in a female and is a typical feature of the reproductive cycle in humans and subhuman primates. The variations in radial artery distensibility are typical in the natural menstrual cycle. Respiratory function is influenced by female sexual hormones, especially progesterone, which could increase ventilator at rest and soon after exercise.

Objective: To study the cardiorespiratory changes during mid-follicular phase and early luteal phases of menstrual cycle before and soon after exercise.

Materials and Methods: The samples were collected from young unmarried and nonpregnant women of age group 17 and 25 years from Government General Hospital, Madras Medical College. Blood was drawn during the mid-follicular phase and early luteal phase of menstrual cycle; the serum was separated and stored at -20°C. The separated serum was used for quantitative determination of estradiol (E_2) concentration by SMAR Test diagnostics and for progesterone determination using hormone kit. Cardiac output, peripheral blood flow, expiratory blast test, performance of isotonic exercise, and cardiac output measurement were performed, and the comparison was made between the different phases of parameters.

Result: Cardiac output, peripheral blood flow, and expiratory blast test were performed, and the comparison was made between the parameters. Female subjects show higher ventilatory responses in the luteal phases than in the follicular phase without a change in VO_2. Progesterone stimulates respiration and the alveolar PCO_2 in women during the luteal phase of menstrual cycle, which is lower than that in men. During exercise, the muscle blood flow can increase a maximum of about 25-fold, the value being 90 mL/100g muscle/min from resting blood flow of 3.6 mL/100 g. In expiratory blast test, a normal subject can increase the mercury column to 55–100 mm or more during a single forceful expiration.

Conclusion: The result suggests that cardiovascular parameters were more affected in follicular phase after exercise. Respiratory parameters were more affected in luteal phase after exercise. Change in peripheral blood flow was found to show marked effect than in cardiac output.

KEY WORDS: Mid-follicular phase, early luteal phase, cardiac output, expiratory blast test

Introduction

Menstruation involves a cyclic expulsion of sanguinous fluid and a sloughing of uterine wall in a female and is a typical feature of the reproductive cycle in humans and subhuman primates. It is under the control of complex neurohormonal influences. Menstruation in most women occurs at regular intervals of 28 days on an average, although most women questioned gave a history of regular intervals of 28 to 30 days,[1] and only 10%–15% of women were found to show cycle at the precise 28 ± 2 days intervals when menstrual calendar was utilized. In normal adult women, the plasma levels of estrogen vary in different phases of ovarian cycles. There are two peaks of estrogen secretion. The first occurs just before the ovulation (12–13th) day of menstrual cycle, which is termed estrogen surge, and the second peak occurs in the mid-luteal phase. During the follicular phase of menstrual cycle, the plasma

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concentration of progesterone is very low about 0.9 ng/mL, and in mid-cycle, its level starts rising owing to secretion from the granulose cells. Progesterone level reaches its peak value of 18 ng/mL during luteal phase, and its level fall to a minimum value toward the end of the cycle.

Estrogen affects systemic and local vasodilation.[2] Estrogen receptors are found on the artery walls. These receptors on stimulation lead to vasodilatation by the endothelial synthesis of nitric oxide (NO) and prostacyclin (PGI2), which are strong vasodilating agents, and result in altering the endothelial production of endothelin, a strong vasoconstriction agent.[3] Finally, estrogen also seems to have blocking effect on calcium channels of the arterial wall, resulting in vasodilatory changes in action and production of these vasoactive substances, which could be responsible for some vasomotor and pressure changes observed in woman during menopause.[4,5] In the luteal phase, the arterial wall stiffening was observed, which was related to a decrease in the flow-dependent endothelial dilatation of the radial artery, as evaluated by the hyperemia after short-term ischemia of the hand. Thus, the variations in radial artery distensibility are typical in the natural menstrual cycle. However, it is likely that the estrogen-dependent decrease in vascular smooth muscle tone causes the larger arterial distensibility of the ovulatory phase, whereas vascular smooth muscle contraction owing to endothelial destruction, resulting in not only a decrease in estrogen level but also in an augment in progesterone and antidiuretic hormone (ADH) levels, leads to the arterial stiffening of the luteal phase.[6] Estrogen supposedly increases the basal release of NO, which is a potential vasodilating substance. In this perspective, nitrate and nitrite levels (metabolites of NO) in serum augmented during the early to late follicular phase of menstrual cycle, in concurrent with the increase in 17 β-estradiol levels.[7] Moreover, luteal phase of the menstrual cycle have shown greater resting values of circulating plasma norepinephrine, during which increased levels of both estrogen and progesterone were observed, which offers additional evidence that both of these hormones exhibit efficiency to impart vascular regulations. It s probable that progesterone or any other altered host factors during the period of the menstrual cycle can counteract against the effect of increased estrogen or vascular responsiveness.[8] A vasodilatory effect of estrogen was reported by Meyer et al.,[9] who found that E2 administration increased vessel diameter and significant reduction in the radial artery resistance from menses to the follicular phase. In the follicular phase, the endometrium exhibited vascular neoangiogenesis.[10] The influence of estrogen to promote vasodilatation appears in large partly because of its effect to promote NO synthase activity in the peripheral vasculature. The endurance time for fatiguing isometric contractions was about one-third longer in women than in men, when contractions were sustained at 40% of each individual's maximum strength.[11] A sinusoidal variation in endurance occurs 7 to 10 days, after the onset of bleeding.

Progesterone is known to stimulate pulmonary ventilation. Female subjects constantly experience a wide fluctuation in estrogen and progesterone levels during their menstrual cycles. Earlier studies have recorded that female sexual hormones affect respiratory function, in particular progesterone, which, during luteal phase, could enhance ventilatory response at rest.[12] Resting minute volume (*VE*) has been documented to be higher (2.3 L/min or equivalent to 7.07 vs. 6.72 L/min) during the luteal phase when compared with the follicular phase.[12] The associations noted between sexual hormones and respiratory control variables and respiratory muscle function advocate a positive effect of sexual hormones regulating the thoracic pump muscles in the luteal phase.[13]

Bruno da Silva et al.[13] evaluated the spirometric and respiratory static pressures of 17 young female subjects at bi-weekly intervals for three consecutive menstrual cycles to determine if respiratory function and spirometric flow and capacity changed throughout the follicular, preovulatory, and early to mid-luteal phases. The menstrual cycle and individual cycle phase exhibited a noteworthy effect on peak expiratory flow and respiratory static pressures. In the luteal phase, reduction in NO-dependent variation of arterial diameter proposes that a rise in smooth muscle contraction could also initiate from endothelial malfunction. Moreover, the results of the White et al. (1983) suggested that female subjects experience greater ventilatory responses in the luteal phase than in the follicular phase without an alteration in VO_2. Progesterone stimulates respiration, and the alveolar PCO_2 in women during the luteal phase of menstrual cycle is lower than that in men. In pregnancy, PCO_2 level lowers as progesterone secretion increases.

In isotonic exercise, there is a change in muscle length and the exercise is phasic in nature, viz., walking, jogging, and running. Proportional rise of heart rate can be noted with the intensity of exercise. Systolic pressure increases with the nature of exercise. Diastolic pressure increases in mild exercise and does not change or decrease in moderate to severe exercise. The venous reservoirs are contracted and compressed by the skeletal muscles, especially those of limbs, during exercise. This results in transfer of huge volumes of blood from the peripheral vessels into heart and lungs, which enhances the cardiac output. Pulmonary blood flow increases, which improves the perfusion of alveoli. Estrogen are alleged to offer defense against cardiovascular disease,[14,15] and proof exists that they possess a number of positive cardiovascular effects, namely, dilatation of coronary and systemic arterioles,[16] enhancement in endothelial function,[17] ceasing fibroblast and vascular smooth muscle cell proliferation,[18] and stopping collagen accumulation in the aortic wall.[19] Moreover, various studies have proposed that another positive cardiovascular effect of estrogen is a raise in arterial distensibility.

Forearm blood flow is an indicator of skin blood flow in the forearm; the varying hormonal pattern occurring in the menstrual cycle can impact skin blood flow during exercise, because it is well known that several estrogenic hormones affect vascular activity.[20,21] Exercise-induced changes in the local, physical, and chemical environments could initiate several specific adaptations in the endothelium, which may amount for the enhanced endothelium-mediated dilatation. Thus, regular aerobic exercise may enhance the potential

for endothelium-mediated dilation in peripheral cerebral vessels through a modification of cell NO synthase. There was a marked increase in endurance for isometric exercise in the preovulatory phase of menstrual cycle.[22]

Normally, cardiac output is measured using dye dilution, thermodilution, or the oxygen consumption estimation methods, which are invasive in nature. However, cardiac output can be done noninvasively by means of thoracic electrical bioimpedance (TEB) method. Pulsatile flow of blood down the aorta during the course of the cardiac cycle induces rhythmic changes in impedance to the electric current-impedance, which decreases slightly during systole and increases during diastole. Typical cardiac output at several levels of exercise were monitored in young subjects and found that maximal cardiac output during exercise in young untrained man and male marathoner were 23 and 30 L/min, respectively, when compared with 5.5 L/min for young man at rest.[23]

Luteal phase shows increases in cardiac output and plasma volume (*Vp*),[24] and a *Vp* increase in the mid to late luteal phase can result in reduction in the blood hemoglobin level.[25] In the mid to late luteal phase, carbon monoxide may exhibit higher pulmonary diffusion capacity owing to a rise in pulmonary capillary blood volume.[26] Estrogen and progesterone are known to affect systemic and renal hemodynamic systems via activation of renin–angiotensin–aldosterone axis, and this may account for a Vp expansion with late luteal phase that has been associated with the decrease in the concentration of serum lipids and/or blood hemoglobin owing to hemodilution,[27] possibly because progesterone exhibits inhibitory effects on erythropoietin production.[28] Alteration in Hb levels, resulting because of both variations in arterial oxygen content alterations in blood volume and changes in output, can impart noteworthy effects on VO_2max.[29]

The peripheral blood flow was measured by the impedance cardiogram based upon impedance cardiovascographic data. The literal meaning of impedance plethysmography is "recording of instantaneous volume of an object by measurement of electrical impedance." During exercise, the muscle blood flow can increase a maximum of about 25-fold, the value being 90 mL/100 g muscle/min from resting blood flow of 3.6 mL/100 g.[30] In expiratory blast test, a normal subject can increase the mercury column to 55–100 mm or more during a single forceful expiration.[31]

Materials and Methods

This study was conducted in the Institute of Physiology and Experimental Medicine in collaboration with Department of Microbiology, Madras Medical College, Chennai, Tamil Nadu, India.

Study Population

Total number of subjects included in the study was 30. They were young unmarried and nonpregnant women of age group between 17 and 25 years from in and outpatient unit of Government General Hospital, Madras Medical College, Chennai.

Methodology

Thirty healthy volunteers in the age group of 17 to 25 years were selected. The scope and details of the study were explained to the individuals and were subjected to the following tests:

1. The selected subjects were observed throughout menstrual cycle to assess the regularity of the cycle during the study period.
2. Blood was drawn during mid-follicular and early luteal phases of menstrual cycle for the estimation of estrogen and progesterone.
3. Blood pressure, cardiac output, and upper limb peripheral blood flow (right forearm) were recorded.
4. Cardiac output and peripheral blood flow were measured by the cardiac output monitor.
5. Respiratory changes were assessed by respiratory efficiency test/expiratory blast test.

Analysis of Blood Samples

Various phases of menstrual cycle was measured using hormone kits, viz. ELISA estradiol (E_2) determination supplied by SMAR Test diagnostics and progesterone determination using hormone kits supplied by DRG Diagnostics, Germany. Hormone analyses were done in various phases of menstrual cycle, i.e., mid-follicular and early luteal phases of the subjects selected for study. The correlation was made with different physiological parameters, viz., cardiac output, peripheral blood flow, and respiratory efficiency evaluation.

Quantitative Determination of Estradiol (E_2) Concentration in Human Serum

Blood was drawn during the mid-follicular and early luteal phases of menstrual cycle during early hours of the day; the serum was separated and stored at –20°C.

1. The desired number of coated wells in the holder was secured.
2. Dispensed 25 μL of standards, specimens, and controls into appropriate wells.
3. Dispensed 100 μL of estradiol-HRP conjugate reagent into each well.
4. Dispensed 50 μL of rabbit anti-estradiol (E_2) reagent to each well.
5. The contents were thoroughly mixed for 30 s.
6. Incubated at room temperature (18–25°C) for 90 min.
7. Rinsed and flicked the microwells five times with distilled or deionized water.
8. Dispensed 100 μL of TMB reagent into each well and gently mixed for 10 s.
9. Incubated at room temperature (18–25°C) for 20 min.
10. The reaction was stopped by adding 100 μL stop solution to each well.

11. Mixed the contents gently for 30 s. It is important to make sure that all the blue colour changes to yellow color completely.
12. Absorbance was read at 450 nm with microtiter well reader within 15 min.

Quantitative Determination of Progesterone in Serum

Blood was drawn during mid-follicular and early luteal phases of menstrual cycle during early hours of the day, and the serum was separated and stored at –20°C for further determination.

Assay Procedure

All standards, samples, and control should be run in duplicate concurrently so that all conditioned of testing are the same. After securing the desired number of microtiter wells in the holder, the following performed:

1. Dispensed 25 μL of each standards, controls, and samples with new disposable tips into appropriate wells.
2. Incubated for 5 min at room temperature.
3. Dispensed 200 μL enzyme conjugate into each well.
4. The contents were thoroughly mixed for 10 s. It is important to have a complete mixing in this step.
5. Incubated for 60 min at room temperature.
6. The contents were briskly shaken out of the wells. Rinsed the wells three times with diluted wash solution (400 μL per well). Stroke the wells sharply on absorbent paper to remove residual droplets.
7. Added 200 μL of substrate solution to each well.
8. Incubated for 15 min at room temperature.
9. The enzymatic reaction was stopped by adding 100 μL of stop solution to each well.
10. Read the OD at 450 ± 10nm with a microtiter plate reader within 10 min after adding the stop solution.

Performance of Isotonic Exercise

Initially, flexor group of forearm muscle strength assessed by loading maximum weight (in kilogram) pulled for 3 s was considered to be the strength of muscle, followed by on loading and off loading of flexor group of muscles of right forearm at 50% of maximum strength for about 2 min by Mosso Ergograph.

Cardiac Output Measurement

The cardiac output was measured by the cardiac output monitor in a supine posture before exercise. Then, the subject was asked to perform isotonic exercise of flexor group of muscles of right forearm for about 2 min by Mosso Ergograph at 50% of the maximum strength. Cardiac output was measured again soon after exercise in a supine posture, and the values were recorded.

The subject was connected to NICOMAN™ (L&T, India) via patient cable attached to eight solid-gel disposable electrodes.

1. The TEB measurement current was passed through the thorax in a direction parallel to the spine between a pair of electrodes placed on the upper neck and a pair of electrodes placed on the abdomen on its way through the thorax.
2. The top and bottom pair is a source and sink of the TEB measurement current, the inner pairs, located at the root of the neck and the diaphragm level, viz., the xiphoid process level were used for sensing both the TEB signal and four different factors of ECG signal.
   Stroke volume (SV) was calculated according to the formula of Kubieek[25]

$$SV = p\,(L/Z_0)^2 \times dz/dt_{max} \times LVET$$

   where p = resistivity of blood;
   Zo = baseline thoracic impedance;
   dz/dt_{max} = the maximum change in impedance during systole.
3. Measurements were made continuously and processed by a computer.
4. SV was calculated with a computer-derived averaged signal of 20 consecutive heartbeats.

Peripheral blood flow measurement was measured before exercise and after exercise. Assessment of respiratory changes during various phases of menstrual cycle was done by expiratory blast test.

Statistical Analysis

All parameters, viz., differences between changes before and soon after exercise of young subjects during mid-follicular and early luteal phases of menstrual cycles, were checked for normality of distribution.

1. Comparison of selected subjects between two phases of menstrual cycle was done using Student's paired sample *t*-test.
2. Correlation between two hormones in different phases of menstrual cycle was carried out using Wilcoxon's signed rank test.

Assessment of Respiratory Changes During Various Phases of Menstrual Cycle Expiratory Blast Test

Sphygmomanometer was used for the assessment of respiratory efficiency of the individual. The rubber tube was disconnected leading from the mercury reservoir to the cuff. The selected group of individuals were subjected to perform expiratory blast test, in such a way that they had to take a deep breath for raising the mercury column to as high a level as possible. The individual was subjected to repeat the expiratory blast test, and the values were recorded.

Results

Tables 1–3 illustrate the effect of exercise on cardiac output, peripheral blood flow, and expiratory blast test during mid-follicular phase of menstrual cycle of the subjects under study, respectively. When compared with the measured values before exercise, there was a uniform increase in all the measured

parameters tested in all the individuals after exercise. This shows the effect of exercise on the measured physiological parameters as expected. Analysis with Student's *t*-test showed that the changes in all the measured parameters were highly significant ($p = 0.00$) in mid-follicular phase of the menstrual cycle.

Tables 4–6 illustrate the effect of exercise on cardiac output, peripheral blood flow, and expiratory blast test during early luteal phase of menstrual cycle of the subjects under study, respectively. When compared with the measured values before exercise, there was a uniform increase in all the measured parameters tested in all the individuals after exercise. This shows the effect of exercise on the measured physiological parameters as expected. Analysis with Student's *t*-test shows that the changes in the peripheral blood flow index showed a significant change ($p < 0.05$) but the changes in the cardiac output and expiratory blast test were found to show a high degree of significance ($p = 0.00$).

Table 7 illustrates the changes in the cardiac output during resting and soon after exercise during various phases of menstrual cycle of the subjects under study. Analysis of pre-and postvalues of the cardiac output did not show any significant difference ($p > 0.05$) between two phases of menstrual cycle. It shows that changes in the cardiac output throughout the menstrual cycle were not significant enough, and no baseline correction was needed for the values measured during both the phases of menstrual cycle.

Table 8 illustrates the changes in the peripheral blood flow during resting and soon after exercise during various phases of menstrual cycle of the subjects under study. The analysis of pre- and posttest values of the peripheral blood flow resulted in the following inferences:

- Highly significant differences in the pretest values between the phases.
- Equally significant differences in the posttest values between the phases.

This shows that the baseline values of these parameters changed during the course of the menstrual cycle. Hence, for analysis of changes in the measured parameters before and soon after exercise in the two phases of menstrual cycle and to compare the quantum of change between these two phases, the percent in these parameters were assessed and tabulated in Table 10.

Table 9 illustrates the changes in the expiratory blast test during resting and soon after exercise during various phases of menstrual cycle of the subjects under study. The analysis of pre- and posttest values of the expiratory blast test resulted in the following inferences:

- Highly significant differences in the pretest values between the phases.
- Equally significant differences in the posttest values between the phases.

This shows that the baseline values of these parameters changed during the course of the menstrual cycle. Hence, for analysis of changes in the measured parameters before and soon after exercise in the two phases of menstrual cycle and to compare the quantum of change between these two phases, the percent in these parameters were assessed and tabulated in Table 10.

Final Analysis in Measured Parameters Between Two Phases of Menstrual Cycle

I. Cardiac Output
- Change was observed to be higher in follicular phase.
- Change was analyzed to be highly significant compared with luteal phase.
- Change reflects the effect of estrogen.

II. Peripheral Blood Flow
- Change was observed to be higher in follicular phase.
- Change was analyzed to be highly significant compared with luteal phase.
- Change reflects the effect of estrogen.

III. Expiratory Blast Test
- Change was observed to be higher in luteal phase.
- Change was analyzed to be highly significant compared with follicular phase.
- Change reflects the effect of progesterone.

IV. Comparison Between Parameters
- Cardiovascular parameters were more affected in follicular phase.
- Respiratory parameters were more affected in luteal phase.
- Change in peripheral blood flow was found to exhibit marked effect than in cardiac output.
- Table 11 shows the mean values of estrogen hormones during mid-follicular and early luteal phases, which were 89 and 53 pg/mL respectively. Statistical analysis evinced that there was a significant difference ($p < 0.05$) between the two phases of menstrual cycle.
- The mean values of progesterone hormone during mid-follicular and early luteal phases were 0.8 and 11.3 ng/mL, respectively. The data were analyzed using Wilcoxon signed rank test and found to be statistically highly significant ($p = 0.00$) between the two phases of menstrual cycle.

Discussion

In this study, the cardiac–respiratory changes were compared between the various phases of menstrual cycles of young women in the age group of 17 to 25 years. Hormonal estimation was done to find out the phases of menstrual cycle.

Cardiac Output

Cardiac output measurement showed no significant changes during mid-follicular and early luteal phases of menstrual cycle under study, but there was a slight increase in cardiac output after exercise, which may be attributed to increase in sympathetic over activity that might have increased the cardiac output by increasing the myocardial contractility, heart rate, and SV.

Table 1: Effect of exercise on cardiac output during mid-follicular phase of menstrual cycle

Physiological parameters	*N*	Cardiac output (L/min)	Standard deviation	*p*
Before exercise	30	3.2	0.08	0.00
After exercise	30	3.3	0.13	

Table 2: Effect of exercise on peripheral blood flow during mid-follicular phase of menstrual cycle

Physiological parameters	*N*	Peripheral blood flow index	Standard deviation	*p*
Before exercise	30	1.0	0.11	0.00
After exercise	30	1.2	0.16	

Table 3: Effect of exercise on expiratory blast test during mid-follicular phase of menstrual cycle

Physiological parameters	*N*	Expiratory blast test (mm Hg)	Standard deviation	*p*
Before exercise	30	39.5	3.50	0.00
After exercise	30	42.50	3.40	

Table 4: Effect of exercise on cardiac output during early luteal phase of menstrual cycle

Physiological parameters	*N*	Cardiac output (L/min)	Standard deviation	*p*
Before exercise	30	3.20	0.07	0.00
After exercise	30	3.30	0.12	

Table 5: Effect of exercise on peripheral blood flow during early luteal phase of menstrual cycle

Physiological parameters	*N*	Peripheral blood flow index	Standard deviation	*p*
Before exercise	30	0.95	0.06	0.00
After exercise	30	0.97	0.10	

Table 6: Effect of exercise on expiratory blast test during early luteal phase of menstrual cycle

Physiological parameters	*N*	Expiratory blast test (mm Hg)	Standard deviation	*p*
Before exercise	30	46.80	3.30	0.00
After exercise	30	48.50	2.40	

Table 7: Comparison of cardiac output between two phases of menstrual cycle before and after exercise

Parameters	*N*	Follicular phase		Luteal phase		*p*
		Mean	SD	Mean	SD	
Before exercise	30	3.20	0.08	3.20	0.07	0.07
After exercise	30	3.30	0.13	3.40	0.12	0.17

Table 8: Comparison of peripheral blood flow between two phases of menstrual cycle before and after exercise

Parameters	*N*	Follicular phase		Luteal phase		*p*
		Mean	SD	Mean	SD	
Before exercise	30	1.00	0.11	0.95	0.06	0.002
After exercise	30	1.20	0.16	0.97	0.10	0.000

Table 9: Comparison of expiratory blast test between two phases of menstrual cycle before and after exercise

Parameters	*N*	Follicular phase		Luteal phase		*p*
		Mean	SD	Mean	SD	
Before exercise	30	39.5	3.50	46.80	3.30	0.07
After exercise	30	42.5	3.40	48.50	2.40	0.17

Table 10: Comparison of percentage change in parameters after exercise between two phases of menstrual cycle

Parameters	Follicular phase		Luteal phase		*p*
	Mean	SD	Mean	SD	
Cardiac output	5.71	1.45	4.13	2.35	0.00*
Peripheral blood flow	16.04	10.96	6.15	3.54	0.00*
Expiratory blast test	12.53	6.25	15.10	7.31	0.04*

*Paired samples *t*-test.

Table 11: Correlation between estrogen and progesterone hormones during mid-follicular phase and early luteal phases of menstrual cycle

Hormones	*N*	Follicular phase		Luteal phase		*p*
		Mean	SD	Mean	SD	
Estrogen (pg/mL)	30	89.00	10.00	53.00	12.00	0.00*
Progesterone (pg/mLl)	30	0.80	0.40	11.30	2.50	0.00**

*Paired sample *t*-test.
**Wilcoxon signed rank test.

Peripheral Blood Flow

In our study, peripheral blood flow exhibited an increasing trend even before exercise during follicular phase of menstrual cycle when compared with the luteal phase, which indicates the influence of estrogen hormone. In addition, the fact it was more after exercise indicates the added effect of sympathetic overactivity and the estrogenic effect. During early luteal phase, there was a decreased peripheral blood flow before exercise, which might be owing to the effect of hormone progesterone, leading to stiffening of the blood vessels and the effects of norepinephrine and ADH. Between the phases of menstrual cycle, there was a significant reduction ($p < 0.05$) in the peripheral blood flow in the luteal phase before exercise but it was insignificantly increased after exercise because of sympathetic overactivity, the mechanism being the vasodilation in the cutaneous and splanchnic circulation. These data suggested conversely that the arterial stiffening occurring in the luteal phase is owing to an increase in vascular smooth muscle contraction resulting from a physiological reduction in estrogen levels.

First, in the luteal phase, NO-dependent modulation of arterial diameter was reduced, indicating that an increase in smooth muscle contraction could also bring about endothelial dysfunction. Second, the luteal phase was additionally characterized by a marked reduction in follicular stimulating hormone, lutenizing hormone, and prolactin and by a marked increase in progesterone and ADH levels. Doppler assessment revealed that blood flow in internal carotid, middle cerebral, and uterine arteries was improved with hormone replacement therapy in the postmenopausal women.

In our study, the peripheral blood flow had shown a significant increase ($p = 0.002$) during mid-follicular phase, but it had decreased significantly during luteal phase at resting phase. Between phases, there was a significant reduction ($p = 0.00$) in the peripheral blood flow during luteal phase soon after exercise, which correlates.

Respiratory Changes

During follicular phase, the readings were not much increased at resting level but increased insignificantly after exercise, which indicates that respiratory minute volume increases linearly with work followed by an increase in the pulmonary blood flow and the perfusion of alveoli, leading to an improved breathing capacity and VO_2max. But, during luteal phase, the subjects were observed to have improved respiratory efficiency even at resting stage.

The major findings of this study suggests that menstrual hormones did not affect breathing responses at rest; submaximal and maximal exercise showed comparable results, which suggested that forced vital capacity and forced expiratory volume and their ratio were not affected by phases of the menstrual cycle.

On the basis of these data, our result support that there was a positive correlation between the ventilation and the progesterone hormone during early luteal phase compared with mid-follicular phase before and after exercise.

Conclusions

Cardiac output measurement showed no significant increase during both phases of menstrual cycle before exercise but there was a insignificant increase soon after exercise owing to sympathetic overactivity. The observed increase in the peripheral blood flow during mid-follicular phase before and after exercise revealed that influence of estrogen increases the arterial distensibility. The observed increase in the respiratory efficiency test during early luteal phase before and soon after exercise revealed the influence of progesterone, which is considered to be a potent stimulator of respiration, and added up effect of hormones and exercise-induced changes. The findings of this research study will be useful for women in various phases

of menstrual cycle, during the performance of strenuous exercise, which requires an appreciable cardiac reserve.

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