INFLUENCE OF GRAVITY ON BLOOD VOLUME AND FLOW DISTRIBUTION

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INTRODUCTION

In our previous experiments during NASA Shuttle flights SLS 1 and 2 (9-15 days) and EUROMIR flights (30-90 days) we observed that pulmonary blood flow (cardiac output) was elevated initially, and surprisingly remained elevated for the duration of the flights. Stroke volume increased initially and then decreased, but was still above 1 Gz values. As venous return was constant, the changes in SV were secondary to modulation of heart rate. Mean blood pressure was at or slightly below 1 Gz levels in space, indicating a decrease in total peripheral resistance. It has been suggested that plasma volume is reduced in space, however cardiac output/venous return do not return to 1 Gz levels over the duration of flight. In spite of the increased cardiac output, central venous pressure was not elevated in space. These data suggest that there is a change in the basic relationship between cardiac output and central venous pressure, a persistent "hyperperfusion" and a re-distribution of blood flow and volume during space flight.

Increased pulmonary blood flow has been reported to increase diffusing capacity in space, presumably due to the improved homogeneity of ventilation and perfusion. Other studies have suggested that ventilation may be independent of gravity, and perfusion may not be gravity-dependent. No data for the distribution of pulmonary blood volume were available for flight or simulated microgravity. Recent studies have suggested that the pulmonary vascular tree is influenced by sympathetic tone in a manner similar to that of the systemic system. This implies that the pulmonary circulation is dilated during microgravity and that the distribution of blood flow and volume may be influenced more by vascular control than by gravity.

The cerebral circulation is influenced by sympathetic tone similarly to that of the systemic and pulmonary circulations; however its effects are modulated by cerebral autoregulation. Thus it is difficult to predict if cerebral perfusion is increased and if there is edema in space. Anecdotal evidence suggests there may be cerebral edema early in flight. Cerebral artery velocity has been shown to be elevated in simulated microgravity. The elevated cerebral artery velocity during simulated microgravity may reflect vasoconstriction of the arteries and not increased cerebral blood flow.

The purpose of our investigations was to evaluate the effects of alterations in simulated gravity (±), resulting in changes in cardiac output (±), and on the blood flow and volume distribution in the lung and brain of human subjects. The first hypothesis of these studies was that blood flow and volume would be affected by gravity, but their distribution in the lung would be independent of gravity and due to vasoactivity changing vascular resistance in lung vessels. The vasodilitation of the lung vasculature (lower resistance) along with increased "compliance" of the heart could account for the absence of increased central venous pressure in microgravity. Secondly, we postulate that cerebral blood velocity is increased in microgravity due to large artery vasoconstriction, but that cerebral blood flow would be reduced due to autoregulation.

METHODS

Simulated gravity was produced by combinations of lower-body negative or positive pressure, the head-down tilt position (6°), graded head-out immersion in water of thermal neutral temperature, or human centrifugation. Gravity was altered progressively or studied as a function of time, up to 6 hr.

Six series of experiments were conducted using 6-10 young health volunteers in each protocol. Data were analyzed by multivariate analysis of variance for repeated measures. During all experiments heart rate was determined from a continuous ECG recording, blood pressure was determined by automated osculation, oxygen consumption by open circuit spirometery and pulmonary blood flow by CO_2 re-breathing. Diffusing capacity (D_L) was determined using CO and NO during re-breathing. Blood flow and volume measurements in the heart and lung were determined by nuclear imaging. Global cerebral blood flow and regional blood flow distribution were determined by Positron Emission Tomography (PET).

RESULTS

Cardiac output and stroke volume increased in simulated microgravity (up to 40%) and decreased in + Gz (by 40%) in all forms of simulation. These changes were associated with decreases in heart rate and total peripheral resistance during 0 Gz and increase during + Gz, while mean blood pressures were not different from1 Gz values. These changes resulted from alterations in sympathetic tone, mediated by the baroreceptors. The changes observed initially in all gravity simulations, persisted through out the time of the experiments.

The changes in pulmonary blood flow and total lung volume paralleled the changes in cardiac output during changes in simulated gravity. The distribution of blood flow and volume in the lung are shown as % of the total in the right lung in Table 1.

Table 1. Percentage of blood flow and volume in lung sections 1-9 during changes in gravity.

----------Top----------				Lung Layer				----------Apex------	
Cond.	1	2	3	4	5	6	7	8	9
1Gz	7.1	7.1	8.5	9.9	12.4	13.1	13.8	13.9	14.2
0Gz	5.2	5.7	8.3	10.2	10.7	13.0	13.1	15.6	18.2
+Gz	6.8	7.6	8.4	9.6	10.0	13.5	14.3	14.7	15.1

The percentage of blood flow and volume in the vertical segments of the lung (1-9) were not affected by gravity This implies all segments of the lung vasodilate or vasoconstrict in parallel. The initial changes in lung blood flow and volume persisted throughout the time period of the experiments, up to six hours.

Cardiac volume measures during simulated gravity demonstrated that end-diastolic volume, end-systolic volume and stroke volume increased in 0 Gz and decreased progressively in +Gz. The rate of change of volume during systole and particularly during diastole increased in +Gz and decreased in 0 Gz. These data are consistent with changes in "compliance" associated with the sympathetically mediated changes in inotropic state of the heart resulting from changes in Gz. Increased cardiac "compliance", when combined with decreased pulmonary resistance, could

explain the absence of increase in central venous pressure in space.

Previous investigators have suggested that the increased cardiac output and cerebral perfusion pressure would result in increased cerebral blood flow and could cause edema. We have determined cerebral blood flow using $H_2{}^{15}O$ and PET during 0.5 hrs erect and 3.0 hrs in the head-down tilt position. In a separate series of experiments, we have examined the effect of nitroglycerin (NG) administration on cerebral blood flow over 3 hrs in the supine position (SUP). The data for global cerebral blood flow (CBF, ml/min/100g) are presented in Table 2 along with similar data collected with the transcranial Doppler technique (TCD) reported in the literature.

Table 2. Cerebral blood flow and velocity are shown for selected time periods.

		Time, Hrs.		
Protocol	Erect	1.0	2.0	3.0
CBF-HDT-PET	53	38	42	40
CBV-HDT-TCD	49	58	57	55
CBF-SUP-NG	49	62	57	56

Cerebral blood flow decreased and cerebral blood flow velocity increased initially during head-down tilt. These data are consistent with a vasoconstriction of the large arteries and autoregulation in the brain, presumably due to myogenic responses to increased cardiac output and perfusion pressure. Over the three hours in the head-down tilt position cerebral blood flow was modulated toward control levels and cerebral blood velocity began to fall. There were regional changes in blood flow distribution and a two-fold increase in scalp flow, perhaps due to a "stealing". Assuming the cerebral blood flow data in 0 Gz are correct, a vasodilator like nitroglycerin could serve as a "countermeasure". Cerebral blood flow in the supine position was increased with nitroglycerin and remained elevated for 3 hrs.

CONCLUSION

The results of this series of experiments demonstrated that the lung vasculature is vasodilated and vasoconstricted by alterations in sympathetic tone in response to decreasing or increasing gravity, respectively. The reduction in pulmonary vascular resistance, when combined with the increased cardiac compliance, may account for the absence of an increase in central venous pressure in space. The increased perfusion pressure and reduced sympathetic tone in 0 Gz is off-set by autoregulation, resulting in reduced cerebral blood flow with a re-distribution of flow to the scalp and within the brain. The absence of an increase in central venous pressure and modifications in cerebral blood flow may contribute to the sustained elevation of cardiac output, facial edema, motion sickness and other problems in and after space flight.

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