

Evaluation of Cutaneous Blood Flow During Lower Body Negative
Pressure To Prevent Orthostatic Intolerance of
Bedrest

Final Report

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ABSTRACT

Orthostatic tolerance is markedly impaired in most of the crewmembers during space flight and could seriously compromise crew safety during and immediately after landing. NASA investigators are studying the use of lower body negative pressure (LBNP) as a countermeasure to this intolerance. It is hypothesized that the continuously changing vascular pressure induced by sinusoidal LBNP with an additional countermeasure of salt and water will help crewmembers to be in a more acceptable physiologic condition to enter the earth's atmosphere. This process is used by crewmembers during space flight itself.

In ground based studies, subjects on bedrest provide the model for studying the physiologic effects of weightlessness. When subjects are treated with sinusoidal LBNP, negative pressures ranging from 0 to -60 mm./Hg. are administered during a two hour period. This increases body fluids in the legs and lower body which assists crewmembers and bedrest subjects to more readily adapt to the earth's gravitational field upon assuming the upright posture.

This paper reports the results of two subjects who were placed on bedrest for six days. The subjects were randomly selected for either the control or treatment mode. The subject receiving the treatment mode ingested salt tablets and water on day 4 of the bedrest period. A ramp LBNP of two hours was next administered to this subject. The control subject did not receive anything during the bedrest period.

Laser doppler was used to measure the cutaneous blood flow of the forearm and calf to monitor vasoconstrictor effects of the baroreceptor reflex. Data indicated that skin blood flow in the treatment subject was higher than baseline in the forearm while the skin blood flow was decreased in the control subject.

The comparison of these two subjects indicated that their responses to LBNP differ, however, the positive results with the treatment subject indicates that these two countermeasures to orthostatic intolerance show promise of success.

INTRODUCTION

Orthostatic tolerance is markedly impaired in most of the crewmembers during space flight and could seriously compromise crew safety during and immediately after landing. NASA investigators are studying the use of lower body negative pressure (LBNP) as a countermeasure to this intolerance. It is hypothesized that the continuously changing vascular pressure induced by sinusoidal LBNP with an additional countermeasure of ingestion of salt tablets and water will help the crewmembers to be in a more acceptable physiologic condition to enter earth's atmosphere. This process is used by crewmembers during space flight itself.

In ground based studies, subjects on bedrest provide the model for studying the physiologic effects of weightlessness. Previous studies have shown that weightlessness in space and bedrest on the ground have similar outcomes on the body. The objectives for using LBNP are to increase plasma volume (as a result of stimulating secretions of aldosterone and anti-diuretic hormones and attenuating release of atrial natriuretic hormone) and by maintaining carotid sinus baroreceptor function, overall autonomic nervous system function and leg compliance.

Sinusoidal LBNP, ranging from 0 to -60 mm/Hg. for a two hour period of time, increases body fluids in the legs and assists crewmembers and bedrest subjects to adapt to gravitational effects, either upon re-entry into earth's gravitational field or upon assuming the upright position after bedrest. This adaptation prevents fainting and other cardiovascular problem.

During the administration of LBNP, it is important to assess the subject's physiologic responses and to monitor the effects, particularly, on the cardiovascular system. One of the significant responses to monitor is the baroreceptor vasoconstriction reflex which can be assessed by measuring cutaneous blood flow in the forearm.

Kellogg et al (1990) reported that cutaneous arterioles are controlled by both vasoconstrictor and vasodilator sympathetic nerves. In their studies, they stated that the baroreflex clearly controls active vasodilation in skin and, therefore, has a major function in regulating cutaneous circulation. In an earlier study, Johnson et al (1973) investigated the competitive responses between cutaneous vasodilator and vasoconstrictor reflexes in man. Their findings document that skin blood flow is under both baroreceptor and thermoregulatory reflex control. Johnson and his associates assert that during heating, the skin retains the ability to vasoconstrict but the vasoconstriction does not completely override the heat induced vasodilation.

Later, Johnson (1986) further elucidated the reflex nature of regulation of circulation. He found that baroreceptor reflexes and reflexes associated with exercise each compete with thermoregulatory reflexes for control of the cutaneous circulation, but neither can overcome thermoregulatory vasodilation. He concluded that regulation of body temperature, maintenance of arterial blood pressure and redistribution of blood flow to working muscles is a result of the competition among the thermoregulatory and nonthermoregulatory reflexes.

Essandoh (1987) examined postural cardiovascular reflexes and their effects upon responses of the forearm and calf resistance vessels. Low pressure mechanoreceptors are deactivated by LBNP below -20 Torr which results in constriction of forearm but not calf resistance vessels. However, unloading both low and high pressure mechanoreceptors by lower body negative pressure of more than -20 Torr causes a large and similar constriction of both the forearm and the calf vessels. During postural changes, from supine to sitting positions, the major reflex adjustments to these changes in posture take place in the forearm.

Skin vasomotion responses may be seen by monitoring circulation with a laser doppler. This method of monitoring red blood cell velocity provides information about blood perfusion in a safe, non-invasive manner at the cutaneous surface. Laser doppler flowmeters work on the principle that a laser light beam is scattered by moving red blood cells. This movement is reflected into the photodetector.

METHODOLOGY

This investigator participated in an ongoing study of subjects on bedrest. At this time, two of the subjects have completed the 6 day bedrest period. Criteria for subject selection included the following: normal, healthy males in the age range of 25-50 (the same age range for selection of astronauts), successful physical examination and successful stress testing on the treadmill.

Prior to entry into the study, each subject received a full explanation of the study and signed a consent form for voluntary participation. The study was approved by the NASA Human Investigation Committee.

The subject then presented himself at the laboratory for a practice protocol of the study. Later, during the data collection phase, the subject during pre-bedrest, during bedrest (for treatment subject) and at post-bedrest, entered the LBNP box or chamber. The subject placed his legs into the chamber with his waist at the iris or the opening of the chamber. A heavy elastic skirt, placed around the subject's waist, was attached to the chamber and provided the seal necessary to prevent leakage of air into the chamber during LBNP.

The subject was connected to a number of monitors of physiologic variables. These were instruments for obtaining the electrocardiogram, echocardiogram, automatic and manual blood pressure indicators, strain gauge on the leg to record volume change, plethysmograph to evaluate blood volume in the arm, and laser doppler instruments to measure blood flow in the forearm and the calf.

This investigator was responsible for monitoring the laser doppler method of measuring blood flow of the skin. The data and results of this part of the study are reported here.

Two laser doppler instruments were used. The Perimed Laser Doppler Flowmeter, Periflux PF2B, was used for recording blood flow in the left forearm through a probe that was placed within a small heater (set at 38 degrees centigrade) and connected to the skin with a two sided adhesive ring. The Perimed instrument has a 2 nW He-Ne laser of 632.8 nm wavelength. At the normal skin, it has a hemisphere of approximately 1 mm. radius. It measures skin blood flow at a depth of 1 mm.

The second laser doppler instrument was the Vasamedics Laserflo BPM 2. The probe from this instrument was placed on the calf of the subject. There was no heater attached to the probe. The wave length of the laser was 780 nm. It measures skin blood flow at a depth of 1 mm.

Monitoring was continuous for collection of data for baseline, during the LBNP, after release of negative pressure and during recovery.

RESULTS

The subjects were randomly selected for either the treatment or the control condition. Subject A was designated as the control subject and Subject B as the treatment subject. The results of the data are presented graphically in illustrations.

In Figure 1, the baseline data is presented prior to LBNP. The data is from the left forearm only of the two subjects. The course of cutaneous blood flow for these two subjects is very dissimilar. Subject A has an inconsistent response and tolerates the negative pressure to a level of -100 mm./Hg. On the other hand, Subject B has a consistent response and tolerates the negative pressure to -70 mm./Hg. This difference may be explained by the difference in states of tension during LBNP. Subject B was much more relaxed than Subject A. Both subjects showed blood flow values above baseline when the negative pressure was released and slightly below baseline during the three minute recovery time.

In Figure 2, Subject A's data are presented for both the pre-

bedrest LBNP and from the sixth day of bedrest. Measurements were made of cutaneous blood flow of the left forearm and the calf. When measurements were repeated, care was taken to measure at the same place on the skin. Post bedrest values of blood flow for the forearm are reduced. The calf blood flow is also reduced below the forearm blood flow and at the negative pressure levels of -50, -60, and -70 mm./Hg. approached zero. In order to more readily view the values for the calf blood flow, the data were increased by a factor of 10. The zero readings may be from stasis within the capillaries or possibly from a collapse of the vessel from the negative pressure. In any event, there is no movement of red blood cells.

Subject B was tested on the fourth day of bedrest prior to ingestion of salt pills and water. In Figure 3, the forearm values show a reduction in blood flow on Day 4. Following the ingestion of salt and water, the subject received a ramp LBNP, using sinusoidal negative pressures going from 0 to -60 mm./Hg. within 5 minute intervals for a period of two hours. On the sixth day of bedrest, this subject's cutaneous blood flow was increased over baseline, indicating that the countermeasures were successful.

In Figure 4, the cutaneous blood flow of the forearm and the calf of Subject B are displayed. Values for the calf blood flow are again increased by a factor of 10. When compared, the blood flow of the right calf was decreased on the sixth day of bedrest during LBNP. At the -70 mm./Hg. of pressure, the blood flow was zero in the calf, just prior to release of the negative pressure.

DISCUSSION

These two subjects had dissimilar responses in cutaneous blood flow during LBNP. However, the data for Subject B, who received the treatment mode, showed that the countermeasures had improved the responses of the forearm and an increased level of blood perfusion which is the desired outcome. Subject A, control mode, did not show this adaptation.

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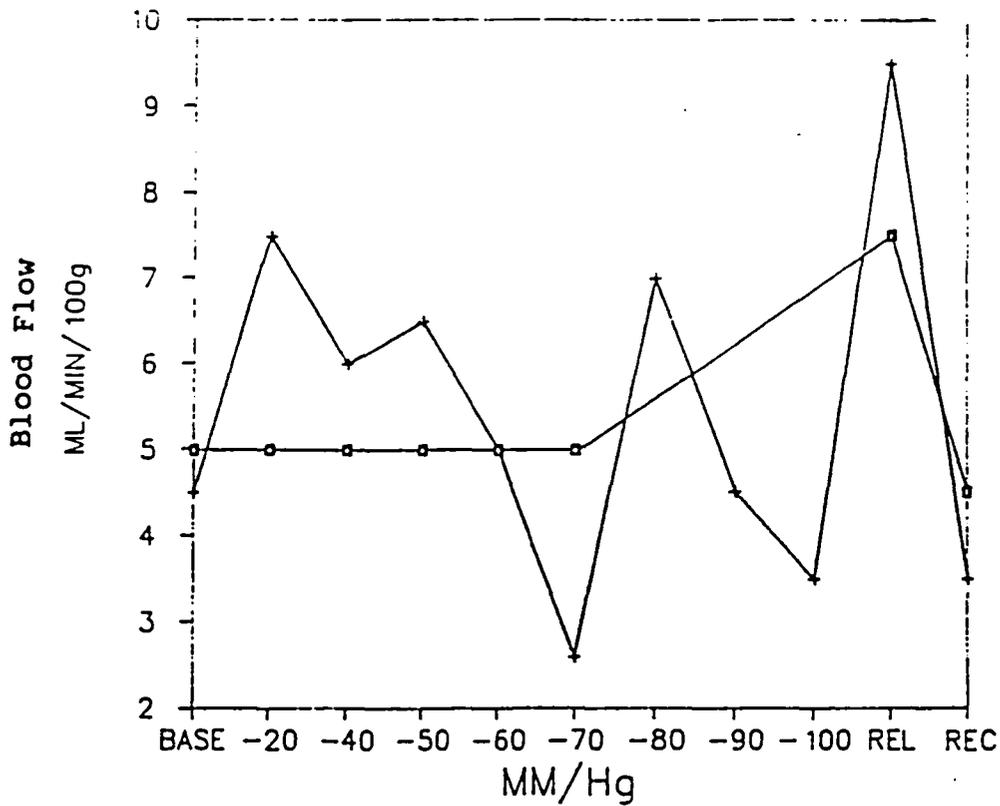


Figure 1. Subjects A and B Pre-bedrest Forearm Blood Flow (○ Treatment, + Control)

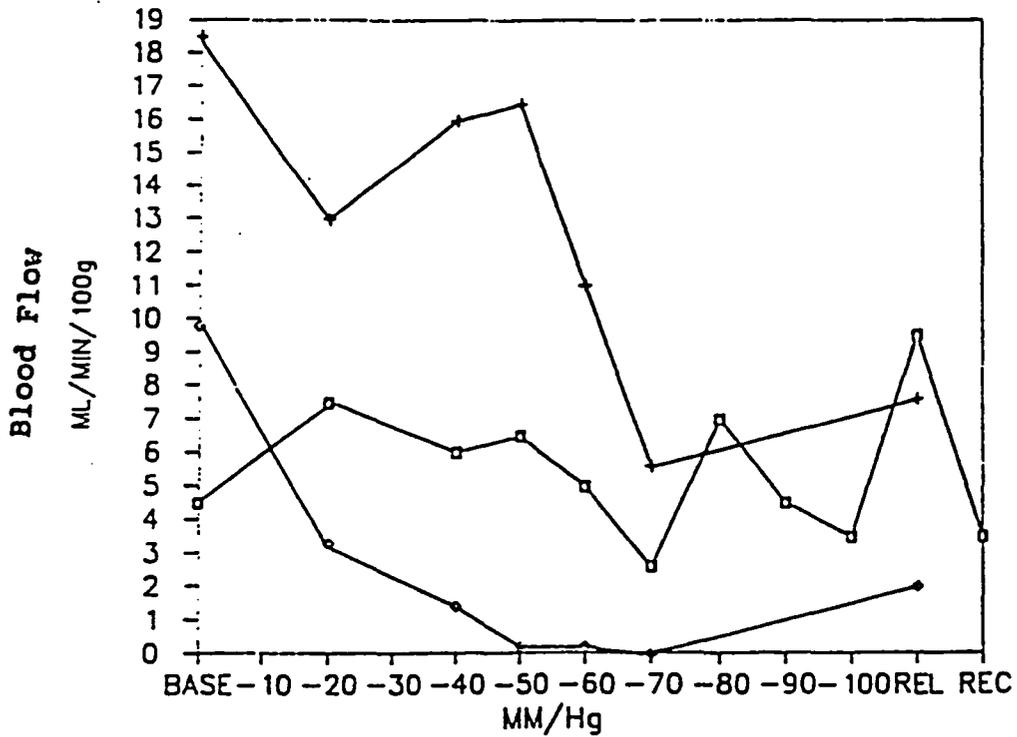


Figure 2. Subject A's Left Forearm and Right Calf Blood Flow (□ left forearm, pre-bedrest, + left forearm, day 6, ◇ right calf, day 6)

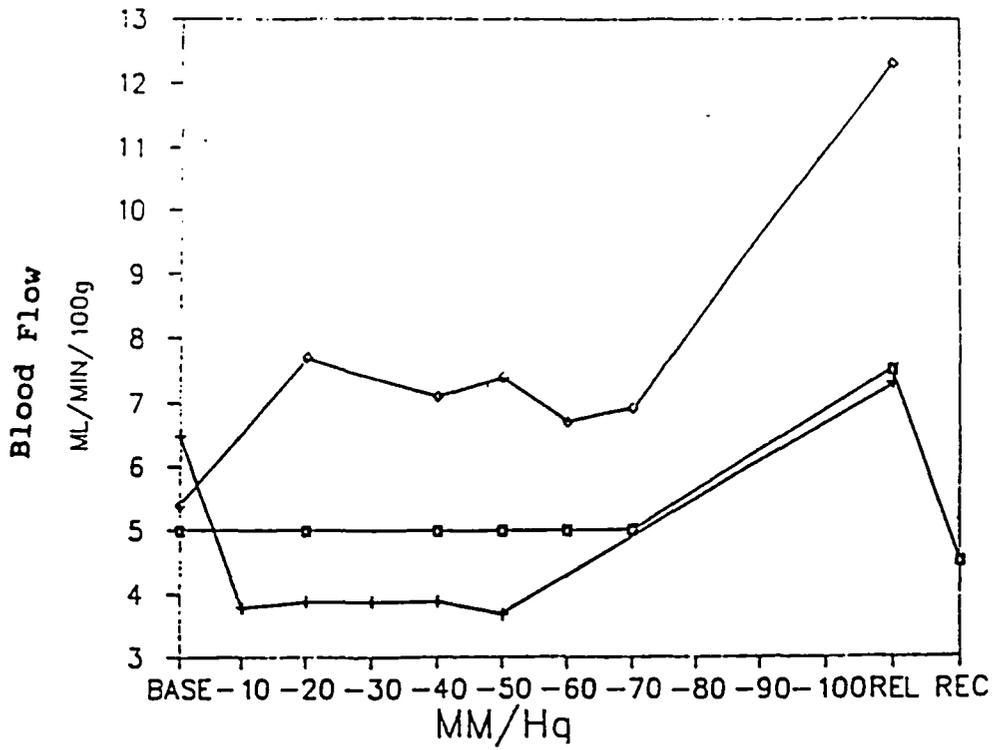


Figure 3. Subject B's Left Forearm Blood Flow (□ pre-bedrest, + day 4, ◇ day 6).

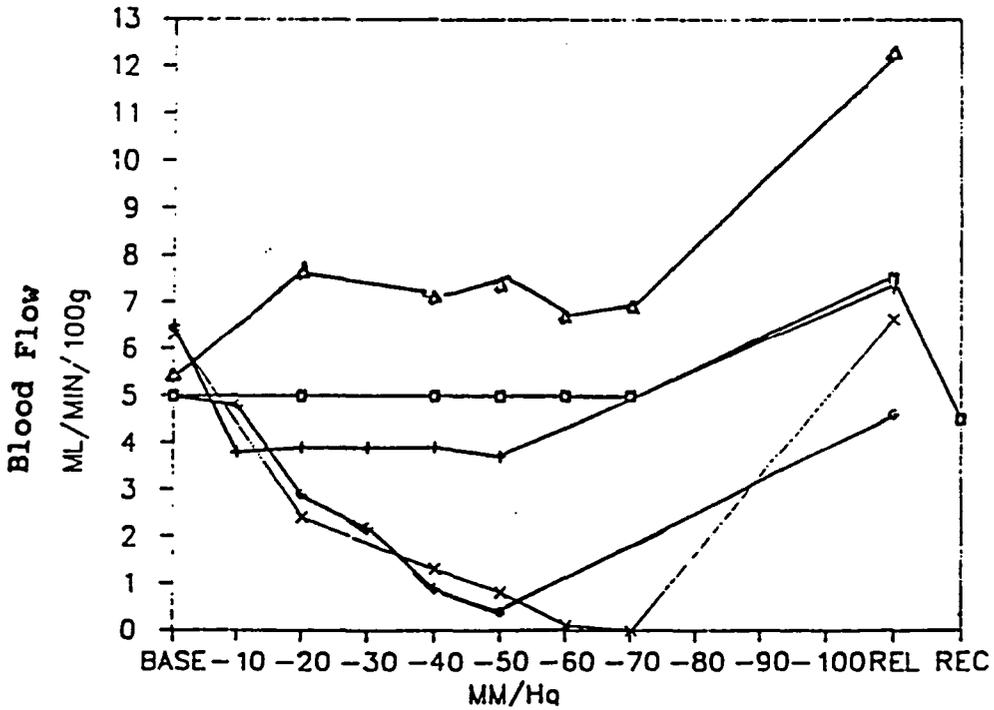


Figure 4. Subject B's Left Forearm and Right Calf Blood Flow (forearm, □ pre-bedrest, + day 4, △ day 6; calf, ◇ day 4, × day 6).