Hemodynamic Variations in the Anesthetized Dog During Simulated Weightlessness

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ABSTRACT

Anesthetized dogs were exposed to the hypodynamic state by flotation in a constant temperature saturated saline bath for periods ranging from 60-350 minutes. Continuous recording of heart rate, carotid and femoral blood pressure and blood flow, femoral vein pressure, and right ventricular pressure was carried out. During the hypodynamic state femoral and carotid artery blood flow increased, femoral and carotid blood pressure decreased, femoral vein and right ventricular pressures decreased, with little or no significant change in cardiac rate. Return to normal gravity produced decrease in femoral and carotid artery blood flows to levels below control values, femoral and carotid artery pressure increases to levels below control values, femoral vein and right ventricular pressures increased above control values, and again insignificant cardiac rate changes. There was some tendency to cardiac irregularities either on entering or leaving the hypodynamic state.

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This research was supported by Contract No. AF 41(609)-1589 (Project No. 7758) from the School of Aerospace Medicine, Brooks Air Force Base, Texas.

THE PURPOSE of this study was to determine the extent of the influence of the hypodynamic state on the hemodynamics of the anesthetized animal. Since it is not possible to readily reproduce true weightless conditions for extended periods in laboratory animals, and at the same time measure all desirable hemodynamic parameters, the use of a water flotation technique, i.e. hypodynamic state, was utilized to partially simulate weightlessness.

In a study of this type the proprioceptive systems of the body are certainly modified by the two factors, anesthesia and flotation. To what extent each of these systems may be influenced by each of the factors is unknown at the present time. The effect of a combination of these two conditions on an animals' cardiovascular system obviously presents many additional problems and questions.

Previous reports in the literature of the effects of sub or zero gravity on animals or humans indicate that definite cardiovascular and sensory[1–10, 12–16] responses are obtained. These studies were carried out in the conscious or unanesthetized state. It is entirely possible that certain aspects of the conscious state may be undesirable when weightlessness is prolonged and thus, reflect adversely into the cardiovascular system as well as effect the psychological stability of the individual.

In all probability, man will not be able to maintain adequate, conscious psychological balance for the sustained periods necessary to traverse even the relatively short distance within our own solar system, much less those extended periods required for more distant exploration. Thus, it would seem reasonable to expect to eliminate the conscious state, either partially or totally, for space travel of any period exceeding several months. Periods of consciousness could be programmed into the flight profile along with selected periods of suspended consciousness by the use of either chemo- or electronarcosis. Possibly hypnosis or suspended animation may prove to be more physiological under the conditions of extended space travel. Obviously, it will be necessary to develop and evaluate the best method through a process of comparative experimentation.

METHODS

Both mongrel and so called "pure line" animals were used throughout the study. All were maintained in the animal quarters for at least two weeks before being used in an experiment. Anesthesia was induced by pentobarbital sodium (33 mg. per kgm.) to a level at which respiration was maintained at or near that observed in the conscious state, e.g. 12-16 per minute. A tracheotomy was performed and a closed external respiration circuit connected to the animal. This consisted of two glass bulb encased Saad valves, one for inspiration and one for expiration which floated near the tracheal opening during the flotation phase. The animals' head was enclosed in a plastic bag to prevent saline from entering the nose, eyes and throat during this phase. Right ventricular pressure was measured by a ACM1 x-ray no. 7 catheter connected to a Statham P23BB strain gauge. Carotid artery and femoral artery and vein blood pressure were measured by inserting polyethylene catheters (#50) into the vessels' lumen and connecting them to Statham P23AA strain gauges. Carotid and femoral artery blood flows were measured by placing Medicon noncannulating flow probes around each of the vessels.

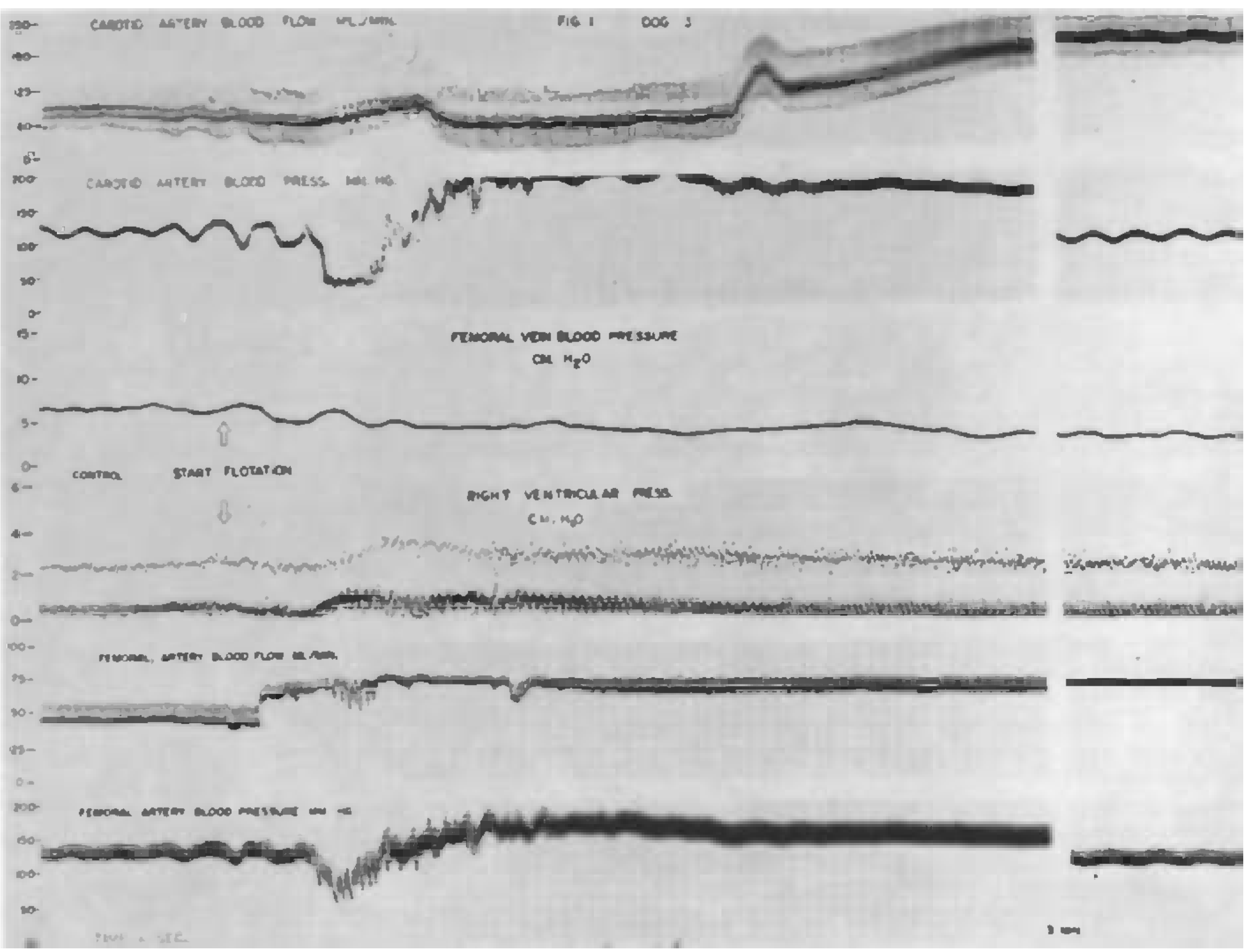

Fig. 1. Note the cardiac irregularities within 1 min. after entering the hypodynamic state. Break in recordings amounts to 3 min.

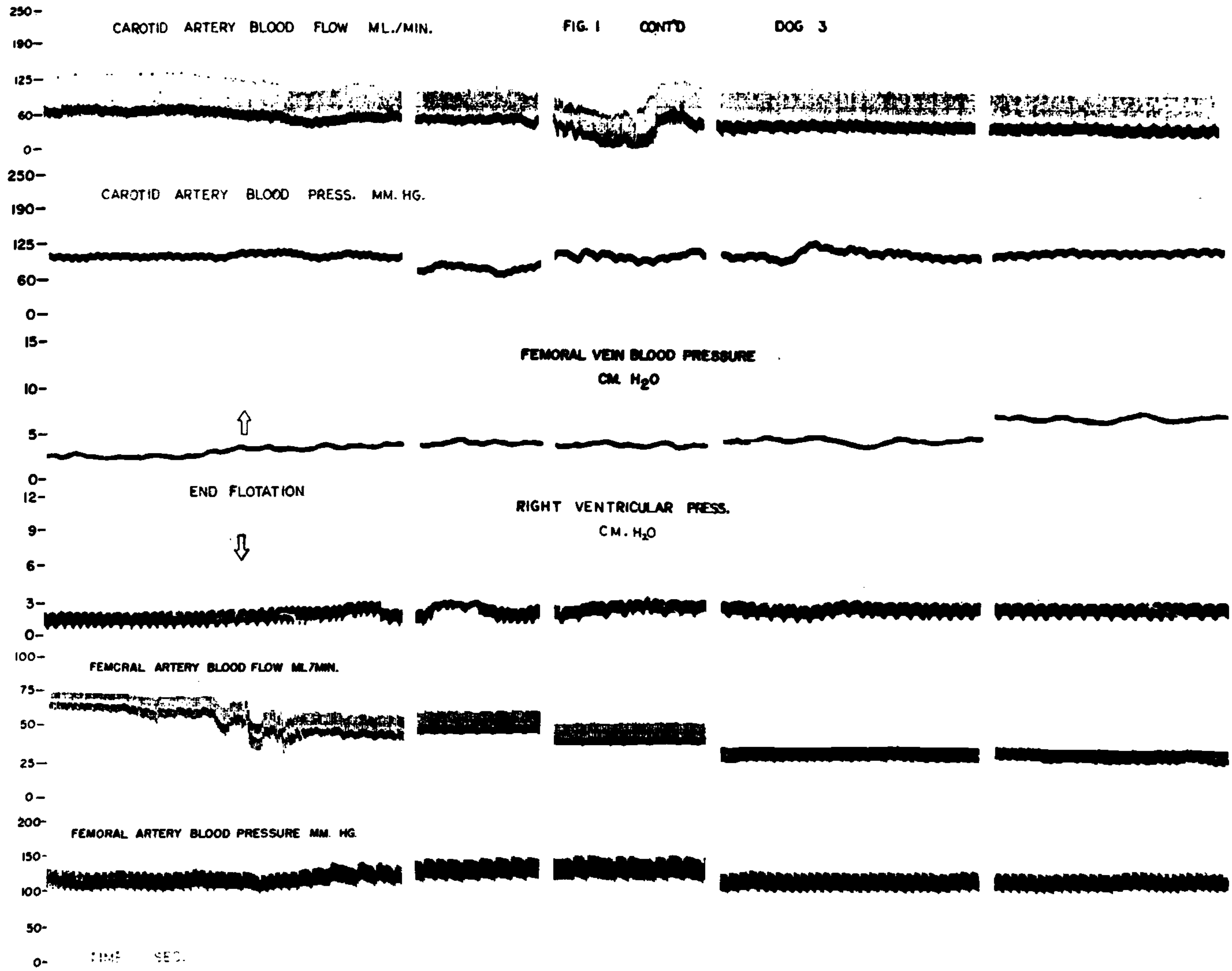

Fig. 1 Cont'd. Note absence of cardiac irregularities as animal returns to control conditions. Flotation time = 245 min. Each time gap on recordings = 3 min.

A control normal gravity period of one to two hours was utilized to determine the various parameters of the individual cardiovascular systems. During this period, the animal lay on a web of 3 inch plastic straps or bands suspended over the immersion tank filled with a saturated salt (NaCl) solution. This composition was found to be necessary to maintain the animal floating just below the surface of the water. The straps and their arrangement were of the general type used in lawn furniture. At the conclusion of the control phase, the animal was slowly lowered into the salt water by means of the plastic straps. Water temperature in the tank was maintained at 32-33° C throughout the flotation period by means of a Bronwill thermoregulator.

Recordings of all measured parameters were continuous throughout the control phase, entry into the water, flotation period, exit from the water, and the final recovery or second control phase. A Sanborn 6 channel Poly-Viso and a Twin-Viso were utilized throughout these studies for the recordings.

Deep rectal temperature was continuously monitored by a YSI thermistor and recording circuit.

All external surgical openings were closed with Eastman 910 Monomer (methyl-2-cyanoacrylate) to prevent the enterance of saline into the body cavities. This plastic suture material was also used to arrest any internal bleeding that was observed. It was also used to "weld" the blood pressure cannulae in place in the blood vessels.

RESULTS

Figures 1 and 2 represent the general responses of the cardiovascular system to the hypodynamic state and recovery from it. It will be noted that once stabilization has occurred all comparable parameters are qualitatively similar in the two dogs. The major differences observed in the series appeared to occur as the animal entered the hypodynamic state and as he returned to control conditions. The time interval required to enter the period of stabilization was somewhat variable as can be clearly seen when dog 3 is compared to dog 7. However, in no instance did it require over 15 minutes. Once stabilization was acquired, all hemodynamic parameters were remarkably constant.

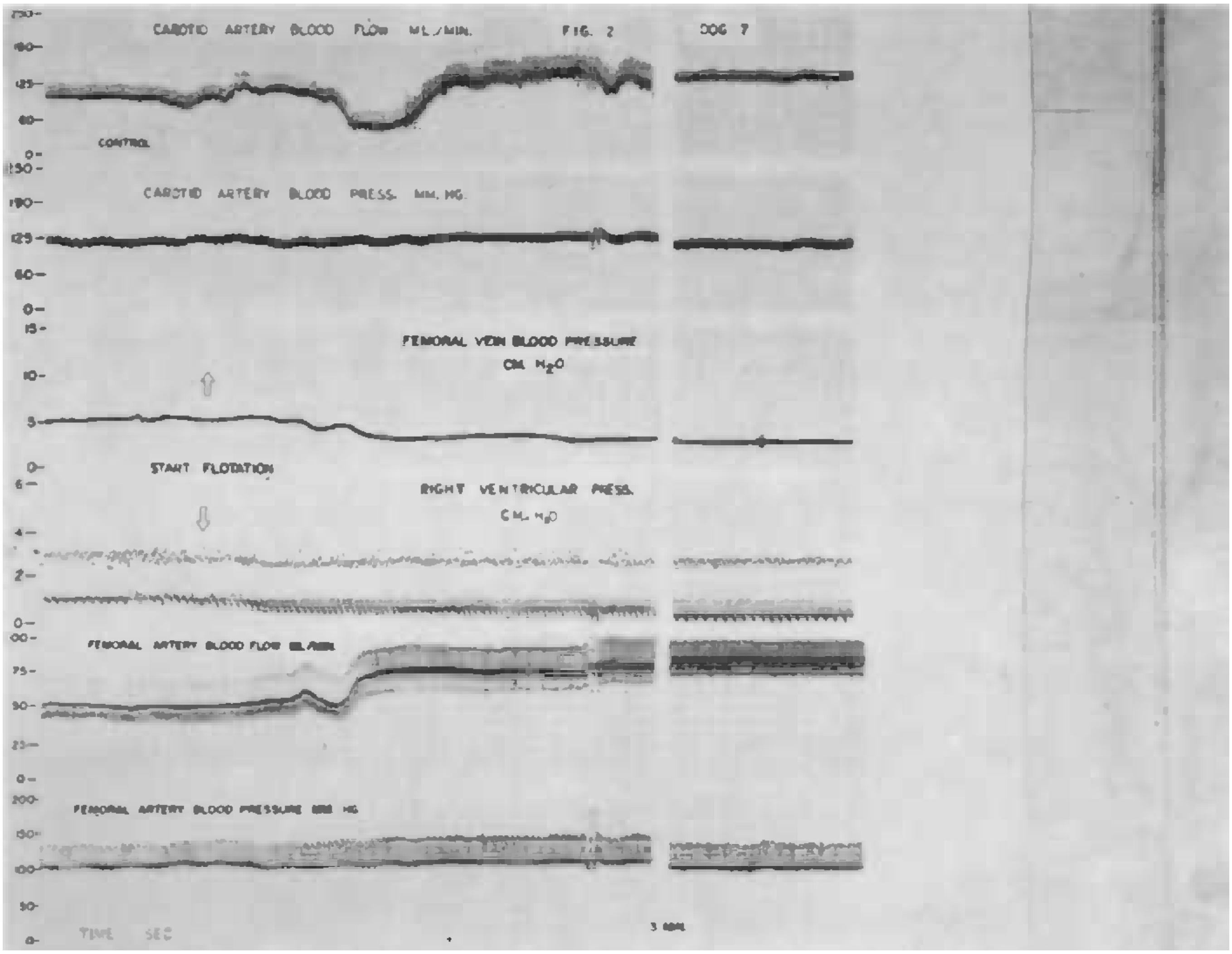

Fig. 2. Note relative absence of cardiac irregularities as animal enters the hypodynamic state. Break in recordings = 3 min.

Quite unexpected was the appearance of cardiac irregularities in those animals which manifest none during the control period, and the augmentation of any irregularity present in the control interval. Note in dog 3 that the irregularities appear upon entering flotation and in dog 7 they appear upon leaving flotation.

Cardiac rate was remarkably stable throughout the three phases of the experiments, with the exception of the irregularities mentioned above. In some animals there was a slight transient tachycardia or bradycardia during the entrance into the hypodynamic state.

Blood pressure in both the carotid and femoral arteries occasionally decreased rapidly upon flotation, but quickly rose above control values, remained there for 3-15 minutes, and then slowly fell to below control levels where it stabilized for the duration of the flotation period.

Blood flow was somewhat more variable during the entrance into the hypodynamic state. Also the carotid and femoral flows did not parallel each other as closely as did the blood pressures. Femoral blood flow increased within a few minutes to the level it would maintain throughout flotation. Carotid flow was increased within a few minutes to the level it would maintain throughout flotation. Carotid flow was observed to decrease for variable periods ranging from 30-180 seconds before increasing to above control values where it stabilized.

Venous pressures decreased in all experiments upon entering the flotation period. Stabilization was reached quickly and maintained throughout this period.

Right ventricular pressures exhibited some initial variations as shown by comparing dog 3 with dog 7. However, they appeared to be of relatively minor magnitude and duration.

Table I is a composite summary of data obtained on seven dogs. Three experiments were unsuccessful in some aspects and are not included in the above data. However, those phases that were valid were in agreement with the successful experiments. Values indicated are means plus or minus the standard deviation.

DISCUSSION

It was previously mentioned in the section on results that three experiments were not run to completion and were not included as such in Table I. One of the major difficulties appeared to be a greater sensitivity to additional doses of anesthetic (pentobarbital I.V.) exhibited by the animals during flotation. It will be recalled that the animals were kept rather lightly anesthetized with respiration at or near normal rates. This meant that additional anesthetic had to be infused every 60-90 minutes of the experimental period. During the flotation phase when it became necessary to infuse additional pentobarbital, extreme caution was necessary to administer it very slowly and in approximately half the amount usually required during control phases. In those instances where this was not followed, the result was a very precipitous death, not characteristic of the pentobarbital death induced at the end of the experimental period. While it is certainly doubtful that three examples are sufficient basis to make an absolute statement that the hypodynamic state is attended by decreased tolerance to additional anesthetic, it is strongly suggestive. In addition, it was noted that this sensitivity appeared to exist in some of the successful experiments although it was not proven, due to fear of loss of the animal if this were attempted. This point bears further carefully controlled study.

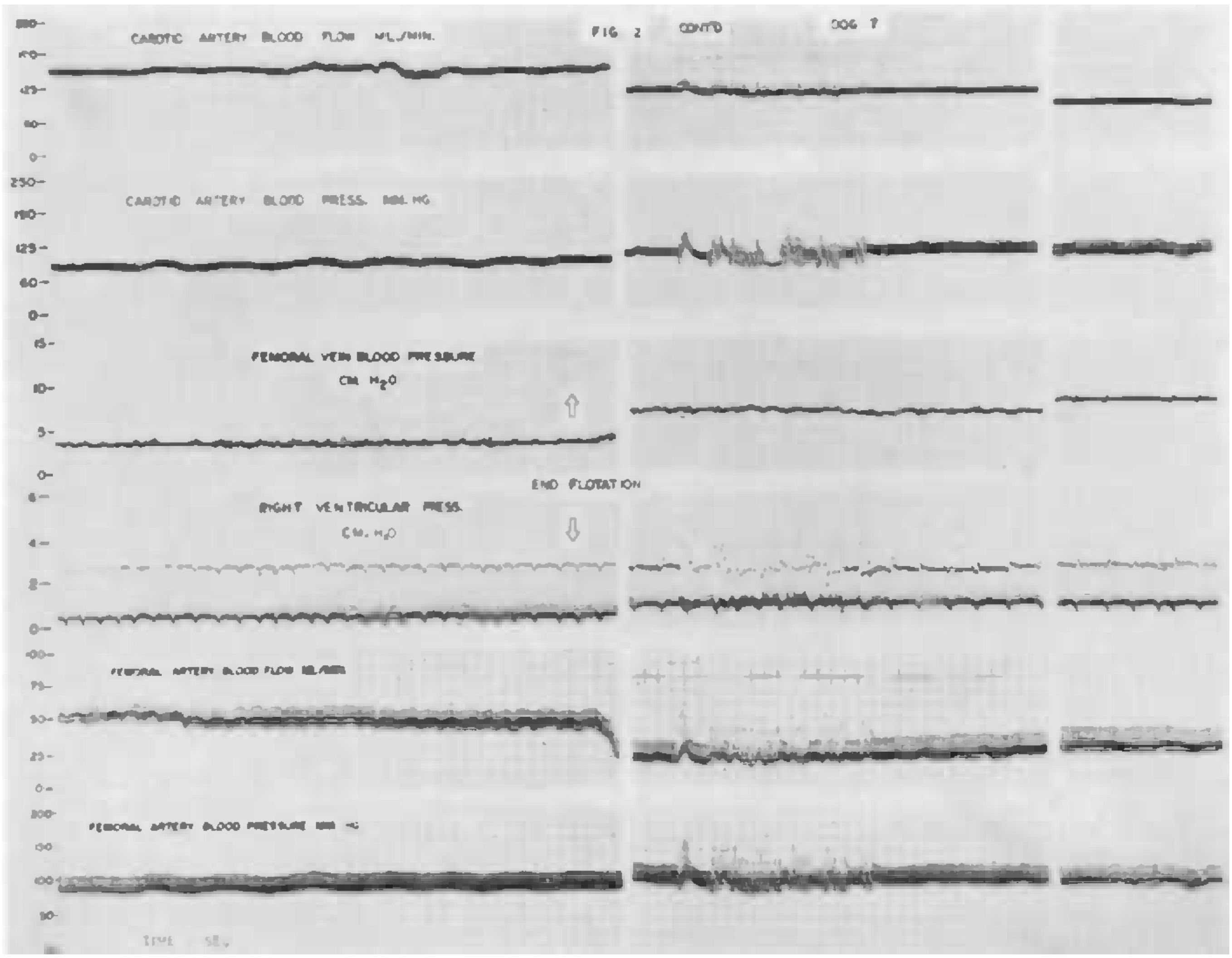

Fig. 2 Cont'd. Note cardiac irregularities as animal returns to control conditions. Flotation time = 235 min. Each time gap on recordings = 3 min.

TABLE I. HEMODYNAMIC RESPONSE TO THE HYPODYNAMIC STATE * (DURATION: 60-350 MINUTES)

Phase of Experiment	Heart Rate beats/min.	Carotid Artery Blood Pressure mm. Hg	Carotid Artery Blood Flow ml./min.	Femoral Artery Blood Pressure mm. Hg	Femoral Artery Blood Flow ml./min.	Femoral Vein Blood Pressure cm. H_2O	Right Ventricular Pressure cm. H_2O
Control	168 ± 11.3	130/100 ± 9.3/6.2	90 ± 7	127/100 ± 12.6/9.5	55 ± 11	6.0 ± 1.5	2.2/0.3 ± 0.3/0.1
Flotation **	168 ± 11.3	105/ 80 ± 10.1/6.7	115 ± 10	102/ 82 ± 9.3/5.8	110 ± 14	4.2 ± 0.9	1.5/0.3 ± 0.2/0.1
Recovery **	168 ± 11.3	120/ 90 ± 6.3/3.1	80 ± 5	122/ 91 ± 8.3/5.6	40 ± 6	6.8 ± 1.0	2.8/0.7 ± 0.3/0.3

* All figures are means ± S.D.
** Taken after stabilization.

One surprising result was the finding of little or no change in heart rate either on entering or leaving the water. In some animals a *very* slight, transient bradycardia or tachycardia was present for 10-30 seconds. This is all the more unusual since rather marked changes occurred in the blood pressures, right ventricular pressure and the blood flows. This would indicate that heart rate is not a reliable or sensitive index of the status of the cardiovascular system under these conditions.

Another unexpected result was the rise in blood flow upon entering the hypodynamic state. Since general body vasoconstriction occurred, as evidenced by the rise in arterial pressure and fall in venous pressure, this might have been expected to produce a decreased arterial blood flow. The data indicate that in the anesthetized animal the hypodynamic state does not appear to adversely affect the most important hemodynamic parameter, blood flow to these areas measured in the present study.

However, if the return to the normal gravity condition is considered during the recovery phase of the experiment, it is evident that the vascular system, and the reflexes which aid in the maintenance of homeostasis, are not capable of sufficient response to prevent a decrease in blood flow to below control level. This is rather surprising since the effect was noted even in those animals subjected to rather short periods of the hypodynamic state, i.e., 60 minutes. The decrease in blood flow is probably a result of a composite of reactions. The failure of the blood pressure to return to preflotation control levels probably represents the major contributory factor. In turn this would represent inability of the vascular/ or total body reflexes to produce sufficient compensatory vasoconstriction to offset the return to the normal gravity state. There is good reason to believe this is due to a type of adaptive relaxation of the vasculature rather than a gradual loss of tone of the vessels due to the prolonged nature of the experiment. This is thought to be true because it was noted that the adaptive state was rather quickly attained, i.e. within 10-15 minutes of the onset of simulated weightlessness, and remained relatively stabilized throughout the entire flotation period.

It is important to realize that the blood flow data in this study were obtained from areas of the body that might be classified as secondary or non-essential from the standpoint of many physiological functions. While it is true that the muscle mass of the body accounts for 45-50 per cent of the total, it is by no means a highly active area. The carotid artery in the dog accounts for relatively little of the blood supply to the brain, most of the flow going to extra cerebral areas. Since the data indicate both carotid and femoral blood flows increased during the hypodynamic state, other areas of the body must have been concomitantly deprived of their normal blood flow. These other areas, by a process of elimination, are the more vital organs of the body, namely the brain, kidney, gastrointestinal tract, etc. This does not mean that all these latter areas were subjected to a reduction in blood flow, but certainly one or two among them must since it is impossible to increase blood flow, by the magnitude measured in this study, in all areas of the body at once.

An important aspect of this study resides in the fact that the response of the cardiovascular system and the proprioceptive reflexes influencing it was not affected by the absolute duration of the hypodynamic state. The same qualitative results were obtained in the studies where flotation lasted 60 minutes as those in which it lasted 350 minutes.

The value of the results may be legitimately questioned on the basis that the animal is anesthetized causing the cardiovascular hemodynamics and reflexes to be altered. In the authors' opinion, there is very much less effect on the total, overall cardiovascular system than is commonly held. With proper control of depth of anesthesia, the parameters of the cardiovascular hemodynamics are altered minimally. This has been reported by other investigators[11] but seems to be largely ignored in most studies. Finally, the overall results of the present studies agree with those of other workers who have compared anesthetized and unanesthetized animals under conditions of subgravity in actual rocket flight.[12] This would indicate that the hypodynamic state as induced by water flotation techniques has many of the same effects on the hemodynamics as does actual orbital flight.

ACKNOWLEDGMENTS

The author wishes to express appreciation to John A. Richardson for the fabrication of the tank used in these studies.

The Eastman 910 Monomer (methyl-2-cyanoacrylate) was generously donated by Ethicon, Inc.

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