Maintenance of Cardiovascular Adaptability During Prolonged Weightlessness

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BECAUSE man in normal gravity is predominantly upright, an efficient system of reflex circulatory mechanisms has been developed which compensates for the hydrostatic pressure due to gravity. This hydrostatic pressure influence is a stimulus to the sympathetic control of the circulatory system so that adequate distribution of cardiac output occurs despite positional changes.

In a weightless environment, there will be no hydrostatic pressure effects and therefore no demand upon these reflex compensatory changes. Analogous situations occur in bed rest where hydrostatic pressure influences are minimized due to the horizontal position and in water immersion where hydrostatic pressure effects are neutralized because of ambient water pressure.

The loss of cardiovascular adaptability because of disuse of these compensatory reflexes is well known from prolonged bed rest and water immersion tests. Following these tests, tilt table studies reveal a deterioration in the capacity of the circulatory system to adjust to the erect posture as well as decreased tolerance to other functional tests such as heat chamber, treadmill and headward acceleration.[1,2,3] It is anticipated that during prolonged zero gravity, similar decrease in the capacity for cardiovascular support will result. In order to provide the orbiting astronaut with optimum tolerance for re-entry stresses, maintenance of cardiovascular adaptability must be insured.

The nature of the circulatory impairment appears to be an increased tendency to peripheral pooling of blood with resultant decreased venous return to the heart. Because of prolonged disuse, reflex sympathetic control has become less efficient, contributing to decreased venoconstrictor tone and increased venous pooling. In support of this are the observations that antigravity suits or other devices such as wrapping the lower extremities with Ace bandages provide complete support of the circulatory system during orthostatic testing. Such devices prevent or minimize peripheral pooling of blood and therefore promote adequate venous return to the heart.

Until recently, it was generally thought that suitable "protection" of the astronaut during zero or sub-gravity conditions could be obtained by an adequate program of exercises—such as, muscle tensing, manipulation of resistive or friction devices, joint resistive suits, etc. However, recent evidence indicates that this concept must be revised considerably. In a recent experiment five subjects were evaluated before and after a two week period of bed rest. Three of the subjects exercised daily in bed doing strenuous exercises of the setup and pushup variety. Although muscle tone was maintained in the three exercise subjects, they showed the same degree of tilt table and treadmill intolerance at the end of the two weeks as the nonexercise controls, reflecting loss of cardiovascular adaptability. Another recent experiment showed that weighting of the subjects during water immersion so that near normal weight sensations and demands for musculoskeletal support existed throughout the 6-hour tests failed to prevent cardiovascular deterioration. In this latter experiment normal muscle tone was maintained and the subjects experienced none of the oppressive heaviness usually noted initially upon emersion, yet they showed the same evidence

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of orthostatic intolerance as existed following their non-exercise immersion tests.

The stimulus for maintenance of cardiovascular adaptability is hydrostatic pressure in-

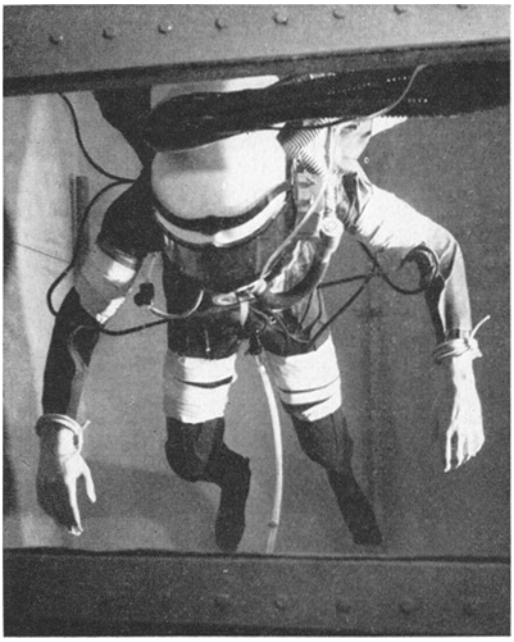

Fig. 1. Subject in the immersion tank during a six-hour test with tourniquet protection.

fluence. In the experiments described above, despite muscular exercise, such influences are absent or minimal and the reflex sympathetic control of circulation deteriorates through disuse. We can logically extend these inferences to the orbital situation and predict that in a weightless environment, even with programmed strenuous muscular exercise, the compensatory cardiovascular reflexes which depend upon hydrostatic pressure influences will not be maintained.

For a number of years, it has been known that an oscillating bed will prevent or significantly modify the loss of circulatory adaptability resulting from prolonged bed rest.[1] The mechanism of action apparently is by intermittently tilting the feet down lower than the heart, the resulting hydrostatic pressure head contributes to increased peripheral venous pressure and decreased venous return to the heart in a manner analogous to standing and adequate to maintain sympathetic reflex control.

Extending this concept further, the author has devised for use in the water immersion studies a system of intermittently obstructing venous return from the periphery by the use of multiple tourniquets. When inflated, they cause increased peripheral venous pressure and decreased venous return to the heart, simulating the hydrostatic pressure effects associated with standing and thereby intermittently "triggering" compensatory cardiovascular reflexes.

The purpose of this article is to present the results of the initial evaluation of this technique for possible application in prolonged zero gravity conditions.

METHODS

A detailed description of the water immersion facility is given in another report.[2] Five healthy young men ranging in age from 21 to 31 years were used as subjects. For all tests, the subjects wore a modified "dry" skin diving suit. A modified partial pressure helmet permitted balanced respiratory pressures. The subjects had unrestricted activity within the confines of the tank. Following the six-hour period of immersion with tourniquet protection, the orthostatic tolerance of each subject was determined and compared with that obtained following his previous six-hour immersion tests done with no protection.

The interconnected tourniquets were applied about the four extremities (Fig. 1) and connected to an air source and mercury manometer outside the tank. Every two minutes, the tourniquets were inflated to an effective pressure of 60 mm Hg, held for one minute, then released. This was done continuously throughout the six-hour immersion tests.

Orthostatic tolerance was determined by tilt-table testing, using a 90° tilt for 10 minutes, during which time electrocardiograms and blood pressures were obtained at minute intervals. The standard auscultatory technique of blood-pressure determination was used.

RESULTS

In all subjects, the tourniquet technique maintained normal or better than normal cardiovascular adaptability as measured by tilt-table had syncope following his previous six-hour immersion tests and was never able to exceed five to seven minutes of the tilt-table testing. Following immersion, with tourniquet protection,

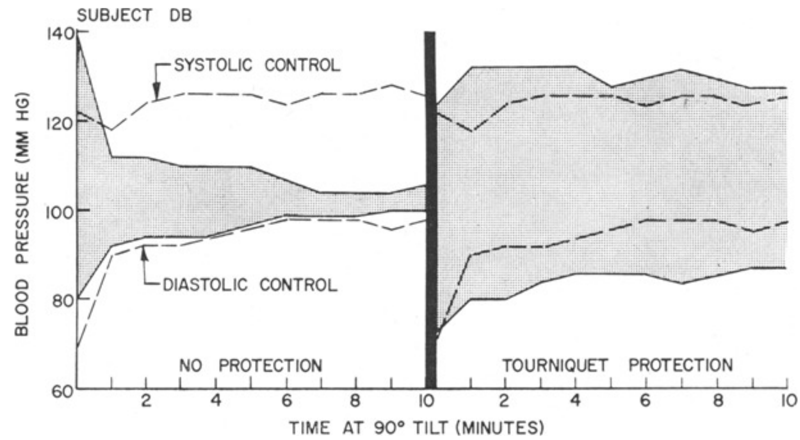

Fig. 2. Subject DB: Blood pressure response to tilt-table testing, demonstrating the changes from control systolic pressures (*top dotted line*) and changes from control diastolic pressures (*bottom dotted line*) observed following immersion tests with no protection (*left*) and with tourniquet protection (*right*).

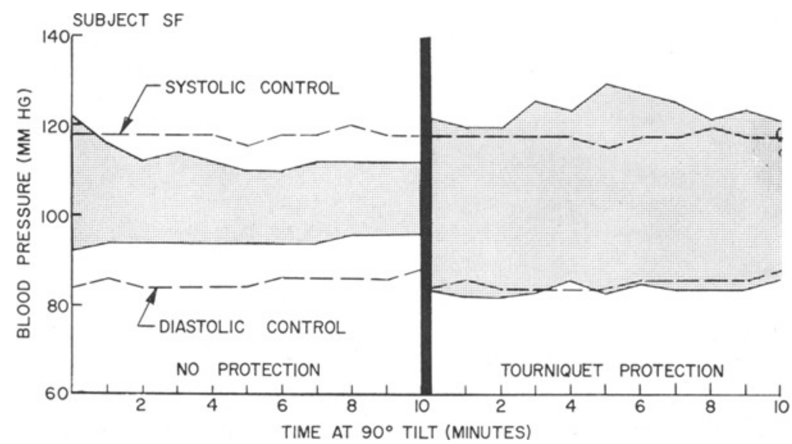

Fig. 3. Subject SF: Blood pressure response to tilt-table testing, demonstrating the changes from control systolic pressures (*top dotted line*) and changes from control diastolic pressures (*bottom dotted line*) observed following immersion tests with no protection (*left*) and with tourniquet protection (*right*).

testing. Following previous immersion tests with no protection, each subject had a decreased systolic and/or increased diastolic blood pressure contributing to significant narrowing of pulse pressure. One subject (RG) routinely the systolic blood pressure was maintained at or above the control range; the diastolic blood pressure was maintained at or below the control range and wide pulse pressures were maintained throughout in all subjects (Figs. 2-6).

The electrocardiograms revealed that the heart rates of each subject remained in the control range during tilt table testing and electrocardiographic changes previously observed, such as, increased amplitude of P waves, shifts in the QRS electrical axis, and orthostatic T wave changes were modified considerably.

During orthostatic testing, all subjects had previously become pale with cold, clammy skin and had demonstrated congestion and cyanosis of the dependent extremities. Following tourniquet protection, these changes were not evident during tilting and the appearance of each subject was essentially normal (control).

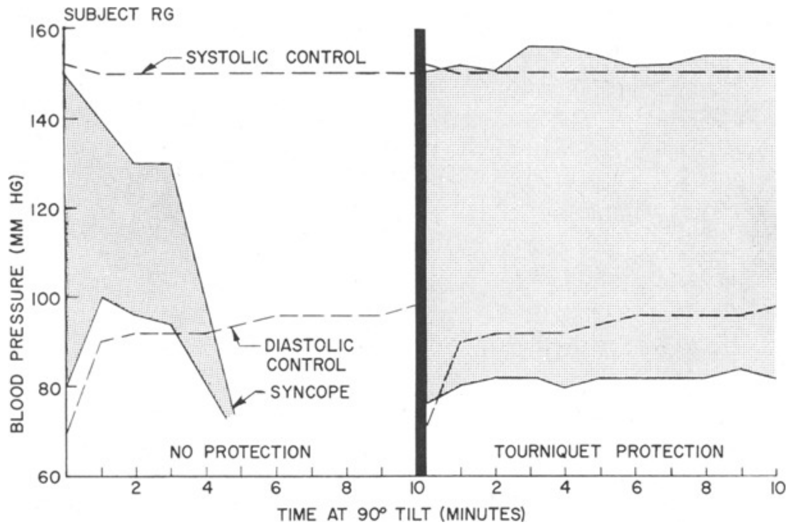

Fig. 4. Subject RG: Blood-pressure response to tilt-table testing, demonstrating the changes from control systolic pressures (*top dotted line*) and changes from control diastolic pressures (*bottom dotted line*) observed following immersion tests with no protection (*left*) and with tourniquet protection (*right*).

DISCUSSION

The use of the tourniquet technique, as described here, is essentially an extension of the oscillating bed principle and probably maintains cardiovascular adaptability by the same general mechanisms. By intermittently obstructing venous return, peripheral venous pressure is increased, blood tends to be pooled in the extremities and venous return to the heart is decreased. In this manner, hydrostatic pressure effects are simulated and the cardiovascular system retains its capacity to adjust adequately during positional changes.

This is the type of protective device which can be integrated readily into any of our currently used pressure garments. The inflation cycle in this study was one minute on, one minute off, throughout the six-hour test, resulting in venous obstruction about 50 per cent of the time. The orthostatic tolerance of all subjects after the immersion test with tourniquet protection was better than control indicating that the inflation profile could be altered either by decreasing effective pressure or by decreasing the total time of obstruction or both.

Much more work is needed to establish the optimum approach. It would certainly be of interest to know whether it is necessary to use the device throughout the test period or just in the latter portion. It should be added that this technique neither inconvenienced the subjects nor caused them discomfort. Several subjects slept for short periods during the test.

Regarding additional protective measures, one should keep in mind that after prolonged bed rest or water immersion, the anti-g suit is a very effective device to prevent peripheral venous pooling and insure more nearly normal circulatory dynamics. It is probable that this same benefit will be obtained following prolonged weightlessness when such a suit could be effectively utilized during re-entry and subsequent gravitational conditions.

It should be emphasized that although muscular exercise devices will be necessary for preventing loss of musculoskeletal effectiveness, such devices cannot be expected to maintain cardiovascular adaptability which depends upon hydrostatic pressure influences. Further research

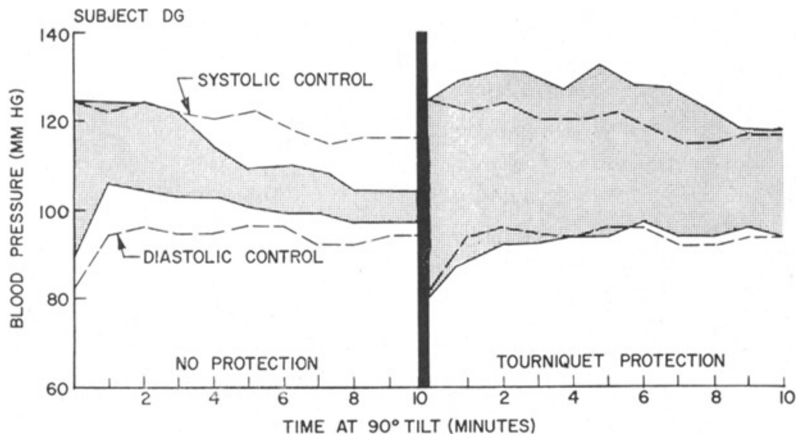

Fig. 5. Subject DG: Blood-pressure response to tilt-table testing, demonstrating the changes from control systolic pressures (*top dotted line*) and changes from control diastolic pressures (*bottom dotted line*) observed following immersion tests with no protection (*left*) and with tourniquet protection (*right*).

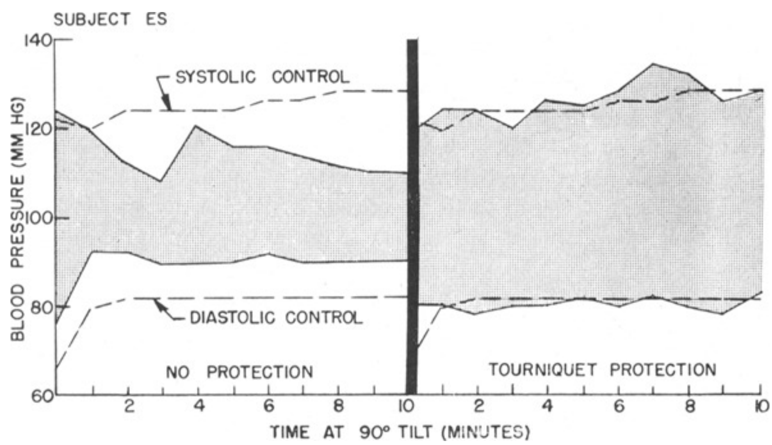

Fig. 6. Subject ES: Blood-pressure response to tilt-table testing, demonstrating the changes from control systolic pressures (*top dotted line*) and changes from control diastolic pressures (*bottom dotted line*) observed following immersion tests with no protection (*left*) and with tourniquet protection (*right*).

is necessary to devise the most efficient approach to protective techniques until such time as adequate artificial gravity is assured.

SUMMARY

It is expected that during prolonged zero gravity, because of the absence of hydrostatic pressure influences, special techniques will be necessary to maintain cardiovascular adaptability and provide the orbiting astronaut with optimum tolerance for re-entry stresses. The author has devised a multiple tourniquet approach to intermittently obstruct venous return from the periphery, simulating the hydrostatic pressure effects of standing and thereby "triggering" compensatory cardiovascular reflexes. Following six-hour periods of water immersion with tourniquet protection, the orthostatic tolerance of five subjects was determined and compared with that obtained following previous six-hour immersion tests with no protection. In all subjects, the tourniquet technique maintained normal or better than normal cardiovascular adaptability as measured by tilt table testing.

REFERENCES

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The Responsibility of the Drug Business

The activities of the universities and their research laboratories and those of the pharmaceutical industry are not competitive but complementary. There is an increasingly broad overlapping of interests. Both do and should have large and effective research programs. It is the prime function of the one to probe and to teach, and it is in our American system the function of the other to do research with the aim of finding and developing new health-giving aids which will come slowly or not at all if we place our dependence upon the government, or for that matter on universities, either state or private.—LOWELL T. COGGESHALL, M.D., Vice President, University of Chicago.