Effect of Extremity Cuff-Tourniquets on Tilt Table Tolerance After Water Immersion

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Tilt table intolerance of four healthy adult young males was studied in two water immersion experiments of six hours duration in an effort to reproduce a previous study reporting a protective effect from cuff-tourniquets applied to the extremities during immersion. Body weight, fluid intake, urine output and leg circumference measurements were made and recorded. After the first period of six hours of water immersion three of the four subjects experienced syncope during a tilt table test. Compared to pre-immersion tilt tests all subjects experienced marked changes in heart rate or blood pressure during tilting after immersion. A significant diuresis was not noted. During the second period of immersion cuff-tourniquets were applied to the four extremities and inflated to a pressure of 60 mm. Hg., with a one-minute-on, and one-minute-off cycle. Some degree of protection against tilt table intolerance after immersion was provided in this test; none of the three subjects experienced syncope or showed the marked blood pressure changes they had shown on the previous immersion test without cuffs.

STUDIES HAVE BEEN CONDUCTED that demonstrate cardiovascular deconditioning occurs with prolonged bed rest,[20,8,30,21,5,25,22,29,6,18] water immersion,[10,14,15,11,12,2,17] chair rest,[16] or space flight.[4,7] The physiological changes that occur in these experimental conditions which are responsible for the increase in heart rate, decrease in blood pressure and signs or symptoms of syncope during tilt table tests are not understood clearly. The lack of knowledge on the mechanism of deterioration of the cardiovascular system thus has made research on preventive and control measures difficult.

Anti-gravity suits have been found beneficial[18,19] in preventing orthostatic cardiovascular intolerance in patients, as well as normal subjects deconditioned by either bed rest or water immersion. Periodic rocking beds[30] in a gravity environment have been reported to produce some protective effect from the deconditioning associated with bed rest. Intermittent occlusive venous cuffs have been reported[10] to prevent the occurrence of tilt intolerance after water immersion. The purpose of the work reported in this paper was to reproduce some of the observations made in the water immersion experiment[10] in which cuffs provided a protective effect.

METHODS

Four healthy adult male college students in the age range 21 to 25 years who had participated previously in extensive bed rest studies[24] were used as subjects. Table I summarizes the subject characteristics.

The subjects underwent two six-hour periods of water immersion, preceded and followed by a tilt table test. During the periods of water immersion the subjects were dressed in bathing trunks and were immersed in a head-out position. They were allowed a minimal amount of activity in the pool but most of the time they remained in a sitting position. Accessory breathing apparatus was not used. The temperature of the water was maintained at approximately 93°F. throughout the periods of immersion.

TABLE I. SUBJECT CHARACTERISTICS

Subject Initial	Age (years)	Weight (kg.)	Height (cm.)	B.S.A.* (m²)	Occupation
C.E.R.	25	84.4	192.4	2.15	Student Athlete
R.S.H.	22	66.5	172.4	1.80	Student Athlete
W.F.M.	23	67.5	171.0	1.81	Dental Student
B.E.H.	21	70.2	177.8	1.88	Student

* From Dubois Body Surface Chart by Boothby and Sandiford

The day following test number one the subjects underwent a second period of immersion, test number two, during which they had cuff-tourniquets applied to all four extremities. The cuffs were 3-¾ inches wide and were held in place by a velcro material. Because of the posture the subjects maintained during immersion the cuffs on the lower extremities were located approximately 60-70 centimeters beneath the surface of the water. The cuffs were inflated from a pressure bottle air source to a pressure of 60 millimeters of mercury, with a one-minute-on, one-minute-off time cycle, and had an inflate and deflate period of approximately five seconds. Cuffs on all subjects were inflated simultaneously.

A tilt table test was performed before and after the water immersion periods using a tilt table with an English saddle type of support described elsewhere.[26] The tilt table was motorized and tilted from horizontal to 70° in thirty seconds. With syncope, or impending syncope, the gear mechanism of the table was disengaged and the subject was tilted down immediately. The subject was transported from the immersion tank to the tilt table test area by means of a stretcher and immediately went into the tilt table test.

The electrocardiogram, impedance pneumogram, cuff-microphone blood pressure and leg circumference changes were measured during the tilt test using an instrumentation system described elsewhere.[28] The impedance pneumogram and electrocardiogram were taken from electrodes placed across the thorax in the fifth

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or sixth intercostal space. Indirect blood pressure apparatus[9] was attached to the right arm with a crystal microphone located over the brachial artery; the cuff was operated in 30 second cycles. Leg circumference measurements were made using a Whitney[31] mercury-in-rubber strain gauge apparatus applied to the calf of each leg. A five-minute baseline recording was obtained prior to a 20-minute tilt to the 70° position. A five-minute period of recording then was obtained after return of the subject to the horizontal position.

The subjects were immersed from 13:00 to 19:00 o'clock to correspond to a urine collection period that was used for a previous 90-day study[24] on this group of subjects. During the periods of immersion intake and output were recorded carefully. Weights were obtained prior to and after immersion. The subjects were allowed to drink fluid *ad libitum*. They were fed after the tilt procedure which immediately preceded the immersion period and this intake was included as part of their over-all intake. A malted milk was given to them after approximately four hours of immersion.

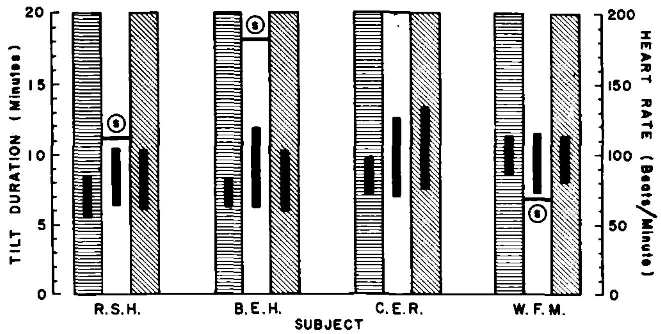

Fig. 1. Summary of tilt characteristics for water immersion subjects. The height of the first bar for each subject represents the tilt duration for the control tilt, the height of the second bar represents the tilt duration for the tilt following 6 hours of water immersion and the height of the third bar represents the tilt duration for the water immersion experiment to which extremity cuffs were added. The occurrence of syncope is represented by S. The solid lines in the bar graphs represent the change in heart rate from a pre-tilt five minute average to the maximum one minute average in the 70° position.

RESULTS

All four subjects showed a normal response to the control tilt prior to water immersion which was comparable with the responses observed in extensive tilt studies performed on them previously over a period of several months. There was noted an increase in heart rate and a slight rise in the diastolic blood pressure and a slight decrease in the systolic blood pressure, with a distinct narrowing of pulse pressure. There was no definite downward trend of systolic or diastolic blood pressure. There were no signs or symptoms of impending syncope during the control tilt table procedure.

Three of the four subjects showed syncopal reactions following the first six-hour period of water immersion. Figure 1 summarizes the duration of tilt procedure by bar graphs. The change from a pre-tilt, five-minute average heart rate to the maximum one-minute average heart rate during tilt for the subjects is shown by a darkened bar line in the center of the bar representing duration of tilting. The third subject, C. E. R., did not show syncope but did demonstrate a significant rise in heart rate in his first post-immersion tilt test.

During the tilt test following the second water immersion period, to which a cuff-tourniquet treatment

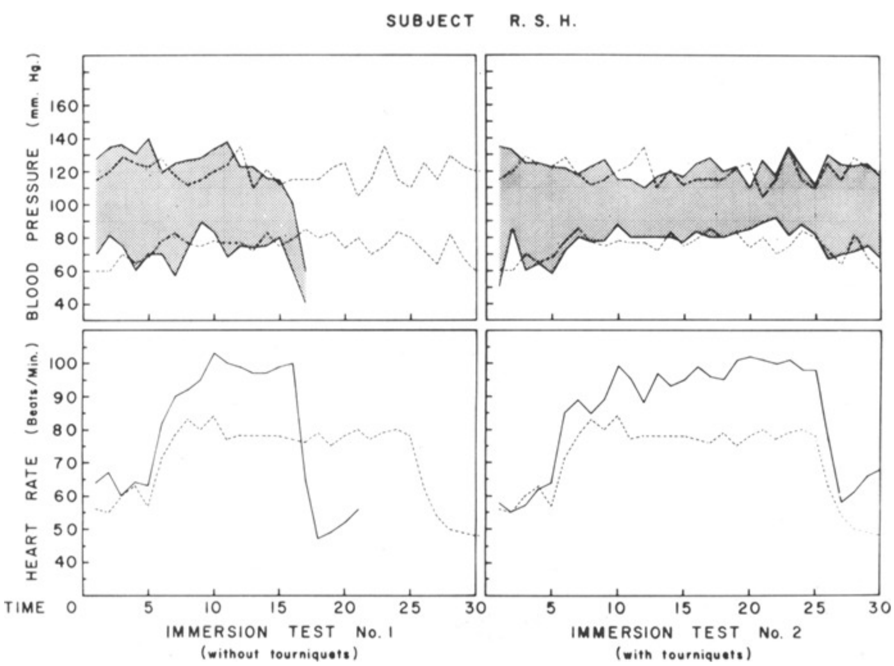

Fig. 2. Blood pressure and heart rate response to tilting before and after water immersion. Tilt-up starts at time five minutes and tilt-down at 25 minutes unless syncope occurs and the subject is tilted down sooner. The dotted lines show results of pre-immersion control tilt and the solid lines show the results to tilting after immersion.

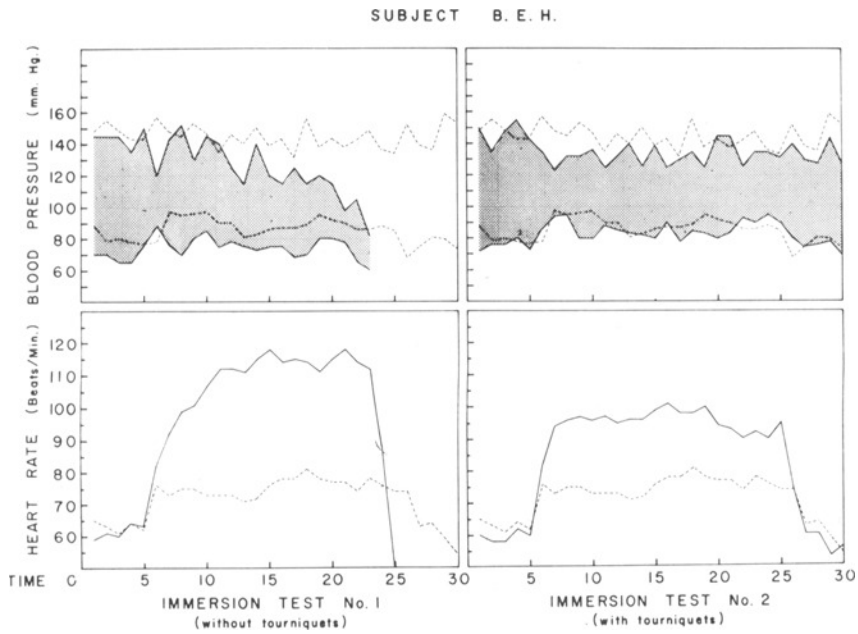

Fig. 3. Blood pressure and heart rate response to tilting before and after water immersion. Tilt-up starts at time five minutes and tilt-down at 25 minutes unless syncope occurs and the subject is tilted down sooner. The dotted lines show results of a pre-immersion control tilt and the solid lines show the results to tilting after immersion.

had been added, none of the four subjects experienced syncope. There was, however, still evidence of an increase in heart rate with tilting compared to control values, although the change in heart rate was not as great as after the first test.

Figures 2, 3, 4 and 5 show the tilt table data in graphic form for each individual to allow ready comparison of the responses for the various test circumstances. Dashed lines represent control values and solid lines the post-immersion values. Five minutes of control data is presented prior to tilting to 70° and five minutes of recovery data is presented after tilt down.

Subject weights did not change significantly during the immersion periods and the minor changes are accounted for by the intake-output differences during the test. None of the subjects complained of excessive thirst at any time. Table II presents the change in body weight, oral intake and urine output data obtained during the two tests. There appeared to be some difference in the volume outputs for the two immersion periods

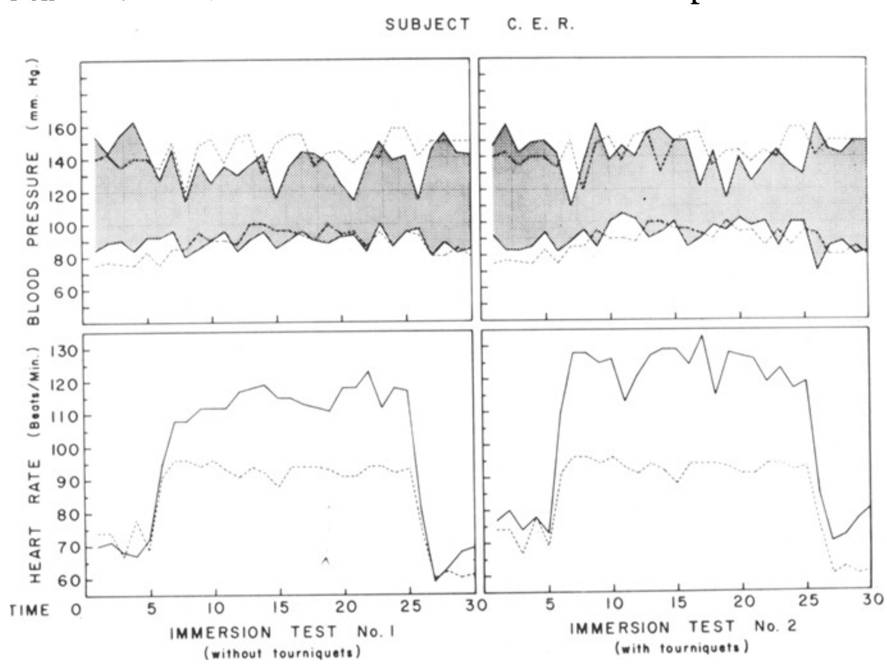

Fig. 4. Blood pressure and heart response to tilting before and after water immersion. Tilt-up starts at time five minutes and tilt-down at 25 minutes unless syncope occurs and the subject is tilted down sooner. The dotted lines show results of a pre-immersion control tilt and the solid lines show the results of tilting after immersion.

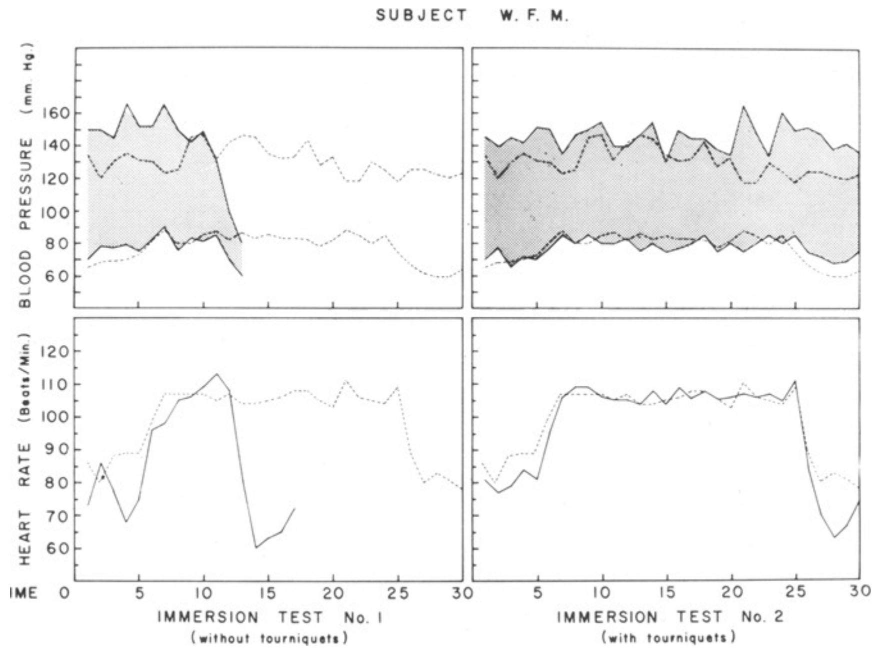

Fig. 5. Blood pressure and heart rate response to tilting before and after water immersion. Tilt-up starts at time five minutes and tilt-down at 25 minutes unless syncope occurs and the subject is tilted down sooner. The dotted lines show results of a pre-immersion control tilt and the solid lines show the results to tilting after immersion.

ORAL INTAKE—URINE OUTPUT DURING WATER IMMERSION

		Test No. 1			Test No. 2.		
Subject	Control (ml.)*	Intake (ml.)	Output (ml.)	Weight Change(kg.)	Intake (ml.)	Output (ml.)	Weight Change(kg.)
C.E.R.	200 290 560	1200	900	—0.2	1160	530	+0.3
R.S.H.	220 295 385	800	510	—0.1	1500	190	+0.9
W.F.M.	270 500 770	800	390	—0.2	1300	360	+0.6
B.E.H.	195 412 770	1000	760	0.0	1500	620	+0.3

* One week control on each subject during normal activity, giving average urine volumes with minimum and maximum values for these periods above and below the average value.

but the urine specific gravity did not change significantly during the period of immersion. Total urine volumes were somewhat higher than the average volume outputs for corresponding timed periods of collection in studies performed previously on the subjects but the range in day-to-day variation in these earlier studies is large enough to make it impossible to say that a significant diuresis existed during this water immersion study.

Leg calf measurements made in the recumbent position on the tilt table prior to tilt did not show significant changes post-immersion compared to pre-immersion. Calf circumference changes during tilt ranged from 3 to 5 per cent during the twenty-minute tilt but there was no good correlation of this with the degree of tilt table intolerance observed.

DISCUSSION

The mechanism of the protective effect of the cuff-tourniquets suggested in Graveline's experiment[10] and reproduced to some extent in this study is not clear. Interpretation of the effects becomes difficult because of the many complicating factors that result from placing a person in a warm and wet environment, and one which provides pressure forces that act upon the body cavities in a poorly understood manner. Of significance, however, is that tilt table intolerance does occur with water immersion in as relatively a short time span as has been found in space flights, and that it is prevented under experimental conditions identical to that which produces the deconditioning except for the addition of extremity cuff-tourniquets. Of even more significance is that this type of treatment or preventive technique offers itself to application to space flight situations since its mechanism of operation does not depend on a gravity environment. However, the likelihood of protection from cardiovascular deconditioning of space flight by a similar cuff-tourniquet technique would likely depend on a common mechanism of production to that found with water immersion. A possible mechanism to explain some of the factors responsible for the tilt table intolerance seen after water immersion is discussed elsewhere[27] in observations made on the same group of subjects who participated in the study reported herein.

The use of subjects in this experiment who have had considerable experience with tilt test procedures lessens the likelihood of any sporadic subject responses because of extreme anxiety or uncertainties of experimental procedures on the part of the subjects. Further, since the two experiments were performed in close time relationship, any bias due to lack of reconditioning of the subjects would be against reproducing the findings of Graveline.[10]

Diuretic responses have been known to occur with prolonged water immersion. Bazett[1] noted this diuresis as early as 1924 and numerous other observers[14,11,12,2,13] have confirmed it. One group,[3] however, did not report a diuresis with water immersion. The failure to observe a significant diuresis in this study raises further questions as to the meaning of diuresis observed by others but the failure to observe a marked diuresis and intense thirst, while at the same time observing considerable signs of cardiovascular deconditioning points to this diuresis being a less significant contributing factor to the tilt intolerance. Consideration must be given to the fact that these subjects previously had undergone many test procedures in the experimental laboratory. Anxiety in an inexperienced subject could result in a chain-reaction of increased-intake, increased-output to explain some of the observations in other studies. It is also possible that this group of subjects may have experienced a diuretic response if they had been immersed for a longer period of time. A more detailed account of the fluid-electrolyte and plasma volume responses found in this experiment is completed and is reported elsewhere in this issue.[27]

Cardiovascular deconditioning is spoken of in terms of the orthostatic increase in heart rate, drop in blood pressure and signs and symptoms of impending or actual syncope. From the experience of the author it would seem that the order of severity of tilt intolerance after prolonged bed rest is reflected first in heart rate changes, next by narrowing of pulse pressure with a trend downward in blood pressure, with systolic pressure falling more predominantly until the presyncopal condition presents, and then finally syncope. It has been noted[23] that in the final minutes before syncope the beat-by-beat variation in heart rate became minimized and the heart rate decreased at the same time that blood pressure decreased. This parallel drop of heart rate and blood pressure is different from the out-of-phase relationship seen when the subject compensates to the upright position. The responses to tilting after water immersion seem comparable to those observed after bed rest, although they may be produced by much shorter exposure to the experimental deconditioning test.

A point that deserves more consideration in evaluating the protective effect of cuff-tourniquets in this experiment is raised because of counteracting effects produced because of varying depths of the cuffs below water level. In this experiment a 60 millimeter mercury pressure referenced to the atmosphere was applied to all cuffs. The effect of this pressure in producing additional constriction to the lower extremities above that resulting from the weight of the water itself is the force difference of the pressure applied to the cuff and the pressure force produced by the weight of the water. The implication in this experiment is that perhaps more of the "treatment effect" resulted from the cuffs on the upper extremities.

The simplicity of this experiment and the complexity of the changes in physiological mechanisms with water immersion raise as many questions as are answered.

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