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# Physiological Responses to Prolonged Bed Rest and Fluid Immersion in Man: A Compendium of Research (1974-1980)

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John E. Greenleaf, Lori Silverstein, Judy Bliss,  
Vicki Langenheim, Heidi Rossow and Clinton Chao

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## TABLE OF CONTENTS

	Page
INTRODUCTION .....	v
BED REST .....	1
References and Abstracts .....	3
Additional Selected Bibliography .....	55
Subject Index .....	58
Author Index .....	71
IMMERSION .....	75
References and Abstracts .....	77
Additional Selected Bibliography .....	99
Subject Index .....	101
Author Index .....	109

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## INTRODUCTION

The purpose of this compendium is to summarize clinical observations and results from more basic studies that help to elucidate the physiological mechanisms of the adaptation of man to bed rest and fluid immersion. Some additional studies are included that provide background information in the form of reviews or summaries.

This volume is a continuation of two previously published volumes: (a) *Adaptation to Prolonged Bed Rest in Man: A Compendium of Research*, by J. E. Greenleaf, C. J. Greenleaf, D. Van Derveer, and K. J. Dorchak (NASA TM X-3307, 1976); and (b) *Physiologic Responses to Water Immersion in Man: A Compendium of Research*, by J. Kollias, D. Van Derveer, K. J. Dorchak, and J. E. Greenleaf (NASA TM X-3308, 1976). Those volumes presented abstracts of material from early works through December 1973. This compendium includes material published from 1974 through December 1980.

The abstracts and annotations are compiled in alphabetical order by first author and are numbered serially. Subject and author indices are provided. Note that numbers shown with the index entries are abstract numbers, not page numbers.

Again, we thank our many colleagues who sent reprints of their work, and apologize to those whose studies we have inadvertently overlooked.

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**Bedrest**

## REFERENCES AND ABSTRACTS

1. **Aleksandrov, A. N.; and Kochetov, A. K.:**  
Effect of 30-Day Hypokinesia in Combination with LBNP Training on Some Indices of the Functional State of the Cardiovascular System at Rest.  
*Kosmich. Biol. Aviak. Med.*, vol. 8, 1974, pp. 71-72.

### Authors' Abstract

The effect of 30-day bed rest and LBNP training on the functional state of the cardiovascular system at rest was studied in two groups of test subjects. A moderate decline in tone and a delay in blood flow rate were noted in the leg vessels (mainly venules). The systolic blood volume decreased. The cardiac output at first decreased and then gradually increased, reaching the initial level by the 30th day, due to an increase in the heart rate. The changes in the EKG T-wave suggested metabolic changes in the myocardium. These changes in the EKG were more distinct in test subjects who were daily subjected to LBNP training.

2. **Anashkin, O. D.; Trushinskiy, Z. K.; Reva, F. V.; and Shatunina, T. P.:**  
Effect of Hydrostatic Factor on Orthostatic Stability and Physical Fitness of Man during 60-Day Antiorthostatic Hypokinesia.  
*Kosmich. Biol. Aviak. Med.*, vol. 13, 1980, pp. 78-80.

### Annotation

**Purpose.** To investigate the influence of the hydrostatic factor on orthostatic tolerance and physical fitness of man in the course of long-term antiorthostatic hypokinesia.

**Method.** Six male subjects, 19-37 yr.

1. Three subjects in bed rest at  $-4.5^\circ$  down for 60 days.
2. Three subjects in 2 hr/day sitting with 22 hr in antiorthostatic position; legs horizontal 45 min.
3. Twenty-minute passive orthostatic test ( $75^\circ$ ) on days 11, 18, 25, 32, 39, 46, 52, and 61.
4. Heart rate and arterial pressure recorded.
5. Physical fitness established by PCW-170.

**Results.** Orthostatic factor (legs horizontal in sitting position) had no beneficial effect on orthostatic stability. Physical work capacity decreased by 33% and 34% in control and hydrostatic-factor groups, respectively.

**Conclusion.** Daily use of a hydrostatic factor during 60 days of bed rest had no beneficial effect on orthostatic stability and physical work capacity.

3. **Artishuk, V. N.; Litsov, A. N.; Stupnitskiy, V. P., and Yakushkov, Yu. V.:**  
Effect of 30-Day Hypokinesia on the Dynamics of Higher Nervous Activity and Sleep of an Operator.  
*Kosmich. Biol. Aviak. Med.*, vol. 8, 1974, pp. 75-79.

### Annotation

**Purpose.** To investigate indices of human higher nervous activity and sleep in hypokinesia and to evaluate prophylactic effect of physical exercise and electric stimulation of muscles.

**Subjects.** Nine males, 22-33 yr.

**Procedure.** Three subjects exercised, three were stimulated electrically, and three served as the control group.

### **Method.**

1. Visual observation of psychic activity and mood-monitoring data.
2. Sensomotor reactions to sonic stimuli.
3. Test problems.
4. Perception of tachistoscopically displayed scales.
5. Time tests.
6. Motor activity in sleep.

**Results.** The study of mood and behavior showed several distinct periods. Period No. 1 (3-4 days) was characterized by a good mood. Period No. 2 (5-15 days) showed decreased psychic tone and instability of mood. Period No. 3 (20-30 days) showed the mood improving.

The sensomotor reactions showed insignificant increase in latent periods and decrease in accuracy and rate of reactant of instrument information.

Decreased duration, decreased percentage of quiet 5-min periods, and a lengthening of time required to fall asleep occurred in all three groups.

4. Asyamolov, B. F.; Panchenko, V. S.; and Pestov, I. D.  
Water Load as a Method for Changing the Orthostatic Reaction in Man After Brief Hypodynamia.  
*Kosmich. Biol. Aviak. Med.*, vol. 7, 1973, pp. 80-82.

### **Annotation**

**Purpose.** To study the effect of hydration on orthostatic tolerance in brief hypodynamia with increased water loads. To investigate simple methods for prevention of orthostatic disorders.

**Method.** Four males, 19-20 yr, were investigated in a series of five tests. Active orthostatic test (OT) treatments:

1. 2% B.W. water load in eighth hour of ordinary activity.
2. 4-hr bed confinement without water load.
3. 12-hr bed confinement; 2% water load at  $t = 8$  hr.
4. 4-hr confinement with 1% water load at  $t = 3$  hr.
5. 4-hr confinement with 0.5% water load at  $t = 3$  hr.

After water intake, 3 to 5 orthostatic tests were carried out at 30-min intervals while subjects were at bed rest.

Pulse rate was used as the index of orthostatic reaction.

### **Results.**

1. Successive (OT) test caused gradual decrease in orthostatic tachycardia.
2. Water load without bed rest led to decrease in pulse rate.
3. With hypodynamia and fluid intake there was a lessening of pulse reaction in OT.
4. At 30 min after water intake, pulse was reliably lower than in OS-1 ( $P < 0.01$ ).

**Conclusion.** There is a direct dependence between the excess fluid in the body and the degree of change in pulse rate in an orthostatic test.

5. **Ayamolov, B. F.; Panchenko, V. S.; Pestov, I. D.; and Tikhonov, M. A.:**  
**Determining Excess Pressure on the Lower Part of the Body Ensuring Prevention of Orthostatic Impairments.**  
*Kosmich. Biol. Aviak. Med.*, vol. 7, 1973, pp. 56-61.

**Authors' Abstract**

Lower-body positive pressure applied by means of an antigravity suit decreased orthostatic reactions of test subjects exposed to simulated weightlessness (18-hr water immersion, 30-day bed rest). Lower-body positive pressures of 50 and 35-mm Hg proved to be effective and well tolerated, whereas that of 20-mm Hg proved to be inadequate for preventing orthostatic disturbances. The greatest effect in the prevention of orthostatic disturbances was achieved by a combination of different countermeasures.

6. **Belay, V. Ye.; and Uglova, N. N.:**  
**Effect of 30-Day Hypokinesia on Body Reactivity to Drugs.**  
*Kosmich. Biol. Aviak. Med.*, vol. 8, 1974, pp. 83-84.

**Annotation**

**Purpose.** To determine the effect of a combination of CNS stimulants on physiological indices of subjects in hypokinesia.

**Method.**

1. Six subjects in two groups.
2. Two subjects underwent LBNP on days 26-30 for 2.5 hr/day, with peak values up to 50-55 mm Hg.
3. Drug complex consisted of benzedrine (0.01 g), caffeine, and sodium benzoate (0.1 g) and securinine (0.002 g) given per os.
4. Investigations were carried out in the morning while subjects fasted or 2-3 hr after food intake.
5. Parameters measured included ECG, arterial pressure, respiration rate, lung ventilation, oxygen consumption, and CO<sub>2</sub> elimination under physical load.
6. Indices were taken 1 hr before and after drug intake.
7. Five investigations were carried out: before hypokinetic exposure, on the 5th and 20th day of bed rest, and on the 2nd and 10th days of recovery.

**Results.**

1. Observed no significant difference in body reactivity among the two groups to the combination of drugs used.
2. Found decrease in frequency of cardiac contractions after drug administration.
3. The indices of external respiration and gas exchange changed in different directions over the course of the experiment, as did the O<sub>2</sub> consumption and CO<sub>2</sub> release.

**Conclusion.** Detected quantitative differences in the cardiovascular system and respiration may indicate a change in reactivity to drugs under hypokinetic conditions.

7. **Belaya, N. A.; Amirov, R. Z.; Shaposhnikov, Ye. A.; Lebedeva, I. P.; and Sologub, B. S.:**  
**Some Features of the Bioelectric Activity of the Muscles with Prolonged Hypokinesia.**  
*Voprosy Kurortologii, Fizioterapii i Lechebnoy Fizicheskoy Kul'tury*, vol. 40, 1975, pp. 238-241.

**Annotation**

**Purpose.** To study bioelectric activity of muscles in hypokinesia.



**Method.** Twenty-four men, 19-34 yr.

1. Eight in bed rest for 30 days.
2. Six in normal activity (control).
3. Treatment-recovery included (two groups, nine persons used) massage, therapeutic physical culture, balneologic procedures, and rehabilitative regimens.
4. Group 1 (six subjects) head down 6°; group 2 (six subjects) head up 6°; and group 3 (six subjects) head down 2°.

**Analyses.** Electromyogram of flexors and extensor of hands and feet were performed by global induction.

**Results.**

1. Some shifts in bioelectric muscular activity were noted (not exceeding Type I EMG) on days 14 and 15.
2. The thigh perimeter at the skin decreased in all subjects by an average of 1.5-2.5 cm.
3. Spontaneous bioelectrical discharges of the type of curtailed rhythmic activity and individual potentials of fasciculations were encountered.

**Conclusion.** Curtailed bioelectric muscle activity may indicate an increase in synchronization of stimulation of the motor neurons which is associated with a change in excitability and lability of their individual groups. The transient nature of these changes is corroborated by their disappearance with maximum contraction which indicates the absence of absolute pathologic changes.

8. **Beregovkin, A. V.; and Kalinichenko, V. V.:**  
Reactions of the Cardiovascular System During 30-Day Simulation of Weightlessness by Means of Antiorthostatic Hypokinesia.  
*Kosmich. Biol. Aviak. Med.*, vol. 8, 1974, pp. 72-77.

#### **Authors' Abstract**

Cardiovascular reactions of nine healthy male test subjects were investigated during 30-day bed rest with their heads tilted down 4° from the horizontal. Before and after the bed-rest experiment the test subjects performed 5-min vertical standing tests. During bed-rest tests the subjects exhibited moderate changes in the functional state of the cardiovascular system. The use of preventive measures – physical exercises, lower-body negative pressure, and muscle electrostimulation – had a favorable effect on cardiovascular conditioning. This was suggested by a faster recovery of the functional state of the cardiovascular system after completion of the experiment. Antiorthostatic hypokinesia is an acceptable weightlessness stimulation method in selecting preventive measures of cardiovascular deconditioning.

9. **Bokhov, B. B.; Kornilova, L. N.; and Yakovleva, I. Ya.:**  
Perception of Coordinates of Two-Dimensional Space in Prolonged Experimental Hypokinesia.  
*Kosmich. Biol. Aviak. Med.*, vol. 9, 1975, pp. 51-56.

#### **Authors' Abstract**

The effect of 30-day hypokinesia on perception of the subjective optical vertical (SOV) was studied. Test subjects who were in an antiorthostatic position (at an angle of 96° to the vertical) exhibited the greatest changes in SOV perception and illusive perception of the spatial position of the body. During the first 2 days of the experiment and 10 days thereafter they exhibited an increase by a factor of 1.5 in the error in SOV perception. In addition, they exhibited asymmetrical perception of the SOV on the right and left sides. In all cases, the direction of SOV displacement from the true line coincided with the body position. Test subjects who were kept at an angle of 84° to the vertical (orthostatic hypokinesia) exhibited only illusions of body position during the first day and a unilateral increase in the error in SOV perception after

the experiment. Test subjects who underwent preventive treatment following antiorthostatic hypokinesia (at an angle of 94° to the vertical) exhibited no asymmetry and an insignificant error in SOV perception. These findings are discussed in relation to changes in functioning of pressure-tension receptors and disorders in skeletal tone during hypokinesia.

10. **Budylna, S. M.; Khvatova, V. A.; and Volozhin, A. I.:**  
Effect of Orthostatic and Antiorthostatic Hypokinesia on Human Taste Sensitivity.  
*Kosmich. Biol. Aviak. Med.*, vol. 10, 1976, pp. 27-80.

#### **Annotation**

**Purpose.** To determine the influence of antiorthostatic and orthostatic hypokinesia on the sensitivity of the tongue and the activity of the gastrolingual reflex.

**Method.** Eighteen young persons were divided into three equal groups and underwent 30 days of strict bed rest. Group 1 experienced bed rest with the head end raised 6° (orthostatic); group 2 experienced bed rest with the head end lowered 2° (antiorthostatic); and group 3 experienced bed rest with the head end lowered 6° (antiorthostatic). The taste sensitivity of the tongue was tested for sweet, salty, acid, and bitter by droplet stimuli. The comparison of taste bud mobilization before and after taking of food was used to ascertain the gastrolingual reflex.

**Results.** In all groups, the threshold of taste sensitivity decreased by the 4th day. In group 1 taste sensitivity (especially to acid and salt) increased. During recovery, normalization occurred, expressed by a greater degree of sensitivity for sweet stimuli. Also during recovery, functional activity of the receptor apparatus normalized during fasting, but amplitude of the gastrolingual reflex remained low.

In group 2, taste sensitivity slightly decreased, but sensitivity to acid and bitter did not change (however, there was a new high at the end of hypokinesia). Normalization was similar to that of group 1, except there was normalization of the gastrolingual reflex during fasting.

In group 3, the sweet and salty sensitivity threshold decreased, but did not change in sensitivity to acid and bitter stimuli. By the 27th day, sensitivity to all taste substances decreased; threshold of taste stimulation increased. Rapid normalization occurred during recovery. There was a considerable increase in the level of the taste buds' activity during fasting. The level of mobilization decreased by the 13th day. The amplitude of the gastrolingual reflex decreased and did not normalize.

**Conclusion.** Restriction of motor activity causes a well-expressed change in the activity of the analyzer systems of the body responsible for perception and analysis of taste stimuli.

11. **Bychkov, V. P.; Borodulina, I. I.; and Sivuk, A. K.:**  
Products of Protein Metabolism in Urine of Man Submitted to 182-Day Antiorthostatic Hypokinesia.  
*Kosmich. Biol. Aviak. Med.*, vol. 13, 1979, pp. 39-42.

#### **Annotation**

**Purpose.** To study the change in nitrogen metabolism in long-term antiorthostatic hypokinesia.

**Method.** Eighteen men (31-40 yrs) were divided into three groups. Group 1 performed exercise at 350 to 500 kcal/hr twice daily; group 2 performed the exercises for 20 min/day; and group 3 served as the control. The mean 24-hr urine was sampled for

1. Total nitrogen (Conway diffusion).
2. Urea (Watt and Shrisp).
3. Creatine and creatinine (Brown).

Total nitrogen in the food was also assayed.

### **Results.**

In group 1, total nitrogen excretion increased until the 90th day of the study.

In group 2, total nitrogen remained elevated until the 30th day.

In group 3, there was no significant change.

Urea excretion followed a similar pattern with a group-1 increase until the 134th day. Group 2 decreased in the first 7 days, then raised above the base excretion level, then dropped off. The control group followed a similar pattern.

Creatinine excretion increased in the first and second groups. The third group had a statistically higher excretion rate than the first.

On the 30th day, nitrogen balance was -0.53 g for the first group, -0.90 g for the second, and -1.19 g for the control. After the 30th day, nitrogen balance started to increase and for group 2 leveled off at about 1.

**Conclusion.** The stability of the second group's nitrogen balance possibly relates to the fact that their energy expenditure was close to their normal level. These data would indicate the desirability of early adaptation to physical activity before weightlessness to prevent such activity from becoming an additional stressor in weightlessness.

### **12. Chambers, A.; and Vykukal, H. C.:**

The Effects of Bed Rest on Crew Performance during Simulated Shuttle Reentry.

*NASA TN D-7503, 1, 1974, pp. 1-29.*

#### **Authors' Abstract**

A centrifuge study was carried out to measure physiological stress and control task performance during simulated Space Shuttle Orbiter reentry. Jet pilots were tested with and without anti-G suit protection. The pilots were exposed to simulated Space Shuttle reentry acceleration profiles before and after 10 days of complete bed rest, which produced physiological deconditioning similar to that resulting from prolonged exposure to orbital zero G. Pilot performance in selected control tasks was determined during simulated reentry and before and after each "flight." Physiological stress during reentry was determined by monitoring heart rate, blood pressure, and respiration rate.

Study results indicate: (1) heart rate increased during the simulated reentry when no G protection was given, and remained at or below pre-bed-rest values when G-suits were used; (2) pilots preferred the use of G-suits to muscular contraction for control of vision tunneling and grayout during reentry, (3) prolonged bed rest did not alter blood pressure or respiration rate during reentry, but the peak reentry acceleration level did; and (4) pilot performance was not affected by prolonged bed rest or simulated reentry.

### **13. Chavarri, M.; Ganguly, A.; Luetscher, J. A.; and Zager, P. G.:**

Effect of Bedrest on Circadian Rhythms of Plasma Renin, Aldosterone, and Cortisol.

*Aviat. Space Environ. Med.*, vol. 48, 1977, pp. 633-636.

#### **Authors' Abstract**

Previous studies of normal men after 5 days of bed rest showed that circulatory instability on head-up tilt or standing is preceded by increased plasma renin activity (PRA) at bed rest. In the present study, the circadian rhythms of PRA, aldosterone, and cortisol have been observed in five normal men on a constant diet. In ambulatory controls, PRA and aldosterone increased normally after standing. On the third morning of bed rest, PRA was higher than before, and at noon, PRA was higher than in standing controls. The nocturnal peaks of PRA, resulting from episodic renin secretion during sleep, were higher after bed rest. Plasma aldosterone was also increased by bed rest. The findings are compatible with the theory that intermittent beta-adrenergic nerve activity during sleep is increased after bed rest, but other factors, such as loss of body sodium and a lower plasma volume, may also be involved.

14. Chekirda, I. F.; Yeremin, A. V.; Stepanov, V. I.; and Borisenko, I. P.:  
 Characteristics of Human Gait after 30-Day Hypokinesia.  
*Kosmich. Biol. Aviak. Med.*, vol. 8, 1974, pp. 48-51.

**Authors' Abstract**

The kinematics and coordination structure of the walking pattern of nine test subjects were analyzed after a 30-day bed rest experiment, using photography (at a frequency of 64 images/sec) and cinematography (at a frequency of 24 frames/sec). The cyclogrammetric procedure helped to reveal characteristic changes in the walking structure induced by bed rest. These changes included a complication of the walking structure, appearance of additional correction signals from the central nervous system, a decrease in the amplitude of waves of spontaneous-innervation origin, and an increase in the amplitude of waves of reactive and reactive-innervation origin. The test subjects who had trained their walking and running habits in the recumbent position with the aid of a special trainer exhibited less marked changes in walking structure in comparison with the controls and the subjects who underwent electric stimulation of the muscles. This gives evidence for lesser deautomatization of the motor skill and for a favorable effect from physical training.

15. Cherepakhin, L. I.; Il'ina-Kakuyeva, Ye. I.; and Fedorenko, G. T.:  
 Evaluation of Effectiveness of Muscular Electrostimulation for the Prevention of Disorders Related to Prolonged Restriction of Motor Activity in Man.  
*Kosmich. Biol. Aviak. Med.*, vol. 11, 1977, pp. 64-68.

**Annotation**

*Purpose.* To evaluate the effectiveness of electrical stimulation of muscles before, after, with, and without physical exercise in the prevention of hypokinesia related disorders.

*Method.* Male subjects were used in two series of studies lasting 7 weeks.

	<u>Group</u>	<u>Number of subjects</u>	<u>Treatment</u>
Series 1	1	4	Control
	2	4	Electrical stimulation with 20 (ES-20) electrodes
	3	4	Electrical stimulation with 12 (ES-12) electrodes
Series 2	1	3	Control
	2	3	Stimulated before exercise
	3	3	Stimulated after exercise

Muscles of the legs, thigh, abdomen, and back were stimulated for 25-30 min in the morning and night in the first experiment and once a day in the second.

The physical exercise consisted of pedaling on a bicycle ergometer in the antiorthostatic (-6°) position. In the morning, subjects pedaled with a load of 600 kg-m/min for 20 min, in the afternoon, they pedaled with a load of 600-700 kg-m/min for 60 min. At 3 weeks they exercised intermittently, and at 7 weeks they exercised for 30 min.

Gas analyzer was used to determine maximum oxygen consumption. Biopsies were taken from the right soleus muscle on the 30th day of the first series of studies; after the second series, samples of muscle tissue from the same muscle of the left foot were taken from all subjects.

### Results.

*First Series:* Histochemical tests showed statistically reliable increases in the size of red and white muscle fibers. The second group showed unchanged or increased muscle fiber size. The third group showed analogous changes. Electron microscopy indicated marked structural changes in the contractile system of muscle fibers as follows: separation of myofibrils, local lysis, and thickening and destruction of stria. With electrostimulation there was variegation of: muscle fiber ultrastructure, mitochondria shape and size, and density of crystal packing.

*Second Series:* Maximum oxygen consumption increased in the subjects who exercised and decreased in the control.

*Conclusion.* Electrostimulation, according to the authors, can be compared with isometric exercise which does not prevent deconditioning of the cardiovascular system. Endurance training combined with electrostimulation elicited a distinct preventive effect on hypokinesia associated disorders.

16. Chestukhin, V. V.; Katkov, V. Ye.; Seid-Guseynov, A. A.; Shal'nev, B. I.; Georgiyevskiy, V. S.; Zybin, O. Kh.; Mikhaylov, V. M.; and Utkin, V. N.:

Activity of the Right Cardiac Ventricle and Metabolism in Healthy Persons during an Orthostatic Test after Short-Term Immobilization.

*Patologicheskaya Fiziologiya Eksperimental'noy Terapiya*, vol. 7, 1979, pp. 36-40.

#### Authors' Abstract

A 15-min orthostatic test was performed on healthy male volunteers under conditions of catheterization of the right ventricle of the heart and the radial (or brachial) artery before and after a 5-day bed rest in an antiorthostatic position of the body (with the foot of the bed raised 4.5°). The change to a vertical position after immobilization was attended by a more marked increase in the rate of cardiac contractions, an increase of maximum  $dp/dt$  pressure in the right ventricle, and a decrease of cardiac and stroke indices. The decrease of the cardiac index was compensated for, to a certain measure, by a further increase in the extraction and utilization of  $O_2$  by the tissues. The arterial blood pH did not change appreciably, and the decrease in  $PCO_2$  and content of standard bicarbonate was more marked.

17. Chobanian, A. V.; Lille, R. D.; Tercyak, A.; and Blevins, P.:

The Metabolic and Hemodynamic Effects of Prolonged Bed Rest in Normal Subjects.

*Circulation*, vol. 49, 1974, pp. 551-554.

#### Authors' Abstract

The metabolic and hemodynamic effects of prolonged bed rest were studied in six normal subjects. Bed rest of 2-3 weeks duration produced exaggerated responses of heart rate, cardiac output, stroke volume, and peripheral vascular resistance to 70° tilt. Sympathetic nerve function and catecholamine metabolism were not impaired by bed rest. Pressor responses to infusions of norepinephrine and angiotensin and reflex vasoconstriction to a cool and warm environment were essentially unchanged during bed rest. Plasma catecholamines and urinary vanillylmandelic acid excretion were somewhat lower during bed rest than during ambulation, but the response of plasma catecholamines to 70° tilt was not diminished. The apparent turnover of norepinephrine in plasma was also similar in bed rest and control periods. Negative sodium and potassium balances and reductions in plasma volume were observed in all subjects, but plasma renin activity and aldosterone secretory rate showed no significant change. The major decreases in sodium balance and plasma volume occurred in the early bed-rest period and did not correlate closely with the degree of orthostatic intolerance. The reductions in potassium balance appeared to be progressive throughout the study.

18. Convertino, V. A.; Stremel, R. W.; Bernauer, E. M.; and Greenleaf, J. E.:  
Cardiorespiratory Responses to Exercise after Bed Rest in Men and Women.  
*Acta Astronautica*, vol. 4, 1977, pp. 895-905.

#### Authors' Abstract

The purpose of this study was to compare cardiorespiratory responses of men and women to submaximal and maximal workloads before and after bed rest (BR). Fifteen male college students (19-23 yr) and 8 female nurses (23-24 yr) underwent 14 and 17 days, respectively, of bed rest. The maximal work capacity test was performed in the supine position on a bicycle ergometer just before and immediately after bed rest. The women's maximal  $O_2$  uptake (maximal  $\dot{V}O_2$ ) was 41% lower ( $P < 0.05$ ) than the men's before bed rest and 42% lower ( $P < 0.05$ ) after bed rest. During bed rest the women's maximal  $\dot{V}O_2$  decreased from 2.06 to 1.86 l/min (-9.7%,  $P < 0.05$ ), and that of the men decreased from 3.52 to 3.20 l/min (-9.1%,  $P < 0.05$ ). Compared with pre-BR values, after bed rest the maximal ventilatory volume was essentially unchanged in the men (+1.8%) and women (+2.3%), but maximal heart rate was elevated from 185 to 193 b/min (+4.3%,  $P < 0.05$ ) in the men and from 181 to 187 b/min (3.3%,  $P < 0.05$ ) in the women. Submaximal  $\dot{V}O_2$  was unchanged after bed rest in the men but was significantly reduced in the women; the women's Hct and RBC levels were lower ( $P < 0.05$ ) than comparable male data. Mean corpuscular volume was unchanged in both groups before and after bed rest. It is concluded that the proportional deterioration in maximal  $\dot{V}O_2$  following prolonged bed rest was essentially the same in young men and women.

19. Degtyarev, V. A.; Voskresenskiy, A. D.; Kalmykova, N. D.; and Kirillova, Z. A.:  
Functional Test with Decompression of the Lower Body in Thirty-Day Antiorthostatic Hypokinesia.  
*Kosmich. Biol. Aviak. Med.*, vol. 8, 1974, pp. 61-65.

#### Authors' Abstract

During a 30-day hypokinetic experiment, 9 test subjects underwent functional tests with LBNP applied at -35 and -45-mm Hg for 10 min. Subjectively they tolerated the tests well. Cardiovascular responses were similar to orthostatic responses but less pronounced. During hypokinesia the response to the tests increased. A statistical analysis of the relationship between the heart rate and integral evaluations revealed a correlation between responses to LBNP of -45-mm Hg and the orthostatic load ( $r = 0.71$ ). This indicates the possibility of predicting orthostatic reactions on the basis of LBNP tests.

20. Dolkas, C. B.; and Greenleaf, J. E.:  
Insulin and Glucose Responses during Bed Rest with Isotonic and Isometric Exercise.  
*J. Appl. Physiol.: Respirat. Environ. Exercise Physiol.*, vol. 43, 1977, pp. 1033-1038.

#### Authors' Abstract

The effects of daily intensive isotonic [68% maximum oxygen uptake ( $\dot{V}O_{2\max}$ )] and isometric (21% maximum extension force) leg exercise on plasma insulin and glucose responses to an oral glucose tolerance test (OGTT) during 14-day bed-rest (BR) periods were investigated in 7 young healthy men. The OGTT was given during ambulatory control and on *day 10* of the no-exercise, isotonic and isometric exercise BR periods during the 15-week study. The subjects were placed on a controlled diet (mean  $\pm$ SD = 344  $\pm$ 34 g CHO/day and 3073  $\pm$ 155 (SD) kcal/day) starting 10 days before each BR period. During BR, basal plasma glucose concentration remained unchanged with no exercise, but increased ( $P < 0.05$ ) to 87-89 mg/100 ml with both exercise regimens on *day 2*, and then fell slightly below control levels on *day 13*. The fall of glucose content (-11 to -15%) during BR was independent of the exercise regimen and was an adjustment for the loss of plasma volume. The intensity of the responses of insulin and glucose to the OGTT (integrated area under the curves) was inversely proportional to the total daily energy expenditure during BR; that is, the largest response with no exercise, then isometric, isotonic, and ambulatory exercise. It was estimated that at least 1020 kcal/day must be provided by supplemental exercise to restore the hyperinsulinemia to control levels.

21. **de Marees, H.; Kunitsch, G.; and Barbey, K.:**  
Investigation of Circulatory Regulation during the Orthostatic Adaptation Phase. Part 3. Influence of Bed-Rest and Endurance Training on Early Orthostatic Regulation.  
*Basic Research in Cardiology*, vol. 69, 1974, pp. 462-478.

#### Authors' Abstract

To examine the question of to what extent changes in vegetative tone influence the adaptation events during orthostatic load, 10 test subjects with healthy circulation were subjected to orthostatic stress before and after a 10-day period of bed rest and also after a 5-week period of progressive endurance training. The changes in the circulation parameters recorded show qualitatively similar curves during early orthostatic adaptation in the three series of experiments performed (control, after bed-rest, after endurance training); however, they do show statistically significant quantitative differences. From the differences found between the values for the control series and those following bed rest, it can be concluded that early orthostatic adaptation following prolonged physical inactivity occurs with signs of pronounced circulatory centralization. Indications of this are the following:

1. A maximum arterial flow into the lower extremities during orthostatic stress after bed rest of 1862 ml/min · 100 ml of soft tissue. On average, this value is 7.1 ml/min · 100 ml below the control group value.
2. A minimum height of the dicrotic wave reached during the period of orthostatic stress, the mean value of which is  $32 \pm 7.1\%$ . This is significantly larger than the comparable value in the control group, although the maximum heart rate of  $123 \pm 5$  b/min during orthostatic stress after bed rest is faster than that of the control series.

In contrast to this, early orthostatic circulatory adaptation after endurance training shows slower heart rates and less pronounced changes in the shape of the temporalis pulse curve. The greater heart volume as a result of the training can be regarded as the cause of this obviously less pronounced centralization of circulation. The mean heart volume of  $819 \pm 40$  ml is significantly larger – by 17.3% – than that of the control group. The obvious conclusion is that the orthostatically induced flow into the periphery can be compensated for, in terms of quantity, more sufficiently by an increased stroke volume following endurance training.

22. **Dygin, V. P.; Maksimov, V. A.; Shubin, V. G.; Sverdlina, N. T.; and Leshchenko, N. M.:**  
Clinical and Morphological Studies of People in the Course of Long-Term Hypokinesia and Subsequent Readaptation.  
*Kosmich. Biol. Aviak. Med.*, vol. 12, 1978, pp. 46-50.

#### Annotation

**Purpose.** To investigate the role of immunological changes as they relate to cardiovascular changes in prolonged hypokinesia.

**Method.** Two series of studies were performed on a total of 30 persons held for 44-46 days of hypokinesia.

**First Series:** The Boyden passive hemagglutination reaction was used to assess antiorganic auto-antibodies in subjects maintained in prolonged (44-46 days) hypokinesia. Nine persons were surveyed on the 15th and 30th days of hypokinesia and on the 10th and 15th days of recovery.

**Second Series:** 21 persons were tested for anticellular and antiorganic antibodies, using complement-fixation reaction with anticardiac serum. An ECG study and an enzyme assay of blood serum asparagine amino transferase, alanine amino transferase, and lactic dehydrogenase were performed.

#### Results.

**First Series:** The Boyden test was negative for all subjects. No subjects presented antibodies in blood serum that were active against antigens of heart, liver, and kidney.

**Second Series:** Cardiac antigens were found in 12 of the 21 subjects tested. The electrocardiographic study showed an increase in contraction period and a decline of Blumberger's coefficient in persons with positive antigen in blood serum. A slowing of atrio-ventricular conduction was also seen in these subjects in the recovery period. One subject had a PQ interval increase to 0.31 sec and another had Wolff-Parkinson Syndrome on the second day of recovery.

An increase in the three enzymes assayed was seen in both the cardiac-positive and cardiac-negative groups with the increase in alanine transaminase being more distinct in the group with positive cardiac antigen.

**Conclusion.** The researchers concluded that long-term hypokinesia may lead to appearance of cardiac antigen in 50% of essentially healthy subjects. This may be a result of increased resorption of protein structures by the myocardium during dystrophic processes. The lack of demonstratable anticardiac antibodies may have indicated that cardiac antigens were liberated in amounts below the threshold of immunological tolerance.

23. **Elfström, J.; and Lindgren, S.:**  
Influence of Bed Rest on the Pharmacokinetics of Phenazone.  
*Europ. J. Clin. Pharmacol.*, vol. 13, 1978, pp. 379-383.

**Authors' Abstract**

The pharmacokinetics of a single dose of phenazone was studied in six subjects while ambulant and during bed rest for 3 days. Elimination of the drug was followed for 12 hr after oral and intravenous administration. *The elimination rate constant and total body clearance were significantly increased during bed rest as compared to the ambulant period, but the differences were small.* The apparent volume of distribution decreased significantly. No consistent change due to bed rest was found in the rate of absorption or bio-availability of the oral dose.

24. **Ellis, J. P.; Lecocq, F. R.; Garcia, J. B.; and Lipman, R. L.:**  
Forearm Amino Acid Metabolism during Chronic Physical Inactivity.  
*Aerospace Med.*, vol. 45, 1974, pp. 15-18.

**Authors' Abstract**

The effect of 14 days of physical inactivity on peripheral amino acid metabolism was determined in a group of five healthy male subjects ranging in age from 18 to 20 years. Blood samples were drawn from the right brachial artery and a left brachial vein during the control period of 2 weeks and on the 14th day of bed rest. None of the 19 amino acids analyzed showed a significant change, either in uptake or release, from the forearm muscles. However, a substantially higher level of alanine was found in both arterial and venous blood of the physically deconditioned subjects. As the forearm retains considerable activity during bed rest, it was suggested that the higher level of alanine in arterial blood probably originated from more gravity-dependent muscles and that the observed higher venous level of alanine was a passive consequence of the corresponding arterial level.

25. **Friman, G.:**  
Effect of Clinical Bed Rest for Seven Days on Physical Performance.  
*Acta Med. Scand.*, vol. 205, 1979, pp. 289-293.

**Authors' Abstract**

Twenty-two healthy men were confined to bed in a hospital ward (clinical bed rest) for 1 week. Variables related to physical fitness were measured before and immediately after the bed-rest period, as well as 1 and 3 months thereafter. As a result of bed rest, maximal oxygen uptake,  $W_{170}$  and total Hb decreased to 94%,



and calculated blood volume to 93% of the initial value. Hb concentration and Hct were unaltered. Thus, red cell and plasma volumes were proportionately reduced. No significant orthostatic dysfunction developed. The blood lactate peak at maximum work remained unchanged (14.0 mM/l). The resting excretion of noradrenaline decreased moderately during the bed-rest period, while that of adrenaline was unchanged. Body weight decreased by a mean of 0.7 kg.

26. **Friman, G.; and Hamrin, E.:**  
Changes of Reactive Hyperaemia after Clinical Bed Rest for Seven Days.  
*Uppsala J. Med. Sci.*, vol. 81, 1976, pp. 79-83.

#### **Authors' Abstract**

As an indication of peripheral circulatory function, reactive hyperaemia was studied in the forearm and calf muscle in 14 healthy young men before and after clinical bed rest for 1 week. Blood flow was measured after different arterial occlusion times with venous occlusion plethysmography. After bed rest, peak flow values in the calf after arterial occlusion for 3 or 5 min decreased moderately (by about 20-23%) and significantly. Peak flow in the forearm decreased as well although not significantly.

27. **Galle, R. R.; Usachev, V. V.; Gavrilova, L. N.; Yelkina, L. G.; Yelkin, P. A.; Krikun, I. S.; Ovechkin, V. G.; and Ustyushin, B. V.:**  
Some Human Reactions to Prolonged Centripetal Accelerations [ $+G_z$ ] of Low Intensities.  
*Kosmich. Biol. Aviak. Med.*, vol. 10, 1976, pp. 35-40.

#### **Authors' Abstract**

The effect of centripetal accelerations ( $+G_z$ ) of low intensities (0.5-0.6 g) imparted for 4 days against a background of relative hypokinesia was investigated. Peripheral and intracranial circulation, equilibrium function, and morphological composition of the capillary blood were examined. During the first 3 days of centrifugation the hemodynamic state differed insignificantly from the initial level. On the fourth day, signs of cardiovascular deconditioning were found. This was indicated by the orthostatic test. Changes in the peripheral blood indicated a moderate stress reaction which persisted throughout the entire experiment. Equilibrium changes, which were observed on the first day of centrifugation, regressed and the post-test function did not essentially differ from the initial level. The experimental results give evidence that inertial forces can be used to lessen the unfavorable effects of hypokinesia.

28. **Gayevskaya, M. S.; Kurkina, L. M.; Kolchina, Ye. V.; Kolganova, N. S.; and Veresomskaya, N. A.:**  
The Change in Protein Fractions of a Human Skeletal Muscle (the Soleus Muscle) Under the Effects of Hypokinesia and the Possibility of Preventing such Exchanges by Means of a Special Set of Exercises.  
*Fiziologiya Cheloveka*, vol. 2, 1976, pp. 997-1001.

#### **Annotation**

**Purpose.** To study and prevent the atrophy of the soleus muscle under the effects of hypokinesia.

**Procedure.** Fifteen subjects were subjected to antiorthostatic hypokinesia (a tilt of  $-4^\circ$ ) for 49 days.

1. No additional effects (three subjects).
2. One-hour exercise two times a day (900 kcal/day) (six subjects).
3. Two times a day, exercised 20 min in morning, 40-60 min in afternoon, 20-min electrical stimulation (450 kcal/day) (six subjects).

Muscle tissue from the left soleus before experiment and from the right soleus 2-5 days after. Fractional protein composition, activity of aspartate transaminase (AST), alanine transaminase (ALT), and of sarcoplasmic proteins, and activity and spectrum of lactate dehydrogenase (LDH) and of some proteins were determined.

#### *Results.*

1. Decrease in quantities of sarcoplasmic proteins; decrease in contractile proteins, actomyosin, and T-fraction proteins; activity of AST and ALP increased.
2. No change in protein fractions of soleus, AST, ALD, or LDH.
3. Sarcoplasmic proteins did not change; actomyosin, T-fraction proteins, AST, ALT, and LDH decreased.

Forty-nine days of hypokinesia caused a decrease in the concentration of sarcoplasmic protein (especially contractile) and an increase in catabolic processes. Strengthening of catabolic processes caused activation of enzymes. The process of protein decomposition was an adaptive reaction to decrease in muscle function. Varied physical stress prevented loss of sarcoplasmic and muscle proteins and changes in enzyme activity. Less stress in combination with electrical stress did not completely prevent changes induced by long-term bed rest.

*Conclusions.* Physical exercise reduced the decrease of contractile proteins in the soleus muscle of men undergoing 49 days of hypokinesia.

29. Gzenko, O. G.; Shumakov, V. I.; Kakurin, L. I.; Katkov, V. E.; Chestukhin, V. V.; Mikhailov, V. M.; Troshin, A. Z.; and Nesvetov, V. N.:  
Central Circulation and Metabolism of the Healthy Man during Postural Exposures and Arm Exercise in the Head-Down Position.  
*Aviat. Space Environ. Med.*, vol. 51, 1980, pp. 113-120.

#### **Authors' Abstract**

The effect of postural exposures and arm exercise in the head-down position on central circulation and metabolism was studied in seven test subjects. Their left ventricle, pulmonary, and femoral arteries were catheterized. The tilt test at +70° for 15 min was accompanied by a decrease of systolic pressure in those compartments, a drop of the end-diastolic pressure in the left ventricle, and an increase in its distensibility. At the same time, contractile parameters remained essentially unchanged and the transpulmonary gradient of the intravascular pressure (mean pressure in the pulmonary artery minus end-diastolic pressure in the left ventricle) increased. Some 10-15 min after the transition from the head-up to the head-down (at -30°) position, a drastic increase in the pulmonary artery pressure and left ventricular end-diastolic pressure and a decline of the left ventricular distensibility and contractility (Veraguth's index) occurred. During the last 55-60 min of the head-down tilt, contractility indices returned to the pretest level and other parameters remained unaffected. Arm workload (100 kg/min for 7 min), performed at the end of the head-down tilt, resulted in an increase of the systolic pressure in the left ventricle and femoral artery without changes in the pulmonary artery. Contractile indices of the left ventricle, cardiac index, and heart rate increased significantly. Compensated metabolic acidosis with hyperventilation developed in the arterial blood.

30. Georgiyevskiy, V. S.; Gornago, V. A.; Divina, L. Ya.; Kalmykova, N. D.; Mikhaylov, V. M.; Plathatnyuk, V. I.; Pometov, Yu. D.; Smyshlyayeva, V. V.; Vikharev, N. D.; and Katkovskiy, B. S.: Orthostatic Stability in an Experiment with 30-Day Hypodynamia. *Kosmich. Biol. Aviak. Med.*, vol. 7, 1973, pp. 61-68.

#### Authors' Abstract

Nine test subjects were kept for 30 days in bed with their heads tilted 4° downward. At the end of the experiment they exhibited a decrease in orthostatic stability. The use of different countermeasures, including physical exercises and lower body negative pressure (LBNP), considerably improved their orthostatic stability. Electrostimulation of the muscles also produced a preventive effect, although to a lesser extent. It should be expected that a combination of physical exercises, LBNP, and electrostimulation of the muscles during prolonged space flight may exert a positive effect on orthostatic stability.

31. Georgiyevskiy, V. S.; Il'inskaya, Ye. A.; Matveyev, V. I.; Mikhaylov, V. M.; and Pervushin, V. I.: Electrostimulation of Muscles for the Prevention of Neuromuscular Disorders during 45-day Anti-orthostatic Hypokinesia. *Kosmich. Biol. Aviak. Med.*, vol. 13, 1979, pp. 40-44.

#### Annotation

**Purpose.** To determine the effects of myoelectrostimulation on the neuromuscular system and physical fitness in preventing the negative effects of hypokinesia.

**Method** Twelve healthy males age 22-35 yr were exposed to 45 days of antiorthostatic (-6.5°) hypokinesia. They were divided into three groups of four, group three being the control. Group 1 (20 electrodes) and group 2 (12 electrodes) experienced electrostimulation of the legs, back, and abdomen twice a day, 6 days a week. Physical fitness tests, blood pressure, and heart rate measurements were conducted before and after the bed-rest period. Group 3 was the control group.

Heart rate was 30-32 b/min higher after bed rest in the first and second groups and 56 b/min higher in the control group. Physical load tests also showed greater physical deterioration in the control group. A tendency toward parameter normalization occurred by the 10th day of recovery, especially in group 1. Muscle biopsies indicated atrophy in the muscles of the control as compared with the treatment groups. The subjects found the electrostimulation pleasurable, similar to massage or light physical work.

**Conclusion.** Apparently, the activation of the central nervous system and metabolic processes of the order of motor-visceral reflexes is the positive element in the effect of electrostimulation on the body. Myoelectrostimulation is effective as an ancillary method of preventing skeletal muscle atrophy. Development of an effective method involving fewer electrodes is necessary for use in space flights.

32. Georgiyevskiy, V. S.; Korol'kov, V. I.; and Mikhaylov, V. M.: Reactions of the Human Cardiovascular System to Orthostasis after Adaptation to the High Mountains. *Kosmich. Biol. Aviak. Med.*, vol. 10, 1976, pp. 45-49.

#### Authors' Abstract

Orthostatic tolerance of 18 healthy test subjects (three groups of 6 persons each) who were exposed to elevations of 2200 m for 12 days and 3200 m for 12 days was studied. Subjects in the first group remained in bed with minimized motor activity. The second group of test subjects rested in bed and twice a day performed physical exercises with energy expenditures of 300 cal/day. Subjects in the third group led a normal mode of life. The studies demonstrated that prolonged restriction of motor activity and a decrease in blood hydrostatic pressure of healthy test subjects in the highlands resulted in their diminished orthostatic

tolerance. Physical exercises proved ineffective in this case. The subjects who led a normal mode of life exhibited increased cardiovascular reactions to orthostatic tests.

33. **Georgiyevskiy, V. S.; and Mikhaylov, V. M.:**  
The Effect of 60 Days of Bed Rest on the Circulatory System.  
*Fiziologiya Cheloveka*, vol. 4, 1978, pp. 871-876.

**Authors' Abstract**

Six healthy males were kept on constant bed rest for 60 days. Three performed a special set of exercises every day while in the horizontal position. Various hemodynamic indices were calculated for a comparison of the effects of the two regimens. The results indicated that hypokinesia has definite harmful effects on circulatory condition, and that execution of physical exercises is beneficial in preventing these harmful effects.

34. **Giannetta, C. L.; and Castleberry, H. B.:**  
Influence of Bedrest and Hypercapnia upon Urinary Mineral Excretion in Man.  
*Aerospace Med.*, vol. 45, 1974, pp. 750-754.

**Authors' Abstract**

Bed rest and hypercapnia affected urinary mineral excretion. An increase in the excretion of magnesium, calcium, and inorganic phosphorus was noted during bed rest. Zinc excretion decreased during hypercapnia; however, this decrease was not significant when the experimental and preexperimental periods were compared. The combined effect of bed rest and hypercapnia was not synergistic for calcium excretion.

35. **Golikov, A. P.; Vorob'yev, V. Ye.; Abdrakhamanov, V. R.; Stazhadze, L. L.; Bogomolov, V. V.;**  
**and Voronina, S. G.:**  
External Respiration and Acid-Base Balance of Human Blood during Long-Term Antiorthostatic Hypokinesia and in the Recovery Period.  
*Kosmich. Biol. Aviak. Med.*, vol. 14, 1980, pp. 42-46.

**Authors' Abstract**

The study of external respiration and acid-base equilibrium of the blood of 35 test subjects exposed to 49-day head-down ( $-4^\circ$ ) tilting and of 6 test subjects exposed to 182-day head-down ( $-4^\circ$ ) tilting demonstrated a trend for a decrease in the respiration rate, lung ventilation, oxygen consumption, and a relative increase in the exhalation time. With respect to the arterialized blood gases, a significant increase in  $\text{PaO}_2$ , an increase in  $\text{PaCO}_2$  and in the  $\text{O}_2$  alveolar-arterial difference were seen during the 49-day head-down tilting. During the 182-day head-down tilting a further increase in the  $\text{CO}_2$  arterio-alveolar difference was noted. These changes suggest shifts of the ventilation-perfusion ration in the lungs and, probably, disturbances of central regulation of respiration induced by head-down tilting. During the recovery period, the above changes diminished gradually and disappeared by the 14th and 30th day after the 49- and 182-day head-down tilting, respectively.

36. **Gornago, V. A.; Rustam'yam, L. A.; Vasil'yev, V. K.; and Katkovskiy, B. S.:**  
Dynamics of Cardiorespiratory Indices for Healthy Persons during Passive Orthostatic Test.  
*Fiziologiya Cheloveka*, vol. 4, 1978, pp. 68-72.

**Authors' Abstract**

A study of the reactions of the cardiorespiratory system of 80 healthy males aged 19-42 to body posture changes (passive orthotest) showed a period when there was a discrepancy between gas exchange and increased metabolic consumption by the organism. In minute 2 (for the 10-min test) of the vertical-attitude,

oxygen consumption and the elimination of carbonic acid gas were considerably lower than in other periods of the passive orthotest. Analysis of the authors' data and the literature data indicated that the reason why oxygen consumption goes down during the first minutes of an orthostatic test lies in hemodynamic changes.

37. Greenleaf, J. E.; Bernauer, E. M.; Juhos, L. T.; Young, H. L.; Morse, J. T.; and Staley, R. W.: Effects of Exercise on Fluid Exchange and Body Composition in Man during 14-Day Bed Rest. *J. Appl. Physiol.: Respirat. Environ. Exercise Physiol.*, vol. 43, 1977, pp. 126-132.

#### Authors' Abstract

To determine the cause of the body weight loss during bed rest (BR), fluid balance and anthropometric measurements were taken from seven men (19-21 yr) during three 2-week BR periods which were separated by 3-week ambulatory recovery periods. Caloric intake was  $3073 \pm 155$  (SD) kcal/day. During two of the three BR periods subjects performed supine isotonic exercise at 68% of  $\dot{V}O_{2\max}$  on the ergometer for 1 hr/day, or supine isometric exercise at 21% of maximal leg extension force for 1 min followed by a 1-min rest for 1 hr/day. No prescribed exercise was given during the other BR period. During BR, body weight decreased slightly with no exercise (-0.43 kg, NS), but decreased significantly ( $P < 0.05$ ) by -0.91 kg with isometric and by -1.77 kg with isotonic exercise. About one-third of the weight reduction with isotonic exercise was due to fat loss (-0.69 kg) and the remainder to loss of lean body mass (-0.98 kg). It is concluded that the reduction in body weight during bed rest has two major components: first, a loss of lean body mass caused by assumption of the horizontal body position that is independent of the metabolic rate; second, a loss of body fat content that is proportional to the metabolic rate.

38. Greenleaf, J. E.; Bernauer, E. M.; Young, H. L.; Morse, J. T.; Staley, R. W.; Juhos, L. T.; and van Beaumont, W.: Fluid and Electrolyte Shifts during Bed Rest with Isometric and Isotonic Exercise. *J. Appl. Physiol.: Respirat. Environ. Exercise Physiol.*, vol. 42, 1977, pp. 59-66.

#### Authors' Abstract

Fluid and electrolyte shifts were measured in seven men (19-21 yr) during three 2-week bed rest (BR) periods, each of which was separated by a 3-week ambulatory recovery period. During two of the three BR periods subjects performed isometric exercise and isotonic exercise. No prescribed exercise was given during the other BR period. On day 4 of BR, plasma volume decreased ( $P < 0.05$ ) 441 ml (-12.6%) with no exercise, 396 ml (-11.3%) with isometric, and 262 ml (-7.8%) with isotonic exercise; the decreases (NS) of extracellular volume were -4.4%, -2.6%, and -2.7%, respectively. By day 13 of BR, plasma volume stabilized at the lower level with isometric and isotonic exercise and continued to decline with no exercise; but the extracellular volume returned to or above control levels due to an overshoot of the interstitial volume of +320 to +430 ml (2.0-2.7%) that was about equal to the plasma volume loss. During BR there were isocontent losses from the plasma of protein, albumin, globulin, urea  $N_2$ , uric acid, creatinine, Na, Cl, osmols,  $PO_4$ , and glucose that were not influenced by either exercise regimen. However, the blood, red blood cell, and plasma volumes, and the Ca and K contents were stabilized during BR by both exercise regimens. The results suggest that, during BR, preservation of the extracellular volume takes precedence over maintenance of the plasma volume, and this mechanism is independent of the effects of isometric or isotonic exercise.

39. Greenleaf, J. E.; Haines, R. F.; Bernauer, E. M.; Morse, J. T.; Sandler, H.; Armbruster, R.; Sagan, L.; and van Beaumont, W.:  
+G<sub>z</sub> Tolerance in Man after 14-Day Bedrest Periods with Isometric and Isotonic Exercise Conditioning.  
*Aviat. Space Environ. Med.*, vol. 46, 1975, pp. 671-678.

#### Authors' Abstract

The purpose of this study was to determine the effects of isometric or isotonic exercise training on post-bed rest +G<sub>z</sub> tolerance. Seven male volunteers (19-22 yr) underwent acceleration of +2.1 G<sub>z</sub> (740 sec), +3.2 G<sub>z</sub> (327 sec), and +3.8 G<sub>z</sub> (312 sec) in a selected, randomized order; the ramp to peak acceleration was 1.8 G/min. The centrifugation runs were terminated by loss of central vision (blackout) to a white light with a luminance of  $3.15 \times 10^{-5}$  log candle/cm<sup>2</sup> (0.092 fL). The study began with a 14-day ambulatory control period, followed by three 14-day bed rest periods (each separated by a 21-day recovery period) and then a final week of recovery. During the ambulatory periods, the subjects exercised on a bicycle ergometer at 50% of their maximal oxygen uptake (max VO<sub>2</sub>) for 1 hr/day. During two of the three bed rest periods, the subjects performed in the supine position one of two routines, either isometric exercise (21% of maximum leg extension force for 1 min followed by 1-min rest) or isotonic exercise (68% of maximum VO<sub>2</sub>) for 0.5 hr in the morning and afternoon. During the third bed-rest period, no exercise was performed. In general, +G<sub>z</sub> tolerance was reduced by 24% to 35% ( $P < 0.05$ ) after bed rest. Compared with control values, there were significant reductions in average tolerance times after bed rest with no exercise and isotonic exercise at all G levels. With isometric exercise, there was a significant decrease in tolerance at 2.1 G<sub>z</sub> but not at 3.2 G<sub>z</sub> or 3.8 G<sub>z</sub>, even though the later tolerances were reduced 15.6% and 10.0%, respectively. Both exercise regimens maintained tolerance at levels equal to or above that obtained with no exercise. Compared with control values, average tolerances were lower ( $P < 0.05$ ) after the two recovery periods between the bed-rest periods (-24% to -26% at 3.2 G<sub>z</sub> and 3.8 G<sub>z</sub>), indicating that 3 weeks of ambulation was not sufficient time for full recovery from the deconditioning induced in this study. A prediction equation was constructed with data from all comparable studies utilizing deconditioned men riding relaxed without protective garments: Tolerance (in seconds) = -334 + (1715/+G<sub>z</sub> level). From this equation, the calculated tolerance after bed rest is 13.5 min at 1.5 G, and the point of zero tolerance is +5.1 G<sub>z</sub>.

40. Greenleaf, J. E.; and Reese, R. D.:  
Exercise Thermoregulation after 14 Days of Bed Rest.  
*J. Appl. Physiol: Respirat. Environ. Exercise Physiol.*, vol. 48, 1980, pp. 72-78.

#### Authors' Abstract

Rectal ( $T_{re}$ ) and mean skin ( $\bar{T}_{sk}$ ) temperatures and sweating responses were measured during 70-min submaximal supine exercise (relative VO<sub>2</sub> 43-48%) in seven men (19-22 yr) during an ambulatory-control (AC) period and after three 2-week bed-rest (BR) periods separated by 3-week ambulatory recovery periods. During each of the three BR periods subjects performed isometric exercises (IME) or isotonic exercises (ITE) for 1 hr/day or no prescribed exercise (NOE). Mean basal oral temperature decreased from 36.0°C to 35.7°C in the last 10 days of the control-recovery periods, but it varied between 35.7°C and 35.9°C during BR. In the exercise-temperature test the equilibrium level of  $T_{re}$  for the IME (37.92°C) and NOE (37.75°C) regimens were higher ( $P < 0.05$ ) than the AC level of 37.51°C. Mean skin temperatures with the IME and ITE regimens increased by only 0.4°C during exercise, and both equilibrium  $\bar{T}_{sk}$  values, 31.98°C and 31.87°C, respectively, were lower ( $P < 0.05$ ) than the AC values of 32.71°C. There were no significant differences between any of the sweat rates (range, 438-565 g/hr) in the four experiments, but calculated skin heat conductances ( $H_{sk}$ ) correlated +0.86 with equilibrium levels of  $\bar{T}_{sk}$ . It was concluded that the excessive increase in  $T_{re}$  during submaximal exercise following BR deconditioning could be influenced by changes in  $H_{sk}$ , but inhibition of sweating may also be a factor.

41. Greenleaf, J. E.; Stinnett, H. O.; Davis, G. L.; Kollias, J.; and Bernauer, E. M.:  
Fluid and Electrolyte Shifts in Women during +G<sub>z</sub> Acceleration after 15 Days' Bed Rest.  
*J. Appl. Physiol.: Respirat. Environ. Exercise Physiol.*, vol. 42, 1977, pp. 67-73.

#### Authors' Abstract

Twelve women (23-34 yr), comprising a bed-rest (BR) group of eight subjects and an ambulatory (AMB) group of four subjects, were centrifuged after 14 days of ambulatory control (C), after 15 days of a 17-day BR period, and on the third day of recovery (R). Venous blood was taken before and after the third +3.0 G acceleration run (1.8 G/min). Relative to (C), the +G<sub>z</sub> tolerance after BR was reduced -49.0% ( $P < 0.05$ ) in the BR group and -38.7% (NS) in the AMB group; during (R) the BR group regained up to 89.4% and the AMB group up to 87.1% of their (C) tolerances. In each of the three test periods, the shifts in plasma Na, Cl, PO<sub>4</sub>, and osmotic contents, which accompanied +G<sub>z</sub>, followed the outward shift of plasma volume (PV). The correlation of the shift of PV during acceleration with the +G<sub>z</sub> tolerance was 0.72 ( $P < 0.01$ ). During acceleration, the PV and electrolyte loss for both groups after BR was about half the loss of (C) and (R). Compared with (C) and (R) values, potassium shifts were variable but the mean corpuscular volume and mean corpuscular Hb contents and concentrations were unchanged during all +G<sub>z</sub> runs. The results indicate that (1) the higher the (C) +G<sub>z</sub> tolerance, the greater the tolerance decline due to BR; (2) relative confinement and reduced activity contribute as much to the reduction in tolerance as does the horizontal body position during BR; (3) bed-rest deconditioning has no effect on the erythrocyte volume during +3.0 G<sub>z</sub>; and (4) about one-half the loss in tolerance after BR can be attributed to PV and electrolyte shifts.

42. Grigor'yev, A. I.:  
Renal Function of Healthy Individuals Tested by Renography with <sup>131</sup>I-Hippuran in the Presence of Prolonged Hypokinesia.  
*Kosmich. Biol. Aviak. Med.*, vol. 12, 1978, pp. 32-35.

#### Annotation

**Purpose.** To investigate changes in the functional state of the kidneys as the chief cause of impaired fluid and electrolyte metabolism in hypokinetic man.

**Method.** Two series of experiments were performed with 28 male subjects (19-40 yr).

**First Series:** 18 subjects at head-down tilt (+6°, -2°, -6°) held for 30 days of complete bed rest.

**Second Series:** Subjects held for 120 days in horizontal bed rest position.

Isotope renography was used to appraise renal function.  $\gamma$ -radiation from <sup>131</sup>I-Hippuran excreted by the kidneys was measured by three scintillation counters.

The experimentors recorded three renogram curves: blood clearance, the left kidney, and the right kidney. Subjects in the first series were tested in the background period, on the 14th and 15th days and 26th and 27th days of bed rest, and on the 9th day of recovery. Subjects in the second series were tested twice in the background period, on the 4th-5th, 18th-20th, 41st-42nd, 82nd-84th, and 116th-118th days of bed rest, as well as on the 9th and 25th-30th days of recovery.

In addition to renography, renal excretion of electrolytes, plasma renal flow, glomerular filtration, and osmoregulatory and ionoregulatory functions of the kidneys were measured at the same time.

**Results.** Subjects in head-down position (series 1) showed delayed <sup>131</sup>I-Hippuran excretion from the kidneys on the 26th-27th days of bed rest as did the series 2 subjects on days 41 and 42. On the 116th-118th days of bed rest (series 2), incorporation of isotope in the kidneys increased in time while elimination of <sup>131</sup>I-Hippuran from blood and kidneys slowed.

Microscopy of sediment in blood of subject O-v showed typical signs of uric acid diathesis.

Tests of days 81-85 showed a statistically significant increase in isotope uptake and elimination over tests on days 41-42. A faster glomerular filtration rate and kidney blood flow were also seen. A comparison

of these two test periods indicated increased evacuation of fluid and Na from the kidneys ( $P < 0.02$ ) while the fraction of reabsorbed Na decreased.

Resorption of osmotically free fluid increased in many cases, indicating high functional activity of the distal nephron segment.

In the early recovery period, the time of uptake and half-life of isotope evacuation from the kidneys increased but did not reach the levels of the background period. By the 25th-30th days of recovery, these parameters reached base-line in all subjects.

**Conclusion.** The inverse relationship between resorption of sodium and uptake of Hippuran leads to the assumption that there is a correlation between transport of these substances in the proximal segment of the kidney nephron. The changes in the renal function and the increased functional activity of the distal segment of the nephron were believed to be induced by the increased blood flow to the kidney.

43. Grigor'yev, A. I.; Dorokhova, B. R.; Kozyrevskaya, G. I.; Namochin, Yu. V.; Arzamazov, G. S.; and Noskov, V. B.:  
Water Salt Metabolism and the Functional State of the Kidneys during Bedrest of Varying Duration. *Fiziologiya Cheloveka*, vol. 5, 1979, pp. 660-669.

#### Authors' Abstract

The functional capability of the kidneys does not suffer under prolonged bed rest. Apparently the anti-orthostatic position, in comparison with the horizontal and particularly the orthostatic, accelerates hemodynamic changes. Basic changes in the electrolyte composition of the blood are apparent in the low hypokalemia and hypercalcemia. Functional load samples make it possible to discover the condition of separate systems for ion regulations when their minimum shifts occur. Hypokinesia causes a change in tissue metabolism accompanied by a loss of electrolytes which are not retained in the tissue; the addition of electrolytes can be only a symptomatic therapy for these conditions.

44. Grigor'yev, A. I.; Pak, Z. P.; Koloskova, Yu. S.; Kozyrevskaya, G. I.; Korotayev, M. M.; and Bezumova, Yu. Ye.:  
Influence of Nerobol on Water-Mineral Metabolism and Kidney Function in Man during 120-day Hypokinesia. *Kosmich. Biol. Aviak. Med.*, vol. 10, 1976, pp. 55-59.

#### Authors' Abstract

The influence of anabolic steroids on fluid-electrolyte metabolism and renal function in man was studied during a prolonged bed-rest experiment. Seven test subjects were kept under surveillance. Three test subjects were administered nerobol and four subjects served as controls. Fluid-electrolyte metabolism and the osmoregulatory function of the kidneys were studied. Nerobol induced a decreased excretion of sodium, potassium, calcium, chlorides, and osmotically active substances. Nerobol produced the most pronounced effect on calcium and potassium metabolism. The effect of the drug used during the prolonged bed-rest experiment depended on the time and dosage, as well as on the state of fluid-electrolyte metabolism and the renal function.

45. Haines, R. F.:  
Effect of Bed Rest and Exercise on Body Balance. *J. Appl. Physiol.*, vol. 36, 1974, pp. 323-327.

#### Authors' Abstract

A battery of 11 body balance tests was administered to seven men before and after 14 days of bed rest. Seven men who had not undergone bed rest served as controls. During bed rest, each subject underwent daily either isotonic, isometric, or no leg exercise. The results showed that, for the bed-rested no-exercise,



isotonic-exercise, and isometric-exercise groups, 2 weeks of bed rest produces significant body balance decrements on 3, 4, and 5 of the 11 tests, respectively. Daily leg exercise did not prevent the debilitating effects of bed rest on body balance. After bed rest balance skill was relearned rapidly so that, in most tests, performance had reached prebed-rest levels by the third recovery day. The rail walk – eyes open – and the left-leg rail balance – eyes open – tests were the most sensitive for measuring the effects of prolonged bed rest. These data suggest that balance impairment is not due to loss of muscular strength in the legs but, perhaps, to a bed-rest-related change in the neurally coded information to postural control centers.

46. Hantman, D. A.; Vogel, J. M.; Donaldson, C. L.; Friedman, R.; Goldsmith, R. S.; and Hulley, S. B.: Attempts to Prevent Disuse Osteoporosis by Treatment with Calcitonin, Longitudinal Compression and Supplementary Calcium and Phosphate. *J. Clin. Endocrinol. Metab.*, vol. 36, 1973, pp. 845-858.

#### Authors' Abstract

Six healthy men were studied during 19 weeks of continuous bed rest and three treatment regimens were tested for their effectiveness in preventing bone mineral loss:

1. Synthetic salmon calcitonin (100 MRC U daily) did not prevent the negative calcium and phosphorus balances which are observed during untreated bed rest. The increase in urinary calcium and hydroxyproline excretion was unusually large in one of the two subjects.

2. Intermittent compression in the longitudinal axis was applied by springs attached to a special suit; a force equal to 80% of body weight was applied 45 times per minute for 4 hr daily. The negative mineral balances were not substantially affected by this regimen.

3. Calcium and phosphate supplements were administered, increasing daily intake of calcium from 1.0 to 1.8 or 2.3 g, and that of phosphorus from 1.7 to 3.0 g. Calcium balances were significantly less negative than those of control subjects in four of five cases; phosphorus balances showed similar patterns.

4. Combined administration of these three regimens to two subjects also produced a beneficial response.

These conclusions, which are based on mineral balance data, were only partially confirmed by gamma ray transmission scanning of the central calcaneus, and some discrepancies were noted. We conclude that the 2-month course of calcium and phosphate supplements retarded the development of disuse osteoporosis, but that the intermittent compression and calcitonin were ineffective.

47. Hoche, J.; and Graybiel, A.: Value of Exercise at One-Half Earth Gravity in Preventing Effects of Simulated Weightlessness. *Aerospace Med.*, vol. 45, 1974, pp. 386-392.

#### Authors' Abstract

Twelve male subjects participated in two identical experimental series to determine the value of exercising 4 hr daily at one-half Earth gravity (simulated) to prevent loss of exercise capacity and orthostatic tolerance when exposed to 14 days of simulated weightlessness. In one series, four subjects exercised at half-gravity (HGE subjects) on treadmills mounted on inclined planes; in the other series the subjects switched exercise devices. Four subjects served as no-exercise controls throughout both series. Orthostatic tolerance was measured in a lower body negative pressure device and exercise capacity was measured with the aid of a treadmill. Additional measurements included plasma volume and red cell mass, urinary sodium and potassium, and peripheral renin activity. The findings revealed no significant differences between the responses elicited during exercise in the centrifuge or on the inclined plane, hence, use of the latter device will greatly increase cost effectiveness in any future experiments. A difference in LBNP tolerance between the two groups was not demonstrated when measurements were made before and at the end of the deconditioning period and after recovery. There was evidence, however, that the time course of 6:00 a.m. peripheral renin activity differed in the two groups. Exercise capacity diminished in both groups, but there was

a twofold greater loss in the control compared with the HGE group. Control subjects manifested greater losses of plasma volume but smaller losses of weight than HGE subjects. No significant differences between the two groups were found in the patterns of urinary electrolytes or the loss in red cell mass. The results are discussed not only in terms of the present experiment but also in terms of their significance for long-range plans involving the use of artificial gravity as a countermeasure on space missions.

48. Hyatt, K. H.; Jacobson, L. B.; and Schneider, V. S.:  
Comparison of 70° Tilt, LBNP, and Passive Standing as Measures of Orthostatic Tolerance.  
*Aviat. Space Environ. Med.*, vol. 46, 1975, pp. 801-808.

#### Authors' Abstract

The present study was performed to assess the reliability of lower body negative pressure (LBNP) as a test of orthostatic tolerance. The need for this assessment arose from the prior observation in this laboratory that some subjects show wide day-to-day variation in heart rate responses to LBNP. The extent of these variations was so great as to raise a serious question as to the value of LBNP as a measure of study-induced alterations (e.g., those produced by bed rest or weightlessness) in orthostatic tolerance. Five healthy volunteers were subjected to a series of tests, consisting of 70° tilt, LBNP, and passive standing, on three occasions preceding and three occasions following a 2-week period of bed rest. Study results show that it is possible to subdivide the volunteers into subgroups that show either great or little day-to-day variability in any of the three tests. All three tests revealed bed-rest-induced alterations in orthostatic tolerances quite adequately. Of the three tests studied, LBNP most frequently resulted in the largest test-induced heart-rate alterations, followed by quiet standing and, finally, 70° tilt.

49. Hyatt, K. H.; Johnson, P. C.; Hoffler, G. W.; Rambaut, P. C.; Rummel, J. A.; Hulley, S. G.; Vogel, J. M.; Huntoon, C.; and Spears, C. P.:  
Effect of Potassium Depletion in Normal Males: An Apollo 15 Simulation.  
*Aviat. Space Environ. Med.*, vol. 46, 1975, pp. 11-15.

#### Authors' Abstract

In the course of Apollo 15, physiologic abnormalities, manifested by ectopic activity on the ECG and unusual alterations in exercise tolerance, occurred in the crew of the Lunar Excursion Module. These were associated with decreases in total body potassium, measured by  $^{42}\text{K}$ , of 10% and 15%. The possibility of inadequate potassium ( $\text{K}^+$ ) intake existed. A simulation study was performed prior to Apollo 16, corresponding in duration to Apollo 15. Subjects endured the same sleep aberrations and caloric expenditure as the Apollo 15 astronauts. Subjects consumed a diet containing only 15 mEq/day of  $\text{K}^+$  during the entire 12 days of absolute bed rest. ECG was continuously monitored, body fluid compartments and total body  $\text{K}^+$  were measured at intervals by radionuclide methods, electrolyte balance was determined daily, and exercise and orthostatic tolerances were determined prior to and after bed rest. In spite of decreases in total body  $\text{K}^+$  measured by  $^{42}\text{K}$  of 14.5% and 10.5%, and by potassium balances of 3.3% and 6.5%, respectively, neither of the two subjects developed symptomatic hypokalemia. Minor ECG abnormalities were noted in one subject. Orthostatic and exercise tolerance showed only those changes expected as a result of bed rest. Muscle strength was unaffected. Study implications and reasons for discrepancies between  $\text{K}^+$  loss measured by balance techniques and  $^{42}\text{K}$  are reviewed.

50. Hyatt, K. H.; and West, D. A.:  
Reversal of Bedrest-Induced Orthostatic Intolerance by Lower Body Negative Pressure and Saline.  
*Aviat. Space Environ. Med.*, vol. 82, 1977, pp. 120-124.

#### Authors' Abstract

Six healthy male volunteers underwent two 1-week periods of bed rest, each preceded and followed by 2-week control and recovery periods. The daily metabolic diet contained 150 mEq of sodium. Following

one 7-day bed-rest period, each man was subjected to LBNP at a level of -30-mm Hg for 4-hr while consuming 1000 ml of beef bouillon containing 154 mEq of sodium. After the other bed-rest period, each man simply consumed the bouillon without LBNP treatment during 4-hr of continued bed rest. Measurements of plasma volume and orthostatic tolerance were made before and after each treatment period. After combined LBNP and saline therapy, plasma volume and response to LBNP testing, as measured by heart rate and systolic BP, showed a return to pre-bed-rest levels. Saline consumption alone had a lesser effect. With continuation of bed rest in three subjects, the beneficial effects of these measures appeared to be largely gone after 18 hr.

51. Il'ina-Kakuyeva, Ye. I.; Portugalov, V. V.; Krivenkov, N. P.; Kakurin, L. I.; Cherepanin, M. A.; Fedorenko, G. T.; Pervushin, V. I.; and Shaposhnikov, Ye. A.:  
Effects of Physical Conditioning and Electric Stimulation on Metabolic Processes in the Soleus Muscle and Structure Thereof in Hypokinetic Man.  
*Kosmich. Biol. Aviak. Med.*, vol. 13, 1979, pp. 35-38.

#### Authors' Abstract

During 49 days a group of test subjects were exposed to head-down tilting, in the course of which they exercised on the bicycle ergometer and were exposed to electrostimulation before and after ergometry. Morphological and histochemical examinations of soleus biopsies showed that 41 rest led to a noticeable atrophy of red and white myofibers. The structural changes were accompanied by metabolic alterations, involving a decrease of oxidative metabolism. Electrostimulation done before exercises prevented atrophy and led to hypertrophy of myofibers, which showed, however, the metabolic changes observed after bed rest per se. The combination of exercises and electrostimulation applied after them, produced the least pronounced changes in the muscle tissue. The countermeasures against the bed-rest induced muscle changes should be developed, taking into consideration both individual characteristics of the muscular system of the test subject and the level of its training.

52. Ioseliani, K. K.:  
Man's Mental Performance Under Conditions of Prolonged Hypokinesia with Use of Lower Body Negative Pressure.  
*Kosmich. Biol. Aviak. Med.*, vol. 8, 1974, pp. 86-87.

#### Annotation

**Purpose.** To determine the effect of prolonged hypokinesia and lower body negative pressure (LBNP) on man's mental performance.

**Method.** Two groups, each composed of three persons, underwent 30 days of hypokinesia. In addition to the hypokinesia, group 1 experienced LBNP at 30-mm Hg for 3 hr twice daily during the entire experiment. Group 2 experienced fractional doses of LBNP only during the last 5 days. Mental performance was measured by "continuous counting at a stipulated rate," "finding numbers with switching," "reproduction of tests," and "a memorization of 15 words" test

**Result.** Group 1 experienced a nonuniform deterioration in productivity of mental activity. By the 24th day, the group was unable to work because of difficulty in concentration. Though the semantic memory productivity did not change ("reproduction of texts" test), the mechanical memory productivity decreased significantly ("memorization of 15 words" test). By the 10th day of recovery, total restoration occurred. Group 2 experienced insignificant decreases in mental productivity.

**Conclusion.** Training with considerable exposure to hypokinesia and LBNP causes a considerable decrease in mental performance in all subjects. The group 2 training program was considered more desirable since it established a high retention of level of performance under conditions of prolonged hypokinesia.

53. Ivanov, L. A.; and Orlov, P. A.  
Effect of 6-Day Hypokinesia on Oxygen Metabolism Indices in Elderly and Senile Subjects.  
*Byulleten Eksperimental'noy Biologii i Meditsiny*, vol. 76, 1973, pp. 35-37.

**Annotation**

**Purpose.** To study hypokinesia as a factor in premature aging through its effect on oxygen absorption, stress in the tissues, and incompletely oxidized product production.

**Method.** Oxygen stress ( $P_{O_2}$ ), evaluation of oxygen supply to subcutaneous cellular tissue, intensity of cellular tissue oxygen consumption, vacat-oxygen of the urine and blood, and the content of incompletely oxidized products in the blood were measured in 21 elderly and senile men (60-89 yr) confined to 6 days of bed rest.

To evaluate oxygen supply, subcutaneous cellular tissue, and intensity of its oxygen consumption, a 10-min oxygen inhalation and pinching of the vessels in the limb for 10-min were used. Spirographic measurements determined oxygen absorption and deficiency.

**Results.** After bed rest, the increase in  $P_{O_2}$  in subcutaneous cellular tissue during oxygen inhalation was reduced, reflecting the decrease of oxygen supply to that tissue. A tendency toward reduction in oxygen consumption of subcutaneous cellular tissue after hypokinesia was seen.

The length of the stabilization period for return to the previous  $P_{O_2}$  level during transition from oxygen to air inhalation was essentially unchanged, as was the amount of  $P_{O_2}$  in the subcutaneous cellular tissue.

The vacat-oxygen of the blood and urine, the coefficient of complete oxidation, and the oxygen deficiency were increased.

**Conclusion.** The increase in concentration of incompletely oxidized products in blood and urine reflects a change in the oxidation-reduction processes resulting in a less complete oxidation of metabolites. The oxygen deficit (excess oxygen absorption from hyperoxic mixes as compared with air) is governed by an accumulation of metabolites needing extra oxygen for oxidation. Thus, the increase in incompletely oxidized product may be an adequate explanation for the changes in oxygen supply and tissue respiration in these elderly subjects.

54. Izakson, Kh. A.:  
The Negative Effect of Hypokinesia Involving Injury and Preventive Measures.  
*Voprosy Kurortologii Fizioteropii Lechebnoy i Fizicheskoy Kul'tury*, vol. ?, 1977, p. 81.

**Author's Abstract**

Determination of the optimum length of bed rest for patients suffering from broken bones is extremely important. The author concludes that as brief a period of bed rest as possible is the best. The negative effects of hypokinesia induced by bed rest include general weakness and deconditioning of the muscles as well as sleeplessness, headaches, muscle pain, constipation, etc. The use of physical therapy plus early activation of the muscles produces the best results.

55. Jacobson, L. B.; Hyatt, K. H.; and Sandler, H.:  
Effects of Simulated Weightlessness on Responses of Untrained Men to  $+G_z$  Acceleration.  
*J. Appl. Physiol.*, vol. 36, 1974, pp. 745-752.

**Authors' Abstract**

Space Shuttle vehicle travel will expose crew and untrained lay personnel to headward-acting ( $+G_z$ ) acceleration stresses that may be as high as 4 G following periods of weightlessness. Previous studies, using bed rest as an analog of weightlessness, demonstrated the orthostatic intolerance and even syncope which occurs on

reexposure to a +1  $G_z$  environment (70° passive tilt) following periods of simulated weightlessness, suggesting that post-bed-rest exposure to still higher + $G_z$  acceleration stresses would exaggerate the undesirable responses. This study documents bed-rest induced metabolic and physiologic changes in six untrained men exposed, following a 2-week period of simulated weightlessness, to possible + $G_z$  acceleration profiles anticipated for space shuttle vehicle travel. All subjects demonstrated decreased + $G_z$  tolerance following simulated weightlessness. While only one of six subjects could not tolerate the + $G_z$  profile in the control phase of the study, three of the six could not complete the post-bed-rest study. The use of an inflated standard Air Force cutaway G-suit improved + $G_z$  tolerance in all subjects, but two of six subjects still failed to complete the profile. These findings are discussed in reference to the selection of untrained humans for Space Shuttle vehicle travel.

56. Jacobson, L. B.; Hyatt, K. H.; Sullivan, R. W., Cantor, S. A., Sandler, H., Rositano, S. A., and Manchini, R.:

Evaluation of + $G_z$  Tolerance Following Simulated Weightlessness (Bedrest).  
*NASA TM X-62,311*, 1973.

#### Authors' Abstract

This study was undertaken to evaluate the magnitude of physiologic changes that are known to occur in human subjects exposed to varying levels of + $G_z$  acceleration following bed-rest simulation of weightlessness. Bed-rest effects were documented by fluid and electrolyte balance studies, maximal exercise capability, 70° passive tilt, lower body negative pressure tests, and the ability to endure randomly prescribed acceleration profiles of +2 $G_z$ , +3 $G_z$ , and +4 $G_z$ . Six healthy male volunteers were studied during 2 weeks of bed rest after adequate control observations, followed by 2 weeks of recovery, followed by a second 2-week period of bed rest, at which time an Air Force cutaway anti-G suit was used to determine its effectiveness as a countermeasure for observed cardiovascular changes during acceleration. Results showed uniform and significant changes in all measured parameters as a consequence of bed rest, including a reduced ability to tolerate + $G_z$  acceleration. The use of anti-G suits significantly improved subject tolerance of all G exposures and returned measured parameters, such as heart rate and blood pressure, toward or to pre-bed-rest (control) values in four of the six cases.

57. Kakurin, L. I.; Arzamov, G. S., and Grigor'yev, A. I.:

Kaliuretic Renal Function in Man as Related to Different Degrees of Exercise during Bedrest.  
*Kosmich. Biol. Aviak. Med.*, vol. 12, 1978, pp. 13-17.

#### Annotation

*Purpose.* To investigate the kaliuretic function of human kidneys in the course of prolonged bedrest as related to a concurrent exercise regimen.

*Method.* Twelve healthy male subjects (22-34 yr) spent 49 days in antiorthostatic (-4°) bed rest. They were divided into two groups of 6 men each. Group 1 exercised in accordance with a special program while group 2 maintained strict hypokinetic conditions.

Salt and fluid intake were monitored and each subject received 80 mEq potassium per day with food. Potassium load tests were conducted twice in the pre-bed-rest period; on the 14th, 34th, and 46th day of bed rest, and on the 2nd day of recovery. Subjects ingested 1.0 or 1.5 mEq potassium per kilogram of body weight. Blood and urine samples were analyzed, before and after the load for potassium and sodium concentration, by flame photometry and for chloride concentration with a radiometer chloridimeter.

**Results.** Potassium excretion increased as a result of the potassium load, reaching a maximum 2-3 hr after the load.

Significant differences between the groups appeared during day-4 bed-rest testing. Group 2 had a greater increase in rate of potassium excretion than did group 1 and than was demonstrated in the pre-bed-rest background tests. The greatest difference occurred within the first 3 hr after the load. A greater increase in potassium concentration in blood plasma was also exhibited. There was less increase in sodium and chloride content during the test.

On the 34th day of bed rest, the group 2 increase in potassium excretion was associated with more marked changes in the potassium content of the blood plasma. Group 1 continued to exhibit results comparable to those of the background tests.

On the 46th day of bed rest, group 2 demonstrated a decrease in potassium excretion significantly lower than that of group 1. Concentration of urine potassium was higher in the subjects of the first group, although diuresis was lower.

**Conclusion.** The decrease in potassium excretion during the 46th day of bed rest was not verified in subsequent studies and remains unexplained. Physical conditioning during bed rest diminishes significantly the development of changes in kaliuretic function of the kidneys.

58. Kakurin, L. I.; Lobachik, V. I.; Mikhailov, V. M.; and Senkevich, Yu. A.:  
 Antiorthostatic Hypokinesia as a Method of Weightlessness Simulation.  
*Aviat. Space Environ. Med.*, vol. 47, 1976, pp. 1083-1086.

**Authors' Abstract**

Physiological effects in eight test subjects during a 5-day bed-rest experiment in the head-down position (0°, -4°, -8°, -12°) were studied. It was shown that the antiorthostatic hypokinesia at -12° could reproduce physiological responses shown by space crewmembers more closely than recumbent bed rest. Our observations help to simulate an acute stage of human adaptation to the weightless state and to assess the part played by gravity-induced blood redistribution in the development of physiological changes.

**Annotation**

**Purpose.** To reproduce sensory, clinical, and physiological responses typical in the acute period of weightlessness adaptation and to assess the use of antiorthostatic bed rest for this function.

**Method.** Eight male subjects (27-37 yr) were each put through two experimental trials. These trials included a 3-day reference period, a 5-day test period, and a 2-day recovery period.

Weeks	Subject			
	1	2	3	4
1-3	0°	-4°	-8°	-12°
7-9	-8°	-12°	0°	-4°
	5	6	7	8
4-6	0°	-4°	-8°	-12°
10-12	-8°	-12°	0°	-4°

Special tests included a tilt test (75° for 10 min pressure measured from auscultation), and a bicycle ergometer test (600 kg/min load for 7 min with heart rate measured from ECG and oxygen consumption and CO<sub>2</sub> measured using an automatic gas analyzer).

**Results.** In the head-down position, decreased taste and olfactory sensitivity were noted. Other symptoms included nasal congestion, increased intranasal resistance, spatial illusions, nystagmus, facial puffiness, and fullness in the eyes. Less severe symptoms included vertigo and nausea.

The tilt test showed a decline in orthostatic tolerance correlating with the angle of head-down tilt. Heart rate changes after 5 days of space flight (Soyuz 6, 7, and 8) were closer to the changes noted in subjects kept at  $-4^{\circ}$  and  $0^{\circ}$ .

In the bicycle ergometer tests, the heart rate of those subjects at  $0^{\circ}$  were virtually unchanged, whereas the rates of subjects at  $-4^{\circ}$ ,  $-8^{\circ}$ , and  $-12^{\circ}$  diminished by 3% for subjects at  $0^{\circ}$ , remained unaltered for subjects at  $-4^{\circ}$ , and increased by 2% and 3% for subjects at  $-8^{\circ}$  and  $-12^{\circ}$ , respectively. When compared with ergometer tests carried out after a 5-day space flight, the changes in test subjects at  $-4^{\circ}$  and  $-12^{\circ}$  were the closest in approximation to those of the astronauts.

**Conclusion.** The authors concluded that head-down bed rest at angles from  $-4^{\circ}$  to  $-12^{\circ}$  can reproduce physiological changes in orbital flight better than recumbent bed rest.

59. Kamforina, S. A.:  
Creatinuria in Man during Prolonged Hypokinesia.  
*Kosmich. Biol. Aviak. Med.*, vol. 13, 1979, pp. 32-35.

#### Annotation

**Purpose.** To study creatine excretion in prolonged bed rest as it is influenced by physical exercise.

**Method.** Six male subjects (20-23 yr) were kept in bed rest for 94 days. Group 1 underwent strict hypokinesia while group 2 performed a set of physical exercises. A 1-week pre-study period served as the control. The diet was analyzed by proximate analysis and creatine urine excretion and urinary nitrogen were measured.

**Results.** Group 1 exhibited an increase in creatine excretion by the third week, with a maximum reached at the end of the second month. Creatine excretion then dropped to the control level. Group 2 showed a less marked increase than group 1, and the maximum level was reached by the third month and maintained until the end of the experiment.

Overall, the correlation between excreted creatine and total urine nitrogen was  $r = 0.53$ .

**Conclusion.** In view of these data, the authors could not determine the cause of creatinuria in bed rest. The authors speculate that the increased creatine excretion seen in the first few weeks may be due to the diminished capacity of the muscles to utilize creatine. Exercise appeared to attenuate creatinuria thereby preserving the energy potential of the muscles.

60. Kas'yan, I. I.; Talavrinov, V. A.; Luk'yanchikov, V. I.; and Kobzev, Ye. A.:  
Effect of Antiorthostatic Hypokinesia and Space Flight Factors on Change in Leg Volume.  
*Kosmich. Biol. Aviak. Med.*, vol. 14, 1980, pp. 51-55.

#### Authors' Abstract

The purpose of the present investigation was to assess, using a specially built sensor, variations and level of fluid redistribution as well as atrophic changes in leg muscles of test subjects exposed to prolonged head-down tilt and cosmonauts in a real space flight. Hypokinetic test subjects were examined before, during, and after head-down tilt, whereas cosmonauts were examined before and during flight. The results obtained show that a change in the hydrostatic component of blood pressure is followed by displacement of a substantial fluid volume (about 7%). Adequate performance of pre-assigned countermeasures seems to prevent atrophic developments of leg muscles.

61. Katkov, V. Ye.; Chestukhin, V. V.; Zybin, O. Kh.; Sukhotskiy, S. S.; Abrosimov, S. V.; and Utkin, V. N.:  
*The Effect of Short-Term Antiorthostatic Hypokinesia on Central and Intracardiac Hemodynamics and Metabolism of a Healthy Person*, pp. 69-75.

#### Authors' Abstract

The right parts of the heart and the radial artery were catheterized in healthy male volunteers before and 5 days after strict bed rest in antiorthostatic position of the body ( $-4.5^\circ$ ). After immobilization, most values of central circulation showed no essential changes; the only exception were indices characterizing the inotropic myocardial condition. A shift in the direction of acidosis of a mixed character was noted in mixed venous blood; the  $\beta$ -lipoprotein content increased. A decrease in the arteriovenous difference in oxygen was encountered in blood draining from the heart (from the coronary sinus).

62. Katkov, V. Ye.; Kauricheva, N. I.; Chestukhin, V. V.; Zybin, O. Kh.; Seyfulla, R. D.; and Utkin, V. N.:  
*Parameters of Acid-Base Equilibrium and Enzymatic Activity of Blood in Man during Brief Antiorthostatic Hypokinesia*.  
*Kosmich. Biol. Aviak. Med.*, vol. 11, 1977, pp. 51-58.

#### Annotation

*Purpose.* To study the effects of brief antiorthostatic hypokinesia on parameters of acid-base equilibrium and aminotransferase and alkaline phosphatase activity in blood flowing from various organs.

*Method.* Subjects included healthy males held for 5 days of bed rest in the antiorthostatic position ( $4.5^\circ$  tilt of body). Catheterization was performed simultaneously with two catheters: a venous one inserted into the punctured ulnar vein and passed into the vessels of different organs, and a soft arterial catheter kept in the radial artery.

Gas composition of blood was measured as well as levels of aspartate and alanine aminotransferase and alkaline phosphatase.

*Results.* The authors noted a decrease in standard bicarbonate, an excess of bases and buffer bases, and a drop in pH in blood from veins after antiorthostatic hypokinesia. These changes were most marked in blood flowing from the brain.

Aminotransferases showed a tendency to increase and alkaline phosphatase decreased. Aspartate aminotransferase increased in activity more than alanine aminotransferase in a statistically significant amount in blood flowing from the brain, liver, and kidneys.

*Conclusion.* The results indicate a decrease in buffer capacity, with an increase in aspartate aminotransferase in blood flowing from the brain. The brain was found to be the most susceptible organ, with a change toward metabolic acidosis and increased enzyme activity. The authors view these changes as a result of immobilization and the subsequent redistribution of body fluids rather than a simple shift in acid-base equilibrium.

63. Katkovskiy, B. S.; and Buzulina, V. P.:  
*Evaluation of the Functional State of the Human Cardiovascular System during Prolonged Antiorthostatic Hypokinesia, Using Different Levels of Physical Exercise on a Bicycle Ergometer*.  
*Kosmich. Biol. Aviak. Med.*, vol. 14, 1980, pp. 86-87.

#### Annotation

*Purpose.* To study the use of physical loads ( $\approx 400$  kg-m/min) in assessing the functional state of the cardiovascular system in space crewmembers.



**Method.** Twelve subjects underwent 45 days of bed rest in the antiorthostatic position ( $-4^\circ$ ). Group 1 (six subjects) performed a special set of exercises two times per day at 300 kcal/hr. Group 2 served as the control. In the background period and on the 45th day, the subjects were tested at 150, 300, 600, and 800 kg-m/min for 5-min periods with 5 min between the first and second loads and 10 to 15 min between subsequent loads. The pulse rate during the 5th minute of each load was recorded.

**Results.** The subjects in group 1 showed insignificant changes in pulse rate as a reaction to physical loads. The subjects in group 2 presented substantially decreased endurance, which was most demonstrable under heavy physical loads.

**Conclusion.** Small physical loads are inadequate for assessing the cardiovascular system's functional changes in prolonged bed rest. The authors suggest a load of 800 kg-m/min be used when assessing the functional state of crewmembers in space flight.

64. **Katkovskiy, B. S.; Georgiyevskiy, V. S.; Machinskiy, G. V.; Mikhaylov, V. M.; and Pometov, Yu. D.:** Some of the Physiological Effects of 30-Day Bed Rest with the Body in Different Positions. *Kosmich. Biol. Aviak. Med.*, vol. 14, 1980, pp. 55-58.

**Authors' Abstract**

Eighteen male test subjects were exposed to a 30-day bed rest with the foot end of the bed tilted at  $+6^\circ$ ,  $-2^\circ$ , or  $-6^\circ$ . Control subjects were allowed a normal mode of life during the same period of time. Hypokinesia was shown to play the leading role in the genesis of most changes, since control subjects displayed no changes. It was concluded that head-down tilt simulated changes occurring during adaptation to weightlessness better than recumbency or head-up tilt.

65. **Katkovskiy, B. S.; and Gornago, V. A.:** External Respiration and Gas Exchange in Orthostatic Syncope. *Byulleten' Eksperimental'noy Biologii i Meditsiny*, vol. 85, 1978, pp. 520-523.

**Authors' Abstract**

Cardiorespiratory reactions to tilt tests were compared in 80 healthy male subjects with an adequate orthostatic tolerance and in 19 subjects who fainted during tilting. They showed significant differences in the gas exchange, hemodynamics and external respiration. Variations in the heart rate, pulmonary ventilation, and the alveolar  $\text{CO}_2$  tension were most demonstrative. The findings, particularly the lack of the expected decrease of oxygen consumption in the presyncopal state, contribute to the concepts of the pathogenesis of the orthostatic collapse.

66. **Katkovskiy, B. S.; Machinskiy, G. V.; Toman, P. S.; Danilova, V. I.; and Demida, B. F.:** Man's Physical Performance after Thirty-Day Hypokinesia with Countermeasures. *Kosmich. Biol. Aviak. Med.*, vol. 8, 1974, pp. 43-47.

**Authors' Abstract**

A 30-day bed-rest experiment in which healthy test subjects were kept in horizontal and antiorthostatic positions revealed a decline in maximum  $\dot{V}\text{O}_2$  and the total amount of the work done. The performance of the test subjects who were exposed to the antiorthostatic position was lower than that of horizontal subjects. The causes underlying the decline in physical performance and the effect of different preventive measures are discussed. The information level of such physical performance parameters as the amount of work done and maximum  $\dot{V}\text{O}_2$  are discussed.

67. **Katkovskiy, B. S.; and Pometov, Yu. D.;**  
**Cardiac Output during Physical Exercises Following Real and Simulated Space Flight.**  
*Life Sci. Space Res.*, vol. 14, 1976, pp. 301-305.

**Authors' Abstract**

During moderate physical work (after 5 min) the cardiac stroke volume in the cosmonauts who made 2-8 day flights in the Soyuz spacecraft was lower and the pulse rate was higher than the pre-flight level. By the end of the 49-day bed-rest experiment the stroke volume during physical exercises (after 5 min) was lower than at the 5th min of the pre-test period in both the supine and sitting positions. The cosmonauts performed physical exercises in the sitting position. Therefore, it can be assumed that the major factor changing cardiac output may be the effect of Earth's gravity against the background of decreased orthostatic tolerance. Results of simulated experiments give evidence that in both cases one of the major factors responsible for changes in the cardiac output was a decline in the contractile capacity of the myocardium.

68. **Keil, L. C.; and Ellis, S.:**  
**Plasma Vasopressin and Renin Activity in Women Exposed to Bed Rest and +G<sub>z</sub> Acceleration.**  
*J. Appl. Physiol.*, vol. 40, 1976, pp. 911-914.

**Authors' Abstract**

To study the effect of prolonged recumbency on plasma vasopressin and renin activity, eight women (23-24 yr) were subjected to 17 days of absolute bed rest. The +3 G<sub>z</sub> tolerance of the subjects was tested before and after 14 days of bed rest. From *day 2* and through *day 17* of bed rest, plasma arginine vasopressin (AVP) levels were reduced 33%. Plasma renin activity (PRA) increased 91% ( $P < 0.05$ ) above ambulatory control values from *days 10* through *15* of bed rest. When compared to precentrifuge values, exposure to +3 G<sub>z</sub> prior to bed rest provoked a 20-fold rise ( $P < 0.05$ ) in mean plasma AVP but resulted in only a slight increase in PRA. After bed rest acceleration increased plasma AVP 7-fold ( $P < 0.02$ ); however, the magnitude of this increase was less than the past +3 G<sub>z</sub> value obtained prior to bed rest. After bed rest, no significant rise was noted in PRA following +3 G<sub>z</sub>. This study demonstrates that prolonged bed rest leads to a significant rise in the PRA of female subjects, while exposure to +G<sub>z</sub> acceleration provokes a marked rise in plasma AVP.

69. **Kimzey, S. L.; Leonard, J. I.; and Johnson, P. C.:**  
**A Mathematical and Experimental Simulation of Hematological Response to Weightlessness.**  
*Acta Astronautica*, vol. 6, 1979, pp. 1289-1303.

**Authors' Abstract**

Two ground-based methods of weightlessness simulation – a computer model of erythropoiesis feedback regulation and bed rest – were used to investigate the mechanisms that lead to loss of red cell mass during spaceflight. Both methods were used to simulate the first Skylab mission of 28 days. Human bed rest subjects lose red cell mass linearly with time, and in this study the loss was 6.7% at the end of 4 weeks (compared with 14% in Skylab). Post-bed-rest recovery of red cell mass was delayed for 2 weeks, during which time a further decline in this quantity was noted. This is consistent with the first Skylab mission but not with the two longer flights of 2 and 3 months. Hemoconcentration, observed early in the study, was essentially maintained despite red cell loss because of continued loss of plasma volume. The computer model, using the time-varying hematocrit data to estimate red cell production rates, predicted dynamic behavior of plasma volume and red cell mass that was in close agreement with the measured values. The results support the hypothesis that red-cell loss during supine bed rest is a normal physiological feedback process in response to hemoconcentration enhanced tissue oxygenation and suppression of red cell production. In contrast, the delayed post-bed-rest recovery of red-cell mass was more difficult to explain, especially in the light of enhanced reticulocyte indices observed at the onset of ambulation. Model simulation suggested the possibilities, still to be experimentally demonstrated, that this period was marked by some combination of

increased oxygen-hemoglobin affinity, small reductions in mean red cell life span, ineffective erythropoiesis, or abnormal reticulocytosis. The question of whether hemoconcentration is the sole contributor to space-flight red cell losses also remains to be resolved.

70. **Kiselev, R. K.; Balakovskiy, I. S.; and Virouets, O. A.:**  
Change in Hemoglobin Mass during Prolonged Hypokinesia.  
*Kosmich. Biol. Aviak. Med.*, vol. 9, 1975, pp. 80-84.

**Authors' Abstract**

Total hemoglobin mass was measured by the carbon dioxide method in 33 test subjects, 21 of whom were exposed to 30 days of bed rest and 6 of whom were exposed to 100 days of bed rest. The hypokinetic test subjects exhibited a decrease in hemoglobin mass by 11-24%. During readaptation the test subjects who had a noticeable reduction of hemoglobin exhibited an increase in the reticulocyte count by a factor of 2.7. It is postulated that the decrease in gravity during bed rest and antiorthostatic hypokinesia results in a reduced rate of hemoglobin synthesis in the bone marrow.

71. **Kolosov, I. A.:**  
Statokinetic Reactions of Man under Conditions of Short-Term Weightlessness.  
*Izv. Akad. Nauk. SSR (Ser. Biolog.)*, vol. ??, 1969, pp. 736-741.

**Authors' Abstract**

The purpose of the study was to investigate the character and acuteness of statokinetic reactions of man under conditions of short-duration weightlessness and their dependence on flight experience, to elaborate criteria for evaluating statokinetic resistance to short-duration weightlessness, and to study the adaptive capacities of the organism. Thirty experienced fighter pilots and 11 persons of non-aviation professions (doctors and engineers) participated in the experiments. The test subjects underwent multiple physiological studies of their sensory, vegetative, motor, and vestibulo-somatic reactions. During the familiarization flights for weightlessness, most of the test subjects showed statokinetic disturbances in the form of psychosensory, vegetative, and motor disorders. The degree of acuteness of the statokinetic disturbance was found to be in inverse relation to flight experience of the test subjects, with disturbances being observed in 16.7% of the pilots and in 81.9% of the non-pilots during the first familiarization flights.

72. **Koroieva-Munts, V. M.:**  
Circadian Rhythm of Physiological Functions in Clinostatic Hypokinesia.  
*Fiziologicheskii Zhurnal SSSR*, vol. 60, 1974, pp. 1145-1149.

**Author's Abstract**

In the first 10 days of a strict bed regimen (for medical reasons) changes were noted in the circadian rhythm of the heart rate, body temperature, minute volume of respiration and openness of the bronchial passages. By the 19-21st day in bed initial rhythms of the first three indices reappeared. Changes in the character of individual rhythm curves and correlations between rhythms of heart rate and body temperature were statistically significant; no significant differences were found for mean values of sinusoid amplitude and phase with which empirical curves of rhythm were appropriate.

73. **Korol'kov, V. I.; and Mirviakhornov, M. M.:**  
Tolerance of Hypokinesia in Subjects Conditioned in High Mountains.  
*Kosmich. Biol. Aviak. Med.*, vol. 10, 1976, pp. 20-24.

**Authors' Abstract**

After a 26-day exposure to an elevation of 3,200 m, test subjects were confined to bed for 10 and 24 days. Each experimental group consisted of six test subjects. Physiological effects of the exposure were measured

with respect to changes in the respiratory, circulatory, and red blood systems as well as in orthostatic and exercise tolerance. High-altitude adaptation which preceded bed rest did not arrest the development of orthostatic intolerance or the decrease in physical performance which resulted from the bed-rest experiment.

74. **Kotov, A. N.:**  
Diffusion of the Human Lungs under the Combined Effect of Hypokinesia and Hypoxia.  
*Kosmich. Biol. Aviak. Med.*, vol. 11, 1977, pp. 85-86.

#### **Annotation**

**Purpose.** To study the diffusion capacity of the human lung in hypokinesia and hypoxia.

**Method.** The subjects included 13 men (25-35 yr) who underwent bed rest for 49 days. Group 1 (10 men) served as control. Group 2 (3 men) subjects breathed a gas mixture (13% O<sub>2</sub>, 77% N<sub>2</sub>) twice daily for 3 hr. CO in expired, mixed expired, and alveolar air was measured, using an infrared analyzer. The amount of blood in the pulmonary capillaries was also measured.

Measures to determine lung diffusion were performed in the background period: 5th, 15th, 25th, 35th, and 45th days of hypokinesia; and the 3rd, 5th, and 7th days of recovery.

**Results.** A phasic change in lung diffusion was observed in body groups of subjects with a return to initial levels occurring 10 days sooner in the treatment group.

In the treatment group, the tendency toward increased diffusion in the first 15 days was significantly related to a change in the amount of blood in the pulmonary capillaries. By day 25, the level returned to the starting point.

Maximum resistance to alveolar-capillary membrane diffusion was observed on the 25th day and restored to normal on the 35th day.

In the recovery period, the lung diffusion gradually decreased.

In the control group, the membrane component of diffusion capacity was indicated as the predominant influence on lung diffusion.

**Conclusion.** The authors concluded that daily sessions of respiration with a hypoxic gas mixture causes marked changes in lung diffusion capacity with the capillary component having the greatest influence when compared with the control group in which the membrane component had the greatest influence.

75. **Krasnykh, I. G.:**  
Roentgenological Study of Cardiac Function and Mineral Saturation of Bone Tissue after Thirty-Day Hypokinesia.  
*Kosmich. Biol. Aviak. Med.*, vol. 8, 1974, pp. 68-71.

#### **Author's Abstract**

Before and on the fourth day of a 30-day bed-rest experiment the cardiac size and output, as well as the contractile function of the myocardium were measured using teleroentgenokymograms. Bone density of the right heel bone and of the first phalanx of the fifth finger on the right hand was determined roentgenophotometrically. In the early recovery period the cardiac size, cardiac output and the force of cardiac contractions decreased, whereas the heart rate increased. Bone density also decreased. The countermeasures applied – physical exercises, lower body negative pressure, and muscle electrostimulation – reduced the mentioned changes but did not eliminate them entirely.

76. **Krasnykh, I. G.:**  
Roentgenological Examination of the Human Heart after 100-Day Hypokinesia.  
*Kosmich. Biol. Aviak. Med.*, vol. 13, 1979, pp. 28-31.

**Annotation**

**Purpose.** To study, using X-ray methods, the effect of long-term hypokinesia on the size and contractile function of the heart.

**Method.** Two groups of males (21-22 yr) were kept in bed rest for 100 days.

Group 1 (three subjects) performed only necessary movements while group 2 (three subjects) performed a set of supine exercises regularly. Teleroentgenokymograms were taken to determine the heart volume in systole and diastole and the stroke volume. The cardiac coefficient (heart volume/body weight) was calculated and myocardial contractility was assessed from the outlines of the roentgenokymograms.

**Results.** After bed rest, all subjects complained of general weakness, fatigue, palpitations, and pain which were more marked in the first group.

In group 1, at the end of bed rest, the heart volume in systole and diastole decreased by 24% and 26%, respectively. The cardiac coefficient was 23% lower than in the background period. The roentgenokymogram showed a decrease in heart size and a change in shape. The right venous return and stroke volumes were reduced. After 1 month of recovery, the heart volume remained 15% smaller, the stroke volume 10% decreased, and the cardiac coefficient 13% lower than in the background period.

In group 2, the change in heart volume on day 100 was 2-2.5 times less marked than in group 1. Stroke volume was 3 times less marked. The parameters of cardiac conditions reached base level 3 months into the recovery period.

**Conclusion.** Decrease in heart volume is due to a decrease in delivery of blood to the heart and weight loss of the myocardium. Since bed rest leads to a loss of plasma, the systole and minute volume of the heart are reduced. The reduction in size of the right and left heart are indicative of a diminished return to the right heart and systolic ejection.

77. **Krotov, V. P.; Kovalenko, Ye. A.; and Katuntsev, V. P.:**  
Effect of Prolonged Hypokinesia on the Water and Fat Composition of the Human Body.  
*Byulleten' Eksperimental'noi Biologii i Meditsiny*, vol. 81, 1976, pp. 279-281.

**Authors' Abstract**

The combined effect of prolonged hypokinesia (30-49 days) and differences in the body position relative to the gravitational vector on the composition of the body was studied in healthy men. The total body water content depends more on the position of the body in space than on the restricted mobility. In the anti-orthostatic position, the loss of water takes place chiefly during the first few days. As a result of prolonged hypokinesia the "lean mass of the body" is reduced and so also is its water content. The water content is rapidly restored when motor activity is resumed.

78. **Krotov, V. P.; and Romanovskaya, L. L.:**  
Effect of Strict Bed Rest for 30 Days on Human Water Metabolism.  
*Byulleten' Eksperimental'noi Biologii i Meditsiny*, vol. 79, no. 2, 1975, pp. 23-25.

**Author's Abstract**

The effect of strict bed rest for 30 days on the state of the water metabolism, the kinetics of water excretion, and the mean daily water loss was studied in man. Hypokinesia was found to reduce the rate of water renewal and to decrease the total water loss of the body. The relative water content as a percentage of body weight on the 25th day of hypokinesia was identical with the control.

79. **Krotov, V. P.; and Romanovskaya, L. L.:**  
**Effect Exerted on Water Metabolism by Body Position Relative to the Gravitational Vector.**  
*Kosmich. Biol. Aviak. Med.*, vol. 10, 1976, pp. 37-41.

**Annotation**

*Purpose.* To study the influence of the combined effect of hypokinesia and the positioning of subjects at different angles to the gravitational vector on the quantity of water in the body and the rate of its renewal.

*Method.* Twenty-one healthy male subjects were divided into four groups.

Group	Size	Treatment
1	3	Unrestricted motor activity
2	6	30 days of bed rest, foot of bed raised 2°
3	6	30 days of bed rest, foot of bed raised 6°
4	6	30 days of bed rest, head raised 6°

Total body water was measured, using tritium oxide during the background period, on the 25th day of bed rest and on the 8th day of recovery. The quantity of water was computed using a dilution formula and extrapolation to the zero point on the isotope elimination curve. Total moisture loss, as well as percent water in the body, was measured.

*Results.* On the 25th day of bed rest, the tendency for a body water decrease was seen in group 2 while group 3 showed a definite decrease. The body water in group 4 increased.

On the 8th day of recovery, body fluid content went back to the pre-treatment level in all groups.

The data indicated a dependency of body water content on the body position relative to the gravitational vector with a decrease in the antiorthostatic position and an increase in head-up tilt.

Extrarenal body losses decreased to about 45-50% of total water losses.

*Conclusion.* The body water of a person in hypokinesia seems dependent on the spatial body position rather than cessation of activity. In hypokinesia, extrarenal water losses are considerably reduced. In a healthy man, water metabolism is affected by motor activity, but water content is influenced by body position.

80. **Krotov, V. P.; Titov, A. A.; Kovalenka, Ye. A.; Bogomolov, V. V.; Stazhadze, L. L.; and Masenko, V. P.:**  
**Changes in Fluid Metabolism during Prolonged Hypokinesia with the Body in Antiorthostatic Position.**  
*Kosmich. Biol. Aviak. Med.*, vol. 11, 1977, pp. 32-37.

**Annotation**

*Purpose.* To define the influence of 49-day antiorthostatic (-4°) bed rest followed by a 25-day recovery period on the dynamics of intravascular fluid content and the total amount of body fluid.

*Method.* Six adult males underwent 49 days of strict antiorthostatic bed rest. A 25-day recovery period followed bed rest where the subjects resumed motor activity and rehabilitated in pools with underwater massage.

Total body fluid was assayed by means of tritium oxide twice during the background period, on the 15th, 26th, and 48th days of bed rest, and on the 13th recovery day. The activity of exhaled air vapor samples was measured with a liquid scintillation counter for 4 hr following administration of the tritium oxide.

Circulating blood volume and components thereof were measured using universal donor erythrocytes labeled with radioactive chromium during the background period, on the 49th day of bed rest, and on the 4th and 23rd days of recovery.

Hematocrits were also measured during the study.

**Results.** On the 15th day of bed rest, body fluid relative to body weight had decreased by  $2.95 \pm 0.52\%$  from the background period. The remaining 2 weeks of bed rest did not have as marked an effect on the hydration status of the subjects. Percentile body fluid had decreased by  $4.68 \pm 0.75\%$  at the conclusion of the bed-rest period. Sixty-two percent of this loss occurred during the first 15 days of bed rest. By the 13th day of recovery, the percentile fluid content had increased by 2.11% over the final bed-rest measurement, and there was an average  $2.72 \pm 0.68$  liter increase in body fluid.

As a result of the 49-day bed rest, circulating blood volume decreased by 1.3 liters, 29% of the background value. The decrease was a result of a decrease in both plasma volume and erythrocyte mass. By the 4th day of recovery, plasma volume had returned to normal but erythrocyte mass remained low at 76% of the background value, keeping the circulating blood volume at 91% of background. At the end of the 25-day recovery period, the circulating blood volume was still 11% below the background values.

**Conclusion.** Under conditions of lengthy hypokinesia, with the subjects in an antiorthostatic position, there is a rather appreciable decrease in body fluid, largely because of intravascular loss. The antiorthostatic position of the subjects caused a greater decrease in erythrocyte mass and plasma volume than a horizontal position. This was probably a result of the Gauer Henry reflex.

81. **Krupina, T. N.; and Tizul, A. Ya.:**  
Clinical Aspects of Changes in the Nervous System in the Course of 49-Day Antiorthostatic Hypokinesia.  
*Kosmich. Biol. Aviak. Med.*, vol. 11, 1977, pp. 26-31.

#### **Annotation**

**Purpose.** To study the nervous system response of subjects in antiorthostatic hypokinesia.

**Method.** Nine subjects (20-35 yr) were kept in antiorthostatic ( $4^{\circ}$ - $6^{\circ}$ ) hypokinesia. Clinical tests, thermoregulation, and the muscular system were studied every 7-10 days.

**Results.** All subjects felt a rush of blood to the head which reached a maximum at 1.5 hr after the start of the study. For the first 2 days, the subjects experienced diuresis and vesical tenesmus.

In the 4th week, nystagmoid beats were observed. Other neurological changes observed included mild digital tremors and changes in the nature and duration of autonomic reflexes. Pulse rate increased 15 b/min.

In tests of the noregulatory dynamics, a temperature drop indicated sluggishness of the thermoregulatory processes.

All subjects showed signs of vegetovascular dysfunction and asthenization.

**Conclusion.** The authors concluded that antiorthostatic hypokinesia can be divided into phases, with the acute phase involving the redistribution of blood. The diminished tonus of vessels in the head, bones, and legs, as well as the diminished tone of the skeletal muscles, elicit changes in the organism that lead to a change in the functional state of the nervous system.

82. **Krupina, T. N.; Yarullin, Kh. Kh.; and Alekseyev, D. A.:**  
Bioelectric Activity of the Human Brain during and after 182-Day Antiorthostatic Hypokinesia.  
*Kosmich. Biol. Aviak. Med.*, vol. 14, 1980, pp. 49-54.

**Authors' Abstract**

Cerebral bioelectric activity of 18 healthy test subjects (31-40 yr) was examined during and after their 182-day head-down tilting. The test subjects were divided into a group that performed countermeasures (exercise, muscle stimulation) against hypokinesia-induced disorders and a control group. During the study, EEG changes were most pronounced in the controls:  $\alpha$ -rhythm amplitude, frequency and index decreased, slow-wave frequency decreased, whereas index of zonal differences and amplitude of  $\beta$ - and slow waves increased. Phasic changes in the central nervous system excitability in response to a flickering light of 6-25 Hz were found. Typical changes in spontaneous EEG during a 3-min pulmonary hyperventilation test were enhanced. The study gives evidence that the dynamics of spontaneous EEG, as well as cerebral bioelectric activity in response to flickering light and pulmonary hyperventilation, are important indicators of the cerebral function, especially of the cortical activity decrease.

83. **Leach, C. S.; Hulley, S. B.; Rambaut, P. C.; and Dietlein, L. F.:**  
The Effect of Bedrest on Adrenal Function.  
*Space Life Sciences*, vol. 4, 1973, pp. 415-423.

**Authors' Abstract**

Eight male subjects were subjected to continuous bed rest for 24-80 weeks for the purpose of studying metabolic responses. Three of the subjects did supine exercises daily during part of the study. Adrenal function was examined in relation to adrenal cortical and medullary excretions. The results reveal an increase in hydrocortisone throughout the test period, a decrease in norepinephrine, and no change in epinephrine. These data suggest that exercise could decrease the severity of deconditioning caused by bed rest.

84. **Lkhagva, L.:**  
Circadian Rhythm of Human Body Temperature in Antiorthostatic Position.  
*Kosmich. Biol. Aviak. Med.*, vol. 14, 1980, pp. 59-61.

**Authors' Abstract**

Circadian rhythms of the oral temperature were studied in three male test subjects kept for 7 days in a head-down position at  $-8^\circ$ . As compared with the controls (kept in a hospital for 3 days) the test subjects showed a statistically significant temperature increase (by  $0.22^\circ\text{C}$  on the average) during circadian minimum points that occurred at night and a decrease of the daily temperature rhythm amplitude (by  $0.20^\circ$  on the average). It is emphasized that study of human responses to various stress-agents should include monitoring of circadian rhythms of various parameters.

85. **Lockwood, D. R.; Vogel, J. M.; Schneider, V. S.; and Hulley, S. B.:**  
Effect of the Diphosphonate EHDP on Bone Mineral Metabolism during Prolonged Bed Rest.  
*J. Clin. Endocrinol. Metab.*, vol. 41, 1975, pp. 533-541.

**Authors' Abstract**

The effect of disodium ethane-1-hydroxy-1, 1-diphosphonate (EHDP<sup>®</sup>) on bone mineral metabolism was tested in four healthy young men during 20 weeks of continuous bed rest. Two subjects received an oral dose of 5 mg/kg/day and the other two received 20 mg/kg/day. The low dose had two minor effects: the increase in bone accretion rate, which usually occurs during bed rest was presented, and there was an accentuation of the bed-rest induced increase in hydroxyproline excretion. Skeletal mineral loss, assessed by calcium balance measurements and gamma ray absorptiometry of the calcaneus, occurred at the rate previously noted in untreated control subjects.



Two types of drug effect were apparent at the higher dosage. One was immediate and sustained – a rise in serum phosphorus concentration and a fall in serum alkaline phosphatase activity. The other was delayed and progressive – a decline in urinary hydroxyproline excretion and in the rates of bone accretion and resorption. Skeletal mineral loss may have been affected; the usual negative mineral balance developed during the first half of the study, then disappeared during the last few weeks. However, gamma ray absorptiometry revealed no attenuation of the calcaneal mineral losses.

86. Lorentsen, E.; Eika, C.; and Godal, H. C.:  
Coagulation Studies in Chronically Bedridden Patients.  
*Acta Med. Scand.*, vol. 195, 1974, pp. 79-80.

**Authors' Abstract**

Twelve patients without clinically recognized venous thromboembolic disease have been studied. In none of them could obvious signs of hypercoagulability of intravascular coagulation be demonstrated. The clinical implications of these findings are briefly discussed.

87. Lubin, A.; Hord, D. J.; Tracy, M. L.; and Johnson, L. C.:  
Effects of Exercise, Bedrest and Napping on Performance Decrement during 40 Hours.  
*Psychophysiology*, vol. 13, 1976, pp. 334-339.

**Authors' Abstract**

Young male naval volunteers were denied normal nocturnal sleep and maintained on a 60-min treatment – 160-min testing schedule during 40 consecutive hours. Ten subjects bicycled, 20 subjects controlled EEG activity during bed rest, and 10 subjects napped. Eight measures of addition, auditory vigilance, mood, and oral temperature were obtained. The bed-rest group showed significant impairment of all eight measures, and thus gave no support to the *forced-rest* theory of sleep function. The exercise group was worse than the nap and bed-rest group for all measures. In spite of fragmented, reduced sleep (about 3.7 hr per 24 hr), the nap group had no impairment of six of the measures. The results suggest that exercise increases the impairment due to sleep loss, and naps reduce or remove this impairment. Bed rest is not a substitute for sleep.

88. MacDougall, J. D.; Elder, G. C. B.; Sale, D. G.; Moroz, J. R.; and Sutton, J. R.:  
Effects of Strength Training and Immobilization on Human Muscle Fibres.  
*Eur. J. Appl. Physiol.*, vol. 43, 1980, pp. 25-34.

**Authors' Abstract**

Seven healthy male subjects were studied under control conditions and following 5-6 months of heavy resistance training and 5-6 weeks of immobilization in elbow casts. Cross-sectional fibre areas and nuclei-to-fibre ratios were calculated from cryostat sections of needle biopsies taken from triceps brachii. Training resulted in a 98% increase in maximal elbow extension strength as measured by a Cybex dynamometer, while immobilization resulted in a 41% decrease in strength. Both fast twitch (FT) and slow twitch (ST) fibre areas increased significantly with training by 39% and 31%, respectively. Immobilization resulted in significant decreases in fibre area by 33% for FT and 25% for ST fibres. The observed nuclei-to-fibre ratio was 10% greater following the training programme. However, this change was non-significant. There was also a non-significant correlation between the magnitude of the changes in fibre size and the changes in maximal strength following either training or immobilization.

89. **MacDougall, J. D.; Ward, G. R.; Sale, D. G.; and Sutton, J. R.:**  
Biochemical Adaptation of Human Skeletal Muscle to Heavy Resistance Training and Immobilization.  
*J. Appl. Physiol.: Respirat. Environ. Exercise Physiol.*, vol. 43, 1977, pp. 700-703.

**Authors' Abstract**

Nine healthy subjects were studied under control conditions and following 5 months of heavy resistance training and 5 weeks of immobilization in elbow casts. Needle biopsies were taken from triceps brachii and analyzed for adenosine triphosphate (ATP), adenosine diphosphate (ADP), creatine (C), creatine phosphate (CP), and glycogen concentrations. Training resulted in an 11% increase in arm circumference and a 28% increase in maximal elbow extension strength. Immobilization resulted in decreases in arm circumference and elbow extension strength of 5% and 35%, respectively. Training also resulted in significant increases in resting concentrations of muscle creatine (by 39%), CP (by 22%), ATP (by 18%), and glycogen (by 66%). Conversely, immobilization significantly reduced CP concentration by 25% and glycogen concentration by 40%. It was concluded that heavy-resistance training results in increases in muscle energy reserves which may be reversed by a period of immobilization-induced disuse.

90. **Maksimov, D. G.; and Domracheva, M. V.:**  
Changes in Central and Peripheral Hemodynamics during Prolonged Antiorthostatic Hypokinesia as Weightlessness Models.  
*Kosmich. Biol. Aviak. Med.*, vol. 12, 1976, pp. 52-57.

**Authors' Abstract**

Central and peripheral circulation were studied rheographically in six test subjects during a 30-day bed rest experiment and in nine test subjects during a 49-day bed rest. The bed-rest subjects were kept in a head-down position at an angle of  $-4^{\circ}$ . At an early stage in the experiments the cardiac output and stroke volume increased, total peripheral resistance decreased, tone of major regional vessels decreased, and that of small vessels increased. During the 3rd to 7th weeks the changes were just the opposite: cardiac output and stroke volume decreased, total peripheral resistance increased, tone of major regional vessels increased and that of small vessels decreased. At the end of the bed-rest experiment the cardiac output and stroke volume increased and the tone of regional vessels changed accordingly. Circulation parameters returned to the pretest level, at least 3-4 weeks after the end of the bed-rest experiments.

91. **McMillan, D. E.; and Donaldson, C. L.:**  
Changes in Serum Proteins, Viscosity, and Protein-Bound Carbohydrates during Prolonged Bedrest.  
*Aviat. Space Environ. Med.* vol. 46, 1975, pp. 132-135.

**Authors' Abstract**

Studies were carried out on eight young males before, during, and after 24 or more weeks of bed rest. Measurements of serum viscosity, total serum protein, serum electrophoretic components, total serum solids, serum protein-bound carbohydrate, and plasma volume were carried out. A loss of plasma volume occurred early in bed rest which produced an increase in total serum protein level. Despite continuing reduced plasma volume during bed rest, the elevated serum protein level returned toward its pre-bed-rest concentration, with stabilization of the levels of all electrophoretic components at values very near those present before bed rest. Serum viscosity changes paralleled total serum protein values. Increase in total serum solids was measured and found to be greater than the rise in total serum protein. The excess total serum solid was nondialyzable and had little effect on viscosity. Increases in protein-bound hexose and fucose level were observed during bed rest which persisted during early reambulation. The proportionate fucose increase was greater than hexose despite stability of the gamma globulin fraction with which the majority of serum protein-bound fucose is normally associated, but no change in fucose content of haptoglobin,

$\alpha_2$ -macroglobulin, or  $\alpha_1$ -acid glycoprotein was detected in two subjects on whom sufficient material was present to allow study.

92. **Melada, G. A.; Goldman, R. H.; Luetscher, J. A.; and Zager, P. G.:**  
Hemodynamics, Renal Function, Plasma Renin, and Aldosterone in Man after 5 to 14 days of Bedrest.  
*Aviat. Space Environ. Med.*, vol. 46, 1975, pp. 1049-1055.

**Authors' Abstract**

Continuous bed rest for 5 to 14 days had no significant effect on resting heart rate, blood pressure or cardiac output in six normal men. Head-up tilt induced greater tachycardia in five of six patients after bed rest than in the control period. Propranolol diminished both the tachycardia and the incidence of hypotension and faintness in upright posture. Body weight, serum electrolytes and resting renal plasma flow, and glomerular filtration rate were unchanged by bed rest. Plasma volume fell, extracellular fluid volume increased, and plasma renin activity were significantly elevated following bed rest. Unusually large increases in plasma renin followed head-up tilt or administration of isoproterenol during bed rest, and after resuming normal activity. During bed rest, plasma aldosterone was often increased in the early morning. We conclude that after bed rest, upright posture evokes strong beta-adrenergic activity, with exaggerated metabolic and circulatory responses which can be reduced or abolished by the beta-adrenergic blocker, propranolol.

93. **Mikhaylov, V. M.; Alekseyeva, V. P.; Kuz'min, M. P.; and Matsnev, E. I.:**  
Antiorthostatic Hypokinesia as an Approximate Model of Weightlessness.  
*Kosmich. Biol. Aviak. Med.*, vol. 13, 1979, pp. 23-28.

**Authors' Abstract**

Eight test subjects were exposed to a 5-day bed-rest experiment in the recumbent and head-down position (at angles of  $0^\circ$ ,  $-4^\circ$ ,  $-8^\circ$ , and  $-12^\circ$ ) to study the physiological effects of the exposure. The head-down tilting at  $-4^\circ$  and  $-12^\circ$  was shown to simulate physiological effects of real space flight better than bed rest at  $0^\circ$ . The results made it possible to model an acute stage of weightlessness adaptation and to assay the contribution of gravity induced blood redistribution to the physiological reactions.

94. **Mikhaylov, V. M.; and Georgiyevskiy, V. S.:**  
Effect of Electric Stimulation of Muscles on the Orthostatic Stability of Man.  
*Kosmich. Biol. Aviak. Med.*, vol. 10, 1976, pp. 37-41.

**Authors' Abstract**

The effect of electric stimulation of muscles on orthostatic stability was assessed in two experimental series. In the first series, 6 healthy test subjects took part. In the second series, 12 test subjects participated (three groups of 4 men each). In the first series electric stimulation was applied for 1 month (30 min per day) on an out-of-clinic basis and favorably affected orthostatic stability. In the second series electric stimulation applied during a 45-day bed-rest experiment (30 min twice a day) yielded different results. The first group of subjects who were stimulated with 20 electrodes exhibited a favorable effect. The second group of subjects who were stimulated with 12 electrodes exhibited a limited effect. The third group of subjects (controls) who were not stimulated during bed rest displayed a marked decrease in orthostatic stability.

95. Minaire, P.; Meunier, P.; Edouard, C.; Bernard, P.; Coupron, P.; and Bourret, J.:  
Quantitative Histological Data on Disuse Osteoporosis.  
*Calcif. Tiss. Res.*, vol. 17, 1974, pp. 57-73.

#### Authors' Abstract

The effect of immobilization on human bone was studied through a longitudinal, as well as cross-sectional, quantitative and dynamic histological analysis of 34 decalcified and undecalcified iliac crest biopsies. They were obtained at various times after the onset of immobilization in 28 patients of whom 22 were suffering from posttraumatic spinal cord lesions. Trabecular bone volume, osteoid volume, trabecular osteoclastic resorption surfaces, size of the periosteocytic lacunae, thickness of iliac cortices, and volume of the cell population of the marrow were measured. The histodynamic study was made by double tetracycline labeling in 19 patients. The histological data were compared with biological data from another group of 68 immobilized patients including 22 of the patients undergoing biopsy. Calcemia, phosphoremia, alkaline phosphatase, calciuria, phosphaturia, and hydroxyprolinuria were measured. The decrease of the trabecular bone volume averaged 33% over 25 weeks and then stabilized. Immobilization also caused an early increase in the trabecular osteoclastic resorption surfaces and later in the size of periosteocytic lacunae, an early depression of osteoblastic bone formation, and a thinning of the cortices. Calciuria was high, as was hydroxyprolinuria which correlates with resorption surfaces. The histological and biochemical changes suggest a histodynamic hypothesis according to which the global lifespan of the BMU (basic multicellular unit from Frost) would be increased. These changes reflect a *transient*, leading to a new *steady state*: rarefied bone with a low rate of subsequent turnover. They emphasize the importance of mechanical factors in the development of bone cells.

96. Mukhina, N. N.; Chestukhin, V. V.; Katkov, V. Ye.; and Karpov, A. P.:  
Effect of Brief Antiorthostatic Hypokinesia on Blood Immunoglobulin Content.  
*Kosmich. Biol. Aviak. Med.*, vol. 14, 1980, pp. 74-75.

#### Annotation

*Purpose.* To examine the change in immunoglobulin levels in peripheral venous blood as it is affected by antiorthostatic hypokinesia.

*Method.* Six male subjects had blood samples removed from different parts of the cardiovascular system before and after a 5-day bed rest in antiorthostatic ( $-4.5^\circ$ ) position. IgA, IgG, and IgM were assayed.

*Results.* Before antiorthostatic hypokinesia (ANOH), IgM was lower and IgA was higher in blood flowing from the brain and lower extremities. The IgG level was higher in blood drained from the liver than in blood from the systemic circulation.

After ANOH, the brain "captured" IgA from blood flowing into it and "discharged" IgG into the systemic circulation to be taken up by the liver and lower limbs. IgM distribution was not affected.

*Conclusion.* In brief, ANOH, Ig levels in systemic circulation do not change appreciably, but levels flowing out of different organs indicated a redistribution of IgA and IgG in hypokinesia.

97. Myasnikov, V. I.:  
Characteristics of the Sleep of Men in Simulated Space Flights.  
*Aviat. Space Environ. Med.*, vol. 46, 1975, pp. 401-408.

#### Authors' Abstract

A study of the sleep of men in simulated space flight has shown that during different effects (diminished motor activity, noise, rotation), monotony and time of the exposure are the general pathogenetic factors producing sleep disturbances. The monotony factor was responsible for typical changes in the sleep function

(difficulty involved in falling asleep, disturbed continuity of sleep as a process, decline in the depth, etc.), whose degree was related not only to the professional importance of the experiment but also to the individual intolerance to the main exposure. In these cases, the action of somnogenic mechanisms developed against the background of the action of analyzers (vestibular, acoustic, proprioceptive) that were under load and whose excitation during hypokinesia, noise, and rotation, especially in poorly adapted people, led to cumulation and was expressed in the phenomenon of spontaneous awakening. In addition to that, the genesis of dyssomnia, particularly during bed rest and water immersion, included hemodynamic disturbances induced by blood redistribution due to the recumbent position and monotonous motor activity. The psychosomatic feelings (congestion, edema, irresistible desire to stand up and stretch) brought about emotional strain which was later enhanced by the duration of the exposure.

98. Newsom, B. D.; Goldenrath, W. L.; Winter, W. R.; and Sandler, H.:  
Tolerance of Females to +G<sub>z</sub> Centrifugation Before and After Bedrest.  
*Aviat. Space Environ. Med.*, vol. 48, 1977, pp. 20-25.

#### Authors' Abstract

Because women may be included as passengers in the proposed Space Shuttle system, this study was designed to investigate the +G<sub>z</sub> tolerance of women and the possible degradation of this tolerance after a period of weightlessness as simulated by bedrest. Twelve healthy Air Force flight nurses served as test subjects. Over a 1-week period, each subject was exposed to +G<sub>z</sub> levels starting at +2 G<sub>z</sub> and increasing by 0.5 G<sub>z</sub> increments to a grayout point. This point was determined by peripheral vision loss with a standard light bar and by reverse blood flow in the temporal artery. Ultimately, each woman was subjected to three runs at the +3 G<sub>z</sub> level; each run was approximately 55 min long, separated by 5-min rest periods. Eight subjects with the best tolerance times were selected for 14 days of bed rest in a horizontal position; the other four were ambulatory controls. Tests before bed rest, immediately following, and 5 days later showed that average +G<sub>z</sub> tolerance decreased by 67% after bed-rest.

99. Nixon, J. V.; Murray, R. G.; Bryant, C.; Johnson, R. L.; Mitchell, J. H.; Holland, D. B.;  
Gomez-Sanchez, C.; Vergne-Marini, P.; and Blomqvist, C. G.:  
Early Cardiovascular Adaptation to Simulated Zero Gravity.  
*J. Appl. Physiol.: Respirat. Environ. Exercise Physiol.*, vol. 46, 1979, pp. 541-548.

#### Authors' Abstract

Physiological responses characterizing the early adaptation to weightlessness were studied in five normal men. Supplementary data on central venous pressure (CVP) were obtained in three additional subjects. Zero gravity was simulated by a 24-hr period of head-down tilt at 5°. Tilt produced a central fluid shift. Orthostatic tolerance and exercise capacity were reduced post-tilt. These changes were similar to those observed during and after space flight and support the validity of the experimental model. CVP increased transiently from 5.6 to a peak of 8.5 cm H<sub>2</sub>O ( $P < 0.02$ ). Control levels for CVP were approached at 90 min. at that time the echocardiographic left ventricular end-diastolic diameter reached a maximum (4.7 cm, control 3.9 cm,  $P < 0.05$ ). There were no changes in arterial pressure, cardiac output, or left ventricular contractile state. Urine flow was 1.98 ml·min<sup>-1</sup> during the initial 8 hr compared with 1.36 during the final 16 hr ( $P < 0.05$ ). Blood volume decreased by 0.5 liter ( $P < 0.05$ ). Plasma renin activity, aldosterone, and antidiuretic hormone were depressed initially but returned to base line within 24 hr. Plasma electrolytes remained unchanged. The results suggest that hemodynamic adaptation occurs rapidly and is essentially accomplished by 6 hr. Adaptation includes a diuresis and reduction in blood volume.

100. Pace, N.; Kodama, A. M.; Price, D. C.; Grunbaum, B. W.; Rahlmann, D. F.; and Newsom, B. D.:  
Body Composition Changes in Men and Women After 2-3 Weeks of Bed Rest.  
*Life Sci. Space Res.*, vol. 14, 1976, pp. 269-274.

**Authors' Abstract**

Several parameters of body composition were measured in eight men before and after 14 days of continuous recumbency, and in eight women before and after 17 days of recumbency. The parameters measured included body weight, body water, body potassium, plasma volume, and plasma protein concentrations. From these, values were derived for body fat content, lean body mass, body cell mass, and circulating plasma proteins. In general, the men and women responded similarly to continuous recumbency. Characteristically, there was significant reduction of plasma volume and body potassium in both groups. The women showed a significant reduction in circulating plasma protein, entirely in the albumin fraction; a similar change was observed in the men. The women, but not the men, showed a significant increase in circulating fibrinogen. Both men and women lost body cell mass, while body fat content remained the same or tended to increase slightly. It is expected that similar changes would occur in weightlessness. It is further concluded that women should tolerate the weightlessness of space flight physiologically as well as men.

101. Panferova, N. Ye.:  
Cardiovascular System during Hypokinesia of Different Duration and Degree of Expression.  
*Kosmich. Biol. Aviak. Med.*, vol. 10, 1976, pp. 15-20.

**Annotation**

*Purpose.* To investigate the effect of varying hypokinetic conditions on orthostatic stability in man.

*Method.* A series of seven experiments with 14 male subjects was carried out involving varying degrees of duration and muscle activity restriction. Conditions included immersion (10 days), supine position in a chair close to the mean physiological rest posture (7-20 days), bed rest (10-120 days), and altitude chambers (3-70 days).

A turntable bringing subjects from a supine to a 85° standing position while pulse rate and arterial pressure were taken, assessed orthostatic stability.

*Results.* In general, after exposure to hypokinetic conditions, the pulse rate increased with a concurrent decrease in systolic and pulse pressure. The diastolic pressure in a number of subjects increased reliably. The minimum degree of expression of orthostatic tolerance parameters measured was noted for subjects with minimum muscular restriction.

*Conclusion.* The authors conclude that the greatest adaptability to an orthostatic test occurs with the greatest restriction of muscular activity.

102. Panferova, N. Ye.:  
Heat Regulation under Prolonged Limitation of Muscular Activity.  
*Fiziologiya Cheloveka*, vol. 4, 1978, pp. 835-839.

**Author's Abstract**

During water immersion, "mean physiological rest" and seated and bed-rest tests, the body temperature under the tongue and armpits, as well as skin temperature of various portions of the trunk and extremities, was measured and the heat and cold thresholds of the back of the hand were tested. Subjective responses of the test subjects also were recorded. It was concluded that the skin temperature of the lower half of the body and the weighted average temperature decreased, coordination of heat production and heat transfer was disordered with a periodic rise of body temperature above 37°C, and the discrimination of temperature stimuli was disrupted.

103. **Pestov, I. D.; Panchenko, V. S.; and Asyamolov, B. F.:**  
Evaluation of the Prophylactic Effect of Lower Body Negative Pressure during a Thirty-Day Bed Rest Regime.  
*Kosmich. Biol. Aviak. Med.*, vol. 8, 1974, pp. 52-54.

**Authors' Abstract**

During a 30-day bed-rest experiment in which six persons participated, the effect of lower body negative pressure (LBNP) applied as a countermeasure and the possibility of detecting orthostatic changes with the aid of a Valsalva maneuver and LBNP test were studied. LBNP used during the last 5 bed-rest days was more effective than LBNP applied daily. The effect of LBNP training was also related to individual characteristics of the test subjects. Cardiovascular responses to the Valsalva maneuver (40 mm Hg, 20 sec) and LBNP test (-35 mm Hg) were similar to the responses to the orthostatic test in their pattern and direction. These tests, used during the simulation of weightlessness, help to reveal potential orthostatic intolerance of test subjects.

104. **Pokrovskaya, Z. A.; Rossinskiy, O. G.; and Shaposhnikov, Ye. A.:**  
Cerebral Bioelectric Activity during Prolonged Antiorthostatic Hypokinesia.  
*Fiziologiya Cheloveka*, vol. 2, 1976, pp. 318-324.

**Authors' Abstract**

Twelve healthy subjects were kept in a state of antiorthostatic hypokinesia (lying in beds with 6-7° head-down tilt angles) for 45 days. Orthostatic tests and tests of work capacity were conducted twice during the recovery period thereafter. Cerebral bioelectric activity was recorded before, during, and after the experiment. Changes in this activity appeared to various extents, but seemed most serious at later stages and onset of bed rest. Impairment of venous return from the head was considered quite significant in the development of the EEG changes, which were believed temporary but important.

105. **Polyakov, V. V.; Agureyev, A. N.; Vlasova, T. F., and Ushakov, A. S.:**  
Some Indices of Phosphocreatine Metabolism in Man, as Related to High and Low Levels of Energy Expenditure.  
*Kosmich. Biol. Aviak. Med.*, vol. 11, 1977, pp. 43-47.

**Annotation**

**Purpose.** To investigate creatine metabolism in activity and hypokinesia, using a low-protein diet and bed rest as the experimental model.

**Method.** Two series of experiments were carried out with 40 men (25-35 yr). Series 1 subjects were placed on a low-protein diet. Series 2 subjects underwent physical loads (group 4) and bed rest (group 4) for 30 days. Blood plasma free amino acids (alanine, glycine, methionine) and urine creatinine were measured.

**Results.** In the second series, by the 20th day of bed rest, the 5th group had reached 150% of their initial creatine index levels. Amino acids remained at control levels.

**Conclusion.** Data reflect a reorganization of protein metabolism occurring under new conditions of vital organism activity.

106. Reck, G.; Beckerhoff, R.; Vetter, W.; Armbruster, H.; and Siegenthaler, W.:  
Control of Plasma Aldosterone in Normal Man during Upright Posture.  
*Klinische Wochenschrift*, vol. 53, 1975, pp. 955-959.

**Authors' Abstract**

Plasma aldosterone, plasma renin activity (PRA), plasma cortisol as parameter of ACTH activity, and the serum concentrations of sodium and potassium were determined at short time intervals in 10 healthy students after an overnight bed rest and during 3 hr of ambulation. While PRA rose significantly within 15 min of orthostasis in all students, plasma aldosterone showed a similar rapid increase in some of the subjects only. These persons demonstrated also a simultaneous increase of serum potassium or of plasma control. Plasma aldosterone rose not before 30-60 min after change to the upright position in subjects who showed neither plasma cortisol nor serum potassium increases. It is concluded that the immediate rise of plasma aldosterone during orthostasis seems to depend on a stimulation by ACTH or by potassium. The main stimulus of plasma aldosterone during orthostasis appears to be the renin angiotensin system. If the aldosterone response to posture is mediated only through this system a delay of 30-60 min is observed.

107. Sawin, C. F.; Rummel, J. A.; and Buderer, M. C.:  
Exercise Response to Simulated Weightlessness.  
*Acta Astronautica*, vol. 6, 1979, pp. 1273-1287.

**Authors' Abstract**

Two bed-rest analog studies of spaceflight were performed; one of 14 days duration, the other of 28 days. Exercise response was studied in detail during the 28-day study and following both the 14-day and 28-day studies. This paper relates the results of these studies to physiologic changes noted during and following space flight. The most consistent change noted after both bed rest and spaceflight is an elevated heart rate during exercise. A second consistent finding is a postflight or post-bed-rest reduction in cardiac stroke volume. Cardiac output changes were variable. The inability to simulate inflight activity levels and personal exercise makes a direct comparison between bed rest and the results from specific spaceflights difficult.

108. Shaposhnikov, Ye. A.; Sidorov, P. I.; and Kolomenskiy, A. I.:  
Changes in the Neuromotor System during 45 Days of Hypokinesia.  
*Kosmich. Biol. Aviak. Med.*, vol. 13, 1979, pp. 35-39.

**Authors' Abstract**

Neurological and electromyographic examinations of test subjects during a 45-day bed-rest study were carried out. Symptoms indicating changes in the suprasegmentary innervation were noted. Shortening of the duration of potentials was shown by needle electromyography. A decline in the threshold of H-reflex and a change in the frequency parameters of EMG were seen. These data suggest a change in the functional state of the central and peripheral motor neuron during prolonged hypokinesia. Prophylactic efficiency of muscle electrostimulation is discussed.

109. Shurygin, D. Ya.; Sidorov, K. A.; Mazurov, V. I.; and Alekseyeva, N. M.:  
The Endocrine System in Hypodynamia and Readaptation.  
*Voyenno-Meditsinskiy Zhurnal*, no. 12, 1976, pp. 55-58.

**Annotation**

**Purpose.** To investigate changes in hormone balance as affected by hypokinesia.

**Method.** Six men (20-29 yr) served as the subjects for 49 days of bed rest. Excretion of somatotrophic hormone (STH), follicle stimulating hormone (FSH), interstitial cell stimulating hormone (ICSH), insulin,



and 17-hydroxycorticosteroids (17-HCS) were measured two times before the experiment, four times during bed rest, and twice after bed rest.

**Results.** On day 4 of hypodynamia, STH decreased significantly and returned to baseline by day 14 of hypodynamia. CTH levels were below baseline on day 45 and returned to normal by day 8-11 of readaptation. FSH fell by the 4th day and continued to fall. The change in ICSH was opposite that of FSH.

On day 14, there was a significant rise in ICSH level to 32 ng/ml, which did not return to normal until the 8th to 11th day of resumed motor activity. Insulin significantly increased by day 28 of hypodynamia but returned to baseline by the readaptation period. Excretion of 17-HCS averaged  $6.33 \pm 0.85$  mg/day for the baseline level but increased on days 3 ( $9.1 \pm 1.2$  mg/day) and 48 ( $8.95 \pm 0.7$  mg/day). Excretion of 17-HCS increased on day 2 of readaptation.

**Conclusion.** The authors conclude that the increase in ICSH was an adaptive reaction to maintain normal protein metabolism. The increase in insulin upholds this conclusion. They suggest that exercises should be performed by persons in hypodynamic to normalize their hormone balance.

110. Smirnov, K. V.; Goland, L. G., Medkova, L. L.; Murashko, V. V.; and Sokolova, T. A.:  
Activity of the Digestive System during 49-Day Antiorthostatic Human Hypokinesia.  
*Fiziologiya Cheloveka*, vol. 2, 1976, pp. 653-660.

#### Authors' Abstract

Antiorthostatic hypokinesia for 49 days had a significant effect on the functions of the organs in the gastrointestinal tract which was expressed in an increase in stimulated juice secretion and acid formation; in the phase changes in the activity of the digestive enzymes; in depression of the gastric motor function; and in intensification of bile formation. It is proposed that the obtained changes in the functional condition of the digestive system during experimental hypokinesia may be of practical importance for clinical medicine in cases in which a patient remains confined to bed for a lengthy period.

111. Stazhadze, L. L.; and Kovachevich, I. V.:  
The Adrenosympathetic System in the Presence of Traumatic Shock during Simulation of Effects of Weightlessness on the Human Body.  
*Kosmich. Biol. Aviak. Med.*, vol. 13, 1979, pp. 31-35.

#### Annotation

**Purpose.** To investigate the changes in catecholamine metabolism in simulated weightlessness as they relate to changes associated with traumatic shock.

**Method.** The adrenosympathetic system of 40 subjects with trauma to the skeletomuscular system and 27 subjects in 49 days of bed rest was investigated.

Group 1 consisted of the hypokinetic subjects with vegetovascular dysfunction. Group 2 hypokinetic subjects underwent physical exercise and pharmacotherapy, and group 3 hypokinetic subjects had no treatments.

Catecholamines and dopa were assayed.

**Results.** Impaired interaction between hormonal and mediatory branches of the adrenosympathetic system was found in all antiorthostatic hypokinetic subjects.

Group 1 showed a decrease in epinephrine excretion, possibly a result of latent insufficiency of functional reserves. Group 2 produced an increase in catecholamine excretion with the change in epinephrine more consistent. Group 3 exhibited an impaired balance between hormonal and mediator elements of the adrenosympathetic system as manifested by a decrease in norepinephrine excretion.

The trauma victim's adrenosympathetic systems exhibited high functional activity and reserve capabilities. A close correlation was found between catecholamine and dopa output and the base level of catecholamine excretion.

*Conclusion.* The sympathoadrenal reactions during traumatic shock and in weightlessness may have certain similarities. The authors conclude that the decrease in adrenosympathetic system function found in hypokinesia can potentially lead to severe arterial hypotension.

112. Storm, W. F.; and Giannetta, C. L.:  
Effects of Hypercapnia and Bedrest on Psychomotor Performance.  
*Aerospace Med.*, vol. 45, 1974, pp. 431-433.

**Authors' Abstract**

Two weeks of continuous exposure to simulated weightlessness (bed rest) or an elevated (300 Torr) CO<sub>2</sub> environment, or both, had no detrimental effect on complex tracking performance, eye-hand coordination, or problem-solving ability. These results were consistent with previously reported behavioral findings which investigated these two factors only as independent stressors.

113. Stremel, R. W.; Convertino, V. A.; Bernauer, E. M.; and Greenleaf, J. E.:  
Cardiorespiratory Deconditioning with Static and Dynamic Leg Exercise during Bed Rest.  
*J. Appl. Physiol.*, vol. 41, 1976, pp. 905-909.

**Authors' Abstract**

Bed-rest deconditioning was assessed in seven healthy men (19-22 yr) following three 14-day periods of controlled activity during recumbency by measuring submaximal and maximal oxygen uptake ( $\dot{V}O_2$ ), ventilation ( $\dot{V}_E$ ), heart rate, and plasma volume. Exercise regimens were performed in the supine position and included (a) two 30-min periods daily of intermittent static exercise at 21% of maximal leg extension force, and (b) two 30-min periods of dynamic bicycle ergometer exercise daily at 68% of  $\dot{V}O_{2\max}$ . No prescribed exercise was performed during the third bed-rest period. Compared with their respective pre-bed-rest control values,  $\dot{V}O_{2\max}$  decreased ( $P < 0.05$ ) under all exercise conditions: -12.3% with no exercise, -9.2% with dynamic exercise, but only -4.8% with static exercise. Maximal heart rate was increased by 3.3% to 4.9% ( $P < 0.05$ ) under the three exercise conditions, while plasma volume decreased ( $P < 0.05$ ) -15.1% with no exercise and -10.1% with static, but only -7.8% (NS) with dynamic exercise. Since neither the static nor dynamic exercise training regimes minimize the changes in all the variables studied, some combination of these two types of exercise may be necessary for maximum protection from the effects of the bed deconditioning.

114. Suvorov, P. M.:  
Influence of Thirty-Day Hypokinesia in Combination with Exposure to LBNP on Tolerance to Accelerations [ $+G_z$ ].  
*Kosmich. Biol. Aviak. Med.*, vol. 8, 1974, pp. 65-68.

**Authors' Abstract**

A study was made of the effect of hypokinesia combined with LBNP on tolerance of accelerations. Before and after hypokinesia, the subjects were centrifuged at 3 G for 30 sec and at 5 G as long as it could be tolerated. Two days after exposure to hypokinesia and LBNP the duration of tolerance to accelerations of 5 G was 24.2-36.5% of the initial level. This may be brought about by the functional activity of the muscular system and venous tone which results in a marked decrease in systolic volume and cardiac output during exposure to accelerations and accordingly in the early development of optic disturbances.

115. Tishler, V. A.; Safonov, V. I.; and Krivitsina, Z. A.:  
Evaluation of Efficacy of the Set of Preventive Measures Referable to the Human Neuromuscular System under Hypokinetic Conditions.  
*Kosmich. Biol. Aviak. Med.*, vol. 14, 1980, pp. 54-57.

**Annotation**

**Purpose.** To study the effects of preventive measures on the excitability and lability of neuromuscular tissue during hypokinesia.

**Method.** The excitation threshold and maximum rhythm of stimulation of the femoral rectus muscle were measured a number of different times before and during 49-days of antiorthostatic hypokinesia.

In the first series, six subjects exercised on a combination athletic exercising unit. In the second series, six subjects exercised, were conditioned with LBNP, and took water and salt supplements. In the third series, six subjects, in addition to following the regimen of the second series, were given pharmacological agents (20 mg ephedrine and 1 mg strychnine daily). Series 4 (36 persons) served as a control with no preventive steps taken.

**Results.** The least decrease in maximum rhythm occurred in subjects of the first series. On the 5th and 47th days of hypokinesia, maximum rhythm declined more in the second series than in the third series. In the fourth series, excitability and lability diminished significantly starting on the 5th day of hypokinesia.

In series 1, 2, and 3, the changes were insignificant from the pre-bed-rest period.

**Conclusion.** Physical exercise is the chief means of preventing hypokinetic disorders of the neuromuscular system. Combination thereof with other preventive measures modifies insignificantly, but does not attenuate, the preventive effect of exercising the human neuromuscular system.

116. Tkachev, V. V.; and Kul'kov, Ye. N.:  
ECG Changes Accompanying Venepuncture in Man during Prolonged Hypokinesia.  
*Kosmich. Biol. Aviak. Med.*, vol. 9, 1975, pp. 83-85.

**Annotation**

**Purpose.** To investigate neuroemotional stress on the cardiovascular system in hypokinesia.

**Method.** Nine males kept under conditions of antiorthostatic hypokinesia ( $-4^{\circ}$ ) for 49 days were venepunctured in the ulnar vein for emotional stimulus. ECG was registered continuously from the application of the tourniquet until 1-1.5 min after the vein was punctured. Frequency of cardiac contractions and the amplitudes of the R- and T-waves were used to measure emotional reactions.

**Results.** Frequency of cardiac contraction increased in seven of the nine subjects by 30-93% over the background levels. In five of the subjects this increase correlated ( $P < 0.05$ ) with a lengthening in the duration of hypokinesia.

By the end of hypokinesia, the amplitude of the T-wave had increased in eight of the nine subjects ( $P < 0.05$ ).

**Conclusion.** Under conditions of prolonged antiorthostatic hypokinesia, the body becomes less tolerant of emotional stimuli. ECG changes during autonomic reactions to a weak emotional stimulus are sufficiently informative for evaluating shifts in body reactivity and man's emotional stability.

117. **Turbasov, V. D.:**  
Effect of Prolonged Antiorthostatic Position on Cardiac Bioelectrical Activity According to EKG Tracings from Corrected Orthogonal Leads.  
*Kosr.ich. Biol. Aviak. Med.*, vol. 14, 1980, pp. 54-59.

**Author's Abstract**

The effect of the time of head-down tilting on electrocardiographic parameters was consistent and significant ( $P < 0.05$ ): a slight increase in heart rate in groups 1 and 3, an increased time of atrioventricular conduction, an increased amplitude of the QRS complex, and a decreased amplitude of T-wave, primarily in groups 1 and 3. No dystrophic signs were detected. The high level of heart rate in group 3 during the recovery period suggests a more pronounced decline of functional capabilities of the heart. There are grounds to believe that countermeasures produce a relatively greater effect on the function of the myocardium than on its metabolism.

118. **Ushakov, A. S.; Ivanova, S. M.; and Brantova, S. S.:**  
Some Aspects of Energy Metabolism in Human Blood Erythrocytes under Hypokinesia and during Space Flights.  
*Aviat. Space Environ. Med.*, vol. 48, 1977, pp. 824-827.

**Authors' Abstract**

The present investigation presents results of studying energy metabolism in blood erythrocytes in cosmonauts who made the first and the second space flights aboard the orbital station Salyut-4 and in test subjects who experienced 49 days of hypokinesia at  $-4^\circ$ . The data obtained throughout the postflight investigations and during the hypokinesia studies appeared to be identical, showing a decrease in glycolytic activity whereas ATP content remained unchanged.

119. **Ushakov, A. S.; and Vlasova, T. F.:**  
Amino Acid Spectrum of Human Blood Plasma during Space Flight and in Orthostatic Hypokinesia.  
*Life Sci. Space Res.*, vol. 14, 1976, pp. 257-262.

**Authors' Abstract**

The paper summarizes results of experiments on the influence of space flight and antiorthostatic hypokinesia on the amino acids spectrum of human blood plasma. Our findings give evidence for: (a) a specific norm of the content of free amino acids in plasma during training, and (b) consistent changes of plasma aminograms during spaceflight related to its duration and to individual features of cosmonauts. The content of free amino acids in the plasma of bed-rested subjects varied phasically and tended to increase practically at every experimental stage. The paper discusses the findings and possible mechanisms of the detected changes.

120. **Van Beaumont, W.; Greenleaf, J. E.; Young, H. L., and Juhos, L. T.:**  
Plasma Volume and Blood Constituent Shifts during  $+G_z$  Acceleration after Bedrest with Exercise Conditioning.  
*Aerospace Med.*, vol. 45, 1974, pp. 425-430.

**Authors' Abstract**

The purpose of the present study was to investigate the influence of isometric and isotonic exercise during bed rest on plasma volume (PV) and blood constituents during  $+G_z$  acceleration in seven young men. During bed rest, PV decreased between 8.0% and 11.5%. During centrifugation before bed rest, the average decrease in PV was between 10.7% and 13.2%, with concomitant plasma protein losses of 2.6% to 3.7%, and albumin losses of 1.2% to 4.6%; after bed rest, the corresponding changes with centrifugation were between -6.3% to -7.1%, -1.1% to -2.0%, and +2.4% to -3.1%, respectively. The average acceleration tolerance during the

pre-bed-rest control runs was  $1,129 \pm \text{S.E. } 27$  sec, while after bed rest the mean tolerance was  $817 \pm \text{S.E. } 31$  sec ( $P < 0.05$ ). For comparative purposes, additional hematological changes with centrifugation were evaluated from nine different hypovolemic, ambulatory subjects. During  $+G_z$  acceleration there was an isotonic loss of plasma fluid (8.6% to 11.2%) with respect to serum sodium, potassium, chloride, creatinine, and osmolarity; however, serum glucose concentration increased between 6.3% and 19.3%. It is concluded that during acceleration (a) the mean reduction in PV and protein contents after bed rest is about half as great as during the control runs before bed rest; (b) isometric and isotonic exercise during bed rest have no effect on the decrease in PV and protein contents during centrifugation; (c) during  $+G_z$  acceleration, in hypohydrated ambulatory subjects, there is an isotonic loss of plasma fluid; (d) centrifugation tolerance was significantly reduced following bed rest; and (e) the two exercise regimens had no statistically significant effect on post-bed-rest centrifugation tolerance; however, both isometric and isotonic exercise reduced the average  $+G_z$  tolerance decrement by 85-100 sec.

121. Vasil'yev, A. I.; and Diskalenko, V. V.:  
Effect of Prolonged Hypokinesia on Hearing.  
*Voyenno-Meditsinskiy Zhurnal*, vol. 7, 1977, pp. 76-77.

#### Annotation

*Purpose.* To investigate the effects of 49-day hypokinesia on hearing and to study the desirability of using exercise and pharmacological agents as preventive measures.

*Methods.* The subjects, 21 healthy men (22-45 yr) were divided into three groups. Group 1 (6 persons) constituted the control. Group 2 subjects (9 persons) were subjected to LBNP or vibration stimulation. Group 3 subjects received Retabolil, Adiucreline, Panagin, and Amitetravit. The hearing thresholds with air and bone conduction were determined before bed rest; on days 10, 30, and 48 of bed rest; and on day 3 of recovery.

*Results.* Hearing deteriorated in all cases, especially with bone conduction. Hearing was least affected in the subjects of group 3. The changes in auditory sensitivity were most pronounced on day 10 of bed rest.

*Conclusion.* Forty-nine days' restriction of motor activity brings about functional changes in the acoustic analyzer and the use of some pharmacological agents that normalize water-salt and protein metabolism substantially level out these changes.

122. Vasil'yev, A. I.; and Kumarichkin, S. D.:  
Effect of Hypokinesia on the Vestibular Function under Modified Microclimate Conditions.  
*Kosmich. Biol. Aviak. Med.*, vol. 9, 1975, pp. 58-61.

#### Authors' Abstract

The functional state of the vestibular system in a human subject confined to bed rest is characterized by a decrease in nystagmic parameters, increase in autonomic reactions, and lengthening of illusory sensations. This may reduce the static and kinetic tolerance of man to acceleration. The bed-rest-induced vestibular changes can be attributed to the functional changes in higher parts of the central nervous system. The influence of a modified atmosphere on the vestibular function is insignificant.

123. Vendt, V. P.; Kindrat'yeva, L. G.; Govseyeva, N. N.; Apukhovskaya, L. I.; Ivashkevich, S. P.; Koval, V. G.; and Tigranyan, R. A.:  
Sterols Bound with Blood Plasma Proteins and Erythrocyte Membranes during Hypokinesia.  
*Kosmich. Biol. Aviak. Med.*, vol. 13, 1979, pp. 43-47.

**Authors' Abstract**

In test subjects exposed to head-down tilting the quantitative and qualitative changes in sterols bound with plasma proteins and erythrocyte membranes were studied. The phasic pattern of changes of unsaponifiable substances and cholesterol was found. The changes in specific and transport proteins were opposite in most cases. Red blood cell membranes showed a change in their strength and permeability, and a gradual increase in the cholesterol content. If the cholesterol content reached maximum in red blood cell membranes (day 48), it fell to a minimum in transport proteins. On the contrary, 14 days after completion of the experiment the content of cholesterol in membranes returned to the normal, and in transport proteins increased significantly. By thin-layer chromatography, gas-liquid chromatography, and ultraviolet and infrared spectroscopy, it was shown that fast sterols, unsaponifiable esters and sterol ketoderivatives emerged at an early stage of bed rest. Their content increased at a late stage and did not return to the norm during recovery.

124. Vernikos-Danellis, J.; Leach, C. S.; Winget, C. M.; Goodwin, A. L.; and Rambaut, P. C.:  
Changes in Glucose, Insulin, and Growth Hormone Levels Associated with Bedrest.  
*Aviat. Space Environ. Med.*, vol. 47, 1976, pp. 583-587.

**Authors' Abstract**

Changes in plasma glucose, insulin, and growth hormone (HGH) resulting from exposure to 56 days of bed rest were determined in five healthy young male subjects. Blood samples were collected by repeated venous puncture at 4-hr intervals for 58-hr periods before bed rest, at 10, 20, 30, 42, and 54 days after confinement to bed, and at 10 and 20 days after bed rest. Changes in the daily levels of these factors for each subject were expressed as the mean of the six samples per 24-hr period. The level of HGH dropped after 10 days of bed rest, then showed a 1.5-fold increase at 20 days ( $P < 0.05$ ) and subsequently decreased gradually reaching levels of 2.5 mg/ml/24 hr, well below pre-bed-rest controls of 4.2 mg/ml/24 hr, by the 54th day. In spite of a marked increase in the daily plasma insulin levels during the first 30 days of bed rest, glucose levels remained unchanged. Beyond 30 days of bed rest, insulin began decreasing toward pre-bed-rest levels and glucose followed with a similar reduction to below the control levels of 75 mg/100 ml/24 hr on day 54. The daily mean changes reflect a change in the amplitude of the diurnal variation. The daily peak in plasma insulin shifted progressively to the late evening during the bed-rest period.

125. Vernikos-Danellis, J.; Winget, C. M.; Leach, C. S.; and Rambaut, P. C.:  
Circadian, Endocrine, and Metabolic Effects of Prolonged Bedrest: Two 56-Day Bedrest Studies.  
*NASA TM X-3051*, 1974.

**Authors' Abstract**

Two bed-rest studies of 56 days each, involving a total of 20 male subjects (19 aged 20-26, 1 aged 40) have been conducted to evaluate the effects of prolonged bed rest on circadian synchrony and endocrine and metabolic function. Measurements included the pituitary-adrenal, thyroid, parathyroid, insulin-glucose-growth hormones, catecholamine excretion, body temperature, and heart rate. The results indicate that a rigorous regimen of isotonic/isometric exercise did not prevent the endocrine and metabolic effects of prolonged bed rest. Changes in circadian, endocrine, and metabolic functions in bed rest appear to be due to changes in hydrostatic pressure and lack of postural cues rather than to inactivity, confinement, or the bleeding schedule. Changes in circulating metabolic and endocrine parameters are unreliable if measured once per day, because their amplitude and time of peak of their diurnal fluctuations are altered during bed rest. Therefore, data should be expressed as units/24 hr. Recovery periods up to 20 days are insufficient for

full recovery from 56 days of bed rest. Bed rest beyond 42 days results in periodic hypoglycemia, possibly in response to meals, which may warrant modification of meal composition.

Prolonged bed rest, particularly beyond 24 days, results in rhythm desynchronization in spite of well-regulated light/dark cycles, temperature, humidity, activity, and meal times and meal composition and in increased lability of all endocrine parameters measured.

It also results in an apparent insensitivity of the glucose response to insulin, of cortisol secretion to ACTH, and of growth hormone secretion to hypoglycemia. This may be due to an effect of bed rest on the number or sensitivity of target organ receptors; it may reflect a change in radioimmunoassayable levels of the peptide hormones, or it may result from an alteration of the central nervous system's input/feedback integrating mechanisms.

126. Vlasova, T. F.; Miroshnikova, Ye. B.; and Ushakov, A. S.:  
Dynamics of Free Amino Acid Levels in Human Blood Plasma during Bed Rest in Head Down Position.  
*Kosmich. Biol. Aviak. Med.*, vol. 12, 1978, pp. 23-27.

#### Annotation

*Purpose.* To investigate protein metabolism in hypokinesia as manifested by the state of blood amino acid levels.

*Method* Eight males were kept for 49 days in a state of antiorthostatic ( $-4^{\circ}$ ) hypokinesia. Background and recovery period were 12 and 30 days, respectively. The first group of men (3) were on a 3100 kcal diet with 117 g of protein; the second group (5) was given 3300 kcal and 144 g of protein. Blood samples were taken from fasting subjects once in the background period, five times during hypokinesia, three times in the recovery period, and once one month after hypokinesia. Free amino acids were analyzed by ion-exchange chromatography.

*Results.* In the bed-rest period, levels of proline, glycine, and aspartic acid remained the same as in the background period; isoleucine, leucine, phenylalanine, valine, methionine, serine, glutamic acid, alanine, and tyrosine increased. Lysine, arginine, and cystine rose in the first days of bed rest then fell to the background levels by the 30th day. Lysine levels reliably dropped over the course of bed rest. Free urea and taurine levels in plasma increased but reversed to base levels by the end of the recovery period.

*Conclusion.* In hypokinesia, there are consistent changes in the free amino acid content of human blood plasma, but the changes appear adaptational.

127. Volicer, L.; Jean-Charles, R.; and Chobanian, A. V.:  
Effect of Head-Down Tilt on Fluid and Electrolyte Balance.  
*Aviat. Space Environ. Med.*, vol. 47, 1976, pp. 1065-1068.

#### Authors' Abstract

The metabolic effects of  $-5^{\circ}$  tilt were studied in eight normal individuals. Exposure to tilt for 24-hr increased sodium excretion and decreased plasma volume. Plasma renin activity and plasma aldosterone levels were not significantly different from supine values during the first 6 hr of tilting, but were increased significantly at the end of the 24-hr tilt period. Creatinine clearance and potassium balance were not affected by the tilt. These findings indicate that head-down tilt induces a sodium diuresis and stimulation of the renin-angiotensin-aldosterone system.

128. **Winget, C. M.; Vernikos-Danellis, J.; Deroshia, C. W.; Cronin, S. E.; Leach, C.; and Rambaut, P. C.:**  
**Rhythms during Hypokinesia.**  
*Biorhythms and Human Reproduction*, M. Ferin, F. Halberg, R. Richart, and R. VandeWiele, eds,  
Wiley and Sons, 1974, pp. 575-587.

**Authors' Abstract**

Asynchrony of the body temperature (BT) and heart rate (HR) circadian rhythms in man was achieved without changing the photoperiod by complete bed rest without exercise. This asynchrony was characterized by marked phase-shifting and a decrease in amplitude of BT and HR which returned to normal in the post-bed-rest period. Bed rest also resulted in hypothermia and a transient bradycardia, which were evident within the first 2 days of bed rest. Although the asynchrony of the rhythms was also present at this time, it became most marked on the 23rd day of bed rest. On this day, sudden phase-shifting occurred in all subjects at 0045 hr and was accompanied by a 50% increase in HR. Neither the prolonged inactivity nor the confinement associated with bed rest was responsible for these effects. It is proposed that reduction of stimuli to proprioceptive receptors requires a compensatory increase of other environmental synchronizers in order to maintain rhythm synchrony.

129. **Yakovleva, I. Y.; Bokhov, V. V.; and Kornilova, L. N.:**  
**Study of Space Perception Functioning during Simulation of Certain Space Flight Factors.**  
*Life Sci. Space Res.*, vol. 14, 1976, pp. 295-300.

**Authors' Abstract**

The results are reported of spatial perception function studies in 130 healthy males (17-35 yr) and in 33 people with complete or partial inhibition of the function of the labyrinth (deaf-mutes). The comparative magnitudes of gravitational vertical perception impairments were studied during vestibular stimulation (Coriolis and linear acceleration) as well as during clino-orthostatic and antiorthostatic hypokinesia. Hypokinesia to a certain extent permitted the stimulation of the blood redistribution in weightlessness. The ability of the subjects to determine the subjective visual vertical was used as the test criterion.

The experiments have shown that the magnitude of the observed changes in the human sensory area depends on the physical properties of the vestibular stimulus, on the angle of inclination of the head of the bed during hypokinesia and on the duration of bed rest, but not necessarily on the level of vestibular tolerance. Possible mechanisms of impairment of perception in the spaceflight environment are discussed. Examinations of spatial perception function are useful during selection procedures for astronauts and airmen.

130. **Yarullin, Kh. Kh.; Vasilyeva, T. D.; and Alekseev, D. A.:**  
**Antiorthostatic Test as a Model to Study Antigravity Mechanisms of the Cardiovascular System.**  
*Life Sci. Space Res.*, vol. 14, 1976, pp. 275-280.

**Authors' Abstract**

The paper presents rheographic investigations of regional haemodynamics (brain, lungs, liver, and limbs) during antiorthostatic exposures of varying intensity ( $-15^\circ$ ,  $-30^\circ$ ,  $-45^\circ$ ; times of exposure 20, 40, and 60 min). Our findings show that the pattern and time of the function of compensatory mechanisms preventing excessive vascular compliance under the influence of the hydrostatic blood column depend on the value and length of antiorthostasis, because prolonged venous congestion results not only in congestive circulatory hypoxia but also in arterial hypoxia due to compensatory limitation of arterial inflow.



131. **Zakutayeva, V. P.; and Matiks, N. I.:**  
**Contractile Function of the Myocardium with Prolonged Hypokinesia in Patients with Surgical Tuberculosis.**  
*Zdravookhraneniye Kirgizii*, no. 5, 1976, pp. 8-12.

**Authors' Abstract**

The changes in the myocardial contractile function with hypokinesia in surgical tuberculosis patients is discussed. The phase nature of the changes is noted, specifically the changes in the various systoles, diastole, and other parts of the cardiac cycle. The data compares these changes during confinement in bed with no motor activity to and with a return to motor activity after leaving the in-bed regimen.

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**SUBJECT INDEX**  
(The numbers refer to abstract numbers)

- Acceleration**  
  blackout effects of, 39  
  Coriolis, 129  
  -G<sub>x</sub>, 12, 41, 56, 68  
  +G<sub>x</sub>, 12, 41, 56, 68  
  +G<sub>z</sub>, 27, 39, 41, 55, 114, 120  
  grayout, 39  
  linear, 129  
  effect of physical exercise on, 14  
  tolerance to, 39, 120
- Accretion rate, bone, 85
- Acid-base equilibrium, 29, 35, 62
- Acidosis, metabolic, 16, 61
- Acoustic analyzer, 124
- Action potentials, 108
- Actography, 3, 97
- Adaptation, orthostatic, 21
- Adenosine triphosphate, 89, 118
- Adiurecrine, 121
- Adrenocortical glucocorticoid activity, 109, 125
- Adrenocorticotrophic hormone, 106, 125
- Adenosympathetic system, 111
- Alanine, 23  
  transaminase, 28
- Albumin, plasma, 38, 100, 120
- Aldosterone  
  plasma, 13, 17, 77, 92, 99, 106, 127  
  urine, 13
- Alkaline phosphatase, 62, 110
- Alpha  
  acid glycoprotein, 91  
  activity, 82, 87  
  macroglobin, 91  
  rhythms, 104
- Altitude  
  adaptation, 32  
  tolerance, 101
- Alveolar-arterial gradient  
  carbon dioxide, 30, 35, 65  
  oxygen, 35
- Ambulatory recovery, 120
- Amino acids, 23, 119  
  blood, 105
- Aminotransferase, 62
- Amitetravit, 121
- Amylase  
  blood, 110  
  duodenal, 110  
  urine, 110
- Amyolytic and proteolytic enzyme systems, 110
- Anabolic steroids, 44
- Anaerobic processes, 118
- Anaxymatic activity, 28
- Antiorganic autoantibodies in serum, 22
- Angiotensinogen, plasma, 17
- Anthropometry, 37, 63
- Antidiuretic hormone, 99
- Antigen, cardiac, 22
- Antigravity, muscles, 108
- Antigravity suit, 5, 12
- Antiorthostatic bed rest, 2, 3, 6, 15, 16, 19, 28,  
  29, 35, 41, 43, 51, 58, 60-64, 66, 70, 77,  
  80-82, 90, 93, 96, 99, 104, 110, 111,  
  117-119, 123, 126, 129, 130
- Antithrombin III, 86
- Antrioventricular conduction, 22
- Appetite, 10
- Arginine, 68, 105, 124
- Arm  
  exercise, 29  
  girth, 89
- Arterial  
  amino acids, 23  
  occlusion, 26  
  pressure, 6, 8, 16, 21, 30, 61, 90, 92-94, 101,  
  107, 114  
  tone, 114
- Artherosclerosis, 123
- Aspartate transaminase, 28
- Aspartic acid, plasma, 126
- Ataxia, 45, 93
- Atherosclerosis, 86
- Atrioventricular conduction, 117
- Atrophy, muscular, 45
- Auditory vigilance, 87
- Autoantibodies, antiorganic, serum, 22
- Auxillary temperature, 72

## Balance

- body, 39
- impairment of, 45
- nitrogen, 11
- potassium, 17
- sodium, 17

## Basal

- beta activity, 82
- blood pressure, 40
- heart rate, 12

## Bath test, Nesterav, 1

- Bed rest, antiorthostatic, 2, 3, 6, 15, 16, 19, 28, 29, 35, 41, 43, 51, 58, 60, 61-64, 66, 70, 77, 80-82, 90, 93, 96, 99, 104, 110, 111, 117-119, 123, 126, 129, 130

## Behavioristic reactions, 3

## Beta-adrenergic blocker, 92

## Bicarbonate, 35

- plasma, 62

## Bicycle

- ergometer test, 15, 18, 20, 29, 31, 43, 58, 62, 64, 93, 97
- exercise, 28

## Bioelectric activity, 7, 104

- in the brain, 82

## Biopsy, muscle, 31

## Biorhythms, 84

## Blood

- alanine, 23
- amino acids in, 105
- amylase in, 110
- antithrombin III in, 86
- arterial pressure of, 6, 8, 16, 21, 30, 61, 90, 92-94, 101, 107, 114
- capillary, 27
  - composition of, 35
- Factor V in, 86
- fibrinogen in, 86
- flow of, 26
  - cerebral, 62
  - liver, 62
  - renal, 42, 62
  - temporal arterial, 98
- gas composition of, 62
- lactate concentration in, 25
- lactic acid in, 118
- lipase in, 110
- oxygenation of, 29
- pH of, 61
- pulmonary capillary, 74
- red cell count in, 18, 41

## Blood (continued)

- trypsin, 110
- urea nitrogen, 37, 38
- volume, 38, 41, 47, 68, 69, 80, 99, 113
  - extremity, 21
  - minute, 1, 27
  - systolic, 27
  - thoracic, 77, 80
  - white cell, 27

## Blood

- circulation, regulation of, 75
- pressure, 12, 31, 33, 40, 48, 50, 56, 58, 94, 107, 127

## Blumberger's mechanical coefficient, 131

## Body

- balance, 39
- circumference, 37
- composition, 37, 77, 100
- density, 37
- fat, 36, 100
- hydration, 4
- mass, 37, 100
- potassium, 100
- temperature, 12, 102, 125, 128
- water, 56, 100
- weight, 12, 13, 25, 26, 37, 39, 40, 48, 56, 76, 79, 80, 100, 113

## Bone

- accretion rate of, 85
- compression of, 46
- density of, 95
- transit of marrow in, 69
- minerals in, 46, 75
- resorption of, 46, 85, 95
- size of, 95
- volume of, 95

## Boyden passive hemoagglutination reaction, 22

## Bradycardia, 128

## Brain

- bioelectric activity in, 82
- blood flow in, 62

## Breathing coefficient, 65

- external, 65

## Bronchial passages, 72

## Caffeine, 6

## Calcaneus, 85

## Calcification rate, 95

## Calcium

- balance of, 46
- fecal, 34, 85

- Calcium (continued)
  - kinetic studies of, 85
  - oral, 46
  - plasma, 37, 95
  - serum, 38, 43
  - urine, 34, 43, 44, 85, 95
- Calcitonin, 46
- Calf, girth of, 26
- Capillaroscopy, 1
- Capillary
  - blood flow, 27
  - composition, 35
- Carbon dioxide
  - alveolar, 30, 35, 65
  - content of in exhaled air, 67, 74, 93
  - elimination of, 6, 30, 107
  - in environment, 112
  - partial pressure of, 34, 73
  - tension of, 35
- Carbon monoxide, 70
  - expired, 74
- Cardiac
  - antigen, 22
  - index, 17, 29
  - minute volume, 8, 114
  - muscle, 61
    - metabolism in, 61
  - output, 67, 92, 99, 107
  - systolic volume, 114
- Cardiorespiratory
  - changes, 71
  - responses, 18
- Cardiovascular responses, 19, 64
- Carotid pulse traces, 107
- Catecholamines, 25, 83, 114, 125
  - metabolism of, 17, 111
- Central venous pressure, 21, 99
- Centrifugation, 39, 41, 55, 56, 68, 98, 114
- Cerebral
  - atherosclerosis, 86
  - bioelectric activity, 104
  - blood flow, 27
  - cortex, 122
- Chair rest, 102
- Chloride
  - plasma, 38, 41, 57
  - urine, 44, 57
  - total, 110
- Cholic acid, 110
- Chromium, radioactive, 80
- Cinematography, 14
- Circadian rhythms, 13, 72, 84, 124, 125, 128
- Circulation
  - cerebral, 27
  - minute volume, 30
  - parameters of, 21
- Comfort, 122
- Complement, plasma, 22
- Complex additions, 87
- Conditioning, 5, 12
- Confinement, 7
- Contractile
  - proteins, 28
  - strength, elbow extension, 89
- Contraction
  - cardiac, 29
  - muscle fiber, 15
  - time of, isovolumetric, 107
  - voluntary muscle, 12, 108
- Coombs reaction, 22
- Coordination, eye-hand, 112
- Coriolis force, 129
- Coronary sinus, 61
- Corpuscular volume, mean, 18
- Cortical neuron excitability, 83, 104, 125
- Corticotropic hormone, 109
- Cortisol
  - plasma, 13, 92, 106
  - urine, 11, 59
- Creatinine
  - clearance of, 17
  - plasma, 37, 38, 127
  - urine, 11, 13, 17, 48, 50, 55, 56, 59, 105, 127
- Creatinine phosphate, muscle, 89
- Culture, therapeutic physical, 7
- Curve, temperalis pulse, 21
- Deautomation of motor skills, 14
- Deconditioning, 12, 113
- Defensive movement, 71
- Dehydration, 5, 77, 120
- Dehydrogenase, lactate, 28, 51
- Deoxycorticosterone acetate, 42
- Dermogaivanic resistance, 71
- Dermographism, 81
- Desiccation, 59
- Diameters, skeletal, 37
- Diastole, 131

Diastolic  
     blood pressure, 19, 30, 81  
     volume, 29  
 Dicrotic index, 130  
 Diet  
     control of, 127  
     low protein, 105  
 1-diphosphonate, 85  
 Discomfort, subjective sensations of, 71  
 Disodium ethane-1-hydroxy-1, 85  
 Disorders, vegetative and motor, 71  
 Diuresis, 43  
 Diuretic hormone, 77  
 Dizziness, 19, 122  
 DOCA, 97  
 Dopamine, urine, 111  
 Doppler  
     flowmeter, 55, 56  
     ultrasound, 98  
 Droplet stimulation, 10  
 Dry residue content, 59  
 Duodenal  
     amylase, 110  
     lipase, 110  
     trypsin, 110  
 Dynamic leg exercise, 113  
 Dysrhythmia, 104  
  
 Echocardiography, 99  
 Edema, 64  
 Elbow extension contractile strength, 89  
 Elderly patients, 53  
 Electric stimulation, 3, 8, 9, 14, 15, 30, 51, 66, 70,  
     75, 82, 94, 108, 115, 129  
 Electrocardiogram (ECG), 1, 6, 12, 19, 21, 22,  
     25, 30, 48, 49, 55, 72, 93, 103, 107, 114,  
     116, 117, 121, 127  
     abnormalities in, 49  
 Electrocoordinograph, 71  
 Electroencephalogram (EEG), 82, 89, 97, 104, 122  
 Electroencephalography, 130  
 Electrogastrograms, 110  
 Electrolytes  
     plasma, 41, 99  
     urine, 36  
 Electromyography, 7, 108  
 Electroplethysmography, 90  
 Electroystygmography, 122  
 Emotional reactions, 71, 116  
 Encephalopathy, venous, 104  
  
 Endocrine system, 83  
 Endurance, 31  
     training, 21, 88  
 Energy metabolism, 118  
 Enteropeptidase, 110  
 Enzymes  
     amylolytic and proteolytic, 110  
     oxidative, 15  
 Eosinopeic reaction, 27  
 Epinephrine, urine, 83, 111, 125  
 Ergometer, 37-39, 40, 45, 66, 67, 69, 73, 113  
 Erythropoiesis, 118, 123  
     clearance, 69  
 Ethanol, test for, in blood, 86  
 Evan's blue dye, 25  
 Excitation threshold, 115  
 Exercise  
     arm, 29  
     bicycle, 28  
     capacity for, 47, 56, 64, 83, 87, 117, 121  
     cardiac output during, 107  
     isometric, 20, 26, 37-40, 45, 120, 125  
     isotonic, 20, 37-40, 45, 120, 125  
     leg, 113  
     physical, 3, 5, 9, 11, 15, 32, 33, 43, 51, 54,  
         57, 59, 66, 67, 76, 105, 115, 129  
     respiratory gas exchange during, 107  
     rowing, 28  
     stair-step, 34  
     supine, 37, 40, 107, 113  
     temperature test during, 40  
     test, 18, 99, 107  
     tolerance to, 49, 67  
     training, 39, 40  
 Expired  
     carbon dioxide, 30  
     gas composition, 35  
     water vapor, 80  
 Exposure, postural, 39  
 Extracellular fluid volume, 38, 56  
 Eye-hand coordination, 112  
 Eye movements, 87  
  
 Facial integument, 71  
 Factor V, blood, 86  
 Fast twitch, 88  
 Fat  
     body, 36, 100  
     content, 59, 77  
 Fatigue, 54, 73, 76, 108



- Fecal  
  calcium, 34, 85  
  magnesium, 34  
  phosphorus, 34, 85  
  zinc, 34
- Females, 41, 68, 72, 98
- Femoral rectus muscle, 115
- Fibrinogen, blood, 86, 100
- Flowmeter, Doppler, 55
- Fluid  
  balance, 47, 56, 68, 80  
  content, intravascular, 80  
  electrolyte metabolism, 43  
  replacement, 37, 48
- Follicle stimulating hormone, 109
- Food intake, 59
- Gait, 14, 31
- Gamma ray transmission, scanning of  
  calcaneus, 85
- Gas composition of blood, 62
- Gas exchange, 64
- Gastric  
  secretion – acidity, free, 110  
  juice activity, 110
- Gastrocnemius muscle biopsy, 31
- Gastrolingual reflex, 10
- Girths, arm, 89
- Globulin  
  blood, 38  
  plasma, 100
- Glomerular filtration rate, 42, 44
- Glucose  
  peripheral uptake of, 23, 124  
  plasma, 20, 38, 124, 125  
  tolerance of, 20, 124
- Glucocorticoid activity, adrenocortical, 109
- Glucosamine, 91
- Glutamic acid, 119
- Glycine, 105, 126
- Glycogen, 89
- Glycoproteins, 91
- Glycolysis intensity, 118
- Glycolytic activity in red blood cells, 118
- Gravitation, one-half Earth,
- Gravitational  
  collapse, 65  
  vector, 77
- G-suit, 55, 56
- +G<sub>x</sub> acceleration, 12, 41, 56, 68  
-G<sub>x</sub> acceleration, 12, 41, 56, 68  
+G<sub>z</sub> acceleration, 27, 39, 41, 55, 114, 120
- Hand grip strength, 26
- Haptoglobin, 91
- Headaches, 54
- Head fullness, 127
- Hearing, 121
- Heart  
  contractility, 29, 75, 76  
  electrical systole, 131  
  expulsion  
    period, 131  
    rate, 131  
  mechanical systole, 131  
  PQ interval, 22  
  rate, 1, 2, 4, 5, 8, 12, 15, 18, 19, 21, 30, 31,  
    39, 40, 48-50, 54-56, 58, 63-66, 71-73,  
    81, 92, 94, 97, 99, 101, 103, 107, 113,  
    114, 117, 125, 127, 128  
  periodicity, 114  
  resting and exercising, 113  
  roentgenological characteristics, 76  
  size, 76  
  stroke volume, 17, 75  
  T-wave, 22  
  volume, 21, 61, 76  
  water, 90
- Heat  
  exchange rate, 102  
  production, 102
- Hemagglutination, Boyden passive reaction, 22
- Hematocrit, 18, 23, 56, 73, 80, 99, 120, 124, 125,  
  127
- Hemodynamic responses, 69
- Hemoglobin, 18, 25, 26, 29, 41, 69, 70, 124, 125  
  mean corpuscular, 18, 41  
  oxygenation of, 69
- Hemopoiesis, 70
- Henry-Gauer reflex, 80
- Hippuran clearance, 42
- Histochemical analysis, 15, 51
- Histology, 95
- Homeostatis, circulatory, 16
- Hormone  
  balance, 109  
  growth, 125
- Hydration, body, 4

- Hydrochloric acid, free, 110
- Hydrocortisone, 83
- Hydrodynamic fluctuations, 64
- Hydrostatic pressure, 64
- Hydroxycorticosteroids, 109
- Hydroxyproline, urine, 85, 95
- Hydroxyprolinuria, 95
- Hyperemia, reactive, 26
- Hypercalcemia, 43
- Hypercalciuria, 46, 95
- Hypercapnia, 34, 65, 112
- Hypercholesterolemia, 123
- Hypercoagulability, 86
- Hyperglycemia, 95, 120
- Hyperkalemia, 43, 57
- Hyperketonemia, 123
- Hypernatremia, 43
- Hyperphosphatemia, 95
- Hypertrophy of muscle fibers, 51, 88
- Hyperventilation, 65, 82, 104, 124
- Hypogravics, 17
- Hypoxia, 69
- Hypophysis, 109
- Hypothalamic dysfunction, 124
- Hypothermia, 128
- Hypovolemia, 120
  
- Illusory sensations, 71
- Immobility, 25
- Immobilization, 16, 23, 89
- Immunoglobulin, 96
- Immunoreactive insulin, 109
- Inertial pressure work, 90
- Ingested potassium, 57
- Injury, 54
- Inotropic effect, 61
- Instability, orthostatic, 16
- Insulin, 20, 61, 92, 109, 124, 125
  - immunoreactive, 109
- Intake of salt and fluid, 57
- Interstitial fluid volume, 38
- Intracardiac conductivity, 1
- Intravascular fluid content, 80
- Intraventricular
  - conductivity, 1
  - pressure, 8
- Intranasal resistance, 93
- Intrathoracic blood volume, 77
- Inulin, 92
- Invertase, 110
- Iodine clearance, 42
  
- Irritability, 54
- Isometric
  - contraction, 131
  - exercise, 20, 26, 37-40, 45
- Isoproterenol, 92
- Isotonic
  - exercise, 20, 37-40, 45
  - loss of plasma fluid, 120
- Isovolumetric contraction time, 107
  
- Kaliuretic renal function, 57
- Khilov swing, 121, 129
- Kidney
  - blood flow in, 62
  - function of, 42, 57
- Kinetocardiogram, 19
  
- Lactate
  - blood, 25
  - dehydrogenase, 28
- Lactic acid, blood, 118
- Lean body mass, 36, 100
- Left ventricular end-systolic and end diastolic
  - dimensions, 99
  
- Leg
  - extension, 113
  - rail balance, 45
  - strength, 37-40
  - volume, 60
- Leucine, plasma, 119
- Leucoagglutination, 22
- Light stimulation, 104
- Limb girths, 31
- Lipase
  - blood, 110
  - duodenal, 110
  - urine, 110
- Lipid-complex
  - bile, 110
  - metabolism, 123
- Liver
  - blood flow in, 62
  - extra secretory function of, 110
- Losses, fluid and electrolyte, 37
- Lower body negative pressure (LBNP), 1, 6, 8, 9,
  - 19, 30, 47, 48, 50, 52, 56, 66, 69, 70, 75,
  - 82, 99, 103, 114, 121
- suits, 39
- Lung
  - diffusing capacity of, 74
  - total capacity of, 35
- Lysine, plasma, 126

- Magnesium**  
 fecal, 34  
 serum, 43  
 urine, 34, 43
- Massage**, 7, 70
- Mathematical model**, 69
- Maximal**  
 exercise testing, 99  
 leg extension, 113  
 leg strength, 37-40  
 oxygen uptake, 15, 18, 20, 37-40, 55, 56, 99  
 work capacity, 18, 25, 67, 113
- Mean corpuscular hemoglobin**, 41
- Mechanical coefficient, Blumberger's**, 131
- Mechanocardiograph**, 1, 5, 8, 103
- Membrane diffusion capacity**, 74, 123
- Memory**, 52
- Mental state**, 52
- Menstruation**, 98
- Metabolic**  
 activity, 70  
 balance, 85  
 diet, 56
- Metabolism**, 16  
 cardiac muscle, 61  
 fluid-electrolyte, 42, 80  
 mineral, 34  
 water-salt, 43, 77
- Methionine**, 105
- Microclimate**, 102
- Microhematocrit**, 38, 41
- Mineral**  
 bone, 46, 85  
 metabolism of, 34
- Mineralocorticoids**, 57
- Minute volume, blood**, 27, 32, 103
- Modified rotary test**, 71
- Mood**, 3, 87
- Morphometry**, 95
- Motor**  
 disturbances, 71  
 function, stomach, 110  
 neurones, 88  
 skills, deautomation of, 14, 32
- Movement, defensive**, 71
- Muscle**  
 adenosine triphosphate in, 89  
 biopsy of, 31  
 cardiac, 61  
 contractions of, voluntary, 12
- Muscle (continued)**  
 creatine phosphate in, 86  
 femoral rectus, 115  
 fibers of, 15, 51, 88  
 glucogen in, 89  
 skeletal, 89, 115  
 soleus, 28, 51  
 stimulation of, 30, 51, 66, 70, 82, 93  
 tone of, 81, 94  
 tonometry of, 31  
 volume of, 60
- Muscular**  
 atrophy, 88, 94  
 strength, 26, 45  
 tone, 7, 94
- Myocardial**  
 contractility, 76, 131  
 stress, 5  
 tension, 131
- Myofibrillar adenosinetriphosphatase**, 88
- Nausea**, 71
- Needle biopsy**, 89
- Nerobol**, 42, 44, 97
- Nervous activity**, 3
- Nesterov bath test**, 1
- Neuromuscular system**, 31, 115
- Neuroemotional stress**, 116
- Neurological response**, 81  
 symptoms, subjectively perceived, 108
- Neuron, cortical excitability**, 104
- Nitrogen**  
 balance of, 11  
 blood urea, 37, 38  
 content, 59  
 metabolism of, 119  
 total, 11
- Noradrenaline, urine**, 25
- Norepinephrine**  
 plasma, 17  
 urine, 83, 111
- Nystagmus**, 81, 122
- Operator activity**, 3
- Ophthalmological test**, 93
- Oral**  
 calcium, 46  
 phosphate, 46  
 temperature, 84, 87
- Orthostasis**, 73

## Orthostatic

- hypotension, 127
- influence, 33
- instability, 16, 65, 94
- stability, 94
- test, 2, 5, 63, 64, 101
- tolerance, 4, 5, 8, 9, 17, 19, 20, 25, 30, 32, 47-50, 55, 58, 99, 101, 103

## Oscillography, 1, 19

## Osmolality

- plasma, 37, 41
- urine, 43, 44

## Osmotic index, 44

## Osmotic resistance of membranes, 123

## Osteoporosis, 46, 95

## Otolaryngological test, 93

## Oxydative enzymes, 15

## Oxygen

- alveolar arterial gradient of, 35
- blood, 29, 69
- consumption of, 35, 64, 66, 70
- maximal, 15, 18, 20, 37-40, 55, 56, 99
- pressure of, 34, 53, 73
- products, 53
- pulse, 64, 65
- saturation, 29
- supply of, 59
- tissue, 69
- uptake of, 15, 18, 20, 30, 35, 37-40, 93, 113
- utilization of, 35

## Palpitations, 76

## Panagrin, 121

## Pancreas, 109

## Para-aminohippuric acid, 92

## Parathormone, plasma, 125

## Paroxysmal activity, 104

## Patients, elderly, 53

## Pepsinogen

- activity of, 110
- plasma, 110
- urine, 110

## PCO<sub>2</sub>, 112

## Perceived neurological symptoms, 108

## Perception

- self, 3
- spatial, 9, 129
- taste, 10

## Performance test, pilot, 12

## Periodogram, 128

## Peripheral

- amino acid metabolism, 23
- circulation, 26
  - cerebral, 27
- glucose uptake, 23
- resistance, 33, 61, 90, 107
- vision, 55, 68, 98

## Penalis, 100

## Petechiae, 56

## pH, blood, 61

## Pharmacokinetics, 23

## Phase change, 128

## Phenazone, 23

## Phonocardiogram, 1

## Phosphate

- oral, 46
- plasma, 95
- urine, 95

## Phosphorus

- balance of, 85
- fecal, 34, 85
- plasma, 37, 41
- serum, 38
- urine, 34, 85

## Phosphatase

- alkaline, 62, 95, 110
- supplementation, 83

## Physical

- exercise, 3, 5, 9, 11, 15, 32, 33, 43, 51, 54, 57, 59, 66, 67, 76, 105, 115, 129
- effect on +G<sub>z</sub> acceleration tolerance, 12
- fitness, 2, 8, 11, 14, 25, 47, 51, 76
- load, 1, 2, 6, 11, 25, 51, 60, 63, 66, 73, 82
- stress, 28

## Pilot performance, 12

## Pituitary dysfunction, 124

## Pituitrin, 42, 97

## Plasma

- adrenocorticotrophic hormone, 125
- albumin, 38, 100, 120
- aldosterone, 13, 17, 77, 92, 99, 106, 127
- alkaline phosphatase, 95
- amino acids, 119, 126
- angiotensin, 17
- antidiuretic hormone, 97
- arginine vasopressin, 68
- aspartic acid, 126
- bicarbonate, 62
- calcium, 37, 95
- chloride, 38, 41, 57

**Plasma (continued)**

cholesterol, 123  
cortisol, 13, 92, 106, 125  
creatinine, 37, 38, 127  
electrolytes, 41, 99  
fibrinogen, 100  
flow, renal, 44  
globulin, 38, 100  
glucose, 38, 124, 125  
glutamic acid, 119  
glycine, 126  
growth hormone, 124, 125  
insulin, 20, 61, 92, 124, 125  
    circadian rhythm of, 124  
inulin, 92  
leucine, 119  
lysine, 126  
norepinephrine, 17  
osmolality, 37, 38, 41  
parathormone, 125  
pepsinogen, 110  
phosphate, 95  
phosphorus, 37, 38, 41  
    in bile, 110  
potassium, 41, 57, 127  
proline, 119, 126  
proteins, 38, 41, 100, 120, 123  
renin activity (PRA), 13, 17, 68, 77, 92, 99,  
    106, 127  
serine, 119  
sodium, 37, 38, 41, 57, 127  
taurine, 126  
thyroxine, 125  
triiodothyronine, 125  
urea, 126  
uric acid, 38  
valine, 119  
volume, 17, 18, 20, 38, 40, 41, 47-50, 55, 56,  
    68, 69, 73, 80, 91, 92, 99, 100, 113, 120,  
    127

Planimetry, 51  
Plethysmography, 17, 26  
 $PO_2$ , 112  
Polycardiogram, 1, 5, 8  
Postrotatory nystagmus, 71  
Postural  
    equilibrium, 45, 93  
    exposure, 29

**Potassium**

balance of, 17, 56  
body, 100  
blood, 41  
chloride, ingested, 57  
depletion of, 94  
ingestion of, 57  
lead test, 57  
metabolism of, 49, 57  
plasma, 57, 127  
serum, 38, 43, 49, 56, 92, 106  
total body, 37, 49  
urine, 13, 17, 34, 43, 44, 50, 56, 57, 92, 127

PQ interval, 117  
Prescribed exercise, 34  
Pressure  
    alveolar carbon dioxide, 65  
    arterial, 2, 6, 8, 16, 30, 54, 61, 90, 92-94,  
        101, 107, 114  
    blood, 12, 21, 31, 40, 50, 56, 58, 94, 127  
        diastolic, 48, 50, 81, 101, 107, 127  
        systolic, 6, 33, 48, 50, 81, 101, 107, 127  
    carbon dioxide, 34  
    central venous, 21, 99  
    excess, lower body, 5  
    hydrostatic component, 33, 64  
    inertial work, 28  
    intraventricular, 8  
    lower body negative, 1, 6, 8, 9, 19, 30, 39, 47,  
        48, 50, 52, 56, 66, 69, 70, 75, 82, 99,  
        103, 114, 121  
    oxygen, 34, 53  
    pulmonary artery, 61  
    pulse, 61, 64, 73, 94

Pre-ejection period, 107  
Presyncope, 48, 50  
Problem solving ability, 112  
Prophylactic  
    effect, 94  
    measures, 3, 9, 50  
Prophylaxis, 102  
Proprandol, 92  
Propranolol, 92  
Proline, plasma, 119, 126  
Proteins  
    contractile, 20  
    diet low in, 105  
    fractional composition of, 28

- Proteins (continued)
  - metabolism of, 121, 126
  - plasma, 38, 41, 100, 120, 123
  - sarcoplasmic, 28
- Psychic activity, 3, 52
- Psychomotor
  - performance, 112
  - repetitive measures, 112
- Pulmonary
  - capillary blood, 74
  - resistance, 61
  - ventilation, 64
- Pulse
  - pressure, 61, 64, 73, 94
  - traces, carotid, 107
  - wave propagation, 114
  - wave velocity, 114
- QRS complex, 117
- QS interval, 107
- Radioactive chromium, 80
- Rail balance, left-leg, 45
- Rail walk, 45
- Rapid eye movement, 97
- Reaction time, 114
- Readaptation period, 3
- Recovery, 6, 10, 22, 31, 35, 45, 56, 57, 66, 69, 80, 98, 126, 128
- Rectal temperature, 40
- Red cell
  - count, 41, 123-125
  - glycolytic activity, 118
  - mass, 56, 70, 80, 99
  - metabolism, 118
  - production, 69
  - volume, 18, 38, 41
- Red muscle fibers, 15
- Reflexes, gastrolingual, 10
- Regulation of blood circulation, 75
- Rehabilitation, 9, 54, 80, 82, 129
- Renal
  - blood flow, 42
  - electrolytes, 42
  - filtration fraction, 44
  - function, 92
    - kaliuretic, 57
    - osmoregulatory, 57
  - osmoregulation, 42
  - plasma flow, 42, 44
- Renin
  - activity, 13, 17, 42, 47, 68, 77, 92, 99
  - substrate, 92
- Renography, 42
- Renoport system, 57
- Residual volume, 37, 106
- Resistance
  - peripheral, 33, 61
  - pulmonary artery, 61
- Respiration, external, 35
- Respiratory
  - coefficient, 66
  - function, 6, 73
  - gas exchange, 107
  - minute volume, 72
  - rate, 6, 12, 40, 71, 73, 97, 107, 114, 122
  - response, 64
  - ventilation, 7
  - water loss, 40
- Response
  - cardiorespiratory, 18
  - cardiovascular, 19, 64
  - respiratory, 64
- Resting and exercising heart rate, 113
- Retabol, 121
- Retention, bicarbonate, 35
- Rheoencephalography, 130
- Rhythms
  - asynchrony, 128
  - circadian, 13
  - excitation, 115
- Roentgenograms, 76
- Roentgenological characteristics of the heart, 76
- Rotary tests, modified, 71
- Rowing exercise, 28
- R-wave amplitude, 116
- Saline
  - consumption, 50, 69
- Salt and fluid intake, 57
- SAM complex coordinator, 172
- Sarcoplasmic proteins, 28
- Saturation, oxygen, 29
- Securinine, 6
- Secretory function
  - stomach, 110
  - liver, 110
- Serum
  - albumin, 91
  - antiorganic autoantibodies, 22

- Serum (continued)
  - calcium, 38, 43, 91, 95
  - chloride, 91
  - cholesterol, 91
  - electrophoretic components, 91
  - globulin, 91
  - glucose, 91
  - inorganic phosphate, 91
  - magnesium, 43
  - phosphate, 95
  - phosphorus, 38
  - potassium, 38, 43, 49, 56, 91, 106
  - protein, 91
    - bound hexose, 91
    - bound fucose, 91
    - bound carbohydrate, 91
  - serine, 119
  - sodium, 38, 43, 56, 91, 106
  - solids, 91
  - triglycerides, 91
  - viscosity, 91
- Shteffen reaction, 22
- Sialic acid, 91
- Sinus, coronary, 61
- Skeletal
  - diameters, 37
  - excitability and lability, 115
  - mineral loss, 85
  - muscle, 89
- Skin
  - heat conductance of, 40
  - temperature of, 1, 7, 40, 102
- Sleep, 3, 87, 97
  - disturbances, 97
- Sodium
  - balance of, 17, 48, 56
  - benzoate, 6
  - blood, 37, 38
  - plasma, 41, 127
  - serum, 38, 43, 56, 92, 106
  - urine, 13, 17, 34, 43, 44, 48, 50, 55-57, 92, 127
- Soleus muscle, 28
- Spatial perception, 9, 129
- Sphedrine, 115
- Sphygmograms, i, 114
- Sphygmography, 27
- Stabilography, 27
- Stair-step exercise, 34
- Stand test, 48
- Static
  - endurance, 31
  - exercise, 113
- Steroids, anabolic, 44
- Stimulation
  - electric, 3, 6, 8, 9, 14, 15
  - light, 104
  - muscular, 30, 75
  - sonic, 3
  - taste threshold, 10
- Stomach
  - motor function, 110
  - secretory function, 110
- Strength
  - hand-grip, 26
  - isometric maximal muscle, 26
- Stress, physical, 28
- Stroke volume, 17, 30, 64, 67, 75, 92, 107
- Strychnine, 115
- Subfebrile temperatures, 102
- Subjective sensations of discomfort, 71
- Supine exercise, 40, 107, 113
- Summation dial technique, 128
- Sweat rate, 40
- Sweating, 54
- Sympatheticoadrenal system, 114
- Syncope, 64
- Synergistic reactions, 108
- Systemic vascular resistance, 92
- Systolic blood
  - ejection of, 76
  - pressure of, 6, 19, 30, 33, 81
  - surge of, 73
  - time interval of, 107
  - volume of, 8, 27, 32, 103
- T-1824, 73
- Tachoscollography, 27
- Tachoscollogram, 1, 19
- Tachycardia, 92
- Taste bud
  - activity, 10
  - perception, 10
  - receptors, 10
  - stimulation threshold, 10
- Taurine, plasma, 126
- Teleroentgenokymogram, 76
- Teleroentgenography, 75

- Temperature
  - axillary, 72
  - body, 12, 56, 102, 125, 128
  - oral, 40, 84
  - rectal, 40
  - sensation of, 102
  - skin, 17, 40, 102
  - subfebrile, 102
- Temporal artery, blood flow in, 98
- Temporalis pulse curve, shape of, 21
- Test, exercise, 18
- Therapeutic
  - exercise, 54
  - physical-culture, 7
- Thermoregulatory responses, 40, 81
- Theta activity, 87
- Thromboagglutination, 22
- Thrombosis, 86
- Thyroxine, plasma, 125
- Tilt test, 29, 58
- Tissue oxygen, 69
- Tolerance
  - exercise, 49, 67
  - glucose, 20
  - +G<sub>z</sub> acceleration, 26, 39, 41, 98, 120
  - orthostatic, 4, 5, 8, 9, 17, 19, 20, 25, 30, 32, 47-50, 55, 58, 99, 101, 103
- Tone, muscular, 7
- Tonometry, muscle, 31
- Total
  - body potassium, 37, 49
  - body water, 77-79, 80
  - fluid intake, 37
  - nitrogen, 11
- Tracking performance, 112
- Training, endurance, 20, 88
- Tramatic shock, 111
- Transaminase
  - alanine, 28
  - aspartate, 28
- Triceps brachii, 89
- Triiodothyronine, 125
- Tritium oxide, 77-80
- Trypsin
  - blood, 110
  - duodenal, 110
- Tuberculosis, surgical, 131
- T-wave, 22, 116, 117
- Twitch
  - fast, 88
  - slow, 88
- Tyrosine, 119
- Ultrasound, Doppler, 56
- Urea
  - blood, 37
  - excretion of, 11
  - nitrogen, 37
  - plasma, 126
- Uric acid
  - plasma, 38
  - urine, 42
- Urine
  - adrenaline, 25
  - aldosterone, 13
  - amylase, 110
  - analysis, 56
  - calcium, 34, 43, 44, 85
  - chloride, 44, 57
  - cortisol, 83, 125
  - creatine, 59
  - creatinine, 13, 17, 48, 50, 55, 56, 59, 105, 127
  - deoxycorticosterone, 42
  - dopamine, 111
  - electrolytes, 37
  - epinephrine, 83, 111, 125
  - hydroxyproline, 85, 95
  - lipase, 110
  - magnesium, 34, 43
  - noradrenaline, 25
  - norepinephrine, 83, 111
  - occlusion
    - arterial, 26
    - venous, 26
  - osmolality, 43, 44
  - output, 48
  - phosphorus, 34, 85
  - potassium, 13, 17, 34, 43, 44, 50, 56, 57, 127
  - sodium, 13, 17, 34, 43, 44, 48, 50, 55-57, 127
  - zinc, 34
- Uropepsinogen, 110
- Vagosympathetic regulation, 117
- Valine, 119
- Valsalva test, 103
- Vanillylmandelic acid, urine, 17



- Vascular
  - elasticity, 130
  - resistance, 92
  - tone, 90, 114, 130
- Vasopressin release, 68
- Vegetative and motor disorders, 70
- Venipuncture, 116
- Venous
  - amino acids, 23
  - hyperemia, 104
  - occlusion, 26
- Ventilation, 107, 113
  - pulmonary, 65
- Ventricle, left
  - ejection time of, 107
  - end diastolic volume of, 29
  - end systolic and end diastolic volume of, 99
  - heart contractility of, 29
  - phase analysis of, 131
  - pressure of, 29, 61
- Ventricle, right, cardiac, 16
- Vestibular
  - function, 122, 129
  - somatic reactions, 122
- Vision
  - during +G<sub>z</sub> acceleration, 98, 114
  - peripheral, 55, 68, 98
- Visual
  - centrifugal impairment of, 56
  - stimulation, 71
- Volume,
  - blood, 38, 41, 47, 68, 69, 80, 99, 113
  - calf, 21
  - cardiac minute, 8, 114
  - cardiac systolic, 114
  - extracellular fluid, 38
  - extremity, 21
  - heart, 21, 75, 76
  - interstitial fluid, 38
  - leg, 21, 60
  - lung, 35
  - mean corpuscular, 18, 41
  - minute, 27, 32
    - circulation, 103
    - respiration, 72
    - stroke, 17, 30, 64, 67, 75, 92, 107
- Volume (continued)
  - muscle, 60
  - plasma, 17, 18, 20, 38, 40, 41, 48-50, 55, 56, 69, 73, 80, 91, 92, 99, 100, 113, 120, 127
  - red cell, 26, 38
  - residual, 37
  - systolic, 8, 27, 32, 103
  - thoracic, 80
- Voluntary
  - fluid intake, 37
  - muscle contractions, 12, 108
- Walking, 14
  - instability, 76
- Water
  - diuresis, 4
  - immersion, 97, 100, 102
  - intake, 4
  - loss, 77, 78
  - metabolism, 77-79
    - as percent of body, 79
    - salt metabolism, 43, 121
  - in total body, 4, 56, 78-80, 100
  - vapor, exhaled, 80
- Weakness, general, 76
- Weight
  - body, 12, 13, 25, 37, 39, 40, 48, 56, 76, 80, 100, 113
    - training, 88, 89
- White blood cell, 27, 124, 125
- White muscle fibers, 15
- Word list, memory, 87
- Work capacity, 18, 25, 67, 113
- Workload, 107
- X-ray, 76
- Zinc
  - fecal, 34
  - urine, 34

**AUTHOR INDEX**

(The numbers refer to abstract numbers)

- Abdrakhmanov, V. R., 35  
Abrosimov, S. V., 61  
Agureyev, A. N., 105  
Aleksandrov, A. N., 1  
Alekseev, D. A., 130  
Alekseyev, D. A., 82  
Alekseyeva, N. M., 109  
Alekseyeva, V. P., 93  
Amirov, R. Z., 7  
Anashkin, O. D., 2  
Apukhovskaya, L. I., 123  
Armbruster, H., 106  
Armbruster, R., 39  
Artishuk, V. N., 3  
Arzamazov, G. S., 43, 57  
Asyamolov, B. F., 4, 5, 103
- Balakhovskiy, I. S., 70  
Barbey, K., 21  
Beckerhoff, R., 106  
Belay, V. Ye., 6  
Belaya, N. A., 7  
Beregovkin, A. V., 8  
Bernard, J., 95  
Bernauer, E. M., 18, 37, 38, 39, 41, 113  
Bezumova, Yu. Ye., 44  
Blevins, P., 17  
Blomqvist, C. G., 99  
Bogomolov, V. V., 35, 80  
Bokhov, B. B., 9  
Bokhov, V. V., 129  
Borisenko, I. P., 14  
Borodulina, I. I., 11  
Bourret, J., 95  
Brantova, S. S., 118  
Bryant, C., 99  
Buderer, M. C., 107  
Budylna, S. M., 10  
Buzulina, V. P., 63  
Bychkov, V. P., 11
- Cantor, S. A., 56  
Castleberry, H. B., 34  
Chambers, A., 12  
Chavarri, M., 3  
Chekirda, I. F., 14  
Cherepakhin, L. I., 15, 51
- Chestukhin, V. V., 16, 29, 61, 62, 96  
Chobanian, A. V., 17, 127  
Convertino, V. A., 18, 113  
Coupron, P., 95  
Cronin, S. E., 128
- Danilova, V. I., 66  
Davis, G. L., 41  
Degtyarev, V. A., 19  
de Marees, H., 21  
Demida, B. F., 66  
Deroshia, C. W., 128  
Dietlein, L. F., 83  
Diskal:enko, V. V., 121  
Divina, L. Ya., 30  
Dolkas, C. B., 20  
Domracheva, M. V., 90  
Donaldson, C. L., 46, 91  
Dorokhova, B. R., 43  
Dygin, V. P., 22
- Edouard, C., 95  
Eika, C., 86  
Elder, G. C. B., 88  
Elfström, J., 23  
Ellis, J. P., 24  
Ellis, S., 68
- Fedorenko, G. T., 15, 51  
Friedman, R., 46  
Friman, G., 25, 26
- Galle, R. R., 27  
Ganguly, A., 13  
Garcia, J. B., 24  
Gavrilova, L. N., 27  
Gayevskaya, M. S., 28  
Gazenko, O. G., 29  
Georgiyevskiy, V. S., 16, 30, 31, 32, 33, 64, 94  
Giannetta, C. L., 34, 112  
Godal, H. C., 86  
Goland, L. G., 110  
Goldenrath, W. L., 98  
Goldman, R. H., 92  
Goldsmith, R. S., 46  
Golikov, A. P., 35  
Gomez-Sanchez, C., 99

- Goodwin, A. L., 124  
 Gornago, V. A., 30, 36, 65  
 Govseyeva, N. N., 123  
 Graybiel, A., 47  
 Greenleaf, J. E., 18, 20, 37, 38, 39, 40, 41, 113, 120  
 Grigor'yev, A. I., 42, 43, 44, 57  
 Grunbaum, B. W., 100  
 Haines, R. F., 39, 45  
 Hamrin, E., 26  
 Hantman, D. A., 46  
 Hoche, J., 47  
 Hoffler, G. W., 49  
 Holland, D. B., 99  
 Hord, D. J., 87  
 Hulley, S. B., 46, 49, 83, 85  
 Huntoon, C., 49  
 Hyatt, K. H., 48, 49, 50, 55, 56
- Il'ina-Kakuyeva, Ye. I., 15, 51  
 Il'inskaya, Ye. A., 31  
 Ioseliani, K. K., 52  
 Ivanov, L. A., 53  
 Ivanova, S. M., 118  
 Ivashkevich, S. P., 123  
 Izakson, Kh. A., 54
- Jacobson, L. B., 48, 55, 56  
 Jean-Charles, R., 127  
 Johnson, L. C., 87  
 Johnson, P. C., 49, 69  
 Johnson, R. L., 99  
 Juhos, L. T., 37, 38, 120
- Kakurin, L. I., 29, 51, 57, 58  
 Kalinichenko, V. V., 8  
 Kalmykova, N. D., 19, 30  
 Kamforina, S. A., 59  
 Karpov, A. P., 96  
 Kas'yan, I. I., 60  
 Katkov, V. Ye., 16, 29, 61, 62, 96  
 Katkovskiy, B. S., 30, 36, 63, 64, 65, 66, 67  
 Katuntsev, V. P., 77  
 Kauricheva, N. I., 62  
 Keil, L. C., 68  
 Khvatova, V. A., 10  
 Kimzey, S. L., 69  
 Kindrat'yeva, L. G., 123  
 Korillova, Z. A., 19  
 Kiselev, R. K., 70  
 Kobzev, Ye. A., 60  
 Kochetov, A. K., 1
- Kodama, A. M., 100  
 Kolchina, Ye. V., 28  
 Kolganova, N. S., 28  
 Kollias, J., 41  
 Kolomenskiy, A. I., 103  
 Koloskova, Yu. S., 44  
 Kolosov, I. A., 71  
 Kornilova, L. N., 9, 129  
 Koroleva-Munts, V. M., 72  
 Korol'kov, V. I., 32, 73  
 Korotayev, M. M., 44  
 Kotov, A. N., 74  
 Kovachevich, I. V., 111  
 Koval', V. G., 123  
 Kovalenka, Ye. A., 77, 80  
 Kozyrevskaya, G. I., 43, 44  
 Krasnykh, I. G., 75, 76  
 Krikun, I. S., 27  
 Krivenkov, N. P., 51  
 Krivitsina, Z. A., 115  
 Krotov, V. P., 77, 78, 79, 80  
 Krupina, T. N., 81, 82  
 Kul'kov, Ye. N., 116  
 Kumanichkin, S. D., 122  
 Kunitsch, G., 21  
 Kurkina, L. M., 28  
 Kuz'min, M. P., 93
- Leach, C. S., 83, 124, 125, 128  
 Lebedeva, I. P., 7  
 Lecocq, F. R., 24  
 Leonard, J. I., 69  
 Leshchenko, N. M., 22  
 Lille, R. D., 17  
 Lindgren, S., 23  
 Lipman, R. L., 24  
 Litsov, A. N., 3  
 Lkhagva, L., 84  
 Lobachik, V. I., 58  
 Lockwood, D. R., 85  
 Lorentsen, E., 86  
 Lubin, A., 87  
 Luetscher, J. A., 13, 92  
 Luk'yanchikov, V. I., 60
- MacDougall, J. P., 88, 89  
 Machinskiy, G. V., 64, 66  
 McMillan, D. E., 91  
 Maksimov, D. G., 90  
 Maksimov, V. A., 22  
 Manchini, R., 56

- Masenko, V. P., 80  
 Matiks, N. I., 131  
 Matsnev, E. I., 93  
 Matveyev, V. I., 31  
 Mazurov, V. I., 109  
 Medkora, L. L., 110  
 Melada, G. A., 92  
 Meunier, P., 95  
 Mikhailov, V. M., 29, 58  
 Mikhaylov, V. M., 16, 30, 31, 32, 33, 64, 93, 94  
 Minaire, P., 95  
 Miroshnikova, Ye. B., 126  
 Mirviakhomov, M. M., 73  
 Mitchell, J. H., 99  
 Moroz, J. R., 88  
 Morse, J. T., 37, 38, 39  
 Mukhina, N. N., 96  
 Murashko, V. V., 110  
 Murray, R. G., 99  
 Myasnikov, V. I., 97  
  
 Namochin, Yu. V., 43  
 Nesvetov, V. N., 29  
 Newsom, B. D., 98, 100  
 Nixon, J. V., 99  
 Noskov, V. B., 43  
  
 Orlov, P. A., 53  
 Ovechkin, V. G., 27  
  
 Pace, N., 100  
 Pak, Z. P., 44  
 Panchenko, V. S., 4, 5, 103  
 Panferova, N. Ye., 101, 102  
 Pervushin, V. I., 31, 51  
 Pestov, I. D., 4, 5, 103  
 Plathatnyuk, V. I., 30  
 Pokrovskaya, Z. A., 104  
 Polyakov, V. V., 105  
 Pometov, Yu. D., 30, 64, 67  
 Portugalov, V. V., 51  
 Price, D. C., 100  
  
 Rahlmann, D. F., 100  
 Rambaut, P. C., 49, 83, 124, 125, 128  
 Reck, G., 106  
 Reese, R. D., 40  
 Reva, F. V., 2  
 Romonovskaya, L. L., 78, 79  
 Rositano, S. A., 56  
  
 Rossinskiy, O. G., 104  
 Rummel, J. A., 49, 107  
 Rustam'yam, L. A., 36  
  
 Sagan, L., 39  
 Safonov, V. I., 115  
 Sale, D. G., 88, 89  
 Sandler, H., 39, 55, 56, 98  
 Sawin, C. F., 107  
 Schneider, V. S., 48, 85  
 Senkevich, Yu. A., 58  
 Seid-Guseynov, A. A., 16  
 Seyfulla, R. D., 62  
 Shal'nev, B. I., 16  
 Shaposhnikov, Ye. A., 7, 51, 104, 108  
 Shatunina, T. P., 2  
 Shubin, V. G., 22  
 Shumakov, V. I., 29  
 Shurygin, D. Ya., 109  
 Sidorov, K. A., 109  
 Sidorov, P. I., 108  
 Siegenthaler, W., 106  
 Sivuk, A. K., 11  
 Smirnov, K. V., 110  
 Smyshlyayeva, V. V., 30  
 Sokolova, T. A., 110  
 Sologub, B. S., 7  
 Spears, C. P., 49  
 Staley, R. W., 37, 38  
 Stazhadze, L. L., 35, 80, 111  
 Stepanstov, V. I., 14  
 Stinnett, H. O., 41  
 Storm, W. F., 113  
 Stremel, R. W., 18, 113  
 Stupnitskiy, V. P., 3  
 Sukhotskiy, S. S., 61  
 Sullivan, R. W., 56  
 Sutton, J. R., 88, 89  
 Suvorov, P. M., 114  
 Sverdlina, N. T., 22  
  
 Talavrinov, V. A., 60  
 Tercyak, A., 17  
 Tigranyan, R. A., 123  
 Tikhonov, M. A., 5  
 Tishler, V. A., 115  
 Titov, A. A., 80  
 Tizul, A. Ya., 81  
 Tkachev, V. V., 116  
 Toman, V. I., 66

Tracy, M. L., 87  
Troshin, A. Z., 29  
Trushinskiy, Z. K., 2  
Turbasov, V. D., 117

Uglova, N. N., 6  
Usachev, V. V., 27  
Ushakov, A. S., 105, 118, 119, 126  
Ustyushin, B. V., 27  
Utkin, V. N., 16, 61, 62

Van Beaumont, W., 38, 39, 120  
Vasil'yev, A. I., 121, 122  
Vasil'yev, V. K., 36  
Vasilyeva, T. D., 130  
Vendt, V. P., 123  
Veresomskaya, N. A., 28  
Vergne-Marini, P., 99  
Vernikos-Danellis, J., 124, 125, 128  
Vetter, W., 106  
Vikharev, N. D., 30  
Virouets, O. A., 70  
Vlasova, T. F., 105, 119, 126  
Vogel, J. M., 46, 49, 85

Volicer, L., 127  
Volozhin, A. I., 10  
Vorob'yev, V. Ye., 35  
Voronina, S. G., 35  
Voskresenskiy, A. D., 19  
Vyukal, H. C., 12

Ward, G. R., 89  
West, D. A., 50  
Winget, C. M., 124, 125, 128  
Winter, W. R., 98

Yakovleva, I. Ya., 9, 129  
Yakushkov, Yu. V., 3  
Yarullin, Kh. Kh., 82, 130  
Yelkin, P. A., 27  
Yelkina, L. G., 27  
Yeremin, A. V., 14  
Young, H. L., 37, 38, 120

Zager, P. G., 13, 92  
Zakutayeva, V. P., 131  
Zybin, O. Kh., 16, 61, 62

# Immersion

## REFERENCES AND ABSTRACTS

1. **Balakhovskiy, I. S.; and Noskov, V. B.:**  
Renal Function and Glucocorticoid Activity of the Adrenal Cortex during Immersion.  
*Kosmich. Biol. Aviak. Med.*, vol. 14, 1980, pp. 47-50.

### Authors' Abstract

The paper presents the study of renal and adrenal function in six normal men during and after 3-day water immersion used as weightlessness simulation. The renal excretion of fluid, basic electrolytes, creatinine and total 17-hydroxycorticosteroids (17-HOCS) for 24 hr and following a provocative water-load test (20 ml/kg) were measured. During the first post-immersion day diuresis increased by 77%, excretion of sodium by 42%, 17-HOCS by 43% and creatinine by 34% as compared to the pre-immersion level. Potassium excretion remained essentially unchanged. The circadian rhythm of excretion of the above substances was normal; at night the excretion decreased and in the morning increased noticeably. The study of renal function and adrenal activity was carried out 56 hr after the beginning of water immersion, using a provocative water-load test. Water excretory and osmoregulatory functions of kidneys, and glucocorticoid activity of adrenals remained normal. These data give evidence that during a 60-hr exposure to water immersion no functional hypocorticism develops.

2. **Begin, R.; Epstein, M.; Sackner, M. A.; Levinson, R.; Dougherty, R.; and Duncan, D.:**  
Effects of Water Immersion to the Neck on Pulmonary Circulation and Tissue Volume in Man.  
*J. Appl. Physiol.*, vol. 40, 1976, pp. 293-299.

### Authors' Abstract

Utilizing the rebreathing of a gas mixture containing  $C_2H_2$ ,  $C^{18}P$ , He,  $O_2$ , and  $N_2$ , we obtained serial measurements of the pulmonary capillary blood flow ( $Q_C$ ), diffusing capacity per unit of alveolar volume ( $D_L/V_A$ ), functional residual capacity (FRC), pulmonary tissue plus capillary blood volume (VTPC), and  $O_2$  consumption ( $\dot{V}O_2$ ) in five normal subjects under the following conditions: (a) 6 hr of sitting, (b) 4 hr of sitting while immersed in thermoneutral water to the neck, and (c) 4 hr of lying in thermoneutral water to the neck. Water immersion (NI) was preceded and followed by 1-hr prestudy and 1-h recovery periods. The measurements were made at 30-min intervals. Seated NI produced a fourfold increase in sodium excretion ( $UN_aV$ ), a 25-36% increase in  $Q_C$ , a 45-59% increase in  $D_L/V_A$ , and a 30-36% decrease in FRC. This occurred as early as the first hour of NI and persisted throughout the 4-hr period of study. Throughout the seated control and NI periods,  $\dot{V}O_2$ , heart rate, and VTPC remained constant. During supine NI,  $Q_C$ , HR,  $D_L/V_A$ , FRC, and  $\dot{V}O_2$  did not differ significantly from supine prestudy. These data demonstrate that seated NI causes a significant increase of  $Q_C$  and  $D_L/V_A$  which persists throughout the immersion period. Furthermore, the lack of change of VTPC suggests that the central vascular engorgement induced by seated NI is not accompanied by extravasation of fluid into the pulmonary interstitial space.

3. **Bondi, K. R.; Young, J. M.; Bennett, R. M.; and Bradley, M. E.:**  
Closing Volumes in Man Immersed to the Neck in Water.  
*J. Appl. Physiol.*, vol. 40, 1976, pp. 736-740.

### Authors' Abstract

Closing volumes (CV), along with residual volume (RV), vital capacity (VC), and expiratory reserve volume (ERV) were determined in 10 subjects in the dry and while immersed to the neck in water. Closing volumes during immersion increased 41.3% ( $P < 0.001$ ) over dry values while RV decreased 9.35% ( $P < 0.001$ ) and VC decreased 9.94% ( $P < 0.001$ ). The large decrease of 71.3% ( $P < 0.001$ ) in ERV resulted in the impingement of closing capacity (CV + RV) on the tidal volume in 9 out of 10 subjects. We interpret this to mean that airway closure occurs during tidal ventilation in immersed subjects and may result in impaired gas

exchange. When tourniquets were applied to all four limbs during immersion, closing volumes increased only 32.1% but increased to 64.3% when they were removed. If engorgement of peribronchial vessels predisposes airways to collapse, a reduction of plasma volume during an extended period of immersion might lessen this possibility. In a series of long-term (2.5 hr) immersion experiments where moderate reductions (-10% to -7%) in plasma volume were observed, we found, however, no correlative changes in closing volume.

4. **Böning, D.; and Skipka, W.:**  
Renal Blood Volume Regulation in Trained and Untrained Subjects during Immersion.  
*Eur. J. Appl. Physiol.*, vol. 42, 1979, pp. 247-254.

#### **Authors' Abstract**

To study the cause of the increased blood volume of endurance-trained athletes, we assessed the renal blood volume regulating mechanisms in eight untrained (UT) and eight endurance-trained (TR) male subjects during a 4-hr head-out immersion. In TR plasma volume remained constant whereas it decreased in UT by 2.4 ml/kg ( $P < 0.025$ ). Immersion diuresis of TR was only half as high as in UT (peak values: 3.22 ml/min in UT, 1.60 ml/min in TR). Free water clearance remained approximately constant in UT but temporarily decreased in TR ( $P < 0.001$ ). This points to poor or even absent inhibition of antidiuretic hormone secretion in the latter group. Osmolar clearance increased less in TR than in UT ( $P < 0.02$ ) which was partly due to a delayed increase of glomerular filtration rate. Plasma osmolality, creatinine, and protein concentrations as well as hematocrit values were reduced during immersion to a similar extent in both groups. The results indicate a reduced renal response of endurance-trained subjects to congestion of the low-pressure system resulting in an increase in blood volume.

5. **Boutelier, C.; Timbal, J.; and Colin, J.:**  
Thermal Conductivity of the Human Body during Immersion at Thermal Neutrality and in a Cold Environment.  
*Arch. Sci. Physiol.*, vol. 27, 1973, pp. 189-205.

#### **Authors' Abstract**

The thermal conductivity of the body immersed in water at thermal neutrality is found to be close to that observed in air, with only slight variations between individuals and no apparent effect due to the quantity of adipose tissue. In cold water, however, conductivity does depend on the fatness or thinness of the subject, since cutaneous vasoconstriction occurs, making use of the layer of subcutaneous fat to insulate the body center from the cold. The effect of cutaneous vasoconstriction is limited, however, and the muscular region is found to contribute to peripheral insulation, a phenomenon which has been considered a characteristic of adaptation to cold.

6. **Buhring, M.; and Spies, H. R.:**  
Pathogenesis of Sudden Death Following Water Immersion (Immersion Syndrome).  
*Zeitschrift für Rechtsmedizin*, vol. 83, 1979, pp. 121-127.

#### **Authors' Abstract**

Predominantly vagal cardio-depressive reflexes are discussed besides currently known mechanisms of sudden death after water immersion. Pronounced circulatory centralization in diving animals, as well as folk wing exposure in cold water, indicates additional sympathetic activity. In cold water baths of 15°C the authors' measurements indicate increase in plasma catecholamine levels by more than 300%. This may lead to cardiac arrhythmias by the following mechanism: Cold water essentially induces sinus bradycardia. Brady- and tachycardiarrhythmias may supervene as secondary complications. Sinus bradycardia may be enhanced by sympathetic hypertonus. Furthermore, ectopic dysrhythmias are liable to be induced by the strictly sympathetic innervation of the ventricle. Myocardial ischemia following a rise in peripheral blood pressure constitutes another arrhythmogenic factor. Some of these reactions are enhanced by alcohol intoxication.



7. **Burki, N. K.:**  
Effects of Immersion in Water and Changes in Intrathoracic Blood Volume on Lung Function in Man.  
*Clin. Sci. Mol. Med.*, vol. 51, 1976, pp. 303-311.

**Authors' Abstract**

In healthy, normal subjects simultaneous peripheral venous occlusion of all four limbs caused a small but significant increase in vital capacity (VC) and single-breath carbon monoxide transfer factor ( $D_{LCO}$ ) without significantly changing total lung capacity (TLC), residual volume (RV), pulmonary gas flow or pulmonary compliance.

Immersion in water to the neck resulted in a small but significant fall in VC,  $FEB_{1.0}/FVC$ , and TLC, and a rise in  $D_{LCO}$ , but flow/volume curves and "closing volume" were unchanged. Peripheral venous occlusion during immersion only significantly increased VC and  $D_{LCO}$ ; pulmonary compliance and flow/volume curves did not alter significantly.

It is concluded that peripheral venous occlusion produces these effects by altering intrathoracic blood volume. Water immersion reduces TLC, mainly from the hydrostatic pressure, and VC is reduced from both the hydrostatic pressure and the increase in intrathoracic blood volume consequent on immersion. The increase in  $D_{LCO}$  is due, almost entirely, to the increase in intrathoracic blood volume.

8. **Crane, M. G.; and Harris, J. J.:**  
Aldosteronism: Observations on Water and Electrolyte Changes during Partial Immersion.  
*J. Clin. Endocrinol. Metab.*, vol. 37, 1973, pp. 790-796.

**Authors' Abstract**

Studies are reported of the effect of posture and immersion on fluid and electrolyte excretion in a 44-yr-old white male with primary aldosteronism.

The patient exhibited excessive retention of sodium and water during a 4-hr period of ambulation after a water load of 15 ml/kg, but he excreted sodium and water normally after a second water load while recumbent for 4 hr.

The effect of partial immersion of the patient (to the neck in water at 94°F) for 4 hr on electrolyte and aldosterone levels was studied preoperatively and 11 weeks after removal of an adrenalcortical adenoma. Preoperatively he exhibited the following changes during the 4-hr period of immersion: there was little or no change in plasma aldosterone; he excreted 187 mEq of sodium and 31 mEq of potassium in 2130 ml of urine; and the creatinine clearance increased normally. Postoperatively, the patient had a 50% decrease in plasma aldosterone into the normal range during immersion; he excreted 14 mEq of sodium, 17 mEq of potassium in 230 ml of urine in the 4-hr period; and creatinine clearance increased normally.

9. **Crane, M. G.; and Harris, J. J.:**  
Suppression of Plasma Aldosterone by Partial Immersion.  
*Metabolism*, vol. 23, 1974, pp. 359-368.

**Authors' Abstract**

The effect of partial immersion in water (94°F for 4 hr) was studied in a group of normal subjects. Plasma aldosterone was measured after the patients had been NPO for 12 hr and ambulatory 2 hr as the initial condition, and then after 1, 2, and 4 hr of immersion. Immersion caused a 71%-73.4% decrease in plasma aldosterone and a 51%-51.5% decrease in plasma renin activity after 2 and 4 hr of immersion. Plasma aldosterone levels under the initial condition (NPO 12 hr plus ambulation 2 hr) was significantly lower in the older age group (46-80) than in the younger age group (20-45). Changing from the ambulatory posture to immersion was also accompanied by the following additional changes: There was a 2.7-2.9 percentage point decrease in hematocrit, which represented approximately a 430-ml increase in plasma volume. There was an

increased rate of elimination of water, sodium, and potassium in the urine, with an extra loss above the preimmersion rate of 323 ml of water, 39.1 mEq of sodium, and 9.8 mEq of potassium for the 4-hr period. There was, on the average, a maximum increase of 74% in creatinine clearance and an increase of 230% in urea clearance above the rate before immersion.

10. Crittendon, G.; Morlock, J. F.; and Moore, T. O.:  
Recovery Parameters following Underwater Exercise.  
*Aerospace Med.*, vol. 45, 1974, pp. 1255-1260.

**Authors' Abstract**

Five male subjects were monitored for energy cost and recovery profiles after mild ( $433 \pm 13$  kg·m/min) work in air and immersed at water temperatures of 26°C and 20°C. Recovery measurements included heart rates, rectal temperatures, and oxygen consumptions. Heart rates were not different during work under all conditions, but post-exercise recovery to resting rate was faster after exposure to 20°C water. Rectal temperatures dropped faster during working immersions than during immersions without work, and continued to fall during recovery, with the greatest rate of fall following 20°C water exposure. Oxygen uptakes were greater in water than air, the highest cost being in 20°C water, although the oxygen cost of the work per se was not different. The results suggest that thermal recovery is retarded after work in colder water and the energy cost may constitute a significant percentage of daily caloric intake even for mild exposures.

11. Epstein, M.; Bricker, N. S.; and Bourgoignie, J. J.:  
Presence of a Natriuretic Factor in Urine of Normal Men Undergoing Water Immersion.  
*Kidney International*, vol. 13, 1978, pp. 152-158.

**Authors' Abstract**

Immersion of normal subjects in water to the neck (NI) results in a redistribution of blood volume, relative central hypervolemia, and a significant natriuresis which is equal in magnitude to that produced by 10% expansion of the extracellular fluid volume by isotonic saline. The natriuresis of NI is independent of changes in GFR and is not prevented by the administration of DOCA. The present study was undertaken to determine whether the NI natriuresis is associated with increased activity of the natriuretic factor (NF) that has been observed in volume-expanded dogs and uremic dogs and patients. Twelve normal subjects were studied under control conditions, during NI in the seated position, and at the same time of day.  $U_{Na}V$ , while remaining constant during control studies, increased significantly during NI. Bioassays for natriuretic activity were performed in rats by using urine fractions from NI and control studies. The NI fractions in the test animals resulted in significant increments in both  $U_{Na}V$  ( $1.27 \pm 0.28 \mu\text{Eq}/\text{r.in}$ ) and  $FE_{Na}$  ( $1.39 \pm 0.21\%$ ) ( $P < 0.001$  for both). With the control fractions, there was no significant change in  $U_{Na}V$ , and there was a small increment in  $FE_{Na}$  ( $0.70 \pm 0.25\%$ ,  $P < 0.05$ ). The natriuresis of NI, thus, is associated with increased activity of natriuretic factor. The demonstration of increased NF in normal subjects during a period of increased sodium excretion strengthens the possibility that the natriuretic factor may participate in the regulation of sodium excretion and of sodium homeostasis.

12. Epstein, M.; De Nunzio, A. G.; and Ramachandran, M.:  
Characterization of Renal Responses to Prolonged Immersion in Normal Man.  
*J. Appl. Physiol.*, vol. 49, 1980, pp. 184-188.

**Authors' Abstract**

During the initial phase of spaceflight, there is a translocation of fluid from the lower parts of the body to the central vascular compartment with a resultant natriuresis, diuresis, and weight loss. Whether this natriuresis and diuresis result in the attainment of a new steady state or whether the circulatory adjustment

is incomplete is the subject of continuing controversy. Because water immersion is regarded as an appropriate model for studying the redistribution of fluid that occurs in weightlessness, we carried out an immersion study of relatively prolonged duration in order to characterize the temporal profile of the renal adaptation to central hypervolemia. Twelve normal male subjects underwent an immersion study of 8-hr duration in the sodium-replete state. Immersion resulted in marked natriuresis and diuresis which were sustained throughout the immersion period. The failure of that natriuresis and diuresis of immersion to abate or cease despite marked extracellular fluid volume contraction as evidenced by a mean weight loss of  $-2.2 \pm 0.3$  kg suggests that central blood volume was not restored to normal and that some degree of central hypervolemia probably persisted.

13. Epstein, M., Lifschitz, M. D.; Hoffman, D. S.; and Stein, J. H.:  
Relationship between Renal Prostaglandin E and Renal Sodium Handling during Water Immersion in Normal Man.  
*Circulation Res.*, vol. 45, 1979, pp. 71-80.

#### Authors' Abstract

Previous studies from this laboratory have demonstrated that the central hypervolemia induced by water immersion to the neck (NI) constitutes a suitable model for assessing the hormonal response to volume expansion without concomitant alterations in plasma composition. The NI model was used to assess in a kinetic fashion the relationship between renal prostaglandin E (PGE) and renal sodium handling. Nine normal subjects were studied twice in the sodium-replete state during NI: with indomethacin (Ind) pretreatment (50 mg q6h  $\times$  5)(NI + Ind) and without indomethacin (NI). Urinary sodium, potassium, and PGE excretion ( $U_{PGEV}$ ) were measured hourly. NI was associated with marked increases in  $U_{NaV}$  [from  $87 \pm 20$  (SE) to  $219 \pm 25$   $\mu$ Eq/min ( $P < 0.05$ )] and  $U_{PGEV}$  [from  $6.4 \pm 1.4$  to  $12.9 \pm 2.5$  ng/min ( $P < 0.05$ )]. Although indomethacin administration lowered the basal rate of  $U_{PGEV}$  prior to immersion, it neither prevented the subsequent augmentation of  $U_{PGEV}$  during NI + Ind nor affected the magnitude of the natriuresis during NI + Ind. Subsequently, six of the subjects were restudied following dietary sodium restriction (10 mEq/day). The changes in  $U_{PGEV}$  during NI and NI + Ind were qualitatively similar to those observed in the sodium-replete state. In contrast to the sodium-replete studied, however, the natriuresis of immersion was attenuated markedly by indomethacin pretreatment. In summary, the data demonstrate that immersion-induced central volume expansion is associated with a striking increase in renal PGE excretion which is attenuated but not prevented by indomethacin. In addition, indomethacin administration attenuates markedly the natriuretic response of immersion in sodium-depleted, but not in sodium-replete, normal subjects. These observations are consistent with the suggestion that renal PGE may constitute a determinant of the renal response to volume expansion in sodium-depleted man.

14. Epstein, M.; Pins, D. S.; Arrington, R.; DeNunzio, A. G.; and Engstrom, E.:  
Comparison of Water Immersion and Saline Infusion as a Means of Inducing Volume Expansion in Man.  
*J. Appl. Physiol.*, vol. 39, 1976, pp. 66-70.

#### Authors' Abstract

Although previous studies have demonstrated that water immersion to the neck (NI) results in both central hypervolemia and a significant natriuresis, it is unclear whether the magnitude of the "volume stimulus" of NI is comparable to that induced by the extracellular fluid volume expansion (ECVE) induced by acute saline administration. The present study was undertaken, therefore, to compare the natriuresis induced by these two different stimuli. All subjects were studied on four occasions while in balance on a diet containing 150 mEq of sodium and 80 mEq of potassium daily; seated control; seated immersion; and saline administration in both the seated and recumbent posture. The increment in  $U_{NaV}$  during NI was indistinguishable from that of seated saline. Similarly, the kaliuretic response during NI was similar to that induced by seated

saline infusion. In contrast, supine saline infusion resulted in a greater increment in  $U_{Na}V$  than either NI or seated saline. The present data indicate that the "volume stimulus" of immersion is identical with that of standard saline-induced ECVE in normal seated subjects. Furthermore, the ability of NI to induce a natriuresis without a concomitant increase in total blood volume and with a decrease in body weight, rather than the increase which attends saline infusion, suggests that NI may be a preferred investigative tool for assessing the effects of ECVE in man.

15. Epstein, M.; Pins, D. S.; and Miller, M.:  
Suppression of ADH during Water Immersion in Normal Man.  
*J. Appl. Physiol.*, vol. 38, 1975, pp. 1038-1044.

#### Authors' Abstract

Since previous studies from this laboratory have demonstrated that the redistribution of blood volume and concomitant relative central hypervolemia induced by water immersion to the neck cause a profound natriuresis and a suppression of the renin-aldosterone system, it was of interest to assess whether the diuresis induced by immersion was mediated by an analogous inhibition of ADH. The effects of water immersion on renal water handling and urinary ADH excretion were assessed in 10 normal male subjects studied following 14 hr of overnight dehydration on two occasions, control and immersion. The conditions of seated posture and time of day were identical. During control ADH persisted at or above prestudy values. Immersion resulted in a progressive decrease in ADH excretion from  $80.1 \pm 7$  (SEM) to  $37.3 \pm 6.3$   $\mu$ U/min ( $P < 0.025$ ). Cessation of immersion was associated with a marked increase in ADH from  $37.3 \pm 6.3$   $\mu$ U/min to  $176.6 \pm 72.6$   $\mu$ U/min during the re-covery hour ( $P < 0.05$ ). Concomitant with these changes urine osmolality decreased significantly, beginning as early as the initial hour of immersion, from  $1044 \pm 36$  to  $542 \pm 66$  mosmol/kg  $H_2O$  during the final hour of immersion ( $P < 0.001$ ). Recovery was associated with a significant mean increase in  $U_{osm}$  of  $190 \pm 40$  mosmol/kg  $H_2O$  over the final hour of immersion ( $P < 0.001$ ). The suppression of ADH occurred without concomitant changes in plasma tonicity. These studies are consistent with the suggestion that in hydrated subjects undergoing immersion suppression of ADH release contributes to the enhanced free water clearance, which has been previously documented.

16. Epstein, M.; Re, R.; Preston, S.; and Haber, E.:  
Comparison of the Suppressive Effects of Water Immersion and Saline Administration on Renin-Aldosterone in Normal Man.  
*J. Clin. Endocrinol. Metab.*, vol. 49, 1979, pp. 358-363.

#### Authors' Abstract

Although previous studies have demonstrated that water immersion to the neck (NI) results in a relative central hypervolemia and a profound suppression of PRA and plasma aldosterone (PA), it is unclear whether the magnitude of suppression of the renin-aldosterone axis is comparable to that induced by extracellular fluid volume expansion associated with acute saline administration. The present study was undertaken, therefore, to compare the relative suppressive effects of NI and saline administration on the renin-aldosterone axis. Nine normal subjects were studied on three occasions while in balance on a 10-mEq Na, 100-mEq K diet: control, NI, and saline. Blood for PRA and PA was obtained at 30-min intervals for 6 hr. The conditions of seated posture and time of day were identical. NI produced a profound suppression of PRA ( $54 \pm 10\%$ ) and a 59% suppression of PA which were similar both in magnitude and temporal profile to those observed during saline. The present study characterizes the dynamics of PRA and PA responsiveness during NI, demonstrating that in addition to similar central hemodynamic effects, the alterations of renin-aldosterone during NI and saline are similar. The delineation of the NI model commends its use as an alternative investigative tool for assessing renin-aldosterone responsiveness in a variety of edematous states.

17. Epstein, M.; Stone, R. A.; DeNunzio, A. G.; and Fregon, R. P.:  
Relationship between Urinary Kallikrein and Renal Sodium Handling during Water Immersion in Normal Man.  
*J. Clin. Endocrinol. Metab.*, vol. 50, 1980, pp. 122-127.

#### Authors Abstract

Considerable controversy exists with regard to the physiological role of the renal kallikrein-kinin system in regulating renal sodium handling. It has been both suggested and denied that a positive relationship exists between urinary sodium excretion and kallikrein activity. This discrepancy may relate in part to the experimental manipulations used to achieve extracellular fluid volume expansion, since the infusion of exogenous solutions is frequently accompanied by alterations in plasma composition and urine flow which may affect the kallikrein-kinin system independently of volume alterations. The successful characterization of the water immersion model (NI) and the demonstration that it induces acute central hypervolemia without concomitant alterations in plasma composition commended its utilization in the present study. The NI model was used to assess in a kinetic fashion the relationship between urinary kallikrein excretion and renal sodium handling. Normal subjects were studied after 11 hr of dehydration on two occasions: control (C; seven studies) and during 4 hr of NI (six studies). Urinary sodium, potassium, and kallikrein excretion were measured hourly. NI was associated with a marked increase in urinary Na excretion [from  $70 \pm 15$  to  $206 \pm 18$  (SE)  $\mu\text{Eq}/\text{min}$ ;  $p < 0.005$ ]. Concomitantly, urinary kallikrein excretion was unchanged. The current demonstration that NI failed to augment kallikrein excretion despite the marked concomitant natriuresis is consistent with the formulation that the kallikrein-kinin system may not participate in the acute regulation of sodium homeostasis in man.

18. Farhi, L. E.; and Linnarsson, D.:  
Cardiopulmonary Readjustments during Graded Immersion in Water at 35°C.  
*Respir. Physiol.*, vol. 30, 1977, pp. 35-50.

#### Authors' Abstract

Six normal male volunteers (25-34 yr), suspended vertically in a harness that allowed them to completely relax their postural muscles, were studied in four randomly ordered conditions, namely in air at 28°C and immersed in water at 35°C to the level of the hips, the xiphoid, or the chin. In each situation, several variables were measured by noninvasive techniques. Cardiac output rose from  $5.11 \cdot \text{min}^{-1}$  (air) to  $8.31 \cdot \text{min}^{-1}$  (chin), the increase in each of the three steps being significant at the 0.001 level. Heart rate dropped from 76 to 68  $\text{min}^{-1}$  ( $P < 0.001$ ) from air to xiphoid immersion but appeared to rise again ( $P < 0.02$ ) during chest immersion. Functional residual capacity decreased marginally during lower limb submergence, and considerably in each of the following stages. Pulmonary capillary blood volume rose significantly during abdomen immersion. The arterial endtidal  $\text{P}_{\text{CO}_2}$  difference was minimally reduced as water reached hip level and then remained steady. Mixed venous  $\text{P}_{\text{O}_2}$  increased during abdomen submergence, and  $\text{PV}_{\text{CO}_2}$  was unaltered throughout. Analysis of the step-to-step changes demonstrates that some variables are set by a combination of processes which may counteract each other, and explains the difference between results obtained by previous investigators.

19. Folinsbee, L.:  
Cardiovascular Response to Apneic Immersion in Cool and Warm Water.  
*J. Appl. Physiol.*, vol. 36, 1974, pp. 226-232.

#### Author's Abstract

The bradycardia and vasoconstriction that occur during breath-hold diving in man are apparently the resultant of stimuli from apnea, relative expansion of the thorax, lung volume, esophageal pressure, face immersion, and thermal receptor stimulation. We studied the cardiovascular response to breath-hold diving in a

thermoneutral (WW), 35°C, and a cool (CW), 21°C, water bath. There was an equal decrease in calf blood flow (CBF) of 1.2-1.3 ml/100 ml·min at both water temperature despite a significantly lower ( $P < 0.01$ ) resting CBF in CW (2.0 ml/100 ml·min) than in WW (3.5 ml/100 ml·min). However, the CBF was reduced more rapidly in WW than in CW. CBF decreased more rapidly when breath holds were preceded by a full inspiration. The heart rate (HR) decreased more rapidly in CW than in WW, with an average decrease of 7-8 b/min at both water temperatures. Immersion of the face had no effect on the apneic change of HR or CBF. We concluded that the bradycardia and vasoconstriction associated with breath holding during body immersion are not attenuated by a preexisting bradycardia and vasoconstriction due to cold.

20. **Gazenko, O. G.; Fedorov, B. M.; Pikus, V. G.; Tarrannikov, V. A.; and Sinitsina, T. M.:**  
Attention under the Influence of Reduced Motor Activity.  
*Doklady Akademii Nauk, SSSR*, vol. 230, 1976, pp. 1240-1241.

#### Annotation

**Purpose.** To determine the effects of hypokinesia on human attention and short-term memory.

**Method.** Six healthy male subjects were subjected to antiorthostatic hypokinesia (4°). Ten subjects served as control. In the treatment group, attention indicators were measured at 6-8 and 10-12 days after the end of hypokinesia. An indicator board with random numbers served as the task used to test attention. The task was performed without interference, with sound interference, with threat of electric shock, and with interference and electric shock.

ECG was monitored during task performance.

**Results.** Indicators of attention were sharply lowered at 6-8 days (as compared with control data) after hypokinesia termination. At 10-12 days, the active attention indices of five out of six subjects were restored to normal.

The ECG gave indications of psycho-emotional stress.

**Conclusion.** Antiorthostatic hypokinesia has a pronounced effect on the human brain, specifically in lowering indicators of active attention.

21. **Girandola, R. N.; Wiswell, R. A.; Mohler, J. G.; Romero, G. T.; and Barnes, W. S.:**  
Effects of Water Immersion on Lung Volumes: Implications for Body Composition Analysis.  
*J. Appl. Physiol.: Respirat. Environ. Exercise Physiol.*, vol. 43, 1977, pp. 276-279.

#### Authors' Abstract

Lung volumes of 20 healthy young men were measured before and after water immersion to the neck level. Immersion resulted in significant decreases ( $P < 0.01$ ) in forced vital capacity (FVC) (8.9%), expiratory reserve volume (ERV) (61%), total lung capacity (TLC) (5.6%), and functional residual capacity (FRC) (2.9%). Significant increases were observed in inspiratory capacity (IC) (10%) and residual volume (RV) (6.7%). The increase in RV was attributed to a possible "stiffness" of the lung tissue caused by pulmonary vascular engorgement. Densitometric analysis was made on each subject using hydrostatic weighing techniques. Subsequent calculation of body density and percent body fat indicated significant ( $P < 0.01$ ) differences when using RV measured on land and in water. Body fat was 14.0%, using the land RV in the computation of density, and decreased to 13.4%, using the RV measured in water. It was concluded that when obtaining body density values, RV should be measured concurrently while the subject is in the water.

22. **Gogolev, K. I.:**  
Correction of Transcapillary Exchange in Man under the Influence of Rotation on a Centrifuge while Immersed in Water.  
*Kosmich. Biol. Aviak. Med.*, vol. 13, 1979, pp. 72-74.

**Annotation**

*Purpose.* To investigate the effect of acceleration and periodic rotation on hydrocolloid equilibrium in man after immersion.

*Method.* Subjects were immersed (dry submersion) for 3 days. Some subjects underwent brief rotation during the period of submersion. A functional load test at three units  $+G_z$  for up to 5 min was conducted before and after immersion.

Hematocrit and blood plasma protein concentration were analyzed to examine transcapillary exchange before and at 2 and 12 min after a functional test rotation.

*Results.* Hemodynamic changes during centrifugation before immersion led to an increase in shift of fluid to the interstitial space in the second minute of the after-effect period. After 12 min the levels of fluid migration were restored with the exception of albumin, which stayed in the blood.

In subjects who underwent pure immersion, an increased passage of fluid from the bloodstream was noted. Globulin exhibited a tendency to pass into the perivascular space. In the 12th minute of the functional test after 3 days of immersion, a significant amount of globulins passed into the bloodstream and albumin passage into the interstitial space increased.

Subjects undergoing periodic rotation and immersion exhibited protein shifts that were analogous to the background findings, with the exception of transcapillary exchange of fluids that migrated into the bloodstream. Data indicated a globulin shift into extravascular space in the 12th minute, but the protein returned to its normal compartment during the background period.

*Conclusion.* The restoration of hydrocolloid composition at the end of immersion with rotation may be indicative of the efficacy of periodic centrifugation to correct hydrocolloid balance disorders arising as a result of circulatory changes in acceleration.

23. **Golovkina, O. L.:**  
External Respiration and Gas Exchange Reactions to Exercise during Rotation of Man on a Short-Radius Centrifuge.  
*Kosmich. Biol. Aviak. Med.*, vol. 13, pp. 58-60.

**Annotation**

*Purpose.* To study the effect of rotation and exercise on external respiration and gas exchange during prolonged immersion.

*Method.* The reactions to exercise and to exercise combined with rotation were studied on four subjects against a background of 28-day immersion. At the third week of immersion, the subjects exercised daily in the morning and evening on the bicycle ergometer at 600 kg-m/min three times for 10 min with 10-min breaks. In the fourth week of immersion, the subjects were rotated on a short-radius centrifuge as well as exercised.

Heart rate, pneumotachogram, and minute volume were recorded. Energy expenditure, oxygen pulse, coefficient of oxygen uptake, oxygen debt, and recovery coefficients were calculated.

Five subjects who underwent the program without immersion acted as the control group.

**Results.** After exercising, oxygen debt was 38% greater than when exercising without immersion. In tests with immersion, recovery coefficients were 33% lower. A 17% decrease in oxygen pulse in subjects who had been immersed was indicative of decreased physical efficiency.

The studies of exercise with rotation revealed a reliable increase in heart rate, a decrease in oxygen debt, and an increase in recovery coefficients, compared with exercise without rotation.

In the studies of immersion with a combination of rotation and exercise, heart rate was higher (25%), oxygen pulse was lower (20%), and oxygen debt was higher (25%), compared with similar studies without immersion.

In experiments involving exposure to acceleration combined with exercise and water immersion, heart rate increased (32%), minute volume increased (11%), oxygen debt increased (36%), oxygen pulse decreased (16%), and recovery coefficients decreased (25%).

**Conclusion.** The authors conclude that gravitational loads in addition to dynamic exercise create better conditions for oxygen supply in the body.

24. Goode, R. C.; Duffin, J.; Miller, R.; Romet, T. T.; Chant, W.; and Ackles, K.:  
Sudden Cold Water Immersion.  
*Respir. Physiol.*, vol. 23, 1975, pp. 301-310.

#### Authors' Abstract

Cold water is known to facilitate the drowning process. To gather information on the possible relationship between ventilation and cold stimuli, measurements of inspired and expired breath by breath ventilation and alveolar  $P_{CO_2}$  were made on eight male subjects suddenly immersed in both cold (11°C) and warm water (28°C). The mean ventilation for all subjects for the first three breaths following cold water immersion was 94.5, 71.3, and 94.6 liters/min (BTPS) as compared to 60.0, 36.2, and 38.5 liters/min (BTPS) for warm water immersion. Alveolar  $CO_2$  fell dramatically in cold water from a pre-immersion mean value of 36.4 Torr to 23.9 Torr, whereas there was only a change associated with the first few breaths following immersion in warm water. In prolonged cold exposure, ventilation was still markedly above that observed in warm water after 5 min. There was no relationship between skin-fold thickness and ventilatory response over the period studied. A large increase in ventilation is likely to result in inefficient swim stroke mechanics. This, combined with a high probability of inspiration of water, may contribute to death as a consequence of cold water exposure.

25. Graham, T.; and Baulk, K.:  
Effect of Alcohol Ingestion on Man's Thermoregulatory Responses during Cold Water Immersion.  
*Aviat. Space Environ. Med.*, vol. 51, 1980, pp. 155-159.

#### Authors' Abstract

A number of studies on alcohol and cold water immersion have demonstrated no differences in thermal regulation. In the present study, young, volunteer, male subjects ( $n = 4$ ) were immersed in cold water (13°C) for 24 min. When they got out of the water, they stood for a further 24 min in a room temperature of 22.5°C before being allowed to dry themselves. The subjects were tested twice: once, a solution of alcohol (40% by volume, 2.5 ml/kg body weight) and water was consumed; and once, an equivalent volume of water was ingested. In the control state, core temperature ( $T_{core}$ ) fell linearly 0.6°C in 24 min and continued to decline an additional 0.8°C in 24 min in the recovery. During the recovery period, 68% of the heat lost during the immersion was regained. With alcohol ingestion, blood alcohol levels reached approximately 20 mM/l. The rate of decline in  $T_{core}$  (0.9°C in each 24-min period) was greater ( $P < 0.05$ ) during immersion. During recovery, only 59.9% of the lost heat was regained ( $P < 0.05$ ). The onset of shivering was delayed with alcohol ingestion and the time spent shivering was less throughout the immersion and recovery periods. Nevertheless, the subjects consistently ( $P < 0.05$ ) rated the environment as warmed both in the



water and in the air recovery when they had ingested alcohol. The study demonstrated that  $T_{\text{core}}$  continues to decline during recovery from water immersion, even in the control state. The greater heat loss with alcohol ingestion could be due, at least in part, to impaired shivering thermogenesis. Coupled with reduced perception of the stress, the alcohol-impaired thermoregulation could be very dangerous, not only during water immersion but also during the recovery afterwards.

26. Greene, R.; Hughes, J. M. B.; Sundlow, M. F.; and Milic-Emili, J.:  
Regional Lung Volumes during Water Immersion to the Xiphoid in Seated Man.  
*J. Appl. Physiol.*, vol. 36, 1974, pp. 734-736.

#### Authors' Abstract

During immersion in water to the xiphoid, FRC fell 10.4% VC (7.9% TLC) in four seated subjects. Regional lung volumes using  $^{133}\text{Xe}$  were measured. Regional lung volumes at FRC during immersion in water were less at all lung heights than at FRC in air, reflecting a reduction in overall lung volume at FRC during immersion. At the same overall lung volume in air as at FRC during immersion, regional lung volumes were the same. Similarly at about 73% TLC regional lung volumes were the same during immersion in water and in air. These results indicate that in man the effect of gravity on the abdomen-diaphragm, which is abolished during immersion in water to the xiphoid, has no significant effect on regional lung volumes when compared to the same overall lung volume in air. From this it can be inferred that the distribution of pleural surface pressures in man is similarly unaffected by the action of gravity on the abdomen-diaphragm.

27. Greenleaf, J. E.; Shvartz, E.; Kravik, S.; and Keil, L. C.:  
Fluid Shifts and Endocrine Responses during Chair Rest and Water Immersion in Man.  
*J. Appl. Physiol.: Respirat. Environ. Exercise Physiol.*, vol. 48, 1980, pp. 79-88.

#### Authors' Abstract

To determine the effect of external water pressure per se on intercompartmental fluid volume shifts, plasma and urine electrolytes, osmotic and endocrine responses were compared in four men (21-22 yr) during 8 hr of water immersion ( $T_{\text{H}_2\text{O}} = 34.4^\circ\text{C}$ ) and during 8 hr of chair rest ( $T_{\text{a}} = 22.5^\circ\text{C}$ ), followed by 16 hr of bed rest in both regimens. Water intake was 1,800 ml during 8-hr exposures. Urine volume during immersion was 2,954 ml/8 hr and 1,538 ml/8 hr ( $P < 0.01$ ) during chair rest; the respective decreases in extracellular volume (ECV) were 2,230 ml/8 hr and 1,890 ml/8 hr. Losses from the interstitial volume (1.81 vs 1.67 liters) and plasma volume (0.43 vs 0.23 liters) during immersion and chair rest, respectively, were approximately proportional to their normal ratios. With a negative  $\text{H}_2\text{O}$  balance (corrected for blood withdrawal) during immersion of 1,234 ml and a positive balance (190 ml) during chair rest, there appeared to be a shift of ECV to the intracellular compartment in both regimens. There was suppression of both plasma arginine vasopressin (AVP) and renin activity (PRA) during chair rest and immersion. It appears that the increased central blood volume, as opposed to increased plasma osmolality, is the primary stimulus for AVP suppression. In hyperhydrated subjects, about half (6.7%) of the immersion plasma volume loss of 12.6% could be attributed to orthostatic responses associated with the upright body position during chair rest and the remaining half to the external water pressure.

28. Grigor'yev, A. I.; and Shul'zhenko, Ye. B.:  
The Functional State of the Kidneys of a Person during a 13-Day Immersion.  
*Fiziologiya Cheloveka*, vol. 4, 1978, pp. 1065-1071.

#### Authors' Abstract

During a 13-day stay of a healthy person in an immersion medium, significant shifts in the osmotic and ion-regulatory functions of the kidneys were apparent; these were characterized by an increase in excretion of fluid and electrolytes. The greatest increase in output of water and sodium by the kidneys was observed on the first and second and the eighth and twelfth days. In the second half of the experiment an increase

in excretion of K, Ca, and Mg was noted. The change in functional state of the kidneys in the first two days and immediately after completion of the experiment was basically caused by volumetric shifts. The changes in water-salt exchange and the systems regulating activity of the kidneys in the second half of the experiment were mainly a result of metabolic disturbances from the prolonged limitation of motor activity.

29. Grigor'yev, A. I.; and Shul'zhenko, Ye. B.:  
Effects of Minimal Gravitational Loads on Fluid-Electrolyte Metabolism and Renal Function of Man during Prolonged Immersion.  
*Kosmich. Biol. Aviak. Med.*, vol. 13, 1979, pp. 27-31.

#### Annotation

*Purpose.* To determine the effects of periodic gravity loads on fluid-electrolyte metabolism, osmoregulatory and ionregulatory renal function during long-term immersion.

*Method.* Ten males (25-39 yr) were immersed for 13 days. The first group (five men) was submitted to accelerations of 0.6-2.0 G for 60 to 90 min a day starting on the eighth day of immersion. The second group (five men) did not undergo acceleration.

Renal function was tested 3 days in the background period, daily during immersion, and for 11 days of the recovery period. Serum and urine values of sodium, potassium, calcium, magnesium, creatinine, urea, and osmotic concentration were recorded.

*Results.* On the first day, glomerular filtration rate increased and the Na/K ratio decreased. Fluid elimination increased but stabilized by the 3rd to 8th day. After the first rotation on the centrifuge, the rate of renal excretion of fluid, creatinine, sodium, potassium, calcium, and osmotically active substances decreased but increased within 4 to 8 hr after the gravitational load. Glomerular filtration rate was restored to base levels within 1 hr after rotation, so the decrease in sodium and fluid was attributed to a change in transport in the tubules.

Statistically significant differences between groups with regard to calcium and magnesium excretion were demonstrable only on the last day of the study. On the 10th and 12th days, the serum potassium concentration showed no significant decrease as compared to the control.

*Conclusion.* Periodic gravity loads can be used to normalize fluid-electrolyte metabolism and renal function during long-term immersion. A decrease in glomerular filtration rate and a change in water and ion transport were identified as the major mechanisms of change.

30. Hoar, P. F.; Raymond, L. W.; Langworthy, H. C.; Johnsonbaugh, R. E.; and Sode, J.:  
Physiological Responses of Men Working in 25.5°C Water, Breathing Air or Helium Tri-Mix.  
*J. Appl. Physiol.*, vol. 40, 1976, pp. 605-610.

#### Authors' Abstract

Fourteen scuba divers in swim trunks did ergometer work while breathing air at 3 m in 25.5°C water. They were stressed by work and cold. Exercise produced increases in heart rate, minute ventilation ( $\dot{V}_E$ ), oxygen consumption ( $\dot{V}O_2$ ), and catecholamine excretion. Cold lowered rectal temperature ( $T_{re}$ ) despite exercise, and contributed to the increase in  $\dot{V}O_2$  and catecholamine excretion. Immersion, cutaneous vasoconstriction, work, and scuba breathing contributed to a brisk diuresis, probably by centralizing blood volume and thus stimulating central vascular volume receptors. Similar exercise in 25.5°C water, breathing helium tri-mix (gas density less than air) produced higher  $\dot{V}_E$  but lower  $\dot{V}O_2$  when compared to air breathing. Tri-mix scuba breathing resulted in a smaller diuresis, perhaps because its lower density leads to lesser atrial distension during work. The fall in  $T_{re}$  during work in 25.5°C water was identical whether air or helium tri-mix was respired, since helium does not accentuate respiratory convective heat transfer.

31. Jankowski, L. W.; Portmann, M.; Martin, P.; Roy, L. E.; and Vallee, J.:  
Controlled Leg Exercise in Water.  
*Canad. J. Appl. Sport Sci.*, vol. 1, 1976, pp. 277-280.

**Authors' Abstract**

The purposes of this study were to compare the effects of prone immersion physical exercise (PIPE), a modified form of tethered swimming, and traditional bicycle ergometer exercise and to determine the facility and practicality of controlling leg exercise in the water. Oxygen consumptions ( $\dot{V}O_2$ ) and heart rates of 10 active young men during submaximal and maximal bicycle ergometry were compared to those for PIPE. After one 30 to 60 min learning trial, the mean  $\dot{V}O_2$  max for PIPE ( $X = 3.71 \pm 0.78$  liters/min) was not significantly ( $P < 0.05$ ) different from that for bicycling ( $X = 3.90 \pm 0.80$  liters/min). Heart rates in the water averaged 12.8 b/min lower than bicycling and were significantly lower at  $\dot{V}O_2$  max. Regression analysis revealed no significant difference in the  $\dot{V}O_2$ /heart rate relation under the two conditions. PIPE appears to be a practical method of performing aquatic leg exercise which is easily controlled by monitoring heart rate. This exercise can be conveniently prescribed using bicycle ergometry and could find application in swim training and physical rehabilitation programs where controlled aquatic exercise is indicated.

32. Johnson, L. F.; Lin, Y. C.; and Hong, S. K.:  
Gastroesophageal Dynamics during Immersion in Water to the Neck.  
*J. Appl. Physiol.*, vol. 38, 1975, pp. 449-454.

**Authors' Abstract**

This investigation was undertaken to study the effect of hydrostatic pressure on gastroesophageal dynamics during immersion in thermoneutral water to the neck. In five healthy male subjects (normal end-expiratory), gastric pressure ( $P_G$ ), esophageal pressure ( $P_E$ ), location and pressure of distal esophageal sphincter (DES), location of respiratory inversion point (RIP), and gastroesophageal pH gradient were measured standing in air (A), standing in water to the neck (B), and standing in air with abdominal compression (C). The pressure was measured with a Honeywell esophageal catheter (model 31) with built-in pressure transducer. A Beckman stomach pH electrode (No. 39042) was positioned adjacent to the pressure transducer.  $P_G$  increased from  $4.6 \pm 0.6$  (SE) mm Hg in A to nearly 20 mm Hg in B and C, while  $P_E$  increased from  $-6.0 \pm 0.8$  mm Hg in A to  $-0.8 \pm 1.0$  and  $-3.4 \pm 0.9$  mm Hg in B and C, respectively. However,  $P_{DES}$  was always 11-15 mm Hg higher than  $P_G$ . The superior limit of DES was displaced cephalad by 3.0 cm while the inferior limit was displaced by 1.6 cm in B, indicating a stretching of DES and a shortening of the esophagus. Qualitatively similar findings were obtained in C. In all experiments, the esophageal pH remained above 6, and no alteration in the amplitude of primary peristaltic waves was seen. It is concluded that a head-out immersion with increased gastroesophageal pressure gradient predisposes to gastric reflux in the absence of a competent DES mechanism.

33. Kamenskiy, Yu. N.; and Shul'zhenko, E. B.:  
Prophylaxis for Disturbances of External Breathing in Immersion.  
*Kosmicheskoye Issledovaniya*, vol. 14, 1976, pp. 474-476.

**Annotation**

**Purpose.** To study the reaction of external breathing during overloading (acceleration) after pure water immersion and immersion combined with gravitational conditioning effects.

**Method.** Group 1 (five men) was subjected to pure immersion without additional treatment. Group 2 (five men) was subjected to "head-pelvis" overloads starting on the 6th day of immersion for up to 1.5 hr duration. Before and after immersion both groups were subjected to a 300-sec overload test during which breathing frequency (BF), respiratory volume (PV), momentary respiratory volume (MRV), volume flow rate

of air at intake ( $W_i$ ), duration of inhalation,  $T_i$ , coefficient of oxygen use ( $CVO_2$ ), coefficients of variation of; breathing frequency, respiratory volume, duration of inhalation, and oxygen consumption were recorded and calculated, using Douglas-Holdern and pneumatochography.

### Results.

#### Changes in external breathing indices relative to the initial level (after overload)

	<u>Before</u>	<u>After</u>	<u>Before</u>	<u>After</u>
Plateau	300 sec	226 ±29 sec	300 sec	256 ±38 sec
BF	29%	73%	31%	22%
RV	70%	29%	70%	91%
$W_i$	83%	115%	90%	159%
$T_i$	10%	39%	12%	12%
$\dot{V}O_2$	82%	104%	81%	124%
$CVO_2$	6%	22%	13%	9%

During the after-effect period, it was noted that the normalization of the indices measured occurred more slowly in the first group after immersion. Pulmonary ventilation returned to normal 2 to 3 min later and  $\dot{V}O_2$  was 35% larger compared with the men in the second group, whose ventilation was normalized in 1 to 2 min and whose  $\dot{V}O_2$  was only 27% higher than before immersion.

**Conclusion.** The authors conclude that the data collected expresses the physical deconditioning of the subjects. The post-immersion effects possibly include disturbed gas exchange in the lungs. Gravitational "conditioning" effects were shown to have a prophylactic effect in prolonged immersion.

34. Kamenskiy, Yu. N.; Shul'zhenko, Y. B.; and Andreyeva, V. G.:  
Effect of Systematic Exposure to Gravity on the External Respiration Function during Prolonged Immersion.  
*Kosmich. Biol. Aviak. Med.*, vol. 4, 1976, pp. 40-45.

#### Authors' Abstract

Test subjects were exposed to 13-day immersion alone or combined with centrifugation. The immersion did not influence the state of ventilation and gas exchange at rest, but significantly diminished the functional capabilities of external respiration. An exposure of the test subjects to acceleration during the second half of water immersion resulted in the normalization of the functional reserves of external respiration. This may be a consequence of an increase in overall physical tone of the body.

35. Khosla, S. S.; and DuBois, A. B.:  
Fluid Shifts during Initial Phase of Immersion Diuresis in Man.  
*J. Appl. Physiol.: Respirat. Environ. Exercise Physiol.*, vol. 46, 1979, pp. 703-708.

#### Authors' Abstract

The object was to study fluid shifts in man during the first hour of immersion diuresis. Control experiments were done on subjects lying down in air for 4 hr with and without vasopressin. During immersion up to the neck, seven of nine subjects had significant diuresis and natriuresis. In the first 20 min of sitting in 33°C water, a hemodilution of 2% of blood volume was observed. As diuresis progressed, hemoconcentration began. When vasopressin was given just before immersion to prevent the diuresis, the hemodilution observed was greater and lasted longer. Thus the hematocrit fell by 1.7 U, plasma osmolality by 6.0 mosmol/kg, plasma proteins by 0.33 g/100 ml, and plasma sodium by 5.0 mEq/liter. We conclude that a hemodilution

of about 4% of blood volume occurs during the early phase of immersion and the degree of hyposmolality observed suggests that the fluid shifted was more hyposmotic than the interstitial fluid alone, possibly because some intracellular water may have shifted into the bloodstream during immersion.

36. **Khudyakova, M. A.; and Shul'zhenko, Ye. B.:**  
Blood Clotting Function during 12-Day Immersion in Water, and the Preventive Role of Revolving on a Centrifuge.  
*Kosmich. Biol. Aviak. Med.*, vol. 2, 1977, pp. 79-81.

#### Annotation

**Purpose.** To study the changes in various indices of hemostasis during a 12-day immersion in water and to determine whether it is possible to use increased gravitation for prevention of "deconditioning" of the organism during immersion.

**Methods.** Fourteen subjects were divided into two groups. The first group (six men) was submitted to "pure" immersion and the second (eight men) to immersion combined with centrifuge rotation 1-2 times a day at 1-2 G for 60-90 min starting on the 7th day of immersion. The immersion lasted for 12 days. From blood samples taken twice before immersion and six times during immersion the following measurements were determined: plasma recalcification time, heparin tolerance of plasma, plasma thromboplastin time, plasma thrombin time, prothrombin complex concentration, plasma heparin content, fibrin content, and plasma fibrinolytic activity.

**Results.** On the 2nd day of immersion hypercoagulation was detected. This condition is characterized by a decrease in fibrinolytic activity and plasma heparin content, and increase of heparin tolerance of plasma. Preventive rotation on a centrifuge, starting on the 8th day, caused all of the indices to revert to initial levels.

#### Conclusion.

1. Analysis of the obtained data is indicative of phasic changes in the system of hemostasis in man during a 12-day immersion.
2. Periodic rotation on the centrifuge was an effective means of preventing disturbances referable to hemostasis of the organism during immersion in water.

37. **Lollegen, H.; Nieding, G. V.; and Horres, R.:**  
Respiratory and Hemodynamic Adjustment during Head Out Water Immersion.  
*Int. J. Sports Med.*, vol. 1, 1980, pp. 25-29.

#### Authors' Abstract

In this study, the effect of head out water immersion on cardiopulmonary function was investigated in six healthy male subjects. Resistance to breathing, pulmonary capillary volume, and cardiac output increased during immersion. Constancy was observed for shunt perfusion, diffusing capacity, and diffusing capacity of the membrane. Carbon monoxide transfer factor (T<sub>CO</sub>) in relation to alveolar volume (VA) increased significantly. Due to nonuniform distribution of ventilation during immersion, PaO<sub>2</sub> dropped during immersion while AaDO<sub>2</sub> increased significantly. The described changes are due to the blood shift and hydrostatic pressure during immersion to the neck. The functional changes counteract each other, partly worsening and partly improving cardiopulmonary function. However, in summary, respiratory and circulatory function are slightly reduced during head out water immersion.

38. **Martin, S.; and Cooper, K. E.:**  
**Alcohol and Respiratory and Body Temperature Changes during Tepid Water Immersion.**  
*J. Appl. Physiol.: Respirat. Environ. Exercise Physiol.*, vol. 44, 1978, pp. 683-689.

**Authors' Abstract**

Resting subjects were immersed for 30 min in water at 22°C and 30°C after drinking alcohol. Total ventilation, end-tidal  $P_{CO_2}$ , rectal temperature, aural temperature, mean skin temperature, heart rate, and oxygen consumption were recorded during the experiments. Blood samples taken before the immersion period were analyzed by gas-liquid chromatography. The mean blood alcohol levels were  $82.50 \pm 9.93 \text{ mg} \cdot (100 \text{ ml})^{-1}$  and  $100.6 \pm 12.64 \text{ mg} (100 \text{ ml})^{-1}$  for the immersions at 22°C and 30°C, respectively. There was no significant change in body temperature measured aurally or rectally, mean surface skin temperature, or heart rate at either water temperature tested. Total expired ventilation was significantly attenuated for the last 15 min of the immersion at 22°C after alcohol consumption as compared to the ventilation change in water at 22°C without ethanol. This response was not consistently significantly altered during immersion in water at 30°C. It is evident that during a 30-min immersion in tepid water with a high blood alcohol level, body heat loss is not affected but some changes in ventilation do occur.

39. **Martin, S.; and Cooper, K. E.:**  
**The Relationship of Deep and Surface Skin Temperatures to the Ventilatory Responses Elicited during Cold Water Immersion.**  
*Can. J. Physiol. Pharmacol.*, vol. 56, 1978, pp. 999-1004.

**Authors' Abstract**

Subjects were immersed for 10 min in water at 14.5°C, after exposure either to ambient temperature or sauna heating. During the immersions, total ventilation, end-tidal  $P_{CO_2}$ , the mean of three surface skin temperatures, and deep skin temperatures were measured. There was a statistically significant correlation between the rate of change of deep skin temperature and the initial ventilatory responses evoked during both cold water immersions. After the sauna heating and cold water exposure, the temperature gradient through the skin appeared to be related to the ventilatory response. There was no significant correlation between the rate of change of mean surface skin temperature and the ventilatory response. The results suggest that the primary drive to increased ventilation during cold water immersion is the rate of change of deep skin temperature.

40. **Martin, S.; Diewold, R. J.; and Cooper, K. E.:**  
**Alcohol, Respiration, Skin and Body Temperature during Cold Water Immersion.**  
*J. Appl. Physiol.: Respirat. Environ. Exercise Physiol.*, vol. 43, 1977, pp. 211-215.

**Authors' Abstract**

Subjects who had not been exercising were immersed for 20 min in water at 13°C after ingestion of alcohol. During the immersion period, total ventilation, end-tidal  $P_{CO_2}$ , rectal temperature, aural temperature, and mean skin temperature were recorded. Control experiments were carried out at the same water temperature. Blood samples (3 ml), taken immediately before the immersion period, were analyzed by gas liquid chromatography. The mean blood alcohol level was  $90 \pm 11.2 \text{ mg} \cdot (100 \text{ ml})^{-1}$ . There was no significant difference in ventilatory responses, rectal temperatures, aural temperatures, or mean skin temperatures achieved during the two cold water immersions. It would appear that for a 20-min immersion at 13°C, relatively high blood alcohol levels do not affect ventilatory responses or increase body heat losses.

41. **Murakhovskiy, K. I.; and Golod, L. Z.:**  
**Mineralization of Human Bone Tissue under Water Immersion Conditions (Roentgenophotometric Investigation).**  
*Kosmich. Biol. Med.*, vol. 7, 1973, pp. 72-75.

**Authors' Abstract**

Two experimental series consisting of 10 experiments were carried out to assess the effect of 5-day water immersion on the mineral content of bones in subjects when wearing and not wearing a pronylactic load suit. The suit consists of a system of units imparting an additional load on the muscular and skeletal system. The bone mineral content was measured roentgenophotometrically in milligrams of Ca per 1 mm<sup>3</sup> before and on the second day of immersion. The objects studied were the navicular bone, ankle bone, heel bone, distal metadiaphysis of the hip bone and proximal metadiaphysis of the tibia. In experiments without the suit the level of bone density in the studied areas decreased by 4-8%. Statistical analysis revealed that the decrease was significant with  $P = 0.05$ . In experiments with the suit the bone density level increased in most cases, but the data were not statistically significant. A comparison of the significance of the differences between bone density changes in experiments with and without the suit demonstrated that they are statistically significant for the navicular bone, ankle bone and heel bone and not significant for the tubular bones.

42. **Prefaut, C.; Lupi-h, E.; and Anthonisen, N. R.:**  
**Human Lung Mechanics during Water Immersion.**  
*J. Appl. Physiol.*, vol. 40, 1976, pp. 320-323.

**Authors' Abstract**

We measured lung volumes, static deflation pressure-volume curves of the lung, maximum expiratory flow-volume curves, and closing capacities in five men standing immersed to the neck in water. FRC was decreased 27%, while other lung volumes did not change significantly. At high lung volumes immersion tended to increase lung elastic recoil while recoil was decreased at low lung volumes, changes compatible with vascular congestion. Maximum expiratory flow was increased at high lung volumes, probably because of hydrostatic pressure. At low lung volumes maximum expiratory flow was decreased. This was probably due to decreased recoil since the relationship between elastic recoil and maximum flow was unchanged. Closing capacities by the N<sub>2</sub> technique were unchanged but the slope of the alveolar plateau and the amplitude of cardiogenic oscillations were decreased in some individuals. Static and dynamic lung properties were unchanged by 5 min of immersion with tidal volume restricted to 0.5 liter. Though immersion produced volume restriction comparable with that reported with chest strapping, it did not produce similar changes in lung mechanics.

43. **Prefaut, C.; Ramonatxo, M.; Boyer, R.; and Chardon, G.:**  
**Human Gas Exchange during Water Immersion.**  
*Respirat. Physiol.*, vol. 34, 1978, pp. 307-318.

**Authors' Abstract**

We measured lung volumes, closing volume (CV), alveolo-arterial oxygen difference ( $P(A-a)O_2$ ) and steady-state diffusing lung capacity per liter ventilation ( $DL_{CO}/V$ ) in 18 men immersed up to the neck in water. The subjects were divided into three groups, according to relative changes in  $P(A-a)O_2$  and  $DL_{CO}/V$ . In group 1 ( $n = 6$ ),  $P(A-a)O_2$  decreased and  $DL_{CO}/V$  increased probably because of the hemodynamic changes induced by immersion. Their end expiratory level was above closing volume in water. In group 3 ( $n = 6$ ),  $P(A-a)O_2$  increased and  $DL_{CO}/V$  decreased, probably as a result of a decrease in ventilation in the dependent parts of the lung, considering that breathing range ( $ERV + VT$ ) was less than closing volume. In group 2 ( $n = 6$ ),  $P(A-a)O_2$  increased significantly and  $DL_{CO}/V$  only slightly. Tidal volume was only partially included in closing volume. The increase in exchange surface area was probably unable to compensate for the arterial

hypoxia brought on by the decrease in ventilation in the dependent parts of the lung. The relationship between end expiratory level and closing volume, which seemed to explain the results observed during immersion, was itself a consequence of the subjects' age and body build.

44. Robertson, C. H., Jr.; Engle, C. M.; and Bradley, M. E.:  
Lung Volumes in Man Immersed to the Neck: Dilution and Plethysmographic Techniques.  
*J. Appl. Physiol.: Respirat. Environ. Exercise Physiol.*, vol. 44, 1978, pp. 679-682.

**Authors' Abstract**

Previous studies of lung volumes during immersion have utilized dilution techniques for residual volume. We have compared lung volumes obtained by the use of a dual inert gas dilution technique with those determined by the Boyle's law technique in a plethysmograph designed to allow measurements in air and with subjects submersed to the neck in water. Both techniques gave similar results dry, but during immersion the dilution residual volume (RV) was 0.200 liter (16%) lower than the plethysmographic value ( $P < 0.001$ ), which suggests that there is a significant amount of gas trapping during immersion due to breathing at low lung volumes and the central shift of blood. The unchanged RV due to hydrostatic force on the chest wall is balanced by the tendency to increase RV due to vascular congestion, which increases closing volume and stiffens the lung to compression.

45. Rochelle, R. D.; and Horvath, S. M.:  
Thermoregulation in Surfers and Nonsurfers Immersed in Cold Water.  
*Undersea Biomedical Res.*, vol. 5, 1978, pp. 377-390.

**Authors' Abstract**

During immersion to the neck in  $19 \pm 0.6^\circ\text{C}$  water, surfers maintained higher toe temperatures than nonsurfers. The Lewis hunting response was seen only in the toes of the surfers. The shivering response of the surfers occurred later and was of lesser intensity. Threefold increases in metabolic heat production ( $140 \text{ kcal/m}^2\text{-h}$ ) above rest level were found in both groups. Rectal temperature changes were similar in both groups, with a mean decline of  $1.2^\circ\text{C}$  over the 1-hr exposure period. Individual changes in rectal temperature were negatively correlated to percent of body fat. An initial hyperventilation upon immersion was followed first by a decline and then by a rise to 3 times that of rest. A transient rise in heart rate (35 b/min) occurred in the initial stage of immersion in both groups and subsequently fell to basal levels, rising slightly thereafter. Sinus arrhythmias were observed during the first few minutes of immersion. In nonsurfers, plasma cortisol approximated the decrease anticipated because of the circadian cycle but was elevated in the surfers. Plasma volume decreased 12.2% (surfers) and 17.6% (nonsurfers). Diuresis was observed in both groups, and was 3.2 and 5.0 ml/min for surfers and nonsurfers, respectively.

46. Shulzhenko, E. B.; Panfilov, V. E.; Gogolev, K. I.; and Aleksandrova, E. A.:  
Comparison of Physiological Effects of Head-Down Tilting and Immersion on the Human Body.  
*Aviat. Space Environ. Med.*, vol. 50, 1979, pp. 1020-1022.

**Authors' Abstract**

Among the methods for simulating weightlessness effects on the human body, head-down tilting and water immersion are very useful. The purpose of the present investigation was to carry out a comparative study of water balance and water-protein composition of the blood using the above two methods to simulate the physiological effects typical of an acute stage of weightlessness adaptation. The results of the 7-day head-down tilting and immersion experiments allow the following conclusions: More pronounced changes in water balance and water-protein composition of the blood during immersion seem to indicate that immersion produces a greater effect on the human body; the pattern of changes during immersion and tilting suggests that the adaptation period to immersion takes a longer time. These findings give evidence that immersion,



compared with head-down tilting, reproduces more closely effects of acute adaptation to simulated weightlessness.

47. Shulzhenko, E. B.; Vil'-Vilyams, I. F.; Aleksandrova, E. A.; and Gogolev, K. I.:  
Prophylactic Effects of Intermittent Acceleration Against Physiological Deconditioning in Simulated Weightlessness.  
*Life Sci. Space Res.*, vol. 17, 1979, pp. 187-192.

**Authors' Abstract**

The prophylactic effect on adult human males of intermittent acceleration against physiological deconditioning in weightlessness simulated by water immersion was studied at +0.8, +1.2, and +1.6 G. These prophylactic exposures reduced renal excretion of fluid and plasma volume changes, and increased venous compliance and the time at which the subjects could tolerate an acceleration field of +3 G.

48. Shulzhenko, E. P.; Vil'-Vilyams, E. F.; Khudyakova, M. A.; and Grigoryev, A. I.:  
Deconditioning during Prolonged Immersion and Possible Countermeasures.  
*Life Sci. Space Res.*, vol. 14, 1976, pp. 289-294.

**Authors' Abstract**

Test subjects covered with a waterproof highly elastic cloth were exposed to 15-day water immersion up to the neck. They were divided into two groups. The first (control) group consisting of six persons was exposed to immersion alone and the second (experimental) group was exposed daily to accelerations of +0.6-2 G<sub>z</sub> for 60-90 min during the last 6 days of immersion. Before and after immersion all the test subjects were exposed to +3 G<sub>z</sub> for 5 min which served as a provocative test. These experiments give evidence that the use of dry immersion allows experimentation during prolonged immersion without concomitant complications. Variations in the physiological parameters (cardiovascular system, fluid-electrolyte balance, blood-coagulatory system) are indicative of the preventive effect of periodic accelerations during 13-day immersion.

49. Shvartz, E.; Bhattacharya, A.; Sperinde, S. J.; Brock, P. J.; Sciariello, D.; Haines, R. F.; and Greenleaf, J. E.:  
Deconditioning-Induced Exercise Responses as Influenced by Heat Acclimation.  
*Aviat. Space Environ. Med.*, vol. 50, 1979, pp. 893-897.

**Authors' Abstract**

Five young men were tested on a cycle ergometer before (Test 1) and after (Test 2) 8 days of heat acclimation (exercise at 50% of  $\dot{V}O_{2\max}$  at 39.8°C DB, 30.0°C WB) and after 8 hr of water immersion (Test 3). A control group of five subjects underwent a similar procedure in a temperate environment of 23.8°C. Heat acclimation resulted in the usual decreases in exercise heart rate (30 b/min) and rectal temperature (0.6°C) and an increase in sweat rate (19%). The control group showed effects of moderate training by decreases in exercise heart rate (11 b/min), rectal temperature (0.3°C), and sweat rate (24%). Water immersion resulted in substantial diuresis in both groups, despite 1800 ml of water consumed by each subject. In the acclimation group, exercise responses in Test 2 were better than in Test 1, with little improvement shown by the control group. The acclimation group maintained exercise responses in Test 3 as in Test 1, with more adverse responses shown by the control group. The results show that heat acclimation provides an effective method to prevent the adverse effects of water-immersion deconditioning on exercise tolerance.

50. Skipka, W.; Böning, D.; Deck, K. A.; Külpmann, W. R.; and Meurer, K. A.:  
Reduced Aldosterone and Sodium Excretion in Endurance-Trained Athletes before and during  
Immersion.  
*Eur. J. Appl. Physiol.*, vol. 42, pp. 255-261.

#### Authors' Abstract

Aldosterone excretion (AE) and plasma renin activity (PRA) were measured in eight untrained (UT) and eight endurance-trained (TR) male subjects before and during 4 hr of head-out immersion to study the mechanism of reduced renal sodium excretion in athletes. AE was significantly lower before immersion, and decreased less during immersion, in TR than in UT. Fractional sodium excretion, too, was lower and increased less during immersion in TR than in UT. PRA decreased in the water bath in all subjects ( $P < 0.001$ ). The attenuated response of AE in TR may be due partly to this increase of plasma potassium concentration. The generally reduced aldosterone release in TR might be caused by a training induced adaptation of the adrenals to corticotropin. The lowered renal sodium excretion of TR in spite of the decreased AE suggests an intensified aldosterone effect in these subjects, diminishing the salt loss during exercise.

51. Skipka, W.; Deck, K. A.; and Böning, D.:  
Effect of Physical Fitness on Vanillylmandelic Acid Secretion during Immersion.  
*Eur. J. Appl. Physiol.*, vol. 35, 1976, pp. 271-276.

#### Authors' Abstract

The effects of eight 4-6 hr head-out immersion on excretion of vanillylmandelic acid (VMA), blood pressure and plasma volume were estimated in eight endurance-trained (TR) and eight untrained (UT) subjects. In the trained, only a slight increase of VMA excretion occurred (4-hr value:  $+2.7 \pm 10.9$  ng/ml GFR), but there was a highly significant increase in the UT ( $+29.0 \pm 17.2$  ng/ml GFR). VMA values during control experiments in supine position tended to decrease in both groups.

Systolic and diastolic blood pressure fell by 20 mm Hg after beginning of immersion; in the UT plasma volume was reduced while it remained constant in TR.

The results indicate that orthostatic intolerance (o.i.) after immersion is not effected by decreased sympathetic innervation of vessels; in contrast it seems to be partly compensated for by an elevated sympathetic activity at least in the UT. As a main cause for the post-immersion o.i. one might suggest a decrease in renin activity.

52. Vil'-Vil'yams, I. F.; and Shul'zhenko, Ye. B.:  
Cardiac Arrhythmia Following Postimmersion  $+G_z$  Accelerations.  
*Kosmich. Biol. Aviak. Med.*, vol. 12, 1978, pp. 68-75.

#### Annotation

**Purpose.** To investigate the effect of immersion followed by head-pelvis accelerations on distinctions of development of cardiac arrhythmia.

**Methods.** Weightlessness effects were simulated by means of "dry" immersion in an immersion medium up to the neck on healthy male volunteers. In the first series (13 subjects), immersion lasted 3 days and in the second (6 subjects), 13 days. Accelerations of  $+3 G_z$  were conducted for up to 5 min on a centrifuge with a radius of 7.25 m. EKG, photoplethysmograms of earlobe vessels, and pneumograms were recorded. Visual impairment served as criteria of resistance to head-pelvis accelerations.

**Results.** During immersion there was a tendency toward slower cardiac function. Sinus tachycardia was much higher during acceleration after immersion, although there was no appreciable difference between the 3-day and the 13-day immersion groups. Extrasystolic arrhythmia occurred 4 times more often and was prognostically more serious during acceleration after immersion.

**Conclusion.** There is a significant change in the functional state of the cardiovascular system during many days of immersion. The following factors probably play the leading role in the genesis of breakdown of compensatory mechanisms of regulation of cardiac function with exposure to  $+G_z$  accelerations after immersion: increased tonus of the parasympathetic nervous system, changes in systemic and regional circulation, and impairment of the fluid-electrolyte balance of the body.

53. Vil'-Vil'yams, I. F.; and Shul'zhenko, Ye. B.:  
Functional State of the Cardiovascular System under the Combined Effects of 28-Day Immersion, Rotation on a Short-Arm Centrifuge and Exercise on a Bicycle Ergometer.  
*Kosmich. Biol. Aviak. Med.*, vol. 14, 1980, pp. 42-45.

**Authors' Abstract**

The cardiovascular function of four test subjects exposed to 28-day "dry" immersion was examined before and after 6-day cycles of rotation in a short-arm centrifuge to provide  $+1-2 G_z$ , bicycle ergometer exercise, and their combination. An exposure to acceleration of  $+3 G_z$  in a 7.25-m-arm centrifuge was used as a provocative test. The above countermeasures reduced but did not eliminate entirely immersion-induced cardiovascular deconditioning. From this study a combined use of acceleration of  $+1-2 G_z$  in a short-arm centrifuge and bicycle ergometer exercise can be recommended as a countermeasure against cardiovascular deconditioning in weightlessness.

54. Wade, C. E.; Dacanay, S.; and Smith, R. M.:  
Regional Heat Loss in Resting Man during Immersion in  $25.2^\circ\text{C}$  Water.  
*Aviat. Space Environ. Med.*, vol. 50, 1979, pp. 590-593.

**Authors' Abstract**

Five male subjects having a wide range of relative body fat, 9.2-20.2%, were studied during total body immersion in water at  $25.2^\circ\text{C}$ . The regional surface area of each subject was calculated from anthropometric data utilizing a segmental geometric model. Skin temperatures ( $T_{sk}$ ) and regional skin heat loss were measured prior to and during 30-min immersion at 13 sites. During immersion, mean  $T_{sk}$  was  $25.9^\circ\text{C}$  and remained significantly higher than the water temperature. A measurable temperature gradient for heat flow was observed from all body segments. Segmental temperature in water ranged from  $26.7-25.4^\circ\text{C}$ , being warmest at the neck and coolest at the foot. Heat flow per regional area was highest in the neck,  $187 \text{ W/m}^2$ , and least at the foot,  $14 \text{ W/m}^2$ . Heat flow from each body region was dependent on regional  $T_{sk}$ . Skinfold thickness was a minor factor in altering regional heat flow in the foot, hand, lower arm, upper arm, thigh, and calf; in the torso, neck, and head regions it was of major importance in deterring heat loss.

55. Zborovskaya, B. I.:  
Use of Short-Arm Centrifuge to Prevent Deconditioning When Immersed in Water (According to H-Reflex).  
*Kosmich. Biol. Aviak. Med.*, vol. 13, 1979, pp. 78-79.

**Annotation**

**Purpose.** To study the possibility of using periodic rotation on a short-arm centrifuge as a means of preventing the adverse effects of immersion.

**Methods.** Subjects were immersed for 3 days. Each subject was submitted to +3  $G_z$  after pre-immersion and immersion with periodic rotation on a short-arm centrifuge at various accelerations and for various durations. In all, 61 tests were conducted involving 12 subjects. Neuromuscular functions were tested by the methods of the H-reflex and electromyography.

**Results.** The fewest number of cases of secondary inhibition of the H-reflex was observed after immersion combined with +1.6  $G_z$  for 60 min twice a day.

**Conclusion.** The use of periodic rotation on a centrifuge with a 7.25-m arm increases resistance of the body to head-pelvis accelerations after immersion; in particular, it reduces significantly the development of hemodynamic disturbances.

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- Epstein, M.: Renal Effects of Head-Out Water Immersion in Man: Implications for an Understanding of Volume Homeostasis. *Physiol. Rev.*, vol. 58, 1978, pp. 521-581.
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- Hong, S. K.: Pattern of Cold Adaptation in Women Divers of Korea (ama). *Fed. Proc.*, vol. 32, 1973, pp. 1614-1622.
- Shul'zhenko, Y. B.; and Vil'yams, I. F.: Possibility of Carrying Out Prolonged Water Immersion by the 'Dry' Submergence Method. *Kosmich. Biol. Aviak. Med.*, vol. 10, 1976, pp. 82-84.

## SUBJECT INDEX

(The numbers refer to abstract numbers)

- Adominal compression, 32
- Acceleration, 22, 33, 47
  - +G<sub>z</sub>, 36, 52, 53, 55
  - head-pelvis, 23, 29
  - tolerance to, 34
- Acclimatization, 45
- Activity
  - plasma renal, 11
  - renal glucocorticoid, 1
- Adipose tissue, 5
- Adrenalcortical adenoma, 8
- Adrenal function, 1
- Adrenaline, 6
- Aerobic capacity, 4
- Air, total expired, 39
- Airway
  - closure of, 3
  - impedance of, 37
- Albumin
  - concentration of, 22
  - urine, 35
- Alcohol
  - blood, 25, 38, 40
  - consumption of, 38, 40
  - ingestion of, 25
- Aldosterone, 4, 28
  - plasma, 8, 9, 11, 16, 17
  - urine, 8, 50
- Alveolar
  - nitrogen, 21
  - oxygen, 24
  - P<sub>CO<sub>2</sub></sub>, 18, 24
  - ventilation, 37
  - volume, 37
- Angiotensin II, 16, 28
- Anhydrase inhibitor, benzolamide carbonic, 13
- Ankle, 41
- Antidiuretic hormone (ADH), 4, 14-16
  - reflex, 47
- Arrhythmia
  - cardiac, 52
  - extrasystolic, 52
- Arterial
  - baroreceptors, 15
  - end tidal P<sub>CO<sub>2</sub></sub>, 18
  - oxygen, partial pressure of, 37
  - pressure, 53
  - receptor, 16
- Atrial
  - pressure, right, 18
  - stretch receptors, 18
- Atropine, 52
- Attention span, 20
- Aural temperature, 38, 46
- Baroreceptor reflex, 19, 30
- Baroreceptors, 18
- Bed rest, 27
- Bicycle ergometer exercise, 53
- Blood
  - alcohol in, 25, 38, 40
  - alkalosis of, 4
  - carbon dioxide in, 37
  - coagulation of, 36
  - flow
    - in calf, 19
    - in muscle, 10
    - in pulmonary capillary, 2
    - medullary, renal, 15
    - renal, 4, 17
    - at rest, 19
  - gases in, 43
  - glucose in, 25
  - heparin in, 36
  - hypercoagulation of, 36
  - pH of, 37
  - pressure of, 6, 8
    - systemic, 16
  - redistribution of, 47
  - saturation of, oxygen, 37
  - volume of, 15, 16
    - central, 12, 27
    - intrathoracic, 3, 7
    - pulmonary capillary, 2
    - thoracic, 10, 18
- Body
  - demineralization of, 41
  - density of, 21
  - fat percentage of, 10, 21
  - heat content of, 45
  - plethysmography of, 26
  - temperature of, 49
  - weight of, 12

- Bone
  - mineral content of, 41
  - tissue, calcination of, 41
- Bradycardia, 19
  - reflex, 10
  - sinus, 6
- Breath holding, 19
- Breathing
  - external, 33
  - negative pressure, 18, 44, 47
  - volume, tidal, 3
- Calcium
  - serum, 29
  - urine, 29
- Calf, blood flow in, 19
- Capacity
  - carbon dioxide, diffusion, 37
  - functional residual, 2, 42-44
  - membrane, 37
  - vital, 3
- Carbon dioxide
  - concentration of, 3
  - tension of oxygen in, 24
- Carbonic anhydrase, benzolamide inhibition of, 13
- Carbon monoxide transfer factor, 7
- Cardiac
  - activity, 20
  - arrhythmia, 52
  - index, 2
  - output, 15, 18, 37
  - pressure receptors, 47
  - stretch receptors, 14, 15
  - volume receptors, 15
- Cardiogenic oscillations, 3
- Cardiopulmonary
  - function, 37
  - receptors, 16
- Cardiovascular function, 53
- Carotid artery sphygmogram, 53
- Casts, urine, 35
- Central
  - blood volume, 12, 27
  - expansion of, 17
  - stimulus of, 13
  - hemodynamics, 12
  - hypovolemia, 11, 12, 14, 16
- Centrifugation, 22, 23, 48, 52, 55
- Centrifuge, 36
  - short arm, 53
- Chair rest, 27
- Chloride, plasma, 27
- Chlorothiazide, 13
- Cholinergic mechanism, 32
- Circadian cycle, 8
- Closing
  - capacity, 42
  - volume, 3, 7, 43, 44
- Cold stress, 6
- Coagulation, blood, 36
- Cold water, 30
  - immersion in, 5, 6, 24, 25, 39, 40, 45
- Compression, abdominal, 32
- Convective heat transfer coefficient, 54
- Core temperature, 25
- Cortisol, 45
- Countermeasure, 48
- Creatinine
  - clearance of, 8, 9, 13, 14
  - plasma, 4
  - serum, 2, 29
  - urine, 1, 2, 29
- Cricopharyngeus, 32
- Cutaneous convective heat transfer, 30
- Cyanomethemoglobin, 27
- Cycle ergometer, 31
- Dead space ventilation, 37
- Deconditioning, 53
- Dehydration, 9, 47
- Densitometric analysis, 21
- Deoxycorticosterone acetate, 11
- Diaphragm, 26
- Diffusing capacity, carbon dioxide, 37
- Diffusion, 43
  - pulmonary, 2
- Diuresis, 1, 4, 8, 9, 12, 14-16, 28, 30, 35, 46, 48, 49
- Divers, 24
- Diving
  - physiology of, 44
  - response to, 19
- Dry immersion, 22, 29
- Electrocardiogram (ECG), 18, 20, 38, 52, 53
- Electromyogram, surface, 25
- Electrolytes
  - excretion of, 14, 15
  - plasma, 8
  - serum, 2
- End expiratory pressure, 43
- Endocrine regulation, 4

- Endogenous prostaglandin, 13
- End tidal-gas concentration, 37
  - gas tensions, 18
  - $P_{CO_2}$ , 38-40
- Endurance training, 4
- Energy
  - expenditure of, 23
  - requirement for, 10
- Equivalent lung tissue volume, 18
- Ergometer, 23, 53
  - cycle, 31
- Esophagus
  - length of, 32
  - pH in, 32
  - pressure in, 7, 32
  - sphincter pressure of, 32
- Excretion rate of potassium, 11
- Exercise, 10, 23, 40, 41
  - leg, 31
  - physical, 31
  - tolerance to, 49
- Expiratory
  - pressure, 43
  - reserve volume, 3, 21, 32, 43
  - volume, 24
- External respiration, 23, 33, 43
- Extracellular volume, 11, 13, 14, 16, 17, 27
- Extrasystolic arrhythmia, 52
- Evan's blue space, 27
  
- Face immersion, 19
- Facial temperature receptors, 19
- Fat thickness, skinfold subcutaneous, 5
- Femoral artery rheogram, 53
- Fibrinolytic activity in plasma, 36
- Filtration rate, glomerular, 11-13
- Flow
  - of pulmonary capillary blood, 2
  - volume curves, 7, 42
- Fluid and electrolyte homeostasis, 14
- Fluid
  - balance of, 27
  - electrolyte balance in, 52
  - electrolyte metabolism in, 48
  - intake of, 29
  - shift of, 18, 35
- Forced
  - hydration, 27
  - vital capacity, 21
- Fractional sodium excretion, 11
  
- Free water clearance, 13
- Function
  - adrenal, 1
  - cardiopulmonary, 37
  - renal, 1
- Functional
  - load test, 22
  - reserve capacity, 34
  - residual capacity, 2, 3, 18, 21, 26, 42-44
  
- Gas
  - exchange, 23, 34
  - end-tidal tensions, 18
- Gastric
  - pressure, 32
  - reflux, 32
- Gauer-Henry reflex, 30
- Globulin concentration, 22
- Glomerular filtration rate, 4, 11-13, 28, 29, 50, 51
- Glucocorticoid activity, renal, 1
- Glucose
  - blood, 25
  - plasma, 30
- Gravitational load, 29, 53
- +G<sub>z</sub> acceleration, 23, 29, 36, 52, 53, 55
  
- Heart rate, 2, 10, 16, 19, 23, 27, 30, 31, 38, 49, 53
  - at rest, 19
- Heat acclimation, 49
  - cutaneous convective transfer during, 30
  - regional flow during, 54
- Heat transfer coefficient, convective, 54
- Helium, 30
  - concentration of, 3
- Hematocrit, 8, 9, 22, 35, 46
- Hemodilution, 35
- Hemodynamics, central, 12
- Hemoglobin, 37
- Hemostasis, 36
- Heparin, in the blood, 36
- Homeostasis, of fluid and electrolytes, 14
- Humoral natriuretic factor, 11
- Hydration, forced, 27
- Hydrostatic
  - pressure, 18, 32, 37
  - weighing technique, 21
- Hydroxycorticosteroids, in urine, 1
- Hypercoagulation, 36
- Hypertension, 8
- Hyperventilation, 40
  - Lewis hunting response to, 45



- Hypervolemia, central, 11, 12, 14, 16
- Hypodynamia syndrome, 53
- Hyposmolality, in plasma, 35
- Hypothermia, 54
- Hypovolemia, 12, 27
  
- I<sub>131</sub>, in human serum albumin, 4
- Immersion
  - in cold water, 5, 6, 24, 25, 39, 40, 45
  - dry, 22, 29
  - prone, 31
  - seated, 2
  - supine, 2
  - in warm water, 24, 35
- Impedance of airway, 37
- Index, cardiac, 2
- Indomethacin, 13
- Interstitial fluid volume, 27, 49
- Intrapulmonary pressure, 34
- Intrathoracic
  - blood volume, 3, 7, 15
  - pressure, 19
- Inspiratory
  - capacity, 21
  - volume, 24
- Ion, sodium, 16
  
- Kaliuresis, 14, 16
  
- Leg exercise, 31
- Lewis hunting response, 45
- Load suit, prophylactic, 41
- Lung
  - elastic recoil of, 42
  - equivalent tissue volume of, 18
  - regional volume of, 25
  - static pressure of, 26
  - volume, 26
  - total capacity of, 7, 21, 26, 43
- Lyophilization, 11
  
- Magnesium
  - plasma, 27
  - serum, 29
  - urine, 29
- Maximal oxygen uptake, 10, 31
- Mean
  - skin temperature, 38, 40
  - ventilation, 24
- Metabolic rate, 54
  
- Metabolism
  - fluid electrolyte, 48
  - water-salt, 28
- Microhematocrit, 27
- Mineralocorticoids, 11, 17
- Minute
  - ventilation, 37
  - volume, 23, 34, 53
- Motor-visceral reflexes, 34
- Muscle blood flow, 10
  
- Natriuresis, 2, 8, 11-16, 28, 35, 49
- Natriuretic factor, 11
- Navicular bone, 41
- Negative pressure, 34
  - breathing at, 18, 44, 47
- Neuromuscular functions, 55
- Norepinephrine, 6
  
- Orthostatic tolerance, 51
- Osmolality
  - plasma, 27, 35
  - serum, 29
  - urine, 27-29
- Output, cardiac, 15, 18, 37
- Oxygen
  - capacity, 10
  - concentration, 3
  - consumption, 10
  - and carbon dioxide tensions, 24
  - debt, 23
  - pulse, 23, 31
  - uptake, 2, 18, 23, 27, 31, 33, 34, 38
  - maximal, 10, 31
  
- Partial pressure
  - arterial O<sub>2</sub>, 37
  - of CO<sub>2</sub>, 37
- Percent body fat, 21
- Peripheral
  - vasoconstriction, 19, 30
  - venous occlusion, 3, 7
- Perfusion, shunt, 37
- Photoplethysmogram, 52
- Physical
  - exercise, 10, 23, 30, 31, 41
  - fitness, 50, 51
  - training, 49
- Physiology of diving, 44

## Plasma

- aldosterone, 8, 9, 11, 16, 17
  - arginine vasopressin, 27
  - calcium, 27
  - catecholamines, 6
  - chloride, 27
  - creatinine, 4
  - electrolytes, 8
  - fibrinolytic activity, 36
  - glucose, 30
  - magnesium, 27
  - osmolality, 4, 27, 35
  - potassium, 27
  - protein, 4, 35
  - protein fractions, 46
  - prothrombin, 36
  - renin activity, 8, 9, 11, 13, 16, 27, 50
  - thrombin, 36
  - volume of, 3, 9, 27, 45, 49, 51
- Plethysmography, 19
- Pleural pressure gradient, 26
- Pneumograms, 52
- Pneumotachogram, 23, 33
- Potassium
- excretion of, 11, 16
  - plasma, 16, 27
  - serum, 8, 29
  - urine, 1, 2, 8, 9, 15, 27, 29, 48
- Pressure
- arteriolar, 53
  - hydrostatic, 18, 32, 37
  - intrapulmonary, 34
  - partial
    - of carbon dioxide, 37
    - of oxygen, 37
  - right atrial, 18
- Pressure-volume curves, 42
- Prone immersion, 31
- Prophylactic load suit, 41
- Prostaglandin
- endogenous, 13
  - renal, 13
- Protein
- albumin, 22
  - globulin, 22
- Prothrombin in plasma, 36
- Pulmonary
- capillaries, blood flow in, 2
  - circulation, 44
  - volume, 2, 18, 37
- Pulse rate, 6

## Radioimmunoassay, 9

- Rebreathing method, 2
- Recovery, 2, 10, 20
- Rectal temperature, 5, 6, 10, 25, 27, 30, 38, 40
- Recumbency, 8
- Reflex
- bradycardia, 10
  - sinus bradycardia, 6
- Refractive index of urine, 35
- Regional
- gas distribution, 26
  - heat flow, 54
  - lung volumes, 26
- Renal
- acid excretion, 14
  - blood flow, 4, 17
  - clearances, 4, 13, 15, 17
  - electrolyte homeostasis, 14
  - function, 1
  - glucocorticoid activity, 1
  - hemodynamics, 17
  - kallikrein-kinin system, 17
  - medullary blood flow, 15
  - osmotic clearance, 15
  - prostaglandin E, 13
  - potassium, clearance of, 15
  - sodium, 13, 17
    - clearance of, 15
  - vasoconstriction, 16
  - water, 15
- Renin activity
- aldosterone system, 14-16
  - angiotensin system, 15
  - plasma, 8, 9, 11, 13
  - secretion, 16
- Reserve volume, expiratory, 3
- Residual capacity
- functional, 2
  - volume, 3, 7, 21, 44
- Resistance
- respiratory, 37
  - total peripheral, 53
- Respiration
- external, 23, 34
  - rate of, 10, 30, 34
- Respiratory
- frequency, 33, 34
  - inversion point, 32
  - mechanics, 44
  - resistance, 37

**Respiratory** – continued  
     volume, 33, 34  
     minute, 23  
**Resting**  
     blood flow, 19  
     heart rate, 19  
**Rheogram of femoral artery, 53**  
**Right atrial pressure, 18**  
  
**Saline**  
     infusion, 8, 14, 16  
     load, 14  
**Saturation, blood oxygen, 37**  
**Sauna heating, 39**  
**Scuba, 10**  
     divers, 30  
**Seated immersion, 2**  
**Serum**  
     calcium, 29  
     creatinine, 2, 29  
     electrolytes, 2  
     human, 4  
     magnesium, 29  
     osmolality, 29  
     potassium, 8, 29  
     sodium, 29  
     urea, 29  
**Shivering thermogenesis, 25**  
**Short-arm centrifuge, 53**  
**Shunt perfusion, 37**  
**Sinus tachycardia, 52**  
**Skin**  
     fold thickness, 5, 24, 54  
     temperature, 5, 25, 39, 54  
**Sodium**  
     balance of, 14  
     excretion of, 12  
         fractional, 11  
         rate of, 11  
     plasma, 27, 35  
     renal, 13, 17  
         clearance of, 15  
     restriction of, 8  
     serum, 29  
     urine, 1, 2, 8, 9, 17, 27, 29, 48, 50  
**Sodium ion, 16**  
**Space**  
     Evan's blue, 27  
     interstitial, 8  
**Specific gravity of urine, 35**  
  
**Sphygmogram of carotid artery, 53**  
**Spirometry, 3, 26, 44**  
**Stroke volume, 2**  
     cardiac, 18, 49  
**Sugar in urine, 35**  
**Supine immersion, 2**  
**Surface**  
     area, 5  
     electromyogram, 25  
**Sympatho-adrenal system, 51**  
**Systemic vascular resistance, 15**  
**Systolic volume, 53**  
  
**Tachycardia, 6**  
**Temperature**  
     aural, 38, 40  
     body, 49  
     core, 25  
     facial receptors, 19  
     skin, 5, 25, 39, 54  
         deep, 39  
         mean, 38, 40  
**Test water load, 1**  
**Thermogenesis, shivering, 25**  
**Thermoregulatory responses, 10, 45**  
**Thoracic**  
     blood volume, 10, 18  
     venous return, 11  
**Thrombin in plasma, 36**  
**Tibia, 41**  
**Tidal**  
     breathing, 3  
     gas concentrations, end, 37  
     volume, 3, 18, 21  
**Tilt tolerance, 49**  
     head-down, 46  
**Tissue, gas tensions in, 18**  
**Total**  
     expired volume, 38, 40  
     lung capacity, 7, 21, 26  
     peripheral resistance, 53  
     plasma calcium, 27  
     plasma protein, 46  
     ventilation, 38, 39, 40  
**Training, endurance to, 4**  
**Transcapillary exchange, 22**  
**Transdiaphragmatic pressure, 32**  
**Transfer factor of carbon monoxide, 7, 37**  
**Tubular reabsorption of sodium, 15**

Underwater ergometer, 10

Urea

- clearance of, 9
- serum, 29
- urine, 29

Uremia, 11

Urinary

- ADH excretion, 15
- creatinine, 2
- potassium, 2
- sodium, 2
- solute concentration, 13

Urine

- adrenaline, 51
- albumin, 35
- aldosterone, 8
  - release of, 50
- calcium, 29
- casts, 35
- cells, 35
- creatinine, 1, 29
- excretion volume of, 4
- hydroxycorticosteroids, 1
- noradrenaline, 51
- osmolality, 4, 8, 9, 13, 15, 27-29
- potassium, 1, 8, 9, 27, 29, 49
- refractive index, 35
- sodium, 1, 8, 9, 27, 29, 48, 50
  - excretion of, 17
- specific gravity, 35
- sugar, 35
- vanillylmandelic acid, 51
- volume of, 1, 8, 29, 35

Vascular colloid composition, 22

Vasoconstriction, 18, 54

peripheral, 15

Vasodilation, peripheral, 18

Vasopressin, 28, 35

Venous

- bicarbonate, 4
- occlusion, peripheral, 3, 7
- pH, 4
- pressures, 18

Ventilation, 31, 34

- alveolar, 37
- dead space, 37
- maximal lung, 34
- mean, 24
- minute, 37
- perfusion ratio, 43

Ventilatory efficiency, 3, 38

Ventilometer, 24

Vessel elasticity, 53

Vital capacity, 3, 7, 34

forced, 21

Volume

- alveolar, 37
- blood, 2, 15, 16
  - central, 12
  - pulmonary capillary, 2, 18, 37
  - thoracic, 10
- buffering capacity, 3
- central expansion, 17
- closing, 3, 44
- equivalent lung tissue, 18
- expiratory, 24
- extracellular, 11, 13, 14, 16, 17, 27
- homeostatis, 14, 16
- inspiratory, 24
- interstitial fluid, 27, 49
- limb, 19
- lung, 19, 42
  - static, 26
- minute, 34
- plasma, 3, 9, 27, 45, 49, 51
- pulmonary, 2
- receptors, 11, 28
- reserve expansion, 21, 32, 43
  - minute, 53
  - systolic, 53
- residual, 3, 7, 21, 44
- respiratory, 33
- stimulus, central, 13
- stroke, 15, 49
- tidal, 3, 18, 21
- total expired, 38, 40
- urine, 1, 8, 29, 35

Warm water, 38

immersion, 24, 35

Water

- balance of, 46
- free, clearance of, 13
- load test, 1
- salt metabolism, 28
- temperature of, 19

Weighing technique, hydrostatic, 21

Weight, 12

Weightlessness, 12

Xenon, 26  
X-ray, 41

## AUTHOR INDEX

(The numbers refer to abstract numbers)

- Ackles, K., 24  
 Aleksandrova, E. A., 46, 47  
 Andreyeva, V. G., 34  
 Anthonisen, N. R., 42  
 Arrington, R., 14
- Balakhovskiy, I. S., 1  
 Barnes, W. S., 21  
 Baulk, K., 25  
 Begin, R., 2  
 Bennett, R. M., 3  
 Bhattacharya, A., 49  
 Bondi, K. R., 3  
 Böning, D., 4, 50, 51  
 Bourgoignie, J. J., 11  
 Boutelier, C., 5  
 Boyer, R., 43  
 Bradley, M. E., 3, 44  
 Bricker, N. S., 11  
 Brock, P. J., 49  
 Buhning, M., 6  
 Burki, N. K., 7
- Chant, W., 24  
 Chardon, G., 43  
 Colin, J., 5  
 Cooper, K. E., 38, 39, 40  
 Crane, M. G., 8, 9  
 Crittendon, G., 10
- Dacanay, S., 54  
 Deck, K. A., 50, 51  
 De Nunzio, A. G., 12, 14, 17  
 Diewold, R. J., 40  
 Dougherty, R., 2  
 DuBois, A. B., 35  
 Duffin, J., 24  
 Duncan, D., 2
- Engle, C. M., 44  
 Engstrom, E., 14  
 Epstein, M., 2, 11, 12, 13, 14, 15, 16, 17
- Farhi, L. E., 18  
 Fedorov, B. M., 20  
 Felinsbee, L., 19  
 Fregon, R. P., 17
- Gazenko, O. G., 20  
 Girandola, R. N., 21  
 Gogolev, K. I., 22, 46, 47  
 Golod, L. Z., 41  
 Golovkina, O. L., 23  
 Goode, R. C., 24  
 Graham, T., 25  
 Greene, R., 26  
 Greenleaf, J. E., 27, 49  
 Grigor'yev, A. I., 28, 29, 48
- Haber, E., 16  
 Haines, R. F., 49  
 Harris, J. J., 8, 9  
 Hoar, P. F., 30  
 Hoffman, D. S., 13  
 Hong, S. K., 32  
 Horres, R., 37  
 Horvath, S. M., 45  
 Hughes, J. M. B., 25
- Jankowski, L. W., 31  
 Johnson, L. F., 32  
 Johnsonbaugh, R. E., 30
- Kamenskiy, Yu. N., 33, 34  
 Keil, L. C., 27  
 Khosla, S. S., 35  
 Khudyakova, M. A., 36, 48  
 Kravik, S., 27  
 Kulpmann, W. R., 50
- Langworthy, H. C., 30  
 Levinson, R., 2  
 Lifschitz, M. D., 13  
 Lin, Y. C., 32  
 Linnarsson, D., 18  
 Lollegen, H., 37  
 Lupi-h, E., 42
- Martin, P., 31  
 Martin, S., 38, 39, 40  
 Meurer, K. A., 50  
 Milic-Emili, J., 26  
 Miller, M., 15  
 Miller, R., 24  
 Mohler, J. G., 21

Moore, T. O., 10  
Morlock, J. F., 10  
Murakhovskiy, K. I., 41

Nieding, G. V., 37  
Noskov, V. B., 1

Panfilov, V. E., 46  
Pikus, V. G., 20  
Pins, D. S., 14, 15  
Portmann, M., 31  
Prefaut, C., 42, 43  
Preston, S., 16

Ramachandran, M., 12  
Romanatxo, M., 43  
Raymond, L. W., 30  
Re, R., 16  
Robertson, C. H., Jr., 44  
Rochelle, R. D., 45  
Romero, G. T., 21  
Romet, T. T., 24  
Roy, L. E., 31

Sackner, M. A., 2  
Sciaraffa, D., 49

Shul'zhenko, Ye. B., 28, 29, 33, 34, 36, 46, 47,  
48, 52, 53

Shvartz, E., 27, 49  
Sinitsina, T. M., 20  
Skipka, W., 4, 50, 51  
Smith, R. M., 54  
Sode, J., 30  
Sperinde, S. J., 49  
Spies, H. F., 6  
Stein, J. H., 13  
Stone, R. A., 17  
Sundlow, M. F., 26

Tarrannikov, V. A., 20  
Timbal, J., 5

Vallee, J., 31  
Vil'-Vilyams, I. F., 47, 48, 52, 53

Wade, C. E., 54  
Wiswell, R. A., 21

Young, J. M., 3

Zborovskaya, B. I., 55