FLUID / ELECTROLYTE
LEACH - ALEXANDER

FLUID/ELECTROLYTE CHANGES IN APOLLO ASTRONAUTS

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With the December launch of Apollo 17, NASA brings to an end the highly successful Apollo program. The complexities of multiple docking in space, landing on the moon and returning to orbit required emphasis on engineering and navigation with biological studies taking a subsidiary role. As the missions became more routine the medical directorate under Dr. Charles Berry was given authority to perform progressively more complex physiological studies designed to insure the medical safety of the crews and to describe the adaptive processes in the weightless environment. In the overall operational medical program, our task was to document the study of the endocrine and fluid volume changes of the returning crewmembers.

Prior to Apollo 7, considerable knowledge had been accumulated concerning the fluid and endocrine changes associated with the Mercury and Gemini earth orbital missions (1) (2). As an example, it was known that our astronauts always weighed less on their return than they did prior to the mission. This decrease in weight was interpreted generally as being associated with modest decreases in plasma volume. These results showed that while "cardiovascular deconditioning" was similar to that found after bedrest, the fluid changes after weightlessness were greater but the plasma volume changes smaller. There was evidence after Gemini that the re-entry sequence caused a sudden increase in epinephrine release as was shown by a short-lived granulocytosis. These findings indicated that re-entry and recovery were also stressful experiences. Prior to Mercury, there was considerable apprehension among the medical community that weightlessness would produce life-threatening hypercalcemia and hypercalciuria. This apprehension subsided when no evidence of a calcium abnormality was found. Even after the 14 day Gemini 7 mission, X-ray bone densitometry showed modest or nonexistent loss of bone mineral. From this background, the more extensive endocrine and metabolic studies were planned for Apollo 7 and have been continued to the most recent mission, Apollo 16. As with other portions of the medical program, these studies were designed to assist the medical monitors in maintaining the crew's health during the mission. It is our purpose to summarize the endocrine and metabolic results obtained before and after the Apollo missions. From these results it is possible to obtain an idea of the nature and extent of the endocrine adaptation by the men who flew these missions.

METHODS

The same general protocol has been followed for most of the Apollo missions. Deviations from these procedures have been due only to the constraints imposed by quarantine missions (11, 12 and 14).

With crewmembers reclining for 30 minutes, approximately 45 ml peripheral venous blood was drawn three times (30, 15 and 5 days) before spaceflight and about two hours after recovery. All of the blood samples were drawn with the subject in a fasting state at 7:30 to 8:00 AM except the sample drawn following splashdown which is drawn regardless of the time of day or food intake by the crew. For the pre-flight control samples, the crew had been up and about less than one hour.

Twenty-four hour urine samples were collected from each crewman on the same day as the blood workup. The pooled urine was collected with no additive; then aliquoted, stabilized with acid and frozen for future analysis.

Ground control subjects have been used during each mission as a quality check on the effects of collection and transport of biological samples. Their results showed that transporting the samples to the NASA laboratories produced no change in the values.

Analyses on the blood (plasma or serum) samples included among others: osmolality, sodium, potassium, chloride, ACTH, angiotensin I and hydrocortisone, creatinine, BUN, calcium, phosphorus, magnesium and parathormone. The twenty-four hour urine samples were analyzed for electrolytes, osmolality, volume, creatinine, aldosterone and antidiuretic hormone.

All data were analyzed by two-way analysis of variance and the standard error of the mean was calculated from the error mean square. In all cases, data obtained 15 days prior to the flight were used for the control data point and the data obtained immediately postflight was compared to the preflight control. These data points were selected for statistical analyses after it was determined that there were no significant differences between the three pre-flight control days for blood or urine results.

RESULTS

Postmission body fluid losses have been found in crewmen of both United States and Russian manned spaceflights. Nearly every crewman has shown a 2.5 - 5 percent decrease in body weight postflight. In Apollo this loss averaged 6 lbs or a mean weight loss of 3.5% $\pm$ 2.3 SD as shown in Table I. Over 50 percent of the weight was regained within the first 24 hours after recovery.

These body weight changes have indicated significant fluid changes among all crewmembers exposed to weightlessness. This fluid and/or tissue loss does not seem to be related to the duration of the mission. Because of this, studies were undertaken to investigate the cations and anions which serve critical roles in the homeostatic regulation of fluid volume. Serum electrolyte data from the Apollo crewmen is summarized in Table II. It was observed that there is a 7% decrease in serum potassium, a 0.9% decrease in the serum sodium and a 5% decrease in magnesium immediately postflight (ASAP). These changes were accompanied by no change of statistical significance in chloride or osmolality.

The twenty-four hour urine samples obtained at the time of these serum samples exhibited significant changes when the immediate postflight samples are compared to the control samples acquired 15 days before flight. Table III shows the electrolyte analysis. In the first 24 hours following flight, sodium, potassium, magnesium and chloride are significantly decreased.

To aid in the understanding of water and electrolyte balance and renal function, renin activity was measured as angiotensin I in blood samples and the adrenal mineral corticoid, aldosterone was measured in the urine. Table IV gives these results. The plasma angiotensin I values show a 555% increase in the crewmen tested on the day of recovery. This elevation is followed by a significant increase (62%) in urinary aldosterone during the first day following recovery.

Table V gives the summary data on urinary volume, antidiuretic hormone (ADH) and osmolality. These results indicate a 39% decrease in urine volume postflight with significant increases in osmolality (24%) and ADH (339%).

Plasma cortisol and adrenocorticotrophic hormone (ACTH) results are given in Table VI. Although no significant change was found, a mean decrease was demonstrated.

Table VII gives the BUN and creatinine clearance data. The creatinine clearance results indicate no significant change in renal function postflight. A slight increase in BUN was found.

The calcium and phosphorus changes are summarized in Table VIII along with parathormone (PTH) from the two missions from which these results were obtained. It is thought that the Ca, PO_4 and PTH results not only reflect normal bone metabolism but also give evidence of normal renal function. These results are in agreement with photon absorptiometry studies also conducted on several Apollo flights which showed small to insignificant losses of bone calcium following these missions.

There has been a mean 5.6% decrease in plasma volume after those missions in which this measurement was made. Although these changes are less than would be predicted from bedrest studies, the decrement measured over 5 missions is statistically different from zero ($p < 0.005$).

DISCUSSION

Taking into consideration all of these data along with the clinical condition of the returning Apollo crewmen, the following hypothesis has been proposed to explain these changes. As a crewman enters the weightless environment his circulating blood volume and extracellular fluid is redistributed from the dependent extremities and the lower abdomen equally throughout the vascular space. This equalization of the blood volume is predictably interpreted as a relative volume expansion. This fluid redistribution necessitates a compensatory change in water balance with net loss of fluid and electrolytes. The extent of the fluid and electrolyte loss is also related to dietary intake which has been variable and generally below basal requirements during the first 24 hours of the mission. It is thought the changes in water balance occur principally within the first or second day as they do in bedrest. This would explain why the crewmembers show weight decreases even after short Mercury and Gemini missions (3).

On return to earth and the 1G environment, 50% of the weight loss is regained within the first twenty-four hours. A rapid weight gain of this magnitude supports a profound renal and endocrine response to this new environment.

It is believed that the remainder of the weight loss can be accounted for by loss of cellular mass. Consistently measured decreases in red cell mass and decreases in individual cell electrolyte content add support to this hypothesis. Furthermore, significant decrease in serum magnesium indicate losses in intracellular electrolyte concentrations since Mg along with K is concentrated in the intracellular space.

A 20% postflight decrease in total body potassium has been measured by gamma spectrometric measurement of the total body potassium 40. In the Apollo 15 mission, total body exchangeable potassium, K_e was measured. This measurement is made using ^{42}K in an isotope dilution technique (4). The results may be expected to differ from total body potassium since it does depend on complete equilibration and some slow to equilibrate pools may not be completely exchanged in the 24 and 48 hour periods analyzed. However, since we are comparing measurements before and after spaceflight on the same individuals, the relative changes are meaningful. In the three Apollo 15 crewmen, the K_e was found to be decreased about 13%. The crewmembers of the Gemini 7 mission demonstrated positive potassium balance before and after the flight with a negative balance during the mission. The Gemini 7 results were accompanied by increased urinary aldosterone excretion during the flight (5). These Gemini results and the data available from crews of the Apollo mission suggest that aldosterone is elevated during spaceflight. This elevation could be produced by decreases in renal blood flow, carotid artery or right heart pressures. The specific etiology of this event must await further experimentation.

During the recovery operations the crews are exposed to increased ambiant temperature both in the spacecraft, in the helicopter and on the carrier deck due to the tropical location of the recovery operations. The crews do not eat or drink between the time they leave the spacecraft and the blood drawing. Thereafter, they can eat or drink anything they desire. The postrecovery diet is generally a high salt, high protein, high calorie diet. The postrecovery urine generally shows increased osmolality with a decrease in electrolyte content. This combination indicates increased excretion of non-electrolyte osmotic substances. Part of this increase in osmolality may be a result of the increased BUN found postrecovery. The clinical laboratories have found similar elevations in uric acid. Because of the increased environmental heat during the first four hours after recovery, we would expect a slight increase in serum sodium and later osmolality. Serum sodium was actually less postmission than before the mission. Osmolality was unchanged. This suggests that serum sodium may have been even lower prior to re-entry. This combined with the BUN change suggests that renal blood flow is decreased during weightlessness and this could be in part responsible for the increased aldosterone excretion via the renin-angiotensin system.

Balakhovshiy has suggested that the postflight weight loss in the American astronauts was due to dehydration caused not by spaceflight but by environmental temperatures in the tropical recovery zones (6). Our data do not substantiate dehydration as the causative factor for the fluid/electrolyte results since serum osmolality was not changed significantly postflight.

At recovery there is an increase in catecholamine excretion associated with an increase in the number of circulating granulocytes. It would be logical to expect a similar increase in ACTH and cortisol excretion at that time. The data to the present shows no evidence of cortisol and ACTH increase. Thus, we can assume that the stress of re-entry is not great enough to produce a change in these hormones; however, the time of recovery is generally at a different point in the diurnal cycle of the pituitary-adrenal axis than is the preflight control (7). Without stress we would expect higher values at the time of the control specimens (8:00 A.M.) than we would at the time of recovery (anywhere from morning to early afternoon). Thus the re-entry stress may have elevated these hormones compared to what they would have been 24 hours before recovery.

Prolonged bedrest is associated with a negative calcium balance particularly in the second week (8). It has been postulated that exposure to weightlessness would produce similar losses of calcium from the skeleton. The results of the Apollo missions do not appear to indicate significant changes in calcium metabolism. First, no increase in parathormone has been found at recovery. Second, urine and serum calcium have not been elevated and third, bone densitometry has failed to show consistent decreases in bone mass (9). Therefore, for missions up to 14 days, it is not apparent that significant calcium losses have occurred. Hypercalcemia does not account for the loss of sodium, as has been suggested (10). However, it is expected that if changes are occurring in calcium dynamics, they have just begun during this time frame.

The complete explanation of endocrine - metabolic changes associated with the spaceflight environment will not be possible until the in-flight medical experiments are conducted on the Skylab mission next year.

TABLE I

WEIGHT CHANGE SUMMARY IN APOLLO ASTRONAUTS

	N	MEAN WEIGHT LOSS	MEAN PERCENT CHANGE	MEAN WEIGHT RE-GAINED (R+24 hrs.)	MEAN % CHANGE
All crewmembers on Apollo Missions 7, 8, 9, 10, 11, 12, 14, 15	24	-5.8	-3.5	+3.0	+1.9
Non Lunar Eva Crew-men	16	-6.8	-4.1	+3.1	+1.9
Lunar Eva Crewmen	8	-3.8	-4.0	+2.9	+1.8
		lbs.	%	lbs.	%

Note: Apollo 13 data not included.

TABLE II

SERUM ELECTROLYTES

ELECTROLYTE	N	F-15 MEAN ± SE	ASAP MEAN ± SE	% CHANGE	SIGNIFICANCE
Na (meq/l)	27	142 ± .2	140 ± .4	.9 ↓	$P < 0.025$
K (meq/l)	26	4.1 ± .06	3.8 ± .06	7 ↓	$P < 0.005$
Cl (meq/l)	25	104 ± .6	103 ± .6	1.2 ↓	$P < 0.10$
Mg (Mg/100 ml)	26	2.2 ± .05	2.1 ± .05	5 ↓	$P < 0.001$

TABLE III

URINE ELECTROLYTES

ELECTROLYTE	N	F-15 MEAN ± SE	ASAP MEAN ± SE	% CHANGE	SIGNIFICANCE
Na (mEq/vol)	20	175 ± 15	97 ± 11	44 ↓	$P < 0.01$
K (mEq/vol)	20	74 ± 6	46 ± 4	38 ↓	$P < 0.001$
Cl (mEq/vol)	20	165 ± 15	74 ± 9	55 ↓	$P < 0.001$
Mg (mg/vol)	17	9.5 ± 0.5	6.8 ± 0.7	28 ↓	$P < 0.005$

TABLE IV

SODIUM RETAINING HORMONES.

TEST	N	F-15 MEAN $\pm$ SE	ASAP MEAN $\pm$ SE	% CHANGE	SIGNIFICANCE
Plasma Angiotensin (mug/ml/hr)	14	$2.0 \pm .5$	13.1 ± 3.0	555↑	$P < 0.005$
Urine Aldosterone (ug/volume)	17	14.3 ± 2	23.2 ± 2	62 ↑	$P < 0.005$

TABLE V

TWENTY-FOUR HOUR URINE VOLUME DATA

TEST	N	F-15 MEAN ± SE	ASAP MEAN ± SE	% CHANGE	SIGNIFICANCE
Urine Volume (ml)	20	1711 ± 179	1048 ± 99	39 ↓	$P < 0.005$
Osmolality (mosmo)	20	737 ± 47	908 ± 41	24 ↑	$P < 0.005$
ADH (m Units/volume)	16	17.3 ± 3	75.9 ± 22	339 ↑	$P < 0.025$

TABLE VI

ADRENAL-PITUITARY PLASMA HORMONE CONCENTRATION.

TEST	N	F-15 MEAN $\pm$ SE	ASAP MEAN $\pm$ SE	% CHANGE	SIGNIFICANCE
Hydrocortisone (ug/100 ml)	23	14.8 $\pm$ 0.8	12.3 $\pm$ 2.0	17↓	$P < 0.25$
ACTH (pg/ml)	6	46 $\pm$ 10	30 $\pm$ 5	35↓	$P < 0.25$

TABLE VII

INDEX OF RENAL FUNCTION

TEST	N	F-15 MEAN ± SE	ASAP MEAN ± SE	% CHANGE	SIGNIFICANCE
BUN (mg/100 ml)	29	18.2 ± 0.5	20.8 ± 0.7	14↑	$P < 0.001$
Creatinine Clearance (1/24 hours)	26	148 ± 9	138 ± 9	7↓	$P > 0.25$

TABLE VIII

CALCIUM METABOLISM RESULTS.

TEST	N	F-15 MEAN ± SE	ASAP MEAN ± SE	% CHANGE	SIGNIFICANCE
Calcium Serum (mg/100 ml)	26	9.6 ± 0.06	9.7 ± 0.06	1 ↑	$P > 0.25$
Urine (mg/vol)	17	103 ± 9	93 ± 11	10↓	$P > 0.25$
Phosphorus Serum (mg/100 ml)	26	3.5 ± .07	3.6 ± 0.10	3 ↑	$P > 0.25$
Urine (mg/vol)	17	1038 ± 77	1067 ± 85	3 ↑	$P > 0.25$
Parathormone Serum (Pg/ml)	6	0.34± 0.03	0.28± 0.06	18 ↓	$P > 0.25$

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