MEDICAL RESULTS OF APOLLO 14 –
IMPLICATIONS FOR LONGER DURATION SPACE FLIGHTS

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Introduction

The Apollo 14 mission was quite successful in its basic objective of verifying and expanding techniques for lunar exploration. A more rugged portion of the lunar terrain was selected for landing; new navigation procedures were assessed; surface exploration times were extended. As a test and verification mission, Apollo 14 was significant from a medical standpoint in that it affirmed man's capability to operate effectively on the lunar surface and did much to pave the way for the greatly increased exploration activities of Apollo 15.

Specific medical objectives for the Apollo 14 mission did not differ greatly from those of earlier Apollo flights, centering on insuring crew safety and obtaining information on the biomedical effects of space flight. Of particular interest in the Apollo 14 biomedical program were the verification of earlier mission results from the Gemini and Apollo series, the opportunity to use new and more sensitive measurement techniques, and the evaluation of one-sixth G as an ameliorative measure against the effects of extended exposure to weightlessness.

Biomedical measures obtained during the Apollo 14 mission should be viewed as additional data points extending knowledge obtained particularly from the Apollo 11, 12, and 13 flights. The crews of these earlier space flights have rather consistently shown weight loss, some indication of mineral loss from the bones, reduced orthostatic tolerance evidencing cardiovascular adaptation to zero gravity, reduced exercise capacity, and some indication of fluid shifts within body compartments (Berry, in preparation). On the positive side, the crew of Apollo 13 showed a capability to operate intelligently and effectively under crisis conditions when the stresses of space flight were greatly increased.

Basic mission parameters for Apollo 14 are shown in Table 1. The principal crew activities during the two periods of extravehicular activity (EVA) consisted of collecting lunar samples in the vicinity of the Lunar Module (LM), utilizing the wheeled MET (Modular Equipment Transporter) by pulling it to such sites as the Cone Crater, and deploying instruments for the collection of scientific data.

Table 1

Apollo 14 Mission

Launch: 31 January 1971		Recovery: 7 February 1971
Landing Site: Fra Mauro Highlands		
Total Mission Duration:		217:03 hours
Time on Lunar Surface:		34:11
Time of Lunar EVA's	First:	4:49
	Second:	4:20

Environment of the Apollo 14 Astronauts

Atmosphere

As in all Apollo flights, the Apollo 14 spacecraft was launched with a mixed oxygen-nitrogen (60/40) atmosphere provided at a 5 psi pressure. The purpose of the gaseous mix, of course, is to minimize fire hazard during the launch period and, combined with a three-hour period of denitrogenation prior to launch, to preclude possible dysbaric episodes at the reduced pressure. During the early hours of the mission, a waste management dump valve is left open to establish a fixed leak rate which is balanced by the provision of pure oxygen. The result is a gradual oxygen enrichment during the mission, although a very small percentage of nitrogen may remain through much of the flight.

Toxicological evaluations of the environment in Apollo 14 were conducted through analyses of the charcoal used in the absorption canisters of the carbon dioxide removal system. This procedure gives an approximate value of the average concentration of toxic agents in the spacecraft cabin. Exact values are not obtained since both the absorption efficiency of the charcoal and the extraction efficiency of the removal process are not known for each compound. In general, however, results for the Apollo 14 mission were found to be quite consistent with the data for earlier Apollo flights. The data indicate about 50 to 80 contaminants were present, all in extremely small concentrations of no biological importance. Very low contaminant concentrations were expected since the materials used in the spacecraft interior were selected for low off-gassing properties. The compounds most commonly found were fluorohydrocarbons introduced in the prelaunch cleaning process. Other compounds clearly present were halocarbons, acetone, methylisobutyl ketone, butylacetate, and alcohols.

To determine the nature and extent of particulate matter in the atmosphere, swabs were taken from the eyes and noses of the astronauts. These showed the presence of some fiber glass particles and gave some evidence of lunar dust accretions. Again, the low concentrations caused no concern.

Radiation

Table 2 shows the average radiation dose received by each crew on Apollo missions 7 through 14. It is apparent that the Apollo 14 crew received a higher radiation dose than crews on any prior Apollo mission, but still a dose of no hazard or biological significance. In fact, the crewmembers on this flight received the largest dose experienced on any manned mission to date. This was a result of two factors. First, the Apollo 14 trajectory, particularly the outbound portion, took the spacecraft close to the heart of the trapped radiation belts. Second, since the mission occurred at a time of solar minimum, the cosmic ray flux was much higher than for previous missions.

Table 2

Radiation Exposure for Apollo 14

Comparison of Apollo Missions

	Rad		Rad
Apollo 7	.16	Apollo 11	.18
8	.16	12	.58
9	.20	13	.24
10	.48	14	1.14

Apollo 14 Exposure (Rad)

	Chest	Thigh	Ankle
CDR	.996	1.095	1.073
CMP	1.126	1.145	1.279
LMP	1.078	1.204	1.248

Table 2 also shows the individual recordings of the thermoluminescent dosimeters at three body positions for each Apollo 14 crewmember. Although some variability is noted in these measures, there appears to have been a rather uniform radiation flux within the spacecraft. There also is no indication of a differential dose rate for crewmembers operating on the lunar surface versus the member in lunar orbit.

Visual Phenomena

Each crewman reported seeing the streaks, points, and flashes of light that have been noted by previous Apollo crews. The frequency of the light flashes averaged about once every two minutes for each crewman. The visual phenomena were observed with the eyes both open and closed, and the crew was more aware of the phenomena immediately upon awakening than upon retiring. In a special observation period set aside during the transearth coast phase, the CMP determined that dark adaptation was not a prerequisite for seeing the light phenomena if the level of spacecraft illumination was low. Furthermore, several of the light flashes were apparently seen by two of the crewmen simultaneously. Coincidence of light flashes for two crewmen, if a true coincidence, would substantiate that the flashes originated from an external radiation source and would indicate that they were generated by extremely-high-energy particles, presumably of cosmic origin. Low-energy highly-ionizing particles would not have the range through tissue to have reached both crewmen.

Biomedical Evaluation

Physical Examinations

Physical examinations are performed as part of the total health evaluation of each crewman. The examinations are done to detect and treat, if necessary, any health problems, to recertify the physical qualifications of the crew for the mission, and to detect the effects of space flight on the health of the crewmen. Apollo 14 astronauts Shepard, Roosa, and Mitchell received physical examinations 26, 15, and 6 days preflight, daily medical checks from six days to launch day, and a final examination on the flight day. Nothing remarkable was noted during routine physical examinations, and electrocardiogram recordings and chest X-rays were normal. Each of the men, as is typical during the preflight period, lost weight, averaging five pounds by the day of flight.

Eight postflight physical examinations were made, four on the first day and two on the second day after the mission, and finally at four days and one week postflight. Compared with preflight weight levels, immediately postflight the Command Module Pilot (MP) had lost 12 pounds, the Lunar Module Pilot (LMP) one pound, and the Commander (CDR) had gained one pound. This is the first weight gain recorded after space flight exposure. One week after the flight, the CMP was still four pounds below his preflight weight.

Food Consumption

The foods carried in Apollo 14 and the methods for preparation and service differed little from those of previous flights. The food list included freeze-dried rehydratable, wet-pack, and spoon-bowl foods. Aboard the Command Module, both hot and cold water were available for rehydrating food, with only cold water available for this purpose in the Lunar Module.

Balanced meals for five days were packed in man/day wraps, with similar items for use as desired during the remainder of the mission stored in a snack pantry. Six new foods were included in the menu, packaged in aluminum cans with easy-open, full-span, pull-out lids. The planned menus provided approximately 2100 Kcal for each crewmember.

No difficulties were reported in removing the new pull-out lids or eating the food contained in the cans with a spoon. However, there were substantial differences in the amount of food eaten by crewmembers. Both the CDR and LMP maintained food intake at almost exactly the desired level. The CMP, on the other hand, did not eat as well, as shown in Table 3, and exhibited a considerable loss of weight at the completion of the mission. The failure of the other two crewmembers to show weight loss, however, may be at least in part a function of a particularly deliberate effort on their part to increase fluid consumption during the return portion of the mission.

Table 3

Food Consumption and Weight Change of Apollo 14 Crewmembers

	Flight Day Weight (lbs)	Average Daily Intake (Kcal)	Weight Change (lbs)
Commander	168	2310	+ 1
Lunar Mod. Pilot	176	2330	− 1
Command Mod. Pilot	165	1720	−12

Sleep

The shift of the crew's normal terrestrial sleep cycle during the first four days of flight was the largest experienced so far in the Apollo series. The displacement ranged from seven hours on the first mission day to 11 1/2 hours on the fourth. The crew reported some difficulty sleeping in the zero-g environment, particularly during the first two sleep periods. They attributed the problem principally to a lack of kinesthetic sensations and to muscle soreness in the legs and lower back. Throughout the mission, sleep was intermittent; i.e., never more than two to three hours of deep and continuous sleep.

The LM crewmen had little, if any, sleep between their two EVA periods. The lack of an adequate place to rest the head, discomfort of the pressure suit, and the seven-degree starboard list of the LM caused by the irregularity of the lunar terrain were believed responsible for this insomnia.

The crewmen looked out the window several times during the sleep period and used a hanging upright as a plumbob for reassurance that the LM was not starting to tip over.

Following transearth injection, the crew slept better than they had previously. The LM crewmen required one additional sleep period to make up the sleep deficit that was incurred while on the lunar surface.

The crewmen reported during postflight discussions that they were definitely operating on their physiological reserves because of inadequate sleep. This lack of sleep caused them some concern; however, all tasks were performed satisfactorily.

Weightlessness

Adaptation to the weightless state was readily accomplished. Shortly after orbital insertion, each crewman experienced the typical fullness-of-the-head sensation that has been reported by previous flight crews. No nausea, vomiting, vertigo, or disorientation occurred during the mission, and the crew did not observe the distortion of facial features reported by previous crewmen.

The muscle soreness and lower back discomfort which disrupted initial sleep periods were attributed to postural changes during weightlessness. Inflight exercise did, however, provide relief.

Cardiovascular Response

Cardiovascular indices were within expected ranges throughout and after the mission. The average crew heart rates for work and sleep in the CM and LM are listed in Table 4.

Table 4

Average Heart Rates for Work and Sleep

	CDR	CMP	LMP
Command Module			
Work	57 bpm	66 bpm	62 bpm
Sleep	52	46	50
Lunar Module			
Work	77	– – –	76
Sleep	70	– – –	– – –

The heart rate averages for lunar descent and ascent were the lowest observed on a lunar landing mission. During powered descent, the Commander's heart rate averages ranged from 60 to 107 beats per minute and from 69 to 83 beats during ascent. The Commander's average heart rates during lunar surface activity were 81 and 99 beats per minute for the first and second period, respectively; the LMP's averages were 91 and 95 beats per minute.

Orthostatic Tolerance Tests. Postflight reduction of orthostatic tolerance has so far been the most pronounced and consistent finding in the area of cardiovascular response to space flight. Orthostatic intolerance, to the point of presyncope, was first noted upon capsule egress of the Mercury 8 pilot and has therefore been investigated on subsequent flights. The use of a lower body negative pressure (LBNP) device as a gravity simulation stressor to assess the extent of postflight decrement in orthostatic tolerance has been abandoned during the quarantine missions due to lack of room in the mobile quarantine facility. Instead of LBNP, a 90° static stand is used which was found to produce heart rate responses equivalent to 40 or 50 mm Hg negative pressure when the individual was calibrated against LBNP.

The static stand procedure is simple and requires minimum testing time. After demonstrating stable heart rate and blood pressure in the resting, supine position for five minutes, the subject is assisted to a standing position with minimum delay and movement. The subject remains motionless in the upright position for five minutes while heart rate and blood pressure are again recorded each minute.

Static standing tests were conducted immediately after the recovery phase of the Apollo 14 mission and subsequently at 12, 24, and 36 hours postrecovery. The results of these tests were compared with each crewmember's preflight heart rate and blood pressure levels and with the same measures made on two sets of controls who followed the same protocol as the flightcrew. The control group, in addition to providing comparative physiological data, permitted testing and verification of the measurement equipment. The backup crew and a group of scientists served as control subjects.

Table 5 shows heart rate and blood pressure measures taken pre- and postflight during the supine and standing phases of the static standing test. The figures given represent averages over each of the five-minute test periods. Of the three crewmembers, the CMP exhibited the greatest increase in heart rate over the preflight mean immediately postflight. His heart rate continued to increase during the provocative tests and reached an average of 100 beats per minute 36 hours after the flight. The LMP showed the highest statistically significant increase over the preflight mean at one day postflight, but his heart rate began to normalize at 36 hours. Heart rate data do not, however, correspond with blood pressure records. The CDR, who alone showed no heart rate effects, exhibited a significant increase in diastolic blood pressure during the supine phase of the static standing test at both 12 and 36 hours postflight.

Table 5
Apollo 14 Cardiovascular Summary

	F – 26 5 Jan 71 Sup	F – 26 5 Jan 71 Sta	F – 14 16 Jan 71 Sup	F – 14 16 Jan 71 Sta	F – 2 25 Jan 71 Sup	F – 2 25 Jan 71 Sta	Preflight Mean ± S. D. Sup	Preflight Mean ± S. D. Sta	R + 0 9 Feb 71 Sup	R + 0 9 Feb 71 Sta	R + 12 9 Feb 71 Sup	R + 12 9 Feb 71 Sta	R + 24 10 Feb 71 Sup	R + 24 10 Feb 71 Sta	R + 36 10 Feb 71 Sup	R + 36 10 Feb 71 Sta
Heart Rate																
CDR	60	81	53	67	55	75	56 ±3.6	74 ±7.0	54	69	53	67	58	71	60	75
CMP	58	68	60	69	71	80	63 ±7.0	73 ±6.7	80	↑ 91	↑ 83	↑ 95	79	↑ 104	77	↑ 100
LMP	67	84	65	78	64	75	65 ±1.5	79 ±4.6	63	86	67	86	69	↑↑ 91	↑ 71	89
Systolic Blood Pressure																
CDR	102	95	101	105	101	109	101 ±0.6	103 ±7.2	100	98	↑ 108	116	↑ 108	116	↑ 111	115
CMP	102	107	124	127	133	140	120 ±16.0	126 ±16.6	123	129	116	98	118	118	112	115
LMP	107	103	109	112	116	107	111 ±4.7	106 ±4.5	113	104	119	107	112	95	117	111
Diastolic Blood Pressure																
CDR	56	65	54	62	69	90	60 ±8.1	70 ±15.3	68	75	71	81	70	70	66	67
CMP	66	79	69	78	80	100	72 ±7.4	86 ±12.4	89	93	77	75	73	88	68	80
LMP	56	51	56	64	69	71	60 ±7.5	62 ±10.1	76	74	72	73	55	66	56	52

NOTE: Directional arrows denote statistically significant postflight values; One = $p<0.05$, Two = $p<0.01$. Figures represent averages over 5-minute testing intervals.

Figure 1 permits a closer look at the heart rate data for the CMP recorded immediately postflight. The graph shows his heart rate during resting and passive standing and also presents a preflight record for purposes of comparison. In the first minute of the passive standing test immediately after recovery, the CMP's heart rate reached 115 beats per minute and he became presyncopal. Prior to the test, he also had a presyncopal reaction on assuming the upright position after resting in bed. The CMP completed the test in the seated position. On subsequent tests, the presyncopal reaction did not recur but heart rates were still significantly elevated above preflight levels.

Hematological Effects

In Apollo 9 and Apollo 14, a moderate postflight decrease in red blood cell mass has been observed. Immediately postflight in the Apollo 14 crew, RBC mass losses were 1.7, 9.1, and 4.0 percent for the CDR, CMP, and the LMP, respectively, compared with preflight levels. When RBC mass was corrected for body weight, these losses averaged only 0.4 percent. When compared with controls, however, this loss is statistically significant.

The reason for the slight loss of red blood cell mass is not definitely known. The possibility of some slight oxygen effect cannot be altogether dismissed. Although the launch atmosphere was 60 percent oxygen and 40 percent nitrogen, repressurization with 100 percent oxygen substantially reduced, if it did not altogether eliminate, the nitrogen from the environment of the CM. On the lunar surface, the gaseous environment was essentially pure oxygen. The prophylaxis that nitrogen diluent gas appeared to provide in earlier missions (Apollo 7 and 8) could not reasonably be expected in a mission with the extensive extravehicular activity of Apollo 14. Table 6 shows red blood cell mass data for the Apollo 14 crew and controls.

Table 6

Red Blood Cell Mass Data
for Apollo 14 Astronauts and Controls

	CDR	CMP	LMP	Controls	
F – 15*	2054 ml	2135	2542	1711	2300
ASAP**	2019	1940	2440	1786	2220
% Change	–1.7	–9.1	–4.0	+4.4	–3.5

*15 days preflight.
**As soon as possible postflight.

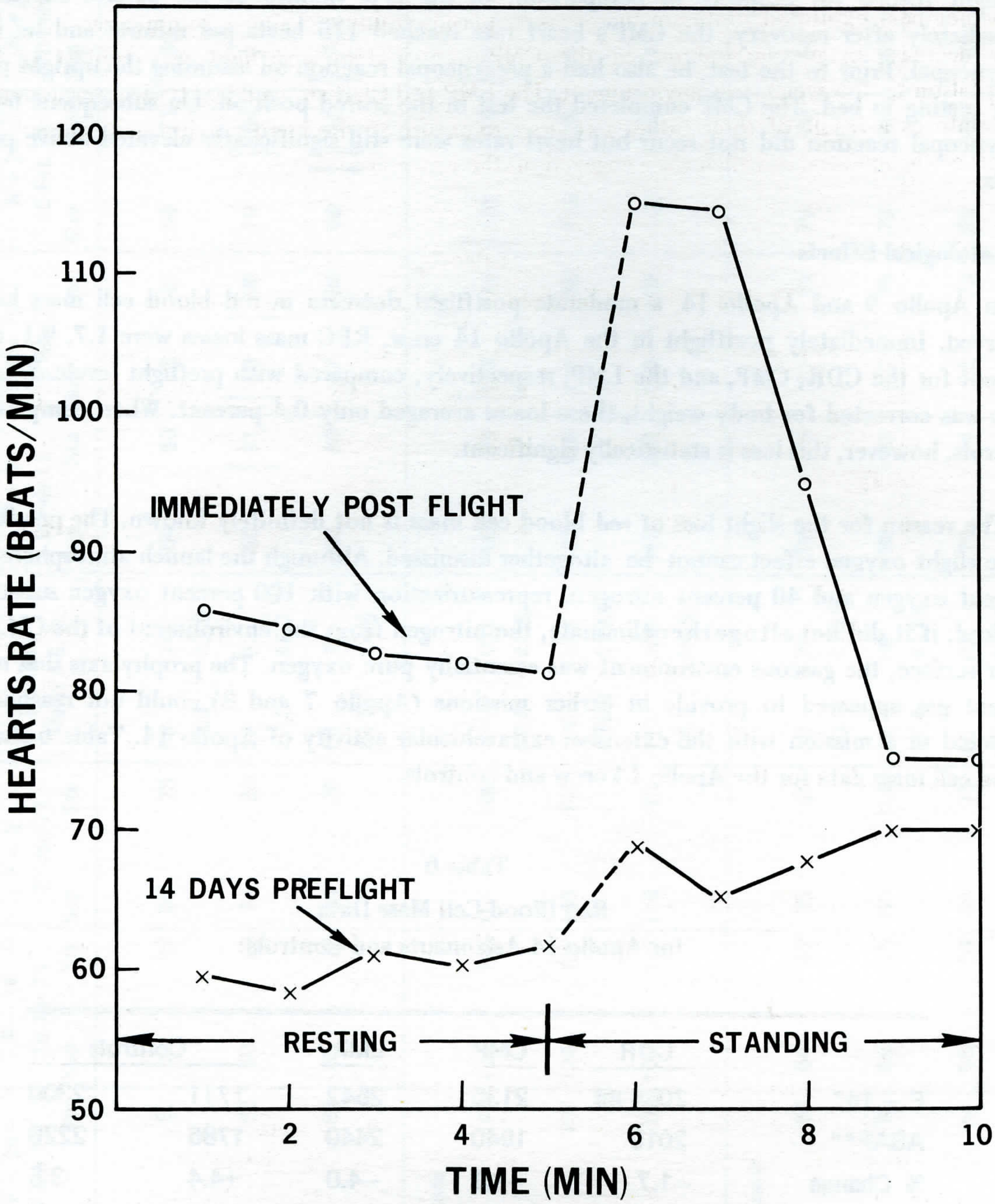

Figure 1. Heart Rate Data of Apollo 14 Command Module Pilot in Static Stand Test

Plasma volume determinations made immediately postflight indicate that only one crewmember, the CMP, had a significant plasma volume decrease. By the end of the first day postflight, all three crewmembers exhibited dramatic increases in plasma volume. Table 7 summarizes these findings. The decrease in plasma volume in the CMP immediately postflight was typical of classical adaptation to the weightless environment. The LMP and CDR showed less typical responses, almost certainly as a result of their rather extensive exposure to the lunar gravity environment and as a result of the exercise in which they engaged on the lunar surface.

Table 7

Plasma Volume Changes for Apollo 14 Crew and Controls

	CDR	CMP	LMP	Controls	
F – 15*	3369 ml	2912	3526	2723	3172
ASAP**	3410	2629	3530	2888	3366
R + 1†	3932	3077	3720	3092	3344
% Change					
ASAP	+1.2	–9.7	+0.1	+6.0	+6.1
R + 1	+16.7	+5.7	+5.5	+13.6	+5.4

*15 days preflight.
**As soon as possible postflight.
† < 24 hour postflight.

Body Fluid Loss and Fluid Shifts

Recent analysis of earlier space flight data indicates that consistently observed weight losses are nearly recovered at about the same time that cardiovascular measurements show a return toward preflight baselines or "normal" for that crewman. The rapidity of the weight gain indicates a positive water balance during the initial hours of recovery. Whether the weight decrease is a function of a total body water deficit alone or is in part due to a loss in tissue is unclear. Since the mean weight loss of the crews is several times larger than the decrease in plasma volume, this could represent loss of extracellular water, loss of intracellular water, or loss of tissue mass. There are hints in the data which point to the latter two. These include (1) negative potassium balance in the Gemini 7 crew; (2) an increase in tubular reabsorption of potassium immediately postflight in Apollo crews at a time when increased epinephrine, renin, and aldosterone levels should produce a potassium diuresis; and (3) a postmission total body potassium deficit (based on serum potassium values). Each of these changes would be expected to accompany a loss of intracellular fluid since there is a proportionality between body potassium and nitrogen on the one hand and intracellular water on the other.

The Apollo 14 mission provided an additional opportunity to investigate more closely the fluid loss and fluid shift phenomena. Fifteen days prior to liftoff, the following measures were made for the crew and three ground controls: total body water, extracellular fluid, intracellular fluid, plasma volumes, and RBC mass. Table 8 presents these data, including the measurement method used for each, and compares them with measures taken immediately postflight and approximately one day postflight. The data depict the status of body fluid redistribution as a function of the adaptive process. It should be noted that extracellular fluid is essentially unchanged whereas the plasma volume increased to greater than preflight values in the face of a decreasing red blood cell mass. If total circulating blood volume is normal or increased over preflight levels, and if extracellular fluid is unchanged, then total body water deficit must be attributed to a decrease in the intracellular fluid volume.

Table 8

Percent Change in Body Fluid Volume
(Preflight versus Immediately Postflight)

	Measurement Technique	CDR	CMP	LMP	Controls		
RBC	Cr^{51}	–1.7	– 9.1	–4.0	+4.4	–3.5	+ 0.3
Plasma Volume	I^{125}alb.	+1.2	– 9.7	+0.1	+6.0	+6.1	+10.7
Extracellular Fluid	SO_4	–0.5	0.0	–0.5	+4.2	–2.8	+ 3.3
Total Body Water	H^3_2O	–1.9	–17.7	–1.8	+1.6	–2.1	+ 3.0
Intracellular Fluid	(TBW – ECF)	–2.7	–27.0	–2.6	0.0	–1.6	+ 2.9

The data points are admittedly scant and it is therefore not yet possible to say whether the weight loss invariably found after weightlessness can be totally accounted for by water loss. However, these results support the hypothesis that the weight deficit includes tissue loss as well as water loss. If there is tissue loss, the low ratio of water loss to weight loss for the CMP and LMP indicate that the tissue either contained very little water or weight loss was partially compensated for by water retention. The high ratio in the CMP, on the other hand, definitely indicates significant loss of intracellular fluid. These postulates are supported by the data in Table 8. Attempts will be made in subsequent missions to evaluate the precise extent of tissue loss.

Endocrine/Electrolyte Balance

Man adapts to zero gravity, this is clear, but he does so at some physiological cost. Readaptation to one gravity has also been completely successful, but again not without cost. This cost does not so far appear to be excessive, but it is measurable. Endocrine studies therefore were made during the Apollo mission program to clarify the mechanisms of the decompensated adaptation response to zero gravity and the responses associated with readaptation to the one-gravity environment. The endocrine status of the crew postflight can be compared with preflight levels to provide a valuable clue both to the mechanisms underlying the fluid balance responses which have been consistently observed and to the levels of stress experienced during flight. At this time, data are too limited to reveal trends because of the limited number of individuals involved. Moreover, individuals who have participated in space missions have shown a very high degree of individual variability.

In the Apollo 14 crew, the CMP and the LMP exhibited endocrine responses more "typical" of space flight exposure than did the CDR. They have shown characteristic postflight elevations of such hormones as aldosterone and antidiuretic hormone, indicative of an attempt to regain fluid lost during the adaptation to weightlessness. The CDR's responses were qualitatively similar but the magnitude of response was far smaller. The reason for the difference is not known.

Significant increases were observed in renin activity postflight. Since renin stimulates the adrenal gland to produce aldosterone upon sensing a decrease in blood volume or a decrease in salt concentration in the kidney, these findings are consistent with the picture of a total body attempt to regain lost fluid.

On the Apollo 14 mission, parathormone levels were measured for the first time in an effort to clarify the mechanism of suspected calcium loss from the bones observed in previous flights. No changes in parathormone levels were noted. Neither, however, were bone mass losses found for the crew on this mission. These measures will be repeated in future flights and supplemented with a determination of calcitonin levels in hope of clarifying the mechanism of calcium depletion.

Work Capacity

Using oxygen consumption as an index of energy expenditure, Blomquist, Mitchell and Saltin (1969) demonstrated in a 20-day bed rest study that healthy subjects experience a decrease in physical work capacity under these conditions. A reduction in mean maximal oxygen uptake ranging from 20 to 46 percent was found. The relative magnitude of the decrease was the same for previously-trained versus previously-sedentary subjects. Recovery for sedentary subjects, however, was more rapid, with previously-active subjects taking as long as 43 days to reach their control value.

Work capacity evaluations have been performed for Gemini and Apollo crewmen using oxygen uptake per kilogram of body weight and systolic blood pressure as indices. These have consistently revealed reduced physical competence, similar to that observed in bed rest subjects, for set levels of heart rate.

Postflight quarantine requirements precluded obtaining work capacity data for the Apollo 12 and 13 crews but, with the elimination of this requirement, the evaluations were reintroduced. The test, administered within four hours after recovery, involves the use of graded levels of physical work provided by means of a bicycle ergometer. Heart rate is used as the independent variable while oxygen consumption and blood pressure recordings are made at various workload levels.

Oxygen consumption, the most reliable indication of change in cardiopulmonary response to exercise, was significantly decreased for the CMP, as was systolic blood pressure when compared with preflight levels. The CDR showed no decrease in either measure. The LMP exhibited decrease in both oxygen consumption and blood pressure, but these changes were much smaller than those experienced by the CMP. Table 9 summarizes these findings.

Table 9

Work Capacity Indicators for Apollo 14 Crew

		O_2 Consumption/ 160 H. R.	Systolic Blood Pressure/160 H. R.
CDR			
	Preflight	2.40 l/min.	233 mm Hg
	R + 0	2.48	238
LMP			
	Preflight	3.05	225
	R + 0	2.86	207
CMP			
	Preflight	2.40	216
	R + 0	1.81 ↓	156 ↓

↓ = statistically significant decrease.

In an attempt to elucidate further the physiological mechanisms underlying this response, a third measure, cardiac output, was added with the Apollo 14 mission. Since cardiac output is related to the two variables which have shown consistent changes postflight, oxygen consumption and blood pressure, it was the next logical factor to be investigated. Cardiac output assessment was made in an attempt to determine whether a decrease in peripheral resistance plays a part in the observed work capacity decrement.

Cardiac output is now being measured by means of an indirect spectrometric technique which determines the instantaneous respiratory exchange ratio. This ratio is then used to estimate arterio-venous pCO_2 levels. Carbon dioxide production is measured directly. From these data, cardiac output can be estimated. An increase in cardiac output accompanied by a decrease in systolic blood pressure at a fixed heart rate would indicate decreased peripheral resistance. Preliminary data indicate that changes in these cardiovascular relationships occurred. Measures made on future flights will help to verify or reject the validity of the observed changes.

Vestibular Function

In the early days of our space program, it was feared that exposure to weightlessness might produce significant functional disruption of the body's principal balance mechanism, the vestibular system. Fortunately, these early fears were not borne out. There have been no episodes of debilitating disorientation or impairment of vestibular function. There have been, however, a number of instances in which crewmembers have developed symptoms of motion sickness, on rare occasions of some severity. Although Apollo 14 crewmembers did experience the typical fullness-of-the-head sensation (related to redistribution of blood volume) that has been reported by previous flight crews, they reported no motion sickness, vertigo, or disorientation during the flight.

One feature of the Apollo 14 flight was especially noteworthy for those interested in the functioning of the vestibular apparatus under space conditions. One crewmember had been afflicted by Meniere's disease some years earlier. The symptoms were severe, including serious vertigo episodes, a partial hearing loss, and tinnitus. As a result, the individual was grounded from astronaut flight status. Twenty-nine months before the Apollo 14 flight, the condition was alleviated through surgery involving the implacement of an endolymphatic shunt allowing the endolymph to drain into the cerebrospinal fluid. The operation was completely successful, with the crewmember becoming totally asymptomatic. Prior to the lunar flight, the individual was tested through clinical observation, a large number of centrifuge runs and altitude chamber tests, and many zero gravity parabolic aircraft flights. Results under all evaluation procedures were termed excellent.

During the lunar flight, the crewmember experienced no symptoms indicating vestibular dysfunction. Pre- and postflight audiograms and vestibular tests showed no change. The success of this flight, representing the first time an astronaut had flown with a history of prior vestibular problems, was considered an excellent verification of the preflight medical evaluation program.

Microbiological Studies

Earlier Apollo mission data have suggested that the space flight environment might enhance the growth rate and mutation of microorganisms. Apollo 7 through 11 data indicate the growth of opportunistic organisms might be favored (Berry, 1970). Accordingly, an extensive and carefully controlled investigation was conducted for the Apollo 14 mission designed to identify and stabilize crew microbial loads preflight and to isolate any organisms of significance postflight.

Specimens obtained immediately postflight from crew clothing, the CM sample areas, and the crew themselves revealed no organisms of possible medical importance and indicated microbial loads very similar to those found preflight. Neither was there evidence of any viral replication in any host system innoculated with postflight specimens.

Immuno-Hematological/Biochemical Evaluations

Biochemical and immuno-hematological analyses on the Apollo 14 crewmen's body fluids were performed to determine the time course, extent, and etiology of any changes in these fluids as a result of exposure to space flight and lunar excursion.

A slight increase in white cell count was noted for the CMP. This was probably due to the catecholamine released during recovery. Significant increases in haptoglobulins and a-2 macroglobulins in all three crewmen were noted. Similar increases were observed on previous missions and were probably related to stress since haptoglobulin and a-2 macroglobulins are acute phase proteins.

Bone Mineral Measurements

Gravity and countergravitational muscular effort are thought to be important for the maintenance of normal skeletal and muscle volume. In zero or reduced gravity conditions, elimination or reduction of mechanical forces such as those produced by weight bearing and muscle tension can result in loss of calcium, nitrogen, and other related elements from muscles and bones. A one to two percent per month figure has been predicted as reasonable for the rate of bone loss for persons in the weightless state (Hattner & McMillan, 1968). It is possible, on the other hand, that stabilization could occur at some point in time. Calcium balance does, for example, appear to normalize after some years in paralyzed patients (Heaney, 1962). Mineral balance data collected from both American and Russian space missions prior to Apollo 14 have shown a negative balance trend indicative of calcium loss from the bones. Bone densitometric and biochemical studies have confirmed these findings.

Bone mineral content measurements made for the Apollo 14 crew have, however, not confirmed earlier findings. Pre- and postflight examination of the left central os calcis and the right distal radius and ulna by means of a monoenergetic photon absorption technique (I^{125}) revealed no significant mineral losses during the 10-day mission. The reason for the divergence of these results from earlier findings is unclear.

Conclusions

The Apollo 14 flight represents in many respects a new page in the biomedical support of our manned space program. Prior to this, the focus of attention was on issues directly related to the safety of the astronaut. The development of life support items and the prevention and treatment of inflight disease were matters of greatest concern. Efforts also were made to examine certain specific effects of space flight, for example, changes in bone density, which the practice of medicine under normal conditions on earth indicated might undergo change in the environment of space. Now, although crew safety is no less important, success in dealing with these matters allows attention to be turned toward the more broad issues of describing man-in-space. What is the nature of the process whereby man adapts to the space environment? What are the requirements for an effective biomedical support program for the longer missions of the future? The Apollo 14 results are beginning to supply us with some of the answers.

There are three features of the Apollo 14 biomedical program which are worth noting and which represent, to some degree, a departure from the procedures and philosophies of earlier missions. These are:

Measurement of Specific Response Effects. The medical assessment of astronauts on return was improved through application of new measurement procedures never used before in our space program. For example, measures were obtained of total body water and extracellular fluid, both pre- and postflight. This information is of great importance in evaluating the significance of the weight loss seen in virtually all astronauts. The fact that weight is regained in a matter of hours or days causes one to presume that the loss is largely due to dehydration. Now, with the new measurement procedures, it is possible to determine with increasing precision the nature of the shift of body fluids during flight and the specific mechanisms within the body which cause these shifts. This information, of course, is most important in developing long-term diets as well as in developing any drug therapy program which might be warranted.

Improvement of Medical Evaluation Procedures. The understanding gained in Mercury, Gemini, and earlier Apollo flights of the response of man to the stresses of space now can be used in developing more rational and less rigid policies for the determination of fitness-to-fly. In Mercury and Gemini days, for example, medical personnel would not have considered allowing an individual with a history of a serious vestibular problem to fly. Now, however, we have sufficient confidence in our ground-based evaluation techniques that decisions can be based more on current evaluation results and less on the medical history of earlier events. Simulation techniques such as centrifuge runs, zero gravity flight parabolas in aircraft, water immersion tasks, use of the lunar landing trainer, and full mission simulation provide information which, when combined with appropriate medical testing, allows more rational and meaningful decisions to be made concerning the biomedical and psychological fitness of an individual. In short, the practice of space medicine is entering a period of increasing maturity.

Development of a Conceptual Analog of the Adaptation Process. Sufficient information now is becoming available, much of it from the Apollo 14 mission, that a realistic attempt can be made to develop a conceptual model illustrating the manner in which an astronaut adapts to the weightless environment of space. In general, a model of this kind will provide a structure within which the myriad of test results now on hand can be placed into useful perspective. Specifically, there are several ways in which the model will be of value. First, the development of such a model means that specific features of the adaptation process then can be tested for validity, both in ground simulation and in later flights. An inflight measurement program will feed directly into updating the model. Second, the model should provide insights into possible interactive effects normally not considered in single point testing. Specific tests then can be developed to examine these interactions. Third, the model, when perfected, will allow meaningful predictions to be made of the effects of much longer flights than now planned and for which ground testing will be inadequate.

Table 10 is a greatly simplified illustration of the conceptual model now being developed (Leach, Alexander, & Fischer, 1970) and deals principally with the loop of the model describing fluid shifts within the body. Upon initial entry into weightlessness, there is a total redistribution of the circulating blood volume. The increase in right atrial filling is interpreted by the body as a need to reduce total fluid volume which it does by increased urination. This event is governed by a decrease in antidiuretic hormone and a decrease in aldosterone production. This causes a loss of water, sodium, and potassium through the kidneys with a resulting decrease in total body weight. The response of the body is a decrease in plasma volume and a reversal of the previous aldosterone and ADH decrease. The body has now entered a phase of electrolyte and fluid imbalance. Sodium levels are increasing while potassium levels continue to decrease. Intracellular fluids become acidotic while extracellular fluids become alkalotic.

It is hypothesized that the response of the body to the new fluid and electrolyte balance is an intracellular exchange of potassium and hydrogen ions. Associated with the potassium deficit is a decrease in bone density and muscle mass. Loss of muscle mass might possibly extend to the heart muscle.

In the final phase of this adaptation loop, the hyperacidity of the cell stimulates the respiratory system to decrease plasma carbon dioxide by increasing the rate of ventilation. Renal compensation commences as the renal tubules begin to reabsorb potassium. The loss of body weight now ceases. This part of the body's overall adaptation process now becomes complete. The body stabilizes with a new load on the cardiovascular system and a new fluid and electrolyte balance, negative to that existing previously. It is reasonable to presume that the new stabilized condition is appropriate for long-term existence under weightlessness. The extent to which it is appropriate for work activities on planetary surfaces or for sudden and vigorous return to the unit gravity of earth are questions remaining to be answered.

Space flight measures taken to date do not indicate whether the adaptation process hypothesized above is completed by the time of return to earth. Much of the data indicate that some such process does take place, however. The hypothesis is consistent with the cardiovascular deconditioning seen in all flights, with changes in bone density and muscle mass, with alterations in body fluid volumes, with decreased work capacity, and with what appear to be negative potassium balance trends.

Table 10

Overview of Current Hypothesis Concerning
Processes Involved in Man's Adaptation to Zero Gravity

Event	Response of Body
Entry into zero gravity. Redistribution of circulating blood volume.	Body attempts to reduce volume. ADH decreases, aldosterone production decreases.
Loss of water, sodium, potassium (loss of body weight).	Decrease in plasma volume. Aldosterone produced.
Increased sodium. Potassium loss continues. Cell: acidotic; extracellular fluid: alkalotic.	Intracellular exchange of potassium and hydrogen ions. Decrease in bone density and muscle mass, possibly including cardiac muscle.
Respiratory and renal compensation. Halt to weight loss trend.	Stabilizes with new cardiovascular load. New body fluid and electrolyte balance.

One-Sixth Gravity Therapy

In the Apollo 14 flight, one crewmember spent a total of 217 hours in weightlessness. For the other two crewmen, the weightless exposure was interrupted by a period of 34 hours in a one-sixth gravity environment, of which over nine hours was spent in moderate to strenuous work activity. It is of interest, therefore, to compare the postflight medical data for the single crewmember who remained in lunar orbit with those of the other two. In general, as shown in Table 11, it was found that the CMP, who did not experience one-sixth G, was in somewhat worse condition than the other two. His weight loss was significant; his reduced orthostatic tolerance was more severe, including a presyncopal episode; his red cell mass decrease was greater; his work capacity was lower; and he showed a greater decrease in all body fluid volumes.

Interpretation of the results shown in Table 11 is not straightforward. They must, for example, be viewed in the light of such variables as increased fluid intake for the CDR and LMP during the return voyage and lunar surface exercise loads for the same two crewmen. Even with these reservations, however, there is certainly a suggestion of a positive therapeutic effect from the application of a one-sixth gravity force at an intermediate point in exposure to weightlessness. Results of later flights, with an increased period of lunar exploration, will be examined carefully in an attempt to assess the therapeutic role of partial gravity.

Table 11

Comparison of Pre- and Postflight Data
for Crewmembers under Continuous Zero Gravity
with Crewmembers Experiencing 1/6th Gravity

Medical Effect	Zero G CMP	1/6th G CDR	1/6th G LMP
Weight Loss	−12 lb	+1 lb	−1 lb
Heart Rate (Reduced orthostatic tolerance)	Significant Increase	Minimum Change	Minimum Change
Red Blood Cell Mass	− 9%	−4%	−2%
Plasma Volume	−10%	+1%	No Change
Total Body Water	−18%	−2%	−2%
Intracellular Fluid	−27%	−3%	−3%
Work Capacity (O_2 consumption; systolic blood pressure)	Significant Decrease	No Change	Slight Decrease

Implications for Longer Duration Space Flights

Space flights to date demonstrate that man can live and work productively in the space environment for periods of at least several weeks. Further, there is no reason at this time to believe that he cannot also travel on missions of much greater length. There remain, however, a number of issues to be resolved before flights of several months or years should be undertaken.

Various facets of the process of adaptation to weightlessness have been defined. More information is now needed concerning the nature of the process itself. It is particularly important that we know the time period in which any self-limiting adaptation effects occur and the extent of change when the process is complete. It is also imperative that information be gotten concerning the nature of the mechanisms which control the adaptation process. Such information is needed for the development of any therapeutic techniques which may later be required. Results from the Skylab program, with the opportunity it affords to conduct biomedical experiments, should provide more information concerning the nature of this adaptation.

The differences found in Apollo 14 results for the CMP versus the other two crewmembers suggest certain benefits for 34 hours at one-sixth gravity and for lunar surface exercise. These findings indicate that the extent of the adaptation of astronauts to weightlessness, and any resulting change in subsequent ability to enter and work in new force environments, can be controlled to some degree. An effective preventive medicine program for long-duration space missions may require the application of appropriate control measures. Investigations should be undertaken to develop optimum control techniques for possible future use.

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