CHAPTER 6
NUTRITIONAL STUDIES

by

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Introduction

The importance of nutrition in the adaptation of man to weightlessness was recognized long before the first Apollo flight. Nutrition remained a primary concern despite the fact that early projections of difficulties in swallowing, defecating, and urinating in weightlessness had proved unfounded. By the conclusion of the Gemini Program, space life scientists had noted several subtle changes with possible nutritional etiology.

Changes in musculoskeletal function appeared to be significant among these findings (Rambaut et al., 1973; Vogel et al., 1974). Prior to the first manned space flight, it had been suspected that the musculoskeletal system would be particularly susceptible to prolonged withdrawal of gravitational stress. Astronauts were subjected to a nullified gravitational field while they were confined in a vehicle in which mobility and physical activity were restricted. These conditions singly, or in combination, were expected to cause deterioration of bones and muscles.

The control studies by Deitrick, Whedon, and Shorr (1948) of the immobilization of four young, healthy men for as long as seven weeks clearly demonstrated that immobilization in body casts led to marked increases in urinary calcium. These levels more than doubled in five weeks and were accompanied by negative calcium balances as well as by related changes in nitrogen and phosphorus metabolism. In addition, a decrease in the mass and strength of the muscles of the lower extremities occurred, and deterioration in circulatory reflexes to gravity resulted within one week.

Other studies with immobilized subjects indicated that the clinical disorders most likely to be encountered during prolonged space flight are primarily a consequence of an imbalance between bone formation and resorption. As a result of these conditions, there is a loss of skeletal mass, which could eventually lead to hypercalcemia, hypercalciuria, osteoporosis, and possibly nephrolithiasis (Issekutz et al., 1966).

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Since the most meticulous work has disclosed that the greatest loss of calcium during bed rest is a result of increased urinary excretion, studies in which only urine calcium was measured are pertinent. The total evidence indicates that a one to two percent per month loss of body calcium is a reasonable prediction for persons in a weightless environment (Hattner & McMillan, 1968).

With the advent of space flight, additional studies have been performed on the effects of simulated weightlessness on skeletal metabolism. Graybiel and co-workers (1961) found there was no increase in urinary calcium excretion after one week of almost continuous water immersion. Negative balances of small magnitude and changes in bone density of the calcaneus during bed rest are indicated by Vogt and co-workers (1965).

The role of simulated altitude in modifying the metabolic effect of bed rest has been investigated (Lynch et al., 1967). In a study of 22 healthy men, four weeks of bed rest at ground-level atmospheric pressure conditions resulted in expected increases in urinary and fecal calcium and in urinary nitrogen, phosphorus, sodium, and chloride. In similar metabolic studies performed with another 22 subjects at bed rest at simulated altitudes of 3000 and 3700 meters, urinary calcium losses were significantly less as the altitude increased (Lynch et al., 1967). Urinary losses of phosphorus, nitrogen, sodium, and chloride were less at a simulated altitude of 3700 meters than they were during bed rest studies at ground level. Results of these studies indicate that diminished atmospheric pressure, or perhaps a decreased partial pressure of oxygen or a change in pH, may have a preventive effect on mineral loss from the skeleton. Limited data available from inflight studies tend to support the use of immobilization as a terrestrial model to simulate alterations in calcium metabolism during space flight. During the 14-day Gemini 7 flight, loss of calcium occurred in one of the two astronauts, and the changes in phosphorus and nitrogen balance also indicated a loss of muscle mass (Lutwak et al., 1969; Reid et al., 1968).

As evidenced from bed rest studies lasting from 30 to 36 weeks, mineral losses are likely to continue unabated during prolonged space flight. In balance studies (Vogel & Friedman, 1970; Donaldson et al., 1970), calcium losses from the skeleton during bed rest averaged 0.5 percent of the total body calcium per month. In the same subjects, tenfold greater rates of localized loss from the central portion of the calcaneus were detected by gamma-ray-transmission scanning.

Inflight weight losses were experienced throughout Project Mercury, Gemini, and the Apollo missions. Such weight losses were attributed, in part, to losses in body water. Since weight was not regained completely in the 24-hour period immediately postflight, it was probable that tissue had also been lost. What part of these losses was brought about by insufficient caloric intakes was unknown.

Speculation on the theoretical energy requirements of man during space flight began before the United States Project Mercury and the Soviet Vostok flights. At one time, it had seemed logical to assume that activity in a weightless environment would require less energy than at one g because work associated with counteracting the force of gravity would be eliminated. However, caloric requirements are affected by numerous variables including age, physical and mental activity, stress, body size and composition, together with relative humidity, radiation, pressure, and environmental temperature. During the

Apollo missions, therefore, the question of inflight caloric requirements was explored in much greater depth.

Metabolic changes in addition to those associated with an inadequate intake of energy were also elucidated during the Gemini Program. The possibility remained that space flight conditions would exert exaggerated demands on the micronutrients and would thus lead to some marginal deficiency state. It is believed that Soviet nutritionists provided their crewmen with elevated quantities of water-soluble vitamins, and that they had observed increased destruction of the B vitamins under conditions of prolonged low frequency vibration of test subjects. These observations were not confirmed during the Gemini Program. However, because alterations were seen in red cell mass and plasma volume, the vitamin E content of the diet in the presence of the hyperoxic Gemini spacecraft atmosphere was questioned (Fischer et al., 1969).

The development of future space food systems necessitated an accurate knowledge of inflight human nutrition requirements. Food systems having minimum weight and minimum volume are required for space flight (Heidelbaugh et al., 1973). For this reason, the Apollo foods were generally dehydrated and formulated to occupy little volume. The nutritional consequence of these measures was a matter of continuing interest in the Apollo Program.

Approach

Food Analysis

With very few exceptions, all foods used during the Apollo Program were analyzed for nitrogen, fat, carbohydrate, crude fiber, calcium, phosphorus, iron, sodium, potassium, and magnesium content. Some composite Apollo menus were analyzed for water- and fat-soluble vitamins. It was not always feasible to analyze the same lot of food that was actually used during the mission, and the variation in analytical values from one lot to another and from one item to another must be considered when the intake data are reviewed.

Dietetics

The menus used by the Apollo astronauts were formulated from flight-qualified Apollo foods in combinations that complied with the personal preferences of the crewmen and that met the Recommended Daily Dietary Allowances (NAS, NRC, 1968). The menus were primarily composed of dehydrated foods that could be reconstituted before eating. The foods were consumed in a prearranged sequence but could be supplemented by a variety of additional items that were packaged in an individually accessible form.

Nutrient Intake Measurements

The quantity of individual nutrients consumed during all Apollo missions is presented in table 1 as a composite estimate derived from numerous measurements. The crewmen were provided with prepackaged meals that were normally consumed in a numbered sequence. Foods omitted or incompletely consumed were logged. During the Apollo 16 and 17 missions only, these deviations from programmed menus were reported to flight controllers in real time. Snack items consumed that were not in the programmed prepackaged menus were also recorded in the flight logs. On all Apollo flights, most food residue and unopened food packages were returned; the residue was weighed only to provide more precise information on inflight food consumption and to verify inflight logging procedures. For the Apollo 16 and 17 missions, nutrient intake information was obtained for 72 hours before flight and for approximately 48 hours after flight.

Table 1

Average Nutrient Intake During Apollo Missions

Mission Number	Mission Duration, Days	Nutrient, gm			
		Protein	Fat	Carbohydrate	Fiber
7	10	84	69	269	–
8	6	64	40	229	–
9	10	77	53	257	–
10	8	51	31	211	–
11	10	81	64	279	–
12	10	64	47	264	3.9
13	7	58	49	234	–
14	8	83	75	286	–
15	11	112	99	370	7.8
16	11	73	61	272	4.9
17	12	91	86	285	4.8
Average, all Apollo missions		76	61	269	5.4

For the Apollo 17 mission, a five-day metabolic balance study was performed approximately two months before the mission by using the flight menus and collecting urine and fecal wastes. Low residue diets were generally used commencing three days before each Apollo flight in order to reduce fecal mass and frequency during the first few days of flight.

Fecal Measurements

Fecal samples were returned from all Apollo flights and analyzed for a variety of constituents either by nuclear activation analysis or by wet chemistry techniques.

Metabolic Balance

Analysis of blood obtained postflight on early Apollo missions, together with certain endocrinological and electrocardiographic changes in Apollo 15, made it desirable to measure urine volume and bring back samples of urine on Apollo 16. During this mission, it was also possible to continue to return fecal samples and to continue to measure nutrient intake. Sufficient data were therefore available to conduct a partial metabolic study.

For a more detailed metabolic balance study in conjunction with Apollo 17, accurate measurements of fluid intake and output were performed approximately two months before the mission. A five-day food compatibility/metabolic study was performed in which the three Apollo 17 prime and backup crewmembers consumed their flight foods, and metabolic collections were performed. The study was designed to obtain baseline data on the excretory levels of electrolytes and nitrogen in response to the Apollo 17 flight menus. The crewmembers consumed the flight menu foods for five complete days. During the last three days of this test, complete urine and fecal collections were made.

Beginning 64 hours before Apollo 17 lift-off and continuing throughout the mission until 44 hours following recovery, all food and fluid intake was measured. For the Lunar Module Pilot, these collections continued until suit donning; for the Commander and the Command Module Pilot, collection continued until approximately 12 hours before lift-off. All urine was collected, measured, sampled, and returned for analysis. Urine was collected before and after flight in 12-hour pools. Complete stool collections were performed.

All deviations from programmed food intake were logged and reported. All foods were consumed according to preset menus arranged in four-day cycles. Every food item used during the flight was derived from a lot of food that had been analyzed for the constituents to be measured. Inflight water consumption was measured by use of the Skylab beverage dispenser. During the preflight and postflight periods, conventional meals were prepared in duplicate for each astronaut. One duplicate of each meal was analyzed in addition to the residue from the other duplicates to measure intake and output.

Apollo 17 inflight urine samples were collected by means of a biomedical urine sampling system (BUSS). Each BUSS consisted of a large pooling bag, which could accommodate as much as four liters of urine collected during a day, and a sampling bag, which could accommodate as much as 120 cc. The BUSS was charged with 30 mg of lithium chloride. The lithium chloride concentration in the sample bag was used as a means of determining total urine volume. Each BUSS also contained boric acid to effect stabilization of certain organic constituents.

The inflight urine collection periods began with suit doffing at approximately 00:07:00 ground elapsed time (GET). The collection periods were the times between scheduled effluent dumps and were approximately 24 hours each. During undocked flight of the Command Module, urine was collected only from the Command Module Pilot. During periods in which the crewmen were suited, urine was collected in the urine collection and transfer assembly and subsequently dumped overboard without sampling. However, urine collected in the Commander and Command Module Pilot assemblies during the Command Module extravehicular activities (255:00:00 to 260:00:00 GET) was also returned. For the Apollo 17 mission, the periods during which urine was not collected are as follows:

1. Commander and Command Module Pilot – lift-off to suit doffing (00:00:00 to 00:07:00 GET)
2. Command Module Pilot – Lunar Module activation and lunar descent (108:00:00 to 114:30:00 GET)
3. Command Module Pilot – rendezvous (187:00:00 to 195:00:00 GET)

4. Commander and Lunar Module Pilot – Lunar Module activation, lunar descent, lunar surface operations and rendezvous (107:00:00 to 208:00:00 GET)

Urine collected from the Commander and the Command Module Pilot from rendezvous to the beginning of the first collection period after rendezvous (approximately 197:00:00 to 208:00:00 GET) was also dumped directly overboard.

Each BUSS was marked with the name of the crewmember and the ground elapsed time of collection. Following each collection period, the urine pool was thoroughly mixed before a sample was taken. The urine samples represented a 24-hour void and were subsequently analyzed for electrolytes, nitrogen, and creatine.

All fecal samples collected from each crewmember for the following periods were returned: beginning 64 hours before lift-off, during the mission, and for 44 hours after the flight. Inflight fecal samples were chemically preserved for storage in the spacecraft.

Body Volume Measurements

For the Apollo 16 crewmembers, a measurement of body volume was made by stereophotogrammetry, using a special computer program, three times before the flight and three times after the flight (Peterson & Herron, 1971). Body density was calculated from body volume and weight. Density was used to calculate the percentage of fat by means of the following formula.

$$\frac{495}{\text{body density}} - 450 = \text{percent fat}$$

Changes in calculated lean body mass and total body fat were converted into caloric equivalents by means of standard values of 37.6 kJ/gm* for fat and 16.7 kJ/gm for protein.

Total body water was measured by means of potassium-42 dilution (Johnson et al., 1974). Lean body mass was calculated as follows.

$$\text{LBM} = \frac{\text{total body water}}{0.73}$$

$$\text{body weight} - \text{LBM} = \text{total body fat}$$

Findings

The nutritional composition of the typical Apollo inflight diet is given in table 2. This diet, which is characteristically high in protein and carbohydrate and low in residue and fat, was not necessarily consumed by all astronauts in its entirety.

*1 Joule = .239 calorie.

Table 2

Nutritional Composition of Typical Apollo Diet

Nutrient	Percent of Dry Weight
Protein	18
Fat	17
Total carbohydrate	61
Fiber	1.0
Minerals	3.0

A typical Apollo diet was analyzed for vitamins, and results were compared with Recommended Daily Dietary Allowances (NAS, NRC, 1968). The data indicate the Apollo diet provided an excess of some vitamins (A, E, C, B_{12}, B_6, and riboflavin) and marginal amounts of others (nicotinate, pantothenate, thiamine, and folic acid).

The average intake of protein, fat, and carbohydrate for the Apollo 7 through 17 crewmen is given in table 3. Fiber intake measurements are given for the Apollo 12, 15, 16, and 17 missions.

The quantity of energy supplied by dehydrated food for the Apollo 15 to 17 missions is given in table 4. The average energy intake of each Apollo crewmember is given in table 5. These energy values were calculated from the composition of the food consumed. Average energy intakes expressed on the basis of body weight are given in table 6. For comparison, the average energy intake of selected Apollo crewmembers during a mission and on the ground is given in table 7.

The average intakes of calcium, phosphorus, sodium, and potassium for each Apollo crewman are given in table 8. Diets for the Apollo 16 and 17 missions were fortified with potassium gluconate. The contribution of supplementary potassium gluconate to the total intake for the Apollo 15, 16, and 17 crewmen is given in table 9.

Inflight fecal samples were analyzed for inorganic constituents using nuclear activation analyses and wet chemistry techniques. The findings were summarized by Brodzinsky and co-workers (1971). Inflight fecal samples were also analyzed for total fat, fatty acids, and conjugated and unconjugated bile acids (tables 10 and 11). Data on fat absorption in flight (Apollo 16 and 17) are given in table 12.

Apollo 16 Metabolic Study

The input and output of various elements, particularly potassium, were carefully examined in the Apollo 16 balance study and a detailed assessment of energy metabolism was made (Johnson et al., 1974). The average daily inflight potassium intake for the Commander was 113.6 milliequivalents. During the mission, potassium was lost by the fecal route at a rate of approximately 6.4 mEq/day, whereas approximately 18.8 mEq/day were lost before the flight and 20.5 mEq/day after the flight. During the mission, absorbed potassium levels were 107.2 mEq, whereas preflight and postflight levels were 94.8 and 77.6 mEq, respectively. During the extravehicular and lunar surface periods, the Commander consumed a maximum of 152.4 mEq daily.

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Table 3
Nutrient Intake During Apollo Missions

Mission Number	Mission Duration, Days	Crewman	Nutrient, gm			
			Protein	Fat	Carbohydrate	Fiber
7	10	CDR	81	72	259	–
		CMP	96	78	280	–
		LMP	74	56	268	–
8	6	CDR	59	39	231	–
		CMP	80	49	240	–
		LMP	52	33	217	–
9	10	CDR	86	60	280	–
		CMP	78	53	240	–
		LMP	66	47	252	–
10	8	CDR	58	34	213	–
		CMP	46	30	213	–
		LMP	49	30	208	–
11	10	CDR	79	65	290	–
		CMP	71	54	224	–
		LMP	94	73	322	–
12	10	CDR	70	50	263	4.6
		CMP	65	49	249	3.9
		LMP	57	42	280	3.3
13	7	CDR	59	50	239	–
		CMP	57	47	235	–
		LMP	57	49	228	–
14	8	CDR	90	76	309	–
		CMP	79	61	230	–
		LMP	81	89	319	–
15	11	CDR	126	115	356	8.2
		CMP	109	94	334	7.9
		LMP	100	89	421	2.2
16	11	CDR	88	73	319	6.2
		CMP	79	60	295	5.3
		LMP	52	50	203	3.1
17	12	CDR	88	68	248	3.9
		CMP	87	87	293	5.3
		LMP	98	104	314	5.3

Table 4

Energy Supplied by Dehydrated Food
(Values in percent of total Joules consumed)

Apollo Mission Number	Crewman		
	CDR	CMP	LMP
15	57.7	63.9	57.3
16	57.7	59.4	62.4
17	43.0	46.9	44.2

Table 5

Average Energy Intake During Apollo Missions
[Values in kJ/day (kcal/day)]

Apollo Mission Number	Crewmen		
	CDR	CMP	LMP
7	8235 (1970)	8945 (2140)	7524 (1800)
8	6186 (1480)	7064 (1690)	5601 (1340)
9	8026 (1920)	7190 (1720)	6855 (1640)
10	5643 (1350)	5267 (1260)	5225 (1250)
11	8527 (2040)	6855 (1640)	9530 (2280)
12	7315 (1750)	6981 (1670)	7064 (1690)
13	6604 (1580)	6437 (1540)	6354 (1520)
14	9656 (2310)	7190 (1720)	9739 (2330)
15	12 134 (2903)	10 456 (2492)	10 751 (2572)
16	10 044 (2403)	6542 (1565)	9890 (2366)
17	7545 (1805)	9547 (2284)	8389 (2007)

The average daily inflight potassium intake for the Lunar Module Pilot was 114.7 mEq, compared with an average daily preflight intake of 110.5 mEq and an average daily postflight intake of 97.5 mEq. During the preflight, inflight, and postflight phases, the average daily fecal losses were 33.5, 11.1, and 31.0 mEq, respectively. The absorbed daily potassium levels for preflight, inflight, and postflight phases were 77.0, 103.6, and 66.5 mEq, respectively. Although these levels were less than the recommended levels of 150 mEq per day, they were adequate for ground-based requirements. A peak level of 148 mEq per day was consumed by the Lunar Module Pilot during lunar surface activities.

Table 6
Apollo Inflight Energy Intake Based on Body Weight
[Values in kJ/kg/day (kcal/kg/day)]

Apollo Mission Number	Crewmen		
	CDR	CMP	LMP
7	93.7 (22.4)	128.8 (30.8)	106.7 (25.5)
8	80.8 (19.3)	92.0 (22.0)	84.5 (20.2)
9	109.9 (26.3)	97.0 (23.2)	92.5 (22.1)
10	71.1 (17.0)	68.7 (16.4)	66.1 (15.8)
11	108.7 (26.0)	90.8 (21.7)	122.2 (29.2)
12	109.9 (26.3)	99.1 (23.7)	101.1 (24.2)
13	84.1 (20.1)	71.9 (17.2)	89.8 (21.5)
14	123.4 (29.5)	95.8 (22.9)	117.2 (28.0)
15	149.7 (35.8)	141.8 (33.9)	145.2 (34.7)
16	125.5 (30.0)	104.6 (25.0)	135.4 (32.4)
17	93.7 (22.4)	123.8 (29.6)	110.5 (26.4)

Table 7
Comparison of Apollo Inflight and
Ground-Based Average Energy Intake
[Values in kJ/kg (kcal/kg)]

Mission Number	Crewman	Ground-Based Intake *	Inflight Intake **
9	LMP	151.4 (36.2)	92.5 (22.1)
12	CDR	157.3 (37.6)	109.9 (26.3)
	LMP	147.3 (35.2)	101.3 (24.2)
16	CDR	184.1 (44.0)	125.4 (30.0)
	CMP	150.9 (36.1)	104.5 (25.0)
	LMP	176.8 (42.3)	135.6 (32.4)
17	CDR	129.6 (31.0)	93.7 (22.4)
	CMP	163.9 (39.2)	123.8 (29.6)
	LMP	130.8 (31.3)	110.5 (26.4)

* Mean value is 154.7 ± 18.4 kJ/kg (37.0 ± 4.4 kcal/kg)
**Mean value is 110.8 ± 13.8 kJ/kg (26.5 ± 3.3 kcal/kg)

For the Command Module Pilot, average daily preflight, inflight, and postflight dietary potassium intakes were 94.3, 79.9, and 82.4 mEq, respectively. Fecal samples for the same periods indicated that potassium levels were 27.6, 6.3, and 26.2 mEq, respectively. Available daily preflight, inflight, and postflight potassium levels were, therefore, 66.7, 73.6, and 56.2 mEq, respectively.

Table 8
Inflight Intake of Calcium, Phosphorus, Sodium, and Potassium
(Values in milligrams)

Apollo Mission Number	Crewman											
	Commander				Command Module Pilot				Lunar Module Pilot			
	Calcium	Phosphorus	Sodium	Potassium	Calcium	Phosphorus	Sodium	Potassium	Calcium	Phosphorus	Sodium	Potassium
7	644	1060	3810	1879	938	1125	4000	1958	925	841	3480	1336
8	427	847	3170	1229	479	983	3980	1571	366	760	2730	986
9	562	1146	4000	1677	489	1073	3770	1708	494	892	3410	1386
10	836	814	2970	1463	808	746	2290	1376	854	701	2670	1182
11	1036	1050	2770	1751	851	901	2060	1441	1114	1225	3220	2061
12	1095	1090	3580	1835	1022	1028	3240	1685	1291	965	3290	1484
13	870	780	3630	2036	871	720	3480	1942	786	716	3350	1964
14	802	1308	4870	2485	809	1109	3780	2147	843	1304	4750	2576
15	810	1914	6529	3554	748	1624	5274	2720	790	1636	5131	2923
16	811	1696	3860	4432	470	1074	2743	3345	683	1500	3547	4208
17	655	1376	3657	2847	692	1563	4324	3627	659	1447	3611	3237

Table 9
Potassium Intake
(Values in milliequivalents)

Apollo Mission Number	Crewman	Total Potassium Intake	Supplementary Potassium as K-gluconate
15	CDR	91.1	0
	CMP	69.7	0
	LMP	74.9	0
16	CDR	114.2	23
	CMP	81.8	26
	LMP	106.9	26
17	CDR	77.2	10
	CMP	88.5	18
	LMP	98.1	19

Input and output data on sodium, chloride, and calcium levels for the Apollo 16 crewmembers are summarized in table 13.

In the analysis of the balance study performed for the Apollo 17 mission, inflight metabolic data were compared with those obtained during the five-day control study conducted approximately two months prior to flight. Rigorous intake and output measurements were accomplished immediately before the flight and after the flight to detect gross changes; however, the duration of these periods was not sufficient to establish reliable metabolic baselines.

For the Apollo 17 Command Module Pilot, water consumption from all sources was considerably lower during the flight than during the control balance study (table 14). Inflight urine outputs were also proportionately lower for all three crewmembers than those established during the control study. When the conditions of temperature and humidity that prevailed during the flight are considered, it is estimated that in insensible water loss of 900 to 1200 cc/day occurred. This loss was equivalent to the preflight loss. Total body water measurements also did not support the tendency toward negative water balance (see Section III, Chapter 2, Clinical Biochemistry).

Based on numbers adjusted for equilibrium during the control phase and insensible losses, all three crewmembers were in negative calcium balance during the inflight period (table 14). The negative balance was particularly pronounced for the Command Module Pilot. For two of the crewmembers, the negative calcium balance persisted after the flight. All crewmembers had exhibited a pronounced positive balance during the five-day control period study possibly because the flight diets contained a higher calcium level than did the customary daily intake of these crewmembers (table 14). As can be expected from the negative calcium balance, phosphorus balance was generally negative during the flight.

All three crewmembers demonstrated a sustained negative nitrogen balance during the flight (table 14). Occasional negative nitrogen balances of small magnitude were also detected before the flight. Diminished nitrogen retention is supportive evidence for the

Table 10
Analysis of Fecal Samples Based on Dry Weight
(Values are averages ± standard deviation)

Test	Apollo Mission Number							
	7	8	9	11	12	13	14	15
Moisture, percent	6.78 ± 1.11	5.99 ± 1.53	6.31 ± 0.794	7.72 ± 5.42	6.67 ± 0.778	7.53 ± 1.32	9.56 ± 0.933	4.94 ± 1.73
Nitrogen, percent	4.05 ± 0.44	5.87 ± 0.394	5.70 ± 0.85	5.76 ± 1.42	4.94 ± 0.570	5.34 ± 0.778	4.45 ± 0.428	5.50 ± 0.14
Protein, percent	25.3 ± 2.71	38.46 ± 3.13	35.61 ± 5.30	36.70 ± 9.92	30.90 ± 3.56	33.39 ± 4.86	27.79 ± 2.66	34.38 ± 0.87
Total lipids, percent	12.9 ± 5.40	11.74 ± 4.46	12.64 ± 4.25	15.14 ± 0.509	17.75 ± 4.54	15.26 ± 3.92	23.76 ± 5.91	12.9 ± 3.25
Crude fiber percent	7.57 ± 2.47	5.22 ± 1.42	21.81 ± 4.46	7.06 ± 1.79	13.20 ± 7.46	14.05 ± 5.42	14.44 ± 6.08	5.97 ± 0.75
Energy value, *kcal/100 gm	533.68 ± 27.46	530.8 ± 42.7	523.58 ± 38.03	519.15 ± 20.55	501.33 ± 33.9	547.17 ± 55.43	521.8 ± 42.3	573.40 ± 20.78
Potassium, mg/100 gm	1435.57 ± 357.07	1571.6 ± 239.1	1724.1 ± 516.0	1318.35 ± 503.17	1377.5 ± 352.05	1967.8 ± 284.8	1524.5 ± 448.5	1884.7 ± 557.6
Nickel, mg/100 gm	4.21 ± 2.08	2.70 ± 1.48	18.27 ± 10.10	3.37 ± 0.948	10.58 ± 0	4.60 ± 2.88	— —	9.70 ± 6.94

*1 kcal = 4.184 kJ

Table 11

Fatty Acid Analysis of Fecal Samples Based on Total Fat
(Values are percentage of total fat ± standard deviation)

	C12	C14	C16	C18	C18:1	C18:2	C18:3	C2X
Apollo 7	0.60 ± 0.18	0.88 ± 0.51	24.84 ± 7.28	32.63 ± 11.84	30.8 ± 10.07	5.01 ± 3.79	—	14.22 ± 11.34
Apollo 8	1.00 ± .52	1.70 ± .99	24.34 ± 8.11	22.85 ± 6.30	32.72 ± 3.80	7.95 ± 5.35	—	12.20 ± 3.26
Apollo 9	1.50 ± 1.22	2.76 ± 1.14	31.07 ± 7.70	38.02 ± 4.67	22.10 ± 6.41	2.88 ± 2.66	—	5.01
Apollo 11	1.10 ± .18	2.24 ± .30	21.44 ± 1.56	24.72 ± 13.04	16.10 ± 1.27	2.55 ± 1.27	—	16.81 ± 5.52
Apollo 12	1.70 ± 1.19	4.44 ± 1.99	30.36 ± 7.25	33.99 ± 8.68	17.06 ± 6.31	2.05 ± 1.96	0.58	—
Apollo 13	1.38 ± 1.58	1.48 ± .72	19.8 ± 5.63	37.92 ± 11.66	32.84 ± 12.65	4.94 ± 3.10	0.858 ± 0.316	—
Apollo 14	1.34 ± .81	1.78 ± 1.41	17.06 ± 5.96	30.44 ± 17.81	25.00 ± 9.75	5.85 ± 9.34	.82 ± .01	5.70 ± 4.74
Apollo 15	1.44 ± .78	16.28 ± 1.94	20.81 ± 6.00	49.32 ± 2.28	10.56 ± 8.80	2.11	1.05	—

general musculoskeletal deterioration noted on previous flights and during ground-based hypokinetic simulations of flight-type conditions.

Table 12

Analysis of Fat Absorbed

Measurement	Sample Number					
	1	2	3	4	5	6
			Apollo 16 mission			
Food, gm/day	135	73	100	50	98	60
Feces, gm/day	10.28	2.33	7.84	4.99	7.61	1.21
Fat absorbed, percent	92	97	92	90	92	98
			Apollo 17 mission			
Food, gm/day	114	68	87	104	73	87
Feces, gm/day	6.03	.86	1.63	2.10	1.87	1.83
Fat absorbed, percent	95	99	98	98	97	98

Sodium intakes during the flight were all less than 250 mEq/day. Intake and output measurements for sodium indicated positive balances for this element during the flight for all three crewmembers (table 14). However, sodium output in sweat was not measured and this route of excretion could have accounted for all the apparent "positive balance" and even have resulted in a slight negative balance for sodium. Sodium balance was positive during the flight for all three crewmembers (table 15) if insensible losses are neglected.

In compliance with previous recommendations based on observed inflight potassium deficits, inflight potassium intakes were maintained above normal ground-based intakes (73 to 97 mEq/day) (table 15). Potassium retention during the flight was significantly less than that established during the control study. A summary of overall metabolic balance for Apollo 17 crewmembers with all numbers adjusted to reflect equilibrium during the control period is presented in table 15.

Anthropometric Measurements

A summary of body weight changes based on the mean of the weights on 30, 15, and 5 days before lift-off compared to those obtained immediately after recovery is presented in table 16. The weight changes during the 24-hour period immediately following recovery are also given.

Body volume was measured before and after the Apollo 16 mission by stereophotogrammetry. An analysis of densitometric data is presented in table 17.

Table 13

Intake and Absorption Data – Apollo 16

Commander

Day	Item	Water (gm)	kcal	Protein (gm)	Fat (gm)	CHO (gm)	Crude Fiber (gm)	Ash (gm)	Ca (mg)	P (mg)	Na (mEq)	K (mEq)	Mg (mg)	Cl (mEq)
F-3	Total intake	3645	3989	147.7	200.8	366.1	0	22.88	1033	2270	222.3	128.0	473	130.1
	Feces	54	108	6.7	1.7	7.3	.86	2.10	269	298	4.4	8.7	127	.3
F-2	Total intake	3442	3217	134.6	126.8	391.5	0	21.95	1130	1924	183.9	126.2	424	123.5
	Feces	123	351	15.8	12.5	22.4	3.25	5.40	919	851	3.6	25.3	364	1.3
F-1	Total intake	2631	2402	103.5	92.9	265.7	0	14.24	580	1677	121.5	86.4	226	60.1
	Feces	76	276	16.8	9.3	12.5	2.17	5.39	945	803	20.9	22.5	342	.6
F+0	Total intake	1229	2047	79.9	115.3	166.0	1.69	11.74	561	1285	158.7	73.7	184	106.5
	Feces	36	78	5.2	2.4	4.1	.44	1.70	340	249	.7	7.4	120	.009
F+1	Total intake	2448	2421	81.8	84.2	412.4	8.98	19.3	882	1622	183.5	129.9	262	187.3
	Feces	82	321	16.1	11.3	15.9	3.00	8.4	1095	945	35.1	27.4	401	3.3
F+2	Total intake	1750	1627	74.8	55.6	221.8	2.70	16.1	564	1106	184.7	77.5	140	148.5
	Feces	–	–	–	–	–	–	–	–	–	–	–	–	–
F+3	Total intake	1629	2586	105.6	73.3	412.5	7.18	19.1	791	2002	207.9	129.4	242	168.9
	Feces	–	–	–	–	–	–	–	–	–	–	–	–	–
F+4	Total intake	1846	2059	61.5	61.0	338.5	6.06	19.0	938	1144	175.2	152.4	192	121.1
	Feces	–	–	–	–	–	–	–	–	–	–	–	–	–
F+5	Total intake	2029	2007	91.5	48.1	322.9	5.86	19.9	990	1624	123.0	81.9	252	103.7
	Feces	–	–	–	–	–	–	–	–	–	–	–	–	–
F+6	Total intake	1869	2425	92.4	59.4	400.9	5.84	20.8	962	1481	219.9	147.0	276	186.3
	Feces	–	–	–	–	–	–	–	–	–	–	–	–	–
F+7	Total intake	1907	2302	69.3	62.4	414.8	4.07	16.3	1037	1513	141.1	124.0	216	80.5
	Feces	–	–	–	–	–	–	–	–	–	–	–	–	–
F+8	Total intake	1437	2405	96.9	103.3	269.8	6.00	19.9	1055	1683	253.5	133.1	272	169.5
	Feces	10	*	1.18	1.9	1.5	.22	1.3	97	66	16.6	1.8	21	*
F+9	Total intake	1216	1432	71.4	36.5	240.6	6.99	14.7	516	1072	130.0	101.1	197	167.2
	Feces	–	–	–	–	–	–	–	–	–	–	–	–	–

*Insufficient sample.

Table 13 (Continued)

Intake and Absorption Data – Apollo 16

Day	Item	Water (gm)	kcal	Protein (gm)	Fat (gm)	CHO (gm)	Crude Fiber (gm)	Ash (gm)	Ca (mg)	P (mg)	Na (mEq)	K (mEq)	Mg (mg)	Cl (mEq)
Commander (Continued)														
F+10	Total intake	2301	2363	121.8	105.4	268.0	5.54	25.8	563	1472	253.3	100.0	209	200.5
	Feces	88	268	17.7	6.8	16.2	2.35	8.5	1927	1193	18.2	29.6	333	2.3
R+0	Total intake	2432	1816	71.5	76.6	200.3	0	12.19	728	1268	97.6	93.0	242	54.2
	Feces	59	145	8.9	4.4	9.0	1.42	3.36	654	456	1.3	15.7	167	.4
R+1	Total intake	2895	2744	97.9	92.3	388.2	0	13.80	755	1293	120.1	117.6	214	83.6
	Feces	156	329	22.4	4.9	22.5	5.85	7.95	1221	1039	5.5	45.9	374	1.1
R+2	Total intake	1655	1101	48.1	58.8	95.4	0	8.93	314	881	91.7	83.4	143	61.0
	Feces	*	*	*	*	*	.54	*	*	*	*	*	*	*
Lunar Module Pilot														
F-3	Total intake	4050	3369	120.7	114.0	352.5	0	18.20	811	1872	179.6	119.6	391	132.1
	Feces	—	—	—	—	—	—	—	—	—	—	—	—	—
F-2	Total intake	4285	3375	128.7	93.1	396.2	0	16.66	734	1743	147.2	113.3	362	117.3
	Feces	59	179	11.3	4.2	9.6	1.18	4.80	653	747	11.3	20.2	369	.7
F-1	Total intake	3348	2929	118.5	76.5	305.7	0	14.74	515	1914	130.2	98.5	353	83.2
	Feces	162	435	31.9	14.1	29.0	3.25	16.10	2121	1896	5.1	54.7	1008	3.4
F+0	Total intake	1808	2233	69.7	111.4	252.2	.67	11.32	669	1300	125.6	91.5	176	82.1
	Feces	71	*	10.8	5.3	9.2	1.54	4.07	653	601	1.8	19.0	320	.8
F+1	Total intake	2365	1980	64.4	56.6	328.9	4.29	16.7	596	1136	169.5	110.2	197	210.2
	Feces	87	306	17.2	10.2	14.5	1.92	6.5	931	70	4.4	29.9	443	1.8
F+2	Total intake	1794	1588	59.4	51.1	244.0	2.92	13.4	507	938	140.7	83.7	136	167.3
	Feces	—	—	—	—	—	—	—	—	—	—	—	—	—
F+3	Total intake	1484	1904	112.0	55.2	274.0	6.04	18.9	513	1627	209.3	129.5	227	190.7
	Feces	—	—	—	—	—	—	—	—	—	—	—	—	—
F+4	Total intake	2059	1986	49.0	44.4	406.5	5.67	17.0	862	923	161.9	145.8	172	138.0
	Feces	—	—	—	—	—	—	—	—	—	—	—	—	—

*Insufficient sample.

Table 13 (Continued)
Intake and Absorption Data – Apollo 16

Day	Item	Water (gm)	kcal	Protein (gm)	Fat (gm)	CHO (gm)	Crude Fiber (gm)	Ash (gm)	Ca (mg)	P (mg)	Na (mEq)	K (mEq)	Mg (mg)	Cl (mEq)
Lunar Module Pilot (Continued)														
F+5	Total intake	1968	1615	89.6	40.0	250.2	5.19	17.86	885	1354	102.3	76.9	232	96.0
	Feces	–	–	–	–	–	–	–	–	–	–	–	–	–
F+6	Total intake	1995	2369	16.4	63.9	383.7	7.35	19.96	876	1607	192.1	148.6	283	150.4
	Feces	–	–	–	–	–	–	–	–	–	–	–	–	–
F+7	Total intake	1756	2034	64.0	51.1	332.5	3.32	13.20	989	1329	133.4	114.2	175	81.2
	Feces	–	–	–	–	–	–	–	–	–	–	–	–	–
F+8	Total intake	1783	2133	93.0	75.2	295.6	5.10	18.03	932	1582	187.5	126.4	268	180.0
	Feces	177	390	29.4	8.9	16.3	3.88	16.71	2191	1607	6.0	45.9	367	2.5
F+9	Total intake	1126	1388	70.4	36.1	232.6	7.22	14.0	532	1027	127.6	142.3	177.3	168.1
	Feces	–	–	–	–	–	–	–	–	–	–	–	–	–
F+10	Total intake	1645	1679	70.4	71.7	213.7	2.73	17.93	389	1114	153.5	93.3	177	178.0
	Feces	54	319	15.9	13.6	14.0	1.97	6.55	681	495	51.3	27.5	187	5.9
R+0	Total intake	2298	2585	74.1	97.7	347.4	0	11.30	568	1147	129.3	87.8	165	85.2
	Feces	394	913	49.9	33.1	57.1	13.26	19.70	2636	2953	79.4	93.0	684	6.6
R+1	Total intake	3175	3373	125.1	108.2	482.5	0	16.67	851	1705	166.0	120.1	264	100.8
	Feces	–	–	–	–	–	–	–	–	–	–	–	–	–
R+2	Total intake	2246	2436	71.9	111.3	292.3	0	13.01	487	1245	142.7	84.7	185	98.3
	Feces	–	–	–	–	–	–	–	–	–	–	–	–	–
Command Module Pilot														
F-3	Total intake	2141	2202	76.0	113.3	202.9	0	13.63	566	1141	130.1	98.0	305	101.5
	Feces	130	293	19.2	9.4	21.2	3.90	6.46	925	866	8.9	29.6	414	1.0
F-2	Total intake	2610	1855	77.6	93.5	136.2	0	11.55	410	1004	100.3	94.3	322	90.1
	Feces	29	(a)	7.8	4.2	10.0	.75	3.30	514	(a)	1.6	14.2	219	.6

*Insufficient sample.

Table 13 (Continued)

Intake and Absorption Data – Apollo 16

Day	Item	Water (gm)	kcal	Protein (gm)	Fat (gm)	CHO (gm)	Crude Fiber (gm)	Ash (gm)	Ca (mg)	P (mg)	Na (mEq)	K (mEq)	Mg (mg)	Cl (mEq)
Command Module Pilot (Continued)														
F-1	Total intake	2356	2338	78.2	82.2	303.9	0	12.10	434	1208	127.4	90.6	224	94.5
	Feces	99	329	22.3	9.3	12.6	1.89	7.00	1185	977	2.0	34.1	471	1.0
F+0	Total intake	1753	2057	48.2	105.8	221.4	1.30	11.92	630	1046	167.7	91.1	175	109.1
	Feces*	–	–	–	–	–	–	–	–	–	–	–	–	–
F+1	Total intake	1292	1394	30.0	58.0	201.3	3.38	11.7	382	681	136.7	79.1	110	194.0
	Feces	37	115	4.8	3.4	7.3	1.26	2.3	345	*	5.7	10.9	131	.7
F+2	Total intake	1227	1052	48.0	31.5	147.8	1.54	10.71	306	658	130.7	53.5	90	107.2
	Feces	–	–	–	–	–	–	–	–	–	–	–	–	–
F+3	Total intake	1432	1706	83.2	46.3	267.5	4.41	12.5	614	1389	123.9	95.0	159	100.8
	Feces	–	–	–	–	–	–	–	–	–	–	–	–	–
F+4	Total intake	1086	1115	25.1	24.5	200.9	1.68	5.70	400	495	55.2	45.4	97	41.0
	Feces	32	110	4.9	2.3	7.6	1.52	2.21	382	309	2.0	11.3	126	.4
F+5	Total intake	1476	1348	82.2	44.4	175.5	2.61	13.3	425	1216	124.2	82.6	165	85.7
	Feces	–	–	–	–	–	–	–	–	–	–	–	–	–
F+6	Total intake	1089	1165	24.0	57.3	151.0	2.16	11.3	228	546	68.5	75.9	128	38.5
	Feces	–	–	–	–	–	–	–	–	–	–	–	–	–
F+7	Total intake	1475	1437	48.6	24.7	233.8	2.29	10.0	856	995	99.4	91.7	118	52.5
	Feces	144	343	21.9	7.5	20.8	2.52	10.0	1612	1352	28.3	47.2	416	2.6
F+8	Total intake	1186	1263	31.2	55.1	177.3	4.22	11.0	340	613	88.9	81.1	142	75.5
	Feces	–	–	–	–	–	–	–	–	–	–	–	–	–
F+9	Total intake	1048	919	41.7	20.1	156.6	3.12	9.9	251	640	85.1	73.3	139	105.0
	Feces	–	–	–	–	–	–	–	–	–	–	–	–	–
F+10	Total intake	1526	2037	103.2	90.7	224.7	2.94	17.7	714	1551	215.6	110.4	219	136.3
	Feces	–	–	–	–	–	–	–	–	–	–	–	–	–

*Insufficient sample.

Table 13 (Continued)

Intake and Absorption Data – Apollo 16

Command Module Pilot (Continued)														
Day	Item	Water (gm)	kcal	Protein (gm)	Fat (gm)	CHO (gm)	Crude Fiber (gm)	Ash (gm)	Ca (mg)	P (mg)	Na (mEq)	K (mEq)	Mg (mg)	Cl (mEq)
R+0	Total intake	2387	2084	58.3	94.8	250.1	0	10.75	474	1016	108.3	73.1	194	73.8
	Feces	—	—	—	—	—	—	—	—	—	—	—	—	—
R+1	Total intake	2712	2474	83.8	112.6	289.0	0	13.76	670	1173	121.2	87.0	271	93.3
	Feces	190	428	26.2	7.6	26.8	3.32	9.87	1678	1365	8.3	53.5	477	2.1
R+2	Total intake	1927	2022	64.1	101.0	216.2	0	11.93	488	1012	126.2	87.0	215	92.5
	Feces	62	214	13.4	3.7	13.0	1.36	4.67	791	655	1.8	25.2	234	.8

Table 14

Balance of Water, Calcium, Phosphorus, Nitrogen, and Sodium During the Apollo 17 Mission

Parameter	Control Measurement			Inflight Measurement		
	CDR	CMP	LMP	CDR	CMP	LMP
Water						
Intake, ml	2666	3734	2268	2143	2705	2270
Urine, ml	1750	2516	1279	1120	1518	992
Feces, ml	63	146	73	68	142	116
Water absorbed, ml	853	1072	916	955	1045	1162
Water absorbed, cc/kg body weight	10.6	13.9	12.1	11.8	13.5	15.3
Calcium						
Intake, mg	673	811	622	675	704	643
Urine, mg	98	204	118	117	182	89
Feces, mg	257	247	269	540	721	591
Calcium absorbed, mg	318	360	235	18	−199	− 37
Phosphorus						
Intake, mg	1603	1883	1544	1430	1646	1438
Urine, mg	1139	1056	1087	1267	1561	1253
Feces, mg	239	227	281	280	592	510
Phosphorus, absorbed, mg	225	600	176	−117	−507	−325
Nitrogen						
Intake, N/day/gm	17.6	17.9	15.9	13.2	16.5	13.7
Urine, N/day/gm	14.0	13.3	16.7	15.7	16.4	15.0
Feces, N/day/gm	2.1	2.2	1.5	1.4	1.9	2.1
Nitrogen absorbed, N/day/gm	1.1	2.4	− 2.3	− 3.9	− 1.8	− 3.4
Sodium						
Intake, mEq	216	209	185	168	205	163
Urine, mEq	149	139	192	143	164	135
Feces, mEq	2	5	3	17	26	7
Sodium absorbed, mEq	65	65	−10	8	15	21
Potassium						
Intake, mEq	99	117	95	73	81	97
Urine, mEq	75	81	82	76	75	89
Feces, mEq	4	7	5	12	13	16
Potassium absorbed, mEq	20	29	8	−15	− 7	− 8

Table 15
Twelve-Day Totals for Apollo 17 Metabolic Balance

Parameter	Crewman		
	CDR	CMP	LMP
Water, ml	1224	− 324	2952
Sodium, mEq	− 684	− 600	+ 372
Potassium, mEq	− 420	− 444	− 180
Calcium, mg	−3600	−11 028	−3264
Phosphorus, mg	−4104	−13 284	−6012
Nitrogen, gm	− 60	− 101	− 13
Protein (N x 6.25), gm	− 375	− 631	− 75
Mass, kg *	− 4.56	− 2.68	− 3.06
Mass, kg **	.25	− 1.50	− 2.50

* Measurement made on day of recovery.
** Measurement made 24 hours after recovery.

Discussion

Most of the Apollo crewmembers did not eat all the food available. Among the reasons for reduced appetite were decreased hunger, a feeling of fullness in the abdomen, nausea (Berry & Homick, 1973), and preoccupation with the critical mission tasks. Dislike of the food and inadequate rest during the mission were minor problems (Berry, 1970). The evidence suggests that either weightlessness or some other aspect of the mission environment caused the crewmen to restrict their food intake below quantities available and below quantities necessary to maintain body weight.

A reasonable estimate of the energy requirement during a flight can be obtained by correlating careful measurements of food intake with losses or gains in body tissue. The data reveal a mean energy intake of 7854 ± 1735 kJ/day for astronauts during the Apollo missions. If this intake is compared to the NAS, NRC Recommended Daily Dietary Allowance of about 12 000 kJ/day, it is apparent that an average energy deficit was incurred by each Apollo astronaut.

To quantitate the metabolic energy demands throughout the mission and to help define body composition changes, efforts were made during the Apollo 16 mission to control nutrient intake at a constant level throughout the preflight, inflight, and postflight periods. It was believed that stabilizing dietary intake would afford maximum opportunity for detecting body composition changes caused by adaptation to weightlessness.

The mean loss in body weight between the day of the preflight total body water determination and the day of recovery was 3.9 kg. Measurements of total body water loss by tritiated water dilution indicated a mean decrease of 1.77 liters.

Table 16

Total Weight Changes During and Following the Apollo Missions (Values in kilograms)

Mission Number	Crewman		
	Commander	Command Module Pilot	Lunar Module Pilot
Weight losses during mission			
7	−2.29	−2.86	−2.86
8	−3.77	−2.41	−3.77
9	−3.41	−3.77	−4.90
10	−3.04	−4.45	−5.49
11	−4.09	−3.50	−2.86
12	− .82	−3.54	−6.36
13	−4.54	−5.04	−3.04
14	−1.73	−5.90	−3.00
15	−2.18	−1.54	−3.59
16	−4.81	−4.04	−2.63
17	−4.56	−2.68	−3.06
Weight gains during first 24 hours following each mission			
7	.75	3.50	4.00
8	2.75	.75	.50
9	2.75	8.50	4.25
10	2.25	1.75	1.50
11	6.00	—	4.00
12	2.00	4.00	3.00
13	—	—	—
14	1.00	7.00	1.00
15	—	—	—
16	2.50	3.00	2.50
17	.25	−1.50	−2.50

Total 17

Apollo 16

Densitometric Data Uncorrected for Lung Volume

	CDR	CMP	LMP
Preflight Weight (kg)	78.822	62.514	72.480
Volume (l)	75.499	62.136	73.199
Density (kg/l)	1.044	1.006	.990
Postflight Weight (kg)	75.425	59.343	70.442
Volume (l)	74.859	57.854	71.399
Density (kg/l)	1.008	1.026	.987

When body water loss was converted into lean body mass lost, it was determined that the three crewmembers lost fat in addition to lean body mass because the lean body mass loss does not equal the recorded weight loss. The daily caloric expenditure of the Apollo 16 crewmen can be calculated from the known caloric value of metabolized fat (37.6 kJ/gm and of lean body mass (16.7 kJ/gm). For the three crewmembers, the mean daily caloric expenditure was 17 347 kJ.

Changes in total body potassium measured both by radioactive (potassium 42) dilution and by balance techniques did not reveal a significant loss of lean body mass, an indication that a fat and fluid loss occurred rather than a lean body mass loss. If only body fat were lost, the energy requirement for the three Apollo 16 crewmen would be 21 556, 12 043, and 14 291 kJ/day, with a mean of 15 963 kJ (Johnson et al., 1970).

In an alternate method of summarizing the data, each crewman's body mass loss was calculated from the differences between his mean body weight obtained 30, 15, and 5 days before flight and his weight immediately after flight.

Total body water lost was defined as the mass regained by each astronaut during the 24-hour period following recovery. In this instance, it was assumed that the mean weight loss that was not due to either water or protein loss was due to loss of fat. By this method, a larger loss in body fat was calculated to have occurred in all crewmembers.

Because of difficulties in controlling the respiratory cycle during body volume measurement (Peterson & Herron, 1971), the calculated changes in body composition included the effect of respiration as a random variable; thus, the data have too large a variance for calculation of individual changes in body fat.

During the Apollo 17 mission, a complete collection of urine and feces samples was added to a record of dietary intake so that metabolic balance measurements could be made. By using the results of this study, the energy balance of each crewmember during the Apollo 17 mission was estimated. Each crewmember decreased his intramission energy intake. During the mission, this intake decreased from a mean of 141.3 kJ/kg body weight to 109.1 kJ/kg and represented a 23 percent decrease in the caloric intake of the crewmen. This decrease would result in a net mean deficit in caloric intake of 30 129 kJ throughout the mission (Johnson et al., 1974).

The mean weight loss of the Apollo 17 crewmen was 3.3 kg. Nitrogen balance data reveal a loss of approximately 1 kg of protein, and the remaining loss can be attributed to fat. A mean caloric deficit of approximately 104 500 kJ is, therefore, assumed to have occurred (Johnson et al., 1974; Leach et al., 1974).

Body tissue losses were first calculated for each astronaut by averaging successive body weights obtained before the mission and subtracting the body weights measured 24 hours after recovery (Rambaut et al., 1973). It had been assumed that any decrease in body mass between the preflight weight and the weight recorded 24 hours after recovery represented water lost. An average of 1.5 kg weight was not regained during this 24-hour period. If this loss was composed entirely of fat, it would represent an additional inflight expenditure of approximately 5643 kJ/day. Commencing with Apollo 16, food and fluid intake, urinary and fecal output, and total body water were measured for each crewman before, during, and after the flight. From these measurements were derived estimates of protein loss, lean body mass, and total body fat. Body volume was estimated by stereophotogrammetry, and body density was calculated. From all these data, it became apparent that crewmembers had lost fat in addition to losing lean body mass.

Losses of musculoskeletal constituents (Rambaut et al., 1973; Vogel et al., 1974) and a variety of fluid and electrolyte anomalies have been detected by biochemical investigations associated with the Gemini, Apollo, Voskhod, and Soyuz flights. The electrolyte anomalies were particularly pronounced during the Apollo 15 mission and may have been associated with inflight cardiac arrhythmias and postflight changes in exercise performance and cardiovascular responses.

Certain therapeutic measures including the elevation of dietary potassium intake were partly responsible for the lack of significant metabolic disturbances following the Apollo 16 mission. Similar elevations in dietary potassium were effected for the Apollo 17 crewmembers.

The negative nitrogen and potassium balances that were observed during the Apollo 17 mission are indicative of a loss in the body mass.

Summary

Apollo nutrient intakes have been characteristically hypocaloric. Estimates of body composition changes from metabolic balance data, from preflight and postflight weights and volumes, and from total body water and potassium provide no evidence for diminished caloric requirements during a flight.

As observed during the Gemini Program and during periods of bed rest, measurements of bone density and metabolic balance confirm a tendency toward loss of skeletal tissue in weightlessness.

No evidence exists that any inflight metabolic anomaly, including hypokalemia, was induced by marginal or deficient nutrient intakes. In general, the Apollo crewmen were well nourished and exhibited normal gastroenterological functions, although appetite was somewhat diminished and the organoleptic response to food was somewhat modified during flight.

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