ASD
APOLLO SYSTEMS DEPARTMENT
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HOUSTON, TEXAS

NASA - CR - 167460

TECHNICAL INFORMATION RELEASE

TIR 741-LSP-9017

FROM	TO
J. I. Leonard, Ph.D.	J. A. Rummel, Ph.D./SB3

DATE	WORK ORDER REF:	WORK STATEMENT PARA:	REFERENCE:
9/24/79		NAS9-15487	

SUBJECT

Quantitation of Tissue Loss During Prolonged Space Flight

(NASA-CR-167460) QUANTITATION OF TISSUE LOSS DURING PROLONGED SPACE FLIGHT (General Electric Co.) 44 p HC A03/MF A01 CSCL 06P

N82-12752

Unclas
G3/52 03356

This report is an analysis of the weight loss which was observed on the Skylab crewmembers during the inflight phase of the three missions. A simple model of body composition was used whereby weight loss consists of a lean body mass components (water plus protein) and a body fat component. Six different methods for determining lean body mass were employed to compute these components. These methods included those based on changes in total body water, total body potassium, nitrogen balance, potassium balance and body density. Calculations are presented for each of the nine Skylab crewmembers and their combined averages. Errors in the various methods are discussed. A discussion of muscle atrophy during gravity unloading is also included.

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Attachment
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QUANTITATION OF TISSUE LOSS DURING PROLONGED SPACE FLIGHT

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June 1979

QUANTITATION OF TISSUE LOSS DURING PROLONGED SPACEFLIGHT

Introduction

One of the more consistent findings in astronauts returning from spaceflight has been a loss in body weight. Interpretation of this weight loss in terms of the major body elements and tissues is essential for understanding metabolic processes in weightlessness and predicting weight losses in future missions. Also, since diet and activity affect lean and fat tissues differently, a knowledge of expected changes will assist in establishing caloric and exercise requirements.

Based on our collective experience from Mercury through Skylab, and including bed rest studies which mimic some of the hypogravic effects of weightlessness, significant changes in gross body composition can be expected during spaceflight (Berry, 1973; Johnson, et al, 1975; Johnson & Dietlein, 1977; Greenleaf , et al, 1976). These include alterations in water balance resulting from headward shifts of fluid, loss of musculoskeletal tissue as a result of "deconditioning" and postural disuse, and alterations in fat depending upon the balance between caloric intake and energy expenditure.

A definitive analysis of the effects of weightlessness on body composition changes has been hampered by the difficulty in quantitating inflight physical activity and ensuring an adequate caloric intake as well as the operational constraints which precluded direct measurements of tissue loss. While these considerations existed on all previous flights, a major effort was directed at describing, if not controlling, the more essential components of body weight on the more recent Skylab missions. The present paper is an integrative analysis of the most important data gathered during the Skylab missions related to tissue loss in space.

Background

Previous analysis of body composition changes have been presented for crews of the short term (6-12 days) Apollo flights (Johnson, et al, 1973; Johnson, et al, 1974; Rambaut, et al, 1973) and for the longer term (1-3 months) Skylab missions (Rambaut, et al, 1977a; Rambaut, et al, 1977b;

Whittle, 1979). The average weight loss for the 33 Apollo and 9 Skylab crewmen was 3.5 kg (range: 0.82 to 5.9 kg) and 2.8 kg (range: -0.1 to 4.2 kg), respectively (Rambaut, et al, 1975; Thornton, 1978). The source of this weight loss was not readily apparent in all cases, although after the shorter flights (including Mercury and Gemini) the weight was regained in 12-24 hours, suggesting a shift in water balance (Webb, 1967; De Dombal, 1969). Only on the last two Apollo missions did flight operations permit complete caloric, potassium and nitrogen metabolic balance as well as body water and exchangeable potassium by isotope dilution. These preliminary data indicated that after 12 days in space about half the weight loss was due to water and the remainder consisted of fat and cell solids (mostly protein). The loss in fat was attributed to a caloric intake deficiency of 1000 kcal/day (Rambaut, et al, 1973).

The Skylab biomedical findings added considerably to our knowledge of metabolic and body composition changes. Although much of these data describing mineral, tissue and fluid losses have been reported in one form or another (Rambaut, et al, 1977a, 1977b; Whedon, et al, 1977; Whittle, 1979; Leach, et al, 1975, 1976, 1977), there have been no systematic attempts to integrate the total quantity of information directly related to changes in body protein, lean body mass and fat. Direct evidence permitting quantitation of lean body mass included pre- and postflight measurements of total body water, total body potassium and body volume. In addition, daily inflight metabolic balance (potassium and nitrogen) and body mass measurements provided, for the first time, a description of the time course of some of the most significant components of weight loss. Established relationships are available for equating these quantities to direct measures of lean body mass. One of the purposes of this analysis was to assess the agreement among these various methods to arrive at the best estimate of body composition change for the Skylab astronaut population and to recommend the most promising techniques for use in the next generation of Shuttle Spacelab experiments.

METHODS

Assumptions and Calculations

Table I summarizes the methods used in this study to quantitate lean body mass (LBM). According to the references cited in Table I, the LBM* has a water content of about 73%, a potassium content of about 60-70 meq/kg (in men), and a density of about 1.1 gm/cm^3. In contrast, body fat contains negligible water and potassium content and has a lower density of about 0.9 gm/cm^3. Thus, by measuring total body water (TBW), total body potassium (TBK), or body density (D), and assuming a simple two compartment model (fat and fat-free), it is possible to estimate the relative proportions of fat and lean tissue in the body. Body density is commonly derived from body mass or weight (BWgt) divided by body volume (BVol). All of these measurements were available from the various Skylab experiments (see Table II). Relationships have been suggested for predicting lean body mass from combinations of either TBW and TBK or TBW, TBK, BVol and BWgt. Losses in lean body mass were obtained by using these relationships shown in Table I and comparing the preflight period with the first postflight day of recovery. An inflight metabolic balance on nitrogen provided an additional measure of lean tissue loss. The cumulative algebraic sum of nitrogen balances, obtained each day of the mission, indicates the net loss (or gain) of body nitrogen. Since protein contains an average of 16% nitrogen by weight and lean body mass is composed of 19.4% protein, it is possible to quantitate these other parameters from a cumulative nitrogen balance (Grande, 1968; Yang & Itallie, 1976).

Measurements

Total body water and total body potassium were obtained by the isotopic dilution of isotopic hydrogen and potassium, respectively (Leach & Rambaut, 1977). Body volume was computed from a stereophotogrammetric

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*In this paper we will assume that the difference between the lean body mass (body mass less storage fat) and fat-free mass (body mass less all ether extractable fat); i.e. the essential body fat (about 2% of body weight), is negligible.

TABLE I

MATHEMATICAL DESCRIPTION OF METHODS USED IN DETERMINING BODY COMPOSITION CHANGES*

METHOD	CONCEPT	EQUATION
Total Body Water	Lean body mass is 73.2% water (Pace & Rathbun, 1945)	$LBM = TBW/0.732$
Total Body Potassium	Lean body mass contains 65 meq K^+/kg (Edmonds, 1974; Allen, 1960). This value is age dependent and has been adjusted to mean age of astronauts (40.7 years)	$LBM = TBK/65$
Total Body Water and Potassium	Lean body mass is estimated from sum of body water + cell solids + bone mineral. Cell solids estimated from TBK and bone mineral assumed to be a constant proportion of cell solids (Allen, 1960). Assume inflight bone mineral loss does not contribute significantly to body weight change (Whittle, 1978).	$LBM = TBW + \frac{TBK}{320.6} + \frac{0.334\ TBK'}{320.6}$ where TBK' = preflight value
Cumulative Nitrogen Balance	Cumulative inflight nitrogen balance assumes negligible loss of sweat component. Protein contains 16% nitrogen (Calloway, 197); LBM contains 19.4% protein (Grande, 1968).	$N\ Bal = N(diet) - N(urine) - N(feces)$ $\Delta Protein = N\ Bal \times Mission\ Length \times 6.25$ $\Delta LBM = \Delta Protein/0.194$
Body Density (Stereophotometric)	Body segmented into fat and essential body mass compartments, each having characteristic density. Densities determined from average of four different studies (Chien, et al, 1975; Siri, 19 ; Pace & Rathbun, 1954; Brozek, et al, 1963): Fat (0.9168 gm/cm^3), LBM(1.0997 gm/cm^3).	$LBM = BWgt(6.01 - \frac{5.51}{D})$
"Combined" Method (Stereophotometric)	Lean body mass is the difference between body weight and fat mass.Body fat is estimated as the difference between measured volume of body and sum of the calculated volumes of body water and cell solids(Allen,1960). Method uses combination of all data shown in Table II. Results of this method reported here were taken directly from Whittle (1978) and cannot be derived precisely from values given in Table II because of the use of certain correction factors in the original calculations.	$LBM = PWgt - 0.901(Body\ Vol - \frac{TBW}{.994} - \frac{TBK}{448.6} - \frac{.334\ TBK'}{847.8})$

* Note 1. All quantities expressed as kg (LBM, FAT, BWgt, Protein) or milliequivalents (TBK).
Note 2. Assume essential body fat is negligible; i.e., fat free mass = lean body mass.
Note 3. Symbols: TBW = total body water, TBK = total body potassium, LBM = lean body mass, BWgt = body weight. D = body density, N = nitrogen

TABLE II

BODY COMPOSITION PARAMETERS BEFORE
AND AFTER SKYLAB MISSION

	BODY WGT (Kg)[1]			BODY VOLUME (liters)			TOTAL BODY WATER (liters)			TOTAL BODY POTASSIUM (meq)		
SUBJECT	PRE	POST	Δ	PRE	POST	Δ	PRE	POST	Δ	PRE	POST	Δ
1	62.2	60.2	-2.0	59.00	56.62	-2.38	41.55	40.8	-0.75	3270	3000	-270
2	77.9	74.3	-3.6	75.22	70.65	-4.57	48.80	48.0	-0.80	3915	3680	-240
3	80.2	76.0	-4.2	76.42	71.26	-5.16	52.15	50.0	-2.15	3865	3530	-340
4	68.6	64.6	-4.0	63.55	59.98	-3.57	42.50	41.9	-0.60	3340	3150	-190
5	61.8	58.7	-3.1	56.74	53.58	-3.16	39.10	39.6	+0.50	3060	3030	-35
6	88.0	84.1	-3.9	81.23	77.36	-3.87	53.60	51.9	-1.70	4645	4485	-160
7	67.8	67.8	+0.1	63.87	64.52	+0.65	41.85	41.0	-0.85	3230	3110	-120
8	71.5	68.6	-2.9	68.38	65.04	-3.34	45.40	44.9	-0.50	3675	3350	-325
9	67.6	66.1	-1.5	63.71	61.98	-1.73	45.65	45.1	-0.55	3615	3170	-445
MEAN	71.7	68.9	-2.8*	67.57	64.55	-3.02*	45.62	44.8	-0.82*	3625	3390	-235*
SD	±8.7	±8.1	±1.4	±8.36	±7.56	±1.72	±5.00	±4.4	±0.75	±484	±471	±125

* $p > .995$ that postflight is different from preflight.

Note 1: Preflight body weight is mean of daily measurements during 2-3 week period prior to launch.
Postflight value is the first shipboard measurement after reentry.
Measurements of other parameters were made less frequently preflight and were made on
on either the 1st or 2nd day postflight.

method involving four cameras to make two stereoscopic pairs of photographs from front and back and using computer analysis to determine the volume of different body regions and of the body as whole (Whittle, et al, 1977). Body mass was measured by conventional scales in terrestrial environment and by the principles of oscillating masses during spaceflight (Thornton & Ord, 1977). The nitrogen balance consisted of daily monitoring of dietary intake and daily collections and analysis of urine and fecal excreta (Whedon, et al, 1977). Only preflight and postflight measurements were possible for TBW, TBK and BVol. Body mass and metabolic balances of nitrogen and potassium were determined daily throughout the preflight, inflight and postflight period.

Pooling of Subjects

The periods of weightlessness associated with each of the three Skylab missions were 28 days, 59 days and 84 days. Data are presented in this and other reports (Rambaut, et al, 1977c) showing that the largest losses in weight occurred during the first month and suggesting that minimal changes are associated with the last two months, especially with regard to body weight, body water and lean body mass. For this reason, as well as the limited number of subjects available (three crewmembers on each flight), it was decided to pool the results of all nine subjects in summarizing changes in body composition. However, the data were also examined and discussed with respect to duration of flight. Paired t-tests were used to assess statistical significance of inflight changes.

Results

A summary of the preflight values and inflight changes of LBM, protein, and fat obtained from the various methods are presented in Table III. Supportive calculations for each method and each subject are shown in the appendix (Table A-1 to A-9).

The inflight body weight changes associated with each method are not all the same in Table III primarily because of the assumptions in computing the preflight control value. For example, total body water was, in general, measured twice over a two-week interval prior to launch, while total body potassium and biostereometry data were obtained more often over a two to four week preflight period. The body weight control value was based on an average of these measurement days. A grand average of 71.73 $\pm$ 8.71 (MSE) kg body weight is obtained from all the daily preflight mass measurements and this value did not change significantly during the control period (Thornton, 1978). The change in body weight measured from the morning of launch to the first shipboard weight immediately after recovery was -2.63 $\pm$ 1.33 (sd) kg for the nine subjects.

The method based on total body potassium did not at first provide reasonable results (labeled "uncorrected" in Table III). The preflight values indicated a higher fat content and lower lean body mass compared to a normal athletic adult population (Wood, 1976; Snyder, 1975) and compared to the other methods used in this study. In addition, the inflight changes in LBM are greater than the total weight changes; as a result the analysis indicated a net mean increase in body fat, which is clearly unacceptable based on a variety of other measurements (Leach & Rambaut, 1977; Whittle, 1979). A corrected lean body mass loss was calculated on the assumption that a significant amount of potassium leaves the cellular compartment independent of other cell constituents due to osmotic gradient considerations. This method yielded more reasonable inflight results, but did not affect preflight values. A full discussion of these calculations and the assumptions on which they are derived are provided in the Discussion, Appendix B and Tables A-3 and A-5.

With the exception of the total body potassium method, there was close agreement in estimates of preflight LBM and fat content among the various methods employed (Table III). The individual subject values of

TABLE III

SUMMARY OF LEAN BODY MASS, PROTEIN AND FAT CHANGES

FOR SKYLAB CREW (H=9) DETERMINED BY VARIOUS METHODS

METHOD	PREFLIGHT		INFLIGHT CHANGES			
	LBM (kg)	% FAT	ΔLBM(kg)	ΔFAT(kg)	ΔPROTEIN(kg)	ΔBODY WGT(kg)
1. Total body water	62.3 ± 6.8	12.8 ± 3.1	-1.12 ± 1.03**	-1.37 ± 1.73*	-0.22 ± 0.20**	-2.49 ± 1.47**
2. Total body potassium						
a) Uncorrected	55.8 ± 7.4	22.3 ± 3.3	-3.63 ± 1.93**	+0.94 ± 2.56	-0.70 ± 0.38**	-2.69 ± 1.53**
b) Correct for inflight osmotic effect	"	"	-1.55 ± 1.96*	-1.14 ± 2.78	-0.31 ± 0.38*	"
3. Total body potassium and total body water						
a) Uncorrected	60.7 ± 6.9	15.3 ± 2.8	-1.56 ± 0.96**	-1.13 ± 1.63	-0.30 ± 0.19**	"
b) Correct for inflight osmotic effect			-1.14 ± 0.85	-1.56 ± 1.63*	-0.22 ± 0.17*	"
4. Nitrogen Balance			-1.63 ± 0.87**	-1.00 ± 1.82	-0.32 ± 0.17**	-2.63 ± 1.46**
5. Biostereometry						
a) Body density	60.3 ± 9.3	16.0 ± 8.6	-1.74 ± 4.03	-1.28 ± 3.75	-0.34 ± 0.78	-3.03 ± 1.64**
b) "Combined" Method	61.3 ± 7.0	14.9 ± 4.5	-1.83 ± 1.25**	-1.20 ± 1.40	-0.36 ± 0.24**	"

* $p < .05$

** $p < .01$

preflight LBM for each method are shown in Table IV along with the correlation coefficients which show a significant degree of correlation between almost all methods. The nitrogen balance method is not amenable for determining absolute values of LBM.

The inflight LBM losses by the various methods ranged from 1.12 to 1.83 kg and from 42% to 62% of total body weight loss*. Protein and fat losses were estimated in Table III to range from 0.22 kg to 0.36 kg and from 0.94 kg to 1.56 kg, respectively. Table V presents the individual subject results for inflight LBM changes derived from each of these methods. Except for an expected strong correlation between the TBW and combined TBW-TBK methods, all other simple correlations between pairs of these methods were not significant at the 95% level. However, weaker relationships were consistently found between the corrected TBK method and all other methods. The biostereometry-body density method, although agreeing on the average with the other methods, exhibited the poorest subject-to-subject correlation with other methods (both preflight and postflight), the highest coefficient of variation and consequently, the least statistically significant inflight losses.

No meaningful trends could be observed between lean body mass loss and flight duration (subjects no. 1-3 were on the shortest flight and subjects no. 7-9 were on the longest flight). This observation helps justify the pooling of all subjects for estimates of mean inflight losses. However, there was consistent agreement among the various methods that the least loss in fat occurred on the longest mission, the same flight on which the least body weight loss occurred.

Losses of nitrogen and potassium from the body are often considered indices of cellular, and hence, lean body mass losses. In addition to measurements of total body potassium, daily metabolic balances (accounting for diet, urine and feces, but not sweat or skin losses) were performed on nitrogen and potassium. A comparison between these two balances is presented in Table A-10 in terms of entire flight averages, and in Table A-11 and Figure 1 in terms of monthly averages. In all cases, the inflight loss of potassium and nitrogen has been expressed as a shift from the preflight

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*In this and subsequent discussions of overall results, the estimates based on uncorrected total body potassium measurements will not be included.

TABLE IV

(A) PREFLIGHT LEAN BODY MASS FROM ALL METHODS*

SUBJECT	METHOD				
	TBW	TBK	TBW & TBK	BODY DENSITY	COMBINED
1	56.8	50.3	55.2	52.2	55.3
2	66.7	60.3	65.1	54.8	63.7
3	71.3	59.5	68.2	66.7	69.1
4	58.1	51.4	56.4	62.7	58.0
5	53.4	47.1	51.8	59.8	53.8
6	73.2	71.5	72.9	81.7	75.4
7	57.2	49.7	55.3	57.3	56.3
8	62.0	56.5	60.7	52.7	59.7
9	62.4	55.6	60.7	55.3	60.3
MEAN	62.3	55.8	60.7	60.4	61.3
SD	6.8	7.5	6.91	9.3	7.1

* in kilograms

(B) CORRELATION COEFFICIENTS FOR METHOD-TO-METHOD COMPARISON

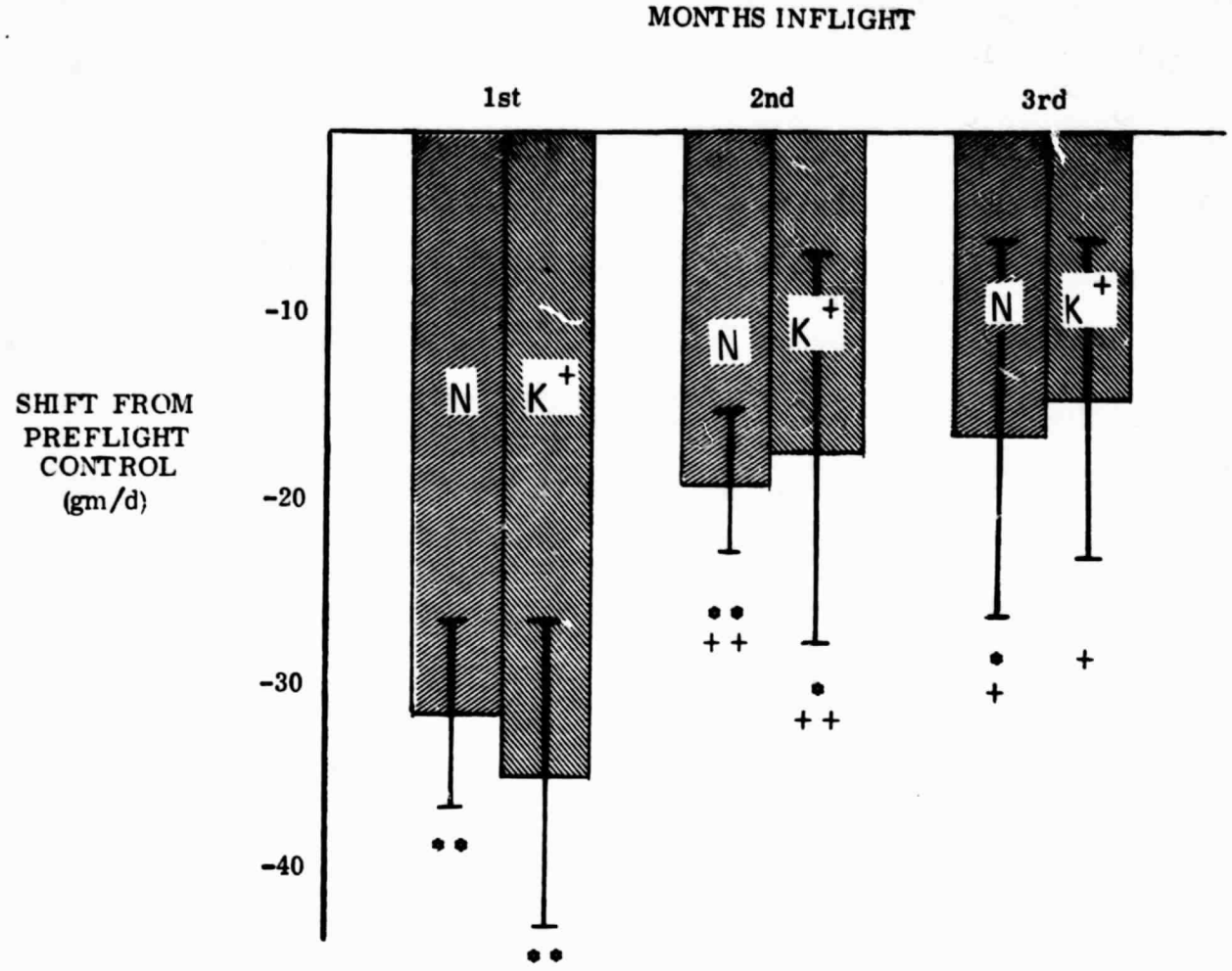
	TBW	TBK	TBW & TBK	BODY DENSITY	COMBINED
TBW	-	-	-	-	-
TBK	0.94**	-	-	-	-
TBW &TBK	1.00**	0.97**	-	-	-
BODY DENSITY	0.64	0.70*	0.66*	-	-
COMBINED	0.97**	0.96**	0.98**	0.79**	-

* ($p < .05$)
** ($p < .01$)

TABLE V

INFLIGHT CHANGES IN LEAN BODY MASS

SUBJECT	METHOD					
	TBW	TBK	TBW & TBK	CUMULATIVE NITROGEN BALANCE	BODY DENSITY	COMBINED METHOD
1	-1.02	-2.09	-1.17	-0.866	-2.43	-1.96
2	-1.10	-1.80	-1.16	-2.00	+2.21	-0.86
3	-2.93	-2.91	-2.74	-1.54	-4.20	-3.65
4	-0.82	-0.32	-0.67	-1.88	-7.47	-2.85
5	+0.69	-0.09	+0.48	-1.48	-4.61	-1.12
6	-2.32	+1.34	-1.43	-1.54	-2.07	-3.38
7	-1.16	-0.45	-0.94	-3.35	-4.49	-1.89
8	-0.68	-2.15	-0.94	-1.84	+3.31	-0.39
9	-0.75	-5.45	-1.65	-0.16	+4.06	-0.36
MEAN	-1.12	-1.57	-1.14	-1.63	-1.74	-1.83
SD	1.03	1.96	0.85	0.87	4.03	1.25
Normalized to ΔBWgt = -2.72	-1.22	-1.58	-1.15	-1.85	-1.56	-1.64



MEAN (±SD) MONTHLY NITROGEN & POTASSIUM BALANCES
EXPRESSED AS INFLIGHT PROTEIN LOSS RELATIVE TO PREFLIGHT

FIGURE 1

* Different from Preflight * ($P<.05$), ** ($P<.01$)

\+ Different from 1st month + ($P<.05$), ++ ($P<.01$)

control value. The mean daily losses of nitrogen and potassium have been converted to the common units of grams of protein by using the factors 6.25 gm protein per gm nitrogen (Calloway, 1974) and 2.23 gm muscle protein per meq potassium (Snyder, 1975). In Figure 1, the entire population of nine subjects is represented in the first months data, while the second and third months include six and three subjects, respectively. The control group followed the same pattern. This balance analysis demonstrates a similar time profile for both constituents. Both show the largest losses during the first month with losses half as large thereafter. Similar losses during the last two months suggest an attainment of a steady-state loss rate.

DISCUSSION

Accuracy

The estimates for preflight lean body mass and fat content (Table II) all fall within the range previously reported for either active or athletic males (Wood, 1976; Ward, et al, 1975). In addition, the coefficient of variation for each of the different methods is, on the average, considerably less than demonstrated for at least one other comprehensive comparative study (Ward, et al, 1975) attesting to the narrow variability in the combined population variability plus measurement error. There is less precision in estimation of the changes in LBM during flight although all methods indicate a loss of at least one kilogram. Losses of this magnitude encroach upon the limits of accuracy of all the methods employed (Keys & Brozek, 1953; Krzywicki, et al, 1974; Siri, 1956; Whittle, 1978).

There have been few other comparative studies which measure relative accuracy in body composition by several methods (i.e. Krzywicki,et al, 1974; Ward, et al, 1975) and none to our knowledge in which changes in body composition were estimated by multiple methods following a stress or treatment phase. Absolute accuracy of any of these indirect methods is hampered by lack of a suitable direct method for verification. The stereophotometrically-determined body density method used in the Skylab studies is a relatively recent innovation and its accuracy still needs to be assessed (Whittle, 1978; Herron, 1971). Although the mean values for

LBM derived from this method are in agreement with results obtained from the other methods, it was the only procedure that failed to achieve statistical significance for inflight losses. There are certain methodological considerations with regard to the other procedures considered herein which could have contributed toward method-to-method variations. These are discussed below.

Methodological Considerations

The determination of body composition from the methods used in this study assumes that the body tissues (fat and fat-free) have a fixed density as well as an unvarying proportion of water or potassium. Furthermore, estimates of changes in body composition demands that water, potassium and nitrogen be lost from the lean body in the same proportion as they exist in the normal intact individual. Agreement between the different methods may be limited by the degree to which these assumptions are correct.

There appears to be much more evidence available verifying the accuracy of these methods in measuring absolute values in a control population than there is regarding the ability to estimate changes in body composition resulting from some disturbance. For example, while total body potassium is clinically useful in predicting total LBM (Edmonds, et al, 1975), this does not demonstrate that small changes in body potassium are a reliable measure of corresponding changes in LBM or body protein. It has been emphasized that the normally strong correlations between total body water, total body potassium or nitrogen, and lean body mass are invalidated in certain conditions (Muldowney & Healy, 1967). It has also been noted that in starvation, infection, tissue ischemia, and anoxia tissues are depleted of potassium and water in amounts proportionally greater than the protein loss (Grande, 1968; Black, 1964). Other investigators have reported large variability of results in assessing body composition changes using potassium-based methods as opposed to nitrogen balance (Yang & Van Itallie, 1976). Potassium loss from cells can occur not only from actual breakdown of protein, but also from loss of intracellular fluid and inefficiency of the energy metabolism process on which the maintenance of the transcellular membrane

potassium gradients must depend (Black, 1964). A constancy of lean body density (i.e. the premise underlying this method) would demand proportional losses of both tissue solids (protein and electrolytes) and water.

In weightlessness, the quantities of protein, electrolytes and water are known to change. More importantly, they are believed to be depleted from the body at widely different rates. Water and sodium, for example, exhibit large reductions within the first several days of hypogravity mainly due to internal fluid disturbances while changes in the cell protein pool are influenced by slower acting metabolic processes (Leach & Rambaut, 1977). Anorexia associated with space motion sickness early in flight would be expected to augment loss of cell components including fat. These findings are supported by ground-based hypogravic stress studies such as water immersion (Kollias, et al, 1976) and bed rest (Greenleaf, et al, 1977 ; Pace, et al, 1976). Thus, it is questionable that the proportions between whole-body constituents observed during preflight conditions are maintained during the non-steady-state conditions of the inflight period. Whether or not the net results of these inflight changes are to establish a new equilibrium level appropriate to the zero-g state with the same proportions of body composition as in 1-g is not known. Analyses of data that utilized this assumption, such as those presented here, should be interpreted with some caution. In our favor, is the fact that the data analyzed herein was obtained after one to three months inflight, a period long enough to perhaps have achieved a new steady-state. More direct measurements such as can be obtained from tissue biopsy samples may provide further information regarding the dynamic relationships between water, mineral, and protein at the cell level.

Errors in TBK Method

The unreasonably high values for LBM losses derived from the TBK method was examined by considering the following factors:

a) The factor of 65 meq K^+/kg LBM is not appropriate for the astronaut population. Values from the literature show that the potassium content of the lean body mass is within the range 60 - 70 meq K^+/kg (Snyder, 1875; Allen, 1960; Womersley, 1976). If we accept the mean inflight LBM loss of about 1.5 kg obtained by the other methods (see Table III), then

the measured inflight loss of 236 meq K would require a concentration of 236/1.5 = 157 meq K^+/kg LBM, a value so far out of the normal range that other explanations must be sought.

b) From the above discussion, the possibility must be considered that the measured values of TBK are erroneous and the potassium losses were overestimated. The total accuracy of the isotope dilution method for K^{40} may be several percent (Pierson, et al, 1974). If there were a systematic error of this amount in the technique used in the Skylab study, it could explain most of the discrepancy in the calculation of LBM loss. It has been noted that in certain pathological situations this technique is subject to large errors in predicting LBM (Muldowney & Healey, 1967). Preflight values were reasonable, and it is not clear that the inflight conditions represents a departure from the suitability of this method.

c) A significant fraction of the measured TBK loss was unaccompanied by other cellular components such as nitrogen and water (which constitute about 90% of LBM). We have discussed earlier that the ratios water:potassium:nitrogen in lost body mass is often greater than one would expect from the normal cellular ratios of these components. Although the reasons for this are not clear, and the metabolic balance data for the nitrogen and potassium (Figure 1) admittedly does not support this conclusion, it is possible that this phenomena occurred in the Skylab crew.

In addition to the high values of lean body mass loss predicted by the uncorrected TBK method, the expected intracellular water loss also appears rather high. Using a value of 160 meq/liter for the intracellular potassium concentration (Pitts, 1968), it would be expected that 1.5 liters of cell water would be lost with 236 meq potassium assuming potassium to be the most significant osmotically active substance undergoing change. This is large compared not only to the total weight loss, but also to the measured total body water change of 0.8 liters and the derived intracellular water loss of 0.5 liters (Leach and Rambaut, 1977).

In search of an explanation for these discrepancies, we noted a mild, but persistent dilution of sodium concentration and osmolarity in extracellular fluid as measured from plasma samples obtained at regular intervals throughout the flight (Leach and Rambaut, 1977). This was also noted in several bed rest studies (Chobanian, 1974; Johnson & Mitchell, 1977),

and while it has not yet been explained, osmotic balance demands that intracellular fluid was similarly dilute (Bland, 1963). Also, it can be shown that a lesser amount of water will be expected to accompany potassium osmotically from the cell if body fluids become hypotonic. We have, therefore, postulated two components of potassium loss: an osmotic loss which satisfies osmotic balance in the face of extracellular dilution and a muscle atrophy loss which is accompanied by nitrogen and other cellular constitutents. This assumption has been translated into quantitative terms using the changes in plasma sodium concentration as correction factors. A sample calculation appears in the appendix and results for individual subjects are shown in Table A-3.

While this is admittedly a speculative exercise, the predicted LBM and intracellular water losses are in much close agreement with other independent measurements after the correction is applied (Appendix B and Table III). The significant increases in aldosterone, cortisol and catecholamines observed during the flight (Leach & Rambaut, 1977) support the concept that unusual potassium losses from cells may have occurred.

Nitrogen and Potassium Balances

The loss rates of nitrogen and potassium, as measured by metabolic balance and computed as change from control, are in a ratio consistent with the normal skeletal muscle composition. The overall inflight loss ratio, Δ K: ΔN = 11.9 meq/d: 4.2 gm/d = 2.86 (Table A-8), compared to 2.80 given for the normal potassium:nitrogen content of skeletal muscle tissue (Snyder, 1975). However, when these losses are expressed in terms of equivalent protein (about 26 gm/d) and summed over the average Skylab flight of 57 days, a total depletion of 1.5 kg protein or 7.7 kg LBM (assuming protein is 19.4% of LBM) is calculated. This is over three times the total weight loss and is obviously erroneous in spite of the good correlation between relative changes in nitrogen and potassium balance. Explanations for this discrepancy could include: a) a true positive balance of body protein during the control phase which when subtracted from the inflight balance overestimates the true inflight loss, and b) errors in balance collection and chemical analysis which do not cancel by subtracting preflight control

balance from inflight balance because the errors are different during these two mission phases. For example, sweat or skin losses may not be the same in 1-g and zero-g (Leach, et al, 1978). Even when maximal nitrogen losses from body surfaces are accounted for (i.e. 0.5 - 1.0 gm/d; Calloway, et al, 1971), the preflight nitrogen balance still indicates a high retention rate. A similar analysis argues for preflight potassium retention, although total body potassium measurements performed throughout the preflight period do not suggest any change in this quantity, a discrepancy we cannot resolve. The interpretation of positive protein retentions derived from metabolic balances, although observed by many other, have been questioned (Hegsted, 1976), but sources of methodological errors in carefully controlled studies are not apparent (Steffee, 1976). The inflight nitrogen balance, without correction for sweat losses or preflight balance, provides reasonable estimates of inflight loss and is the basis for one of the methods for determining LBM loss in our analysis.

Muscle Atrophy

It is now well known that atrophy of skeletal muscle occurs in response to disuse, inadequate functional load, insufficient food intake and lack of exercise (Goldspink, 1972; Booth, 1977; Fedorov, et al, 1977). Spaceflight may be associated with more than one of these conditions since the absence of gravity favors diminished use of the lower limbs for postural support and locomotion, a reduced loading on weight-bearing tissues, and interference with proprioreceptor reflexes which can influence muscle metabolism and function (Parin, 1975; Thornton, et al, 1977). Also, the amount of exercise varied several fold among the three Skylab crews, ranging from what could be considered minimal to intensive work (Rummel, et al, 1975). Dietary intake was reduced considerably during periods of space motion sickness (Rambaut, et al, 1977c),a condition known to promote net protein breakdown (Golden, et al, 1977; Steffee, et al, 1976).

Different types of muscles are known to be affected to different extents depending upon the specific stress. Thus, simple disuse (i.e. immobilization) will preferentially affect slow-twitch, fatigue resistant red fibers which normally control anti-gravity or postural functions

(Dorchak & Greenleaf, 1976). Major postural muscle groups in man are found in the calves, trunk and neck (Lockhart, 1972). Recent ground-based animal studies have demonstrated that rates of protein synthesis and muscle weight in slow fiber groups diminish significantly within one to three days after limb immobilization (Booth, 1977). On the other hand, exercise of high intensity will preferentially cause hypertrophy of slow-twitch fibers while starvation appears to degrade the fast-twitch, easily fatigable,white fibers. While the biochemical mechanisms involved in these processes are not well understood, muscle atrophy is associated with the following characteristics: a) a diminished muscle mass, fiber diameter, contractile strength and number of myofibrils, b) increased stiffness and fatigability, and c) changes in isozyme spectrums (Goldspink, 1972; Petrova & Portugalov, 1977).

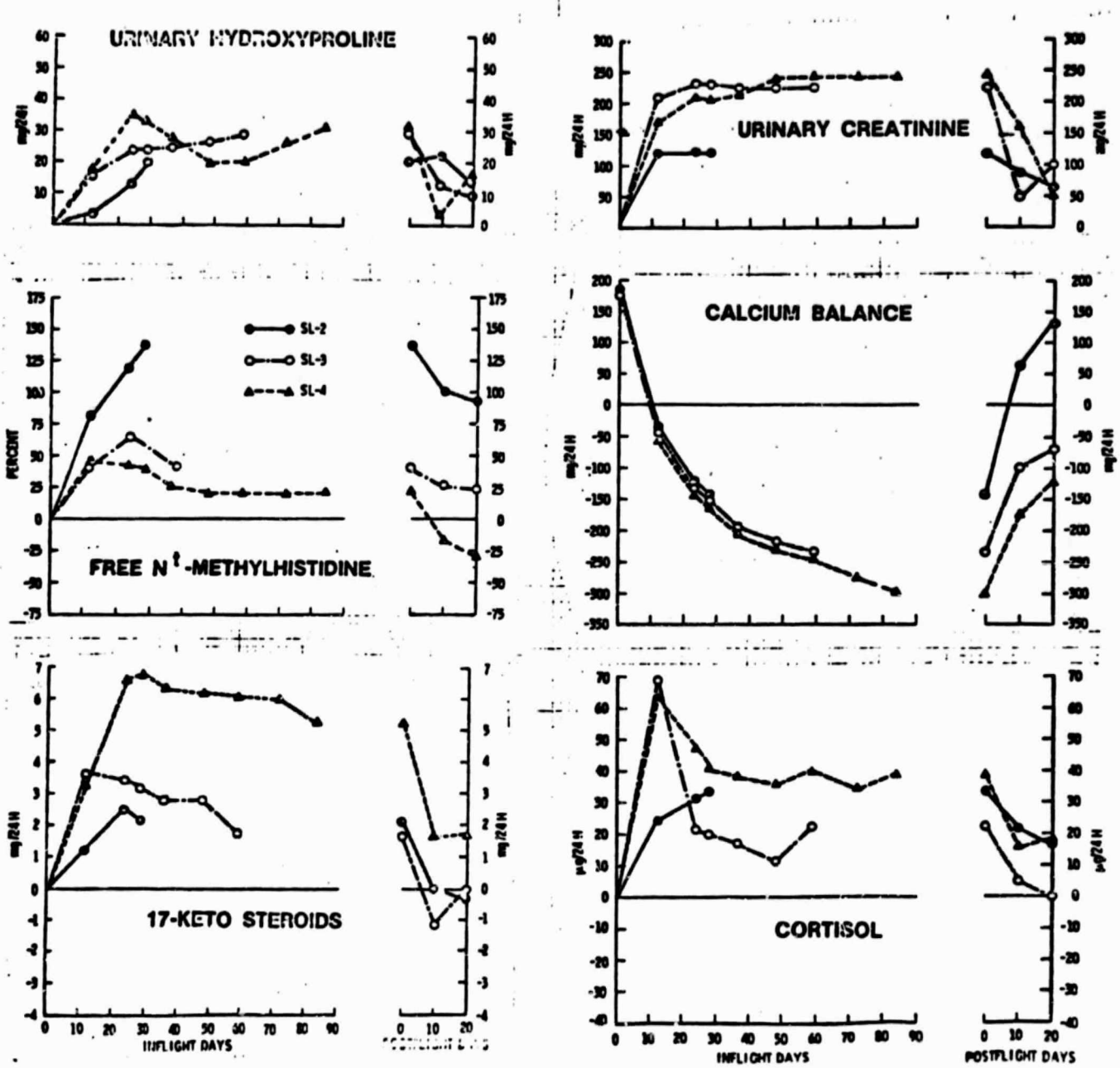
Spaceflight studies conducted on rats have confirmed that weightlessness results in unloading of slow anti-gravity muscles accompanied by diminished strength and mass and demonstrated a similarity between lack of gravity during spaceflight and lack of movement during immobilization (Oganov and Potapov, 1976; Il'ina-Kakuyeva, et al, 1977). It would be expected that subjects performing intensive physical exercise in flight would tend to counterbalance and perhaps conceal these atrophic effects (Mailyan & Kivalenko, 1976). The Skylab data supports these findings by demonstrating: a) a consistent loss of lean body mass, b) a reversal of nitrogen balance from positive to negative within two days for all nine subjects, c) diminished leg strength and volume which showed marked improvement associated with intensive exercise (leg tissue is relatively fat-free), and d) altered electromyographic response from calf muscles indicating dysfunction characteristics and heightened fatigability (Johnson & Dietlein, 1977; LaFevers, et al, 1975). The observation of bone demineralization during spaceflight (Whedon, et al, 1977; Rambaut, et al, in press) is also relevant to the concept of a generalized atrophic response of the musculoskeletal system in toto during hypodynamic and hypogravity (Pace, 1977; Pestov & Gerathowohl, 1975). In addition, analysis of the nitrogen balance data (Figure 1) suggests that muscle atrophy

during the first several weeks of spaceflight proceeds at a high rate independent of the level of exercise. Thereafter, the rate of loss diminishes considerably perhaps due to gradual adaptive changes or to increasing levels of exercise. Taken as a whole, this discussion supports the premise that some muscle loss, especially slow twitch, postural maintaining fibers, is inevitable during the initial phases of flight. It, therefore, follows that the most beneficial zero-g exercise for counteracting this effect might be that which affects postural muscle groups (i.e. toe and heel rises, and body bends against an elastic restraint (Thornton & Rummel, 1977)). Other aerobic type exercise (i.e. bicycle ergometer) may be more useful to maintain cardiovascular conditioning.

Conclusions and Recommendations

The general conclusion of this study, obtained from averaging results of the six methods, is that a weight loss of 3.8% observed during the Skylab missions can be attributed to a 2.5% loss in lean body mass and a 10.4% loss in body fat corresponding to the following inflight losses: Δ body weight = 2.7 ± 0.3 kg, ΔLBM = 1.5 ± 0.3 kg and Δbody fat = 1.2 ± 0.3 kg. Using the relationships that protein is 19.4% of LBM and water is 73.2% of LBM we find total body decrements of water and protein to be 1.1 kg and 0.3 kg, respectively. Supportive evidence for these losses, although not suitable for quantitative evaluation of whole body changes, comes from measurements of leg volume (Hoffler, 1977) and other body segments (Whittle, 1979), intracellular and extracellular fluid volumes (Leach & Rambaut, 1977; Johnson, et al, 1977), urinary methylhistidine, cortisol creatinine, 17-keto steroids, and hydroxyproline, (see Figure 2) plasma pottasium concentrations (Leach & Rambaut, 1977), metabolic balances for cellular electrolytes (i.e. magnesium, phosphorus, calcium; Rambaut, et al, 1977c), limb strength tests (Thornton & Rummel, 1977) and skinfold measurements (Rambaut, et al, 1977a).

There was no apparent trend to indicate that losses continued with increasing periods of weightlessness. In fact, the longest mission (84 days) was characterized by the smallest losses in weight and body fat. Inasmuch as dietary caloric intake and exercise was also increased



Indices of musculoskeltal degradation measured on the three Skylab missions. Urinary hydroxyproline, methylhistidine, 17-keto steroids and creatinine reflect losses of connective tissue and lean body mass. The negative calcium balance is indicative of bone demineralization. Protein catabolism is often associated with release of cortisol.

FIGURE 2

by this crew, it is difficult to separate out the effects of flight duration, exercise and diet. However, this does suggest that with an adequate diet and appropriate exercise weight losses can be minimized, but probably not eliminated. The weight changes which may be the most difficult to prevent are those associated with the musculoskeletal system (see discussion above) and water loss. An obligatory loss in body water has long been suspected due to volume receptor reflexes responding to headward shifts of fluid in hypogravity (McCally & Graveline, 1963; Leach & Rambaut, 1977). Decrements in body water and plasma volume have been repeatedly demonstrated during water immersion and bed rest (Kollias, et al, 1976; Greenleaf, et al, 1976).

All of the methods examined in this study are indirect and none truly measures the compartment usually designated as lean body mass. While measurements of total body water, potassium and metabolic balances are useful for the quantities they measure directly we have discussed the problems associated with their assessment of LBM during periods of acute loss when cellular constituents are rapidly changing. The next generation of spaceflight missions will involve flights of one or two weeks, much shorter than the Skylab flights. Body density methods may be a more reliable indicator of body composition changes if it can be shown that overall densitites of lean and fat tissues are reasonably constant under these conditions. The value of stereophotometry in spaceflight has been demonstrated for examining regional body volumes and anthropometric changes (Whittle, 1979), but at the present time, underwater hydrostatic weighing would appear to be a superior system for determining body density. In addition, inflight muscle biopsy procedures in man or animals could provide information regarding proportionate changes of cellular constituents. The problems raised in this paper concerning total body potassium measurements and metabolic balances should be addressed. Losses of nitrogen and electrolytes from the skin during rest and exercise should be directly measured inflight. Recent innovations in neutron-activation analysis seem promising for providing simplified procedures and improved accuracy in measuring whole-body components of lean body mass. Measurements of this nature performed during spaceflight could also be applied to understanding tissue degradation and recovery rates of patients confined to bed or immobilized by casts.

APPENDICES

TABLE A-1

LBM FROM TBW OF SKYLAB CREW*

	PREFLIGHT				POSTFLIGHT				DIFFERENCES			
SUBJECT	BWgt (Kg)	TBW (l)	LBM (Kg)	Fat (%)	BWgt (Kg)	TBW (l)	LBM (Kg)	Fat (%)	ΔBwgt (Kg)	ΔLBM (Kg)	ΔFat (Kg)	ΔProtein (Kg)
1	62.0	41.55	56.76	8.5	60.2	40.8	55.74	7.4	-1.80	-1.02	-0.78	-0.198
2	77.65	48.8	66.67	14.1	73.8	48.0	65.57	11.1	-3.85	-1.10	-2.75	-0.213
3	79.95	52.15	71.27	10.9	76.0	50.0	68.31	10.1	-3.95	-2.93	-1.02	-0.568
4	68.4	42.5	58.06	15.1	64.6	41.9	57.24	11.4	-3.80	-0.82	-2.98	-0.159
5	62.5	39.1	53.41	14.5	58.7	39.6	54.10	7.8	-3.80	+0.69	-4.49	+0.134
6	86.7	53.6	73.22	15.5	84.1	51.9	70.90	15.7	-2.6	-2.32	-0.28	-0.450
7	67.8	41.85	57.17	15.7	67.9	41.0	56.01	17.5	+0.1	-1.16	+1.26	-0.225
8	71.3	45.4	62.02	13.0	69.8	44.9	61.34	12.1	-1.5	-0.68	-0.82	-0.132
9	67.4	45.65	62.36	7.5	66.2	45.1	61.61	6.9	-1.2	-0.75	-0.45	-0.146
MEAN	71.52	45.62	62.32	12.8	69.03	44.8	61.20	11.1	-2.49	-1.12	-1.37	-0.217
SD	±8.30	±5.0	±6.82	±3.1	±8.0	±4.4	±5.99	±3.6	±1.47	±1.03	±1.73	± .199
									(p<.01)	(p<.01)	(p<.05)	(p<.01)

* $LBM = \frac{TBW}{0.732}$

FAT = BWgt - LBM

PROTEIN = 0.194 x LBM

TABLE A-2

LBM FROM TBK OF SKYLAB CREW*

	PREFLIGHT				POSTFLIGHT				DIFFERENCES			
SUBJECT	BWgt[1] (Kg)	TBK (meq)	LBM (Kg)	Fat (%)	BWgt (Kg)	TBK (1)	LBM (Kg)	Fat (%)	ΔBWgt (Kg)	ΔLBM (Kg)	ΔFat (Kg)	ΔProtein (Kg)
1	62.21	3269	50.3	19.2	60.2	2998	46.1	23.4	-2.01	-4.17	+2.16	-0.81
2	77.89	3917	60.3	22.6	73.8	3678	56.6	23.3	-4.09	-3.68	-0.41	-0.71
3	80.18	3867	59.5	25.8	76.0	3528	54.3	28.6	-4.18	-5.21	+1.03	-1.01
4	68.56	3339	51.4	25.1	64.6	3151	48.5	24.9	-3.96	-2.89	-1.07	-0.56
5	61.82	3062	47.1	23.8	58.7	3029	46.6	20.6	-3.12	-0.51	-2.61	-0.10
6	88.01	4647	71.5	18.8	84.1	4485	69.0	18.0	-3.91	-2.49	-1.42	-0.48
7	67.75	3228	49.7	26.7	67.9	3108	47.8	29.6	+0.15	-1.84	+1.99	-0.35
8	71.51	3673	56.5	21.0	69.8	3348	51.5	26.2	-1.71	-5.00	+3.29	-0.97
9	67.60	3614	55.6	17.8	66.2	3169	48.8	26.3	-1.40	-6.85	+5.45	-1.33
MEAN	71.73	3624	55.8	22.3	69.03	3388	52.18	24.5	-2.69	-3.63	+0.93	-0.70
SD	±8.7	± 484	±7.4	±3.3	±8.0	±471	±7.2	±3.7	±1.53	±1.93	±2.56	± .38
									(p<.01	p<.01)	N.S.	(p<.01)

* $LBM = \frac{TBK}{65}$

1 Body Wgt: Preflight values are means for entire 2-3 wk. preflight period
Postflight values from day of TBK measurement (R+0 or R+1)

TABLE A-3
INFLIGHT LBM FROM TBK METHOD
- Corrected for Dilution Effect -

SUBJECT	ICF (liters)	[ΔNa] (meq/l)	ΔTBK Estimated Osmotic Loss (meq)	ΔTBK Measured (meq)	ΔTBK Corrected (meq)	ΔLBM (Kg)	ΔProtein (Kg)	ΔFat (Kg)	ΔBWgt (Kg)
1	25.4	- 5.3	- 135	-271	-136	- 2.09	- .406	+ 0.08	- 2.01
2	33.3	- 3.65	- 122	-239	-117	- 1.80	- .349	- 2.29	- 4.09
3	36.6	- 4.10	- 150	-339	-189	- 2.91	- .565	- 1.27	- 4.18
4	24.6	- 6.8	- 167	-188	- 21	- 0.32	- .062	- 3.64	- 3.96
5	24.4	- 1.11	- 27	- 33	- 6	- 0.09	- .018	- 3.03	- 3.12
6	34.7	- 7.18	- 249	-162	+ 87	+ 1.34	+ .260	- 5.25	- 3.91
7	28.0	- 3.25	- 91	-120	- 29	- 0.45	- .087	+ 0.60	+ 0.15
8	29.0	- 6.37	- 185	-325	-140	- 2.15	- .417	+ 0.44	- 1.71
9	30.3	- 3.0	- 91	-445	-354	- 5.45	-1.06	+ 4.05	- 1.40
MEAN	29.6	- 4.53	- 135	-236	-101	- 1.55	-0.30	- 1.14	- 2.69
SD	4.4	2.02	64	125	128	1.97	0.38	2.78	1.53
		(p <.001)	(p <.01)	(p <.01)	(p <.05)	(p <.05)	(p <.05)	NS	(p <.01)

Key: ICF = Intracellular fluid (measured preflight)

[ΔNa] = Average change in sodium plasma concentration (measured inflight)

ΔTBK (osmotic loss) = ICF x [ΔNa]

ΔTBK (corrected) = ΔTBK (measured) - ΔTBK (osmotic loss)

ΔLBM = ΔTBK/65

ΔProtein = ΔLBM x 0.194

TABLE A-4

LBM FROM COMBINED TBW AND TBK OF SKYLAB CREW*

	PREFLIGHT		POSTFLIGHT		DIFFERENCES		
SUBJECT	LBM (Kg)	% Fat	LBM (Kg)	% Fat	ΔLBM (Kg)	ΔFat (Kg)	ΔProtein (Kg)
1	55.2	11.4	53.6	11.0	-1.60	-0.42	-0.31
2	65.1	16.4	63.6	13.8	-1.55	-2.54	-0.30
3	68.2	14.9	65.0	14.5	-3.21	-0.97	-0.62
4	56.4	17.8	55.2	14.6	-1.19	-2.77	-0.23
5	51.8	16.1	52.2	11.1	+0.40	-3.52	+0.77
6	72.9	17.1	70.7	15.9	-2.21	-1.71	-0.43
7	55.3	18.4	54.1	20.3	-1.22	+1.37	-0.24
8	60.7	15.1	59.2	15.2	-1.51	-0.20	-0.29
9	60.7	10.2	58.8	11.2	-1.94	+0.54	-0.38
MEAN	60.7	15.3	59.2	14.2	-1.56	-1.13	-0.30
SD	±6.92	±2.8	±6.2	±3.0	±0.96	±1.63	±0.19
					(p<.01)	(p<.05)	(p<.01)

NOTE: 1) Use TBW and TBK from tables of "LBM from TBW" and "LBM from TBK"

2) Use body weights given in table of "LBM from TBK"

$$LBM = TBW + \frac{TBK}{320.6} + \frac{0.334 - TBK'}{320.6}$$

where TBK' = preflight value

TABLE A-5

INFLIGHT ΔLBM FROM COMBINED TBW-TBK METHOD

(Corrected for Dilution Effect)

SUBJECT	ΔTBK* Cor. (meq)	ΔTBW** (l)	ΔLBM*** (Kg)	ΔFAT (Kg)	ΔPROTEIN	ΔBWgt (Kg)
1	- 136	-0.75	-1.17	-0.84	- 0.23	-2.01
2	- 117	-0.80	-1.16	-2.93	- 0.23	-4.09
3	- 189	-2.15	-2.74	-1.44	- 0.53	-4.18
4	- 21	-0.60	-0.67	-3.29	- 0.13	-3.96
5	- 6	+0.50	+0.48	-3.60	+ 0.093	-3.12
6	+ 87	-1.70	-1.43	-2.48	- 0.28	-3.91
7	- 29	-0.85	-0.94	+1.09	- 0.18	+0.15
8	- 140	-0.50	-0.94	-0.77	- 0.18	-1.71
9	- 354	-0.55	-1.65	+0.25	- 0.32	-1.40
MEAN	- 100.6	-0.82	-1.14	-1.56	- 0.22	-2.69
SD	128	-0.75	0.85	*1.63	0.17	1.53
	p <.05	p <.05	p <.01	p <.05	p <.05	p <.01

* From Table A-3

** From Table A-1

*** See Table A-4 for equation

TABLE A-6

ΔLBM FROM NITROGEN BALANCE*

SUBJECT	INFLIGHT NITROGEN BALANCE (gm/d)	INFLIGHT CHANGES			
		ΔPROTEIN (gm)	ΔLBM (Kg)	ΔFAT (Kg)	ΔBWGT (Kg)
1	- 0.96	-168	-0.866	- 0.23	- 1.1
2	- 2.22	-389	-2.00	- 0.70	- 2.7
3	- 1.71	-299	-1.54	- 1.66	- 3.2
4	- 0.99	-365	-1.88	- 2.02	- 3.9
5	- 0.78	-288	-1.48	- 2.12	- 3.6
6	- 0.81	-299	-1.54	- 2.66	- 4.2
7	- 1.24	-650	-3.35	+ 3.35	0
8	- 0.68	-356	-1.84	+ 0.44	- 1.4
9	- 0.06	-314	- 0.16	- 1.24	- 1.4
MEAN	- 1.05	-316	- 1.63	- 0.76	-2.39
SD	± 0.62	±168	± 0.87	± 1.82	±1.46
	(p <.01)	(p <.01)	(p <.01)	N.S.	(p <.01)

* ΔProtein = mission length x 6.25 x N Bal.

Mission Length: 28 days (Subjects 1-3)
59 days (Subjects 4-6)
84 days (Subjects 7-9)

$$\Delta LBM = \frac{\Delta Protein\ (Kg)}{.194}$$

TABLE A-7

CORRECTED BODY DENSITIES OF SKYLAB CREW*

SUBJECT	RESIDUAL VOLUME (liters)	PREFLIGHT			POSTFLIGHT			
		BWgt. (Kg)	Volume (cor)* (l)	Density (gm/ml)	BWgt (Kg)	Volume (unc) (l)	Volume (cor) (l)	Density (g/ml)
1	1.94	62.77	59.00	1.064	60.21	60.82	56.62	1.063
2	2.01	78.09	75.22	1.038	74.28	74.78	70.65	1.051
3	1.87	81.15	76.42	1.062	75.98	75.25	71.26	1.066
4	1.90	68.68	63.55	1.081	64.18	64.11	59.98	1.070
5	2.10	61.95	56.74	1.092	58.29	57.97	53.58	1.088
6	1.85	88.07	81.23	1.084	84.14	81.27	77.36	1.088
7	1.91	68.11	63.87	1.066	67.93	68.61	64.52	1.053
8	1.73	71.44	68.38	1.045	68.95	68.95	65.04	1.060
9	1.96	67.62	63.71	1.061	66.68	66.15	61.98	1.076
MEAN SD	$\pm^{1.92}_{-}$ .104	$\pm^{71.99}_{-}$ 8.74	$\pm^{67.57}_{-}$ 7.56	$\pm^{1.0659}_{-}$ .0177	$\pm^{68.96}_{-}$ 8.12	$\pm^{68.66}_{-}$ 7.44	$\pm^{64.55}_{-}$ 7.56	$\pm^{1.0683}_{-}$ .013

* All data shown, except corrected postflight volumes and postflight densities, taken from Whittle (1978).

** Vol. (cor) = Vol (unc) x 1.01 - 2868 - Resid. Vol.

TABLE A-8

LBM FROM BODY DENSITY
OF SKYLAB CREW*

MAN	PREFLIGHT		POSTFLIGHT		DIFFERENCES (Kg)			
	LBM(Kg)	% Fat	LBM(Kg)	% Fat	ΔBWgt	ΔLBM	ΔFat	ΔProtein
1	52.21	16.8	49.78	17.3	- 2.56	- 2.43	- 0.13	-0.471
2	54.81	29.8	57.02	23.2	- 3.81	+ 2.21	- 6.02	+0.429
3	66.70	17.8	62.50	15.9	- 5.17	- 4.20	- 0.97	-0.815
4	62.71	8.7	55.24	13.9	- 4.50	- 7.47	+ 2.97	-1.45
5	59.75	3.6	55.14	5.41	- 3.66	- 4.61	+ 0.95	-0.894
6	81.66	7.3	79.59	5.41	- 3.93	- 2.07	- 1.86	-0.402
7	57.31	15.9	52.82	22.2	- 0.18	- 4.49	+ 4.31	-0.87
8	52.69	26.2	56.00	18.8	- 2.49	+ 3.31	- 5.80	+0.642
9	55.25	18.3	59.31	11.1	- 0.94	+ 4.06	- 5.00	+0.788
MEAN	60.34	16.0	58.60	14.8	- 3.03	- 1.74	- 1.28	- .338
SD	±9.30	±8.57	±8.66	±6.5	± 1.64	± 4.03	± 3.75	± .782
					(p<.01)	N.S.	N.S.	N.S.

* a) $\text{LBM} = \text{BWgt}\left[6.0098 - \frac{5.5095}{D}\right]$

b) Fat = BWgt - LBM

c) Δ Protein = .194 x LBM

TABLE A-9

LBM FROM "COMBINED" METHOD USING STEREOPHOTOGRAPHY*

SUBJECT	BODY WEIGHT (KG)			LEAN BODY MASS (KG)			BODY FAT (KG)		
	PREFLIGHT	POSTFLIGHT	DIFFERENCE	PREFLIGHT	POSTFLIGHT	DIFFERENCE	PREFLIGHT	POSTFLIGHT	DIFFERENCE
1	62.77	60.21	-2.56	55.31	53.35	-1.96	11.9	11.4	-0.60
2	78.09	74.28	-3.81	63.73	62.87	-0.86	18.4	15.4	-2.95
3	81.15	75.98	-5.17	69.14	65.49	-3.65	14.8	13 8	-1.52
4	68.68	64.18	-4.50	58.03	55.18	-2.85	15.5	14.0	-1.65
5	61.95	58.29	-3.66	53.79	52.67	-1.12	13.2	9.6	-2.54
6	88.07	84.14	-3.93	75.37	71.99	-3.38	14.4	14.4	-0.55
7	68.11	67.93	-0.18	56.32	54.43	-1.89	17.3	19.9	+1.71
8	71.44	68.95	-2.49	59.66	59.27	-0.39	16.5	14.0	-2.10
9	67.62	66.68	-0.94	60.25	59.89	-0.36	10.9	10.2	-0.58
MEAN	71.99	68.96	-3.03	61.29	59.46	-1.83	14.9	13.6	-1.20
SD	8.74	8.12	1.64	7.04	6.44	1.25	4.5	3.1	1.40
			(p<.01)			(p<.01)			(p<.05)

* Results taken from Whittle, 1978.

TABLE A-10

NITROGEN AND POTASSIUM BALANCES

OF SKYLAB CREW

MAN	NITROGEN BALANCE (gm/d)			POTASSIUM BALANCE (meq/d)		
	Preflight	Inflight	Δ	Preflight	Inflight	Δ
1	2.95	- 0.96	- 3.91	21.71	5.53	- 16.18
2	3.12	- 2.22	- 5.34	24.94	5.04	- 19.90
3	3.00	- 1.71	- 4.71	17.33	5.11	- 12.22
4	3.07	- 0.99	- 4.06	17.84	5.01	- 12.88
5	3.42	- 0.78	- 4.20	14.03	6.43	- 7.60
6	4.05	- 0.81	- 4.86	23.19	12.79	- 10.40
7	3.31	- 1.24	- 4.55	12.30	1.13	- 11.17
8	2.20	- 0.68	- 2.88	13.62	6.93	- 6.69
9	2.78	- 0.06	- 2.84	17.48	7.79	- 9.69
MEAN	3.10	- 1.05	- 4.15	18.05	6.20	- 11.86
SD	±0.50	± 0.62	± 0.85	± 4.43	±3.09	± 4.13

Correlation coefficient: ΔN vs. $\Delta K = 0.59$ ($p < .01$)

* No corrections for sweat

Avg. Protein Loss

From ΔN: $\left[\sum_{i}^{9} (\Delta N_i \times ML_i)\right] /9 \times 6.25 = 1400$ gm

From: ΔK: $\left[\sum_{i}^{9} (\Delta K_i \times ML_i)\right] /9 \times 2.23 = 1360$ gm

TABLE A-11

NITROGEN AND POTASSIUM BALANCES OF SKYLAB CREW:

MONTHLY AVERAGES

INFLIGHT PERIOD	N	NITROGEN BALANCE (gm/d)					POTASSIUM BALANCE (meq/d)				
				DIFFERENCES					DIFFERENCES		
		PREFLIGHT	INFLIGHT	ΔN	ΔPRO	$\Delta\overline{PRO}$	PREFLIGHT	INFLIGHT	ΔK	ΔPRO	$\Delta\overline{PRO}$
1st Month	9	3.10 ± .50	-1.95** ± .48	-5.05 ± .80	-31.6 ± 5.0	-0.44 ± .07	18.05 ±4.43	3.77** ±2.43	-14.3 ± 3.6	-34.8 ± 8.0	-0.49 ± .11
2nd Month	6	3.14 ±.62	+0.10** ± .17	-3.04++ ± .58	19.0 ±3.6	-0.27 ± .05	16.42 ±4.00	8.71* ±6.61	-7.7++ ±4.7	-17.2 ±10.6	-0.24 ± .15
3rd Month	3	2.76 ±.55	+0.17* ±1.31	-2.59++ ±1.61	-16.2 ±10.1	-0.24 ± .15	14.47 ±2.69	7.97 ±6.07	-6.5+ ±3.8	-14.5 ± 8.9	-0.21 ± .12
Entire Mission	9	3.10 ± .50	-1.05** ± .62	-4.15 ± .85	-25.9 ± 5.3	-0.36 ± .07	18.05 ±4.43	6.20** ±3.09	-11.9 ± 4.1	-26.5 ± 9.2	-0.37 ± .13

Δ = Inflight Balance - Preflight Balance

ΔPro = ΔN x(6.25 gm protein/gm N)
= ΔK x(2.23 gm muscle protein/meq K^+)

$\Delta\overline{Pro}$ = ΔPro ÷ Preflight BWgt (gm or meq/d-Kg)

Different from preflight: * = p< .05;** = p < .01
Different from 1st month: + = p< .05;++ = p < .01

N = nitrogen

K = potassium

Pro = protein

APPENDIX B

CALCULATION OF TBK CORRECTION FACTOR

Assume: a) a portion of the potassium leaving cellular compartment unaccompanied by protein and water is equivalent to the amount necessary to dilute intracellular potassium to the same extent as sodium is diluted in the extracellular compartment (i.e. a mean change in sodium concentration of 4.53 meq/l measured throughout inflight phase),

b) that this is a generalized loss throughout the intracellular compartment; i.e. 29.6 liters (measured preflight).

Therefore, this component of the potassium loss, to satisfy osmotic equilibrium, can be estimated to be

$$\underline{\text{osmotic loss}} = 4.53 \text{ meq/l} \times 29.6 \text{ liters} = 134 \text{ meq } K^+$$

The actual loss of potassium which can be claimed to be a result of muscle atrophy (i.e., accompanied by nitrogen and water) is the difference between the measured inflight loss and the osmotic loss:

$$\underline{\text{muscle atrophy loss}} = 236 - 134 = 102 \text{ meq } K^+$$

The lean body mass loss attributed to muscle atrophy is obtained from the relationship:

$$\Delta LBM = \frac{\Delta TBK}{65} = \frac{102}{65} = 1.57 \text{ kg}$$

The protein loss is taken as 19.4% of the LBM loss:

$$\Delta \text{protein} = 0.194 \times 1.57 = 0.30 \text{ kg}$$

Alternatively, the protein:potassium ratio of the LBM is known to be 3.06 gm/meq (Snyder, 1974), so that

$$\Delta \text{protein} = 3.06 \times 102 = 0.31 \text{ kg}$$

Fat loss is:

$$\Delta Fat = \Delta BWgt - \Delta LBM = 2.69 - 1.57 = 1.12 \text{ kg}$$

The intracellular water loss accompanying 102 meq K^+ can be estimated from the concentration of cell K^+ (Pitts, 1960):

APPENDIX B (CONTINUED)

$$\text{intracellular water} = \frac{102}{160}_{\text{meq/l}} = 0.64 \text{ liters}$$

These values are more in accord with other methods for measuring LBM loss (range -1.12 to -1.83 kg), fat loss (range - 0.76 to -1.20 kg) and cell water loss (-0.5 liters).

Summary:

Body Composition Changes from TBK Loss

	Uncorrected	Corrected for Dilution
ΔLean body mass (kg)	-3.63	-1.57
ΔFat (kg)	+0.94	-1.12
ΔProtein (kg)	-0.70	-0.31
ΔCell Water (l)	-1.50	-0.64

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