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Spacelab 1 Hematology Experiment (INS103): Influence of Space Flight on Erythrokinetics in Man

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SPACELAB 1 HEMATOLOGY EXPERIMENT (1NS103): INFLUENCE OF SPACE FLIGHT ON ERYTHROKINETICS IN MAN

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TABLES

ACRONYMS

ADH	antidiuretic hormone
ATP	adenosine triphosphate
DPG	2,3-diphosphoglyceric acid
EDTA	ethylenediaminetetraacetate
Ep	erythropoietin
Hb	hemoglobin
Hct	hematocrit
IBCS	Inflight Blood Collection System
MCH	mean corpuscular hemoglobin
MCHC	mean corpuscular hemoglobin concentration
MCV	mean corpuscular volume
MD	mission day
MS	mission specialist
OHCS	hydroxycorticosteroids
PS	payload specialist
PV	plasma volume
RBC	red blood cell
RCD	red cell distribution width
RCM	red cell mass
RCP	red cell production
RNA	ribonucleic acid
RPI	reticulocyte production index
SS	statistically significant
STS	Space Transportation System

ABSTRACT

An experiment conducted on the 10-day Spacelab 1 mission aboard the ninth Space Shuttle flight in November to December 1983 was designed to measure factors involved in the control of erythrocyte turnover that might be altered during weightlessness. Blood samples were collected before, during, and after the flight. Immediately after landing, red cell mass showed a mean decrease of 9.3 percent in the four astronauts. Neither hyperoxia nor an increase in blood phosphate was a cause of the decrease. Red cell survival time and iron incorporation postflight were not significantly different from their preflight levels. Serum haptoglobin did not decrease, indicating that intravascular hemolysis was not a major cause of red cell mass change. An increase in serum ferritin after the second day of flight may have been caused by red cell breakdown early in flight. Erythropoietin levels decreased during and after flight, but preflight levels were high and the decrease was not significant. The space flight-induced decrease in red cell mass may result from a failure of erythropoiesis to replace cells destroyed by the spleen soon after weightlessness is attained.

INTRODUCTION

The most consistent finding in studies of the influence of space flight on the hematologic system in man has been a significant reduction in the circulating red cell mass (RCM). This phenomenon has been observed in the American Gemini (Fischer et al., 1967), Apollo (Kimzey et al., 1975), Skylab (Johnson et al., 1977) and Apollo-Soyuz Test Project (Kimzey and Johnson, 1977) missions and Soviet Soyuz-Salyut missions (Ushakov et al., 1977). Data from the Skylab flights suggest that suppression of normal erythropoiesis may be a cause of red cell mass reduction found after space flight (Kimzey, 1979).

An experiment conducted on the 10-day Spacelab 1 mission aboard the ninth Space Shuttle flight in November to December 1983 was designed to measure factors involved in the control of erythrocyte turnover, particularly erythropoiesis, in man which might be altered soon after the beginning of exposure to weightlessness. Many of these hematological and biochemical parameters have not previously been measured in blood specimens collected during space flight.

METHODS

The mission specialists (MS1 and MS2) and payload specialists (PS1 and PS2) aboard Spacelab 1 were the subjects in the experiment. As a control for the blood draw protocol and a comparison of actual flight to bed rest, which simulates some of the effects of space flight (Kakurin et al., 1976; Nixon et al., 1979), the mission was simulated on the ground with a group of five subjects selected from a human subject pool. The simulation subjects were selected on the basis of similarity of age, weight, sex (male), physical condition, and overall health status to those of the Spacelab crew. For

simulation of the inflight period, control subjects were placed at -6° head-down bed rest for a time equal to the flight period (about 10 days). Each crewmember and simulation subject acted as his own control: inflight and postflight results were compared to preflight baseline data. For both studies, guidelines for appropriate institutional human experimentation and radiation safety were followed.

Blood samples were obtained from each crewmember and simulation subject three or four times during the preflight (pre-bed rest) period, two or three times inflight (during bed rest) and four times during the postflight (post-bed rest) period. Radionuclide measurements of red cell mass and plasma volume were made 65 days before flight (F-65), on landing day (L+0), and 8 days postflight (L+8). The total volumes of blood collected during each phase of the mission are shown in table 1. During the 88 days of each study, 470.5 to 538.5 ml of blood were withdrawn from each individual. Biomedical Laboratories staff members collected preflight and postflight blood samples and all samples from the simulation subjects by venipuncture with the use of standard clinical materials and procedures.

One of the mission specialists and one of the payload specialists had been trained in the use of the Inflight Blood Collection System (IBCS) and collected blood samples on 2 days during the mission. The IBCS is an assemblage of standard blood collection equipment and supplies which can be used in zero gravity in the same manner as in ground-based laboratories. The system included three trays, each containing the materials required for a single day's blood collection. Each tray contained several Corvac® evacuated blood collection tubes with disodium ethylenediaminetetraacetate (EDTA) and several tubes with heparin, as well as plain Corvac® tubes, fixative tubes for scanning electron microscopy and reticulocyte age classification, and other blood collection supplies. The Corvac® tubes had been treated to withstand liquid nitrogen temperature. They contained a gel which kept the cellular and fluid phases separated after centrifugation. The IBCS also contained a work kit including a minicentrifuge for hematocrit determinations, materials for preparation of blood smears (including a reticulocyte stain, new methylene blue N), and other supplies.

All samples were stabilized or processed by centrifugation within minutes of collection. Mission inflight samples were collected in plain tubes for serum and in heparin and EDTA tubes for plasma. Samples were immediately separated by centrifugation into fluid and cellular phases. Following separation, these samples were stored in an onboard cryogenic freezer (-195° C) and after landing they were taken to the laboratory and stored frozen until analysis of plasma and serum was performed. Hematocrit was determined and slides for reticulocyte and white cell differential and reticulocyte age classification were prepared inflight. After landing, hematology analyses were performed on whole blood that had been stored at the spacecraft ambient temperature during the flight.

The procedures used for analyses are listed in table 2. Reticulocytes were counted by the standard manual method (Wintrobe, 1974) and by flow cytometry of cells stained with pyronin Y for ribonucleic acid (RNA) (Tanke et al., 1983). One-parameter (integrated green fluorescence gated on forward angle light scattering) analysis was performed on fixed, stained samples of whole blood. Samples were stained with pyronin Y for 2 hours (instead of 30 minutes as in the method of Tanke et al.) at pH 4.7. A peak of strongly-fluorescing cells separated from the red cell peak, and the area under it was

used as the number of reticulocytes in each sample of 50,000 red blood cells. Histogram contouring of stained blood cells was used to produce measurements of the amount of RNA in reticulocyte cytoplasm (Bessis et al., 1973).

The preflight and postflight diet of crewmembers was not controlled or monitored, but the Shuttle diet was consumed inflight. Simulation subjects ate a standard hospital diet. Two hours before landing, MS1 took the equivalent of 1 liter of physiological saline solution (1 liter of water with 8 g of salt tablets) as a countermeasure for postflight gravity stress to the cardiovascular system. MS2 drank about 750 ml of water and took 4 g of salt tablets. These crewmen also ingested an anti-motion sickness drug (scopolamine/dexedrine) before the flight. During the first 3 days of the mission, the mission specialists and PS2 took scopolamine/dexedrine and PS1 took promethazine/ephedrine on mission day 1. Only MS1 was not sick during the first 2 or 3 days of the flight.

The STS-9 Spacelab 1 mission was in continuous operation. The crewmembers worked in two different shifts; MS2 and PS2 slept from 10:30 p.m. to 6:30 a.m. and MS1 and PS1 slept from 10:30 a.m. to 6:30 p.m., central standard time. Two weeks before launch, the sleep-wake cycle of MS1 and PS1 was shifted by 12 hours. The cycle of two of the ground control subjects approximately matched that of these "second-shift" crewmembers. To attempt to monitor the shift in metabolic functions, urine specimens were collected from MS1 and PS1 throughout several 24-hour periods 6 months before the flight, when crewmembers were on their normal daytime work schedule, and during the preflight period, when these crewmembers were adapting to their new work-rest schedule (appendix A). These samples were analyzed for calcium, potassium, and cortisol and compared to samples taken immediately postflight to determine if the individual had adapted to the imposed time change.

A multi-way analysis of variance for repeated measures was used for statistical analysis of the results. No data were disregarded and only one flight sample was missing. The Student-Newman-Keuls stepwise multiple comparison test (Newman, 1939; Keuls, 1952) was used to compare measurements from different days of the experiment. For each parameter, the mean of values for the first 2 preflight days was determined and used for comparison with the other days on which samples were taken. Separate analyses were done for the flight and simulation. A more detailed description of the statistical analysis is given in appendix B.

RESULTS

Preflight Period

Several parameters shown in table 3 increased or decreased in three or all four crewmembers during the preflight period. The percentage and concentration of lymphocytes increased between F-7 and F-1, and albumin and 2,3-diphosphoglyceric acid (DPG) increased between F-65 and F-7 and between F-7 and F-1. The percentage and number of reticulocytes, reticulocyte production index (RPI), number of platelets, percentage of neutrophils, and levels of gamma globulin and transferrin decreased between F-65 and F-1. Hematocrit and the percentage and number of monocytes increased between F-65 and F-7, but decreased between F-7 and F-1. Because of these consistent differences,

some of which were statistically significant (table 3), F-1 was omitted from the preflight mean for all parameters. No consistent preflight changes occurred in simulation subjects.

Effects of Flight

Red Cell Mass

Red cell mass (ml/kg) was decreased on landing in all four crewmen (table 3), with a significant mean decrease of 9.3 percent (table 4). By postflight day 8, only 3.3 percent had been replaced and the decrease was still significant.

Red cell mass (ml/kg) was also decreased in all simulation subjects (table 5), with a greater decrease (8.4 percent) on L+8 than on L+0 (4.6 percent) (table 6). Both decreases were significant.

Erythrocyte Hematology

Hematocrit and erythrocyte (RBC) numbers were significantly decreased 12 hours after landing (tables 3 and 4). During flight and on landing day, hemoglobin (Hb) was significantly increased from preflight and it was not found to be significantly decreased until L+8. Erythrocyte count and indices and hematocrit were also increased on mission day 1 (MD1), but the increases were not significant. Mean corpuscular hemoglobin (MCH) was significantly increased on L+0 and L+1, and mean corpuscular hemoglobin concentration (MCHC) was significantly increased on MD7 and L+0.

The only significant change in erythrocyte hematology in the simulation experiment was an increase in MCHC on L+13 (table 5).

Erythrocyte Production and Destruction

The percentage of reticulocytes was determined by flow cytometry as well as by the standard method. The two methods did not produce the same results. The number of reticulocytes, based on manual reticulocyte counts, was decreased (55 percent, table 4) on the second inflight sampling day, and on landing day, the number and percentage of reticulocytes and the RPI decreased. None of these changes were statistically significant, however. The flow cytometry results showed that in three crewmembers the percentage of reticulocytes had decreased by 24 h after launch, but in one crewmember, PS1, it had more than doubled by the same time. From MD7 until L+8, the mean percentage of reticulocytes decreased slightly at each sampling time. On L+12/13, the percentage increased by 39 percent, more than it increased (10 percent) when cells were counted manually. PS1 had reticulocyte levels lower than preflight at all time points after landing. None of the changes detected by flow cytometry were statistically significant.

Image analysis data showed that the amount of RNA per reticulocyte was lowest on L+0 and was significantly different from its preflight level then, but by L+8 it was 10 percent greater than the preflight mean. By L+12/13, the amount of RNA per cell was very close to the preflight amount. Inflight and simulation results were not obtained for this parameter.

Although for most crewmembers erythropoietin levels decreased during the flight, increased (but not to preflight levels) during the first week after

landing, and decreased again on postflight day 12/13, none of these changes were significant (table 3). There was no significant difference in erythropoietin levels throughout the simulation part of the experiment (table 5).

The effect of space flight on erythrocyte survival time was measured by injecting ^{51}Cr-labeled red blood cells (RBC's) immediately after landing and determining the percentage that remained 8 days later. Survival time was almost exactly the same in crewmembers as it was in the simulation subjects: on L+8, 76 percent (standard error (SE) = 0.7) of the ^{51}Cr-labeled RBC's injected on L+0 remained in the blood of crewmembers; in subjects, 75 percent (SE = 2.1) remained.

Iron Kinetics

Serum transferrin concentration did not change significantly during or after the flight, and serum iron and iron-binding capacity showed little change except that immediately after landing, serum iron decreased from its last inflight value in all crewmembers (table 3). The saturation level of transferrin, calculated by dividing serum iron by total iron-binding capacity and multiplying by 100 percent, did not change significantly during the experiment. In the simulation part of the experiment, there was no significant change in serum iron, unbound or total iron-binding capacity, transferrin, or saturation level of transferrin (table 5). On landing day (11 days after injection of isotope), 88 percent (SE = 3.5) of injected ^{59}Fe had been incorporated by crewmembers and 91 percent (SE = 2.4) by simulation subjects.

Erythrocyte Shape Classification

The number, but not the percentage of discocytes (normal cells), was significantly decreased 8 and 13 days after landing (table 3). The percentage and number of echinocytes (stages 1 and 2) had increased significantly by day L+8. Echinocytes are classified into three stages on the basis of spine development: in stage 1 echinocytes only a bump may be visible on the cell surface, whereas stage 3 cells are covered with spines. Stage 3 echinocytes were seen in blood from only two crewmembers, a week or more postflight. Only two crewmembers had increased numbers of stage 2 echinocytes, but in all crewmembers stage 1 echinocytes increased on L+8 or L+12/13. The percentage of echinocytes (all stages added together) had increased by 160 percent on day L+8, but by only 82 percent on the last postflight day (table 4).

Red cell shape classification was not performed for the simulation part of the experiment.

Leukocytes and Platelets

The total white blood cell (WBC) count did not change significantly during or after the mission although the mean number increased during flight (table 3). The percentage and number of neutrophils (the term "neutrophils" is used here to refer to segmented neutrophils and does not include band neutrophils), lymphocytes, eosinophils and basophils remained unchanged during and after flight. The percentage of lymphocytes was lower (29 percent) at the first inflight sampling than it was preflight (F-65 and F-7), but on other days it was little changed from preflight (table 4). The percentage and number of band neutrophils were significantly increased on the first

inflight sampling day, and the percentage and number of monocytes were significantly increased on the last postflight sampling day. The number of platelets did not change significantly during and after the flight.

Only one parameter in this group was significantly different from preflight level in the simulation experiment: on L+0 the number of neutrophils was significantly higher than during the preflight period (table 5).

Plasma and Blood Volume

Plasma volume (ml/kg) was decreased on landing (table 4), but the 6 percent decrease was not significant and recovery was complete by postflight day 8. Blood volume (ml/kg) was significantly decreased (10.5 percent) on landing, but was close to its preflight level a week later.

Decreases in plasma and blood volume of simulation subjects at L+0 were not significant (table 5).

Serum Chemistry

Sodium was slightly, but significantly, decreased inflight and on L+1 and L+12/13 (table 3). On all postflight days osmolality was lower than its preflight level, but only on L+8 and L+12/13 was the decrease significant. Potassium, adenosine triphosphate (ATP), and 2,3-DPG did not change significantly.

Osmolality generally had the same pattern of variation in the simulation subjects as it had in the astronauts (increase on F-1, decrease on MD1 and MD7, increase on L+0) (table 5), but there were no significant changes. Sodium had almost the same pattern of variation as osmolality in the simulation subjects, but it was not significantly different from preflight at any time. Potassium was significantly increased in simulation subjects on MD1.

Proteins

Total serum protein was decreased from the preflight value by 3.8 percent on MD7 (table 4). The decrease in serum protein was significant (7.6 percent) on L+8, when albumin, alpha-2 globulin, and beta globulin as well as gamma globulin were decreased (table 5). Albumin, haptoglobin, and beta globulins did not change significantly, but on L+12/13 alpha-1 and alpha-2 globulin were significantly increased. In all crewmembers gamma globulin decreased during the preflight period to levels similar to those of simulation subjects, which did not change throughout the experiment.

From the second inflight measurement (MD7) through at least 12 hours after landing, ferritin in crewmembers increased significantly over its preflight level. In the simulation part of the experiment, ferritin was significantly decreased on L+8 and L+12/13; these were the only significant changes in serum proteins of simulation subjects.

Effects of Countermeasures and Change in Sleep-Wake Cycle

Since the number of crewmembers was small, changes that might have been caused by taking countermeasures were sought in simulation subjects as well as crewmembers. On landing day and/or L+1, after the mission specialists and their counterparts in the simulation had ingested extra fluid and taken salt

tablets, they had a lower eosinophil percentage, monocyte percentage and number, and level of transferrin (appendixes D and E). The difference in monocyte number was significant ($p < .05$) when analyzed by an unpaired t-test. On landing day, serum protein did not increase in crewmembers and subjects who had taken countermeasures as it did in the others.

Crewmembers or subjects were divided into groups by work-rest shift to perform analyses to determine effects of shift on the results. The following differences between shift groups were seen in both parts of the experiment: on MD1, the number of erythrocytes and leukocytes increased only in crewmembers or subjects on the first shift. RPI and the percentage and number of reticulocytes increased only in the second shift of crewmembers on MD1 and in the second shift of simulation subjects on F-1. On F-1, mean corpuscular volume (MCV) did not decrease as much in the first shift as in the second and the percentage and number of eosinophils increased in the first shift and decreased in the second shift.

DISCUSSION

Circadian Rhythms

Cortisol, calcium, and potassium were found to have statistically significant circadian rhythms 6 months before flight, but there appeared to be no significant phase change in these rhythms during the experiment (appendix A). Urinary cortisol is considered to be a very reliable index of circadian system function (Klein and Wegmann, 1979; Reinberg, 1979). Six months before the flight, the peak level of urinary cortisol occurred between 0700 and 1000 hours in crewmembers who were to be on the second shift. This peak time had not changed significantly 3 days before launch in spite of the change in work-rest schedule begun 11 days before; even after the flight no significant difference was observed in the phase of the cortisol rhythm. Therefore, it appears that no shift in circadian rhythm of metabolic functions occurred in response to the altered work-rest schedule (see appendix A for a more detailed discussion).

Preflight Period

The preflight changes in lymphocytes, monocytes, reticulocytes, hematocrit, and other parameters which were observed in the mission and payload specialists of Spacelab 1 did not occur in the commander or pilot and have not been observed in other flight series or in previous Shuttle flights. A consistent preflight change observed by another team of Spacelab investigators (Kirsch et al., 1984) was an increase in central and peripheral venous pressure between F-8 and F-1. The cause of the preflight changes is unknown. Relatively few of the preflight measurements were outside the normal range for the individual, but the fact that changes in the same direction occurred in all four subjects for so many parameters indicates that the changes were not due to chance alone, circadian rhythm shifts, or premedication with anti-motion sickness drugs. The fact that preflight changes did not occur in simulation subjects suggests that the crew showed the effects of preflight preparations not shared by the non-astronaut subjects.

The mission and payload specialists participated in other experiments before, during, and after the mission, and baseline (preflight) data for these experiments were collected at the Baseline Data Collection Facility at the Dryden Flight Research Center in California at F-65 and F-7. Blood was drawn before the crewmembers engaged in any other experiment activities, however. Blood volume has been found to increase by 10 to 30 percent as a result of exposure to heat (Maxfield et al., 1941; Bass et al., 1955), and it is possible that the change of climate between Houston and California or Florida had an effect on blood volume and therefore on other parameters. The differences in time zones may also have had physiological effects.

Some of the preflight changes were opposite to those that occur during stress or infection: the number of neutrophils increases as a result of stress (Athens et al., 1961) or inflammation (Finch, 1972), whereas it decreased during the preflight period in this experiment. Also, the number of lymphocytes decreases as a result of stress (Hoagland et al., 1946), whereas it increased during the Spacelab 1 preflight period, and gamma globulin levels increase as a result of infection, whereas they decreased during the preflight period. Monocytosis and lymphocytosis, both of which are associated with some types of infection, did occur during the preflight period, but at different times, with monocytosis occurring first. The number of monocytes increased from 0.09 to 0.49 X 10^9/liter between F-65 and F-7, and the number of lymphocytes increased from 1.9 to 2.7 X 10^9/liter between F-7 and F-1. The number of lymphocytes may have been affected by anti-motion sickness medication, since it was higher in premedicated crewmembers. Withdrawal of blood during the preflight period might be expected to result in an increase in reticulocyte production, but instead the proportion and number of reticulocytes decreased. RPI was high at the beginning of the preflight period.

The preflight changes complicated interpretation of the results insofar as comparison of inflight and postflight changes to the preflight period is concerned; inflight and postflight measurements were compared to the mean of measurements from F-65 and F-7 samples.

Sample Storage

Storage of blood samples during the flight is not thought to have had significant effects on the conclusions from this experiment. The effects of storage at room temperature (22° C) and at 4° C were investigated with 18 control samples. In some samples, swelling of erythrocytes apparently occurred at both temperatures; hematocrit, MCV, and RBC distribution width increased significantly and MCHC decreased significantly within 3 days at room temperature. The number of platelets had decreased after 7 days of storage. After storage at 22° C for 15 days, hemoglobin increased by 3 percent and leukocytes increased by 11 percent (unpublished observations). Storage may therefore have caused part of the change in these parameters in the MD1 samples, which were stored for 12 days. Erythrocyte count was not affected by storage at room temperature for at least 25 days. Storage of 10 control samples in cryogenic tubes at -20° C affected some of the clinical chemistry parameters slightly.

Summary of Time Course of Changes

On the first inflight sampling day, hemoglobin, hematocrit, MCH, and band neutrophils were increased and erythropoietin, percentage and number of reticulocytes and lymphocytes, gamma globulin, osmolality, and sodium were decreased from preflight levels. Similar results were obtained on the second inflight sampling day except that the lymphocyte number was increased instead of decreased, ferritin and erythrocyte counts had increased, and the percentage and number of monocytes had decreased. Hematocrit was lower than it had been on MD1. (Many of these changes were not statistically significant.)

Immediately after landing, hemoglobin, reticulocyte percentage and number, ferritin, erythropoietin, and gamma globulin remained changed as they were during flight, but MCHC had increased and serum iron, discocyte percentage and number, monocyte percentage, erythrocyte count, hematocrit, and a proportion of reticulocyte cytoplasm occupied by RNA had decreased. Red cell mass, plasma volume, and blood volume, which had not been measured inflight, had decreased. Twelve hours after landing (L+1), hematocrit, erythrocyte count, MCHC, ferritin, erythropoietin, reticulocyte percentage and number, serum iron, discocytes, and gamma globulin remained changed to approximately the extent that they were during flight. The main changes from L+0 were decreases in osmolality and sodium. Reticulocyte RNA had increased again.

A week after landing, many parameters had not returned to their preflight levels. Erythrocyte count, erythropoietin, osmolality, sodium, reticulocyte percentage and number, serum iron, discocytes, hematocrit, and gamma globulin remained lower than they were before the flight. Red cell mass also had not recovered, but plasma volume and reticulocyte RNA were slightly higher than preflight levels. There was an increase in percentage and number of echinocytes and a decrease in total protein. Even after almost 2 weeks on the ground, hemoglobin, erythropoietin, sodium, serum iron, discocytes, osmolality, hematocrit, erythrocyte count, and gamma globulin remained significantly lower than during the preflight period. Monocyte percentage and number and alpha-2 globulin were increased at this time.

Erythrocyte Production and Destruction

The postflight decrease in red cell mass is the normal finding after space flight. It could have been caused by a suppression of erythrocyte production, sequestration of erythrocytes in an organ such as the spleen or bone marrow, cell lysis, loss of blood, or extravasation. Red cell mass decrease after Skylab flights was thought to be a result of bone marrow inhibition because of the lower postflight levels of reticulocytes and the long delay before the preflight level of red cell mass was attained (Johnson et al., 1977). Because other American astronauts whose red cell mass has been measured were exposed to elevated oxygen partial pressures at some time before or during flight, oxygen inhibition of bone marrow function or even peroxidation of red blood cell membrane with shortened red blood cell life span were possible causes of red cell mass decreases (Johnson, 1983). Since Spacelab 1 crewmen were not exposed to 100 percent oxygen or hyperoxia at any time during this flight, hyperoxia was not a cause of the decrease in red cell mass in this experiment. Since MCV did not decrease substantially at any time, a loss of corpuscular volume is unlikely to have contributed to the

red cell mass loss. Such a rapid decrease in red cell mass is unlikely to have been caused entirely by lack of production.

Six of the eight crewmembers who participated in the first four Space Shuttle missions showed decreases in reticulocyte numbers (Taylor, 1983). Reticulocyte levels were as low as 44 percent of preflight values on day L+0 after Skylab missions (Kimzey, 1979). After the shortest mission (28 days), reticulocyte count had not attained normal levels by 21 days after landing. On the other hand, after the longer Skylab missions (59 and 84 days), reticulocyte counts had surpassed normal levels by 7 days postflight.

In the present study, the number of reticulocytes did not change significantly during or after the flight. However, some of the changes occurred in all crewmembers at the same time. When reticulocytes were counted manually, the reticulocyte number was decreased from preflight levels in all crewmembers on MD7 (55 percent) and L+0 (61 percent). By L+1 the number of reticulocytes had increased to only 15 percent below the preflight level, and by L+12/13 the number was only 2 percent below preflight levels.

Results obtained by flow cytometry were somewhat different. When it was measured by flow cytometry, the percentage of reticulocytes was more stable on the 3 preflight days than it was when measured by the manual method. The percentage decreased in three crewmembers on MD1, but in one person the proportion of reticulocytes more than doubled. (He was also the only crewmember in whom plasma volume increased instead of decreasing on L+0. His preflight red cell mass was higher than that of any other crewmember and it had decreased the least when measured on L+0.) When the data from that person were omitted from the calculations, a decrease of 10 percent occurred on MD1, but it was not statistically significant. Except for an increase in two crewmembers on L+12/13, the postflight increase in percentage and number of reticulocytes seen when reticulocytes were counted by the manual method was not seen when they were counted by flow cytometry.

Reasons for the discrepancy in results obtained by the two methods are unclear. Results obtained by the manual counting method were reproducible, but a much larger number of cells (50,000 in each sample) was counted by flow cytometry. On the other hand, the manually-obtained counts may be more clinically relevant.

The amount of RNA in reticulocyte cytoplasm is considered to be a measure of reticulocyte age (Bessis et al., 1973). The time at which the greatest proportion of young reticulocytes was measured was L+8. It is possible, however, that during weightlessness RNA is removed from reticulocyte cytoplasm sooner than it is on the ground.

Erythropoietin levels were higher than the normal range (Dunn et al., 1984) in all crewmembers on all three preflight sampling days. During the flight erythropoietin decreased in all crewmembers, to very low levels in three of them, but in the analysis of data from all crewmembers the changes were not significant. Most subjects in the simulation part of the experiment had high preflight erythropoietin levels also, especially on the day before bed rest began. After 24 hours of bed rest, the mean level of erythropoietin was only slightly lower than the preflight mean (F-65 and F-7), but it was considerably lower than on day F-1. The failure to find a significant decrease in serum erythropoietin inflight suggests that inhibition of erythropoietin secretion, which could have resulted from a change in the perfusion rate of the kidneys, did not occur. The method used should have been able to measure as significant a 50 percent decrease if it had occurred

consistently (coefficient of variation = 25 percent). However, there was a large between-subject variation in these determinations; use of a larger number of subjects might have resulted in a difference of statistical significance. Salyut-4 cosmonauts, especially those on short flights (16 to 30 days) had increased blood and urine levels of erythropoietin after landing (Legen'kov et al., 1977).

It would be desirable in future experiments to use more than one method for the erythropoietin assay, because several methods which complement each other are available (Lange et al., 1980) and might indicate why preflight levels appear to be increased.

There was no statistically significant change in transferrin, serum iron, or iron-binding capacity (which was at the upper end of the normal range although percentage saturation of transferrin was at the lower end). Incorporation of ^{59}Fe injected before launch was normal on landing. These results indicate that there was no deficiency of iron available for erythropoiesis during flight. The nonsignificant decrease in transferrin during flight might have been due to lack of exercise compared to preflight exercise levels (Poortmans, 1971; Haralambie, 1973). The fact that ATP and 2,3-DPG did not change significantly indicates that high blood levels of phosphate probably did not contribute to suppression of erythropoiesis (Johnson, 1983).

Deviations from the unique biconcave discoid shape of the red blood cell are associated with a number of hemolytic disorders (Bessis et al., 1973). Properties of the plasma can cause reversible changes in red cell shape. Therefore red cell shape changes can indicate disturbances of cell function or of plasma composition. An extensive study of erythrocyte shape in preflight, inflight, and postflight blood samples from Skylab astronauts was made by Kimzey (1975, 1977). These studies indicated that the proportion of stage 1 echinocytes increased inflight, but had returned to normal by the first blood draw after landing. In the present study, the proportion and number of echinocytes increased during and after flight. Red cell shape was not examined in the simulation part of this experiment, but in ground simulations of Skylab flights, there were no significant changes in red cell shape (Kimzey, 1973). For this reason the red cell shape changes during Skylab missions are thought to have been a result of weightlessness.

Some of the extrinsic factors that are known to cause transformation of discocytes to echinocytes are fatty acids, detergents, hypertoxicity, increased pH, certain drugs, and tannic acid (Kimzey, 1977). In squirrel monkeys (Dunn et al., 1983) and rats (Rao et al., 1979), changes in erythrocyte shape distribution have been shown to result from dietary changes; in the study by Rao et al., the shape changes were reversible upon return to a normal diet. The rapidity of the elimination of echinocytes immediately after the Skylab and Spacelab missions suggests that the rate of clearance of echinocytes was increased or that a readily reversible change in plasma constituents was responsible for echinocyte formation. It was not possible to determine what constituent might have been responsible because most of the substances (including cholesterol, lecithin, lysolecithin, free fatty acids, and albumin) known to cause transformation of the type observed were not measured inflight. The only one of these substances that was measured in the present study was albumin, and it did not change significantly.

Echinocytes are thought to be removed early from the circulatory system by the reticuloendothelial system (Rifkind, 1966), and it seems likely that shape transformation of erythrocytes was responsible for part of the decrease

in their number. Radioactive tracer studies showed that for the crewmembers, the percentage of injected labeled red blood cells remaining at 8 days was the same as it was for simulation subjects and was normal. However, the number of echinocytes was so small compared to the total number of red blood cells that an increase in clearance rate of echinocytes probably would not have been detected.

The fact that significant increases in hemoglobin were observed when RBC count and hematocrit were not significantly different from preflight (MD1, L+0) indicates that at these times the plasma may have contained free hemoglobin from intravascular hemolysis. However, during the same period of time hemoglobin was highly correlated with RBC number ($r = .91$) and with hematocrit ($r = .83$), so that most of its variance was explained. Intravascular hemolysis should also lead to decreased serum haptoglobin, but haptoglobin increased slightly (not significantly). One crewmember had a normal level of haptoglobin higher than the population normal or astronaut range. (The same crewmember had the lowest erythrocyte count and hemoglobin level, highest MCV and erythropoietin, and greatest increase in band neutrophils.) Normally low haptoglobin levels in most of the crewmembers indicate that they may have "sports anemia" (Hiramatsu, 1960; Lindemann, 1978), although they do not appear to have the decreased hematocrit associated with this condition. Haptoglobin increased after the Apollo flights (Kimzey et al., 1975).

Serum ferritin was increased in the second inflight sample and at L+0 and L+1. In simulation subjects, ferritin did not increase, but decreased significantly at L+8 and L+12/13. An increase in serum ferritin, which is thought to be secreted by the reticuloendothelial system, can indicate the presence of stress or an abnormal condition such as inflammation, liver disease, red cell hemolysis, abnormal erythropoiesis, or hemochromatosis (Lipschitz, 1980; Pilon et al., 1980; Cook and Skikne, 1982). The increase in number of white blood cells and in the proportion of neutrophils would be consistent with the occurrence of inflammation (Finch, 1972), but no other symptoms of inflammation were noted. Intravascular hemolysis seems unlikely because haptoglobin levels did not change. The increase in ferritin may have affected the calculated percentage saturation of transferrin, but at L+0 a relatively large (but not statistically significant) change in saturation level occurred while the ferritin level remained stable.

Fluid Redistribution and Its Effects

Hemoglobin, the only erythrocyte hematology parameter measured in inflight samples from the Skylab missions, was elevated in the first inflight sample, but returned to normal during each flight (Kimzey, 1975). Inflight specimens from the Spacelab mission and simulation showed increases in erythrocyte count, hemoglobin, and hematocrit, but most of these were not statistically significant. The increase in number of erythrocytes occurred only in crewmembers on the first shift.

Data obtained as soon as possible after the landing of Skylab 2 showed that the red cell count, hemoglobin concentration, and hematocrit were below preflight levels, whereas after the two longer Skylab flights they were elevated. In the Spacelab study, erythrocyte count, hematocrit, and plasma volume were decreased and hemoglobin was increased immediately after landing, but a week later, the erythrocyte parameters were lower than during the preflight period, whereas plasma volume was greater by 3 percent than its

preflight level. The L+0 decrease (6 percent) in plasma volume was greater than that found after previous flights. In the present study, decreases in red cell mass and plasma volume contributed to a decrease in blood volume on L+0. Osmolality was slightly increased, but sodium and potassium were decreased.

The very early inflight and bed rest increases in erythrocyte count, hematocrit, and hemoglobin are believed to be effects of an early decrease in plasma volume. In head-down bed rest studies (Nixon et al., 1979; Blomqvist et al., 1980), plasma volume has been observed to decrease as early as 6 hours after bed rest began. A later effect of decreased plasma volume may be a decrease in production or a delay in release of erythrocytes, which would tend to bring hematocrit back to normal. In Spacelab crewmembers, hematocrit was closest to preflight levels on MD7.

The early decrease in plasma volume observed in bed rest studies is presumed to be a result of cephalad fluid shifts, and it has been proposed (Gauer and Henry, 1963; Leach, 1979) that a similar phenomenon occurs in space flight. Head-down bed rest studies indicate that early changes in central venous pressure lead to a decrease in plasma volume (Leach et al., 1983). In the present study, plasma volume was not measured during flight, but venous pressure was measured (Kirsch et al., 1984). Venous pressure was lower in all crewmembers on MD1 than on F-1. The fluid shift is thought to have occurred during the first 3 to 6 hours of flight. At L+0 plasma volume was decreased by about the same percentage in simulation subjects as it was in the Spacelab 1 crew, an indication that fluid shift caused by bed rest or space flight was responsible for the change in plasma volume.

Red cell mass and several other parameters associated with erythrocyte production did not recover within 12 to 13 days after landing. Hemoglobin, hematocrit, and the number of erythrocytes and discocytes were significantly lower than preflight levels. Soviet investigators have found that erythrocyte count did not return to normal until 6 weeks after the end of 96- to 175-day flights (Vorobyov et al., 1983).

By contrast, changes in plasma volume and venous pressures were not so long-lived. Peripheral venous pressure, which increased at L+0 (1 hour after landing), decreased again by L+1, but had begun to return to preflight levels by L+8. Central venous pressure did not increase so much at L+0 as peripheral venous pressure did, but it still decreased in most crewmembers by L+1. In two crewmembers it decreased again between L+1 and L+8 (Kirsch et al., 1984). The high pressures at L+0 were thought to be due to redistribution of shifted fluid. By L+8, the central venous pressure corresponded better with the body's water balance (Kirsch et al., 1984). Plasma volume had increased slightly above the preflight mean by L+8, and blood volume was close to its preflight mean. The decrease in hematocrit was probably related to the increase in plasma volume.

The late increase in echinocytes (at L+8), in view of the fact that an increase in echinocytes occurred during flight in the Skylab missions (which were considerably longer than the Spacelab mission), may be due to the setting in motion inflight of processes that continued postflight. Increases in the proportion of RNA in reticulocytes at L+8 and in the percentage of reticulocytes at L+12/13 indicate that the level of mature erythrocytes will increase later. These increases seem inconsistent with the continuously low levels of erythropoietin, and it is possible that they resulted from release of sequestered erythrocyte precursors rather than from resumption of

interrupted erythropoiesis. Analysis of blood samples taken later during the postflight period would be useful in construction of a more complete time course of red cell mass loss and recovery.

A computer simulation of the Spacelab 1 experiment has been performed in which zero gravity was simulated by decreasing plasma volume by 500 ml in the first 12 hours of the "flight" and blood volume was reduced according to the blood draw schedule (appendix C). In this simulation, red cell mass decreased during "flight" (though only about half as much as during the actual flight) and had not recovered by 3 weeks after "landing." Hematocrit increased during the simulated flight more than during the actual flight, but had decreased by 12 hours after "landing" and remained low for 3 weeks. Erythropoietin decreased early in the "flight", but increased soon after "landing;" this was the greatest qualitative difference between the simulation and the flight results. Results of the computer simulation lend support to the idea that an early decrease in plasma volume caused some of the hematologic changes found in the present study, but the differences between results for the actual flight and those for the computer simulation indicate a need for continued refinement of the computer model.

The response of plasma volume and related parameters in the Spacelab 1 crewmembers was qualitatively similar in several respects to that of subjects taken to high altitude and returned to sea level. When subjects are exposed to high altitude (2300 meters or higher) for several weeks, their plasma volume decreases and hematocrit increases during the exposure (Dill et al., 1969; Hannon et al., 1969; Dill et al., 1974). When they are returned to sea level, plasma volume returns to normal after about a week, but hematocrit and hemoglobin usually decrease and remain low for 3 weeks or more. High altitude natives normally have high hematocrit (due to an increase in red cell mass) and hemoglobin (Merino, 1950), which decrease when subjects are taken to sea level and return to their normal high levels upon return to high altitude (Jain et al., 1981).

If there is indeed an early decrease in plasma volume during space flight, in Spacelab 1 it occurred while plasma levels of antidiuretic hormone (ADH) in at least two crewmembers were very high (Dr. K. A. Kirsch, personal communication). This result contrasts with a reported early decrease in plasma ADH during bed rest (Nixon et al., 1979). Although a decrease in urinary ADH occurred in the two longer Skylab flights (Leach and Rambaut, 1977), 24-hour urine results are not necessarily comparable to plasma concentrations. The former measurement is a summation of excretion while the latter is a single time-critical measurement. Aldosterone, which decreased during the Spacelab flight, increased sharply between L+0 and L+1 and had returned to preflight levels by L+8 (Dr. K. A. Kirsch, personal communication). Apparently the ADH was not effective in retaining enough fluid to prevent a decrease in plasma volume, but when aldosterone, which also causes water and sodium retention, increased, plasma volume did also. All four crewmembers lost 4 to 5 percent of their body weight between F-1 and L+0 (Kirsch et al., 1984), but began to regain it soon after landing.

Decreased fluid intake, which was not monitored during the present study, could have contributed to the decrease in plasma volume. The antimotion sickness medications used can decrease hunger and thirst. This could have affected the initial inflight specimen by accelerating any dehydration resulting from adaptation to microgravity, but the fact that decreases in sodium during flight are matched by decreases in osmolality indicates that

dehydration did not occur. Use of physiological saline solution as a countermeasure had no apparent effect on plasma volume when it was measured.

Leukocytes and Serum Proteins

Leukocytes were increased on day L+0 in Apollo (Kimzey et al., 1975), Skylab (Kimzey, 1977), and Shuttle test flight (Taylor, 1983) astronauts, and in all cases the increase was attributed to an increased number of neutrophils. In the present study, the number of leukocytes and neutrophils did not change significantly; the number of leukocytes increased only in crewmembers on the first shift. The proportion of eosinophils and monocytes may have been affected by salt and water ingestion, although a mechanism for such an effect is not obvious. An increase in the proportion and number of eosinophils in crewmembers on the first shift and a decrease in these parameters in crewmembers on the second shift is also not readily explained.

The early inflight increase in band neutrophils, which are immature cells, was seen in all crewmembers, although the band neutrophil percentage was higher in premedicated crewmembers. Infection or stress could have caused this response, but it could also have been caused by sudden release of cells from the bone marrow (Finch, 1972), possibly related to the preflight decrease in the proportion of neutrophils. No other blood cells appear to have been released at that time. An increase in band neutrophils did not occur in the bed rest subjects.

Data from the Skylab missions (Kimzey, 1977) showed no indication of a response of the plasma proteins to weightlessness. It is believed that the combination of the metabolic diet, the large amount of physical activity, and mission duration of Skylab flights prevented changes in plasma protein profiles which were found postflight in serum protein profiles of Apollo astronauts (Fischer et al., 1972; Kimzey et al., 1975). Changes in serum proteins in Spacelab 1 crewmembers were also different from those described in studies of Apollo crewmen, whose total serum proteins increased after flight largely as a result of an increase in alpha-2 globulin. In the present study, nonsignificant decreases in total protein probably resulted from significant decreases in gamma globulin which began during the preflight period, when gamma globulin levels were higher in crewmembers than in control subjects. Such a change in gamma globulin is apparently not characteristic of Shuttle crewmembers (Taylor, 1983) and did not occur in the bed rest subjects. The reason for the elevated gamma globulin at the first preflight sampling is unknown.

The mission specialists and payload specialists exhibited a decrease in percentage and number of lymphocytes on the first inflight sampling day. It is possible that stress caused this change, but as mentioned above, some of the preflight hematologic results were not consistent with a stress response. Immunoglobulins of Spacelab 1 crewmembers showed no significant effects of space flight (Voss, 1984).

CONCLUSIONS

The relatively long-lasting postflight decrease in red cell mass found in Spacelab 1 crewmembers was comparable to that found in other flights. Its magnitude (9.3 percent) and rapidity of development indicate that it was not

caused solely by a decrease in erythrocyte production. Neither hyperoxia nor an increase in blood phosphate was a cause of the decrease in red cell mass. There was no lack of serum iron available for erythropoiesis.

Red cell shape transformation and early removal of transformed cells may have contributed to the decrease in red cell mass, but red cell survival time postflight was not significantly different from survival time preflight. The failure of serum haptoglobin to decrease indicates that intravascular hemolysis was not a major cause of red cell mass change. An increase in serum ferritin that occurred by the second inflight sampling day was statistically significant; this may indicate abnormal erythropoiesis or early erythrocyte breakdown, but it has a number of possible causes. Erythropoietin levels decreased during and after flight, but preflight levels were high and the decrease was not significant.

Early inflight increases in erythrocyte count, hematocrit and hemoglobin are thought to have resulted from a hypothesized decrease in plasma volume caused by cephalad fluid shifts in microgravity. It appears possible that a decrease in production or a delay in release of erythrocytes could be a later effect of decreased plasma volume; either of these would cause a decrease in red cell mass. However, plasma volume returned to preflight levels at least a week before red cell mass recovered.

The major cause of the decrease in red cell mass resulting from space flight remains uncertain, although this experiment has ruled out or decreased the plausibility of several previously suggested causes such as hyperoxia. It now appears that red cell mass decreases during space flight due to premature loss of erythrocytes, possibly by destruction in the spleen, along with the failure of the erythropoiesis rate to increase and make up for the loss.

The number of subjects in this experiment was quite small. Because of differences in their sleep-wake cycle and use of anti-motion sickness medication and countermeasures, the subjects were far from being a homogeneous group, and problems such as changes during the preflight period need to be investigated. It is therefore necessary to view these results as preliminary until more experiments can be done. Further studies with more subjects under more homogeneous conditions should provide many of the answers to the questions raised by this study.

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TABLE 1. - SPACELAB 1 BLOOD DRAW SCHEDULE[a]

Day	Date	Time (CST)	Volume (ml) of blood drawn from each crewman			
			MS1	MS2	PS1	PS2
F-65	9/24/83	1130	69.5[b]	69.5[b]	61	61
F-55	10/4/83	0800	0	0	10.5[b]	10.5[b]
F-7	11/21/83	0730 or 1930[d]	61	61	61	61
F-1, 1-1/2	11/26/83	2030[e]	61[c]	61[c]	61[c]	61[c]
	or 11/27/83	0830[f]				
Preflight Total			191.5	191.5	193.5	193.5
MD1 (24 h MET)	11/29/83	0800	15	37	15	37
MD3 (70 h MET)	12/2/83		0	22	0	22
MD7 (190 h MET)	12/6/83	1000	23	41	23	45
Inflight Total			38	100	38	104
L+0	12/8/83	1900-1930	69.5[b]	69.5[b]	69.5[b]	69.5[b]
L+1	12/9/83	0820-1220	51[c]	51[c]	51[c]	51[c]
L+8	12/16/83	0730	69.5[b]	69.5[b]	69.5[b]	69.5[b]
L+12,13	12/20/83	0730[g]	51	51	51	51
	or 12/21/83	0730[h]				
Postflight Total			241	241	241	241
Mission Total			470.5	532.5	472.5	538.5

[a]MET = Mission Elapsed Time; MD = Mission Day
[b]Radioisotope procedures were done on this day.
[c]Radioisotope procedures without additional blood loss requirements were done on this day.
[d]0730 for MS2 and PS2, 1930 for MS1 and PS1
[e]MS1 and PS1
[f]MS2 and PS2
[g]PS1 and PS2
[h]MS1 and MS2

TABLE 2. - METHODS OF ANALYSIS

Tests and units	Methods	Population normal range	Astronaut normal range
Blood volume			
Red cell mass, ml/kg	^{51}Cr red blood cell dilution (Johnson et al., 1971)	20-35[a]	24.2-33.4[a]
Plasma volume, ml/kg	^{125}I-albumin dilution (Johnson et al., 1971)	35-50[a]	37.8-52.1[a]
Blood volume, ml/kg	Calculation		63.5-83.9[a]
Erythrocyte hematology			
Erythrocyte number, $X10^{12}/l$	Electronic particle counting (Wintrobe, 1974)	4.4-6.0[a]	4.1-5.5
Hemoglobin, g/dl	Cyanmethemoglobin (Wintrobe, 1974)	14.0-18.0[a]	12.9-16.5
Hematocrit, l/l	Electronic calculation (Wintrobe, 1974)	0.41-0.51[a]	0.39-0.49
Erythrocyte indices	Calculation (Wintrobe, 1974)		
Mean corpuscular volume, fl		80-97	82-100
Mean corpuscular hemoglobin, pg/cell		27-34	28-33
Mean corpuscular hemoglobin concentration, g/dl		31-36	31.5-36
Erythrocyte production and destruction			
Reticulocyte count, percent	Microscopy (Wintrobe, 1974) and flow cytometry (Tanke et al., 1983)	0.8-2.5[a]	0.3-1.4
Reticulocyte age classification	Image analysis of cells stained for RNA (Bessis et al., 1973)		
Reticulocyte production index	Calculation (Wintrobe, 1974)	1	
Erythropoietin, U/ml	Mouse fetal liver cell (Dunn et al., 1984)	.020-.075	
Erythropoietin inhibitors	Mouse fetal liver cell (modification of Kawada, 1974)		
Erythrocyte survival, percent	Percent ^{51}Cr RBC's remaining day 8 (Johnson et al., 1957)	70-85	75-85[a]
Effective erythropoiesis, percent	Percent ^{59}Fe RBC's incorporation (Weinstein and Beutler, 1955)	80-100	80-100[a]
Iron			
Transferrin, mg/dl	Radial immunodiffusion (Sternberg, 1977)	204-360	204-360
Serum iron, µg/dl	Colorimetry (Persijn et al., 1971)	35-140	
Total iron-binding capacity, µg/dl	Colorimetry (Persijn et al., 1971)	245-400	
Saturation of transferrin, percent	Calculation (Tietz, 1976)	25-30	
Erythrocyte shape	Scanning electron microscopy (Kimzey, 1977)		

[a]Range given applies to males only.

TABLE 2. - (Concluded)

Tests and units	Method	Population normal range	Astronaut normal range
Platelets and leukocytes			
Platelets, $X10^9/l$	Electronic particle counting (Wintrobe, 1974)	140-440	132-348
Leukocytes and differential	Microscopy (Wintrobe, 1974)		
Neutrophils, percent		24.8-62.3	36.8-72.4
, $X10^9/l$		1.1-6.05	
Lymphocytes, percent		19.6-52.7	21.5-57.9
, $X10^9/l$		1.5-4.0	0.8-3.5
Monocytes, percent		2.4-11.8	0-6
, $X10^9/l$		0.2-0.95	0.2-0.4
Eosinophils, percent		0-8	0-8
, $X10^9/l$		0-0.7	0-0.5
Basophils, percent		0-7.8	0-1.5
, $X10^9/l$		0-0.7	0-0.09
Neutrophil band cells, percent		0-1.8	0-2.7
Serum chemistry and proteins			
Osmolality, mosm/kg	Freezing point depression (Johnson and Hoch, 1965)	289-308	279-303
Sodium, meq/l	Ion selective electrode (Tietz, 1976)	135-148	138-145
Potassium, meq/l	Ion selective electrode (Tietz, 1976)	3.5-5.3	3.7-4.8
2,3-diphosphoglyceric acid, mol/g Hb	Spectrophotometry of coupled enzyme reaction (Lowry et al., 1964)	10.5-15.0[a]	
Adenosine triphosphate, mol/g Hb	Spectrophotometry of coupled enzymatic reaction (Adam, 1965)	3.65-4.45	
Total protein, g/dl	Refractometry (Naumann, 1964)	6.4-7.8	6.4-7.8
Protein distribution	Agarose gel electrophoresis (Cawley et al., 1962)		
Albumin, g/dl		3.7-5.2	3.7-5.2
Alpha-1 globulin, g/dl		0.1-0.4	0.1-0.4
Alpha-2 globulin, g/dl		0.3-0.8	0.3-0.8
Beta globulin, g/dl		0.6-1.0	0.6-1.0
Gamma globulin, g/dl		0.6-1.5	0.6-1.5
Haptoglobin, mg/dl	Radial immunodiffusion (Sternbery, 1977)	27-139	27-139
Ferritin, ng/ml	Radioimmunoassay (Addison et al., 1972)	19-210[a](<45 yr) 24-248[a](>45 yr)	

[a]Range given applies to males only.

TABLE 3. - LEVELS OF BLOOD PARAMETERS DURING SPACELAB 1 MISSION

Parameter	Preflight F-65 and F-7		F-1		MD1		MD7		L+0		L+1		L+8		L+12 or L+13	
	Mean[a]	SE	Mean[a]	SE	Mean[a]	SE	Mean	SE	Mean[a]	SE	Mean[a]	SE	Mean[a]	SE	Mean[a]	SE
Blood volume																
Red cell mass, ml/kg	27.54	0.57							25.00[c]	0.89			25.11[c]	1.04		
Plasma volume, ml/kg	44.88	1.94							42.24	3.23			46.28	1.70		
Blood volume, ml/kg	72.36	2.18							64.73[c]	1.70			71.39	2.15		
Erythrocyte hematology																
Erythrocyte count, $X10^{12}/l$	4.96	.12	4.85	0.24	5.02	0.11	5.30[b,c]	0.16	4.67	.18	4.52[c]	0.09	4.40[c]	.18	4.31[c]	0.16
Hemoglobin, g/dl	14.6	.3	14.3	.4	15.2[c]	.2	16.2[b,c]	.6	15.2[c]	.4	14.5	.5	13.2[c]	.4	13.4[c]	.4
Hematocrit, l/l	.43	.01	.41[c]	.01	.45	.01	.44[a]	.02	.42	.01	.41[c]	.01	.40[c]	.01	.41[c]	.01
Mean corpuscular volume, fl	87	1	85	3	89	3	85[b]	1	90	2	91	1	90	1	91	1
Mean corpuscular hemoglobin, pg/cell	30	.4	30	.8	31	.7	30[b]	.3	33[c]	.7	32[c]	0	30	.3	30	0
Mean corpuscular hemoglobin concentration, g/dl	35	.3	35	.7	34	.6	36[b,c]	.3	36[c]	.6	36	.3	33	.3	33	.4
Erythrocyte production																
Reticulocyte count, % of RBC's	1.3	.1	.6	.1	1.0	.3	.6[a]	.1	.5	.1	1.2	.1	1.1	.2	1.5	.3
Reticulocyte number, $X10^9/l$	64	5	31	7	49	15	27[b]	5	24	8	54	6	48	5	64	13
Reticulocyte production index	1.4	.2	.8	.1	1.0	.3	.6[a]	.1	.5	.1	1.3	.2	1.2	.1	1.5	.4
Reticulocyte count (flow cytometry) percent of RBC's	3.09	.24	3.03	.31	3.24	1.33	2.38[a]	.53	2.26	.48	2.35	.53	2.25	.20	4.14	1.15
Reticulocyte RNA, percent of cytoplasm	11.9	1.1	10.5	.7					8.8[c]	.3	10.1	.4	12.8	.3	11.8	.2
Erythropoietin, units/ml	.32	.03	.38	.09	.19	.11	.12[a]	.1	.09	.03	.21	.04	.22	.05	.07	.05
Iron																
Transferrin, mg/dl	298	17	264	12	271	16	271[a]	13	266	53	253	23	258	11	270	6
Serum iron, µg/dl	89	9	89	18	84	12	88[a]	15	59	3	81	12	63	9	69	9
Unbound iron-binding capacity, µg/dl	311	16	294	10	297	22	325[a]	21	268	20	290	4	298	7	306	19
Total iron-binding capacity, µg/dl	399	21	383	9	381	27	413[a]	15	327	18	370	12	361	16	375	22
Saturation of transferrin, percent	22	2	23	4	22	3	21[a]	4	18	2	22	2	17	2	18	3

[a] $n=4$

[b] $n=3$

[c] Significantly ($p < .05$) different from preflight measurement

TABLE 3. - (Continued)

Parameter	Preflight F-65 and F-7 Mean[a]	SE	F-1 Mean[a]	SE	MD1 Mean[a]	SE	MD7 Mean	SE	L+0 Mean[a]	SE	L+1 Mean[a]	SE	L+8 Mean[a]	SE	L+12 or L+13 Mean[a]	SE
Erythrocyte shape																
Discocytes, percent of RBC's	86.6	1.1	83.5	1.4	84.2	2.0	84.8[a]	1.6	83.0	1.3	85.4	2.1	81.8	0.9	86.1	1.4
Knizocytes, percent of RBC's	3.2	.7	3.5	.3	3.4	.9	3.0[a]	.8	2.4	.8	1.3	.4	1.0	.2	1.7	.4
Stomatocytes, percent of RBC's	5.6	.9	6.8	.3	8.2	.7	5.6[a]	.8	7.8	.7	8.3	1.9	4.3	.7	4.6	1.3
Echinocytes, stages 1-3, percent of RBC's	4.1	.7	5.8	1.4	3.8	1.1	5.8[a]	.4	6.7	.3	4.8	1.2	13[c]	1.8	7.7	1.2
Discocytes, $X10^9/l$	4330	130	4040	156	4220	72	4460[b]	20	3880	134	3860	129	3600[c]	174	3710[c]	182
Knizocytes, $X10^9/l$	150	30	170	14	170	48	190[b]	41	110	38	58	19	41	10	70	16
Stomatocytes, $X10^9/l$	280	49	330	25	410	41	310[b]	50	370	49	380	89	190	35	190	50
Echinocytes, stages 1-3, $X10^9/l$	20	29	290	76	190	60	320[b]	5	310	8	210	52	500[c]	53	330	57
Platelets and leukocytes																
Platelet count, $X10^9/l$	270	15	215	19	245	19	230[b]	24	299	19	272	12	272	38	265	19
Leukocyte count, $X10^9/l$	6.1	.3	6.1	.5	7.7	1.1	7.1[b]	1	7.2	1.2	6.3	.5	6.2	.5	6.8	1.1
Neutrophils, percent of WBC's	63	2	51	3	70	6	63[a]	3	67	6	63	5	62	5	56	6
Lymphocytes, percent of WBC's	31	3	44[c]	3	22	5	30[a]	3	28	6	31	5	31	2	32	4
Monocytes, percent of WBC's	5	.7	3	.7	2	.7	3[a]	1	4	.4	4	.9	3	1	9[c]	1
Eosinophils, percent of WBC's	2	.9	3	.8	.8	.5	2[a]	.5	2	.7	2	.8	4	2	2	1
Band neutrophils, percent of WBC's	.1	.1	.8	.5	6[c]	2	1[a]	.5	0	0	0	0	0	0	.8	1
Neutrophils, $X10^9/l$	4.0	.4	3.1	.1	5.5	1.3	4.5[b]	.9	5.0	1.2	4.0	.5	3.9	.6	3.9	1.1
Lymphocytes, $X10^9/l$	1.9	.2	2.7[c]	.4	1.5	.2	2.0[b]	.1	1.8	.2	1.9	.3	1.9	.1	2.1	.1
Monocytes, $X10^9/l$	.2	.06	.2	.05	.2	.05	.3[b]	.1	.2	.02	.3	.07	.2	.07	.6[c]	.09
Eosinophils, $X10^9/l$	.08	.04	.2	.04	.5	.03	.2[b]	.06	.1	.06	.1	.07	.2	.1	.1	.06
Band neutrophils, $X10^9/l$	.06	.06	.05	.03	.5[c]	.1	.1[b]	.04	0	0	0	0	0	0	.07	.05

[a] $n=4$

[b] $n=3$

[c] Significantly ($p < .05$) different from preflight measurement

TABLE 3. - (Concluded)

Parameter	Preflight F-65 and F-7 Mean[a]	SE	F-1 Mean[a]	SE	MD1 Mean[a]	SE	MD7 Mean[a]	SE	L+0 Mean[a]	SE	L+1 Mean[a]	SE	L+8 Mean[a]	SE	L+12 or L+13 Mean[a]	SE
Serum chemistry																
Osmolality, mosm/l	295	1	297	1	290	1	290	2	297	1	292	2	289[c]	1	288[c]	1
Sodium, meq/l	143	1	142	.4	141[c]	.5	140[c]	.9	142	.6	140[c]	1	142	.6	140[c]	.4
Potassium, meq/l	4.0	.1	3.9	.1	3.9	.2	3.8	.2	3.9	.3	3.9	.1	3.9	.1	3.9	.2
2,3-DPG, mol/g Hb	12.1	.1	14.1	1	13.5	.6	13.2	1.3	10.9	.9	11.5	.4	14.3	.8	13.8	.9
ATP, mol/g Hb	3.26	.18	3.52	.10	3.60	.03	3.90	.25	3.04	.50	3.31	.43	3.17	.11	3.84	.55
Serum proteins																
Total serum protein, g/dl	7.1	.2	6.9	.2	7.1	.2	6.8	.3	6.9	.2	6.9	.1	6.6[c]	.2	6.7	.2
Albumin, g/dl	4.7	.1	5.0	.1	5.0	.1	4.7	.2	4.7	.2	4.9	.1	4.5	.1	4.4	.1
Alpha-1 globulin, g/dl	.3	.03	.2	.03	.2	.03	.2	.03	.3	.00	.3	.03	.3	.05	.4[c]	.03
Alpha-2 globulin, g/dl	.5	.07	.4	.03	.5	.04	.6	.05	.6	.05	.5	.03	.4	.03	.7[c]	.03
Beta globulin, g/dl	.7	.04	.5	.05	.5	.1	.7	.05	.7	.05	.6	.03	.7	.03	.6	.03
Gamma globulin, g/dl	1	.1	.7[c]	.09	.7[c]	.08	.7[c]	.1	.7[c]	.07	.7[c]	.1	.7[c]	.1	.8[c]	.1
Haptoglobin, mg/dl	113	45	99	49	118	52	147	68	126	63	122	65	141	53	147	51
Ferritin, ng/ml	108	31	98.7	24.5	111	33	145[c]	29	144[c]	18	157[c]	32	104	27	90.9	25.0

[a] $n=4$
[b] $n=3$
[c] Significantly ($p < .05$) different from preflight measurement

TABLE 4. - CHANGE IN BLOOD PARAMETERS DURING SPACELAB 1 MISSION

Parameter	Preflight F-65 and F-7		Percent change on MD1		Percent change on MD7		Percent change on L+0		Percent change on L+1		Percent change on L+8		Percent change on L+12 or L+13	
	Mean[a]	SE	Mean[a]	SE	Mean[a]	SE	Mean[a]	SE	Mean[a]	SE	Mean[a]	SE	Mean[a]	SE
Blood volume														
Red cell mass, ml/kg	27.54	0.57					-9.30[c]	1.60			-6.04[c]	0.72		
Plasma volume, ml/kg	44.82	1.94					-5.98	4.30			3.39	1.86		
Blood volume, ml/kg	72.36	2.18					-10.50[c]	.87			-1.34	.34		
Erythrocyte hematology														
Erythrocyte count, $X10^{12}/l$	4.96	.12	1.41	1.10	4.30[b,c]	0.94	-5.83	1.03	-8.83[c]	1.04	-11.4[c]	1.1	-12.9[c]	3.4
Hemoglobin, g/dl	14.6	.3	3.7[c]	1.6	8.4[b,c]	1.1	3.4[c]	.3	-1.0	.6	-10.3[c]	.7	-8.8[c]	1.3
Hematocrit, l/l	.43	.01	3.5	1.6	1.9[a]	2.0	-3.2	.8	-4.9[c]	1.0	-7.9[c]	1.1	-6.1[c]	1.2
Mean corpuscular volume, fl	87	1	2.2	1.5	-1[b]	.5	2.9	1.0	4.1	.4	3.8	.7	4.4	.5
Mean corpuscular hemoglobin, pg/cell	30	.4	3.5	3.5	2.3[b]	1.1	8.3[c]	.9	6.7[c]	1.4	.9	.9	.1	1.4
Mean corpuscular hemoglobin concentration, g/dl	35	.3	-1.5	1.5	2.9[b,c]	1.7	5.1[c]	1.4	2.9	0	-3.6	.7	-4.3	.9
Erythrocyte production														
Reticulocyte count, percent of RBC's	1.3	.1	-17	32	-54[a]	10	-59	8	-6.0	11	-14	9	10	20
Reticulocyte number, $X10^9/l$	64	5	-17	31	-55[b]	15	-61	8	-15	9	-24	9	-1.8	17
Reticulocyte production index	1.4	.2	-19	32	-53[a]	11	-60[c]	8	-3	13	-18	3	11	20
Reticulocyte count (flow cytometry), percent of RBC's	3.09	.24	9.1	45.2	-21.4[a]	18.0	-22.6	22.7	-24.0	14.2	-26.1	8.2	38.5	42.0
Reticulocyte RNA, percent of cytoplasm	11.9	1.1					-24.7[c]	3.1	-13.6	6.2	10.4	8.0	1.3	8.2
Erythropoietin, units/ml	.32	.03	-50	27	-73[a]	21	-72	10	-33	12	-33	14	-73	23
Iron														
Transferrin, mg/dl	298	17	-8.6	4.5	-8.6[a]	3.6	-10.7	7.5	-14.7	6.5	-12.9	4.7	-8.5	6.4
Serum iron, µg/dl	89	9	-5.8	8.1	.7[a]	15	-32	6.6	-8.8	7.9	-28	8.1	-16	21
Unbound iron-binding capacity, µg/dl	311	16	-4.6	2.1	4.9[a]	5.4	-13.7	5.9	-6.2	3.6	-3.2	6.9	-.4	8.4
Total iron-binding capacity, µg/dl	399	21	-4.8	2.5	4.0[a]	4.2	-17.5	6.1	-6.6	4.5	-8.6	7.0	-4.7	8.6
Saturation of transferrin, percent	22	2	-.7	7.0	-2.9[a]	13	-17	4	-2.2	4.5	-21	3	-10	14

[a] $n=4$

[b] $n=3$

[c] Significantly ($p < .05$) different from preflight measurement

TABLE 4. - (Continued)

Parameter	Preflight F-6b and F-7 Mean[a]	SE	Percent change on MD1 Mean[a]	SE	Percent change on MD7 Mean[a]	SE	Percent change on L+0 Mean[a]	SE	Percent change on L+1 Mean[a]	SE	Percent change on L+8 Mean[a]	SE	Percent change on L+12 or L+13 Mean[a]	SE
Erythrocyte shape														
Discocytes, percent of RBC's...	86.6	1.1	-2.7	3.3	-1.5[a]	1.2	-4.1	2.4	-1.5	1.3	-5.6	0.9	-0.6	1.5
Knizocytes, percent of RBC's...	3.2	.7	26	48	15[a]	42	-10	37	-63	8	-68	9.5	-45	16
Stomatocytes, percent of RBC's.	5.6	.9	55	27	3.8[a]	21	41	12	45	21	-23	8.6	-14	27
Echinocytes, percent of RBC's.. stages 1-3	4.1	.7	14	54	54[a]	30	78	31	9.5	16	210[c]	9.9	120	65
Discocytes, $X10^9/l$.....	4330	130	-1.5	3.6	.3[b]	3.7	-9.8	2.3	-10.3	1.0	-16.4[c]	1.7	-13.5[c]	4.6
Knizocytes, $X10^9/l$.....	150	30	38	58	61[b]	51	-10	38	-65	7	-70	9	-53	11
Stomatocytes, $X10^9/l$.....	280	49	57	28	14[b]	33	34	13	31	20	-33	7	-26	24
Echinocytes, stages 1-3, $X10^9/l$.....	20	29	15	53	84[b]	29	69	31	1	16	160[c]	20	82	47
Platelets and leukocytes														
Platelet count, $X10^9/l$.....	270	15	-9.7	2.2	-12.0[b]	4.1	12.0	10.7	2.0	8.5	-.9	8.6	-2.1	1.8
Leukocyte count, $X10^9/l$.....	6.1	.3	26	18	14[b]	9	17	16	3.3	5.4	2.1	8.1	1.3	19
Neutrophils, percent of WBC's..	63	2	8.5	6.5	.1[a]	5.3	5.5	9.3	-1.3	4.6	-3.1	6.4	-13	6
Lymphocytes, percent of WBC's..	31	3	-29	16	1.3[a]	14	-8.0	19	.8	11	3.6	5.5	4.6	8.8
Monocytes, percent of WBC's....	5	.7	-60	20	-30[a]	30	-20	20	-5	30	-30	40	100[c]	50
Eosinophils, percent of WBC's..	2	.9	-40	20	60[a]	70	40	60	80	70	100	40	50	50
Band neutrophils, percent of WBC's.....	.1	.1	Cannot be determined because preflight value was zero for three crewmembers											
Neutrophils, $X10^9/l$.....	4.0	.4	27	23	13[b]	20	34	14	-.6	7.8	-4.6	6.7	-4.4	18
Lymphocytes, $X10^9/l$.....	1.9	.2	-17	10	10[b]	15	-.4	13	2.2	3.8	6.5	13	15	13
Monocytes, $X10^9/l$.....	.2	.06	-10	50	5[b]	20	40	50	30	30	10	50	300[c]	100
Eosinophils, $X10^9/l$.....	.08	.04	-40	20	80[b]	90	80	100	100	80	100	40	10	50
Band neutrophils, $X10^9/l$.....	.06	.06	Cannot be determined because preflight value was zero for three crewmembers											

[a] n=4
[b] n=3
[c] Significantly ($p < .05$) different from preflight measurement

TABLE 4.- (Concluded)

Parameter	Preflight F-65 and F-7		Percent change on MD1		Percent change on MD 7		Percent change on L+0		Percent change on L+1		Percent change on L+8		Percent change on L+12 or L+13	
	Mean[a]	SE	Mean[a]	SE	Mean[a]	SE	Mean[a]	SE	Mean[a]	SE	Mean[a]	SE	Mean[a]	SE
Serum chemistry														
Osmolality, mosm/l	295	1	-1.6	0.7	-1.6	0.4	0.6	0.3	-1.1	0.5	-2.1[c]	0.7	-2.3[c]	0.5
Sodium, meq/l	143	1	-1.4[c]	.4	-1.9[c]	.2	-.4	.2	-1.9[c]	.4	-.2	.2	-1.8[c]	.3
Potassium, meq/l	4.0	.1	-.8	3.7	-5.1	4.3	-1.5	6.5	-1.2	3.3	-1.2	2.2	-.7	5.1
2,3-DPG, mol/g Hb	12.1	.1	12.0	4.8	9.4	-9.7	-9.3	6.9	-4.3	4.1	18.9	6.6	14.4	7.6
ATP, mol/g Hb	3.26	.18	11.5	6.4	22.2	14.1	-6.9	14.2	1.9	12.8	-2.4	4.2	17.4	15.0
Serum proteins														
Total serum protein, g/dl	7.1	.2	-.1	.6	-3.8	2.4	-3.0	1.7	-2.8	2.2	-7.6[c]	1.3	-5.0	1.7
Albumin, g/dl	4.7	.1	6.2	1.5	-.3	2.7	-0.7	3.9	3.1	320	-4.0	0.5	-7.2	2.1
Alpha-1 globulin, g/dl	.3	.03	-20	10	-20	10	10	10	4	10	9	30	30[c]	30
Alpha-2 globulin, g/dl	.5	.07	-2	10	6	6	10	10	4	4	-30	10	30[c]	10
Beta globulin, g/dl	.7	.04	-30	20	-.3	6	-3	8	-20	8	-6	8	-20	3
Gamma globulin, g/dl	1	.1	-30[c]	2	-30[c]	4	-30[c]	5	-30[c]	12	-30[c]	4	-30[c]	3
Haptoglobin, mg/dl	113	45	-.4	5.9	24	18	12	8	-5	24	26	12	35	9
Ferritin, ng/ml	108	31	1.5	2.9	53[c]	26	62[c]	36	63[c]	.4	1.9	9.2	-15	3

[a] $n=4$

[b] $n=3$

[c] Significantly ($p < .05$) different from preflight measurement

TABLE 5. - LEVELS OF BLOOD PARAMETERS DURING SPACELAB 1 SIMULATION

Parameter	Preflight F-65 and F-7		F-1		MD1		MD7		L+0		L+1		L+8		L+12 or L+13	
	Mean[a]	SE	Mean[a]	SE	Mean[a]	SE	Mean[a]	SE	Mean[a]	SE	Mean[a]	SE	Mean[a]	SE	Mean[a]	SE
Blood volume																
Red cell mass, ml/kg	28.15	1.51							26.93[b]	1.74			25.79[b]	1.43		
Plasma volume, ml/kg	41.40	3.75					38.65	2.53	38.69	2.71			41.87	2.92		
Blood volume, ml/kg	69.54	4.96							65.62	4.27			67.66	4.15		
Erythrocyte hematology																
Erythrocyte count, $X10^{12}/l$	5.00	.27	4.99	0.22	5.06	0.21	5.16	.13	5.14	.15	4.87	0.14	4.69	.15	4.71	0.20
Hemoglobin, g/dl	14.6	.7	14.9	.5	15.2	.5	15.2	.3	15.1	.5	14.5	.4	14.0	.3	14.0	.5
Hematocrit, l/l	.44	.02	.44	.02	.45	.01	.46	.01	.45	.01	.43	.01	.42	.01	.42	.01
Mean corpuscular																
Mean corpuscular volume, fl	88	2	89	2	89	2	89	2	88	2	89	2	89	2	89	2
Mean corpuscular hemoglobin, pg/cell	29	1	30	1	30[b,c]	1	29	1	30	1	30	1	30	1	30	1
Mean corpuscular hemoglobin concentration, g/dl	33	.2	34[b,c]	0	34	.2	33	0	34	.2	34	.2	34	.2	34[b,c]	0
Erythrocyte production																
Reticulocyte count, percent of RBC's	.7	.1	.9	.2	.7	.1	.8	.1	.7	.1	.7	.1	.7	.2	.8	.1
Reticulocyte number, $X10^9/l$	35	6	43	8	36	4	39	5	38	6	34	5	32	9	40	6
Reticulocyte production index	.7	.1	.9	.2	.7	.1	.8	.1	.8	.1	.7	.1	.7	.2	.8	.1
Erythropoietin, units/ml	.16	.03	.38	.10	.12	.07	.23	.07	.25	.08	.21	.07	.18	.07	.18	.04
Iron																
Transferrin, mg/dl	281	16	299	23	283	11	276	8	285	16	277	15	253	11	279	17
Serum iron, µg/dl	108	11	108	8	79	11	127	14	74	15	90	17	76	5	80	14
Unbound iron-binding capacity, µg/dl	337	20	305	22	306	21	357	25	291	20	308	19	315	18	324	34
Total iron-binding capacity, µg/dl	445	27	412	22	370	37	484	40	365	23	398	25	392	23	404	48
Saturation of transferrin, percent	24	2	26	2	21	2	26	1	20	2	23	1	19	1	19	1

[a]n=5

[b]Significantly ($p < .05$) different from preflight measurement

[c]The computer program, which uses more decimal places than are used in this table, found a significant difference at this time point.

TABLE 5. - (Concluded)

Parameter	Preflight F-65 and F-7		F-1		MD1		MD7		L+0		L+1		L+8		L+12 or L+13	
	Mean[a]	SE	Mean[a]	SE	Mean[a]	SE	Mean[a]	SE	Mean[a]	SE	Mean[a]	SE	Mean[a]	SE	Mean[a]	SE
Platelets and leukocytes																
Platelet count, $X10^9/l$	238	20	251	22	242	19	244	15	246	17	239	18	252	17	257	13
Leukocyte count, $X10^9/l$	5.4	.9	5.9	.7	6.0	1	6.8	1	7.3	1.6	6.2	.7	5.7	.8	5.2	.5
Neutrophils, percent of WBC's	57	3	56	3	63	2	55	1	63	3	59	3	56	2	59	4
Lymphocytes, percent of WBC's	37	3	36	3	32	2	37	3	31	2	32	2	35	1	33	4
Monocytes, percent of WBC's	4	1	4	.4	3	1	4	.8	4	2	6	2	6	.9	4	1
Eosinophils, percent of WBC's	2	.8	4	1	2	.6	3	1	1	.4	2	1	2	2	3	1
Band neutrophils, percent of WBC's	.5	.3	0	0	.2	.2	1	.5	.4	.2	.4	.2	.6	.2	0	0
Neutrophils, $X10^9/l$	3.1	.5	3.3	.4	3.9	.7	3.8	.6	4.7[b]	1.0	3.7	.5	3.2	.5	3.2	.4
Lymphocytes, $X10^9/l$	2.0	.30	2.1	.2	1.9	.3	2.4	.2	2.1	.3	1.9	.2	2.0	.3	1.7	.2
Monocytes, $X10^9/l$	.2	.08	.3	.04	.2	.06	.3	.10	.3	.1	.3	.08	.4	.08	.2	.08
Eosinophils, $X10^9/l$	.07	.04	.2	.08	.09	.04	.2	.1	.08	.05	.1	.08	.1	.09	.2	.05
Band neutrophils, $X10^9/l$	.03	.02	0	0	.01	.01	.10[b]	.04	.04	.03	.02	.02	.04	.02	0	0
Serum chemistry																
Osmolality, mosm/l	289	1	289	1	286	1	286	1	291	2	286	1	290	1	286	1
Sodium, meq/l	142	.3	143	.7	140	.6	140	.2	144	.6	141	.5	143	0	141	.6
Potassium, meq/l	3.9	.03	3.9	.04	4.5[b]	.2	4.0	.1	4.3	.2	4.2	.1	3.9	.2	4.1	.1
2,3-DPG, mol/g Hb	13.9	.5	14.2	.3	12.0	1.2	14.2	.6	13.3	1.4	13.6	.4	14.9	.4	12.3	.8
ATP, mol/g Hb	4.50	.16	4.17	.11	4.62	.20	4.19	.35	4.31	.21	4.33	.26	3.93	.19	4.23	.38
Serum proteins																
Total serum protein, g/dl	6.9	.2	7.2	.1	7.0	.2	6.9	.2	7.1	.1	7.0	.1	6.6	.1	6.8	.1
Albumin, g/dl	4.8	.08	5.0	.2	5.1	.2	4.9	.1	5.0	.1	4.9	.1	4.8	.1	4.8	.1
Alpha-1 globulin, g/dl	.2	.01	.2	.02	.2	.02	.2	0	.2	.04	.2	0	.2	0	.2	0
Alpha-2 globulin, g/dl	.5	.04	.5	.04	.4	.02	.5	.04	.6	.02	.5	0	.5	.02	.5	.02
Beta globulin, g/dl	.6	.05	.7	.10	.6	.04	.6	.06	.6	.06	.6	.05	.5	.04	.5	.03
Gamma globulin, g/dl	.7	.06	.8	.1	.7	.08	.7	.07	.8	.07	.7	.06	.7	.05	.8	.07
Haptoglobin, mg/dl	76	10	74	5	77	7	94	1	90	9	83	5	74	3	77	7
Ferritin, ng/ml	103.2	21.0	97.2	15.0	101.8	20.0	84.8	15.3	88.6	17.1	87.2	14.5	63.2[b]	11.6	68.8[b]	15.7

[a] n=5

[b] Significantly ($p < .05$) different from preflight measurement

TABLE 6. - CHANGE IN BLOOD PARAMETERS DURING SPACELAB 1 SIMULATION

Parameter	Preflight F-65 and F-7		Percent change on MD1		Percent change on MD7		Percent change on L+0		Percent change on L+1		Percent change on L+8		Percent change on L+12 or L+13	
	Mean[a]	SE	Mean[a]	SE	Mean[a]	SE	Mean[a]	SE	Mean[a]	SE	Mean[a]	SE	Mean[a]	SE
Blood volume														
Red cell mass, ml/kg	28.15	1.51					-4.55[b]	1.23			-8.35[b]	1.94		
Plasma volume, ml/kg	41.40	3.75			-5.60	3.08	-5.40	4.36			2.01	2.52		
Blood volume, ml/kg	69.54	4.96					-5.26	2.81			-2.38	1.61		
Erythrocyte nematology														
Erythrocyte count, $X10^{12}/l$	5.00	.27	1.64	2.08	3.99	4.04	3.53	3.82	-1.93	3.03	-5.69	3.00	-5.43	2.29
Hemoglobin, g/dl	14.6	.7	4.6	1.9	4.6	3.7	4.1	4.0	-.2	3.0	-3.6	2.8	-3.5	2.5
Hematocrit, l/l	.44	.02	2.2	2.3	4.3	3.8	3.8	4.4	-1.2	3.7	-4.9	2.8	-4.6	2.4
Mean corpuscular volume, fl	88	2	.9	.4	.9	.5	-.2	.4	.4	.3	.9	.5	.7	.7
Mean corpuscular hemoglobin, pg/cell	29	1	3.1[b]	.8	.3	.8	1.0	.7	1.7	.04	1.7	.04	2.3	.6
Mean corpuscular hemoglobin concentration, g/dl	33	.2	1.8	.3	-.6	.6	1.2	.7	1.8	.3	1.8	1.0	2.4[b]	.6
Erythrocyte production														
Reticulocyte count, percent of RBC's	.7	.1	7.5	22	10	8.3	8.9	18	3.0	13	13	41	29	26
Reticulocyte number, $X10^9/l$	35	6	9.3	20	14	10	11	17	-.7	10	1.9	34	22	26
Reticulocyte production index	.7	.1	6.1	23	7.1	8.9	12	23	4.9	16	16	47	25	26
Erythropoietin, units/ml	.16	.03	-38	37	81	72	45	36	45	36	7.6	35	14.5	22
Iron														
Transferrin, mg/dl	281	16	1.2	3.4	-1.1	3.2	1.6	4.9	-1.4	3.5	-9.9	1.5	-.9	1.3
Serum iron, µg/dl	108	11	-24	13	22	16	-27	11	-27	11	-24	13	-22	16
Unbound iron-binding capacity, µg/dl	337	20	-9.2	2.9	6.0	3.7	-13.5	2.4	-13.5	2.4	-6.0	3.5	-4.0	7.6
Total iron-binding capacity, µg/dl	445	27	17.1-	5.6	8.9	6.4	-17.4	14.5	-17.4	4.5	-11.2	5.6	-8.9	9.8
Saturation of transferrin, percent	24	2	-9.5	12	9.9	10	-13.5	9.2	-13.5	9.2	-17	9	-18	9

[a] $n=5$

[b] Significantly ($p < .05$) different from preflight measurement

TABLE 6. - (Concluded)

Parameter	Preflight F-65 and F-7 Mean[a]	SE	Percent change on MD1 Mean[a]	SE	Percent change on MD7 Mean[a]	SE	Percent change on L+0 Mean[a]	SE	Percent change on L+1 Mean[a]	SE	Percent change on L+8 Mean[a]	SE	Percent change on L+12 or L+13 Mean[a]	SE
Platelets and leukocytes														
Platelet count, $X10^9$/l	238	20	2.0	3.1	3.6	4.0	3.8	1.8	0.7	2.4	6.3	2.1	9.5	4.6
Leukocyte count, $X10^9$/l	5.4	.9	12	3	29	10	31	10	18	7	6.5	3.1	2.3	10
Neutrophils, percent of WBC's	57	3	12	5	-1.7	6.4	11.2	2.7	5.3	3.9	-.8	4.6	4.1	3.2
Lymphocytes, percent of WBC's	37	3	-14	6	-.6	7.8	-6	6	-14	5	-4.6	5.4	-11.2	8.4
Monocytes, percent of WBC's	4	1	80	100	100	100	40	50	300	200	300	300	300	300
Eosinophils, percent of WBC's	2	.8	Cannot be determined because preflight value was zero for two subjects											
Band neutrophils, percent of WBC's	.5	.3	Cannot be determined because preflight value was zero for two subjects											
Neutrophils, $X10^9$/l	3.1	.5	25	9	25	10	45[b]	14	23	7	4.6	3.3	5.9	11
Lymphocytes, $X10^9$/l	2.0	.30	-2.9	5.1	30	15	9.7	7.1	3.4	11.6	3.1	7.1	-9.5	11
Monocytes, $X10^9$/l	.2	.08	100	100	200	200	90	70	300	300	400	400	400	400
Eosinophils, $X10^9$/l	.07	.04	Cannot be determined because preflight value was zero for two subjects											
Band neutrophils, $X10^9$/l	.03	.02	Cannot be determined because preflight value was zero for two subjects											
Serum chemistry														
Osmolality, mosm/l	289	1	-.9	.3	-1.0	.3	.9	.4	-1.0	.3	.6	.5	-.8	.6
Sodium, meq/l	12	.3	-1.2	.5	-1.2	.3	1.2	.6	-.9	.4	.6	.2	-.8	.5
Potassium, meq/l	3.9	.03	17[b]	5.2	3.9	1.7	10.1	6.4	7.6	3.7	1.8	4.2	5.4	.9
2,3-DPG, mol/g Hb	13.9	.5	-12.9	8.7	2.7	2.6	-4.5	8.6	-4.5	8.6	7.8	2.3	-10.8	5.2
ATP, mol/g Hb	4.50	.16	3.90	8.10	-6.79	7.04	-4.27	2.06	-4.27	2.06	-12.5	3.18	-6.33	6.27
Serum proteins														
Total serum protein, g/dl	6.9	.2	1.6	3.0	.4	3.2	4.0	2.1	1.4	3.2	-3.3	2.5	-1.7	1.1
Albumin, g/dl	4.8	.08	6.4	4.2	1.4	3.5	3.5	3.2	2.3	3.9	-1.1	2.5	-1.2	1.4
Alpha-1 globulin, g/dl	.2	.01	-30	11	-12	5	8.0	23	-12	5	-12	5	-12	5
Alpha-2 globulin, g/dl	.5	.04	-10	4	1	13	21	6	9	8	4	7	13	9
Beta globulin, g/dl	.6	.05	-9	4	.2	7	-9	6	-3	2	-20	3	-20	6
Gamma globulin, g/dl	.7	.06	-4	5	0	5	9	6	0	5	-5	4	9	2
Haptoglobin, mg/dl	76	10	2.3	6.8	34	32	27	24	17	18	1	9	9	17
Ferritin, ng/ml	103.2	21.0	1.3	5.4	-13.9	6.7	-11.6	6.8	-11.6	6.8	-34.2[b]	7.3	-33.0[b]	5.1

[a] $n=5$

[b] Significantly ($p < .05$) different from preflight measurement

APPENDIX A

EFFECTS OF ALTERED WORK-REST SCHEDULE ON CIRCADIAN RHYTHMS

The activities planned for Spacelab 1 necessitated work performance throughout each 24 hours. In order to meet this need, crewmembers were assigned to either diurnal work and nocturnal rest (relative to Houston time) or to nocturnal work and diurnal rest. Astronauts 1 and 3 were assigned to the latter shift work schedule.

During the period of isolation before flight when these astronauts were being adapted to a daytime rest, nighttime activity pattern, an attempt was made to determine whether there was a shift in the peak time (acrophase) of their circadian rhythms. Several urinary variables that had exhibited a statistically significant ($p < .05$) circadian rhythm in a study done 6-8 months before the flight were selected for study. The variables used were calcium, potassium, 17-hydroxycorticosteroids (17-OHCS) and oral temperature. Sequential urine voidings and frequent measurements of oral temperatures were obtained during the waking spans of the 3 days prior to flight (Julian days 325-329) and 4 to 6 days after landing (Julian days 343-349). Calcium and potassium were determined by standard clinical methods (Trudeau and Freier, 1967; Tietz, 1976), and cortisol was determined by radioimmunoassay (Foster and Dunn, 1974). The data were analyzed by the cosinor method to determine to what extent, if any, phase shifting of these circadian functions occurred.

Figures 1 to 3 depict the results of the cosinor analyses applied to the data. In these figures, the ordinate scale indicates by a positive or negative sign an advance or delay in the circadian acrophase (ϕ) relative to the baseline circadian acrophase (as determined in the previous study and shown for each astronaut on the graphs). To ensure a sufficient data base to obtain the best possible estimates of the circadian acrophase on a day-by-day basis, cosinor analyses were conducted on data sets of 48-hour duration. Analyses proceeded in a stepwise fashion; data for each sequential 24-hour span were added as data for the earliest 24 hours were deleted. For example, the acrophase shown for the 48-hour span labeled (Julian days) 343-344 on the abscissa was derived from a cosinor analysis of the data from 0000 hours (Houston time) on the day of landing (343) until 2359 hours on the next day (344); the acrophase for the span labeled 344-345 on the abscissa was derived from a cosinor analysis of data obtained during the 48 hours extending from 0000 of day 344 until 2359 of day 345, and so on. The same procedure was used for the preflight data.

Since the baseline acrophase of each variable was determined from data obtained while the astronauts were adhering to diurnal activity and nocturnal sleep, it was expected that a 12-hour shift in the activity-sleep schedule would induce a corresponding shift in the circadian time structure, if not before flight then certainly by the end of the mission, assuming complete adjustment of the circadian system to the new routine. Thus, the acrophase values for each of the variables were expected to exhibit a significant displacement ($\Delta\phi$) of about 12 hours (180 degrees) from the baseline by the end of the flight.

Only for urinary calcium (figure 1) for both astronauts and perhaps potassium (figure 2) for astronaut 1 was there any evidence of circadian adjustment as detected by acrophase shifts. The acrophase of urinary calcium began to shift in opposite directions in the two astronauts before flight,

but immediately after landing it had shifted by about 150 degrees in the same direction (negative) in both astronauts. In astronaut 1 the acrophase for potassium exhibited a large phase shift (about 165 degrees) from baseline just before flight. Yet, postflight data were in fairly good agreement with the baseline reference. Of particular interest is urinary 17-OHCS (figure 3), which usually exhibits a rhythm with relatively slow adjustment of its acrophase with changes in the work-rest routine. Figure 3 reveals at most only slight differences in the phase of this rhythm from the (diurnal activity) baseline phase, both immediately before flight and afterward. Only for brief times (days 326-327 and 343-344 for astronaut 1 and days 344-345 for astronaut 3) were there deviations from the baseline phase and these were insignificant, constituting a phase shift of no more than 3 hours.

Sufficient data on oral temperature were available from only astronaut 3 during the postflight period. In most persons the oral temperature circadian rhythm exhibits rather rapid adjustment to alterations in synchronizer schedule, but in astronaut 3 the acrophase was displaced by a only a few hours before and after flight, and during the postflight period the timing of the acrophase did not stabilize around the baseline reference time.

It is difficult to determine whether the phase shifts that did occur represent a true alteration in the staging of the circadian rhythms or "masking" effects due to variation in meal composition and scheduling under the conditions of the different studies. Since urinary 17-OHCS is considered to be a very reliable index of circadian system staging (Reinberg, 1979; Klein and Wegmann, 1979), it is suggested that chronobiologic adjustment to the altered rest-activity schedule did not occur. An alternative explanation of the data is that the circadian rhythm structure of the astronauts was desynchronized due to incomplete phase adjustment of the many circadian variables with the occurrence of free-running rhythms. The latter possibility is suggested by the fact that the circadian rhythms of calcium and oral temperature exhibited phase delays relative to baseline values even by 5 days postflight. Perhaps in the Space Shuttle environment other, more dominant, synchronizers of circadian rhythms are in operation than the one currently believed to be most important for human beings on Earth, the rest-activity schedule. The small amount of data available so far prevents us from drawing any conclusions about why most of the circadian rhythms studied did not undergo a phase shift.

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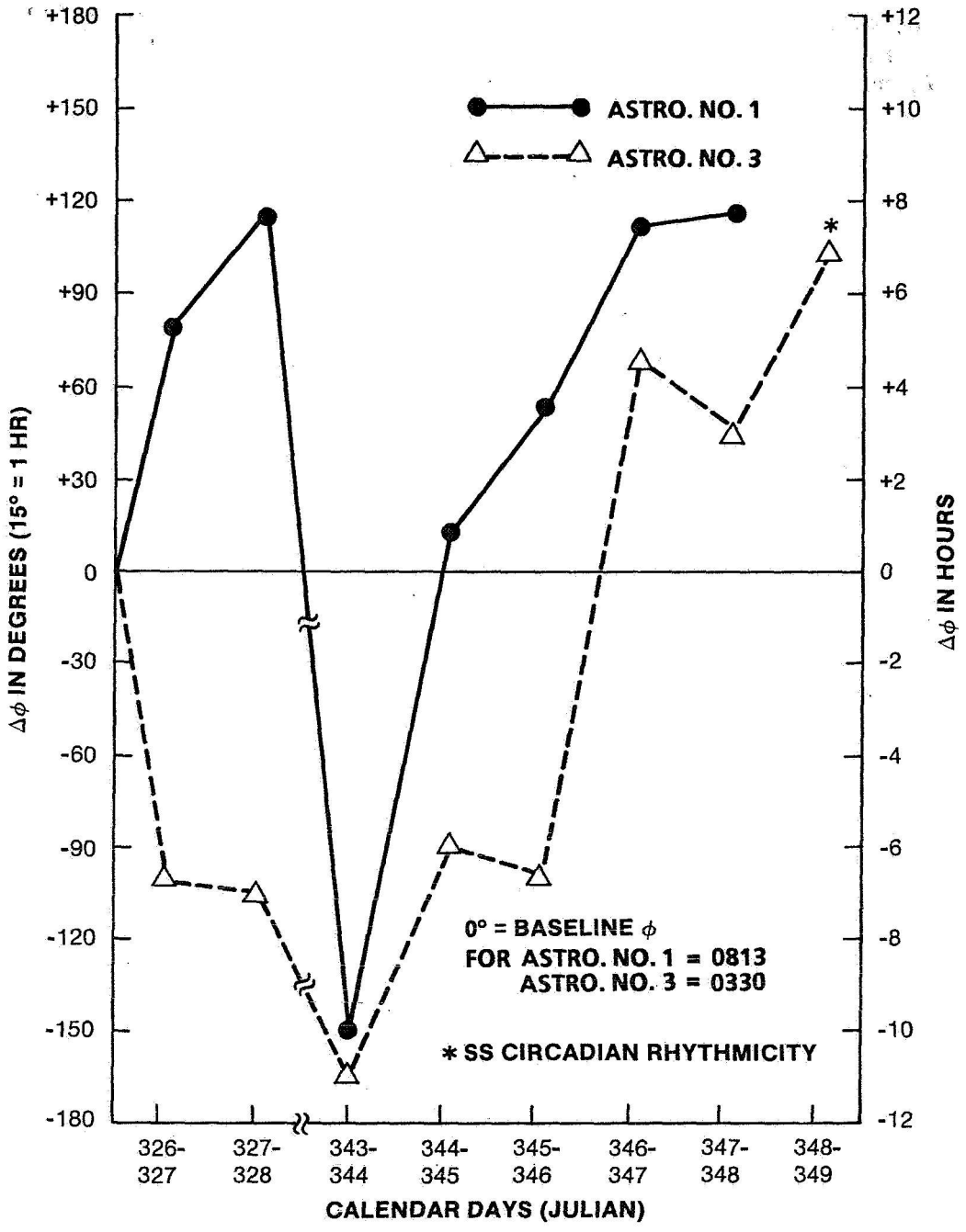

Figure 1 - Alteration in circadian acrophase of the urinary calcium rhythm immediately before (days 326-328) and after (days 343-349) space flight. Baseline ϕ was derived by Cosinor using data from 2 to 3 28-hour studies during which urines were collected void by void. (For astronaut 1, number of samples (N) = 54 and for astronaut 3, N = 3) For urinary Ca^{++}, a $\Delta\phi$ of ~ 8 h was exhibited by each astronaut before flight on days 327-328. This $\Delta\phi$ of ~ 8 h was similar to that immediately postflight, although with the passage of time, the ϕ did not stabilize around the baseline values. Note that the fit of the cosine approximation of 24 h in most cases was not statistically significant (SS). This could be due to "noisy" data or to the bioperiodicity being different from exactly 24 h (i.e., free-running). $+\Delta\phi$ represents a phase advance in ϕ; $-\Delta\phi$ represents a phase delay.

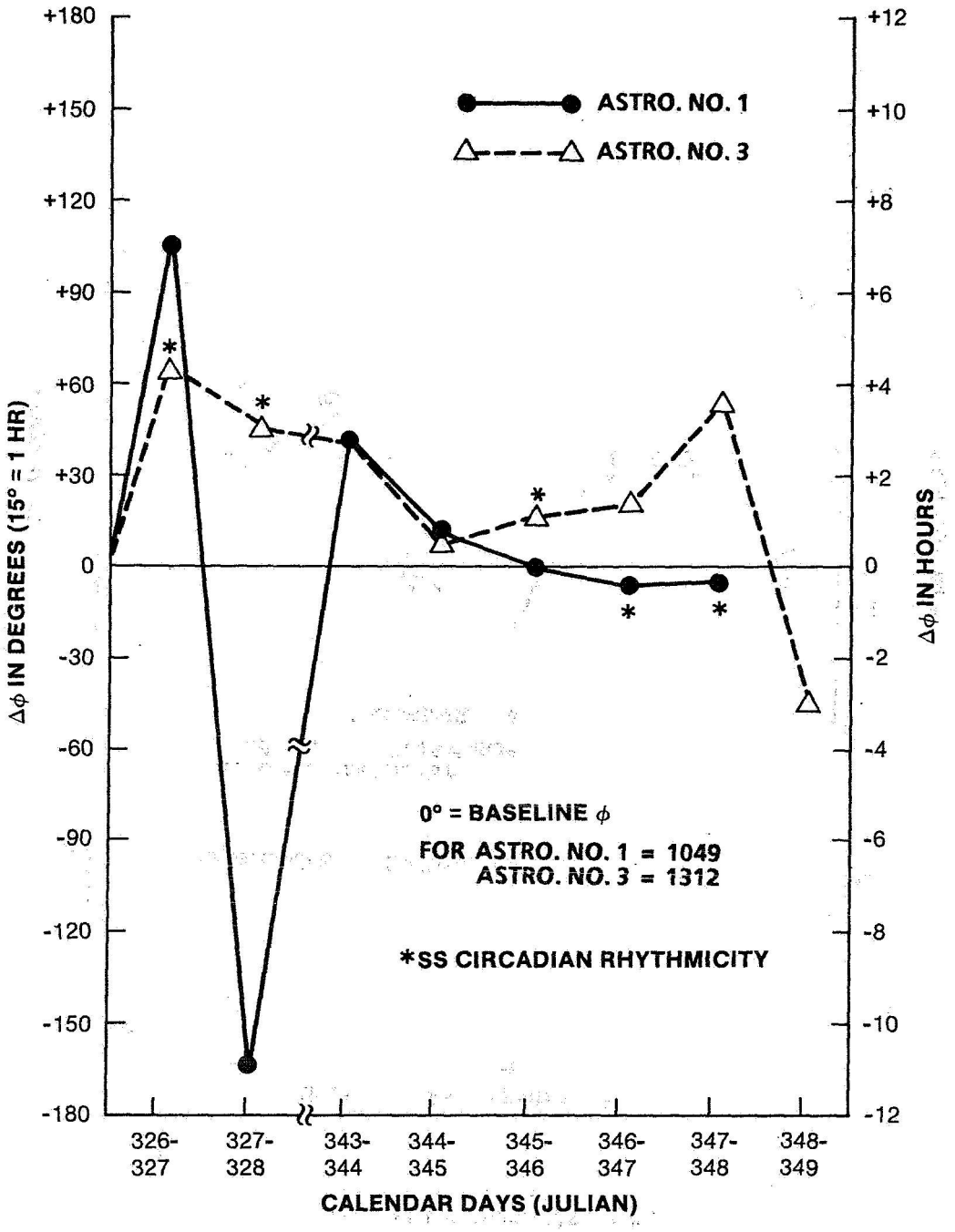

Figure 2 - Alteration in the circadian acrophase of the urinary potassium rhythm immediately before (days 326-328) and after (343-348) space flight. Baseline ϕ derived from cosinor analysis of data obtained from 2-3 28-hour studies during which sequential urine voidings were collected. (For astronaut 1, the number of samples (N) = 54; for astronaut 3, N = 30) Immediately before flight the $\Delta\phi$ for astronaut 1 was approximately 11 h; this was not the case for astronaut 3. After flight (343-349), the $\Delta\phi$ from baseline was minor, equaling about 2 h without a suggestion of free-running behavior. In the case of astronaut 3, nearly all the cosinor analyses were found to be statistically significant (SS) for circadian rhythmicity. $+\Delta\phi$ represents a phase advance in ϕ; $-\Delta\phi$ represents a delay.

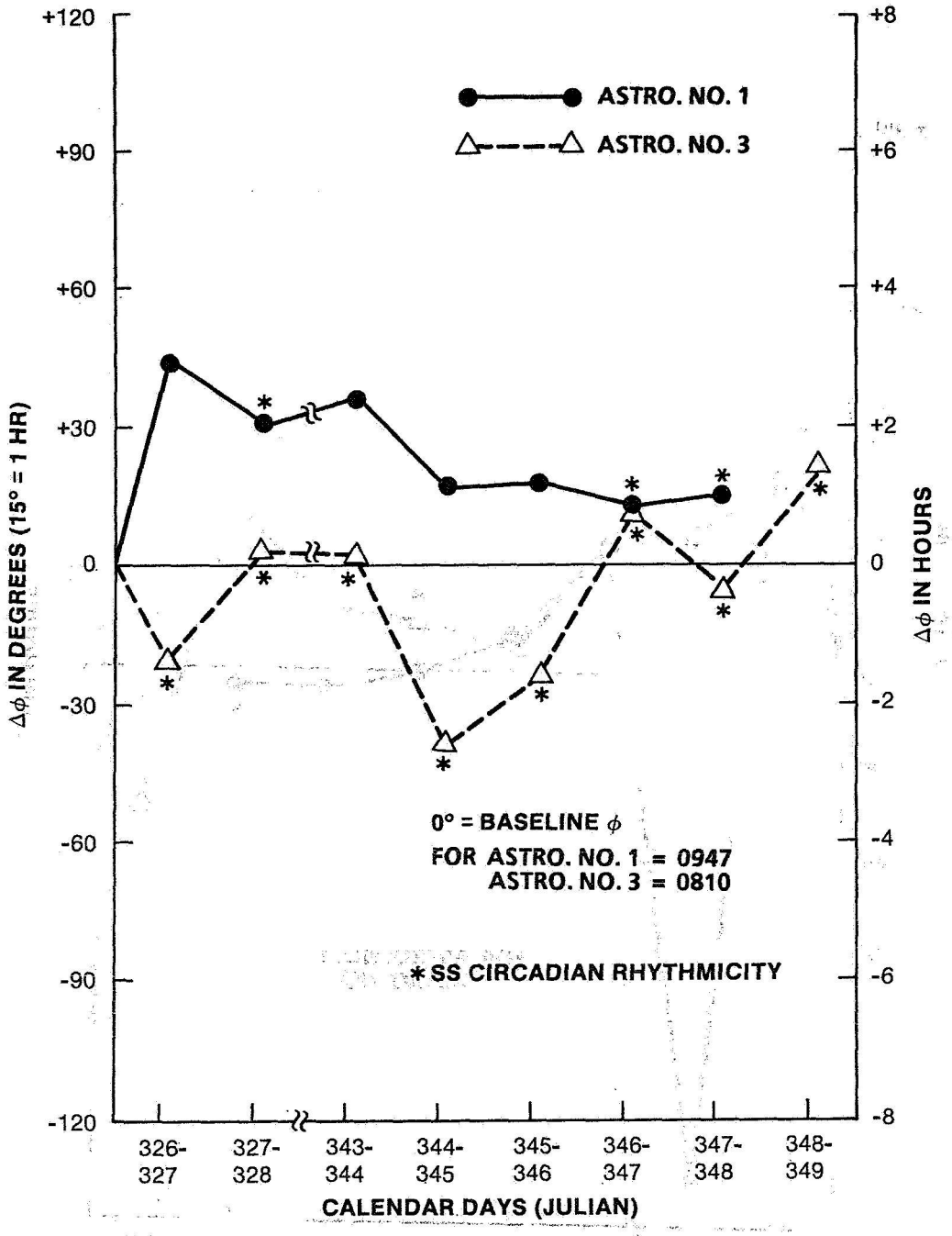

Figure 3 - Alteration in the circadian acrophase of the urinary 17-hydroxy-corticosteroid rhythm immediately before (days 326-328) and after (343-348) space flight. Baseline ϕ for each astronaut was derived from cosinor analysis of data obtained from 2-3 28-hour studies during which sequential urine voidings were collected. (For astronaut 1, the number of samples (N) = 54; for astronaut 3, N = 30) Immediately before (days 326-328) and after flight (343-349), the circadian ϕ varied by no more than 3 h (in most instances less than 2 h) from the baseline value even though the sleep-wake routine was supposedly shifted by ~12 h; i.e., activity at night and rest by day relative to Houston time. $+\Delta\phi$ represents a phase advance in ϕ; $-\Delta\phi$ represents a delay. (SS = statistically significant).

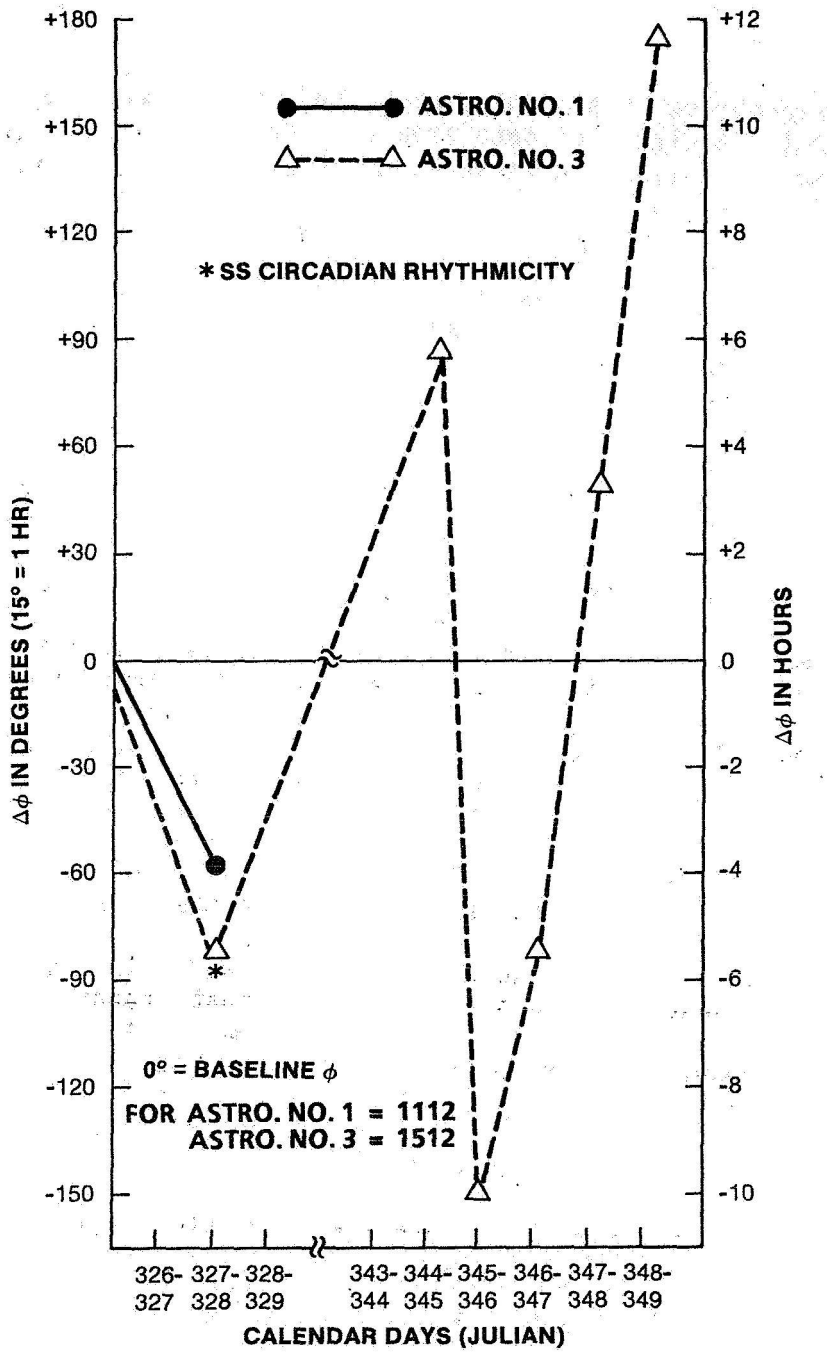

Figure 4 - Alteration in the circadian acrophase of the oral temperature rhythm immediately before (days 326-328) and after (343-348) space flight. Baseline ϕ derived by cosinor using data obtained from 2-3 28-hour studies during which oral temperature was measured several times daily during the waking span. (For astronaut 1, number of samples (N) = 8; for astronaut 3, N = 30) Due to the small amount of data, the values for days 326-328 were analyzed together as a single time series with the ϕ plotted on day 327. $+\Delta\phi$ represents a phase advance in ϕ; $-\Delta\phi$ represents a delay. (SS = statistically significant).

APPENDIX B

STATISTICAL ANALYSIS

Computer programs of the SAS series (SAS Institute, Inc., Cary, N. C.) were used for the analysis of data from this experiment. A multi-way repeated measures analysis of variance was conducted. In this type of analysis each subject is his own control and the measurements made at different times on the same subject are compared. Although the program was not specifically designed for repeated measures, the analysis was set up so that the F statistics would be the same as they would for a repeated measures program. No data were disregarded and only one flight sample was missing. An unbalanced design was used in the program to allow for the missing sample.

The hypothesis that there is no difference in subject responses on the different days of the experiment was tested. The program for analysis of variance was used to determine which parameters showed significant differences between any days; then the Student-Newman-Keuls stepwise multiple comparison test (Newman, 1939; Keuls, 1952) was used to determine which days were different.

The mean value for the first two preflight days was used as one day in the analysis of all parameters. For several parameters in the Spacelab experiment, measurements on samples from day F-1 were significantly different from those on samples from the other two preflight days. Therefore, F-1 was not included in the preflight mean. Blood samples were taken from two crewmembers on day L+12 and from the other two on day L+13; since these days are so close together, they were treated as a single day in the analysis. Separate analyses were done for the flight and simulation.

The crewmembers were classified according to whether they had taken countermeasures and which shift they were on, and significant differences between these groups (countermeasures vs. no countermeasures and day shift vs. night shift) were determined by the program at the same time as the analysis of other factors (day, subject) was performed. The number of crewmembers (2) in each group was so small, however, that graphs of the data were used along with the analysis of variance information to obtain what was thought to be a more accurate picture of the results.

The repeated measures analysis adjusted for within-subject variability, as well as for variability due to the different shifts and use or non-use of countermeasures when values on the different days of the experiment were compared.

One analysis was done to compare the different phases of the experiment (preflight, inflight, and postflight). Significant interactions between classes (phase and shift, for example) were found for very few parameters. When the analysis comparing days instead of phases was done, no interactions were significant.

A more thorough analysis was performed on selected parameters: serum osmolality, reticulocyte count and number, transferrin, erythropoietin, ferritin, and haptoglobin. Data from annual physical examinations of 64 astronauts were used to analyze the distribution of these parameters, and all but three of them had a normal distribution. Transformations of those three - ferritin, haptoglobin, and erythropoietin - were tested, and the square root of ferritin and the logarithm of haptoglobin and erythropoietin were found to have normal distributions. Analysis of variance with repeated measures and the Student-Newman-Keuls multiple comparison test were done on transformed

and untransformed variables. Results of the Kruskal-Wallis nonparametric test (Kruskal and Wallis, 1952) corroborated results of the parametric analysis of variance test.

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APPENDIX C

A COMPUTER SIMULATION OF THE EFFECT OF THE PROPOSED SPACELAB 1 BLOOD DRAW PROTOCOL ON THE HUMAN RED CELL SYSTEM

The Spacelab 1 medical experiments were expected to require 10 blood draws per subject over a 7-week period for a total blood collection of approximately 500 ml. On Earth, after a blood draw red cell production (RCP) will tend to increase in order to compensate for lost red cell mass (RCM). If the red cell mass loss that occurs in microgravity is the result of a decrease in bone marrow RCP, the effect of blood draws may compete with the effect of hypogravity. In order to investigate the quantitative aspects of this problem, the effect of multiple blood draws on the erythropoietic system was investigated using a previously developed mathematical model.

The model was developed to investigate the relative influence that the controlling factors of erythropoiesis have on total RCM (Leonard et al., 1981). It has been useful in elucidating the mechanisms involved in the control of erythropoiesis under a variety of stress situations, including space flight. The model is based on the concept that the overall balance between oxygen supply and demand regulates the release of the hormone erythropoietin from renal tissues sensitive to oxygen tension levels. Erythropoietin controls bone marrow RCP. The model has been validated for a variety of stresses including altitude hypoxia, descent from altitude, red cell infusion, and dehydration (Dunn et al., 1981; Leonard et al., 1981).

Computer simulation studies of the following three stresses were performed: 1) zero-g stress only (no blood draws), 2) blood draw stresses only (Spacelab 1 protocol, no zero-g stress), and 3) combined zero-g and blood draw stresses.

Simulation 1: Zero-g was simulated by decreasing the total blood volume by 500 ml of plasma over a 12-hour period starting at launch. This represents the amount of fluid loss that is thought to occur following entry into zero-g (Leonard et al., 1981). The total blood volume was maintained at this reduced level until the beginning of reentry (7 days after launch), at which time the blood volume was allowed to linearly return to the preflight value over a 24-hour period. The model interprets the decrease in plasma volume (PV) as a hemoconcentrating stress and acts to decrease RCP and RCM. This approach to simulating the effects of zero-g represents one of the major hypotheses explaining the observed decrease in RCM. Three additional weeks were simulated in order to show the postflight response of the erythropoietic system to the "zero-g" stress.

Simulation 2: The Spacelab 1 blood draws were simulated by reducing the total blood volume by the amount specified by the protocol for that day (table 1). In order to more realistically simulate the effects of blood draws on the erythropoietic system, it was assumed that the RCM lost from each blood draw was replaced immediately by an equivalent amount of plasma. The simulation was run over the same time period as the zero-g simulation.

Simulation 3: This simulation consisted of a combination of simulations 1 and 2 described above.

This study addressed the following two questions: "Do the Spacelab 1 blood draws significantly perturb the erythropoietic system?" and "Does this perturbation amplify or attenuate the expected space flight changes?" According to the simulations, both the zero-g stress and the Spacelab 1 blood draws have a significant impact on the erythropoietic system. The results

for plasma volume, erythropoietin (Ep) concentration, hematocrit (Hct), and RCP showed that the two stresses have opposite effects on these system parameters during the inflight phase of the simulations. The model predicts that the zero-g stress will be the dominant stress during the flight period, since the combined simulation (table 7) qualitatively resembles the zero-g simulation and not the Spacelab 1 blood-draw simulation (not shown). The blood-draw protocol tended to attenuate the expected inflight zero-g changes and amplify the expected postflight zero-g changes for PV, Ep, Hct and RCP, while amplifying the inflight and postflight changes in RCM and red cell distribution width (RCD).

Problems may occur in interpreting the results of the combined simulation when they are presented as percentage changes from preflight averages. The problems arise from the fact that the preflight baselines, from which the control values are determined, change with each preflight blood draw. Because the red cell system will not be in a steady state during the preflight period, the inflight and postflight results will be biased by the changing baseline. The effects of the blood draws in conjunction with the changing baseline could produce two types of misleading experimental results. First, RCM (on MD2 and MD4) and Hct (on L+1) are predicted by the zero-g simulation to change less than two percent (table 7), an amount that probably could not be measured experimentally. The combined simulation for Hct, however, predicts that this change will be greater than four percent, an amount which might be measured experimentally. Second, experimental results may show directional responses opposite to those predicted by the zero-g simulation (the Ep results are an example for Spacelab 1). The examples described above highlight the caution that must be exercised when using preflight values as controls for inflight and postflight treatment periods, especially if sampling methods change the system being studied.

The results of the combined zero-g and blood draw simulation (simulation 3 above) were qualitatively similar to the zero-g only simulation (simulation 1 above), in spite of the volume and frequency of the proposed blood draws. Simulation 3 predicts that the blood draws tend to attenuate the expected inflight changes and to amplify the expected postflight changes for all parameters measured except RCM and RCD. These three simulations suggest that a 1-g group of subjects undergoing the same blood draw protocol would provide the most appropriate experimental control group for a multiple blood draw experiment in space, at least for experiments concerned with the red cell system.

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TABLE 7. - RESULTS OF COMPUTER SIMULATION OF SPACELAB 1 MISSION

	Percent change from preflight						
	Inflight			Postflight			
	MD2	MD4	MD8	L+0	L+1	L+7	L+14
Hematocrit							
Without blood draws	11.0	11.0	9.0	9.0	-1.0	-3.0	-2.0
With blood draws	9.4	8.4	7.4	5.4	-4.6	-6.7	-4.6
Erythropoietin							
Without blood draws	-16.0	-22.0	-21.0	-19.0	-10.0	8.0	6.0
With blood draws	-12.9	-17.8	-16.0	-12.9	0	18.9	13.9
Red cell mass							
Without blood draws	0	-1.0	-2.0	-2.0	-2.0	-3.0	-2.0
With blood draws	-1.7	-2.7	-3.7	-4.6	-6.7	-6.7	-4.6
Red cell production							
Without blood draws	-4.0	-17.0	-31.0	-33.0	-32.0	3.0	11.0
With blood draws	0	-12.3	-24.0	-25.0	-23.1	21.7	28.6
Red cell distribution width							
Without blood draws	0	0	-1.0	-1.0	-2.0	-3.0	-2.0
With blood draws	-1.7	-2.7	-3.7	-4.7	-6.7	-6.7	-4.7

APPENDIX D

DATA COLLECTED FROM SPACELAB 1 EXPERIMENT 1NS103

TABLE 8. - BLOOD VOLUME, IRON INCORPORATION, AND RED CELL SURVIVAL

Crew-member	Day	RCM, ml/kg	Plasma volume, ml/kg	Blood volume, ml/kg	Body weight, kg	^{59}Fe incorporation[a] at day 11, percent	Remaining ^{51}Cr RBC's[a] at day 8, percent
MS1	F-65	27.61	41.98	69.60	76.7	80	75
	L+0	24.35	37.22	61.57	74.0		
	L+8	26.04	42.40	68.44	75.8		
MS2	F-65	27.10	41.01	68.11	64.4	84	75
	L+0	24.01	38.69	62.71	61.3		
	L+8	22.70	44.47	67.17	73.6		
PS1	F-65	29.06	48.63	77.69	71.3	96	76
	L+0	27.66	51.56	69.21	70.0		
	L+8	27.45	48.74	76.20	71.5		
PS2	F-65	26.39	47.65	74.04	85.9	90	78
	L+0	23.97	41.48	65.44	84.7		
	L+8	24.25	49.51	73.76	87.2		

[a]Corrected for change in RCM

TABLE 9. - ERYTHROCYTE HEMATOLOGY

Crew-member	Day	Erythro-cytes, $X10^{12}/l$	Hemo-globin, g/dl	Hemato-crit, l/l	MCV, fl	MCH, pg/cell	MCHC, g/dl
MS1	F-65	5.35	15.2	.450	84	28	34
	F-7	5.17	15.7	.460	88	30	35
	F-1	5.42	15.2	.430	79	28	33
	MD1	5.25	15.7	.460	88	33	34
	MD7	5.58	17.0	.480	86	30	35
	L+0	5.10	16.0	.440	86	31	36
	L+1	4.69	15.1	.420	90	32	36
	L+8	4.80	14.2	.420	88	30	34
	L+13	4.06	14.0	.420	90	30	33
MS2	F-65	4.88	14.0	.430	88	29	33
	F-7	4.28	13.7	.400	93	32	35
	F-1	4.35	13.5	.400	92	31	34
	MD1	4.74	14.9	.450	95	31	33
	MD7[a]	-	-	.400	-	-	-
	L+0	4.27	14.3	.400	94	34	36
	L+1	4.31	13.9	.400	93	32	35
	L+8	3.99	12.3	.370	93	31	33
	L+13	4.08	12.3	.380	93	30	32
PS1	F-65	5.16	14.5	.440	85	28	33
	F-55	4.77	14.4	.430	90	30	33
	F-7	5.05	15.4	.450	89	31	34
	F-1	5.07	14.6	.420	83	29	35
	MD1	5.07	15.1	.455	90	30	33
	MD7	5.31	16.4	.460	86	31	36
	L+0	4.82	15.5	.440	91	32	35
	L+1	4.65	14.8	.430	91	32	35
	L+8	4.57	13.5	.420	91	30	33
	L+12	4.75	14.2	.430	91	30	33
PS2	F-65	5.09	14.0	.410	81	28	34
	F-55	4.72	14.4	.420	89	30	34
	F-7	4.67	14.4	.410	88	31	35
	F-1	4.56	14.0	.390	86	31	36
	MD1	5.03	15.0	.420	83	30	36
	MD7	5.02	15.1	.420	83	30	36
	L+0	4.50	14.8	.390	87	33	38
	L+1	4.41	14.2	.390	88	32	36
	L+8	4.22	12.6	.380	89	30	33
	L+12	4.35	13.0	.390	89	30	34

[a]Blood clotted in needle during draw. Quantity not sufficient for postflight analysis of all parameters.

TABLE 10. - RETICULOCYTES AND ERYTHROPOIETIN

Crew-member	Day	Reticu-locytes, percent	Reticulo-cytes, $X10^9/l$	RPI	Reticulocytes, percent (flow cytometry)	Reticulocyte RNA, percent of cytoplasm	Erythropoietin units/ml
MS1	F-65	1.00	53.5	1.00	4.03	11.9	.20
	F-7	1.00	51.7	1.00	3.04	10.9	.26
	F-1	.80	43.4	.80	2.76	9.3	.23
	MD1	1.70	89.2	1.70	1.72		.01
	MD7	.70	39.1	.70	2.50		.01
	L+0	.60	30.6	.60	1.64	8.7	.12
	L+1	1.20	56.3	1.30	3.88	11.0	.19
	L+8	.80	38.4	.90	2.29	13.2	.20
	L+13	1.40	65.3	1.40	5.73	11.6	.22
MS2	F-65	1.60	78.1	1.70	2.96	10.5	.48
	F-7	1.30	55.6	1.40	1.92	11.4	.42
	F-1	.40	17.4	.90	3.70	11.3	.54
	MD1	.70	33.8	.70	2.50		.38
	MD7[a]	.80	-	.90	1.92		.41
	L+0	.70	29.9	.70	3.45	8.6	.14
	L+1	1.00	43.1	1.10	2.12	9.6	.25
	L+8	1.10	43.9	1.30	2.29	12.3	.31
	L+13	1.70	69.4	1.80	5.73	11.2	.01
PS1	F-65	1.20	61.9	1.20	2.99	9.6	.33
	F-55	1.20	57.2	1.20			
	F-7	1.10	55.6	1.10	3.02	10.3	.31
	F-1	.40	20.3	.60	3.33	9.5	.50
	MD1	1.00	50.7	1.00	7.19		.35
	MD7	.40	21.2	.40	3.80		.01
	L+0	.30	14.5	.30	1.32	8.2	.01
	L+1	1.00	46.5	1.00	1.90	9.3	.29
	L+8	1.30	59.4	1.40	1.72	12.6	.27
	L+12	.60	28.5	.60	1.89	12.1	.01
PS2	F-65	1.80	91.6	2.00	3.88	19.4	.35
	F-55	1.80	84.9	1.80			
	F-7	1.40	65.4	1.40	2.83	10.5	.22
	F-1	.90	41.0	1.00	2.31	11.9	.23
	MD1	.40	20.1	.40	1.56		.01
	MD7	.40	20.1	.40	1.31		.03
	L+0	.50	22.5	.50	2.62	9.7	.07
	L+1	1.60	70.6	1.70	1.49	10.3	.11
	L+8	1.20	50.6	1.30	2.69	13.2	.08
	L+12	2.10	91.3	2.30	2.47	12.1	.02

[a]Blood clotted in needle during draw. Quantity not sufficient for postflight analysis of all parameters.

TABLE 11. - IRON KINETICS

Crew-member	Day	Transferrin, mg/dl	Serum iron, µg/dl	Unbound iron-binding capacity, µg/dl	Total iron-binding capacity, µg/dl	Percent saturation of trans-ferrin
MS1	F-65	348	80	308	388	20.6
	F-7	275	114	333	447	25.5
	F-1	248	66	303	369	17.9
	MD1	244	70	308	378	18.5
	MD7	254	63	384	447	14.1
	L+0	221	58	252	310	18.7
	L+1	221	83	298	381	21.8
	L+8	236	64	288	352	18.2
	L+13	255	65	354	419	18.4
MS2	F-65	327	70	283	353	19.8
	F-7	284	53	288	341	15.5
	F-1	284	129	278	407	31.7
	MD1	293	57	262	319	17.9
	MD7	283	75	298	373	20.1
	L+0	259	54	293	347	15.6
	L+1	240	57	283	340	16.8
	L+8	265	50	298	348	14.4
	L+13	265	89	293	382	23.3
PS1	F-65	246	101	369	470	21.5
	F-7	249	87	333	420	20.7
	F-1	239	52	318	370	14.1
	MD1	244	97	354	451	21.5
	MD7	244	80	328	408	19.6
	L+0	240	57	308	365	15.6
	L+1	231	70	295	365	19.2
	L+8	245	49	286	335	14.6
	L+12	274	49	264	313	15.7
PS2	F-65	348	124	309	433	28.6
	F-7	302	77	259	336	22.9
	F-1	284	108	277	385	28.1
	MD1	303	110	264	374	29.4
	MD7	303	132	291	423	31.2
	L+0	342	66	218	284	23.2
	L+1	321	113	282	395	28.6
	L+8	284	89	318	407	21.9
	L+12	284	73	314	387	18.9

TABLE 12. - ERYTHROCYTE SHAPE

Crewmember	Day	Percent of Each Shape										
		Disco-cytes	Knizo-cytes	Stomato-cytes	Reticulo-cytes	Echino-cytes 1	Echino-cytes 2	Echino-cytes 3	Kerato-cytes	Ellipto-cytes	Toro-cytes	Poikilo-cytes
MS1	F-65	88.6	2.8	6.6	0.0	1.6	0.2	0.0	0.0	0.0	0.2	0.0
	F-7	85.2	2.0	9.6	0.0	2.8	0.4	0.0	0.0	0.0	0.0	0.0
	F-1	80.8	2.6	7.4	0.2	8.0	0.4	0.0	0.0	0.4	0.2	0.0
	MD1	80.4	4.0	8.8	0.0	6.8	0.0	0.0	0.0	0.0	0.0	0.0
	MD7	83.8	3.8	6.0	0.0	4.8	0.8	0.0	0.4	0.0	0.4	0.0
	L+0	80.0	3.6	9.6	0.0	6.4	0.0	0.0	0.0	0.0	0.4	0.0
	L+1	84.8	0.8	12.8	0.0	1.6	0.0	0.0	0.0	0.0	0.0	0.0
	L+8	83.8	1.4	6.0	0.4	7.6	0.2	0.0	0.0	0.6	0.0	0.0
	L+13	82.6	2.4	5.0	0.0	9.8	0.2	0.0	0.0	0.0	0.0	0.0
MS2	F-65	85.6	3.8	6.0	0.0	4.2	0.2	0.0	0.0	0.2	0.0	0.0
	F-7	82.4	6.8	4.0	0.0	6.0	0.0	0.0	0.0	0.0	0.8	0.0
	F-1	87.4	3.4	6.8	0.0	1.8	0.2	0.0	0.0	0.2	0.2	0.0
	MD1	88.0	2.8	7.2	0.0	1.6	0.0	0.0	0.2	0.0	0.0	0.2
	MD3	86.6	3.0	4.0	0.0	6.4	0.0	0.0	0.0	0.0	0.0	0.0
	MD7	88.8	1.2	4.8	0.0	4.8	0.0	0.0	0.0	0.4	0.0	0.0
	L+0	84.8	2.0	6.0	0.0	7.2	0.0	0.0	0.0	0.0	0.0	0.0
	L+1	80.4	2.4	9.6	0.0	6.4	0.8	0.0	0.0	0.0	0.0	0.0
	L+8	80.0	1.2	4.0	0.0	10.8	4.0	0.0	0.0	0.0	0.0	0.0
	L+13	85.4	2.0	7.8	0.0	4.4	0.2	0.2	0.0	0.0	0.0	0.0
PS1	F-65	82.8	4.2	6.8	0.2	5.6	0.0	0.0	0.0	0.4	0.0	0.0
	F-7	90.0	1.6	3.2	0.0	4.4	0.2	0.0	0.0	0.2	0.4	0.0
	F-1	83.4	3.8	6.0	0.2	6.2	0.2	0.0	0.0	0.2	0.0	0.0
	MD1	87.2	1.2	6.8	0.0	3.6	0.0	0.0	0.0	1.2	0.0	0.0
	MD7	87.6	2.0	4.0	0.0	6.0	0.0	0.0	0.0	0.2	0.0	0.2
	L+0	85.6	0.4	8.0	0.0	6.0	0.0	0.0	0.0	0.0	0.0	0.0
	L+1	85.6	1.6	6.8	0.2	5.6	0.2	0.0	0.0	0.0	0.0	0.0
	L+8	80.8	0.4	2.8	0.0	12.4	3.2	0.4	0.0	0.0	0.0	0.0
	L+12	87.4	1.6	1.6	0.0	9.4	0.0	0.0	0.0	0.0	0.0	0.0
PS2	F-65	90.0	2.6	5.4	0.0	2.0	0.0	0.0	0.0	0.0	0.0	0.0
	F-7	88.4	2.0	3.2	0.4	5.2	0.0	0.0	0.2	0.2	0.4	0.0
	F-1	82.2	4.2	6.8	0.0	6.2	0.0	0.0	0.0	0.6	0.0	0.0
	MD1	81.2	5.6	10.0	0.0	2.8	0.2	0.0	0.0	0.2	0.0	0.0
	MD3	83.4	1.8	6.6	0.0	7.2	1.0	0.0	0.0	0.0	0.0	0.0
	MD7	80.8	4.8	7.6	0.0	6.4	0.2	0.0	0.0	0.2	0.0	0.0
	L+0	81.6	3.6	7.6	0.0	7.2	0.0	0.0	0.0	0.0	0.0	0.0
	L+1	90.8	0.4	4.0	0.0	4.4	0.0	0.0	0.0	0.4	0.0	0.0
	L+8	82.6	0.8	4.2	0.2	11.6	0.4	0.0	0.0	0.2	0.0	0.0
	L+12	88.8	0.6	4.0	0.0	6.4	0.2	0.0	0.0	0.0	0.0	0.0

TABLE 13. - ERYTHROCYTE SHAPE

Crewmember	Day	Number of cells of each shape $X10^9/l$										
		Disco-cytes	Knizo-cytes	Stomato-cytes	Reticulo-cytes	Echino-cytes 1	Echino-cytes 2	Echino-cytes 3	Kerato-cytes	Ellipto-cytes	Toro-cytes	Poikilo-cytes
MS1	F-65	4740	150	353	0	86	11	0	0	0	11	0
	F-7	4400	103	496	0	145	21	0	0	0	0	0
	F-1	4380	141	401	11	434	22	0	0	22	11	0
	MD1	4220	210	462	0	357	0	0	0	0	0	0
	MD7	4680	212	335	0	268	45	0	22	0	22	0
	L+0	4080	184	490	0	326	0	0	0	0	20	0
	L+1	3980	38	600	0	75	0	0	0	0	0	0
	L+8	4020	67	288	19	365	9.6	0	0	29	0	0
	L+13	3350	97	203	0	398	8.1	0	0	0	0	0
MS2	F-65	4180	185	293	0	205	9.8	0	0	9.8	0	0
	F-7	3530	291	171	0	257	0	0	0	0	34	0
	F-1	3800	148	296	0	78	8.7	0	0	8.7	8.7	0
	MD1	4170	133	341	0	76	0	0	9.5	0	0	9.5
	MD7	-	-	-	-	-	-	-	-	-	-	-
	L+0	3620	85	256	0	307	0	0	0	0	0	0
	L+1	3470	103	414	0	276	34	0	0	0	0	0
	L+8	3190	48	160	0	431	60	0	0	0	0	0
	L+13	3480	82	318	0	180	8.2	8.2	0	0	0	0
PS1	F-65	4270	217	351	10	289	0	0	0	21	0	0
	F-7	4550	81	162	0	222	10	0	0	10	20	0
	F-1	4230	193	304	10	314	10	0	0	10	0	0
	MD1	4420	61	345	0	183	0	0	0	61	0	0
	MD7	4650	106	212	0	319	0	0	0	11	0	11
	L+0	4130	19	386	0	289	0	0	0	0	0	0
	L+1	3980	74	316	9.3	260	9.3	0	0	0	0	0
	L+8	3690	18	128	0	567	46	18	0	0	0	0
	L+12	4150	76	76	0	447	0	0	0	0	0	0
PS2	F-65	4580	132	275	0	102	0	0	0	0	0	0
	F-7	4130	63	149	19	243	0	0	9.3	9.3	19	0
	F-1	3750	192	310	0	283	0	0	0	27	0	0
	MD1	4080	282	503	0	141	10	0	0	10	0	0
	MD7	4060	241	382	0	321	10	0	0	10	0	0
	L+0	3670	162	342	0	324	0	0	0	0	0	0
	L+1	4000	18	176	0	194	0	0	0	18	0	0
	L+8	3490	34	177	8.4	490	17	0	0	8.4	0	0
	L+12	3860	26	174	0	278	8.7	0	0	0	0	0

TABLE 14. - PLATELETS AND LEUKOCYTES

Crewmember	Day	Platelets $X10^9/l$	Leukocytes, $X10^9/l$	Neutrophils, percent	Lymphocytes, percent	Monocytes percent	Eosinophils, percent	Basophils, percent	Band neutrophils, percent
MS1	F-65	310	6.2	62	36	2	0	0	0
	F-7	256	7.7	55	36	8	2	0	0
	F-1	233	7.5	45	49	4	2	0	0
	MD1	270	7.3	66	24	3	1	0	6
	MD7	270	9.1	68	22	5	3	0	2
	L+0	284	8.6	74	22	3	1	0	0
	L+1	238	7.3	56	36	5	3	0	0
	L+8	287	6.1	62	33	2	3	0	0
	L+13	276	5.8	51	35	9	3	1	1
MS2	F-65	323	6.0	65	32	3	0	0	0
	F-7	281	5.8	67	29	4	0	0	0
	F-1	260	6.3	47	46	3	2	0	2
	MD1	279	7.0	69	19	0	0	0	12
	MD7[a]	-	-	64	32	2	2	0	0
	L+0	266	6.4	59	38	3	0	0	0
	L+1	286	6.8	68	26	6	0	0	0
	L+8	365	5.9	69	30	1	0	0	0
	L+13	311	5.3	55	37	8	0	0	0
PS1	F-65	261	4.9	65	32	0	3	0	0
	F-55	185	5.2	50	43	2	5	0	0
	F-7	201	5.8	54	34	8	4	0	0
	F-1	173	5.4	53	43	1	2	0	1
	MD1	198	5.5	56	36	3	2	1	2
	MD7	188	6.0	54	36	5	3	0	2
	L+0	292	4.3	54	39	5	2	0	0
	L+1	287	4.8	53	41	4	1	1	0
	L+8	183	5.2	47	35	7	10	0	0
	L+12	219	6.1	45	37	13	4	0	0
PS2	F-65	278	7.0	74	24	1	1	0	0
	F-55	217	6.1	74	20	2	3	1	0
	F-7	251	5.1	62	23	13	1	0	1
	F-1	195	5.3	57	36	2	5	0	0
	MD1	233	10.8	84	10	2	0	0	4
	MD7	231	6.1	67	30	1	1	0	1
	L+0	353	9.5	80	14	3	3	0	0
	L+1	278	6.4	74	21	2	3	0	0
	L+8	252	7.6	68	27	3	2	0	0
	L+12	255	10.1	71	20	7	0	0	2

[a]Blood clotted in needle during draw. Quantity not sufficient for analysis of all parameters.

TABLE 15. - NUMBER OF EACH TYPE OF LEUKOCYTE

Crewmember	Day	Neutrophils, $X10^9/l$	Lymphocytes, $X10^9/l$	Monocytes, $X10^9/l$	Eosinophils, $X10^9/l$	Basophils, $X10^9/l$	Band neutrophils, $X10^9/l$
MS1	F-65	3.8	2.2	.12	0	0	0
	F-7	4.2	2.8	.62	.15	0	0
	F-1	3.4	3.7	.30	.15	0	0
	MD1	4.8	1.8	.22	.07	0	.44
	MD7	6.2	2.0	.46	.27	0	.18
	L+0	6.4	1.9	.26	.09	0	0
	L+1	4.1	2.6	.37	.28	0	0
	L+8	3.8	2.0	.12	.18	0	0
	L+13	3.0	2.0	.52	.17	.06	.06
MS2	F-65	3.9	1.9	.18	0	0	0
	F-7	3.9	1.7	.23	0	0	0
	F-1	3.0	2.9	.19	.13	0	.13
	MD1	4.8	1.3	0	0	0	.84
	MD7[a]	-	-	-	-	-	-
	L+0	3.8	2.4	.19	0	0	0
	L+1	4.6	1.8	.41	0	0	0
	L+8	4.1	1.8	.06	0	0	0
	L+13	2.9	2.0	.42	0	0	0
PS1	F-65	3.2	1.6	0	.15	0	0
	F-55	2.6	2.2	.10	.26	0	0
	F-7	3.1	2.0	.46	.23	0	0
	F-1	2.9	2.3	.05	.11	0	.05
	MD1	3.1	2.0	.17	.11	.06	.11
	MD7	3.2	2.2	.30	.18	0	.12
	L+0	2.3	1.7	.22	.09	0	0
	L+1	2.5	2.0	.19	.05	.05	0
	L+8	2.4	1.8	.36	.52	0	0
	L+12	2.7	2.3	.79	.24	0	0
PS2	F-65	5.2	1.7	.07	.07	0	0
	F-55	4.5	1.2	.12	.18	.06	0
	F-7	3.2	1.2	.66	.05	0	.05
	F-1	3.0	1.9	.11	.27	0	0
	MD1	9.1	1.1	.22	0	0	.43
	MD7	4.1	1.8	.06	.06	0	.06
	L+0	7.6	1.3	.29	.29	0	0
	L+1	4.7	1.3	.13	.19	0	0
	L+8	5.2	2.1	.23	.15	0	0
	L+12	7.2	2.0	.71	0	0	.20

[a]Blood clotted in needle during draw. Quantity not sufficient for postflight analysis of all parameters.

TABLE 16. - SERUM CHEMISTRY

Crewmember	Day	Osmolality, mosm/l	Na, meq/l	K, meq/l	2,3-DPG, mol/g Hb	ATP, mol/g Hb
MS1	F-65	302	145	4.0	11.8	3.20
	F-7	290	141	3.5	11.8	3.22
	F-1	299	142	3.6	11.2	3.36
	MD1	288	141	3.5	11.8	3.54
	MD7	295	141	3.6	11.7	3.85
	L+0	299	143	3.5	8.8	3.97
	L+1	296	142	3.7	12.5	3.94
	L+8	287	142	3.9	12.4	2.91
	L+13	289	140	3.6	12.2	4.86
MS2	F-65	302	143	4.4	11.6	3.78
	F-7	287	139	3.8	12.1	3.21
	F-1	299	142	3.9	14.9	3.37
	MD1	290	139	4.4	14.5	3.68
	MD7	289	138	4.1	16.0	3.49
	L+0	298	141	4.8	11.2	2.05
	L+1	293	138	3.7	11.6	2.28
	L+8	287	141	4.1	16.1	3.37
	L+13	285	139	4.2	16.1	4.67
PS1	F-65	296	143	4.2	10.8	3.64
	F-7	288	140	3.8	14.0	3.47
	F-1	294	141	3.8	15.1	3.76
	MD1	293	141	3.7	14.4	3.59
	MD7	286	139	3.3	14.0	3.80
	L+0	293	141	3.5	13.3	3.80
	L+1	287	138	4.0	11.5	4.09
	L+8	292	142	3.9	15.1	3.34
	L+12	289	140	3.5	14.2	3.19
PS2	F-65	298	144	4.1	11.6	3.03
	F-7	295	145	3.8	12.5	2.53
	F-1	296	143	4.2	15.1	3.59
	MD1	290	141	4.1	13.2	3.61
	MD7	291	141	4.0	10.9	4.52
	L+0	297	143	3.8	10.4	2.32
	L+1	291	141	4.2	10.4	2.91
	L+8	289	144	3.7	13.6	3.05
	L+12	290	141	4.4	12.5	2.64

TABLE 17. - SERUM PROTEINS

Crewmember	Day	Total protein, g/dl	Albumin, g/dl	Alpha-1 globulin, g/dl	Alpha-2 globulin, g/dl	Beta globulin, g/dl	Gamma globulin, g/dl	Hapto-globin, mg/dl	Ferritin ng/ml
MS1	F-65	7.2	4.5	.3	.4	.7	1.3	74	26.7
	F-7	7.2	5.0	.3	.4	.5	1.0	46	43.2
	F-1	7.0	5.0	.2	.4	.6	.8	46	33.9
	MD1	7.2	4.9	.3	.5	.6	.9	52	34.5
	MD7	7.4	5.0	.3	.5	.7	.9	98	80.2
	L+0	7.1	4.9	.3	.6	.7	.7	57	91.9
	L+1	7.0	4.9	.3	.5	.5	.8	57	81.7
	L+8	6.8	4.5	.2	.4	.7	1.0	79	44.9
	L+13	6.7	4.3	.3	.6	.5	1.0	74	31.5
MS2	F-65	7.9	4.8	.3	.7	.9	1.1	272	125.0
	F-7	7.2	5.0	.2	.6	.6	.8	219	98.7
	F-1	7.3	5.2	.3	.5	.6	.7	245	101.0
	MD1	7.4	5.1	.2	.6	.2	.7	272	106.0
	MD7	7.1	4.7	.2	.7	.8	.7	350	166.0
	L+0	7.0	4.4	.3	.7	.8	.8	315	160.0
	L+1	6.9	4.6	.3	.5	.6	.9	315	162.0
	L+8	6.7	4.7	.2	.4	.7	.7	296	111.0
	L+13	6.9	4.5	.4	.7	.6	.7	288	100.0
PS1	F-65	7.1	4.5	.2	.5	.7	1.2	74	112.0
	F-7	7.0	4.8	.2	.5	.6	.9	57	88.7
	F-1	6.8	5.0	.2	.4	.5	.7	36	107.0
	MD1	7.1	5.1	.2	.5	.6	.7	61	107.0
	MD7	6.8	4.8	.2	.5	.6	.7	57	122.0
	L+0	7.1	5.0	.3	.5	.6	.7	69	148.0
	L+1	6.9	4.9	.3	.6	.5	.6	46	146.0
	L+8	6.6	4.5	.4	.4	.6	.7	64	87.0
	L+12	7.0	4.6	.4	.6	.6	.8	74	80.1
PS2	F-65	6.7	4.6	.2	.4	.7	.8	74	197.0
	F-7	6.4	4.5	.3	.5	.6	.5	86	173.0
	F-1	6.3	4.9	.2	.4	.4	.4	68	153.0
	MD1	6.6	4.9	.2	.4	.6	.5	87	196.0
	MD7	6.0	4.3	.2	.5	.6	.4	82	213.0
	L+0	6.3	4.4	.3	.5	.6	.5	63	174.0
	L+1	6.7	5.0	.2	.5	.6	.4	69	238.0
	L+8	6.1	4.4	.3	.3	.6	.5	125	173.0
	L+12	6.3	4.1	.4	.7	.6	.5	150	152.0

APPENDIX E

DATA COLLECTED FROM

1NS103 SIMULATION

TABLE 18. - BLOOD DRAW SCHEDULE

Day	Date	Time
F-60	12/22/83	0800
F-8	2/10/84	1930[a]
F-7	2/11/84	0730[b]
F-1,1-1/2	2/16/84	1930[a]
	or 2/17/84	0800[b]
MD1	2/19/84	1000
MD7	2/26/84	0800
L+0	2/28/84	1800
L+1	2/29/84	1000
L+8	3/07/84	0800
L+13	3/12/84	0800

[a]MS1 and PS1. MS1: countermeasures, shift 2; PS1: no countermeasures, shift 2.

[b]MS2 and PS2. MS2: countermeasures, shift 1; PS2: no countermeasures, shift 1.

TABLE 19. - BLOOD VOLUME, IRON INCORPORATION AND RED CELL SURVIVAL

Subject	Day	RCM, ml/kg	Plasma volume, ml/kg	Blood volume, ml/kg	^{59}Fe incorporation at day 11[a], percent	^{51}Cr RBC's remaining at day 8[a], percent
1	F-60	26.98	37.44	64.42		
(MS1)	MD7		36.04			
	L+0	26.09	36.62	62.72	95	
	L+8	26.47	39.48	65.95		79
2	F-60	32.72	43.37	76.09		
(MS2)	MD7		41.78			
	L+0	32.48	43.93	76.41	94	
	L+8	29.37	44.65	74.02		71
3	F-60	28.02	47.30	75.32		
(MS2)	MD7		43.30			
	L+0	26.65	44.30	70.96	84	
	L+8	26.34	46.35	72.70		75
4	F-60	29.48	49.92	79.40		
(PS1)	MD7		42.24			
	L+0	27.80	39.05	66.85	88	
	L+8	26.19	47.34	73.53		78
5	F-60	23.53	28.95	52.47		
(PS2)	MD7		29.90			
	L+0	21.62	29.54	51.16	87	
	L+8	20.60	31.51	52.11		68

[a]Corrected for change in red cell mass.

TABLE 20. - ERYTHROCYTE HEMATOLOGY

Subject	Day	Erythro-cytes, $X10^{12}/l$	Hemo-globin, g/dl	Hemato-crit, l/l	MCV, fl	MCH, pg/cell	MCHC, g/dl
1	F-60	5.44	15.3	.47	87	28	32
(MS1)	F-8	5.38	15.3	.46	86	29	33
	F-1	5.42	15.8	.47	86	29	34
	MD1	5.35	15.4	.46	87	29	33
	MD7	5.43	15.4	.47	86	28	33
	L+0	5.50	15.4	.47	85	28	33
	L+1	5.22	15.0	.45	86	29	33
	L+8	5.01	14.5	.43	86	29	34
	L+13	5.28	15.1	.45	85	29	34
2	F-60	5.30	15.4	.47	89	29	33
(MS2)	F-7	5.05	15.2	.45	89	30	34
	F-1	5.26	15.8	.47	90	30	34
	MD1	5.38	16.5	.48	89	31	34
	MD7	5.38	16.2	.48	90	30	33
	L+0	5.19	15.4	.46	89	30	33
	L+1	4.88	14.8	.43	89	30	34
	L+8	4.74	14.4	.43	90	30	34
	L+13	4.72	14.2	.42	90	30	34
3	F-60	4.91	13.5	.40	81	27	32
(MS2)	F-7	4.70	13.2	.40	84	28	33
	F-1	4.99	14.0	.41	83	28	34
	MD1	5.05	14.3	.42	83	28	34
	MD7	5.20	14.3	.43	83	27	33
	L+0	4.79	13.3	.40	83	28	34
	L+1	4.72	13.2	.39	83	28	34
	L+8	4.79	13.3	.40	84	28	33
	L+13	4.52	12.6	.39	83	28	34
4	F-60	4.10	12.7	.38	94	31	33
(PS1)	F-8	3.98	12.8	.38	96	32	33
	F-1	4.14	13.5	.40	96	33	34
	MD1	4.26	13.8	.41	96	32	34
	MD7	4.68	14.8	.44	96	32	33
	L+0	4.79	15.3	.46	95	32	34
	L+1	4.42	14.2	.43	96	32	34
	L+8	4.13	13.4	.39	95	32	34
	L+13	4.10	13.4	.39	96	33	34
5	F-60	5.78	16.5	.51	87	29	33
(PS2)	F-7	5.36	16.1	.48	89	30	34
	F-1	5.16	15.6	.46	89	30	34
	MD1	5.28	16.2	.47	90	31	34
	MD7	5.10	15.2	.46	90	30	33
	L+0	5.43	16.2	.48	88	30	34
	L+1	5.12	15.3	.46	89	30	34
	L+8	4.76	14.4	.43	90	30	34
	L+13	4.93	14.9	.44	90	30	34

TABLE 21. - RETICULOCYTES AND ERYTHROPOIETIN

Subject	Day	Reticulocytes, percent	Reticulocytes, $X10^9/l$	RPI	Erythropoietin, units/ml
1	F-60	0.5	27.2	0.5	.12
(MS1)	F-8	0.5	26.9	0.5	.23
	F-1	1.0	54.9	1.0	.31
	MD1	0.9	48.2	0.9	.35
	MD7	0.7	38.0	0.7	.26
	L+0	0.5	27.5	0.5	.42
	L+1	0.6	31.3	0.6	.29
	L+8	0.7	35.1	0.7	.36
	L+13	1.1	58.1	1.1	.20
2	F-60	1.2	63.6	1.2	.14
(MS2)	F-7	1.0	50.5	1.0	.33
	F-1	0.7	36.8	0.6	.50
	MD1	0.7	37.7	0.7	.20
	MD7	1.0	53.8	1.0	.34
	L+0	1.1	57.1	1.1	.22
	L+1	1.1	53.7	1.1	.12
	L+8	0.7	33.2	0.7	.35
	L+13	0.9	42.5	0.9	.18
3	F-60	1.0	49.1	1.1	.29
(MS2)	F-7	0.3	14.1	0.4	.13
	F-1	0.5	25.0	0.6	.50
	MD1	0.4	22.0	0.4	.01
	MD7	0.7	36.4	0.7	.01
	L+0	0.5	24.0	0.6	.47
	L+1	0.6	28.3	0.7	.41
	L+8	0.4	19.2	0.4	.01
	L+13	1.0	45.2	1.0	.30
4	F-60	0.7	28.7	0.8	.07
(PS1)	F-8	0.9	35.8	1.0	.13
	F-1	1.6	66.2	1.7	.02
	MD1	0.9	38.3	0.9	.01
	MD7	0.9	42.1	0.9	.16
	L+0	0.7	33.5	0.7	.11
	L+1	0.5	22.1	0.5	.01
	L+8	0.3	12.4	0.3	.12
	L+13	0.7	28.7	0.7	.18
5	F-60	0.5	28.9	0.4	.16
(PS2)	F-7	0.5	26.8	0.5	.01
	F-1	0.6	31.0	0.6	.58
	MD1	0.6	31.7	0.6	.01
	MD7	0.5	25.5	0.5	.38
	L+0	0.9	48.9	0.9	.05
	L+1	0.7	35.8	0.7	.20
	L+8	1.3	61.9	1.3	.05
	L+13	0.5	24.7	0.5	.05

TABLE 22. - IRON KINETICS

Subject	Day	Transferrin, mg/dl	Serum iron, µg/dl	Unbound iron-binding capacity, µg/dl	Total iron-binding capacity, µg/dl	Percent saturation of transferrin
1	F-60	334	139	325	464	30.0
(MS1)	F-8	351	93	264	357	26.1
	F-1	390	97	244	341	28.4
	MD1	314	53	249	302	17.5
	MD7	302	75	274	349	21.5
	L+0	317	57	244	301	18.9
	L+1	315	84	279	363	23.1
	L+8	293	75	279	354	21.2
	L+13	345	46	233	279	16.5
2	F-60	263	126	386	512	24.6
(MS2)	F-7	258	108	386	494	21.9
	F-1	263	95	345	440	21.6
	MD1	247	121	370	491	24.6
	MD7	267	163	406	569	28.6
	L+0	258	84	340	424	19.8
	L+1	233	112	370	482	23.2
	L+8	233	84	365	449	18.7
	L+13	259	137	426	563	24.3
3	F-60	242	77	350	427	18.0
(MS2)	F-7	261	73	345	418	17.5
	F-1	277	101	345	446	22.6
	MD1	275	74	330	404	18.3
	MD7	265	112	370	482	23.2
	L+0	254	73	330	403	18.1
	L+1	255	64	294	358	17.9
	L+8	234	93	355	448	20.8
	L+13	250	77	370	447	17.2
4	F-60	242	73	284	357	20.4
(PS1)	F-8	310	106	289	395	26.8
	F-1	295	137	284	421	32.5
	MD1	290	79	274	283	27.9
	MD7	285	134	330	464	28.9
	L+0	332	88	244	332	26.5
	L+1	299	95	264	359	26.5
	L+8	259	66	279	345	19.1
	L+13	260	77	310	387	19.9
5	F-60	274	130	350	480	27.1
(PS2)	F-7	279	159	386	545	29.2
	F-1	268	[a]	[a]		
	MD1	291	66	305	371	17.8
	MD7	263	152	406	558	27.2
	L+0	263	68	299	367	18.5
	L+1	281	95	335	430	22.1
	L+8	245	64	299	363	17.6
	L+13	282	64	279	343	18.7

[a]Quantity of serum insufficient for this analysis.

TABLE 23. - PLATELETS AND LEUKOCYTES

Subject	Day	Platelets, $X10^9/l$	Leukocytes, $X10^9/l$	Neutrophils, percent	Lymphocytes, percent	Monocytes, percent	Eosinophils, percent	Basophils, percent	Band neutrophils, percent
1	F-60	194	5.4	70	26	0	3	0	1
(MS1)	F-8	221	5.0	49	45	1	5	0	0
	F-1	216	6.0	62	30	5	3	0	0
	MD1	210	5.5	63	32	3	1	0	1
	MD7	213	7.2	52	40	4	2	0	2
	L+0	217	5.4	66	33	1	0	0	0
	L+1	204	6.1	55	32	6	7	0	0
	L+8	232	6.0	52	32	8	8	0	0
	L+13	253	6.2	68	20	8	4	0	0
2	F-60	288	6.0	59	28	11	1	1	0
(MS2)	F-7	298	6.0	62	35	2	1	0	0
	F-1	286	6.4	58	32	3	7	0	0
	MD1	273	6.9	66	26	5	3	0	0
	MD7	273	9.4	58	25	7	8	0	2
	L+0	291	9.1	70	28	2	0	0	0
	L+1	270	7.2	66	25	7	1	0	1
	L+8	302	6.3	55	36	8	0	0	1
	L+13	287	5.7	59	33	5	3	0	0
3	F-60	241	4.0	51	43	4	2	0	0
(MS2)	F-7	194	4.0	39	54	3	3	0	1
	F-1	223	4.3	46	46	5	3	0	0
	MD1	213	4.8	58	33	6	3	0	0
	MD7	221	4.7	55	42	2	1	0	0
	L+0	229	5.4	50	36	11	2	0	1
	L+1	228	4.5	52	34	12	2	0	0
	L+8	237	4.0	51	40	6	1	1	1
	L+13	232	3.8	44	45	3	8	0	0
4	F-60	202	2.7	52	44	4	0	0	0
(PS1)	F-8	185	4.1	70	27	3	0	0	0
	F-1	212	4.7	59	37	4	0	0	0
	MD1	213	3.6	62	36	1	1	0	0
	MD7	228	4.5	53	43	4	0	0	0
	L+0	212	3.8	62	35	2	1	0	0
	L+1	201	4.8	62	35	3	0	0	0
	L+8	208	3.8	62	35	3	0	0	0
	L+13	229	4.4	63	33	4	0	0	0
5	F-60	312	8.3	64	28	8	0	0	0
(PS2)	F-7	246	8.4	51	44	2	0	0	3
	F-1	318	8.1	56	34	5	5	0	0
	MD1	300	9.4	67	32	1	0	0	0
	MD7	287	8.3	57	35	3	3	0	2
	L+0	280	12.6	67	24	6	2	0	1
	L+1	291	8.2	62	33	2	1	0	1
	L+8	279	8.4	59	33	6	1	0	1
	L+13	286	6.1	62	35	1	2	0	0

TABLE 24. - NUMBER OF EACH TYPE OF LEUKOCYTE

Subject	Day	Neutrophils, $X10^9/l$	Lymphocytes, $X10^9/l$	Monocytes, $X10^9/l$	Eosinophils, $X10^9/l$	Basophils, $X10^9/l$	Band neutrophils, $X10^9/l$
1	F-60	3.78	1.40	0	.16	0	.054
(MS1)	F-8	2.45	2.25	.05	.25	0	0
	F-1	3.72	1.80	.30	.18	0	0
	MD1	3.47	1.76	.17	.055	0	.055
	MD7	3.74	2.88	.29	.14	0	.14
	L+0	3.56	1.78	.054	0	0	0
	L+1	3.36	1.95	.37	.43	0	0
	L+8	3.12	1.92	.48	.48	0	0
	L+13	4.22	1.24	.50	.25	0	0
2	F-60	3.54	1.68	.66	.06	.06	0
(MS2)	F-7	3.72	2.10	.12	.06	0	0
	F-1	3.71	2.05	.19	.45	0	0
	MD1	4.55	1.79	.35	.21	0	0
	MD7	5.45	2.35	.66	.75	0	.19
	L+0	6.37	2.55	.18	0	0	0
	L+1	4.75	1.80	.50	.072	0	0
	L+8	3.47	2.27	.50	0	0	.063
	L+13	3.36	1.88	.29	.17	0	0
3	F-60	2.04	1.72	.16	.080	0	0
(MS2)	F-7	1.56	2.16	.12	.12	0	.040
	F-1	1.98	1.98	.22	.13	0	0
	MD1	2.78	1.58	.29	.14	0	0
	MD7	2.59	1.97	.094	.047	0	0
	L+0	2.70	1.94	.59	.11	0	.054
	L+1	2.34	1.53	.54	.090	0	0
	L+8	2.04	1.60	.24	.040	.040	.040
	L+13	1.67	1.71	.11	.30	0	0
4	F-60	1.40	1.19	.11	0	0	0
(PS1)	F-8	2.87	1.11	.12	0	0	0
	F-1	2.77	1.74	.19	0	0	0
	MD1	2.23	1.30	.036	.036	0	0
	MD7	2.39	1.94	.18	0	0	0
	L+0	2.36	1.33	.076	.038	0	0
	L+1	2.98	1.68	.14	0	0	0
	L+8	2.36	1.33	.11	0	0	0
	L+13	2.77	1.45	.18	0	0	0
5	F-60	5.31	2.32	.66	0	0	0
(PS2)	F-7	4.28	3.70	.17	0	0	.25
	F-1	4.54	2.75	.41	.41	0	0
	MD1	6.30	3.01	.094	0	0	0
	MD7	4.73	2.91	.25	.25	0	.17
	L+0	8.44	3.02	.76	.25	0	.13
	L+1	5.08	2.71	.16	.082	0	.082
	L+8	4.96	2.77	.50	.084	0	.084
	L+13	3.78	2.14	.061	.12	0	0

TABLE 25. - SERUM CHEMISTRY

Subject	Day	Osmolality, mosm/l	Na, meq/l	K, meq/l	2,3-DPG, mol/g Hb	ATP, mol/g Hb
1	F-60	290	141	3.7	15.3	5.00
(MS1)	F-8	296	143	4.2	15.0	4.52
	F-1	290	141	3.9	15.2	3.98
	MD1	288	139	5.0	9.8	4.20
	MD7	287	140	4.0	15.1	3.71
	L+0	296	144	4.2	14.7	4.83
	L+1	289	141	3.9	14.6	4.55
	L+8	292	143	3.9	15.8	3.67
	L+13	286	139	4.1	13.1	3.83
2	F-60	289	143	4.0	12.4	4.20
(MS2)	F-7	289	142	3.7	12.8	4.08
	F-1	290	144	3.8	14.5	4.16
	MD1	288	142	4.6	12.1	4.74
	MD7	287	141	3.8	13.0	3.91
	L+0	289	143	3.8	13.1	3.86
	L+1	285	141	4.3	12.6	3.84
	L+8	288	143	3.6	13.9	3.91
	L+13	284	141	4.1	12.2	3.31
3	F-60	289	143	3.9	13.7	5.70
(MS2)	F-7	288	143	3.7	-	4.01
	F-1	289	143	3.8	13.7	4.20
	MD1	284	139	4.9	9.5	4.20
	MD7	286	140	4.0	14.6	4.20
	L+0	293	143	4.0	13.9	4.80
	L+1	286	141	4.5	13.9	4.88
	L+8	289	143	4.2	15.7	4.50
	L+13	286	141	3.9	14.2	5.51
4	F-60	286	142	3.7	13.9	4.03
(PS1)	F-8	285	141	4.0	15.5	4.17
	F-1	286	142	4.0	14.2	3.93
	MD1	285	141	3.9	16.2	5.30
	MD7	282	141	4.1	16.1	3.60
	L+0	291	146	5.2	16.5	3.91
	L+1	286	142	4.2	14.0	4.78
	L+8	290	143	3.6	14.9	3.43
	L+13	288	143	4.1	12.6	3.92
5	F-60	288	142	4.1	13.1	5.18
(PS2)	F-7	287	141	3.7	13.1	4.07
	F-1	291	145	4.0	13.6	4.58
	MD1	285	141	4.3	12.5	4.67
	MD7	287	140	4.2	12.4	5.52
	L+0	287	143	4.1	8.2	4.15
	L+1	283	139	3.9	12.8	3.60
	L+8	293	143	4.4	14.2	4.14
	L+13	288	141	4.2	9.6	4.57

TABLE 26. - SERUM PROTEINS

Subject	Day	Total protein, g/dl	Albumin, g/dl	Alpha-1 globulin, g/dl	Alpha-2 globulin, g/dl	Beta globulin, g/dl	Gamma globulin, g/dl	Haptoglobin, mg/dl	Ferritin ng/ml
1	F-60	7.4	5.3	.2	.4	.8	.7	56	155
(MS1)	F-8	7.3	4.9	.2	.5	.8	.9	60	132
	F-1	7.6	4.4	.3	.6	1.1	1.2	69	120
	MD1	6.8	4.8	.2	.4	.7	.7	65	137
	MD7	7.0	4.7	.2	.6	.8	.7	150	117
	L+0	7.3	4.7	.4	.6	.8	.8	124	120
	L+1	6.9	4.7	.2	.5	.8	.7	102	114
	L+8	6.7	4.7	.2	.5	.6	.7	70	94
	L+13	7.2	4.9	.2	.6	.6	.9	95	119
2	F-60	6.7	4.8	.2	.4	.6	.7	57	96
(MS2)	F-7	7.0	4.9	.2	.4	.6	.9	74	112
	F-1	7.3	5.1	.2	.5	.6	.9	65	113
	MD1	7.4	5.5	.1	.4	.6	.8	66	115
	MD7	7.2	4.9	.2	.5	.7	.9	84	105
	L+0	7.1	4.9	.2	.5	.6	.9	82	114
	L+1	6.8	4.7	.2	.5	.6	.8	79	111
	L+8	6.5	4.7	.2	.4	.5	.7	68	76
	L+13	6.5	4.6	.2	.5	.4	.8	60	69
3	F-60	7.0	4.7	.3	.5	.7	.8	128	124
(MS2)	F-7	6.9	4.8	.2	.5	.6	.8	73	74
	F-1	7.3	5.2	.2	.4	.6	.9	72	105
	MD1	7.5	5.6	.1	.4	.5	.9	79	85
	MD7	7.4	5.3	.2	.4	.7	.8	90	79
	L+0	7.3	5.1	.2	.6	.5	.9	86	74
	L+1	7.4	5.2	.2	.5	.6	.9	80	88
	L+8	7.1	5.0	.2	.5	.6	.8	76	66
	L+13	6.9	4.8	.2	.5	.5	.9	64	64
4	F-60	6.1	4.4	.3	.4	.5	.5	49	26
(PS1)	F-8	6.5	4.8	.2	.4	.5	.6	66	31
	F-1	7.0	5.2	.2	.4	.6	.6	68	38
	MD1	6.4	4.8	.2	.4	.5	.5	68	33
	MD7	6.6	4.9	.2	.4	.5	.6	65	29
	L+0	7.0	5.1	.2	.5	.5	.7	73	28
	L+1	7.0	5.2	.2	.5	.5	.6	73	33
	L+8	6.5	4.8	.2	.5	.4	.6	69	24
	L+13	6.4	4.6	.2	.5	.5	.6	74	20
5	F-60	7.0	5.0	.3	.6	.6	.5	101	138
(PS2)	F-7	6.9	4.8	.2	.6	.7	.6	95	144
	F-1	6.8	4.9	.3	.5	.6	.5	94	110
	MD1	6.8	5.0	.2	.5	.6	.5	100	139
	MD7	6.3	4.7	.2	.4	.5	.5	79	94
	L+0	7.0	5.2	.2	.6	.5	.5	82	107
	L+1	6.7	4.9	.2	.5	.6	.5	81	90
	L+8	6.4	4.7	.2	.5	.5	.5	85	56
	L+13	6.8	5.0	.2	.5	.5	.6	94	72

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16. Abstract

An experiment conducted on the 10-day Spacelab 1 mission aboard the ninth Space Shuttle flight in November to December 1983 was designed to measure factors involved in the control of erythrocyte turnover that might be altered during weightlessness. Blood samples were collected before, during, and after the flight. Immediately after landing, red cell mass showed a mean decrease of 9.3 percent in the four astronauts. Neither hyperoxia nor an increase in blood phosphate was a cause of the decrease. Red cell survival time and iron incorporation postflight were not significantly different from their preflight levels. Serum haptoglobin did not decrease, indicating that intravascular hemolysis was not a major cause of red cell mass change. An increase in serum ferritin after the second day of flight may have been caused by red cell breakdown early in flight. Erythropoietin levels decreased during and after flight, but preflight levels were high and the decrease was not significant. The space flight-induced decrease in red cell mass may result from a failure of erythropoiesis to replace cells destroyed by the spleen soon after weightlessness is attained.

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