# BIOASTRONAUTIC ASPECTS OF APOLLO BIOMEDICAL OPERATIONS

by

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On May 25, 1961, President Kennedy announced that the United States intended to land a man on the Moon in this decade. At the time this presented a tremendous challenge to the medical group within the National Aeronautics and Space Administration. The goal has been achieved by a systematic, step by step advance. Today's report will cover the last series of steps, i.e. the five manned Apollo flights starting with Apollo 7 in October 1968 and ending with the lunar landing of Apollo 11 in July 1969 (Figs. 1 and 2).

| Flight | Crew | Launch | Description | Duration hr:min:sec |
|---|---|---|---|---|
| Apollo 7 | Schirra<br>Eisele<br>Cunningham | Oct. 11, 1968 | Earth orbital checkout of the CSM | 260:09:45 |
| Apollo 8 | Borman<br>Lovell<br>Aders | Dec. 21, 1968 | First lunar orbit (10) flight for checkout of the CSM at lunar distance | 147:00:11 |
| Apollo 9 | McDivitt<br>Scott<br>Schweikart | March 3, 1969 | First manne Earth orbital checkout of the LM, CSM/ /LM rendezvous, and EVA | 241:00:54 |
| Apollo 10 | Stafford<br>Young<br>Cernan | May 18, 1969 | First lunar orbit rendezvous and low pass over lunar surface | 192:03:23 |
| Apollo 11 | Armstrong<br>Collins<br>Aldrin | July 16, 1969 | First lunar landing and EVA on the lunar surface | 195:18:35 |

FIG. 1. Apollo manned flights

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The information obtained from the Mercury and Gemini Programs was important for it was the basis upon which we planned our support and investigation of the Apollo flight series.

| | |
|---|---|
| Mercury | 54 |
| Gemini | 1939 |
| Apollo | 3105 |
| Total | 5098 |

FIG. 2. Man-hours of spaceflight as of September 1969

In the Gemini flights we found loss of bone density which reached a maximum of 14% on the 8th day of flight. The skeletal calcium loss appeared to be progressive, reaching a maximum of 22% in 14 days. The decrease of muscle mass followed a similar pattern with a maximum calculated loss of 7 lb after 14 days. The reduction of red blood cell mass reached 20% after 8 days and apparently it levelled off at that stage. The loss of cardiovascular tonus as indicated by the increase of heart rate when exposed to the tilt table test reached about 100% after 8 days but showed improvement after 14 days. The pulse pressure descrease in response to the tilt table test was roughly 60% independent of the length of the mission.

The Apollo missions were the first ones to take man outside of Earth orbit; they required precision performances in the lunar landing and rendezvous in lunar orbit; they required EVA activities on the lunar surface which involved a number of unknown factors and they called for flexibility to deal with the unpredictable.

The Apollo spacecraft was a new vehicle providing us for the first time with enough cabin volume to allow freedom of movement. The following were established as primary medical objectives:

(1) The assurance of crew safety.

(2) The assurance of mission completion and those activities contributing to mission management.

(3) The prevention of back contamination of our biosphere.

(4) The continuance of the understanding of the biomedical changes incident to manned spaceflight.

The meet these objectives the limited inflight information was supplemented by a detailed pre- and postflight medical program.

The Apollo missions were favored by the absence of solar flares which eliminated radiation as a flight hazard. Mean exposure dose was 230 mrads (Fig. 3).

Inflight observations included voice monitoring, electrocardiogram, and respiration during Command Module operations, and voice and electro-

cardiogram during the Lunar Module operations. On Apollo 7 and 8 we had the capability to monitor the electrocardiogram and respiration of only a single individual at a time during Command Module operations. On Apollos 9, 10, and 11, we were capable of monitoring all three individuals

| | Average dose (rad) |
|---|---|
| Apollo 7 | 0.16 |
| Apollo 8 | 0.16 |
| Apollo 9 | 0.20 |
| Apollo 10 | 0.47 |
| Apolol 11 | 0.18 |

FIG. 3. Apollo missions: radiation dose (thermoluminescent dosimeter

at the same time in the Command Module, and one at a time in the LM except for the time onthe lunar surface when both individuals could be monitored.

Ground evaluations included physical examinations, hematology, immunology, biochemistry, bone densitometry, cardiovascular, exercise capacity, and microbiology.

**General weightlessness**

Flight crews have confirmed the Gemini observations of an initial feeling of fullness in the head on obtaining weightless flight. This sensation has lasted for varying lengths of time during the first day of flight. There is an awareness of lack of weight of objects and clothing and the capability to move objects in the weightless environment has been utilized repeatedly for living and working in the spacecraft. The intravehicular activity has required minimal effort and the crew has been able to move freely frequently in a swimming manner and they have performed a number of acrobatic movements, such as rolling, tumbling, and spinning with no difficulty. The workload is less in weightlessness than it is for mvement in the 1 *g* environment. There have been some instances of soreness in the costal-vertebral areas which the crews have related to their frequently assumed fetal position in the weightless environment. This has not created any real difficulty. In general, the crews have adapted extremely well to the weightless environment, found it pleasant and have utilized it to assist them in accomplishing their inflight activity.

**Work/sleep cycles**

Before manned spaceflight became a reality, some of our colleagues in the medical community predicted that such flights would produce serious disturbance in man's sleep, ranging from narcolepsy to insomnia. These extreme forecasts were incorrect but the Gemini program clearly dmeonstrated that longer Earth-orbital flights do produce conditions which interfere with adequate sleep.

The primary causes of sleep-disturbance were: (1) cyclic noise disturbances produced by thruster firings, communication, or movement within the spacecraft; (2) staggered sleep periods; (3) large displacement of the crew's normal diurnal cycle; (4) the so-called command pilot syndrome; (5) the unfamiliar sleep environment, and (6) excitement.

In Apollo, no new sleep problems have been encountered. Our main difficulty has been in the application of our medical knowledge and expertise to mission planning. Apollo missions are necessarily tailored around an operational trajectory which is by nature inflexible. The astronaut must then be integrated into this fixed mission plan. In other words, man is sized to the mission and not the converse. There is no solution to this dilemma if the program objectives are to be met.

The Apollo 7 work/sleep cycles had an irregular and staggered sleep pattern. The crew never adapted to this bizarre work/sleep schedule and in the postflight debriefing they reported that fatigue and exhaustion once caused one man to fall asleep on his watch and that he took 5 mg of D-amphetamine on another occasion to stay awake during his work period.

For Apollo 8, secobarbital, in 50 and 100 mg doses, was added to the medical kit. But only the LMP used 50 mg secobarbital regularly at bedtime for sleep.

Apollo 9 was the first Apollo flight in which all three astronauts slept simultaneously. A definite improvement over the previous two missions in both quantity and quality of sleep was observed and lack of postflight fatigue was evident during the recovery day physical examination. On the Apollo 11 lunar landing flight the work/sleep cycles were excellent prior to lunar orbit insertion, and the amount of sleep was adequate to medically approve an earlier EVA than was originally flight planned (Fig. 4). During their lunar stay, neither the CDR nor the LMP slept well, due to cold, noise, and poor sleep accommodations. We are continuing our efforts to keep the inflight workday at about 12 hr, allowing 8 hr for sleep and 4 for leisure. Future programs will afford us better tools such as the EEG for assessment of sleep quality.

Two new medications were added for the Apollo 11 mission. Scopolamine and Dexedrine in X combination for the treatment of motion

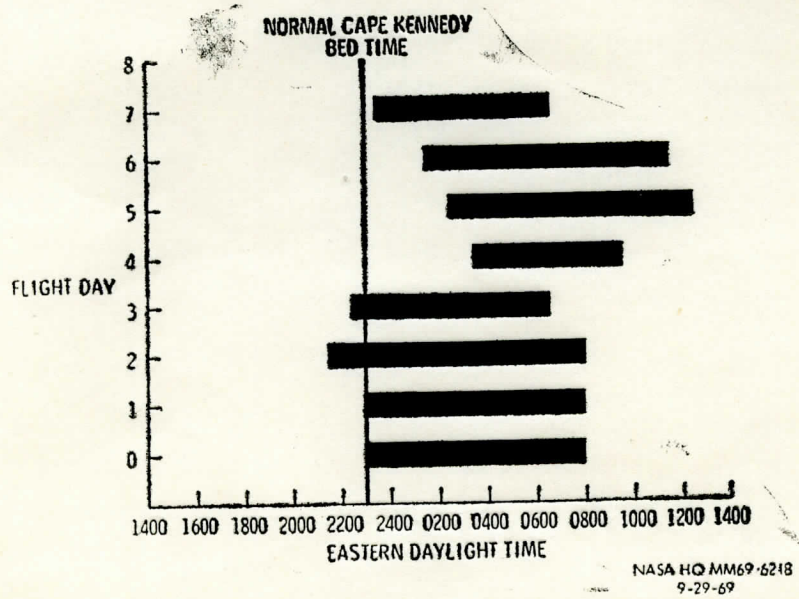



FIG. 4. Apollo 11 crew sleep periods

sickness and mylicion tablets to reduce the size of the gastrointestinal gas bubbles. All crew members are tested for both sensitivity and response to each of the medications of the medical kit. In the case of Seconal, we have been particularly interested in their ability to perform effectively at periods of one, two, three, and four hours following injection of Seconal. Tests have shown very satisfactory performance at all of these time periods.

**Preventive medicine and inflight disease**

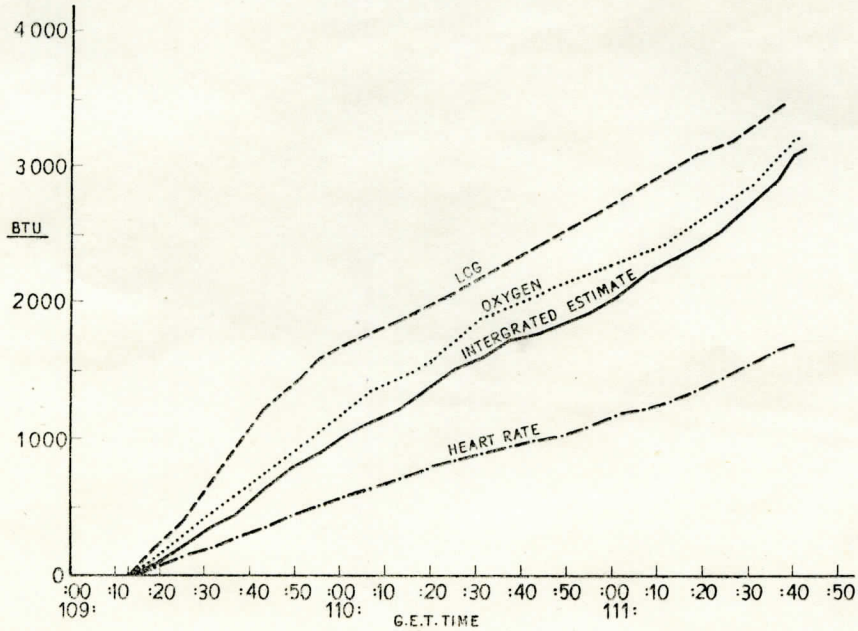
Since Apollo 7, we have maintained a 21-day preflight period of modified isolation of the crew. It is impossible in our operational environment to totally isolate the crew and still have them accomplish the mission. Every attempt has been made to control their environment and to limit their contacts. The only serious failure of this program was the rhinitis and pharyngitis which developed before Apollo 9 and delayed the launch. On the Apollo 11 mission, the 21-day postflight quarantine period made the preflight preventive medicine program assume greater importance. Five of the six crewmen on Apollo 8 and 9 developed some symptoms of motion sickness. The symptoms ranged from mild stomach awareness on head and body motion in the weightless environment up through nausea and vomiting which occurred in one case. The symptoms had durations

ranging from 2 hr up to 5 days. Following these time periods the affected crewmen were able to make any movement within the spacecraft without symptoms. On Apollo 10, one crewman had stomach awareness for a 2-day period. Prior to the mission the crew had been instructed in programmed head movements to speed the adaptive process. These movements were tried by one Apollo 10 crewman on the first and second days of flight and he noted an increase in his symptoms after one minute of head movement. They were tried again on the seventh day of the flight after the astronaut had "adapted" and after the Lunar Module activity and again he noted increasing symptoms of stomach awareness developing after five minutes. The Apollo 11 flight crew was briefed on the procedure for the adaptive programmed head movements and the availability of medication. They were also advised to be cautious in moving about in the spacecraft prior to adaptation. No symptoms were noted nor were special preventive measures used. It appears that the larger volume of the Apollo spacecraft with the opportunity to move about freely in the weightless state is a factor in producing this condition. This is a problem which could interfere with flight performance (Fig. 5). Our medical evaluations are

Apollo 8 and 9 experience
Five crewmen had symptoms (stomach awareness to nausea and vomiting) lasting 2 hr to 5 days. All adapted
Apollo 10 experience
One crewman had stomach awareness for 2 days Preventive head movements tried days 1 and 2 with increase in symptoms after 1 min. Again on day 7 with symptoms developing after 5 min
Apollo 11
Briefed crew on
cautious movement in spacecraft to adapt
availability of head movements and medication
no symptoms

FIG. 5. Apollo motion sickness experience

programmed to start 30 days prior to launch with a detailed crew briefing. Physical examinations are conducted at 14 and 5 days preflight and a brief physical exam is conducted on the day of flight. On the Apollo 11 mission the crewmen were examined on a daily basis for the 5 days preceding the flight. The postflight examinations are done immediately upon recovery and 24 hr after recovery. Daily physical examinations were conducted on the Apollo 11 crew during the 21-day quarantine period.


4 000
3 000
BTU
2000
1000
0
LCG
OXYGEN
INTERGRATED ESTIMATE
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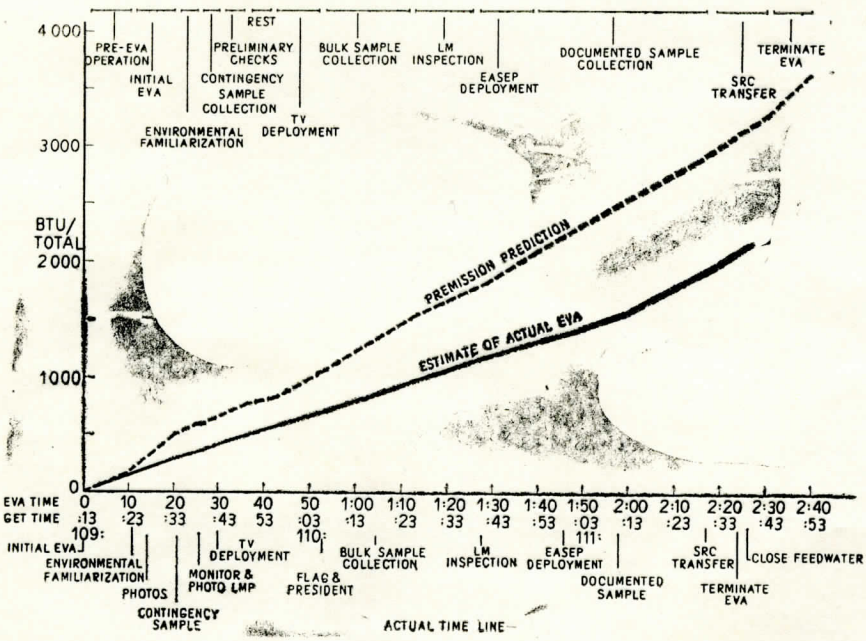
:00 :10 :20 :30 :40 :50 :00 :10 :20 :30 :40 :50 :00 :10 :20 :30 :40 :50
109: 110: 111:
G.E.T. TIME

FIG. 6


4 000
3000
BTU/
TOTAL
2 000
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REST
PRE-EVA OPERATION
INITIAL EVA
PRELIMINARY CHECKS
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ENVIRONMENTAL FAMILIARIZATION
TV DEPLOYMENT
BULK SAMPLE COLLECTION
LM INSPECTION
EASEP DEPLOYMENT
DOCUMENTED SAMPLE COLLECTION
SRC TRANSFER
TERMINATE EVA
PREMISSION PREDICTION
ESTIMATE OF ACTUAL EVA
EVA TIME 0 10 20 30 40 50 1:00 1:10 1:20 1:30 1:40 1:50 2:00 2:10 2:20 2:30 2:40
GET TIME :13 :23 :33 :43 53 :03 :13 :23 :33 :43 :53 :03 :13 :23 :33 :43 :53
109: 110: 111:
INITIAL EVA
ENVIRONMENTAL FAMILIARIZATION
PHOTOS
CONTINGENCY SAMPLE
TV DEPLOYMENT
MONITOR & PHOTO LMP
FLAG & PRESIDENT
BULK SAMPLE COLLECTION
LM INSPECTION
EASEP DEPLOYMENT
DOCUMENTED SAMPLE
SRC TRANSFER
TERMINATE EVA
CLOSE FEEDWATER
ACTUAL TIME LINE

FIG. 7

**Lunar surface activity**

In planning and training for this activity we expected some effect on the men due to 3 days of weightlessness, specifically heart rate change due to cardiovascular deconditioning and decrease in exercise capacity. The three methods used for real time metabolic monitoring were: (1) heart rate compared to a BTU calibration curve obtained by bicycle ergometry; (2) oxygen usage from the portable life support system, and (3) water temperature in and out of the water cooled undergarment (LCG). All of them are only crude approximations. The metabolic estimates of the surface activity for each crewman by each method are shown in Figs. 6, 7, and 8 along with an integrated best estimate of the actual energy cost.

Average hourly total BTU production 900–1200

Work production for a given task is subject to variation between crewmen

Foor-to-five-hour EVA not outside physiological limitations of presently configurated EMU (comparable activity)

LCG method is best for estimating crewman BTU production for utilization in consumable calculations (with more rapid updates oxygen method will be a valuable cross check)

Heart rate method represents a valuable relative indicator of metabolic production and a poor absolute indicator

FIG. 8. Apollo EMU metabolic assessment. Apollo 11 lunar surface activity conclusions

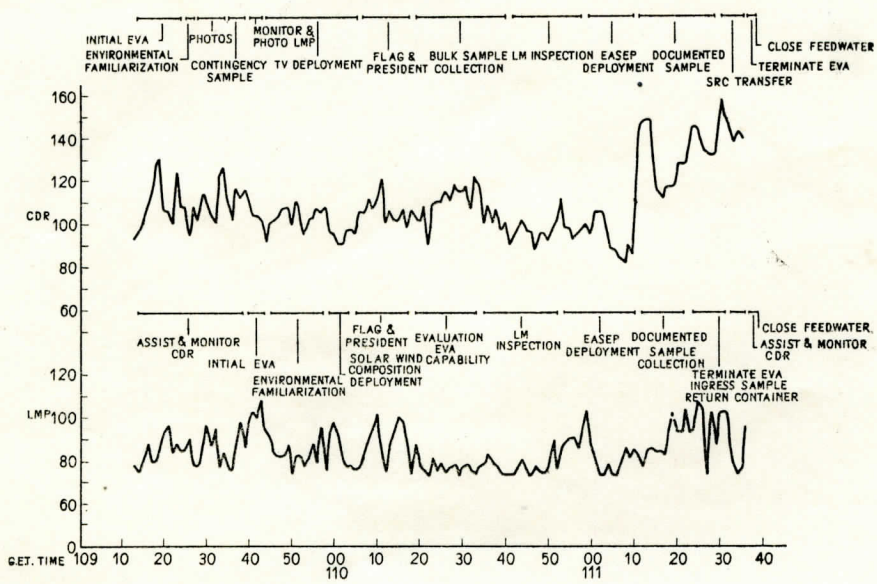



FIG. 9

The estimated energy cost of the entire 146 min of surface activity was 2982 BTU.

The heart rates for each crewman during the lunar surface activity are shown in Fig. 9. The highest rates were 140–160 on the CDR during documented sample collection and transfer of sample box to the LM.

The average hourly total BTU production was 900–1200 BTU/hr.

**Quarantine**

Approximately 3 years prior to the Apollo 11 flight a decision was made to conduct a postflight quarantine operation to preclude the possibility, even though remote, of contaminating our biosphere with lunar organisms. This was based on a National Academy of Sciences report. The quarantine was to start at hatch closure of the LM on the lunar surface and continue for a 21-day period. This was an arbitrary time period based on the incubation period of the bulk of the virulent contagious diseases.

On recovery, the crew remained in a special mobile quarantine facility during three days transit time by ship and aircraft to Houston where they were moved to the Lunar Receiving Laboratory and transferred to the crew reception area (CRA). Daily examinations were conducted on all CRA personnel and blood and microbiological samples taken at intervals. The quarantine period produced no evidence of infectious disease and the Interagency Committee on Back Contamination gave approval for crew release on the 21st day. Continued surveillance will be maintained for 1 year and to date there has been no infection, diseases, or illness of any sort.

The quarantine of the lunar samples continued until 50 days post recovery, when the Interagency Committee on Back Contamination recommended release.

**Cardiovascular**

It has been amply documented that diminished orthostatic tolerance may result from relative inactivity or confinement. Therefore, it was no surprise when cardiovascular deconditioning or diminished orthostatic tolerance was consistently demonstrated during the early postflight periods of the Mercury and Gemini missions. However, such deconditioning posed no serious problems for Earth orbital flights of up to 14 days duration. In Apollo pre- and postflight cardiovascular evaluations were performed on all crewmembers to assess the effects of the new mission parameters on orthostatic tolerance. The test methods used in assessing the degree of cardiovascular deconditioning or orthostatic tolerance included lower body negative pressure and the 70 degree passive tilt test when the

use of LBNP was precluded by quarantine constraints. The physiological measurements obtained during each test were heart rate, blood pressure and calf circumference. Other data were considered in evaluating the test results, including body weight, blood volume, exercise response, and urinary excretion of vasoactive hormones.

Resulting data are incomplete and differences of test periods make it difficult to combine the findings. The following is an indication of the general trend. In Apollo 8, comparing postflight with preflight control, the Commander showed an increase of 23% for the resting heart rate and an increase of 57, 59, and 69% when exposed to a lower body negative pressure (LBNP) of 30, 40, and 50 mmHg respectively, and an increase of about 20% for the leg volume measurement. In Apollo 9, the Commander showed a decrease of 15% for the resting pulse pressure and average decrease of 34% in response to the LBNP. In Apollo 10, Cernan at 2 and 1/2 hr postflight had a decreased pulse pressure of 35% in the supine position which decreased to 50% after 5 min in the erect position. In Apollo 11, comparing the change of heart rate when rising from the supine position preflight and 6 and 1/2 hr postlanding had an increase of 34%. Nine of

| | | Body weight (lb) | | | | Energy (kcal) |
|---|---|---|---|---|---|---|
| | | Avg. preflight (F-28, F-24, F-5) | Launch day (F-0) | Recovery (R+0) | Recovery +1 day (R+1) | Avg. daily inflight caloric intake |
| Apollo 7 | CDR | 195 | 194 | 188 | 191 | 1966 |
| | CMP | 153 | 157 | 147 | 151 | 2144 |
| | LMP | 157 | 156 | 148 | 154 | 1804 |
| Apollo 8 | CDR | 169 | 169 | 161 | 163 | 1477 |
| | CMP | 169 | 172 | 164 | 165 | 1688 |
| | LMP | 146 | 142 | 138 | 139 | 1339 |
| Apollo 9 | CDR | 161 | 159 | 154 | 156 | 1924 |
| | CMP | 181 | 178 | 173 | 181 | 1715 |
| | LMP | 164 | 159 | 153 | 157 | 1639 |
| Apollo 10 | CDR | 175 | 171 | 169 | 171 | 1407 |
| | CMP | 169 | 165 | 160 | 161 | 1487 |
| | LMP | 175 | 173 | 163 | 165 | 1311 |
| Apollo 11 | CDR | 173 | 172 | 164 | 170 | |
| | CMP | 167 | 166 | 159 | 159 | −5300* |
| | LMP | 172 | 167 | 166 | 170 | |
| Totals | | 2526 | 2500 | 2407 | 2453 | 25201 |
| Average | | 168.4 | 166.67 | 160.47 | 163.53 | 1680 |

* Average of 5300 kcal daily for all 3 men based on their estimates.

FIG. 10. Body weight changes and energy intake for Apollo 7 through 11 missions

the 15 Apollo astronauts exhibited significant postflight elevations of their *supine* heart rates, whereas 77% of those stressed by LBNP and 100% of those stressed by simply standing revealed significantly elevated pulse rates. It is clear therefore that provocative or stress testing reveals altered cardiovascular responses which otherwise would not be detected. The measurement of the calf circumference showed marked variability, which may be corrected in future by developing more reliable techniques. Systolic and diastolic blood pressures do not show consistent changes. Resting pulse pressure was decreased in 13 of the 15 astronauts and in all cases during LBNP. The average weight loss was 6.2 lb of which 3.1 lb may be attributed to water loss, i.e. the amount regained within 1 day after recovery. Nearly all subjects have returned to their preflight response levels within 30 to 50 hr postrecovery. This recovery time agrees well with that noted following the Gemini flights (Figs. 10, 11).

| | Wt. loss | Percent change | Wt. regained (R+24 hr) | Percent change |
|---|---|---|---|---|
| Apollo 7 | | | | |
| CDR | −6.3 lb | 3.2 | +2.5 lb | 1.3 |
| CMP | −10.0 lb | 6.4 | +3.5 lb | 2.2 |
| LMP | −8.0 lb | 5.1 | +5.5 lb | 3.5 |
| Apollo 8 | | | | |
| CDR | −8.7 lb | 5.1 | +2.7 lb | 1.6 |
| CMP | −7.8 lb | 4.5 | +0.7 lb | 0.4 |
| LMP | −4.0 lb | 2.8 | +0.5 lb | 0.3 |
| Apollo 9 | | | | |
| CDR | −5.2 lb | 3.3 | +2.7 lb | 1.7 |
| CMP | −5.7 lb | 3.2 | +8.5 lb | 4.8 |
| LMP | −6.1 lb | 3.8 | +4.2 lb | 2.6 |
| Apollo 10 | | | | |
| CDR | −2.0 lb | 1.1 | +2.0 lb | 1.1 |
| CMP | −6.0 lb | 3.6 | +4.0 lb | 2.5 |
| LMP | −9.0 lb | 5.2 | +1.0 lb | 0.6 |
| Apollo 11 | | | | |
| CDR | −8.0 lb | 4.7 | +6.0 lb | 3.7 |
| CMP | −8.0 lb | 4.2 | +0.0 lb | 0.0 |
| LMP | −2.0 lb | 1.2 | +4.0 lb | 2.4 |

FIG. 11. Weight changes—Apollo 7 to 11

**Hematology—biochemistry**

A large number of hematological and biochemical analyses have been performed for all Apollo missions whenever possible. However, certain determinations were not performed in the case of Apollo 10 and 11 missions because of quarantine or other operational constraints. We have

consistently noted immediate postflight and absolute neutrophilia and lymphopenia. This finding is consistent with observations in the Gemini flights. In all cases, this change reverts to normal within 24 hr.

The red cell mass data has been of particular interest to us in view of the Gemini experience of a fairly consistent loss of red cell mass to a maximum of 20%. The Apollo spacecraft, unlike that of Gemini, has been launched with an atmosphere of 60% oxygen, 40% nitrogen. The inflight spacecraft pressure of 5 psia is maintained by oxygen replenishment so that the orbital spacecraft gaseous environment is progressively altered and has generally levelled off at the 93–95% figure. There was essentially no change in red cell mass in the Apollo flights. The only exception is Apollo 9 where a modest but significant loss of red cell mass was observed. This flight, however, was different from other Apollo flights in that early during the mission the LEM activation and EVA activity required decompression of the Command Module (exposure to the space vacuum), following which the spacecraft was repressurized with 100% oxygen. Thus, there was no residual nitrogen in the spacecraft for the remaining 7 days of the 10-day mission. This finding lends further support to the hypothesis that the toxicity of 100% oxygen atmospheres at 5 psia is a major factor in the red cell mass lossobserved during Gemini and to a lesser extent in Apollo 9 (Figs. 12, 13, 14).

| | Apollo | | | | | |
|---|---|---|---|---|---|---|
| | Flight number | | | | | |
| | 7 | 8 | 9 | 10 | 11 | *AOA |
| RBC | 0 | ↑↑ | ↓↓* | ↑↑ | 0 | 0 |
| HCT | 0 | ↑↑ | 0 | ↑↑ | 0 | 0 |
| HGB | 0 | ↑↑ | ↑↑ | 0 | 0 | |
| Retics | 0 | 0 | | 0 | 0 | |
| WBS | ↑↑↑ | ↑↑↑ | 0 | ↑↑ | ↑↑↑ | ↑↑↑ |
| Neuts | ↑↑ | ↑↑ | 0 | ↑↑↑ | ↑↑↑ | ↑↑ |
| Lymphs | ↓↓ | ↓↓ | 0 | ↓↓ | ↓↓ | ↓↓ |
| Monos | 0 | ↓↓ | 0 | 0 | ↓↓ | ↓↓ |
| Eos | | | | ↓↓ | ↓↓ | ↓ |
| Basos | | | | ↓↓ | | 0 |
| Platelets | 0 | 0 | 0 | 0 | 0 | 0 |

* Apollo over all.

FIG. 12. Routine hematology

Biochemical determinations have revealed a transient postflight hyperglycemia, and decreased serum cholestrol and uric acid levels.

Postflight urinary excretion of hydroxyproline and catecholamines

| | Apollo | | | |
|---|---|---|---|---|
| | Flight number | | | |
| | 7 | 8 | 9 | 10 |
| Plasma volume | 0 | ↓↓ | ↓ | ND |
| Red cell mass | 0 | 0 | ↓ | ND |
| Ferrokinetics | ↓ | ↓ | ND | ND |
| $^{14}$C-glycine survival | 0 | 0 | 0 | ND |
| $^{51}$Cr survival | 0 | 0 | ↓ | ND |
| Active RBC Na–K flux | ND | ND | ↓ | 0 |
| Passive RBC Na–K flux | ND | ND | 0* | 0* |

* Technically unsatisfactory.

FIG. 13. Radioisotope—hematology

| Apollo |
|---|
| The hematologic data collected suggest that weightlessness has little or no effect on the RBC mass loss phenomena |
| A postflight leukocytosis associated with an absolute neutrophilia and absolute lymphopenia is often seen. This phenomenon is probably an effect of increased epinephrine and steriod levels |

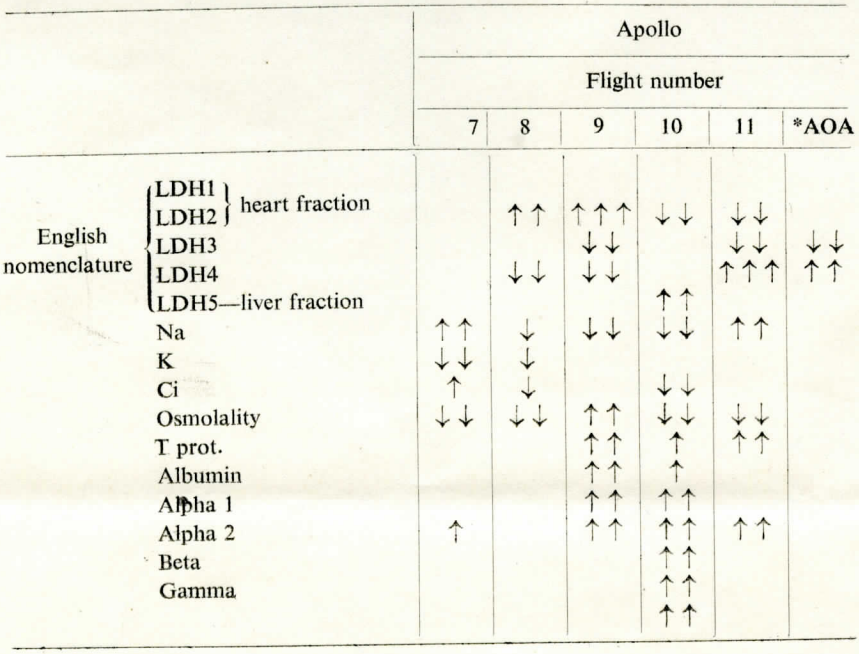
FIG. 14. Hematology program conclusions

| | Apollo | | | | | |
|---|---|---|---|---|---|---|
| | Flight number | | | | | |
| | 7 | 8 | 9 | 10 | 11 | *AOA |
| Glucose | ↑↑↑ | ↑↑ | ↑ | ↑↑↑ | | ↑↑ |
| Cholesterol | ↓ | ↓↓ | ↑ | ↓ | | ↓ |
| SGOT | | | | | | |
| BUN | | | | ↑↑ | | |
| Uric acid | ↓ | ↓↓ | ↓ | ↓↓ | ↓↓ | ↓ |
| Alk. phos. | | | ↑↑↑ | | | |
| Ca | | | | | | |
| Mg | | | | ↓↓ | ↓↓ | |
| Inorganic phosphate | | ↑↑ | ↑↑↑ | ↑↑ | ↓↓ | |
| Bilirubin total | | ↑ | | ↑↑ | | |
| Creatinine | ↑↑ | | | | +2SD | ↑↑ |
| CPK | | ↑↑ | ↓↓ | | | |
| LDH | ↑↑ | | ↓↓ | ↓↓ | ↓↓ | |

* Apollo over all.

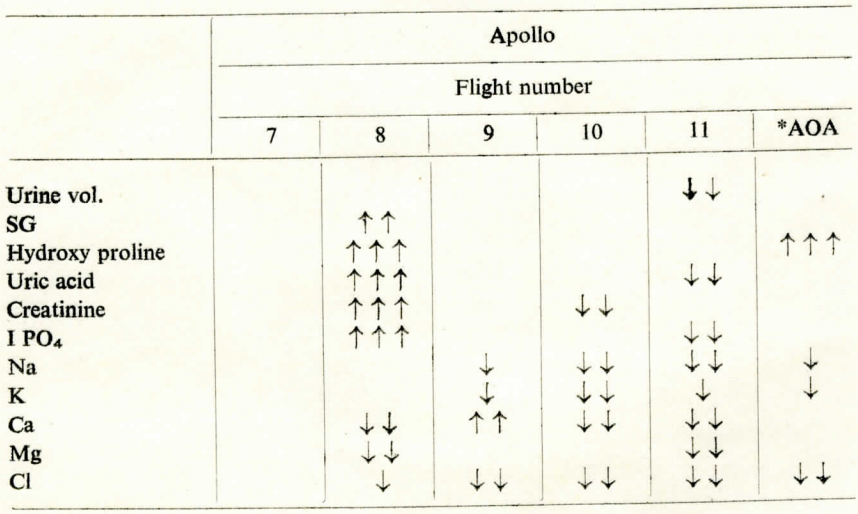
FIG. 15. Biochemistry data summary

was increased and free hydrocortisone was decreased over preflight control levels, and there was consistently diminished excretion of sodium, potassium, and chloride in the immediate postflight period.




* Apollo over all.

FIG. 16. Biochemistry data summary




* Apollo over all.

FIG. 17. Urine (24 hr) chemistry summary

A decline of serum cholesterol and uric acid is attributed to altered diet. Transient decreases of LDH fraction 3 with elevation of fractions 4 and 5 are not considered pathologic in the absence of other symptoms (Figs. 15, 16, 17, 18).

| Apollo |
|---|
| A transient postflight hyperglycemia is regularly seen. A probable result of an increased output of catecholamines and ateroid secondary to the "stress" of reentry |
| Serum cholesterol and uric acid levels generally decline over the flight intervals; a probable result of the crew members altered diet |
| A transient decrease in LDH, fraction 3* associated with elevations of LDH fractions 4* and 5* are often seen. No other biochemical changes supporting liver or other disease have been noted |

* English nomenclature utilized.

FIG. 18. Clinical biochemistry conclusion

**Immunology**

Immunologic studies in Apollo have included a profile of appropriate serum protein fractions, lymphocyte response and RNA and DNA synthesis. Increases in immunoglobulins were observed repeatedly and are related to the episodes of clinical illnesses. Increases in haptoglobin and ceruloplasmin are probably associated with a moderate generalized stress reaction (Figs. 19, 20).

| | Apollo | | | | | |
|---|---|---|---|---|---|---|
| | Flight number | | | | | |
| | 7 | 8 | 9 | 10 | 11 | *AOA |
| Immune globulin G | | | | ↑↑ | ↑ | ↑↑ |
| Immune globulin M | | | ↑↑ | | | |
| Immune globulin A | | | ↑↑ | ↑↑↑ | ↑ | ↑ |
| Haptoglobin | | | | ↑↑ | ↑ | ↑↑ |
| Ceruloplasmin | | | | ↑↑↑ | | |
| Transferrin | | | | ↓↓ | | |
| Alpha 1 antitrypsin | | | | ↑↑ | | |
| Alpha 1 acid glycoprotein | | | | | | |
| Alpha 2 macroglobulin | | | | ↑↑ | ↑↑↑ | ↑↑ |
| C reactive protein | | | | | | |
| Beta 1 alpha globulin (3rd fraction of complement) | | | | ↑↑ | ↑↑ | ↑ |

* Apollo over all.

↑ SIG trend (POS), ↑↑ +2SD, ↑↑↑ +3SD, ↑ SIG trend (NG), ↑↑ −2SD, ↑↑↑ −

FIG. 19. Humoral immunology data summary

| Apollo |
|---|
| Significant postflight increases of IgM, IgA, haptoglobin, ceruloplasmin and alpha 2 macroglobulin have occurred |
| Episodes of clinical disease, manifest pre and intra flight, probably account for the post-flight increases of immunoglobulins |
| The acute phase response, namifest by increases in haptoglobin and ceruloplasmin with occasional decreases in transferring is probably a result of the non-specific spaceflight stresses encountered (i.e. reentry, etc.) |
| The increase in alpha 2 macroglobulin noted often accompanies conditions associated with elevations in proteolytic enzyme activity. (i.e. nephrosis, Zollinger ellison syn drome, etc.) |
| No compromise of mans humoral immune system has been detected to date |

FIG. 20. Humoral immunology program summary

## Microbiology

The microbiology program includes swab samples from eight body areas and specimens of urine, feces, and a throat-mouth gargle collected from each astronaut at intervals of flight minus 30 days (F-30), (8 hr prior to liftoff) and immediately upon return. Approximately 12 data bits on some 4000 microorganisms have been collected during the Apollo 7–11 series and have been stored in a computer. Although demanding Apollo mission schedules have not permitted a thorough analysis of the data, certain consistent findings may be indicative of biological trends. Man to man transfers of potential pathogenic bacteria and fungi are found to be a regular occurrence within the closed ecological environment. This phenomenon is accompanied by a significant increase in the number of crewmembers infected and in the number of sites per man from which organisms can be isolated. The appearance of a limited number of organisms during the postflight sampling interval suggests that microbial shifts may favor the growth of opportunist organisms. These observations suggest that microflora changes occurring in the spacecraft environment may be a hazard to man's health and welfare during extended space missions. No observations have been made which suggest that the spacecraft environment may predispose to viral-induced illness. Rather, the illnesses occurring in Apollo crewmembers have been correlated with the normal seasonal occurrence of upper respiratory infection in the population at large.

## Exercise capacity

The Apollo pre- and postflight exercise capacity test utilized a bicycle ergometer programmed to maintain a constant heart rate. A heart rate of 120 for 3 min was followed by a heart rate of 140, 160, and in 3 sub-

jects, 180—for periods of 3 min at each level. Gas samples were obtained at appropriate times during each test period.

The exercise test is scheduled for each crewmember at 30, 14, and 4 days preflight, and as early as possible after recovery with a repeat 24–36 hr later.

Following the four Apollo missions, 12 of the 15 crewmen have demonstrated a significant decrement in work performed and in oxygen consumed at submaximal levels of heart rate, as compared with their preflight test levels. Of the 3 crewmembers tested at maximal heart rate levels (180), all have exhibited a similar decrement. All subjects exhibited a return to preflight exercise performance levels within 24 to 36 hr after recovery with but a single exception. This particular individual exhibited identical response before and after the Apollo 8 mission. Supplementary supporting data indicated that the decrements in work performance observed were not due to altered ventilatory function nor were they due to an inability of the subjects to extract oxygen from the atmosphere. Efficiency of work performance was essentially unchanged and all pulmonary function tests were well within expected physiological limits. Pinpointing the physiological mechanism responsible for the observed decrement in postflight exercise response remains unclear at this time and must await further investigation (Figs. 21–24).

| Test protocol | |
|---|---|
| Resting | 1 min |
| Light work (120 heart rate) | 6 min |
| Moderate work (140 heart rate) | 3 min |
| Heavy work (160 heart rate) | 3 min |
| Very heavy work (180 heart rate) | 3 min |
| Recovery | 3 min |

FIG. 21. Apollo exercise response test

| Test schedule | |
|---|---|
| Preflight | F−30 |
| | F−14 |
| | F−4 |
| Postflight | R+0 |
| | R+1 |

FIG. 22. Apollo exercise response test

| Oxygen consumption immediately postflight | | | | | |
|---|---|---|---|---|---|
| Heart rate | 120 | 140 | 160 | 180 | Overall |
| $\bar{X}$ (%) | 68.6 | 74.5 | 77.8 | 77.0 | 73.8 |
| S.D. | 15.2 | 11.6 | 10.8 | 8.1 | 12.7 |
| N | 15 | 15 | 15 | 3 | 48 |

100% = mean of 3 preflights.

FIG. 23. Apollo exercise response test

| Summary of changes |
|---|
| Twelve out of fifteen crewmen have demonstrated a significant decrease in work performed and oxygen consumed at submaximal levels of heart rate |
| Three out of three crewmen have demonstrated above response at maximal levels of heart rate |
| Response has returned to preflight values within 24 to 36 hr in fourteen out of fifteen crewmen |
| Changes have been observed in the systolic blood pressure corresponding to set levels of heart rate |
| No significant changes in vital capacity, forced expired volumes, or peak expiratory flow rate have been observed |

FIG. 24. Apollo exercise response test

## Summary

The 3105 man-hours of Apollo spaceflight have added greatly to our knowledge of man's response to the space environment. The absence of solar flare eliminated the radiation problem for Apollo, but for prolonged manned spaceflight the problem has not been solved. Crews have adapted generally to weightlessness and used it to advantage. Weight loss is still noted and it is only partly due to fluid loss. Sleep appears to be impaired and the relationship of work/rest cycles to task requirements needs further consideration. The preventive medicine program has been difficult to conduct but in the later flights it effectively reduced the pre-, in-, and postflight incidence of upper respiratory and gastrointestinal infection. Motion sickeness has been noted in varying degrees but all astronauts have adapted well within a few days. The problem is apparently associated with the greater freedom of movement of the Apollo spacecraft and will require further attention. Cardiovascular deconditioning has been similar in degree and duration to that noted after the Gemini

flights. A significant decrement in postflight work capacity has been noted to last 24–36 hr. The immediate postflight neutrophilia is similar to the one previously noted in Gemini. The loss of red blood cell mass of Gemini was found only in Apollo 9, which was the only Apollo flight were the astronauts were exposed to pure oxygen at 5 psia for prolonged periods. The microbiological studies indicate an increase of intercrew transfer and growth of opportunist organisms, which could become a hazard in future spaceflight. The Apollo 11 lunar surface activity was conducted within the expected level of energy expenditure of 1200 BTU/hr.

## Conclusion

The Apollo flights brought the Moon within the scope of man's investigative endeavor and inspired confidence in our capability to explore the Moon and the further reaches of outer space.