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MEDICAL ASPECTS OF MANNED SPACE FLIGHT

Prepared by

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FOREWORD

Space medicine is that discipline within the broad framework of preventive medicine which seeks to (1) develop information and techniques for manned space flight; (2) provide physiological support during space and planetary exploration; and, (3) protect both man and his terrestial environment from the hazards of space.

Because of our lack of knowledge about man's physiological and psychological responses in the space environment, a vast research and development effort at the national level has been carried out. This has involved both ground-based studies and flight experiments with living organisms. Our actual medical experience in manned space flight is presently limited to that gained in the Mercury and Gemini programs. Physiological data obtained has gone far to validate our R and D effort, and to indicate the direction of our future effort in space medicine.

The present review attempts to provide a brief summary of what we have done and what we have learned as of this moment when mission planners look to the lunar landing and beyond.

Jack Bollerud
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Manned Space Flight

May 15, 1967

MEDICAL ASPECTS OF MANNED SPACE FLIGHT

The manned space flight program in the United States has been planned on an incremental basis. Each flight has either extended the physiological and psychological stresses or else has investigated new parameters of man's capabilities. Short duration flights preceded longer ones; single-man crews orbited the earth before multi-man crews. There has been increasingly complex activity as well as progressive application of new experience and knowledge. This incremental progression is demonstrated not only in the differing objectives of the three major programs--Mercury, Gemini and Apollo--but also in the more limited objectives and sequence of actions which identify each individual mission within a particular program.

The U.S. manned space flight program began with Project Mercury in 1958. Its mission was to place a man in orbit under conditions that would permit him to function effectively, and return him safely to earth. With Project Mercury, space medicine as a scientific discipline extended its range of competence from the theoretical aspects of research and development to become a clinical entity as well.

The second major manned space program was Gemini, the interim follow-on program between Mercury and Apollo, designed to subject two men and necessary equipment to long duration flights up to 14 days. This would also include subjecting man to the stresses of extra-vehicular activity.

The major medical objectives of both Mercury and Gemini were (1) the accumulation of experience about the effects of weightlessness and the physiological reactions of crew members during long duration missions, and, (2) the compilation of medical data necessary for planning later missions and programs. The Gemini spacecraft was, in many ways, a two-man orbiting laboratory by means of which knowledge and experience regarding the space evnironment would be increased by several orders of magnitude.

The third planned project in manned space flight is Apollo, which has the objective of a lunar landing, exploration, and return to earth. Using a three-man crew, the manned missions of this project will follow the Gemini series, now concluded.

All these programs, however, are rooted in the original R and D program which, through the decade of '50s, involved theoretical considerations and ground-based laboratory experiments.

PHYSIOLOGICAL CONSIDERATIONS OF MAN IN SPACE

Space-oriented activities during the International and Geophysical Year (1957-1959) had demonstrated to the international scientific community that there is no clearly defined point at which the earth's atmosphere ends and space begins. The aeromedical community, however, had already determined that from the point of view of the human organism this dividing line is generally about 43,000 feet. Moreover, insofar as the specific physiological functions of man are concerned, it had been theorized that the actual line of demarcation occurs at different altitudes for each different function. This interacting relationship between man's physiological functions and the space environment has been described as the Space Equivalents or the Functional Border of Space.

The dynamics of physiological functions in the atmosphere have been a continuing concern of aviation medicine since man first became airborne; they became a matter of critical concern as he flew at increasingly faster speeds and higher altitudes--indeed, to the threshold of space. Thus, medical scientists, even before the space age which began with launching a Sputnik in 1957, had already anticipated the physiological problems that man would encounter in space. Certain problems had been identified and categorized in part on the basis of ground-based research and clinical observation of known influences of gravity on various body systems, and in part because of the known effects of disease phenomena. Actual space flight experience would shortly provide ever-increasing knowledge in all areas of medical concern.

Space medicine became a clinical entity at the point in Project Mercury when physical standards were established for selection of the first astronauts.

MEDICAL STANDARDS AND SELECTION OF ASTRONAUTS

The first astronauts selected were volunteers from the group of military test pilots then on active duty. Not only were they a highly select group in the medical sense, but also a homogeneous group in terms of experience and motivation.

There were two phases in the selection process. The first was primarily non-medical. Records of all military test pilots were reviewed and screened in terms of such basic criteria as graduation from a test pilot school, a minimum of 1,500 flying hours, qualification in high performance jet aircraft, age not to exceed 39 years, and height not in excess of 71 inches. Prospective candidates were reduced in number to 69. That group was called to Washington, D.C., interviewed, briefed on the technical details of the project, and given the opportunity to volunteer or decline service.

Medical records of those who volunteered were reviewed again, in greater detail, and both a psychiatric and a psychological examination given to each individual.

Thirty-two were selected for the second phase of the selection process. This consisted of intensive medical examinations at the Lovelace Clinic in Albuquerque, New Mexico, and psychological and stress testing at the Aerospace Medical Laboratory at Wight-Patterson Air Force Base. Thirty-one of the volunteers completed the series.

The medical examination at the Lovelace Clinic included the recording of detailed medical and aviation histories. In addition to the conventional medical and family history, this included

investigation into the attitude of the immediate family toward hazardous flying; the candidate's growth, development, and education; travel in areas where parasitic diseases are endemic; and tendency to disorders precluding pressure inflation of the sinuses, lungs, or ears. The aviation history included information about total flying hours, war and peacetime military experiences, and operational experience with pressure suits.

The physical examination was conducted by flight surgeons, internists, and appropriate specialists, including an ophthalmologist, otolaryngologist, neurologist, cardiologist, and others as necessary. Laboratory tests conducted during the course of the examination included tests for:

Hemoglobin, gm/100 ml
Total circ. hemoglobin, gm
Leukocytes, 1,000/mm^3
Sedimentation rate, mm/hr
Cholesterol, mg/ml
Sodium, meq/l
Potassium, meq/l
Chlorine, meq/l
Carbon dioxide, meq/l
Sugar, mg/100 ml
Protein bound iodine, ugm/100 ml
Bromsulphalein, % retention (45 min)
17-ketogenic steriods, mg/24 hr
17-ketosteroids, mg/24 hr

Roentgenograms were made of the teeth, sinuses, thorax, esophagus, stomach, colon and lumboscacral spine. Cineradiograms were made of the heart.

To estimate the candidate's general condition, physical competence measurements were made, including various vital capacity tests and a bicycle ergometer test under electrocardiograph monitoring. Pertinent physiological data recorded included:

Height, cm
Weight, kg
Body surface area, m^2
Lean body mass, kg
Total body potassium, gm
Total body water, liters
Blood volume, liters
Total circ. hemoglobin, gm
Total lung capacity, liters
Functional residual capacity, liters
Vital capacity, liters
Residual volume, liters
Maximum breathing capacity, liters
Nitrogen clearance equivalent
Final O_2 uptake during exercise, l/min

At the Aerospace Medical Laboratory at Wright-Patterson Air Force Base, Ohio, psychological tests were administered to determine personality and motivation as well as intelligence and special aptitudes. A variety of standardized tests were used in both instances. In addition to such standard items as the Rorschach and Thematic Apperception Test, the personality-motivation series also included the Officer Effectiveness Inventory. The intelligence-special aptitudes group included the Air Force Qualification Test and the Navy's Aviation Qualification Test. Also included were the Wechsler Adult Scale and a variety of analogies, comprehension, and spatial orientation tests.

The astronaut candidates were subjected to a large number of stress tests of both a psychological and physiological nature. These included the Harvard Step Test, a treadmill workload test, tilt table test, and a cold pressor test. Other stresses to which the candidates were exposed were noise, vibration, acceleration, isolation (3 hours in a dark sound-proof room), a simulated altitude of 65,000 feet in a MC-1 partial pressure suit, and a complex behavior simulator.

Final evaluation of the candidates was made jointly by representatives of NASA, Aerospace Medical Laboratory, and the Lovelace Clinic.

Seven astronauts were chosen.

In the subsequent Gemini and Apollo selection programs, astronaut selection standards have varied little, except that the requirement that the candidate be a test pilot and qualified in high performance aircraft has been eliminated. Looking to the future, there has been a requirement for scientist-astronauts, including those with medical skills.

Medical examinations for all astronaut candidates following the first group have been given at the U.S. Air Force School of Aerospace Medicine at Brooks Air Force Base, Texas. Stress testing at the Aerospace Medical Laboratory has been eliminated.

The individual astronaut is responsible for maintaining a physical fitness program to suit his own individual needs and preference.

MEDICAL SUPPORT OPERATIONS IN SPACE FLIGHT

The mission operations team for manned space flight must include professional medical competence as well as engineering skills. Medical support is planned on a global basis for three basic situations:

(1) Rapid crew egress and launch-complex rescue during the late countdown and early phases of powered flight.

(2) Short-time recovery throughout all phases of powered flight and landing at the end of each orbital pass.

(3) Some capability in support of an unplanned landing along the orbital track.

Development of mission rules to aid in flight control has been necessary for medical support as well as other operational areas. Range simulations together with actual flight experience have aided in developing mission rules.

Medical support is a part of every operational phase: launch, inflight monitoring recovery, advanced land units,andpost flight operations.

Mission Control Room. The vital nerve center for all operations is the Mission Control Room at the Manned Spacecraft Center, Clearlake, Texas,near Houston.

The Director of Medical Operations, on the basis of global data continuously being fed into the computer console, must be ready at all times to provide a decision as to whether from a physiological point of view the individual astronaut, or crew members, can continue a mission.

As experience increased, the initial rigid medical mission rules were eased so that the evaluation and judgment of the medical flight controlling became the prime determinants in making a decision. The condition of the astronaut as determined by voice and interrogation, rather than physical parameters alone, became a key factor in the medical advice to continue or terminate the mission.

Information upon which these judgments are made is based on a variety of sources, beginning with that available in the medical facility near the launch site at Cape Kennedy where the astronauts will have received their pre-flight medical examination.

Launch Site. At Cape Kennedy, Florida, support is provided by a joint team consisting of a flight surgeon, and scuba-equipped pararescue personnel airborne in a helicopter. Medical technicians capable of rendering first-aid care are also available in LARC vehicles and in small water jet boats. A surgeon and an anesthesiologist with their supporting personnel are stationed in a blockhouse at Cape Kennedy to serve as the echelon of resuscitative medical care in the event of an emergency.

In addition, there was originally a medical-specialty team consisting of a general surgeon, an anesthesiologist, surgical technicians and nurses, a thoracic surgeon, orthopedic surgeon, neurosurgeon, internist, radiologist, pathologist, urologist, plastic surgeon, and supporting technicians. In the early missions, these individuals were deployed to Cape Kennedy and were available should the need arise for their use either at the Cape or in the recovery area, to which they could be dispatched by aircraft. On the last two Mercury missions, a team was

activated at Tripler Army Hospital, Hawaii, to cover the Pacific area as well.

As it became obvious that there were large numbers of highly trained physicians merely waiting out the mission in a deployed state with an unlikely probability that they would be utilized, it was decided that specialty teams could be maintained on standby at state-side hospitals and easily flown either to the Cape or recovery site. In later missions, the astronaut has been returned to medical specialty facilities.

In the past much of the medical assistance for manned space flight has come from the military medical services, but NASA is increasingly developing its inhouse capability. Support, in the form of medical specialty teams, however, continues to be provided by the Wilford Hall USAF Hospital, Lackland AFB, Texas; the U.S. Navy Hospital, Portsmouth, Virginia; the Walter Reed Army Hospital, Washington, D.C.; and the Tripler General Hospital, Honolulu.

Recovery. It is essential that the medical capability for a manned space flight mission provide for any circumstances under which recovery can occur. Original plans were necessarily geared to the most catastrophic contingencies possible.

Medical recovery operations must meet two basic requirements:

(1) The capability of providing prompt, optimum medical care for the astronaut, if necessary, upon his retrieval from the spacecraft.

(2) Provision for early medical evaluation of the astronaut's postflight condition.

The extent of medical care which can be effectively administered to the astronaut during the recovery operation obviously is governed to a large degree by the physical circumstances under which recovery

occurs. The level of medical support at the different recovery areas likewise varies according to the degree of competent medical treatment that can be administered in that area. The most extensive medical support is concentrated in those areas where descent to earth by the astronaut is most probable.

Physicians are stationed throughout the recovery areas aboard destroyers and aircraft carriers in the Atlantic and Pacific. In the early missions each vessel was assigned a surgeon, anesthesiologist, and a medical technician team with care supporting medical equipment chest necessary for evaluation and medical or surgical care. As operational experience was gained, the number and distribution of medical personnel were modified.

Medical Monitoring. Aeromedical monitors are assigned to the tracking stations of the global network to observe the physiological condition of the astronaut crew during flight. For the safety and welfare of the astronaut in training and in flight is always a paramount concern.

Continuous inflight monitoring of pilot physiological data by instrumentation is, however, a relatively recent concept. In the early phase of Project Mercury, there were no readily available techniques for reliably measuring physiological parameters for prolonged flight. But as a safety measure, body temperature, chest movement, and heart action were monitored by use of sensors. Standards established for this monitoring required that the sensors and equipment be comfortable, reliable, compatible with other spacecraft systems, and not interfere with the astronauts' primary mission.

Body temperature was monitored in the Mercury missions with a rectal thermistor,a procedure later modified to use an oral thermistor instead. The range of the thermistor was also changed, so that when it was in the stowed position on the right ear muff it would record suit outlet temperature.

Initially, respiration was measured by an indirect method using a linear potentiometer and carbon-impregnated rubber. This method was soon changed to a thermistor kept at 200°F and placed on the microphone pedestal in the helmet. Neither method provided reliable respiration traces during flight, and a change was made to the impedance pneumograph for the last two Mercury missions.

Electrocardiographic electrodes of a low impedance to match the spacecraft amplifier were required to record during body movements and to remain effective during flight durations of over 30 hours. The electrodes functioned well and provided information on cardiac rate and rhythm. The value of having two leads of electrocardiograph, even though they differed from the standard clinical leads, was repeatedly shown. This permitted easier determination of artifacts, and was helpful in determining the valid sounds of the blood-pressure trace by comparison with the remaining ECG lead. The electrode paste was changed from 30 percent calcium chloride in water mixed with bentonite to a combination of carboxy polymethylene in Ringer's solution. The ten times isotonic Ringer solution retained the necessary conductivity and low impedance required, and also afforded decreased skin irritation after prolonged contact.

Measurement of blood pressures in flight was initially delayed in Project Mercury because no satisfactory system was available. An automatic system using an unidirectional microphone and cuff was subsequently developed for use in the orbital flights. This system without the automatic feature was used on the first manned orbital mission. Because all of the inflight blood pressures obtained during the second manned orbital mission were elevated, an extensive postflight evaluation program was undertaken. It was concluded that these elevations were likely the result of instrumentation error, and careful attention was given to preflight calibration prior to the last two missions. Excellent blood-pressure tracings were obtained on both.

Voice transmissions are a valuable source of monitoring information. Normal flight reports and answers to queries have been used for evaluation of the pilot. In addition to normal reports, verification of actual comfort level has been valuable in determing the importance of temperature readings obtained by way of telemetry.

Inflight photography and television views of the astronaut have also been used as additional data sources. Unfortunately, in the early flights, these sources both proved to be of little value in the medical monitoring because of poor camera positioning and varying lighting conditions resulting from the operational situation.

INFLIGHT MEDICAL RESULTS

Prior to the first manned orbital flights, certain adverse effects of space flight on man were anticipated. Since weightlessness was the one unknown factor which could not be simulated in a laboratory situation on the ground, it was predicted that there would be some kind of effect on almost every body system. This conclusion was reached on the basis of known influences of gravity on certain body systems, on the knowledge of effects of disease phenomena, and in the context of available ground-based research and clinical observation. Vestibular and proprioceptive disturbances were anticipated not only on a theoretical basis, but also as a result of the reported appearance of symptoms in the case of Major Gheman Titov, the Russian Cosmonaut, during his 17.5 orbit flight in 1961. Since the cardiovascular system is markedly influenced by gravity, functional disturbances in the weightless condition were also expected. On the basis of ground-based research in sensory deprivation, there was some expectation of hallucinations. The possibility of impairment of crew performance due to disturbance of circadian rhythm was also considered. As it turned out, none of these were significant in either Mercury or Gemini. The actual experience gained in manned space flight did, however, make it possible to define physiological problem areas on a more realistic basis than had hitherto been possible.

One consideration, for example, was the need to assess the physiological responses of man in space flight when there are multiple stresses acting upon him, thus complicating the analysis of any given response. For he must undergo a number of stresses both in attaining, maintaining, and departing the orbital flight. These stresses may

include such factors as the full pressure suit, confinement and restraint, 100 percent oxygen and 5 psia atmosphere, changing cabin pressure (launch and reentry), varying cabin and suit temperature, acceleration g force, weightlessness, vibration, dehydration, flight-plan performance, sleep need, alertness need, changing illumination, and diminished food intake.

Actual experience in flight also emphasized the need for a detailed inflight event history because peak physiological responses are closely related to critical inflight events. The dynamics of this interelationship are well illustrated by the pulse responses during flight. Peak pulse rates during any launch phase has usually occurred at sustainer engine cut-off. This peak value in Mercury ranged from 96 to 162 beats per minute. Peak rates obtained on reentry have ranged from 104 to 184 beats per minute, and usually occurred either just after peak reentry acceleration, or on drogue parachute deployment. Pulse rates obtained during weightless flight varied from 50 to 60 beats per minute during the sleep periods to 80 to 100 beats per minute during normal wakeful periods. Elevated rates during weightless flight were usually related to flight-land activity. Respiratory rates ranged from 30 to 40 breaths per minute at sustainer engine cut-off, from 8 to 20 breaths per minute during weightless flight, and from 20 to 32 breaths per minute at reentry. Changes noted in electrocardiograms included alterations in the pacemaker activity with wandering pacemakers and aberrant rhythm including atrio-ventricular modal beats and rhythm, premature atrial and ventricular contractions, sinus bradycardia, atrial rhythm, and atrio-ventricular contraction. All these "abnormalities," it has been concluded, can be

considered normal physiological responses when related to the dynamic situation in which they were encountered.

In the course of the Mercury and Gemini flights considerable progress has been made in acquiring medical data and in understanding man's physiological and psychological reactions in the space environment. By the end of the Mercury program in May 1963, it had been demonstrated that man had shown himself able to live and work in a space environment through four days exposure so long as adequate life support was provided. It was also predicted that the changes in man would be gradual rather than catastrophic in nature.

The Gemini series included a 14-day mission together with additional flights which have included both rendezvous and extravehicular activity experience.

The accrual of experience from Mercury and Gemini is impressive. Nineteen men have been exposed to a total weightless experience of about 1900 man-hours. Three astronauts have flown both single and dual crew vehicles and four have flown twice in the Gemini vehicle. Comparison of data on the seven individuals twice exposed to space flight reveals that experience does alter some of the mental attitudes and performance, but it appears to have little effect on physiologic response. All this knowledge has added to man's assurance as he prepares for the next phase of manned space flight, the lunar landing, and return.

The inflight medical results of the manned space flight missions through Gemini are briefly summarized below.

Central Nervous System. Experience has been gained about crew performance, sleep patterns, visual acuity, and vestibular reactions within a weightless environment.

No psychological tests as distinct entities unrelated to actual inflight tasks were conducted. Rather, the evaluation of total performance provided the yardstick by which to measure the adequacy of the central nervous system functions. Crew performance has been excellent on every mission, including launch, rendezvous and docking, extravehicular activities, and the many accurate landings and recoveries. There has been no evidence, either during or postflight, of any psychological abnormalities.

The EEG was utilized to evaluate sleep during the 14-day mission. Interpretable EEG data were obtained for a total of 54 hours and 43 minutes. Variations in the depth of sleep from Stage 1 to the deep sleep of Stage 4 were noted in flight, thus validating ground-based data.

Numerous visual observations have been reported by the crews involving inflight sightings and descriptions of ground views. The actual determination of visual acuity has been made in flight as well as in pre- and postflight examinations. These tests all support the statement that vision is not adversely affected during weightless flight.

Despite conjecture about possible vestibular changes in a weightless environment, no evidence of altered vestibular function in flight has been observed. Pre- and postflight caloric vestibular function studies showed no change and special studies of the otolith response revealed no significant changes. (This is in contrast to data reported by the Russians.) There have been ample motions of the head in flight and during roll rates with the spacecraft but no vertigo or disorientation has been noted, even during the extravehicular activity, with occasional loss of all visual references. Several crewmen have reported a feeling experienced when one is turned upside down. This sensation may have resulted from altered distribution of blood in the weightless state.

This lack of inflight vestibular symptoms is interesting in view of the fact that a number of astronauts have developed motion sickness while in the spacecraft on the water.

Skin. Despite the moisture involved in space suit operations, the skin has remained in remarkably good condition through 14 days of space flight. There was drying of the skin noted in the immediate postflight period after the eight-day flight, but this was easily treated with lotion. There have been no infections. Only minimal reaction around the sensor sites was noted. The occasional problem of dandruff was easily controlled with pre- and postflight medication.

Eye, Ear, Nose, and Throat. Two inflight incidents of rather severe eye irritation have occurred. One was the result of exposure to lithium hydroxide in the suit circuit; the other has not been explained. In a few instances, a postflight conjunctival infection which lasted for only a few hours was noted. The latter condition was interpreted as being the result of the oxygen environment. Nasal stuffiness during the early portions of flight occurred, normally the first two or three days. This also was related to the 100% oxygen environment and usually was self-limited. On occasion the condition was treated locally or by oral medication.

The Respiratory System. Pre- and postflight X-rays failed to reveal any atelectasis. Pulmonary function studies before and after the 14-day mission revealed no alteration. Although no specific difficulties or symptomatology involving the respiratory system were evident, some rather high respiratory rates during heavy workloads in the extravehicular activity were present. Respiratory rates during

all the long-duration missions have tended to vary normally along with heart rate. Hyperventilation has not occurred in flight.

The Cardiovascular System. The cardiovascular system was the first of the major body systems to show physiologic change following flight. Peak heart rates have been observed at launch and at reentry, normally reaching higher levels during the reentry period. The mid-portions of all missions have been characterized by more stable heart rates at lower levels with adequate response to physical demands.

Electrocardiograms were studied in detail throughout all missions. The only abnormalities of note during the Gemini program were very rare premature, auricular and ventricular contractions. There were no significant changes in the duration of specific segments of the electrocardiogram.

The only truly remarkable observation in all blood pressure measurements to date has been the continuing normalcy without significant increase or decrease in prolonged space flight. Data obtained in the Gemini program showed that both systolic and diastolic values remained within the envelope of normality throughout 14 days of space flight.

Cardiac cycle data were derived through synchronous phonocardiographic and electrocardiographic monitoring. Wide functuations in the duration of the cardiac cycle, but within physiological limits, were observed throughout these missions. Fluctuations in the duration of electromechanical systole correlated closely with changes in heart rate. Stable values were observed for electromechanical delay (onset of QRS to onset of first heart sound) throughout the missions, with shorter values observed during the intervals of peak heart rates

recorded during liftoff, reentry, and during extravehicular activity. The higher values observed for the duration of systole and for electromechanical delay in certain astronauts suggests a preponderance of cholinergic influences (vagal tone). An increase in sympathetic tone (adrenergic reaction) was generally observed during liftoff, reentry, and in the few hours preceding reentry.

In Mercury, postflight tilt tests demonstrated the presence of moderate orthostatic hypotension, with far greater heart rates required to maintain effective cardiovascular function. Compensation was achieved, however, and the pilot did not develop even near-syncope. Contributing stress factors including heat stress, the effect of prolonged confinement, dehydration, fatigue, and a possible effect of weightlessness *per se* are thought to be the principal elements responsible for this change.

In contrast, orthostatism resulting from any Geminiflight has been detectable only by means of passive tilt table provocation. Tilt-table procedures were monitored with electronic equipment providing automatic monitoring of blood pressure, electrocardiogram, heart rate, and respiration. The procedure consisted of placing the crewman in a horizontal position for 5 minutes for stabilization, tilting to the 70° head-up position for 15 minutes, and then returning to the horizontal position for another 5 minutes.

In addition to the usual blood pressure and pulse rate determinations at minute intervals, mercury strain gages were used in some instances to measure changes in the circumference of the calf.

On the 4-day, 8-day, and 14-day missions no symptoms of faintness were experienced by the crew at any time during the landing sequence or during the postlanding operation. There has been no increase in the

time necessary to return to the normal preflight tilt response, a 50-hour period, regardless of the duration of the flight. The strain-gage data generally confirm pooling of blood in the lower extremities during the period of roughly 50 hours required to readjust to the 1-g environment.

Blood Volume. On each of the long-duration flights, plasma volume was determined by a technique utilizing radio-iodinated serum albumin. On the 4-day mission, red-cell mass was calculated by utilizing the hematocrit determination. Analysis of the data caused some concern as to the validity of the hematocrit in view of the dehydration noted. The 4-day mission data showed a 7 and 15 percent decrease in the circulating blood volume for the two crewmembers, a 13 percent decrease in plasma volume, and an indication of a 12 and 13 percent decrease in red-cell mass, although it had not been directly measured. As a result of these findings, red cells were tagged with chromium 51 on the 8-day mission in order to obtain an accurate measurement of red-cell mass while continuing to utilize the radio-iodinated serum albumin technique for plasma volume. The chromium-tagged red cells also provided a measure of red-cell survival time. At the completion of the 8-day mission, there was a 13-percent decrease in blood volume, a 4 to 8 percent decrease in plasma volume, and a 20 percent decrese in red-cell mass. These findings pointed to the possibility that the red-cell mass decrease might be incremental with the duration of exposure of the space flight environment.

The 14-day flight results showed no change in the blood volume, a 4 and 15 percent increase in plasma volume, and a 7 and 19 percent decrease in red-cell mass for the two crewmembers. In addition, the red-cell survival time has been reduced. It can, therefore, be concluded that the decrease in red-cell mass is not incremental with increased exposure to the space flight environment. On the 14-day flight, the total blood volume was maintained by increasing plasma volume. Weight loss indicated nevertheless that some fluid loss had occurred in the extracellular compartment even though the loss had been replaced by fluid intake after the flight. The loss of red cells in flight has not interfered with normal function and is generally equivalent to the blood withdrawn in a blood-bank donation, although in the former instance the decrease occurs over a longer period of time, thus allowing for adjustment.

The detailed explanation of the decreased mass is unknown at the present time, although several factors may underlie the red cell destruction. The variables which must be considered as possible causative factors are hyperoxia (i.e., 166 mm O_2 at the alveolar membrane), lack of inert diluent gas (i.e., nitrogen), relative immobility of the crew, dietary factors and weightlessness. Of the factors stated, only increased oxygen tension, immobility, and dietary factors are well known to influence the erythron. Dietary considerations may be of considerable importance, but no indefinite incriminations can be levied against the flight diet at this point. Immobility is effective in reducing cell mass by curtailing erythrocyte production; however, all flight observations support hemolysis as the significant event. Although not demonstrated by any previous studies, it is possible that weightlessness is a contributing factor in the hemolysis

observed. Altered hemodynamics, resulting in hemostasis, could inflict a pre-lytic lesion on the erythrocytes involved and thereby result in the cell's premature demise. The role of a diluent gas (nitrogen) is not well understood; however, there has been shown a significant reduction in hematologic and neurologic toxicity in animals exposed to high pO_2 when an "inert" gas is present. The absence of an "inert" atmospheric diluent could, therefore, be significant at the hyperoxic levels encountered within the Gemini spacecraft. Of all the mechanisms stated, however, oxygen has the greatest proven potential as a hemolytic agent. It has several demonstrated deleterious effects on red cell plasma membranes and metabolic functions, any combination of which could be operative within a Gemini spacecraft.

Biochemical. Analysis of urine and plasma has provided an indication of astronaut physiological status preflight, during flight, and postflight. Analyses of the results obtained on all three phases were performed on the 14-day Gemini 7 flight. As expected, since a prime function of the hemoeostatic mechanisms of the body is to maintain the composition of blood and extracellular fluid as nearly constant as possible, significant changes in plasma were not observed. Pooled samples of flight urine indicated a slight reduction in the output of sodium during flight. This was associated with some increase in aldosterone excretion. Postflight, there was a marked retention of sodium. Chloride excretion parallels the sodium excretion, and potassium excretion during flight appeared depressed and in all but one stance was depressed immediately postflight. This depression was observed both in total 24-hour output and in minute output. The anti-diuretic hormone appeared elevated in

only the first postflight sample of the Gemini 7 pilot.

Calcium, magnesium, phosphate, and hydroxproline were measured in plasma, and in urine obtained preflight, inflight, and postflight as a continuing evaluation of the effects of space flight on bone demineralization. Postflight plasma samples following the 14-day flight showed a marked increase in the bound hydroxyproline, while larger quantities of calcium were excreted later in the flight than during the early phases of the flight, findings consistent with a change in bone structure.

Gastrointestinal System. The design and fabrication of foods for consumption during space flights imposed unique technological considerations. The volume of space food per man-day varied in the Gemini mission from 130 to 162 cubic inches (2131 cc to 2656 cc). Menus consisted of approximately 50 to 60 percent rehydratables (foods requiring the addition of water prior to ingestion). This required food packaging to permit both a method for rehydration and dispensing food in zero G. The remaining foods were bite-size. About 50 percent of both the rehydratable and bite-size foods were freeze-dried products; the remaining were other types of dried or low moisture foods, some of which were compressed.A typical menu had an approximate calorie distribution of 17 percent protein, 32 percent fat, and 51 percent carbohydrate. Total calories provided and eaten per day varied from flight to flight. Although weight loss occurred on all missions, the rate of loss did not increase with mission duration.

Gastrointestinal tract function on all missions was normal. There is no evidence that there was excess nutrient losses because of poor

food digestibility during flight. Before the missions, the crew ate a low residue diet, and, in addition, on all flights beginning with the Gemini 5 mission, oral and suppository dulcolax (bis - (p-acetoxphenl) - 2 - pyridylmethane) for the last two days before flight were utilized. On the shorter EVA missions the crew preparation generally allowed them to avoid defecation in flight.

Genito-Urinary System. No difficulties were encountered in any of the missions. Urination occurred normally both inflight and post-flight, and there was no evidence of renal calculi.

Musculo-Skeletal System. Information on bone and muscle metabolism as affected by space flight is limited to a very few subjects under varying dietary intakes and multiple flight stresses.

Bone demineralization (percent change in density) which occurred in the oscalcis and phalanx 5-2 during the 14-day flight and under equivalent periods of bed rest with analyagous intake of calcium was definitely less in the 14-day flight, where calcium intake approached 1000 mgs per day and the crew routinely exercised. In all instances the data for the bones examined indicate a negative change and the calcium balance data collected on Gemini 7 verify a negative balance tend. While none of the changes are pathological, there is indication that ameliorative methods for use during longer duration flights need to be examined.

It is interesting to note the differences in bone mass change occurring in the several flights. It is probable that the superior findings in the oscalcis during the 14-day Gemini 7 flight could be attributed to a number of factors. The crewmembers of this mission ate a higher proportion of the diet prepared for them than did those of Gemini 4 and particularly of Gemini 5. Also the crew had isometric

and isotomic exercise for prespecified periods of time daily; they used an exerciser routinely, and the crewmen slept for longer periods of time.

Medication. The basic policy regarding medication is that drugs are to be used only if necessary. A list of the drugs supplied routinely is shown in the attached table which includes both injectable and tablet forms. The injectors may be used through the suit, although to date none have been utilized. Varying drugs have been used for symptomatic treatment of minor complaints. The only significant medication used thus far was that of the Gemini 4 crew who used dexedrine to insure an adequate state of alertness during the critical mission period.

Despite the minimal use of medications, it is recognized that they must be available on long-duration missions, and that each crewmember must be pretested to any drug which may potentially be used. Such pretesting of all of the medications in the attached list was carried out with each of the crew who have thus far participated in space flights.

(a) MEDICAL KIT

Medication	Dose and Form	Label	Quantity
Cyclizine H Cl.....	50-mg tablets	Motion sickness	8
d-Amphetamine sulfate.....	5-mg tablets	Stimulant	8
APC (aspirin, phenacetin, and caffeine)	Tablets	APC	16
Meperidine H Cl.....	100-mg tablets	Pain	4
Triprolidine H Cl.....	2.5-mg tablets	Decongestant	16
Pseudoephedrine H Cl.....	60-mg tablets		
Diphenoxylate H Cl.....	2.5-mg tablets	Diarrhea	16
Atropine sulfate.....	0.25-mg tablets		
Tetracycline H Cl.....	250-mg film-coated tablet	Antibotic	16
Methylcellulose solution.....	15-cc in squeeze-dropper bottle	Eyedrops	1
Parenteral cyclizine.....	45-mg (0.9-cc in injector)	Motion sickness	2
Parenteral meperine H Cl.....	90-mg (0.9-cc in injector)	Pain	2

(b) ACCESSORY KIT

Item	Quantity
Skin cream (15-cc squeeze bottle).....	2
Electrode paste (15-cc squeeze bottle.....	1
Adhesive disks for sensors.....	12 for EKG, 3 for phonocardiogram leads
Adhesive tape.....	20 inches

CONCLUSION

The medical results of the United States' manned space flight efforts thus far have been gratifying not only in terms of new knowledge acquired but also in terms of the confidence this knowledge has provided for the role of man in Apollo and future space exploration programs.

Crewmembers experienced no disorientation on any Mercury or Gemini mission. They adjusted easily to the weightless environment and accepted readily the fact that objects will either stay in position in midair or will float. They had no difficulty in reaching various switches or other items in the spacecraft. The crewmen moved their heads at will and noticed no aberrant sensations. They were always oriented to the interior of the spacecraft and could orient themselves with relationship to the earth by rolling the spacecraft and finding the horizon through the window. During the extravehicular operations, the pilot oriented himself by his relationship to the spacecraft during all of the maneuvers. Looking repeatedly at the sky and the earth, he had no sensations of disorientation or motion sickness at any time. The venting of hydrogen on the 8-day flight created some roll rates of the spacecraft that became of such magnitude that the crew preferred to cover the windows to stop the visual irritation of the rolling horizon, thus allowing them to wait for a longer period of time before damping the rates with thruster activity. During the 14-day flight, the crew repeatedly moved their heads in various directions in order to try to create disorientation but to no avail. They also had tumble rates of 7° to 8° per second created by venting from the water boiler, and one time they performed a spin-dry maneuver to empty the water boiler. This created roll rates of 10° per second. On both occasions they moved their heads freely and had no sensation of disorientation.

The crews of all three long-duration missions have noted an increased g-sensitivity at the time of retrofire and reentry. All felt that they were experiencing several g when the g-meter was just beginning to register at reentry. When the peak g-load was reached, however, their sensations did not differ from their centrifuge experience.

The crews described a sensation of fullness in the head that occurred during the first 24 hours of the mission and then gradually disappeared. This feeling was similar to the increase of blood a person notes when hanging on parallel bars or when standing on his head. There was no pulsatile sensation in the head and no obvious reddening of the skin. The exact cause of this condition is unknown, but it may be related to an increase of blood in the chest area as a result of the readjustment of the circulation to the weightless state.

One area of concern prior to long flight missions has been whether or not the crewmembers could get along with one another over an extended period. Every effort was made to choose crewmembers who were compatible, but it is truly remarkable that none of the crews, including the long-duration crews, had any inflight psychological difficulties that were evident to the ground monitors or that were discussed in postflight debriefings. They had some normal concerns for the inherent risks of space flight. There was some normal increased tension at lift-off and also prior to retrorocket firing, and a normal psychological letdown when the Gemini 7 crew saw the Gemini 6A spacecraft depart after their rendezvous. But the Gemini 7 crew accepted this very well and immediately adjusted to the flight-plan activity.

The long-duration flights confirmed previous observations that the flight crews are exposed to very low radiation dose levels at orbital altitudes. The body dosimeters on these missions have recorded only

millard doses which were at an insignificant level.

Finally, it can be stated from the medical point of view that all crewmen performed in an outstanding manner, adjusted both psycholgically and physiologically to the zero-g environment, and then readjusted to a 1-g environment with no undue symptomatology being noted.

The experience gained through the 14-day Gemini 7 mission provides great confidence in any crewman's ability to complete an 8-day lunar mission without any unforeseen psychological or physiological change. It also appears that man's responses can be projected into the future to allow 30-day exposures in larger spacecraft. The predictions thus far have been valid. The outlook for the future is extremely optimistic. Man has shown his capability to fulfill a role as a vital, functional part of the spacecraft as he explores the universe.