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Physical Examination During Space Flight

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• *Objective*: To develop techniques for conducting a physical examination in microgravity and to describe and document the physiologic changes noted with use of a modified basic physical examination.

• *Design*: On the basis of data gathered from physical examinations on KC-135 flights, three physical variables were assessed serially in astronauts during two shuttle missions (of 8- and 10-day duration, respectively). Preflight, in-flight, and postflight examinations were conducted by trained physician-astronauts or flight surgeons, who used this modified examination.

• *Material and Methods*: Five male and two female crewmembers participated in the "hands-on" physical examination of all physiologic systems except the genitourinary system. Level of edema, intensity of bowel sounds, and peripheral reflexes were assessed and graded.

• *Results*: This investigation identified unique elements of a physical examination performed during space flight that will assist in the development of standard methods for conducting examinations of astronauts in weightlessness. In addition, demonstrable changes induced by microgravity were noted in most physiologic systems examined.

• *Conclusion*: The data support the hypothesis that the microgravity examination differs from that conducted on earth or in a 1*g* environment. In addition, alterations in the physiologic response can be detected with use of a hands-on technique. These data are invaluable in the development of optimal medical care for humans in space.

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MET = microgravity examination technique; NASA = National Aeronautics and Space Administration

The practice of medicine in space is an interesting and demanding challenge. During the past 30 years of space flight, many biomedical problems have been described and documented. These studies have shown that many changes will occur as humans spend more time in the microgravity environment.[1] These changes are both time and system specific, affecting different physiologic systems to various degrees. As the space program evolves to missions with longer durations, adaptations in the "normal" physiologic status will become more apparent. Anecdotal information from physician-astronauts who have flown in space suggests that documenting these normal changes will allow space clinicians to become familiar with the inherent differences in the actual examination techniques needed to distinguish pathologic processes from normal adaptation to space. These normal changes must be understood by the physician-astronauts, flight surgeons, and others who assume the responsibility of providing health care. If the field of space medicine is to develop clinically, this understanding is paramount. As part of this overall effort, advancements in our understanding of human adaptation to the microgravity environment will necessitate development of new therapeutic modalities and procedures not dependent on gravity.

From data obtained anecdotally and from in-flight experience with normal physiologic responses to microgravity, a phased study was designed to gain further insight into the clinical practice of space medicine. How will pathologic processes be manifested in such environments, and what are the differences in the physical findings in microgravity in comparison with those observed in astronauts before and after flight? Space clinicians recognized that the techniques of conducting a fundamental physical examination might

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need substantial modification because of the effects of microgravity. Therefore, examination techniques as well as physiologic differences among preflight, in-flight, and postflight data needed to be assessed, recorded, and analyzed. Previously, studies have not addressed the microgravity effects on the body as measured by the physical examination.

BACKGROUND AND SIGNIFICANCE

The medical history and physical examination are the foundation of all traditional medical care. Throughout the years of microgravity research, general physiologic information has been relayed by "word of mouth" or anecdotal accounts. Astronauts and physician-astronauts have noted changes caused by microgravity that generally have been accepted as normal during space flight. For example, edema exhibited by facial puffiness and nasal congestion was readily felt by the astronauts as facial discomfort and evidenced as swollen eyes and face. In addition, "gastroparesis" has been noted as loss of appetite by crewmembers early in flight and, subsequently, has been documented by physicians who listened for bowel sounds. Likewise, changes in normal body position were described by crewmembers as a "flexed" posture during flight.[1,2] Nonetheless, few of these findings have been scientifically documented or studied.

Some investigators have focused on subspecialty areas of study of the effects of microgravity on specific organ systems (cardiovascular, musculoskeletal, and neurosensory) with use of diagnostic equipment such as the echocardiogram.[1-13] Increases in heart rate, decreases in cardiac size, and increases in stroke volume within the first 24 hours that later decreased to a steady state have been noted, as have fluid shifts or redistribution, as measured by total body water, and changes in plasma and urine volumes related to these alterations.[2,3] In addition, alterations have been observed in the musculoskeletal system—most notably, muscle atrophy, loss of strength, and "thinning" of the lower extremities.[2,3] Studies have found that most systems reach a new steady state compatible with normal function in the space environment within 4 to 6 weeks.[2] In space, however, what is the normal state? How does the duration of stay affect this new steady state? What is the normal physiologic response for human beings in microgravity? These findings and questions underscore the need to determine an effective and efficient method for distinguishing normal adaptations from disease states. A review of the literature identified only a few missions (United States and Russian) that assessed the complete human system response to microgravity by using a comprehensive physical examination during space flight.[1-13]

The purpose of this article is to report on the development of a physical examination for use in microgravity and the preliminary data obtained with use of this modified examination. One goal was to develop an adapted physical examination procedure that is reliable and will accurately docu[ment] physiologic responses to microgravity. A modified physical examination was developed by using anecdotal information from crewmembers about the handling and stabilization of objects and people during space flight. The normal process of physiologic adaptation to microgravity results in quantifiable changes in physiologic responses when compared with those observed during a 1g examination. The rationale underlying the modified physical examination technique—called the microgravity examination technique (MET)—is that the use of a standardized physical examination or "hands-on" examination can provide an excellent means of collecting noninvasive data. This method is essential for accumulation of comparable data over multiple missions, across multiple subjects, and by numerous practitioners. Knowledge of the range of normal physiologic responses to microgravity and the time course of their development is crucial if future in-flight physicians are to make accurate diagnoses, and recorded data will be reliable only if valid examination techniques are used.

Thus, the long-term goals are to collect general and targeted physical examination data by using the MET and to assess the feasibility, accuracy, and validity of this modified technique. The results from this study will contribute to (1) the development of modified standardized techniques for conducting a physical examination in space; (2) a reco[rde]d description of the normal physiologic changes of the hu[ma]n body as a result of exposure to microgravity; and (3) assessment of baseline techniques for conducting the microgravity examination. In time, the MET may be the standard approach to clinical assessment of space travelers.

METHODS

Study Design.—The current study was designed as a phased development, evaluation, and validation of the MET. The phases include (1) development and verification, (2) assessment of general and targeted physical variables, and (3) longitudinal in-flight data collection with use of the MET for assessment. Herein we present a description of the MET development, verification procedures, and preliminary assessment data comparing microgravity (in-flight) and 1g (preflight and postflight) responses of the human body.

Development of the MET.—In the first phase, we used specified elements of the basic physical examination technique to develop microgravity techniques and determine the feasibility of obtaining reliable and valid medical data. The standard terrestrial physical examination was modified for collecting data and evaluating the technique. The initial MET was based on information gathered from previous inflight medical experience and anecdotal reports. Initially, six variables were selected and assessed as benchmarks for the study: skin edema, lung sounds, location of diaph[ragm], heart sounds, bowel sounds, and reflexes. These variables were chosen because they address the physiologic changes of interest and can be reproducibly and efficiently observed. Moreover, they allow the skills of inspection—palpation, percussion, and auscultation—to be used by the examiners. A panel of three physicians (National Aeronautics and Space Administration [NASA] physician-astronauts and flight surgeons) reached a consensus on the proposed examination modifications based on the appropriate changes, feasibility, and validity. A handbook was written as a guide for training and conducting the physical examinations, which served as the basis for the in-flight examination.[14]

Preliminary investigations were conducted on the KC-135 (an airplane capable of achieving microgravity for 20- to 30-second intervals through parabolic flight) to identify and refine techniques used for conducting the physical examination in space. Elements of the basic physical examination were used to determine the feasibility of obtaining reliable and valid medical data. On the basis of lessons learned during the KC-135 flights, the examination technique was modified and then used during two space flights (of 8- and 10-day duration, respectively) as part of a continuous evaluation of its feasibility, accuracy, and validity. As part of the ongoing study, additional modifications will be incorporated into the physical examination protocol.

Implementation of the Modified Examination for Data Collection.—After the content validity and the flight testing of the modified examination, all involved NASA physician-astronauts and flight surgeons participated in a review of the standard physical examination and the modified physical examination, highlighting the targeted variables to promote a uniform application of diagnostic techniques. This review process ensured that all techniques for the physical examination and data collection will be performed in a standardized fashion and will be repeated before each future mission. Standard examination equipment and the examination handbook were used to ensure that all physicians receive the same training.

Actual assessment of interrater reliability (the extent to which a clinician agrees with other raters in the assessment of the target physical variables) must be conducted on those evaluations collected with use of the MET. Obviously, the presence of only one examiner per mission and different examiners across missions poses certain problems in addressing interrater reliability issues. Two alternative approaches will be used when possible. The assessment by individual examiners will be compared with available objective telemetry data to establish agreement between subjective and objective assessment—that is, individual reliability. In addition, comparisons across time (and examiners) will establish the reliability of the phenomena being assessed. If individual examiners concur at significant levels with the objective "gold standard" of telemetry ($r = 0.80$) across time as well as report similar findings, both results would signify a sufficiently reliable application of the MET for various examiners and repeated missions.

Data gathered from the ground-based and KC-135 flight examinations resulted in three of the six original variables of the MET being selected for final assessment and grading (Table 1) during space flight: level of edema, intensity of bowel sounds, and peripheral reflexes. These are the variables in which changes during flight are most consistently reported. Targeting these elements allowed a more standardized assessment and may facilitate a higher interrater reliability.

Level of Edema.—The skin and mucosal membranes provide a good avenue for assessment of the level of edema (fluid in the tissues).

Intensity of Bowel Sounds.—Gastric motility was assessed indirectly by documenting the intensity of bowel sounds. Each quadrant of the subject's abdomen was examined by using auscultation with a standard double-bell stethoscope. The bowel sounds were measured and documented during various phases of flight.

Neuromuscular Reflexes.—Another component of the MET was the assessment of lower motor neuron reactivity to standard clinical tendon taps. Responses of subjects to taps of the biceps brachia, patellar, and Achilles tendons were documented.

Assessment of General and Targeted Physical Variables With the MET in Flight. **Study Subjects.**—Participants were seven astronauts (five men and two women) assigned

Table 1.—Grading Scales for Measurement of Various Physical Findings in Space

Grade	Edema	Bowel sounds	Peripheral reflexes
0	Absent; no pitting	Absent	Absent
1	Normal contour	Hypoactive	Diminished
2	Fairly normal contour, slight pitting	Normal	Normal
3	Obvious swelling and persistent pitting	Increased	Brisker than normal
4	Grossly abnormal	Hyperactive	Notably hyperactive in conjunction with clonus

to shuttle flights. All subjects were healthy men and women who had been medically screened and certified for flight by the Flight Medicine Clinic at the NASA Lyndon B. Johnson Space Center. All data were coded to protect the subjects' identities.

Procedures.—Subjects were examined by using a standardized study protocol to evaluate the effects of weightlessness. A complete examination was conducted on all major physiologic systems (head, eyes, ears, nose, and throat; respiratory; cardiovascular; gastrointestinal; musculoskeletal; skin; and neurologic) except for the genitourinary system; no rectal examination was performed, and mental and psychologic status was not determined. Examinations with use of the MET were conducted during the preflight period (10 days and 2 days before launch), in flight—every other day—on alternating crew, on landing, and during the postflight period (days 1, 3, and 4 after return to earth). The preflight and postflight evaluations coincided with scheduled examinations by flight surgeons and baseline data collection. The examinations were conducted by the physician-astronauts and flight surgeons at the NASA Lyndon B. Johnson Space Center, on board the space shuttle, at the NASA John F. Kennedy Space Center, and at the NASA facility at Edwards Air Force Base.

A physician-astronaut conducted the in-orbit physical examinations on cohort crewmembers in accordance with the mission schedule and completed a standardized physical examination form based on the MET. The preflight and postflight examinations also were conducted by the physician-astronaut or flight surgeons, who used the MET. The physician-astronauts and flight surgeons documented the physical findings, described the modifications in the physical examination technique in comparison with the 1*g* examination, and recorded results on the physical examination form provided.

Equipment.—A penlight, sphygmomanometer, ophthalmoscope, otoscope with disposable earpieces, tuning fork, disposable tongue blades, stethoscope, neurologic pinwheel, cotton, reflex hammer, and appropriate restraints were used to conduct the examination.

Data Collection and Analysis.—This study was limited to a hands-on examination only—that is, no invasive diagnostic techniques were used. Technique descriptions (emphasizing the modifications) were collated to develop physical examination techniques for use in space. The graded target variables were compared with diagnostic measures for validation. Reporting forms used to collect data on all physical variables were retrieved from the physician-astronaut after orbiter landing and were transported to the Lyndon B. Johnson Space Center for analysis. The astronauts served as their own control subjects. Data were coded and entered into a computer database for analysis. Comparisons were made among the preflight, in-flight, and postflight profiles and examinations, on a system-by-system basis. The data were examined for mean values, for time trends over the course of the mission, and for differences in comparison with ground-based data.

RESULTS

Technique.—Initial testing during KC-135 flights identified two factors that necessitated modification of the standard physical examination technique and equipment usage in performing a physical examination in microgravity. The first factor involved the mobility of a physician while performing the basic elements of an examination. In a terrestrial environment, both the physician and the patient maintain stationary positions for the required period, whereas in a microgravity environment, both are free to move continuously in any direction. Therefore, the first challenge for modifying the examination technique was to develop a means of restraining the physician and the subject being examined. In orbit, this goal was achieved by placing foot loops and handrails in strategic locations within the shuttle.

Similarly, the second factor involved stabilization and storage of the diagnostic equipment. In an effort to solve the "floating equipment" problem, Velcro was placed on all items such as the stethoscope, otoscope, and ophthalmoscope, which were stored in a clear container. With this approach, the examiner could locate the desired piece of equipment before opening the container and could thus prevent the other items from floating out of the container. The Velcro enabled the examiner to secure the container and diagnostic equipment in the middeck lockers in a location convenient for the examination.

The in-flight examination was conducted with both the subject and the examiner in foot restraints and with use of handrails, as tested on the previous KC-135 flights. Despite these measures, both the subject and the examiner had to use their hands and feet to stabilize themselves and each other throughout the entire examination. The current system of restraint was judged effective for conscious, cooperative participants but would necessitate additional modifications for use with unconscious patients. Classic techniques for physical diagnosis—inspection, palpation, percussion, and auscultation—were used for the actual examination and provided further insight into how to conduct examinations in microgravity. In general, the normal "windows" for percussion and auscultation are different in microgravity because of the shift of organs.

Inspection.—In microgravity, the body assumes a flexed posture when relaxed. The arms rise, caused by flexion at the shoulders and elbow joints, and in combination with flexion of the back and legs, the back becomes arched and the abdomen appears flat.

Palpation.—In microgravity, palpation presents a unique challenge. With use of the MET, two opposing hands must be used, one to counteract the action of the other. During the abdominal examination, one hand was used to probe the abdomen, and the other was placed on the back of the subject for support (Fig. 1).

Percussion.—The most common use for percussion was to determine the level of the diaphragm and the size of the liver. With the subject facing toward the wall and holding the handrails, the diaphragm level could be percussed in the conventional manner. The characteristic and the level of the sound were more difficult than usual to ascertain because of the noisy shuttle environment (mean noise level of 65 dB). Thus, potential problems may be masked, and errors in assessment may be increased.

Auscultation.—Finally, the ambient noise level in the shuttle also affected the examiner's ability to distinguish sounds clearly (for example, breath, heart, and bowel sounds). The ratio of the ambient noise to the physiologic sounds, however, was sufficiently low for adequate determination of changes and abnormal sounds with the use of diagnostic equipment such as a stethoscope.

Comparison of Target Variables. **Edema.**—The recorded data showed that the microgravity environment was quickly associated with facial edema. Within minutes to hours after orbital insertion, the cephalic fluid shift was observed and could be documented. Most crewmembers had at least 2+ edema of the face, demonstrated by swelling of the eyelids (Fig. 2). One of the crewmembers had substantial flushing of the face along with the edema. On questioning, most crewmembers described a sensation of facial fullness, especially behind the cheeks and eyes in the maxillary and frontal sinus area. Generally within 2 to 3 days, the subjective symptoms resolved even though visible evidence of edema remained.

Bowel Sounds.—The previous anecdotal descriptions of decreased bowel sounds were confirmed by using auscultation with a stethoscope over each quadrant of the abdomen. In orbit, bowel sounds were noted to decrease in five of seven crewmembers, especially in those astronauts who experienced space motion sickness. Even though the level of suppression declined during flight, the intensity of perceived bowel sounds never returned to preflight baselines (Fig. 3). In addition, the palpable sites of the liver and spleen are displaced higher in the abdomen during flight in comparison with the preflight level.

Neuromuscular Reflexes.—Results obtained during the tendon tap reflex testing are shown in Figures 4 and 5. The physical measurement of reflexes generally revealed a brisker than normal to hyperactive response to tendon tap.

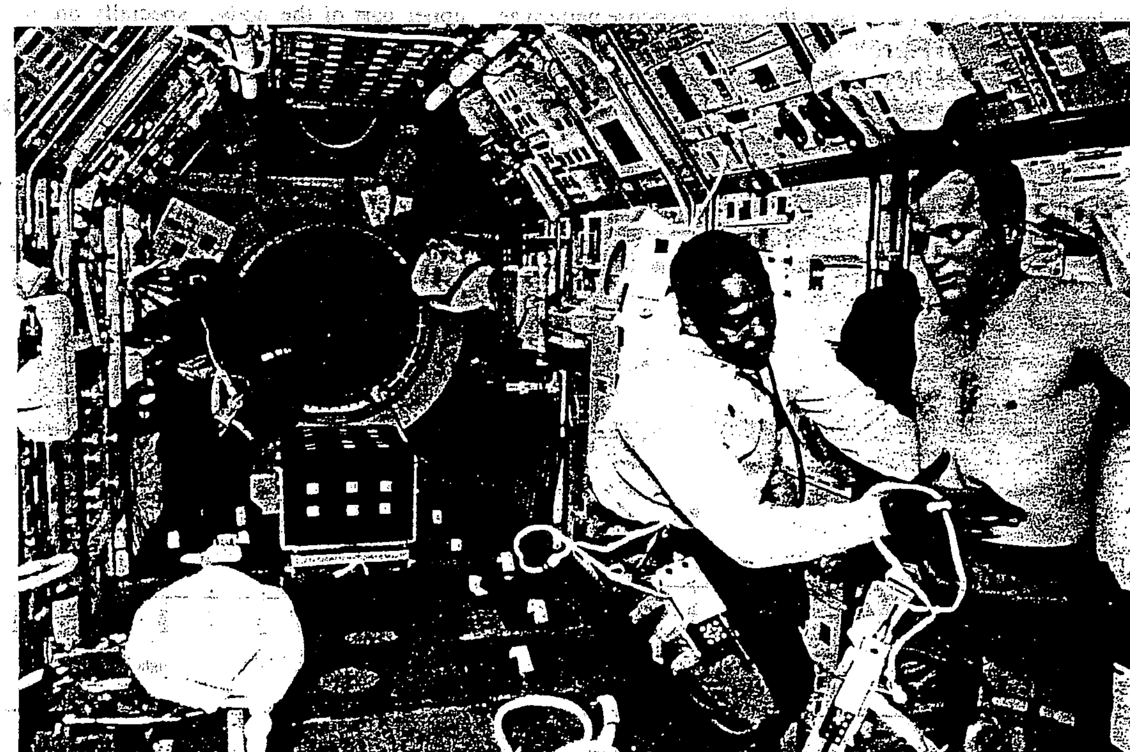

Fig. 1. Technique of two-hand palpation of the abdomen for physical examination in space.

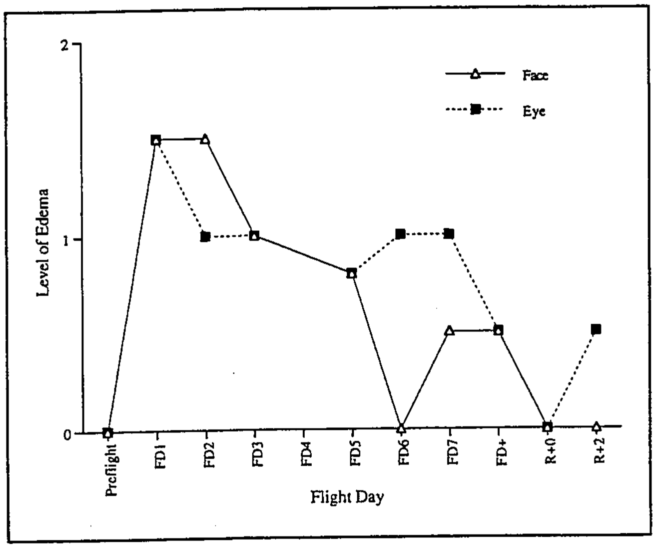

Fig. 2. Mean level of edema of eyelids and surrounding face before, during, and after space flight. *FD* = flight day; *R* = return to earth.

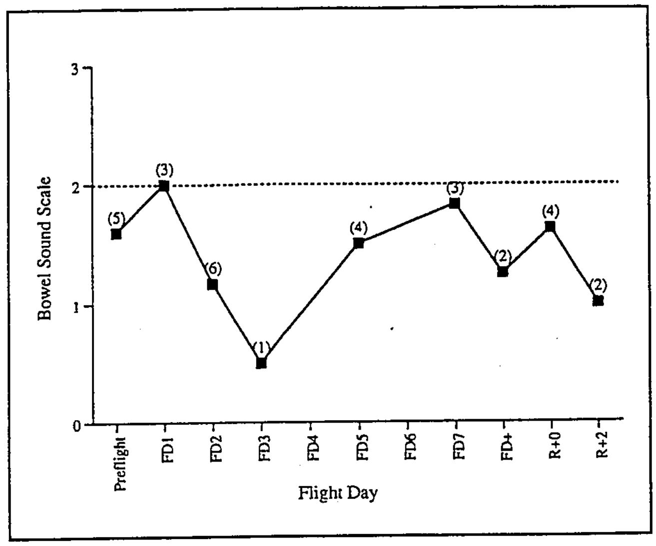

Fig. 3. Intensity of bowel sounds, based on standard grading scale (see Table 1). Number of subjects for each data point is indicated parenthetically. *FD* = flight day; *R* = return to earth.

Only two of seven crewmembers had no measurable changes in comparison with preflight values. The mean change in the biceps and triceps reflexes displayed an initial increase in the intensity (Fig. 4). The biceps showed a gradual return to baseline, whereas the triceps reflex was more abrupt. The tendon tap of the patella showed the same response pattern as that for the biceps (Fig. 5). In contrast, the mean values of the gastrocnemius reflex indicated no change from baseline. In those crewmembers in whom changes were noted, the increase in activity manifested on exposure to microgravity and continued throughout the entire mission. The reflexes of these subjects seemed to remain hyperreflexive when they returned to earth—at least through day 2 after return.

Additional Physical Findings. **Skin.**—The skin on the upper part of the body, especially on the face, rapidly became edematous and hyperemic. During the course of the mission, the skin became oily on the face but remained dry on the rest of the body. In addition, the skin, conjunctivas,

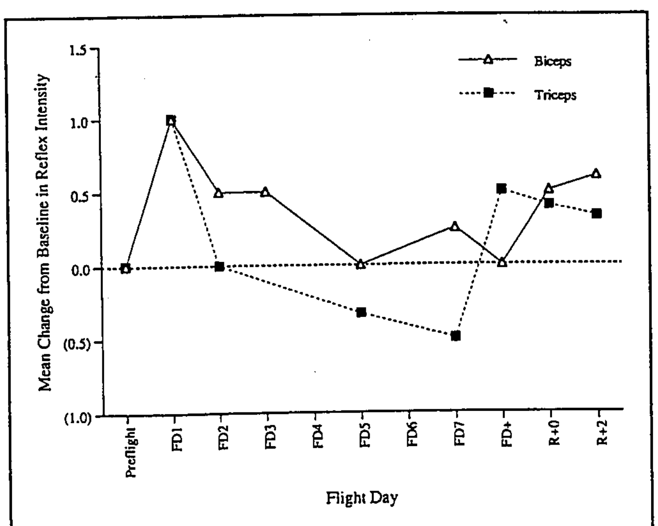

Fig. 4. Mean change (N = 7) in tendon tap reflex of biceps and triceps, based on standard grading scale (see Table 1). *FD* = flight day; *R* = return to earth.

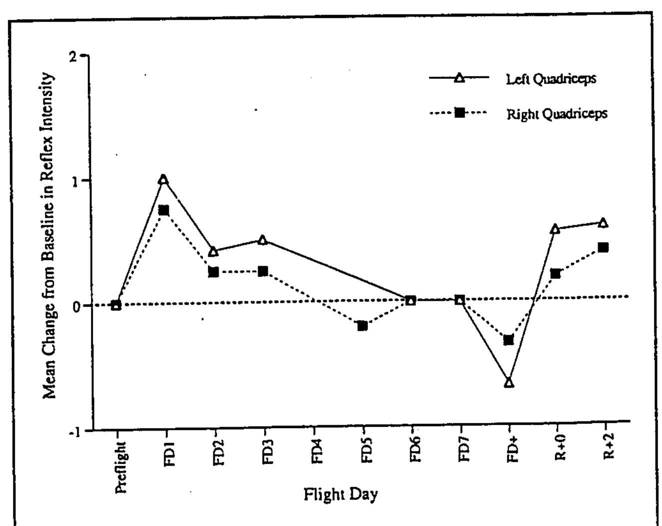

Fig. 5. Mean change (N = 7) in tendon tap reflex of quadriceps, based on standard grading scale (see Table 1). *FD* = flight day; *R* = return to earth.

and mucosal membranes became hyperemic and injected in some subjects.

Neck.—On examination of the neck, the jugular veins were distended on most crewmembers. This distention extended "up" the entire length of the neck.

Chest.—Another notable observation during examination was the barrel shape of the chest of most subjects. This appearance was, in part, due to the hyperextension of the back in combination with the flexion of the shoulders and arms as a result of the absence of gravity. On percussion of the posterior aspect of the chest, an acute elevation of the diaphragm (approximately one to two intercostal spaces over the baseline evaluation) was noted (Fig. 6). This finding was associated with an apparent decrease in breath sounds at the base of both lungs in some crewmembers.

Heart.—Cardiac sounds were slightly more difficult to hear than usual because of the inherent noise of the internal environment. Despite this, no discernible differences were detected in the intensity or rhythm of the heart sounds. Of note was the displacement of the point of maximal impulse. In most crewmembers, this point was palpable at the usual site (the fifth intercostal space and midclavicular line) during the ground-based evaluation, but in microgravity, this point was not palpable in three of the seven subjects and was displaced substernally in the other four.

Abdomen.—During abdominal examination, the contour of the abdomen was invariably observed to be flat. For one crewmember, this profile was unusual because on preflight examination the abdomen normally protruded.

Musculoskeletal.—Within minutes after orbital insertion, changes in ambulation and posture were noticeable. Most crewmembers adapted to microgravity fairly quickly, although movement during the first few hours was awkward. All crewmembers assumed a microgravity body posture, in which the back was hyperextended and the limbs were flexed. The upper body appeared enlarged, and the lower extremities were thinner than in $1g$. In addition, toward the end of the missions (after approximately 5 days), decreases in the size of large muscle groups were evident, primarily noted as thinning of the lower extremities.

Overall.—The rest of the systems evaluated showed either minimal changes or no detectable changes with use of the MET. Eye examination revealed no major changes from preflight findings except for mild redness of the conjunctivas in some crewmembers. Ophthalmoscopic examination showed no papilledema. Examination of the ears disclosed no appreciable changes from the preflight examination. Generally, the subjects had an increased redness and swelling of the mucosal membranes of the nose and slight hyperemia of the mucosal membranes of the mouth and throat. Most physiologic variables, except the neuromuscular reflex, returned to normal on reintroduction to a gravity field.

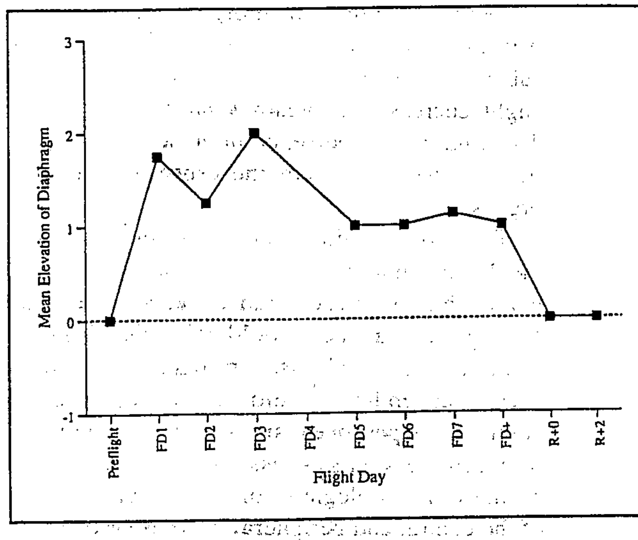

Fig. 6. Mean elevation of diaphragm as determined by percussion. *Dashed line* = baseline; *FD* = flight day; *R* = return to earth. (Vertical scale = intercostal spaces.)

DISCUSSION

Every system of the human body is affected by exposure to the space environment. The responses of the various organ systems of the body to the microgravity environment have been extensively reported and are known to differ from those observed in $1g$.[1-13] The immediate issue for the space medical community is whether these changes can be measured serially with use of the physical examination. In our current study, we have shown that such determinations are possible. The fluid shifts, muscle atrophy, and cardiovascular deconditioning that occur are all normal responses to the microgravity environment. By using a routine physical examination, facial edema, muscle weakness, and orthostatic intolerance can be diagnosed and monitored. The ability to detect and monitor such changes is the necessary foundation for identifying pathologic conditions in microgravity.

Several of the described alterations are due to anatomic shifts. As reported, the point at which the contractions of the heart could be felt through the chest wall in the microgravity environment differed from preflight findings in all subjects. One reasonable explanation is that the heart is held in place by several organs and fibrous tissues (that is, the diaphragm, lungs, vascular system, and pericardium). The position of these organs and tissues is affected by the physical absence of gravity, which in time causes a positional change of the heart. All subjects had elevation of the diaphragm, as determined by percussion. This adjustment in diaphragmatic position may be explained by the effect of microgravity on normal abdominal anatomy. In $1g$, the abdominal contents are held down by gravity, but in orbit, the organs respond to the tissue tension. This response is demonstrated by the rise of the two most prominent organs—the liver and spleen—as well as the diaphragm. Auscultation of the lungs in these subjects revealed clear lung fields except for occasional slight decreases in breath sounds at the bases bilaterally. This finding, of course, could indicate a compression of the base of the lungs from the cephalad shift of the internal organs.

These observations underscore the differences between the 1*g* and microgravity examinations and the effect that gravity has on most organ systems. The implications of findings such as these could affect the diagnosis and treatment of common illnesses in flight. For example, the presence of appendicitis could be overlooked because of alterations in the peritoneal signs in microgravity. The severity of decompression sickness could be masked by the normal changes in neurologic status that occur from the adaptation of the central and peripheral nervous systems. Moreover, a diagnosis of lower lobe pneumonia might be missed because of the normal elevation of the diaphragm during space flight. Many such problems could be prevented and conditions could be appropriately diagnosed if the space clinicians are adequately prepared. This study is only the first step toward identifying the challenges that are before us in the medical management of humans in the space environment.

CONCLUSION

Previous biomedical studies clearly support the fact that the physical and symptomatic changes induced by microgravity can be documented and analyzed. The results of the current study further indicate that sufficient data can be obtained from a noninvasive hands-on examination. In addition, our findings support the conclusion that the microgravity examination differs in several important aspects from that conducted on earth. Although the sample size was limited, clear and consistent changes were successfully documented, assessed, and followed serially in this study by using only a modified physical examination.

The development of the MET as an established approach to examination during space flight will set the stage for longitudinal studies over several missions, in which participants will undergo assessment of physiologic responses to microgravity. All crewmembers on consecutive space missions will be asked to participate so that selection bias will be minimized. With use of the same study protocol, comparisons with ground-based physical examination data will help determine normal in-flight ranges. Data entry and analysis will be facilitated by use of a laptop computer, and intrarater and interrater reliability will be assessed over time.

Once sufficient comprehensive data have been acquired, the foundation for medical management of future space travelers can be established. The physicians for the International Space Station and other long-term space missions will require a comprehensive understanding of physiologic responses and their effect on human survival in microgravity. This understanding will prove essential in recognizing and treating medical conditions of the astronauts and the space travelers of the future.

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