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Cardiovascular Group

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As a starting point, the group defined a primary goal of maintaining in flight a level of systemic oxygen transport capacity comparable to each individual's preflight upright baseline. We did not consider it appropriate to require any specific preflight level of fitness. Medical standards for crewmembers are adequately addressed in many other ways. However, we felt that it is essential to establish measurement procedures for quantitation of preflight fitness levels in all crewmembers. Such procedures should include measurement of maximal oxygen uptake VO_2. Ideally, there should be at least three data points over a period of several months before flight to document the habitual level of fitness for each individual which then defines the level that should be maintained in flight. We realize that a goal of maintaining the preflight level can be achieved in a variety of ways with different exercise regimens. Assuming that one can transpose ground-based methodology (i.e., there are some reasons to believe that one can, including the Skylab data), a minimal regimen included four sessions per week for 30 minutes at an intensity level of 70 to 80 percent of preflight maximal VO_2.

The goal of maintaining capacity at preflight levels would seem to be a reasonable objective for several different reasons, including the maintenance of good health in general and the preservation of sufficient cardiovascular reserve capacity to meet operational demands. It is also important not to introduce confounding variables in whatever other physiological studies are being performed. A change in the level of fitness is likely to be a significant confounding variable in the study of many organ systems.

The principal component of the in-flight cardiovascular exercise program should be large-muscle activity such as treadmill exercise. We realize that other exercise regimens that may have been designed to achieve maintenance of the musculoskeletal system may partly or completely satisfy also the requirements for the cardiovascular system. Furthermore, routine work such as extravehicular activity may replace all or some of the scheduled activity that is required to maintain cardiovascular fitness. It is desirable that at least one session per week be monitored to assure maintenance of proper functional levels and to provide guidance for any adjustments of the exercise prescription. Appropriate measurements include evaluation of the heart-rate/workload or the heart-rate/oxygen-uptake relationship. Respiratory gas analysis is helpful by providing better opportunities to document relative workload levels from analysis of the interrelationships among VO_2, VCO_2, and ventilation.

We considered in addition what should be done to prevent readaptation problems on return to normal gravity. The committee felt that there is no clear evidence that any particular in-flight exercise regimen is protective against orthostatic hypotension during the early readaptation phase. Some group members suggested that maintenance of the lower body muscle mass and muscle tone may be helpful. There is also evidence that late in-flight interventions to reexpand blood volume to preflight levels are helpful in preventing or minimizing postflight orthostatic hypotension. Progress toward this goal can probably be achieved by means of a variety of in-flight interventions that may help in maintaining a normal blood volume; e.g., late fluid loading, administration of vasodilators, exercise combined with thermal loads, or intermittent redistribution of fluid by lower body negative pressure or by combinations of these interventions. All of these and other alternatives should be explored in the future.

Whatever recommendations regarding an exercise prescription are adopted, the first set will be an approximation that will need to be modified appropriately after evaluation of flight data. It is therefore an absolute necessity to begin with an effective system for collection and evaluation of the physiologic characteristics and effects of any exercise program. The individual responses and the benefits that are being derived from the program must be

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documented. An essential part of that task is quantitation of the preflight state. Bear in mind that this committee has only addressed the minimal cardiovascular measurement set. There are many other measurements that should be part of a standard physiological measurement set, including cardiac imaging.

With regard to exercise devices, the modified micro-g treadmill is generally an excellent choice for maintenance of cardiovascular fitness. However, it is important to realize that there are various ways of producing the desired effects. Multiple programs may initially be defined to benefit different organ systems. Regimens will eventually be consolidated and devices will be selected that make it possible to achieve in an efficient manner the specific objectives for all systems that are being targeted.

Muscle Group

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Two different exercise programs are recommended by the muscle group. The first one is intended to maximize performance and extravehicular activity (EVA) and, therefore, focuses on exercise for the upper body. The second exercise program is oriented toward muscles of the leg.

Extravehicular activity demands considerable time and effort and may well be the most dangerous aspect of the early missions on the Space Station (SS). These missions will be characterized by frequent EVA's in order to assemble the various SS components. Therefore, we believe that exercise prescriptions should be designed to train for optimal productivity with an acceptable safety margin for human error. It may be advisable to train the upper body before flight, because of the high demands of the upper body musculature in EVA. Given the specific types of activity that seem to be required during EVA, and considering the minimal experience that we've had characterizing these movements, considerable time and thought was given the topic of training crewmembers in a pressurized suit in the range of 7 to 8 psi. It appears that considerable use of the hands may be required, perhaps for prolonged periods of time, during EVA. Fortunately, in this particular case, we may be able to create a reasonable underwater simulation of EVA for many movements. However, all movements must be analyzed with respect to both displacement and the forces required for the distal digits (fingers) and for other more proximal joints (elbow and shoulder). This analysis can be done by proper instrumentation of the space suits in a way so that movements can be quantified meaningfully. Such instrumentation should help to optimize the exercise training required. This apparatus could be used in practicing movement precision and for endurance training. A general feature of every exercise apparatus should be that it has the capability to record continuously force, displacement, and electromyography. In this way, crewmember movement training can be individualized.

Feedback to the crewmembers on movement precision may increase compliance with the training program as well as optimize the effects of the training sessions for the crewmembers. It is estimated that a crewmember may need to train for a maximum of several hours a day under some circumstances. However, perhaps as little as 30 minutes or less, every other day, may be sufficient. Even though EVA may last for as long as 6 to 8 hours, it is unlikely that the same muscle groups will or could be used safely for 6 to 8 hours. Perhaps one task could be performed for 1 hour and then alternate with tasks that require different muscle groups. It would appear that endurance and the strength capabilities of the upper arm could be maintained with less than an hour a day, and perhaps 30 minutes per day, three to four times a week. Ground-based experiments will be important in addressing this issue. These details can be defined more precisely in ground-based experiments before the Space Station initial operating capability (IOC).

There should be a means for the individuals to maintain their training capability in flight. Preflight training could be extensive in cases for which considerable EVA is required early in a 90-day mission. It should be noted that the exercise apparatus should accommodate the muscles of the shoulder girdle as well as the more distal segments of the arm.

Another exercise-related issue is how to minimize muscle atrophy. This seems to be an issue with respect to the lower body only. Is it important to totally prevent muscle atrophy? One approach would be to ignore it and accept the recovery period required upon return to one g. The general consensus is that we should minimize but not necessarily prevent muscle atrophy. Some tradeoffs between muscle maintenance and work productivity in space may be desirable. For example, suppose 15 min/day is required to maintain muscle function within 90 percent of normal, whereas 2 hours would be necessary to maintain muscle mass at the 100-percent level. All muscles do not atrophy similarly in microgravity. Based on the evidence from Cosmos and NASA flights, most atrophy occurs in the extensor muscles. This category probably includes muscles of the neck, the back, and the legs. How do we minimize this atrophy? We are suggesting several exercise apparatuses. One recommendation is to use a treadmill similar to what Dr. Bill Thornton has demonstrated, particularly if the treadmill can be configured for use so that impact forces are imposed. The U.S.S.R. seems to have a very effective treadmill in this regard. Secondly, a rowing machine would probably be a useful apparatus. Both of these apparatuses require muscular effort of the back, the hips, the knees, and the ankles.

A more specific approach is to exercise one joint at a time. Obviously, this approach is inefficient with respect to the training time required. A rowing machine or a treadmill would seem to be the most suitable apparatus. Furthermore, the more complex exercises would probably result in greater user compliance than would single-joint exercise machines. It is also suggested that an apparatus be devised for jumping. For example, a platform with bungee cords may be effective and feasible. The force/time curves could be recorded from such an apparatus. A jumping apparatus could be an effective way to produce the higher power efforts that would require recruitment of the higher threshold motor units.

Lastly, we recommend apparatuses which can be used to test and, if desired, to train specific joints; for instance, a mechanism whereby muscle lengthening and shortening velocities and torques can be controlled and recorded. Such an apparatus would allow each individual to monitor force-velocity capabilities over time for specific muscle groups before, during, and after flights.

What research is needed to further define these apparatuses? Bed-rest studies are considered to be an important resource. In addition to anthropometric, strength, physiological, and biochemical data from bed-rest and other ground-based studies, data from muscle biopsies are needed. Analyses of muscle biopsies will be needed to test the working hypotheses which underlie the recommendations being made. How selective is muscle atrophy? How severe is the atrophy, and how rapidly does it develop? These issues can be addressed effectively using a combination of ground-based models and the short-duration flights that will take place between now and IOC.

Skeletal Group

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We addressed five key questions within our group. The first one was - Can exercise prevent bone demineralization in flight? The second one, regardless of the answer to the first one, is - Are the skeletal losses sufficient to warrant countermeasures? If so, what countermeasures would we add? What devices would be recommended? The answer to the last question is, of course, interrelated with the countermeasures. And finally, the question we actually could answer: What issues need to be researched further?

The answer to the first question - Can exercise prevent demineralization? - got general support as a concept with the following reservations. The animal data are much stronger than are the human data in providing an answer. There is a lack of prospective studies; therefore, cause and effect relationships cannot truly be established. The mechanisms are not truly known. The best studies, the bed-rest studies, have been varied in their protocols, and they don't provide the conclusive evidence that we need to refer to a flight situation. Secondly, the density measurements that have been taken on the calcaneus are inadequate to give us a global picture of what's happening to the calcium in the body as a whole. So in answer to the question, "Can exercise prevent demineralization?", it is our strong feeling that it can, but that opinion is based on animal studies and human studies which need to be refined.

Turning to the question, "Is it important during a 90- to 180-day space flight to reverse the observed changes?", the answer was an almost unanimous "yes." There was a strong consensus that something should be done despite the fact that it may possibly be ignored without detriment to in-flight performance on a 90-day flight. However, it was pointed out by a number of committee members that the Space Station should be treated as a test for longer interplanetary missions. Therefore, we have a chance to address the problem now, and it should be solved as a prelude to future long-term activity. There is the feeling that if 180 days is the requirement now, that's definitely going to be extended in the future. Concern was voiced that the changes that occur beyond 180 days are not presently known. There was also concern regarding the secondary effects of calcium excretion. In particular, renal status and other potential problems related increased mobilization of calcium. The feeling was voiced that, although calcium loss is not a life-threatening problem, it certainly is sufficient to demand investigation, not just as a solution to the present problem but as a problem that needs solving in longer duration missions. The statement was made by one committee member that a 15-percent loss in the calcaneus may not be worrisome to anybody, but a 15-percent loss in the vertebrae would certainly be cause for concern. Another major reason for concern is that we don't understand the recovery profile. And if it were to be discovered, for example, that the calcaneus recovered quickly, the spine recovered slowly, and the long bones recovered hardly at all over a long period, then that in itself would be cause for concern. So the answer to question 2, "Is it important to prevent calcium loss in a 90- to 180-day flight?", was an almost unanimous "yes."

The third and fourth questions regarding countermeasures and exercise devices, respectively, are obviously interrelated. The general feeling is that countermeasures should be designed to substitute for what has been taken away. And what has been taken away are principally two things. They are the force/time profiles that are input to the lower extremity repeatedly in locomotion-type activities, and they are vigorous eccentric muscle action. Both of these things are absent relative to their normal occurrence in a one-g environment. Therefore, the countermeasure suggested by our group would be mechanisms which involve applying loads to various parts of the human body which would require eccentric muscle action to overcome. Nobody recommended simple passive impacts or passive loads. Other possible modalities include devices that apply bending stresses to bones and muscle stimulation.

With regard to a frequency for application of a bone countermeasure, it was felt that the requirement for this kind of input to the lower extremity should be there on a daily basis. Several people suggested at least twice a day periods of locomotor-type activity. As far as what devices would be recommended if at this time anything should be fixed, it is that the device should have the flexibility to change. And there was a general feeling that, at this point, to specify the device without possibility for change would be premature. However, the almost unanimous recommendation of the group is that the treadmill should be included as the primary exercise device to apply locomotor forces to the lower extremity with the following reservations. The current configuration of the treadmill may need modification. It may need to be an active treadmill with a longer tread. The harness may need review, and the subjects may require training so that it simulates typical one-g impacts. The point was made that the harness for the treadmill could be used for other types of jumping activities where the legs would be subjected to large eccentric actions not possible without the body being harnessed down. Other types of devices that were suggested included the possibility of a trampoline with variable tension.

We spent time discussing the issue of whether the exercise should be voluntary and whether it should be standardized or individualized. And I think that even though there was no consensus on this, it was generally acknowledged that the rates of calcium flux are different in different individuals and this, therefore, raises the possibility that the exercise protocols should be individually tailored. Most people felt the exercise should be compulsory rather than left to individual choice. It should be variable in duration and in magnitude, but compulsory in the fact that it should be done by all crewmembers.

Finally, with respect to the issue of what research needs to be done, there were three issues that deserve emphasis. The first I want to mention is the lack of baseline information on the preflight status of the astronaut corps. Everybody felt that it was indefensible that we do not have epidemiological data on the astronauts from day 1 of their acceptance into the program all the way through their training, through space flight, and through postflight recovery. Various people on our committee had made similar recommendations years ago that this information should be kept. It was perhaps the strongest consensus in our committee that you cannot plan experiments without having good baseline data on the individuals for planning purposes. In our particular point of view, there was the feeling that this must include total-body calcium, which, as was pointed out, takes only 1 hour to measure and results in minimal radioactive exposure. Among the data that should be collected are information on bone density and on individual rates of bone loss, sensitivity to calcium changes, a family history of osteoporosis, presence of lactose intolerance, or limited calcium intake. It was felt that these kinds of things are so basic that it's surprising these data do not exist.

Secondly, we felt that the most important thing that needs to be done is more research to confirm the effects of exercise on bone changes. Concern was expressed over the difference in exercise modes across the various bed-rest studies and the interaction of the exercise posture with the type of exercise. Studies need to be done in a very specific manner; they need to be refined to identify exactly what the various exercise effects and dose relationships are. Some suggestions were made, including an interest in the use of the water exercise as a possible alternative model to bed-rest exercise. It was felt that the uncertainties in the interaction of all these factors affecting the loss or retention of calcium have to be identified. It was also felt that we have to determine the effect of different types of forces on the various parameters in calcium kinetics. We must know the difference between brief-duration forces and prolonged forces. We must know the difference between voluntary muscle forces and electrically stimulated forces. Because there is so much uncertainty as to what types of forces are involved in the maintenance of skeletal mass, the decisions of what to do at the moment are based on educated guesses. It was felt that studies must be done on individuals at both extremes of bone turnover rates in order to maximize the success of the experiments. Preselection of experimental subjects based on their rate of loss may resolve some of the variance in previous results. Individuals with high rates and individuals with low rates of bone turnover should be studied in order to determine whether the members of the astronaut corps lose at the same rate.

It was suggested that we should study the exercise profiles of individuals who are going either into the bed-rest studies or into a zero-g environment so that the history of force application to their lower extremities can be recorded and evaluated. It is thought that possibly an "equivalent" effort can be compacted into a shorter exercise period. We felt that, in light of planned long-term space flight, we must have long-term research and that the duration of any of the simulated studies must be at least as long as the planned duration of the space flight. Furthermore, there is a strong feeling that the recovery kinetics need to be examined. For example, if complete restoration of preflight levels occurs in all locations in 3 months, then perhaps this problem can be given a lower priority. If, however, there is not complete restoration, then one has to worry about repeated flights by the same individuals, and whether there are any long-term cumulative effects.

It was also stated that a lot of the previous data on calcium changes and on bone demineralization were obtained using methods that may now be outmoded, and that there must be an attempt to use the latest techniques and, equally important, to study many different regions of the body. We cannot simply determine the changes in the calcaneus and extrapolate from those data to all regions of the body. The point was made that, clinically, many different interventions have specific effects. More must be known about the differences in losses between cortical and trabecular bone.

We realized all through this deliberation that we couldn't consider bone in isolation, and, at this point, we allowed our focus to broaden. In particular, we must try to consider the various effects on bone and muscle as a single unit where possible. There was some dispute in the group on whether biopsies of bone would be acceptable or not, with support expressed for both sides. The question was raised as to whether or not head-down position accelerates the bone resorption, and even though this was said to be a very heretical point of view, it was thought that because the head-down position per se affects so many other physiological systems, it is worth investigating. In a similar vein, lower body positive pressure protocols should be studied as a potential model. It was felt that hormonal studies are needed, both in flight and during bed rest, because that could be the full extent of the problem. There was general skepticism on the point, but it needs to be disproved because of its possible strong effect. The possibility of pharmacological intervention, such as the use of disphosphonates, was mentioned and deserves some further research. And finally, a rather novel suggestion was made of putting a nonexercising deconditioned person in space as a control to learn what happens to the calcium kinetics of that individual.

This rather lengthy account reflects the fact that our group didn't seem to have the same degree of certainty that some other groups demonstrated. We are in general agreement that there is a problem and that the problem needs to be attacked. We feel that it should be attacked in flight with weight-bearing exercise such as treadmill locomotor or possibly jumping exercise to generate large eccentric muscle actions. Furthermore, we feel that there is a substantial amount of research that needs to be done in order to make us feel stronger in the recommendations we have made.