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LYNDON B. JOHNSON SPACE CENTER

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John M. Vogel
U.S. Public Health Service Hospital
San Francisco, California

Paul C. Rambaut and Malcolm C. Smith
Lyndon B. Johnson Space Center
Houston, Texas 77058

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BONE MINERAL MEASUREMENT FROM APOLLO EXPERIMENT M-078

By John M. Vogel,* Paul C. Rambaut, and Malcolm C. Smith
Lyndon B. Johnson Space Center

SUMMARY

During 36 weeks of bed rest, the loss of mineral from bone was more apparent in the lower than the upper extremity and was observed to exceed 30 percent in the central os calcis. No mineral losses were observed in the upper extremity during this same period of time.

In the Gemini IV, V, and VII studies using X-ray densitometry, large losses of bone mineral were observed in the radius and ulna. This observation was not validated in the Apollo 14, 15, and 16 crewmen when a more precise technique, gamma ray absorptiometry, was used. The large mineral losses reported for the early Gemini missions from the central os calcis were varied and were not observed when the newer measuring technique was used. Seven of the nine crewmen studied lost no mineral from the os calcis; however, because two crewmen did lose mineral from the os calcis, it is clear that losses can occur in these short periods of time, even though such losses are not observed in 14 days of bed rest. If these losses were allowed to continue unabated for a prolonged period of time, the consequences might be severe because the losses observed are probably not confined to the os calcis.

INTRODUCTION

Derangements of bone mineral metabolism can be considered to be one of the major threats to the health of crewmen. The hazards are likely to be greatest during the prolonged expeditions yet to be undertaken.

The integrity of bone and the maintenance of a skeleton capable of resisting the stresses of everyday life are functions of several factors (ref. 1):

1. The pulling forces that are exerted on bone by its attached muscles

2. The forces that are exerted along the longitudinal axis of the skeletal system by gravity

3. The piezoelectric forces

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*U.S. Public Health Service Hospital, San Francisco, California.

4. The hydrostatic forces that permit the proper flow of blood with its nutrient materials to, and the waste products from, the bone

This complex set of stimuli is balanced to provide a bone structure capable, by its chemical composition as well as by its architectural deployment of these materials, of supporting the organism and resisting the forces against which the organism must function. Bone is a living organ that is continuously remodeling itself. When mechanical forces applied to the skeleton during normal activity in a one-g environment are removed, bone mineral is lost because bone resorption is allowed to outstrip bone formation. This factor represents a danger not only because of the risk of fracture in demineralized bones but also because the associated increased urinary calcium excretion might lead to the formation of kidney stones.

Early radiographic densitometric studies by P. B. Mack et al. (ref. 2) revealed significant bone mineral losses in the os calcis, radius, and phalanges of crewmen who were exposed to varying short periods of weightlessness. Because the degree of loss reported for the Gemini V crewmen appeared excessive for such short periods of weightlessness, further evaluation of the data led to a lower estimate of loss (ref. 3). Even though the Gemini V data were revised to reflect smaller losses, their general magnitude was a cause for concern.

It is necessary, however, to view the Gemini results with an appreciation of the problems inherent in the measurement techniques used. X-ray densitometry — with its attendant problems of a polychromatic energy beam, film characteristic changes, film development variables, and ultimate translation of film density to digital analysis — has many sources of error. These errors are magnified when steps are not taken to overcome soft tissue irregularities and changes. Many of the problems associated with the radiographic technique are amplified when measurements are to be made at a variety of locations with wide differences in temperature, humidity, power sources, and equipment, as was the case with the Gemini studies.

A photon absorptiometric technique (ref. 4) that does not suffer from these problems was investigated by applying it to a series of bed-rest studies (refs. 5, 6, and 7). The results showed the technique to be suitable for the measurement of the Apollo crews (ref. 8). Apollo 14 was to be a postflight quarantine mission, and neither the X-ray densitometric nor photon absorptiometric techniques had previously been adapted to these conditions. Because the crew was to be isolated preflight and quarantined postflight, a device had to be designed that was compact, required minimal storage area, was adaptable to measuring mineral in representative upper and lower extremity bones, and was sufficiently portable for use preflight at the Lyndon B. Johnson Space Center (JSC) and the John F. Kennedy Space Center (KSC) and postflight in a mobile quarantine facility (MQF) aboard the recovery carrier and in the quarantine area of the Lunar Receiving Laboratory (LRL) at JSC.

As an aid to the reader, where necessary the original units of measure have been converted to the equivalent value in the Système International d'Unités (SI). The SI units are written first, and the original units are written parenthetically thereafter.

METHODS AND MATERIALS

The rectilinear bone mineral scanner designed and built for the Apollo missions is compact, can easily be disassembled (fig. 1), and has the capacity for operation in two configurations: heel scanning (fig. 2) and arm scanning (fig. 3). The unit consists of a scanning yoke, an apparatus for moving the yoke, and devices for positioning the limb to be scanned. The basic scanning format previously described (ref. 4) is followed.

The scanning yoke holds a collimated source and collimated detector 13 centimeters apart with the apertures alined in direct opposition. The source contains 1480×10^{10} dis/sec (400-millicurie) iodine-125 (^{125}I) and is shielded, except for a 3-millimeter-diameter collimator output hole. The detector is a sodium iodide (NaI) scintillator mounted in a housing collimated to 3 millimeters. The limb to be scanned is placed between the source and detector. The yoke is attached to a movable ram by means of a special mounting stud that allows for two different mounting configurations (figs. 2(a) and 3(a)).

Rectilinear scanning is accomplished by moving the yoke sequentially in two directions. First, a traverse of the ram into and out of its housing constitutes a row during which data are collected (X-axis). Second, a movement by the Y-axis unit at the completion of each row constitutes an increment during which no data are collected. The beam of radiation is oriented parallel to the Z-axis. The conversion of the scanner from one configuration to the other requires a 90° rotation of the frame with respect to the base and a 90° rotation of the yoke with respect to its mounting stud.

A row of data collected during the X-axis traverse contains 256 points, each point representing an interval of 0.397 millimeter for a total row width of 10.16 centimeters (4.0 inches). After the completion of each row, the ram and yoke are moved by 3.0-millimeter increments along the Y-axis. (This length is standard for Y-axis increments.) A full scan is completed when 16 rows of data or 4096 data points have been collected.

The yoke is driven along each axis by means of precision stepper motors. Each stepping impulse turns the motor through 1.8° of arc or 200 steps per revolution. Using 16 pitch screws, this is the equivalent of 126.0 steps per millimeter or 3200.0 steps per inch of linear motion on either axis. (A repositioning accuracy of better than ±0.1 millimeter is achieved.) A microswitch at one extreme of each axis determines an exact zeroing reference point for repositioning.

The devices that hold the limbs stable and in position for scanning consist of two interchangeable tables on a common base that slides on the scanner legs for positioning. The base is locked into position by locking thumbscrews.

Scanner Control

Motion and position are controlled by a miniaturized scanner control module (fig. 4). The motion along the X-axis is controlled by a quartz crystal oscillator and digital frequency synthesizer with a velocity accuracy ±0.15 percent of the indicated

value. Three pushbuttons (ZERO, STOP, and SCAN/INITIALIZE) control all major scanner functions. The ZERO button initializes the internal position registers by moving the yoke along each axis to its zero reference point where the microswitches are tripped. The scanner is "zeroed" once each day to assure that the control registers agree with the yoke's physical position. A STOP button stops all operations and strobes the front panel settings (X-axis velocity, scan format, initial Y-axis position, number of rows, and Y-axis increment in millimeters) into the memory. A front panel control lockout prevents a change in these settings during a scan. The SCAN/INITIALIZE button starts a scan if the yoke is at the selected Y-axis position and at zero on the X-axis. If either of these conditions is not satisfied, the yoke will move by millimeters from the reference point to the selected Y-axis position and to the X-axis zero. An automatic scan can then be started by again pressing the SCAN/INITIALIZE button. During scanning, a preset number of motor pulses is counted to signal the scaler at the end of each X-axis traverse of 0.0397 centimeter (50 pulses). A functional block diagram of this instrument is shown in figure 5.

Data Collection Electronics

To minimize background and to accommodate a low-energy photon gamma output, a Harshaw detector with a 1.5-centimeter-diameter by 3-millimeter-thick NaI crystal covered with a thin beryllium window coupled to a ruggedized RCA 4441 phototube is used.

A preamplifier and single channel analyzer set for 27.5 keV with a ±7 keV window select events for counting by a scaler. The scanner controller generates a signal to dump the total pulses counted during the preset X-axis interval into a buffer register, and the scaler continues accumulating the data for the next scan interval. The buffer in turn is strobed by a paper tape formatter to record the data on paper tape in ASCII code. A linear rate meter also monitors the count rate through the system. A block diagram of the data collection electronics is shown in figure 6.

Scan Procedure

During scanning of the os calcis, the heel rests in a foot mold mounted in a plastic box on a table (fig. 2(b)). The plastic foot mold is fashioned from an impression of each subject's foot made before the study. The box is filled with water to provide a constant tissue-equivalent path length. The scan is started at a point determined from an initial radiograph to include the entire central os calcis in 16 parallel rows, each spaced 3 millimeters apart (fig. 7).

During arm scanning, the arm lays horizontally between two plastic vertical uprights on the arm tabletop (fig. 3(b)). Pegs in a movable handrest position and hold the arm with the ulnar styloid opposite a reference point in the upright. To maintain a constant tissue-equivalent path length, the arm is surrounded by Superstuff (Oil Center Research, Lafayette, La.) and covered with a thin sheet of plastic. Sixteen rows are scanned at 3-millimeter intervals beginning 2 centimeters proximal to the level of the ulnar styloid.

Data Reduction

The data acquired on punched paper tape were either entered into a time-sharing computer by means of a remote teletype terminal or directly into a minicomputer.

The basic algorithm for determining bone mineral content BMC is BMC = $K\sum\ln(I_0^*/I)$, where K is constant, I is the count rate in bone, and I_0^* is the count rate through the soft tissue surrounding bone (fig. 8). The computer programs perform three basic functions.

1. Definition of the bone edge and therefore bone width
2. Calculation of the I_0^*
3. Calculation of the $\sum\ln(I_0^*/I)$ between the bone edge limits

Two basic programs are used specific to the peculiarities of the bones to be measured, namely the arm and heel. The geometry of the arm is basically simple, although the effects of fat may present a problem. The I_0^* is defined by taking all points within 20 percent of an estimated I_0^*. Through an iterative process, a self-consistent I_0^* is obtained. Bone edge is defined as a point 85 percent below I_0^*.

The heel is an irregular trabecular bone with less discretely defined edges. It demands a more precise algorithm. Defining an 85-percent edge is not satisfactory because the presence of a fat pad with a lower absorption coefficient u_m than muscle significantly increases I_0^* on one side of the bone. The edge is determined by calculating the point at which a maximum rate of change of count rate (slope) occurs for any five consecutive points. The I_0^* is determined by skipping the first five channels outside of the bone and averaging the next eight. This gives a different I_0^* for the two sides of the bone. Bone mineral values using both the low and mean I_0^* are calculated. As long as the tissue on either side of the bone does not change in quality during the study, the mean and low I_0^* for any row or any experiment day will remain comparable. Should there be a change from measurement to measurement, an error can be introduced. The plantar side of the os calcis, alined for this particular method of scanning, regularly has a higher I_0^* because of a fat pad. Changes in the ratio (high/low) I_0^* would reflect changes in fat content, if one assumes that protein and water changes are more nearly compensated for by the broad water bath of nearly equivalent u_m. Some estimate of the changes in tissue composition can be obtained by comparing the increase in beam penetration through soft tissue to that through the water bath alone. It was determined that an increase in ln (high/low) I_0^* of 0.14 represents 900 milligrams of fat replacing an equal volume of water. This fat equivalency is computed for each scan to check for soft tissue change.

In evaluating the authors' data, the relative changes in mineral content have been examined by comparing the postflight values with the mean of the preflight values. It is assumed that bone size remains unchanged during the study and, therefore, mean absorption changes through bone can be expressed as percent change in mineral content

in a volume of bone. The low I_0^* appears to provide for the most reproducible and consistent bone mineral data (ref. 9) and is the one used in the reporting of bone mineral changes. The slope edge criterion seems to give more consistent edges resulting in smoother bone profiles.

A third program, using the same algorithm as the arm program, is used for calculating standards. Because of the success of the slope method in calculating os calcis mineral, it is currently being applied to the arm and standard programs.

Scan Repositioning

The heel is positioned in a custom-fitted foot mold, and the ulnar styloid is carefully positioned opposite a reference mark on the arm holder. Even so, differences in positioning do occur. The final choice of areas on a scan is made by matching bone width profiles.

Heel profiles are obtained by plotting bone width as a function of scan row locations. A reference landmark, such as a maximum or a minimum, is used to match sequential scans. Nine rows in the central os calcis that give a minimum variation in mineral content if the positioning varies by one row are usually chosen for analysis. Figure 9 shows three heel profiles and the chosen rows.

Arm scans are matched by comparing widths of the radius, the interbone gap, and the ulna. The distal-most rows (in the more trabecular region) are chosen for most studies.

As a final check on the row matching, contour displays of the scans are compared (fig. 10). The contour displays are photographed from a defocussed oscilloscope screen and represent digital data converted to an eight-level gray scale.

Calibration

In the equation $BMC = K\sum\ln(I_0^*/I)$, the count rate I is highly energy dependent. The ^{125}I source used in scanning produces a spectrum of energies (principally 27.5, 31, and 35 keV, although the 31- and 35-keV peaks are attenuated by a tin filter). Therefore, energy calibration of the single channel analyzer is important to reproduce the 27.5 ± 7 keV window. For this purpose, the 27.5-keV peak of ^{125}I and the 22- and 88-keV peaks of cadmium-109 are used.

The entire system is calibrated before and after each scan by making four passes over a standard consisting of three chambers containing dipotassium hydrogen phosphate to simulate bone attenuation (ref. 10). The prescan and postscan computer unit values $K\sum\ln(I_0^*/I)$ are averaged for each "bone," and a calibration curve of actual bone mineral content (the known values of the standard) as a function of computer units is made. The regression equation derived is used to calculate the bone mineral content. The values of this standard in grams per centimeter have been determined by Witt et al. (ref. 10), and the values in milligrams per square centimeter were determined by comparison with a hydroxyapatite step wedge (ref. 11 and fig. 11). Both values are given in table I.

Mission Schedules

The measurement schedules for the three Apollo missions (14, 15, and 16) are given in table II. During the postflight period of Apollo 14, because of the space restrictions in the MQF and the isolation restrictions of the LRL, only a single scanner could be deployed in each of these areas. For this reason, arm and heel scans were performed separately using the same scanner in each of the two configurations. The scanner setup was performed by the flight surgeon. The data acquisition electronics were located outside of the quarantine area with passthrough cable connectors installed previously in the bulkhead of the MQF (fig. 12) and the wall of the crewmen's communication and visiting area of the LRL (fig. 13). On the two subsequent missions, arm and heel studies were performed simultaneously both preflight and postflight, because quarantine was no longer required. Duplicate sets of equipment were provided (fig. 14).

RESULTS

In general, no mineral losses were observed in the os calcis, radius, and ulna during the 10-day Apollo 14 flight (tables III, IV, and V). The lunar module pilot (LMP) had a change of mineral in the central os calcis of +3.5 percent when immediate preflight and postflight measurements are compared, in contrast to the -0.7 percent for the commander (CDR) and +1.5 percent for the command module pilot (CMP). The preflight measurements varied from +0.8 to -1.1 percent of mean baseline for all three crewmembers. In contrast, there was a greater variation in the three controls of +1.8 to -2.8 percent. Postflight measurements for control subjects 1, 2, and 3 were +2.9, -3.1, and -1.0 percent of mean baseline.

The radius measurements postflight ranged within the values obtained preflight (table IV). When immediate preflight values are compared to postflight values, there were -0.7, +2.2, and -0.3 percent changes for the CDR, LMP, and CMP, respectively.

The ulna mineral content was somewhat more variable, but postflight values were essentially within the preflight range (table V). When immediate preflight and postflight values were compared, there were -3.6, -2.9, and -5.2 percent changes for the CDR, LMP, and CMP. These changes appear to be large; however, there was a ±2.5 to 3.0 percent variation preflight for the CDR and LMP and a -7.2 to +5.7 percent variation for the CMP. This latter variation appears to be technical rather than real.

A significant change in fat equivalency was observed on the plantar side of the os calcis. Changes were seen in all crewmen immediately postflight. The most significant change was in the CMP's recovery-plus-10-hour (R + 10 hour) measurement. There was a 34 percent increase in fat equivalence when compared to the immediate preflight measurement. This increase would have resulted in a 4.3 percent overestimation of bone mineral if the soft tissue contribution had not been measured. In contrast, the CDR had an 8.4 percent increase and the LMP an 8.1 percent increase with a potential 2.2 to 2.5 percent overestimation in mineral.

As with the Apollo 14 crew, no mineral losses were observed during the 11-day Apollo 16 flight. The left os calcis mineral values immediately postflight were +1.2, +0.4, and +0.4 percent of mean baseline for the CDR, CMP, and LMP, respectively

(table VI). The four controls measured on the day before recovery were -0.6, +1.5, +2.5, and -0.3 percent of mean baseline. Therefore, no changes can be attributed to the flight.

The distal radius mineral measurements immediately postflight were +1.0, +2.1, and +1.5 percent of mean baseline for the CDR, CMP, and LMP, respectively (table VII). The four controls were +0.1, +0.1, +0.5, and .0 percent of mean baseline on the day before recovery. These values are within the ±2 percent accuracy of the technique, and no radius mineral losses can therefore be attributed to the flight. The distal right ulna values immediately postflight were -2.2, -3.5, and -3.3 percent of mean baseline for the CDR, CMP, and LMP, respectively (table VIII). Similar values (-2.8, -2.9, -0.5, and -2.7 percent) were observed in the controls on the day before recovery. It is therefore reasonable to conclude that there were no significant changes from preflight in the Apollo 16 crew.

The Apollo 15 data differed somewhat from that obtained on Apollo 14 and 16 in that two crewmen lost mineral from the left central os calcis during this mission (table IX). When compared with the mean baseline values, there were -6.6, -7.3, and -0.5 percent changes in the CDR, CMP, and LMP, respectively. The changes for control subjects 1, 2, and 3 were +0.3, -0.2, and -2.8 percent, respectively. The CDR regained his mineral more rapidly than the CMP, and both were near baseline values by the end of 2 weeks. The magnitude of these losses must be evaluated in terms of the variability in the controls observed during the postflight period. Taken in this context, the losses exhibited by the CDR and CMP could more likely reflect losses of 5 to 6 percent due to the weightless state alone.

There were essentially no changes in radius mineral during flight, namely -1.1, -2.3, and -1.0 percent for the CDR, CMP, and LMP, respectively (table X). Changes for control subjects 1, 2, and 3 were -1.6, -0.9, and +0.1 percent, respectively. Also, the crew's ulna mineral changes were not significant when compared with the control subjects (table XI). Immediate postflight values differed from the mean preflight by -1.4, -3.6, and -1.8 percent for the CDR, CMP, and LMP, respectively. Changes for control subjects 1, 2, and 3 were +0.6, +0.1, and -2.2 percent, respectively. The -3.6 percent mineral change in the CMP may be significant, but he was +1.4 percent of the mean baseline the following day. As noted in the Apollo 14 and 16 crews, there is a greater variation in the ulnar mineral determinations.

Whereas there were significant changes in the soft tissue composition in the CMP of Apollo 14, there were no significant changes in any of the Apollo 15 or 16 crewmembers.

DISCUSSION

The purpose of this study was to anticipate the effect of weightlessness on bone during prolonged space exploration. Ground-based studies designed to mimic the altered physiologic state were used to construct a time-effect curve. Bed rest, which most closely resembles the weightless state, has served as an experimental model to assess the bone mineral changes observed during bed-rest periods of up to 36 weeks and to determine what remedial measures might be used to stem the tide of bone

mineral loss. The loss of bone mineral in the bedridden patient has long been recognized. Contrary to previous reports, total recovery does occur (ref. 5).

The early reports of significant bone mineral losses in the 5- to 14-day Gemini flights served to emphasize the need for correlating the bed-rest-induced mineral losses with those observed during varying periods of weightlessness. Time-effect curves for both situations need to be established so that better estimates can be obtained on the risk of prolonged space flight as translated from the ground-based bed-rest studies.

Using a gamma photon absorptiometric technique, a time-effect curve was constructed for the bed-rest state. The following conclusions were derived:

1. Periods of up to 36 weeks of bed rest can account for a 40 percent mineral loss from the central os calcis (ref. 5). This bone is both highly trabecular as well as weight bearing. In contrast, the radius (a primarily cortical and non-weight-bearing bone) failed to exhibit mineral losses during periods of up to 30 weeks of bed rest (ref. 12). It is acknowledged that the muscular forces may not have been reduced in the case of the radius and that the hydrostatic forces may not have been sufficiently altered to result in a breakdown in homeostasis.

2. The amount of initial mineral content in the os calcis can influence the rate of mineral loss (ref. 12). In a study of 19 subjects on 17 to 36 weeks of bed rest, two groups of subjects emerged: those who exhibited a high mineral content at the onset and eventually lost the least mineral both in percent and in quantity, and those who exhibited a low mineral content at the onset and lost at a greater rate than the other group.

3. The rate of mineral loss in general, but not in all cases, was greatest during the second 12 weeks of bed rest and the least after the 24th week.

4. The mean rate of mineral loss in the os calcis was approximately 5 percent per month, in contrast to a whole body calcium loss of 0.5 percent per month. Therefore, the os calcis is not representative of all the bones in the body, and weight-bearing bones are more inclined to lose mineral in the recumbent state than the non-weight-bearing bones.

5. The rate of mineral regain after reambulation follows a pattern roughly similar to that of the loss; that is, if the maximal loss took 24 weeks, regain to baseline also took approximately 24 weeks.

6. Little or no os calcis mineral loss was observed in less than 21 days of bed rest and often was not observed until after 15 weeks (table XII).

From these data, a predictive model was established for the bed-rest situation. In this model, the ratio of initial mineral content to the initial 24-hour urinary hydroxyproline excretion is related to observed losses (ref. 13). The greater this ratio, the slower and smaller the losses and, conversely, the smaller the ratio, the faster and greater the losses. The accurate measurement of baseline 24-hour urinary hydroxyproline excretion is therefore an essential requirement for this prediction term.

Because of the limited available data, no time-response curve was established for the weightless state. It appears, however, that the time-response curve obtained

from the bed-rest studies may be more prolonged with respect to the time of onset of demineralization than is observed in true weightlessness (refs. 5, 6, and 7). Yet, this does not appear to be true for all crewmen; in particular, the Apollo 14 and 16 crewmen and the LMP of Apollo 15 had no calcaneal mineral losses in 10 to 21 days.

Repetitive studies of normal ambulatory males carried out over 6 to 8 months exhibited a 0.9 to 1.5 percent standard deviation from the mean in repetitive measurements performed every 2 to 3 weeks (table XIII). Furthermore, control subjects 1 and 2 studied during the Apollo 14, 15, and 16 missions had maximal variations from their mean values of -2.7 to +2.1 percent for control subject 1 and -2.4 to +2.1 percent for control subject 2 (table XIV). Therefore, it seems reasonable that not only did the six Apollo 14 and 16 crewmen and the LMP of Apollo 15 fail to lose calcaneal mineral (table XV), but that the 2.9 and 2.8 percent losses for the Gemini VII crewmen, 2.1 and 3.0 percent losses for the CDR and CMP of Apollo 8, and 0.8 and 2.3 percent gain for the LMP and CMP of Apollo 7 could also represent minimal or no losses from this bone (table XVI).

These data must be contrasted to the 7.8 and 10.3 percent losses in Gemini IV, 15.1 and 8.9 percent losses in Gemini V, 7.0 percent loss for the LMP on Apollo 8, 5.4 percent loss for the CDR on Apollo 7, and the reported losses of 6.7 and 7.8 percent for the CDR and CMP of Apollo 15 (table XVII). The 6.7 and 7.8 percent mineral losses for the 12-day mission (Apollo 15) are in line with losses observed during the 18-day Soyuz 9 mission where there was no interlude of 1/6-g lunar gravity (ref. 14).

Losses of this magnitude did not occur in the authors' bed-rest subjects until after the 10th week: very little significant change was evident until the 4th to 6th week of bed rest. This appears to be similar to the comparisons made by Biriukov and Krasnykh (ref. 14) who considered the Soyuz 9 flight to be similar to their 62- to 70-day bed-rest confinement. Krasnykh's studies of 70- to 73-day bed-rest subjects (ref. 15) resulted in an observed average loss of 11.1 percent in five subjects, without total recovery occurring after 20 to 40 days of reambulation. This observation appears to be similar to the authors' studies where an average loss of 10.5 percent was observed in eight subjects after 10 weeks of bed rest, with recovery after reambulation requiring a time approximately equivalent to the duration of bed rest.

Clearly, there are no known experimental differences to account for all of these observations. Only in Apollo 14, 15, and 16 were there exposures to 1/6-g for short periods of time. Of the six crewmen who experienced such an exposure, only the CDR of Apollo 15 had mineral losses in the os calcis, and he experienced a more rapid recovery than the CMP who had no such exposure. Yet, the CMP for Apollo 14 and 16 did not experience any mineral losses. Of the nine crewmen studied, the CDR and CMP of Apollo 15 had the greatest baseline mineral content; that is, 706.2 and 704.7 mg/cm^2, respectively, while the LMP had 576.3 mg/cm^2. The Apollo 14 crew had 562.0, 520.4, and 673.1 mg/cm^2, and the Apollo 16 crew had 606.3, 601.4, and 532.6 mg/cm^2. The losses experienced during Apollo 15 are at variance with the bed-rest observations. Only limited urinary hydroxyproline data are available for deriving prediction terms; therefore, an assessment of these data for such a term must be deferred.

The level of dietary calcium and phosphorus appears to have some effect on the rate of mineral loss in bed-rest subjects (ref. 16). Some initial protective effect is observed when supplemental calcium and phosphorus are administered (ref. 7). In examining the data available, the calcium intake could be considered low only in the case of the crews of Gemini IV and V, the crew of Apollo 8, the CDR of Apollo 7, and the CMP of Apollo 16; all others had an excess of 700 milligrams of calcium in their diet (table XVII). Additional exercise could have been a factor during Gemini VII and the Apollo missions as well as on Soyuz 9. Nevertheless, at this time, no clear-cut pattern can be developed from the data available.

The results of the authors' Apollo studies contrast most sharply with the previously reported flight mineral data in the case of the radius and ulna. In none of these missions were there any significant losses in either of these bones for any of the crewmen or controls. In these studies, the most distal area of the ulna and radius, where the two bones are distinctly separated, was measured. This is the more trabecular area of these bones. As shown in table XVI, there were variations in Apollo 7 of -3.3, +3.4, and -3.6 percent for the radius and -3.0, +2.1, and -3.4 percent for the ulna. These data are not particularly different from the authors' data (table XVII) of -0.1, +1.5, and +1.5 percent for the radius and -1.6, -0.3, and +0.3 percent for the ulna on Apollo 14; 0.0, -0.7, and -1.9 percent for the radius and -1.7, -3.5, and -3.1 percent for the ulna on Apollo 15; and +1.0, +1.5, and +2.1 percent for the radius and -2.2, -3.3, and -3.5 percent for the ulna on Apollo 16. In contrast, the reported values for Gemini V were -25.3 and -22.3 percent for the radius with no data available for the ulna, and those for Apollo 8 were -8.8, -11.1, and -11.4 percent for the radius and -6.4, -12.4, and -16.2 percent for the ulna. Data for these two bones have not been reported for Soyuz 9, and, to date, no data have been reported on Soyuz 11.

It is not possible at this time to attempt any correlations on these conflicting data. Clearly, Gemini VII and Apollo 7 had the greatest similarity to the authors' Apollo 14, 15, and 16 results and Gemini IV and V and Apollo 8 had the least. Based on the bed-rest experience, one would not have expected significant losses from the upper extremity bones. The differences between the photon absorptiometric and X-ray densitometric techniques can account partly for these differences. The accuracy of the radiographic technique has been considered to approach 10 percent, whereas the photon absorptiometric technique can claim a 2 percent accuracy (ref. 17). It would appear that the forces generally applied to the upper extremity bones are still applied during flight, although they are significantly reduced. In contrast, except for the lunar excursion periods, compression forces, most vital to the integrity of the os calcis, are completely removed from that bone. It is hoped that data from the nine Skylab crewmen will resolve the radius and ulna data discrepancies.

Reliable calcium balance data for these missions are not available. The only mission that used a metabolic balance technique was Gemini VII (ref. 18). During this mission, the net calcium balance was distinctly less positive for both crewmen. The mean urinary calcium increased during the second week by 23 percent for the command pilot (CP) and 9 percent for the pilot (P); the latter not being significant. However, the changes in calcium balance were appreciable. In addition to weightlessness, investigators speculate that high oxygen atmosphere, high altitude, exercise, and dietary protein reduction were factors that contributed in varying degrees to the calcium balance changes in these two crewmen. The greater negativity of the CP was supported by a slightly greater mineral loss in the hand phalanx 4-2 (-6.55 percent compared to

-3.82 percent) and distal talus (-7.06 percent compared to -4.0 percent) but not by the os calcis (-2.9 percent compared to -2.8 percent), capitate (-4.31 percent compared to -9.3 percent), or the hand phalanx 5-2 (-6.78 percent compared to -7.83 percent) (tables XVI and XVIII).

The CDR on Apollo 8 is estimated to have had a 1.01-g/day mass balance deficit, and the average for all three crewmen on Apollo 7 was a 0.59-g/day deficit (ref. 19). These data are based on the examination of only fecal calcium and are only approximate because the fecal calcium excretion was assumed to be a constant 80 percent of the daily total. This value has been shown to vary between 69.4 and 91.6 percent. In the authors' bed-rest studies (refs. 5, 6, and 7), the calcium balance became negative almost immediately and reached a peak in the fifth to eighth week with a range of about 250 ± 200 mg/day (two standard deviations) (ref. 7). These Apollo data reflect a greater negative balance that might account for an earlier onset of the mineral loss.

Other bones were studied by X-ray densitometry, and the results obtained are listed in table XVIII for completeness. No specific pattern can be ascribed to these results on the basis of duration of weightlessness (table XIX), calcium intake (table XVII), or physical activity. The crew of Gemini V appears to have had the greatest losses in all of the bones studied.

CONCLUSIONS

It is concluded that loss of mineral from bone incident to periods of weightlessness is comparable to that observed in bed-rest subjects and that the magnitude is not severe. If these losses were allowed to continue unabated for a prolonged period of time, the consequences might be more serious because the losses are probably not confined to the bones described. Because of either biological variability between subjects or factors not yet identified, not all crewmen have been similarly affected during the 10- to 12-day missions. The prediction terms used in the authors' bed-rest studies will be applied to the flight data when the anticipated Skylab data become available. Should a similar relationship become apparent, the conflict in the Gemini and Apollo data may be resolved. These studies can then be used to construct a time-effect curve that can be compared with the bed-rest data, thus permitting a reasonable degree of prediction for longer space missions. It will also allow an assessment of the applicability of the remedial measures tested. Only an adequate number of crew data will accomplish this goal.

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National Aeronautics and Space Administration
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TABLE I. - STANDARD VALUES OF SIMULATED BONE

[From ref. 10]

Simulated bone chambers	Mean in —	
	mg/cm^2	g/cm
1	311.56	0.331
2	351.91	.568
3	671.31	1.278

TABLE II. - MISSION MEASUREMENT SCHEDULES

Mission	Launch date	Mission duration, hr:min	Mission measurements			
			Preflight		Postflight	
			Time	Place	Time	Place
Apollo 14	Jan. 31, 1971	216:42	[a]F - 26 days	JSC	[b]R + 10 hr	MQF U.S.S. New Orleans
			F - 15 days	KSC	R + 30 hr	MQF U.S.S. New Orleans
			F - 6 days	KSC	R + 6 days	LRL
					R + 16 days	LRL
Apollo 15	July 26, 1971	295:12	F - 27 days	KSC	R + 3 to 7 hr	U.S.S. Okinawa
			F - 13 days	KSC	R + 2 days	JSC
			F - 5 days	KSC	R + 5 days	JSC
					R + 14 days	JSC
Apollo 16	Apr. 16, 1972	265:51	F - 30 days	JSC	R + 4 to 7 hr	U.S.S. Ticonderoga
			F - 15 days	KSC	R + 24 to 26 hr	U.S.S. Ticonderoga
			F - 5 days	KSC	R + 3 days	JSC
					R + 7 days	JSC

[a]F = flight (lift-off).

[b]R = recovery.

TABLE III. - APOLLO 14 OS CALCIS MINERAL CONTENT CHANGE

[Percent change from mean baseline[a]]

Time, days	Crewmen			Control subjects		
	CDR	LMP	CMP	1	2	3
F - 26	·0 7	+0 2	+0.2	-1.8	+0.6	+1.0
F - 15	-1.1	-.3	+.8	+1.5	-1.5	-2.8
F - 6	+.3	+.2	-1.0	+.3	+.9	+1.8
R - 8	--	--	--	-.5	+.9	--
R - 2	--	--	--	.0	--	--
[b]R + 10	-.4	+3.7	+.5	--	--	--
[b]R + 30	--	+3.3	--	--	--	--
R + 6	-2 6	+5.9	+.2	+2.9	--	--
R + 16	-1.0	+4.8	+1.2	0	--	--
R + 18	--	--	--	--	-3.1	-1.0

[a]Based on hydroxyapatite equivalency in milligrams per square centimeter, mean value for nine rows scanned

[b]Hours.

TABLE IV - APOLLO 14 RIGHT RADIUS MINERAL CONTENT CHANGE

[Percent change from mean baseline[a]]

Time, days	Crewmen			Control subjects		
	CDR	LMP	CMP (b)	1	2	3
F - 26	-0 7	-3 5	-5 3(--)	-1.6	-1.5	-3.9
F - 15	· 1	+4 1	·3 5(· 8)	· 3	· 1	·1.1
F - 6	· 6	-.7	·1.8(- 8)	· 1 3	· 1 0	· 2 8
R - 6	--	--	--	- 6	+.5	--
R + 1	- 1	·1.5	+1.5(-1.1)	--	--	--
R + 6	- 4	·1 4	·3 5(· 9)	· 2 3	--	--
R + 16	· 3	·3 4	·3 3(· 7)	· 1.8	--	--
R + 18	--	--	--	--	· 2 2	·4 7

[a]Based on corrected computer unit values

[b]Percent values in parentheses based on only two baseline values; the first being omitted

TABLE V. - APOLLO 14 RIGHT ULNA MINERAL CONTENT CHANGE

[Percent change from mean baseline[a]]

Time, days	Crewmen			Control subjects		
	CDR	LMP	CMP (b)	1	2	3
F - 26	-2.1	-0.1	-7.2(--)	-1.5	-1.5	-0.1
F - 15	+.1	-2.5	+1.5(-2.0)	+1.8	-.9	+1.1
F - 6	+2.0	+2.6	+5.7(+2.0)	-.3	+2.3	-.9
R - 6	--	--	--	-1.0	+3.4	--
R + 1	-1.6	-.3	(c)	--	--	--
R + 6	+3.0	-2.7	+.3(-3.2)	+1.1	--	--
R + 16	-.3	0	-.5(-3.8)	-2.0	--	--
R + 18	--	--	--	--	-.5	-2.0

[a]Based on corrected computer unit values.

[b]Percent values in parentheses based on only two baseline values: the first being omitted.

[c]No match in ulna width. Data not val[i]

TABLE VI. - APOLLO 16 LEFT OS CALCIS MINERAL CONTENT CHANGE

[Percent change from mean baseline]

Time, days	Crewmen			Control subjects			
	CDR	CMP	LMP	1	2	3	4
F - 30	-0.4	-0.5	+1.0	-0.1	+2.3	-0.8	+1.9
F - 15	-.1	+.1	-.9	+1.4	-.5	+1.7	-1.2
F - 5	+.5	-.3	-.2	-1.3	-1.8	-1.0	-.7
R - 2	--	--	--	+.4	-.3	0	-.1
R - 1	--	--	--	-.6	+1.5	+2.5	-.3
[a]R + 4 to 7	+1.2	+.4	+.4	--	--	--	--
[a]R + 24	-1.0	-1.5	+1.4	--	--	--	--
R + 3	-.4	-2.5	-.8	-.7	-.2	+.5	-1.1
R + 7	--	-1.4	--	+2.4	+1.6	+2.4	+.3

[a]Hours.

TABLE VII. - APOLLO 16 RIGHT RADIUS MINERAL CONTENT CHANGE

[Percent change from mean baseline]

Time, days	Crewmen			Control subjects			
	CDR	CMP	LMP	1	2	3	4
F - 30	+0.3	+0.2	+1.6	-0.2	-0.2	+0.8	+2.7
F - 15	+.1	+1.2	-.3	+.3	0	+.3	-.7
F - 5	-.4	-1.4	-1.3	-.1	+.3	-1.1	-2.0
R - 2	--	--	--	-.5	-1.6	-1.6	+.1
R - 1	--	--	--	+.1	+.1	+.5	0
[a]R + 4 to 7	+1.0	+2.1	+1.5	--	--	--	--
[a]R + 24	-.9	+2.0	-1.4	--	--	--	--
R + 3	+1.0	-.9	-.2	+1.0	-1.0	-1.2	+1.3
R + 7	--	+1.1	--	+.5	-1.2	+.6	-.3

[a]Hours.

TABLE VIII. - APOLLO 16 RIGHT ULNA MINERAL CONTENT CHANGE

[Percent change from mean baseline]

Time, days	Crewmen			Control subjects			
	CDR	CMP	LMP	1	2	3	4
F - 30	-1.3	+0.4	+1.2	+0.8	+0.4	+0.5	+2.5
F - 15	+.1	-.5	+1.6	-.4	-.5	+1.0	-2.1
F - 5	+1.2	+.2	-2.8	-.4	+.1	-1.4	-.4
R - 2	--	--	--	-3.2	-5.2	+1.7	-.8
R - 1	--	--	--	-2.8	-2.9	-.5	-2.7
[a]R + 4 to 7	-2.2	-3.5	-3.3	--	--	--	--
[a]R + 24	-1.1	+1.5	+1.7	--	--	--	--
R + 3	-1.0	+.3	-4.7	+1.1	-.6	+1.8	+2.6
R + 7	--	-1.8	--	+.6	-1.4	+3.2	+2.5

[a]Hours.

TABLE IX.- APOLLO 15 LEFT OS CALCIS MINERAL CONTENT CHANGE

[Percent change from mean baseline[a]]

Time, days	Crewmen			Control subjects		
	CDR	CMP	LMP	1	2	3
F - 27	+0.1	-0.9	+0.1	-0.7	-1.7	0
F - 13	-.2	+.4	-.2	+.6	+2.0	+.3
F - 5	+.1	+.5	+.1	+.1	-.3	-.3
R - 2	--	--	--	-2.2	-1.1	-1.0
R + 0	-6.6	-7.3	-.5	--	--	--
R + 1	-3.1	-5.7	-1.0	+.3	-.2	-2.8
R + 5	-2.4	-3.5	-.08	-1.7	-1.3	-2.4
R + 14	-1.4	-1.7	--	--	+2.0	+.5

[a]Based on milligrams per square centimeter of hydroxyapatite in nine rows of the central os calcis.

TABLE X.- APOLLO 15 RIGHT RADIUS MINERAL CONTENT CHANGE

[Percent change from mean baseline[a]]

Time, days	Crewmen			Control subjects		
	CDR	CMP	LMP	1	2	3
F - 27	+0.4	+0.7	+0.2	+0.9	+2.5	+1.7
F - 13	+.8	-.3	+.1	-1.0	-1.7	0
F - 5	-1.1	-.4	-.3	0	-.8	-1.7
R + 2	--	--	--	-3.5	-4.0	-1.1
R + 0	-1.1	-2.3	-1.0	--	--	--
R + 1	-4.7	-2.6	-3.3	-1.6	-.9	+.1
R + 5	-.1	-.6	+1.6	-2.5	-.5	-1.3
R + 14	+.1	-.3	--	--	-1.3	-2.5

[a]Based on grams per centimeter of bone mineral as derived by Cameron (ref. 17).

TABLE XI. - APOLLO 15 RIGHT ULNA MINERAL CONTENT CHANGE

[Percent change from mean baseline[a]]

Time, days	Crewmen			Control subjects		
	CDR	CMP	LMP	1	2	3
F - 27	+0.6	+0.4	+0.5	+1.3	+2.1	+3.7
F - 13	-.8	+.1	-2.1	+2.4	-.7	-3.2
F - 5	+.3	-.5	+1.7	-3.8	-1.3	-.4
R + 2	--	--	--	-1.3	-2.8	-1.2
R + 0	-1.4	-3.6	-1.8	--	--	--
R + 1	0	+1.4	+2.1	+.6	+.1	-2.2
R + 5	+.9	+.5	-2.1	-3.3	-5.0	+.4
R + 14	0	+1.4	--	--	-1.0	+.7

[a]Based on grams per centimeter of bone mineral as derived by Cameron (ref. 17).

TABLE XII. - OS CALCIS MINERAL CONTENT CHANGES DURING BED REST

[19 subjects - 29 measurements]

Days of bed rest	Subject	Percent of baseline	Days of bed rest	Subject	Percent of baseline
7	G F.	+2.1	23	A D	-4.5
7	B.L.	-.6	24	R.B.	+.8
7	R.W.	0	24	J.F.	-2.4
8	T.A.	-1 5	24	D.M	-.6
8	A.K.	-1.4	24	M H.[a]	+1.0
9	R.G.	-1.2	25	F C.	+.2
10	M.H.	-.8	25	J C	-1.9
14	J.G.	-2.3	25	W.R.	+2.1
16	F.K.	-.5	28	G.M.	+1.2
17	F.B.	0	30	F B.[a]	+.4
17	R.R.	+.5	30	J.G.[a]	-2 5
21	G F.[a]	- 2	30	R.R.[a]	-1.3
21	B.L.[a]	-5.1	31	R.G.[a]	-3.2
22	T.A.[a]	+3.3	31	F.K [a]	-4.1
22	A K [a]	-2 6			

[a]Os calcis mineral change was measured twice for particular subject.

TABLE XIII.- OS CALCIS MINERAL CONTENT

Date, 1971	Content, mg/cm^2	Mean, mg/cm^2	Standard error of the mean, percent	Standard deviation, percent
Control subject 1				
Mar. 22	447.91	447.55	±0.3	±0.9
Apr. 7	443.19			
May 17	437.74			
May 26	446.76			
June 7	449.63			
June 21	446.70			
July 7	452.39			
July 19	448.10			
July 26	450.87			
Aug. 9	448.28			
Aug. 16	453.63			
Aug. 30	445.43			
Control subject 2				
Mar. 22	597.07	586.63	±0.4	±1.3
Apr. 19	585.97			
May 3	588.99			
May 17	585.84			
May 24	589.86			
June 7	576.06			
June 14	580.38			
June 21	596.84			
June 28	573.26			
July 12	588.88			
July 19	596.51			
Aug. 9	585.77			
Aug. 30	580.71			
Control subject 3				
Mar. 22	535.24	528.84	±0.4	±1.5
Apr. 19	533.88			
Apr. 26	526.21			
May 17	523.10			
May 24	541.80			
June 1	520.00			
June 7	530.03			
June 21	532.13			
July 7	539.16			
July 12	519.66			
July 19	528.92			
July 26	513.37			
Aug. 30	531.41			

TABLE XIV. - BONE MINERAL CONTENT OF LEFT OS CALCIS

Control subject	Date	Mineral content, mg/cm^2	Mean ± standard deviation in —	
			mg/cm^2	Percent
Apollo 14				
1	Jan. 4, 1971	493.74	488.70 ± 8.8	1.8
	Jan. 15, 1971	483.29		
	Jan. 24, 1971	495.37		
	Feb. 2, 1971	495.39		
	Feb. 27, 1971	475.69		
2	Jan. 4, 1971	634.68	625.63 ± 11.71	1.9
	Jan. 15, 1971	610.30		
	Jan. 24, 1971	639.77		
	Feb. 18, 1971	621.27		
	Feb. 27, 1971	622.12		
Apollo 15				
1	June 27, 1971	476.45	483.89 ± 7.1	1.5
	July 13, 1971	493.93		
	July 20, 1971	482.95		
	Aug. 5, 1971	478.88		
	Aug. 9, 1971	483.61		
	Aug. 12, 1971	478.12		
	Aug. 19, 1971	493.86		
2	June 27, 1971	632.03	626.17 ± 8.3	1.3
	July 12, 1971	633.73		
	July 19, 1971	630.16		
	Aug. 5, 1971	625.81		
	Aug. 9, 1971	614.26		
	Aug. 12, 1971	616.69		
	Aug. 20, 1971	635.17		
Apollo 16				
1	Mar. 16, 1972	486.49	487.74 ± 6.4	1.3
	Mar. 30, 1972	493.58		
	Apr. 9, 1972	480.22		
	Apr. 25, 1972	488.29		
	Apr. 26, 1972	483.82		
	Apr. 30, 1972	483.36		
	May 4, 1972	498.59		
2	Mar. 16, 1972	631.03	617.90 ± 6.7	1.1
	Mar. 30, 1972	611.61		
	Apr. 9, 1972	614.42		
	Apr. 25, 1972	618.43		
	Apr. 26, 1972	616.96		
	Apr. 30, 1972	611.95		
	May 4, 1972	620.87		

TABLE XV - BONE MINERAL CHANGES DURING

APOLLO 14, 15, AND 16

[Photon absorptiometric technique, percent change from mean baseline]

Mission	CDR	LMP	CMP
Central left os calcis			
Apollo 14	-0.4	-3.7	-0.5
Apollo 15	-6.6	-.5	-7.3
Apollo 16	-1.2	-.4	-.4
Distal right radius			
Apollo 14	-0.1	-1.5	-1.5
Apollo 15	-1.1	-1.0	-2.3
Apollo 16	-1.0	-1.5	-2.1
Distal right ulna			
Apollo 14	-1.6	-0.9	[a]-0.3
Apollo 15	-1.4	-1.8	-3.6
Apollo 16	-2.2	-3.3	-3.5

[a]R - 1 measurement.

TABLE XVI - GEMINI IV, V, AND VII AND APOLLO 7 AND 8

BONE MINERAL CHANGES DURING FLIGHT

Mission	CP,[a] percent	P,[b] percent	CDR percent	LMP percent	CMP, percent
Central os calcis					
Gemini IV	-7.8	-10.3			
Gemini V	-15.1	-8.9			
Gemini VII	2.9	-2.8			
Apollo 7			-5.4	-0.8	-2.3
Apollo 8			-2.1	-7.0	-3.0
Distal radius					
Gemini V	-25.3	-22.3			
Apollo 7			-3.3	-3.4	-3.6
Apollo 8			-8.8	-11.1	-11.4
Distal ulna					
Apollo 7			-3.0	-2.1	-3.4
Apollo 8			-6.4	-12.4	-16.2

[a]Command

[b]Pilot.

TABLE XVII. - BONE MINERAL CHANGE RELATED TO CALCIUM INTAKE

Mission	Crewmen	Calcium, mg	Os calcis, percent	Radius, percent	Ulna, percent
Gemini IV	CP	679	-7.8	--	--
	P	739	-10.3	--	--
Gemini V	CP	373	-15.1	-25.3	--
	P	333	-8.9	-22.3	--
Gemini VII	CP	945	-2.9	--	--
	P	921	-2.8	--	--
Apollo 7	CDR	644	-5.4	-3.3	-3.0
	LMP	925	+.7	+3.4	+2.1
	CMP	938	+2.3		
Apollo 8	CDR	427	-2.1	-8.8	-6.4
	LMP	366	-7.0	-11.1	-12.4
	CMP	479	-2.9	-11.4	-16.2
Apollo 14	CDR	802	-0.4	-0.1	-1.6
	LMP	843	+3.7	+1.5	-.3
	CMP	809	+.5	+1.5	[a]+.3
Apollo 15	CDR	857	-6.7	0	-1.7
	LMP	778	-.6	-.7	-3.5
	CMP	725	-7.8	-1.9	-3.1
Apollo 16	CDR	805	+1.2	+1.0	-2.2
	LMP	705	+.4	+1.5	-3.3
	CMP	468	+.4	+2.1	-3.5

[a]R + 1 measurement.

TABLE XVIII. - MINERAL CHANGES IN OTHER BONES STUDIED

BY X-RAY DENSITOMETRY

Mission	Bone	CP, percent	P, percent	CDR, percent	CMP, percent	LMP, percent
Gemini VII	Distal talus	- 7.06	- 4.00			
	Capitate	- 4.31	- 9.30			
	Phalanx 4-2	- 6.55	- 3.82			
	Phalanx 5-2	- 6.78	- 7.83			
Gemini V	Distal talus	- 13.24	- 9.87			
	Capitate	- 17.10	-16.80			
	Phalanx 4-2	-9.86	-11.80			
	Phalanx 5-2	- 23.20	-16.98			
Gemini IV	Distal talus	-10.69	-12.61			
	Capitate	-4.48	-17.64			
	Phalanx 4-2	-4.19	-8.65			
	Phalanx 5-2	-11.85	-6.24			
Apollo 7	Central talus			- 3.6	+1.8	+2.9
	Phalanx 4-2			- 9.3	+2.0	-6.5
	Capitate			- 4.1	+3.3	-3.4
Apollo 8	Central talus			- 2.6	-2.8	-3.2
	Phalanx 4-2			- 2.2	-2.4	+4.8
	Capitate			- 9.6	-12.1	- 6.7
Soyuz 9	Phalanx II	--	-4.1			
	Phalanx III	-5.0	-5.0			
	Phalanx IV	-3.1	-4.3			
	Phalanx V	-4.7	-8.9			

TABLE XIX. - DURATION OF WEIGHTLESSNESS

Mission	Duration, hr:min
Gemini IV	097:56
Gemini V	190:56
Gemini VII	330:35
Apollo 7	260:00
Apollo 8	147:00
Apollo 14	216:42
Apollo 15	295:12
Apollo 16	265:51
Soyuz 3	094:51
Soyuz 9	424:59

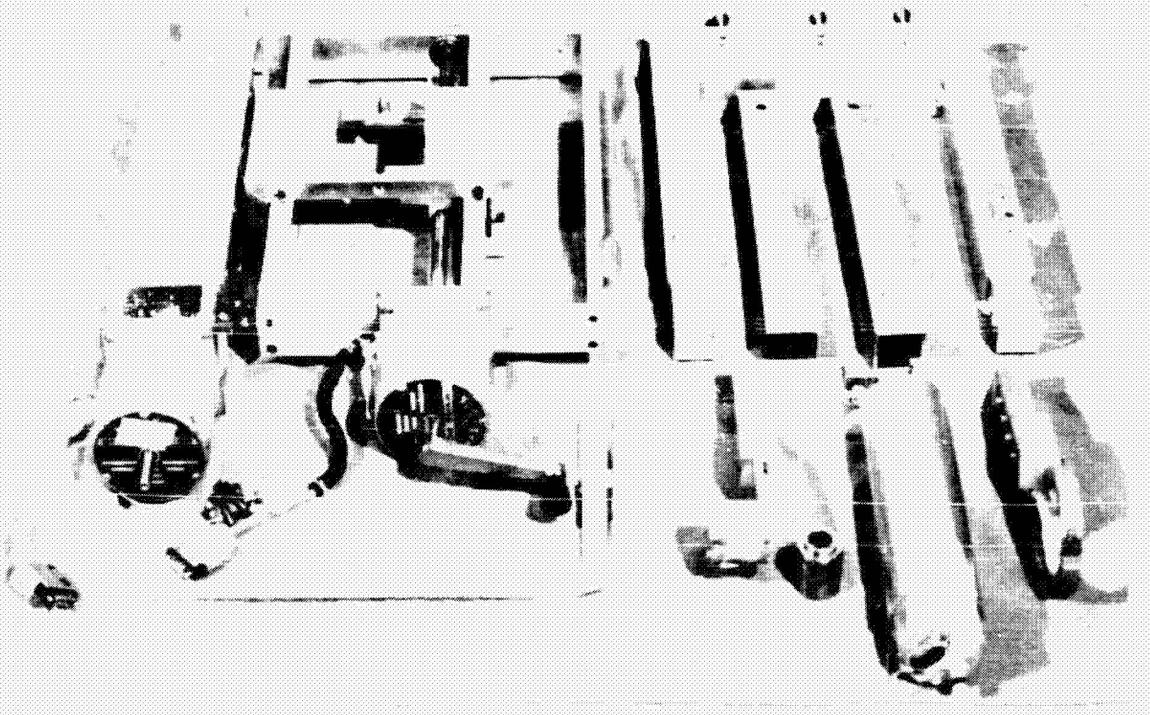
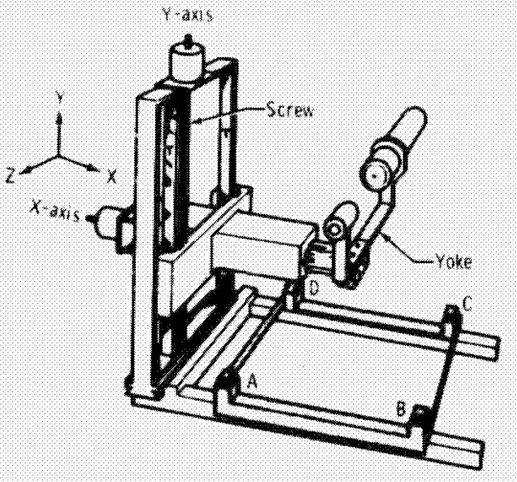
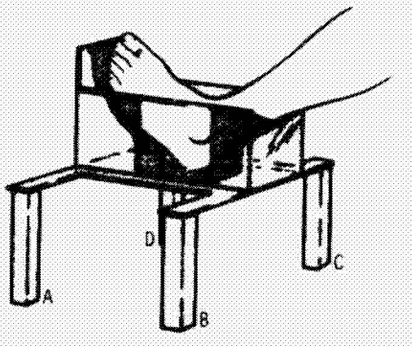


Figure 1.- Scanner disassembled.

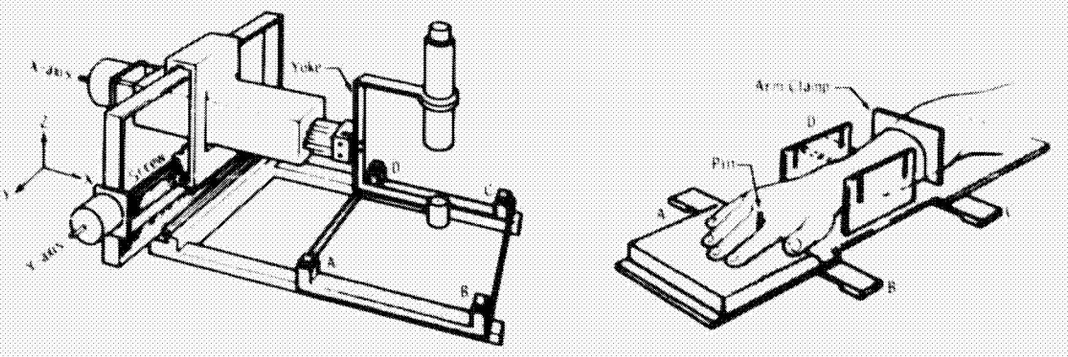


(a) Diagram of heel scanner.



(b) Diagram showing heel mounted and ready for scanning.

Figure 2.- Heel scanner.



(a) Diagram of arm scanner.

(b) Diagram showing arm mounted and ready for scanning.

Figure 3.- Arm scanner.

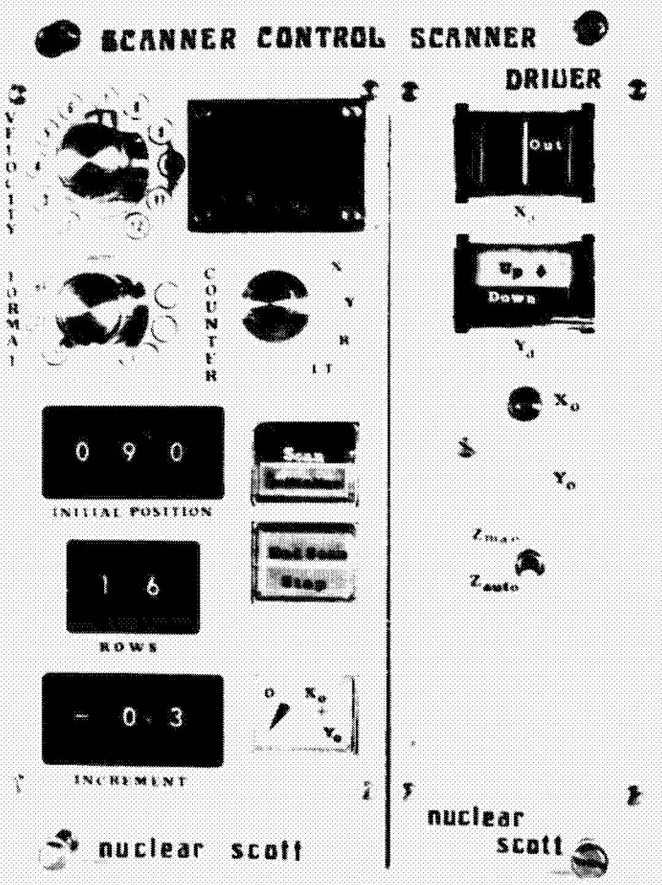


Figure 4.- Scanner control module.

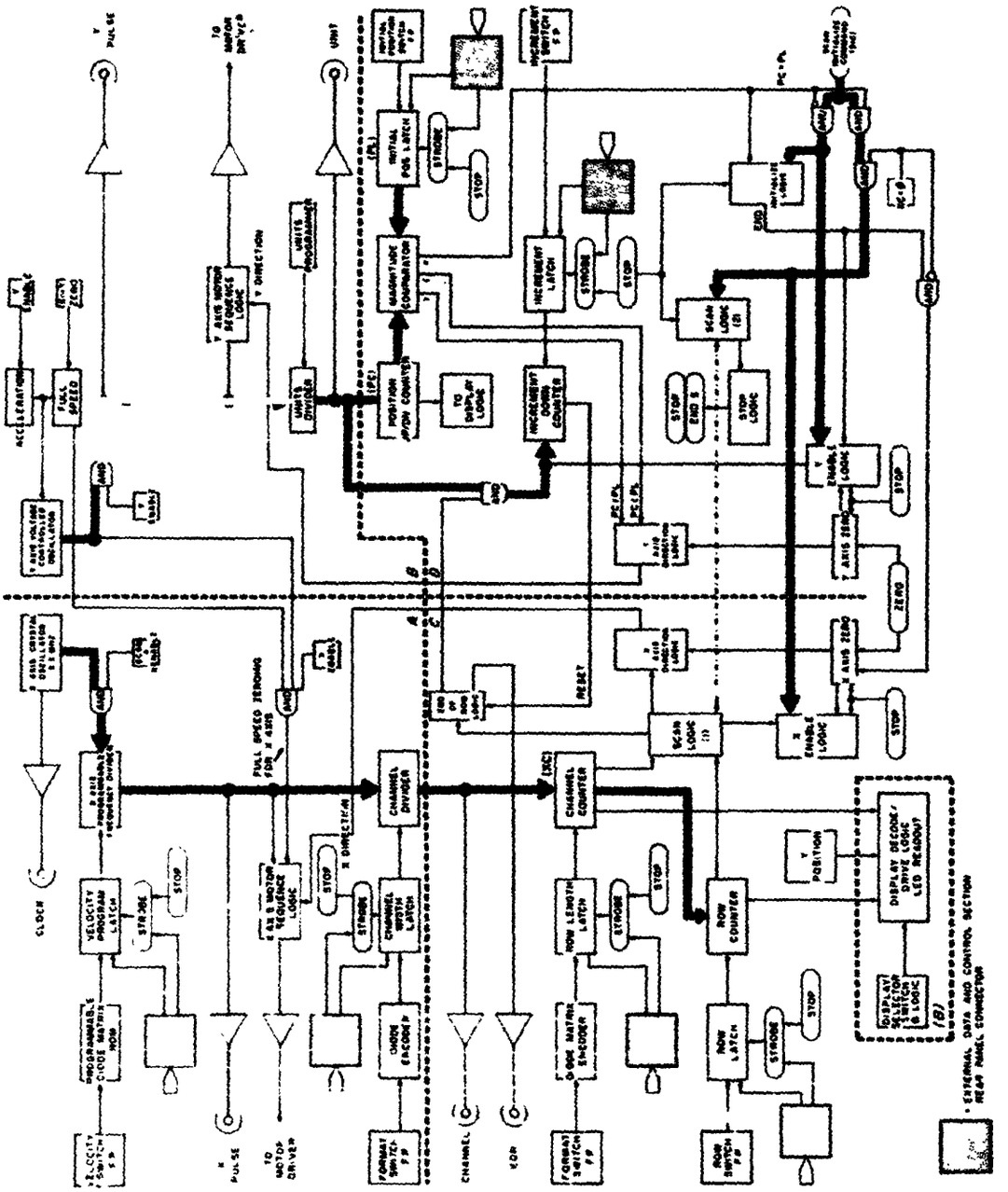


Figure 5. - Block diagram of scanner control module.

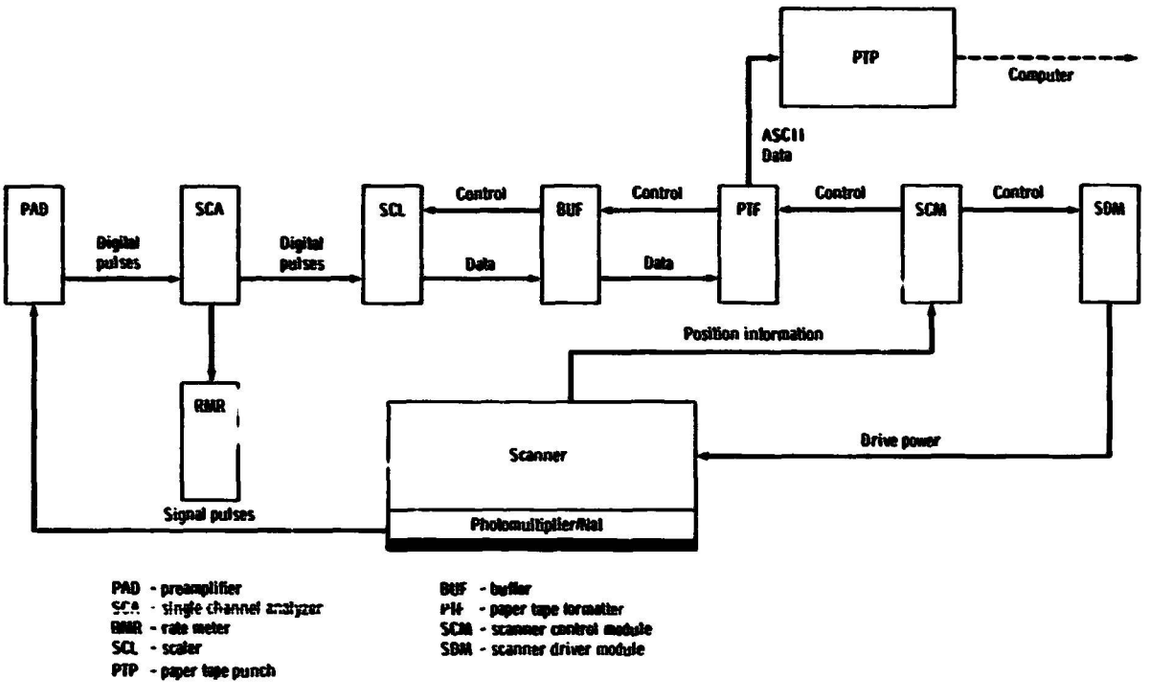


Figure 6.- Data collection electronics.

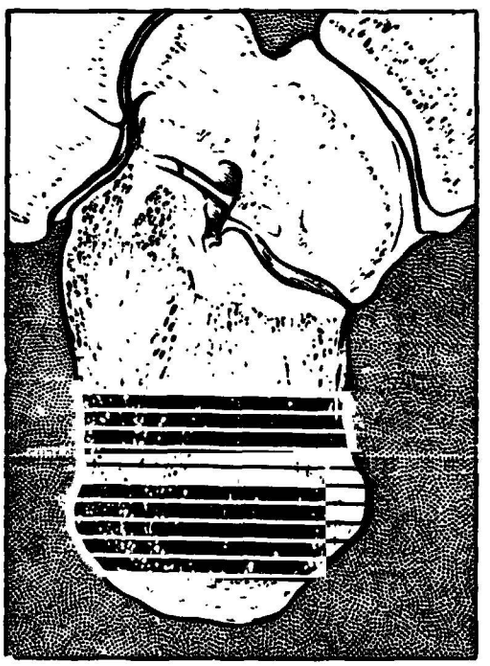


Figure 7.- Schematic representation of os calcis scan rows.

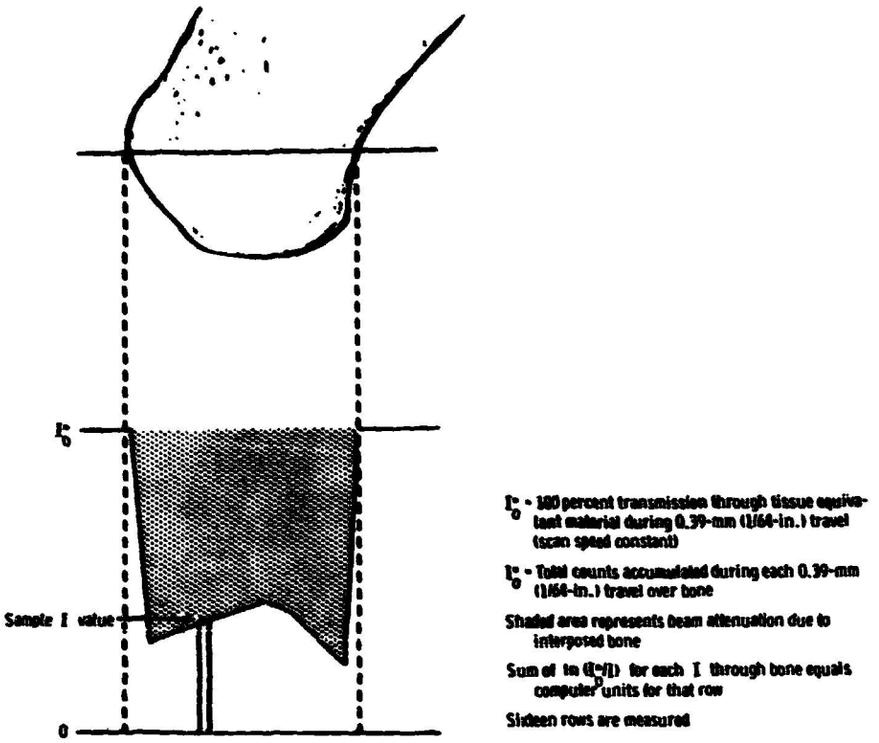


Figure 8.- Method of calculating os calcis bone mineral content.

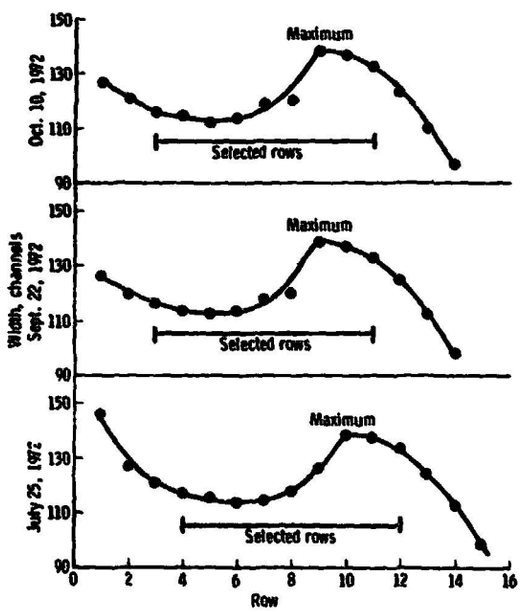


Figure 9.- Heel scan profiles.

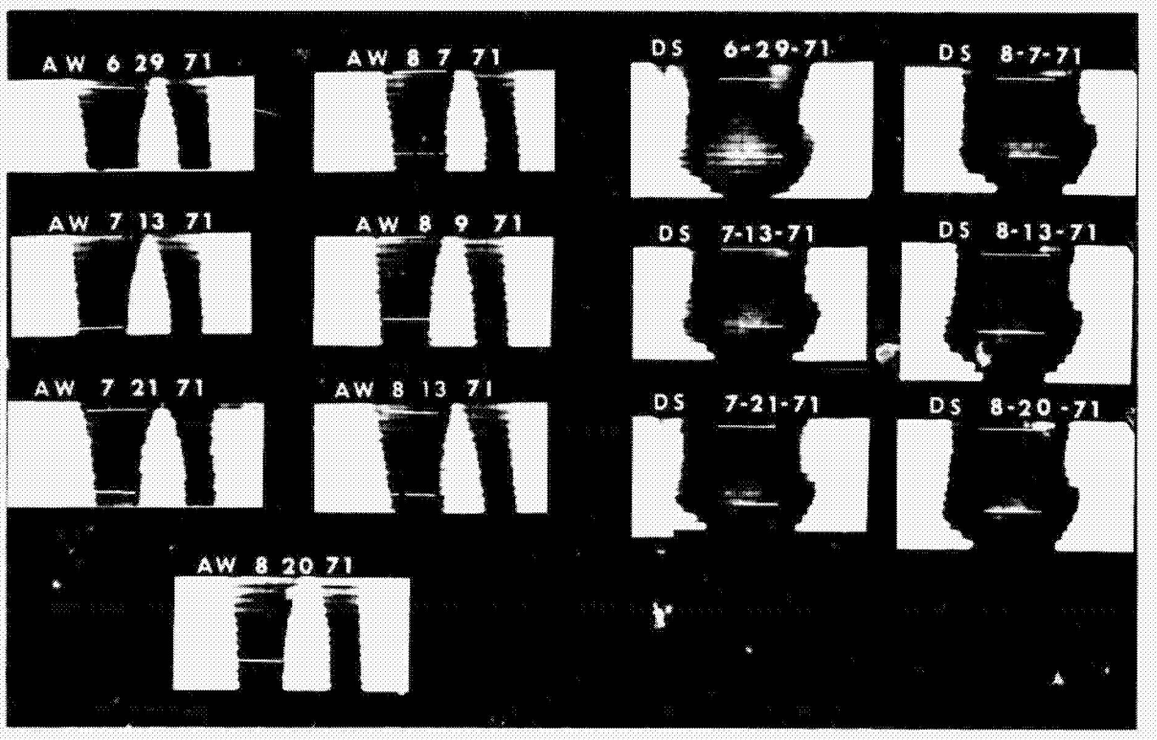


Figure 10. - Contour display of multiple heel and arm scans.

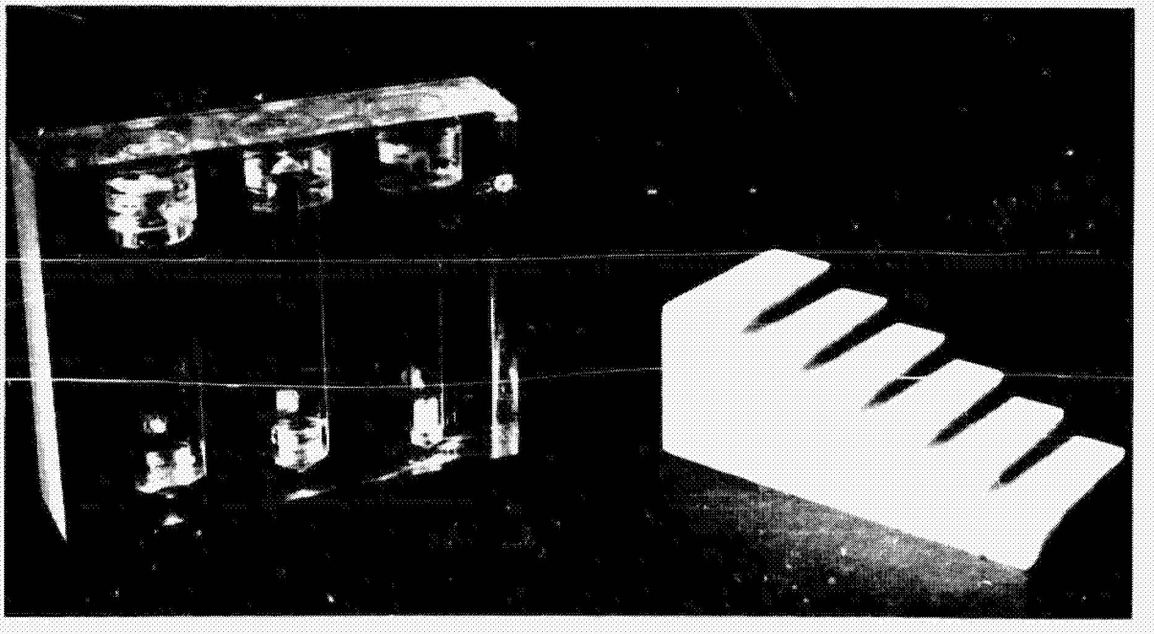


Figure 11. - Witt-Cameron "three-bone" standard and Heuck wedge (hydroxyapatite).

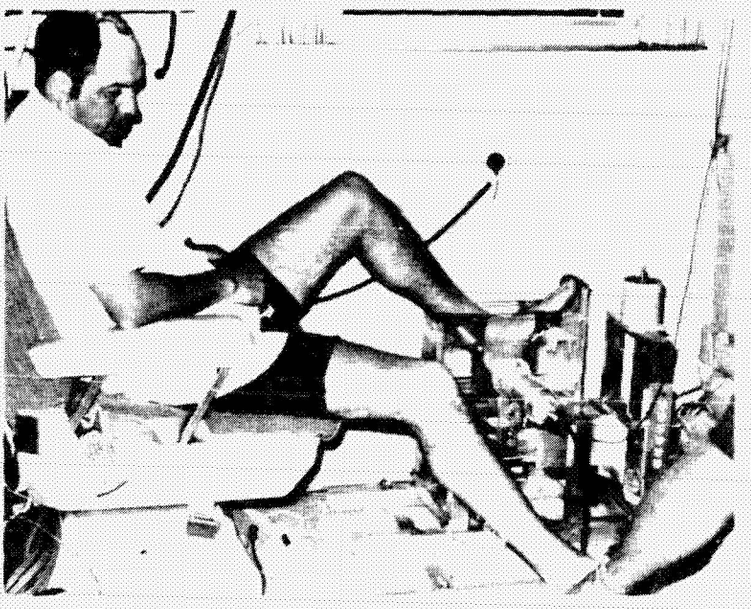


Figure 12. - Heel scanner in the MQF.

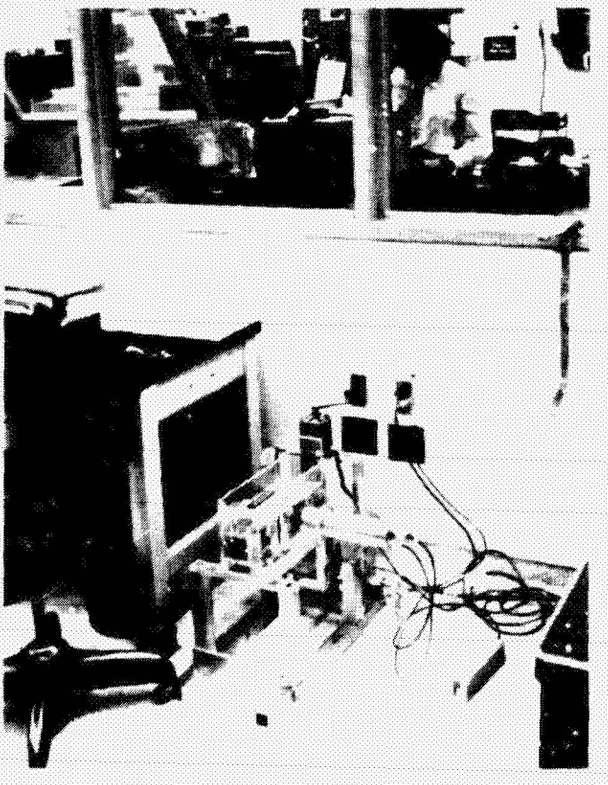


Figure 13. - Heel scanner in the LRL.

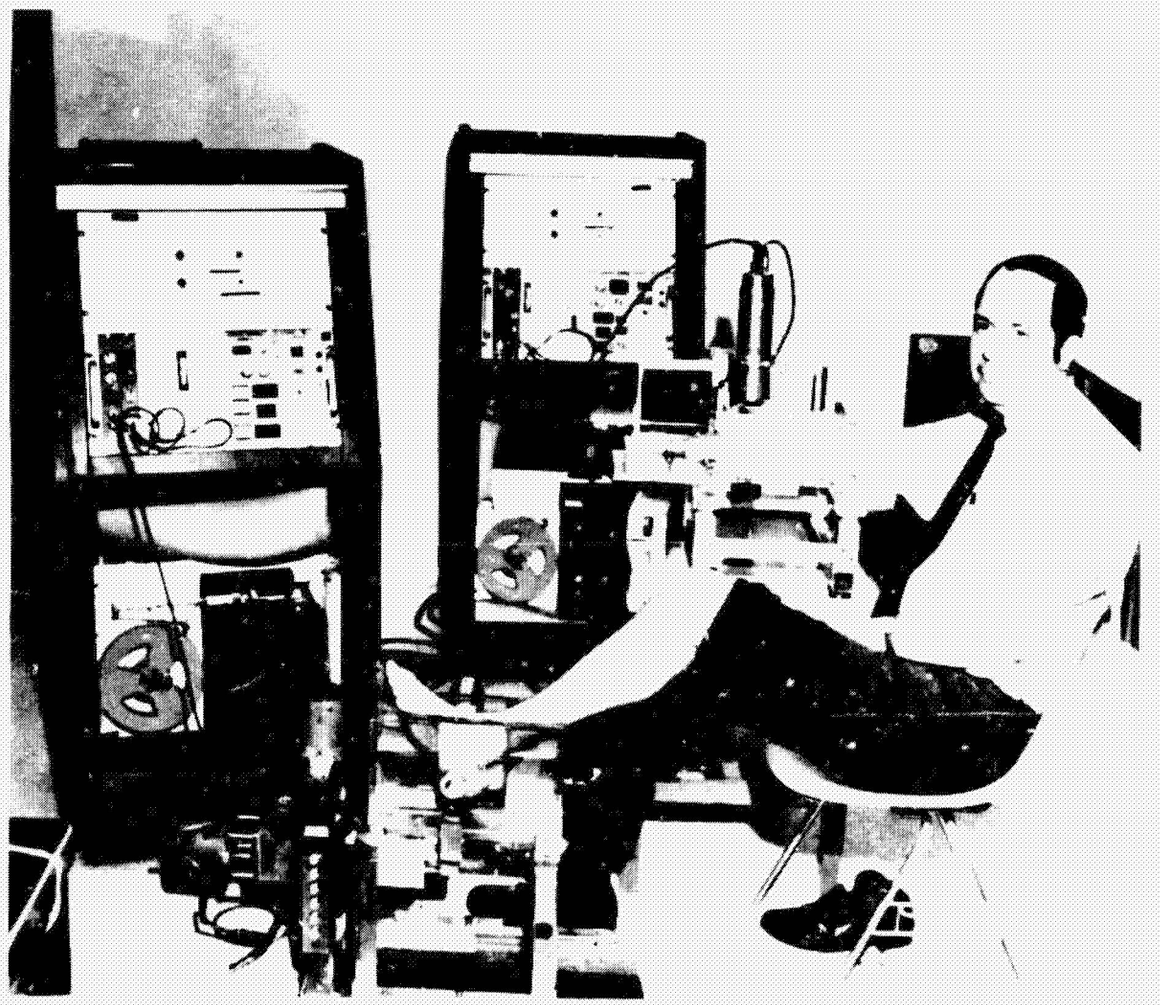


Figure 14. - Dual scanning systems for the arm and heel.