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We hereby recommend that the thesis prepared under our supervision by Jeannette Hardage Johnson entitled QUANTITATIVE AUTOPSY ANALYSIS OF THE SKELETON OF NASA PRIMATE 470, MACACA NEMESTRINA SPACE MONKEY

be accepted as fulfilling this part of the requirements for the Degree of

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INTRODUCTION

The quantitative analysis of the mineral content of the skeleton of Primate 470 described in this thesis is part of an extensive autopsy study conducted by the National Aeronautic and Space Administration in concluding the Biosatellite III program research data.

The Texas Woman's University Research Institute participated not only in these autopsy findings, but in the ground-based tests, simulated flights, and the actual flight of the Biosatellite III space capsule, according to W. R. Adey[1], Principal Investigator of Biosatellite program. The institutions involved in the Biosatellite III program were the University of California at Los Angeles; the University of Southern California; the University of California at Berkeley; the Jet Propulsion Laboratory; the Texas Woman's University Research Institute; and the following branches of the National Aeronautics and Space Administration: Ames Research Center, Kennedy Space Center, and Goddard Space Flight Center. The spacecraft for the Biosatellite III mission was designed and manufactured by the General Electric Company, Re-entry Systems Division.

To become the passenger of the space flight, Primate 470 was selected in an elimination procedure from over 500

Macaca Nemestrina monkeys given training to perform tests in the confinement and isolation of a spacecraft. Approximately a week after final instrumentation surgery, Primate 470 was chosen from the group of the five candidates for flight, all of whom were male, physiologically just past puberty, and approximately six kilograms in weight.

On June 28, 1969, Primate 470, who had been named Bonny by his caretakers, was launched into spatial orbit by a two stage, thrust augmented Delta-N rocket for a mission planned to be 30 days in duration. According to Tejada[2] et al, examination of the vibration profiles for the launch phase showed a maximum acceleration of 7.2 g. just prior to the main engine cut off. The orbit achieved was approximately 370 kilometers in altitude with a period of 92 minutes, according to Hoshiza[3] et al.

On July 8, 1969, the rapid deterioration of the animal prompted the termination of the flight, and the capsule was recovered from the Pacific Ocean. Twelve hours after recovery, Primate 470 died. The preliminary autopsy indicated that the weightlessness might be a prime factor in Primate 470's deterioration and subsequent demise, according to Adey[4].

The skeletal autopsy study outlined in this thesis was conducted in the Nelda Childers Stark Laboratory for Human

Nutrition, a component part of the Texas Woman's University Research Institute. During the course of the study every bone of the skeleton of Primate 470 except those of the skull and upper cervical vertebra were X-rayed in situ, dissected out and X-rayed without soft tissue, ashed, dissolved and brought to volume in solution, and analyzed quantitatively for calcium and phosphorus.

These findings were compared with those reported by Dr. Pauline Beery Mack, director of the TWU Research Institute[5], and with bone studies conducted at T. W. U. using Macaca Nemestrina monkeys studied by other research workers.

R E V I E W O F L I T E R A T U R E

The Biosatellite III experiment had been planned to be a 30 day earth orbiting flight designed to study the effects of a long duration space mission on a highly instrumented primate. Before that time, June, 1969, the longest time which man had experienced a mission involving weightlessness was the 14 day Gemini VII flight of Colonel Frank Borman and Captain James A. Lovell in 1965. The longest time during which any mammal had been subjected to weightlessness was 22 days, the duration of the flight of a Soviet satellite containing two dogs in 1966[6].

Instrumentation and Treatment of Data

According to Adey and Hahn[1], the Biosatellite space capsule could be considered a small laboratory with a single environmental shift, which was unique with respect to any laboratory on earth because of the removal of gravitation. The one laboratory subject and passenger of the spacecraft was Primate 470, a 5.9 kg. Macaca nemestrina monkey. The primate and his capsule were instrumented to produce a comprehensive array of data concerning his physiological reactions to the changes of his environment during a long space flight.

Physiological Instrumentation

Primate 470 was instrumented with bipolar electroencephlographic (EEG) electrodes, electroculogarphic (EOG) sensors, electromyographic (EMG) leads, heart function (EKG) and respiration (ZPG) sensors, vascular catheters intended to monitor venous and arterial pressures, and temperature sensors in the brain and in the peritoneal cavity.

Management of Fluid Intake and Excretion

A urinary catheter was implanted through a perineal urethrostomy to provide accurate measurement of urine volume, calcium, creatine and creatinine concentrations and to assure the animal's cleanliness and comfort during his confinement. The drinking nipple for the water supply system was arranged with a negative pressure of 25 mm. of mercury to minimize leakage. Drinking opportunities of up to 30 ml. each were programmed at 1-hour intervals, starting with the onset of day mode light and at 3-hour intervals, starting with the onset of night mode light for a total of 480 ml. per day.

Environmental Instrumentation

Transducers in the capsule of the spacecraft measured total air pressures, partial pressures of oxygen and carbon dioxide, air temperatures, day/night light status and any changes in spacecraft attitude. Food pellet and water consumption, urine production and task performance of Primate 470 also were monitored.

Dispensation of Food and Psychomotor Tasks

A casein based food pellet of approximately nine kilocalories would be made available to Primate 470 when he successfully performed delayed matching or visuomotor tasks. He could earn a maximum of 20 food pellets two times a day, and he received an ad libitum allowance of 20 pellets near the end of each 12 hour period of day lighting.

Data Telemetry

Each sensor (electrodes, thermistors, pressure transducers, etc.) converted the acquired physiological or environmental variable into an electrical analogue which was conditioned to be compatible with the telemetry system, digitized, coded, and transmitted to the ground. The spacecraft telemetry was received by a network of stations around the world, all routed to Goddard Space Flight Center in Greenbelt, Maryland, where decisions concerning the flight were made based upon quick-look analysis of the data. A total of 21 hours of real time data was acquired during the 210 hour flight. The interval between data captures varied, but usually was less than 100 minutes. In addition to the data telemetered to earth, 7000 frames of 16 mm. film from the on-board camera and 42 hours of data from a seven channel analogue tape recorder were recovered from the capsule of the spacecraft.

Physiological Responses to Lift-Off

Primate 470 was inserted into the capsule 11 hours before launching, according to Tejada, Hahn and Adey[2]. The adjustment of the monkey to the confinement and isolation of the capsule was observed by continuous telemetry. He was alert, ate food pellets and had a mean heart rate of 170 bpm. Audio level inside the capsule averaged 80 dB. At 10 minutes before lift-off, the capsule lighting was in night mode, and Primate 470 was in light sleep alternating with drowsiness.

Lift-Off

Vibration, noise, and acceleration increased immediately upon lift-off. Primate 470 was startled and aroused from drowsiness. He moved his head rapidly. His heart beat increased to 208 bpm, but 60 seconds after launch it had subsided to 192 bpm. Noise level had reached 120 dB inside the capsule just prior to cut-off.

Cut-Off

Immediate decrease in gravity acceleration forces from 2 g. to 1 g. occurred with cut-off in the solid fuel motors 75 seconds into the flight. Although there were response adjustments, there were no marked changes of brain function or temperature. During the 75 to 175 second flight segment the gravity forces increased to 4 g. Primate 470's heart rate increased to a maximum of 234 bpm. From 175 to 203 seconds, the g. forces increased more rapidly to 7 g. Primate 470's EOG sensors registered symptoms of mild motion sickness, and there was irregular breathing.

Main Engine Cut-Off

At 220 seconds the main engine cut-off, and the g. forces dropped to 0.0 g. Primate 470's blood pressure dropped and rose again after 3 seconds, when the second engine started. The remaining powered flight lasted 7 minutes during which the g. forces jumped to 0.4 g. and increased progressively to 1.8 g. at the time of the secondary engine cut-off. During this time Primate 470's heart rate decreased from 185 to 165 bpm. Brain and body temperatures remained unaltered. Tejada et al concluded that, during the last 5 minutes of powered flight, Primate 470 had regained his normal composure and at insertion into orbit appeared to have recovered from launch stresses.

Sleep/Wake Patterns During Weightlessness

Hoshizaki, Durham and Adey[3] explored the time-lapse photographic records of Biosatellite III to present a report of the sleep/wake activity patterns of Primate 470. The remaining four flight candidates were used as ground control animals following by 48 hours the flight animal's scheduled environment except for lift-off and weightlessness.

Data Considerations

Since time-lapse photographs were taken at the rate of one frame every 20 minutes, any activity of the animal between frames could only be verified from the task performance epochs and the food and water consumption records obtained from the telemetry data. Hoshizaki[3] et al refer to the rapid changes in the sleep/wake state of Primate 470 observed in the EEG analysis by Adey[4] et al to account for some discrepancies. Comparison of the sleep/wake pattern of the flight animal to those of the control subjects reveals the finding that the flight animal had more changes in the sleep/wake state.

Phase-shift Possibility

The tendency of Primate 470 to remain asleep for about 2 hours after onset of the day light mode each flight day and to remain awake for 2 hours after the day mode was ended was observed as a possible 2 hour phase-shift from the imposed 24 hour night/day shift. This phase-shift was not observed in the control animals.

Desynchronosis

Hoshizaki[3] et al reviewed the observation of Hahn[7] et al that Primate 470's arterial blood pressure also followed a 24 hour circadian pattern. An approximate 26 hour period length, however, was found in his heart rate, brain and body temperature and environmental partial pressure of carbon dioxide. These investigators concluded that the presence both of a 24 hour and a 26 hour period indicates that an internal desynchronosis occurred in the flight subject and an approximate 16 hour phase difference had accumulated when the experiment was terminated. Such a desynchronosis was not observed in control subjects.

Circadian Rhythms During Weightlessness

Hahn, Hoshizaki and Adey[7] have described the status of Primate 470's circadian rhythms during the Biosatellite III flight. They define circadian rhythms as the rhythmicity of activity levels, metabolism, excretion rates, thermoregulation and cardiovascular measures of the animal while within constant environmental conditions.

Data Analysis Methods

Hahn[7] et al used the technique of day averaging to estimate the periodicity of Primate 470's functions. Data samples obtained during the flight were interpolated to fixed 1.5 hour intervals. The average for a 4 day period then was obtained. Deviations from the average give a cyclic representation of the parameter. Primate 470's brain and body temperatures, heart rate and blood pressures were analyzed for circadian periods.

Results

The environmental partial pressure of carbon dioxide, brain and body temperatures and heart rate of the primate were well correlated, indicating a rhythm of greater than 25 hours. The periodicity of the arterial blood pressure remained at 24 hours.

Controls

None of the four control animals showed any deviation from a 24 hour cycle in any recorded physiological parameter. Applying the day averaging technique of analysis to the data, confirmed a fixed 24 hour rhythm for heart rate, brain and body temperature, and arterial pressure.

Conclusion

Hahn[7] et al concluded that Primate 470 displayed a definite internal desynchronosis of temperature, cardiac and respiratory cycles from the blood pressure and that he experienced an external desynchronosis from the imposed 24 hour night/day routine. They speculated that this desynchronosis may have acted with a commonly theorized space flight derangement of the cardiovascular system to bring about the rapid deterioration of Primate 470.

Analysis of Telemetered Electroencephalographic Data

A report by Hanley and Adey[8] outlined their detailed visual analysis of the telemetered EEG correlates of Primate 470's states of consciousness. In their opinion, there was little previous data on the sleep and wake states of a complex mammalian system in a weightless environment, and that the information gained from the Biosatellite III mission was scientifically significant particularly in showing a need for further study before additional prolonged manned flights are undertaken.

Instrumentation

Ten EEG electrodes were stereotaxically positioned bilaterally in the parietal and visual cortex, the hippocampus and the amygdala and unilaterally positioned in the right centrum medianum and left midbrain reticular formation. EOG leads were placed at the right and left outer conthi, and EMG sensors were implanted in posterior cervical and lower scapular sites. The flight subject was secured with only his head and arms free from restraint.

Results

The EEG, EOG and EMG data showed marked disruptions from the onset of weightlessness. The sleep of Primate 470 was characterized by unusually rapid transitions in state, notable brevity of state, and unusual transitions from one state to another. Although the animal retained essential features of its terrestrial sleep, with all sleep states detected at some time, scarcely any aspect of its sleep was without atypical features, according to Hanley and Adey[8].

Computer Analysis of Neurophysiological Data

Computer analysis of the Biosatellite III data was to serve two functions: short-term analysis for mission control guidance and long-term analysis for general physiological studies, according to Walter, Berkhout, Buchness, Kram, Rovner and Adey[9].

Data Reception

Digital magnetic tapes representing telemetry data were delivered to the Space Biology Laboratory at the University of California at Los Angeles (UCLA) within three to eight hours following the data reception by a prime station. The prime stations were located at Quito, Ecuador; Lima, Peru; Santiago, Chile; and Fort Myers, Florida.

Short-term Analysis

Quality checking, short-term analysis and transmission of graphs to Goddard Space Flight Center was accomplished with the taped data at UCLA using a SDS930/TD-100 or a

SDS9300/IBM360-91 combined machine system. Each tape record contained one telemetry frame, a duplicate and a time of day in milliseconds.

Bone Density Changes During Weightlessness

Mack[5] investigated the density of Primate 470's bones during the weightlessness of the space flight.

Preliminary Densitometry

Between June 15 and June 26, 1969, the five Macaca nemestrina monkeys who were candidates for flight in the Biosatellite III program were radiographed three times. These radiographs were scanned in selected anatomical sites at the Texas Woman's University Bone Densitometry Laboratory for the purpose of ascertaining initial skeletal density and changes in skeletal density in relatively short periods of time.

Subject and Control

Two animals, Primate 470 and Primate 264, were similar in bone density in 17 anatomic areas during the initial trials. These two primates also were closely similar in all of the other physiological data. As a result of the experimenters' conference 24 hours before the flight, Primate 470 was selected as the flight animal, with Primate 264 as the back-up animal.

Method of Determining Bone Density

The radiographs were calibrated by the method rendered by Mack[5] by placing an aluminum reference wedge on each film adjacent to the bone to be evaluated before exposure. The tapered wedge, made of an aluminum alloy which had an x-ray absorption coefficient similar to that of bone, had been calibrated in terms of calcium hydroxyapatite, the major mineral component of bone. The wedge was scanned in the Bone Demsitometer Assembly before the bone traces were made on each radiograph so that the trace of the wedge could be corrected for deviations resulting from slight differences in such factors as film characteristics or development techniques.

Standardization of X-ray Machines

In the Biosatellite III study, the first series of films was made at Kennedy Space Center and the final radiographs after recovery were made in a laboratory at Hickam Field, Hawaii. The two x-ray machines were standardized by using a Victoreen roetgenometer in order to determine the calibrated kilovoltage which would produce identical x-ray beam qualities, and also by evaluating a standard, a bone impregnated in an organic matrix, before and after each series of radiographs made at one time for comparative purposes.

Results

In evaluating the skeletal sections usually scanned in monkeys, only very minor changes in bone density were found in the preflight radiographs which had been taken over an 11 day period. In contrast, somewhat greater bone density losses appeared in the radiographs of Primate 470 at the close of the 8.8 days of weightlessness compared with those of the control, Primate 264.

Conclusions

Mack[5] concluded that the loss of bone density could not be strictly identified with the deterioration of Primate 470 which might be attributed to weightlessness, although there were some strong indications that this could have been the cause of the greater loss of bone density in the flight animal than in the control primate.

Bone Demineralization of Astronauts

In a report on the effect of orbital flights on bone demineralization, Mack, LaChance, Vose and Vogt[10] described their findings in the radiographs of the Gemini-Titan human passengers.

The lowest amount of bone density loss was found in the two astronauts of Gemini VII, which was 14 days of duration. These two men consumed the highest proportion of the diet provided for them, and also carried on exercise during their mission. The astronauts of the Gemini V mission, on the other hand, who had an eight-day orbital flight, consumed the lowest percentage of their food and had the highest negative change in bone mass. The men of Gemini IV, who experienced only a four-day flight were intermediate in bone density loss. Therefore the length of the mission appeared to have no relationship with the loss of bone density in manned flights.

There is additional evidence of the loss of bone density involving human astronauts in a study undergoing publication at the present time by Mack and Vogt[12] covering the missions of Apollo VII and Apollo VIII. In this case the length of the two missions were reversed with respect to the loss of bone mass, with the longer flight having less reduction of bone density. In this case, also, regular exercise appeared to conserve bone mineral, although no method of exercise was provided for Primate 470. Mack and McDonald[13] have described bed rest studies in which those who exercised according to a regular schedule maintained the integrity of their skeletons to a greater degree than those who did not.

PLAN OF PROCEDURE

The data presented in this thesis were obtained in the Texas Woman's University Research Institute Laboratories as part of an extensive autopsy of the skeleton of Primate 470, the Macaca Nemestrina flight monkey, flown on a mission by the National Aeronautics and Space Administration.

Skeletal Analysis

The analysis of various parts of the skeleton of Primate 470 was begun slightly less than one year after the date of the death of the animal which occurred on July 8, 1969. The bones had been preserved in situ within large segments of flesh contained in jars of fixative of considerable size which were delivered from the NASA Ames Research Center at Moffett Field, California, by Pierre Hahn, Research Manager, Biosatellite Project.

Extraction of Bones

The fixative in which the carcass was immersed was discarded, and the pieces of the body of Primate 470 were rinsed in tepid water. They then were soaked in water of approximately 70° C. for 15 minutes, rinsed in tepid water, drained, and spread to dry. All 18 pieces of flesh and bone which were present were radiographed before any soft tissue was removed.

Using sharp, new surgical instruments and a tepid water soak when necessary, all soft tissue was dissected carefully and removed from the skeleton except a small amount of connective tissue which was retained to link the bones together for the final x-rays. After the bone groups were x-rayed, they were cataloged, divided, and assigned to ceramic crucibles. The individual bones and small bone groups were dried at 100° C. for a 24 hour period.

Weighing and Ashing of Bones

The dry bones and crucibles were weighed on a grammatic Balance made by E. Mettler, Zurich, Switzerland. The bone samples then were ashed in a 650° C. muffle furnace during an 18 hour period, and were weighed together with the ceramic crucibles. The bone ash was dissolved in 6 N. hydrocholoric acid to which distilled water was added sufficient to make volumetric solutions of 50, 100, or 250 milliliters depending upon the quantity of the ash. The solutions then were analyzed for the calcium and phosphorus content of the bone ash.

Quantitative Chemical Analysis

The calcium and phosphorus determinations used at the Texas Woman's University Research Institute Bio-nutrition

Laboratories are based on the principle of colorimetry. Absorbance of a beam of light of a specific wave length by the colored sample solutions is measured using a Coleman Junior Spectrophotometer Model 6A. Each sample solution is analyzed in triplicate, and a mean value of the measurement of absorbance is used in the calculations.

Analytical Procedure for Calcium

Calcium in the bone samples was determined analytically by the method of Ferro and Ham[14,15] following the pH adjustment suggested by Chiamori and Henry[16].

Preparation of Samples.--An Aliquot of each bone sample solution was placed in a volumetric flask. The size of the aliquot and that of the volumetric flask were varied so that the final concentration of calcium in the flask would be approximately 10 milligrams of calcium per 100 ml. of solution.

For example, the ash of the right Os calcis was 1.7322 grams which was dissolved in a 100 ml. volumetric solution. A dilution of 100 times was made up by pipeting a 2.0 ml. aliquot into a 200 ml. volumetric flask.

Each flask, with a sample aliquot, was filled about three-fourths full with distilled water. Methyl red indicator was added, and the pH of the solution was adjusted to an orange color (pH 4.5) by titration with dilute ammonium hydroxide. The flasks then were brought to volume with distilled water, and the solutions were mixed.

Analysis Procedure.--The standard solution was made to contain 10 mg. per 100 ml. of calcium. Two ml. each of the pH-adjusted samples, the standard, and a water blank were pipetted into 15 ml. conical centrifuge tubes. One ml. of chloranilic acid reagent was added to each tube, and the tubes were agitated by twirling in order to provide thorough mixing.

The tubes were allowed to stand for a minimum of two hours while calcium chloranilate precipitate formed. The tubes were centrifuged at 1800 revolutions per minute for 15 minutes in order to pack the precipitate. The supernatant liquid was decanted and discarded, and the tubes were inverted to drain for five minutes on absorbant paper. Then the mouths of the tubes were wiped with tissue paper.

Approximately four ml. of 50 per cent isopropyl alcohol were added to each tube, and the precipitate was dispersed and resuspended in the alcohol using a vortex mixer. The tubes again were centrifuged, decanted, and drained.

Two drops distilled water were added to each packed precipitate which was resuspended in the water using the vortex tube mixer. Six ml. of tetrasodium ethylenediaminetetraacetate (EDTA) were added to each tube which was agitated with the vortex mixer until the precipitate was dissolved completely, forming sodium chloranilate and calcium EDTA.

The quantity of calcium in each sample was determined by the colorimetric absorption of the sodium chloranilate at 520 millimicrons using the Coleman Spectrophotometer.

<u>Calculation of Calcium Content</u>.--The calcium content of samples was calculated by comparing them to the relationship of the known concentration of the standard and the colorimetric absorbance measurement of that standard.

$$\frac{\text{Concentration of standard}}{\text{Absorbance of standard}} = K$$

$$K \times \begin{matrix}\text{Absorbance}\\ \text{of sample}\end{matrix} \times \text{Dilution} \times \frac{\text{Volume of Sample}}{100} = \text{milligrams Ca}$$

<u>Analytical Procedure for Phosphorus</u>

The phosphorus content of the bone ash solutions was determined by the method of Fiske and Subbarow[17] as modified by Dryer[18] et al, with some slight modifications in this Laboratory.

<u>Preparation of Samples</u>.--Volumetric solutions of the bone ash solutions were made up so that the quanity of phosphorus would be within the range of that of the standard solutions, 0.25 to 1.50 mg. per 100 ml. Dilutions for the volumetric solutions ranged from 100 to 2500 times for the

bone ash samples which weighed from 0.3386 to 18.1690 g. before being dissolved.

Analysis Procedure.--A potassium dihydrogen phosphate stock solution was used to prepare the standard solutions which contained 0.25, 0.50, 1.00, and 1.50 mg. of phosphorus per 100 ml. Two ml. of each standard solution, each bone ash sample solution, and a water blank were placed in medium-sized test tubes.

Two ml. of 5.0 N sulfuric acid were added to each tube and mixed; two ml. of ammonium molybdate solution were added and mixed; and 4.0 ml. of N-phenyl-p-phenylendiamine (PPPD) solution were added and mixed. The tubes were then allowed to stand for 15 minutes before being poured into 19 millimeter Coleman cuvettes to be read in the Spectrophotometer at 700 millimicrons. The water blank was used to calibrate the Spectophotometer for 0.00 absorbency measurement.

PRESENTATION OF FINDINGS

The findings of this study show the results of the analyses of the bones of the skeleton of Primate 470 for quantity of ash, of calcium, and of phosphorus and a comparison of the results of these analyses of the skeleton with the results of other research workers whose subjects had undergone no treatment except freezing.

Comprehensive Listing of Results

A comprehensive listing of the individual bones or small bone groups and the results of the quantitative analyses of these samples is given in the Appendix of this report in Table I, Parts A through F. This listing contains bone identifications, dry weights, ash weights, and weights of the calcium and phosphorus contents grouped according to body position.

Vertebrae

Part A of Table I gives the grouping of the vertebrae. Cervical vertebrae 1 through 4 were not received at the Texas Woman's University Research Institute Laboratories for analysis. Primate 470 had no caudal vertebrae; tails usually are surgically removed from primates used in space capsule research.

Ash Content.--The thoracic vertebrae were the least dense of the vertebrae in the spinal column, with as percentages of 40.01 and 42.19. The lumbar vertebrae were the most dense with a range of 45.54 to 46.97 per cent ash.

Mineral Content.--The per cent of calcium in the vertebral bone ash ranged from 36.66 to 38.85, with a mean of 37.80 per cent. The phosphorus content ranged from 16.25 to 18.08 per cent with a mean per cent of 16.92.

Trunk Skeleton

Part B of Table I lists the results from the bones in the trunk portion of the skeleton with the exception of the vertebrae.

Pelvic Area.--The ash density of the sacrum was 47.07 per cent of the bone weight which may be compared to 46.97 per cent ash of the lumbar vertebra 7 listed in Part A of the table. The ash content of the dried ilium was 47.08 per cent. The per cent calcium of the sacral ash was 35.34, that of the ilium ash was 36.99 with a difference between sacrum and ilium of 1.65 per cent. The sacral ash percentage of phosphorus was 16.87, and the percentage of the ash in the ilium was 18.55, with a difference of 1.68 per cent.

Thoracic Area.--The thoracic portion of a skeleton consists of the vertebrae, the ribs, and the sternum. A small portion of the ribs were splintered and missing from the skeleton of the primate undergoing analysis.

The per cent ash in the ribs was 42.05 which may be compared with the 41.10 mean per cent of the thoracic vertebrae of the listing in Part A of Table I. The percentage of calcium in the ash of the ribs is 37.68 compared to a mean of 37.92 of the thoracic vertebrae; and the phosphorus percentage of the ribs was 17.33 per cent compared to the mean 17.49 per cent of the total thoracic vertebral ash values in Part A of the table under discussion.

Sternum.--The sternum consists of three parts : the manubrium, the body of the sternum and the xiphoid process. The body of the sternum of Primate 470 was damaged to the extent that it was difficult to assess whether or not the total bone had been retained. The xiphoid process was missing.

The ash per cent within the dried manubrium was 33.93, and that of the body of the sternum was 24.58. Another soft bone that could be compared to the sternum in density was the patella listed on Part E of Table I. The mean per cent of the patella ash was 35.50.

The per cent calcium in the ash of the manubrium was 37.92, and that of the sternum body was 37.26. The phosphorus content of the manubrium was 16.49 per cent of the ash, and that of the sternum body was 16.62 per cent.

Shoulder Area.--The bones in the shoulder area were slightly more dense than those of the pelvic area, which had a mean of 47.07. The right scapula was 52.85 per cent ash, and the left scapula was 52.47 per cent.

The left and right clavicles were 49.86 and 48.47 per cent ash respectively. The calcium percentages of the right and left clavicles were 37.01 and 37.58, and the phosphorus percentages were 17.35 and 18.03, respectively.

The right and left scapulae were more symmetrical than the clavicle bones in the percentages of the mineral content of the ash. The phosphorus percentage ash in the scapulae were almost identical with each other, 17.30 for the right and 17.29 for the left bone. The calcium percentage of the right scapula was 37.44 and, that of the left was 36.20.

Arm and Wrist Bones

Part C of Table I contains the arm and wrist bones.

Long Arm Bones.--The arm bones contained a mean percentage of 55.59 ash with a range of 54.63 to 56.71 per cent. With the exception of the left humerus which had a lower value because of the loss of some solution resulting from a cracked crucible, the mean per cent of the calcium was 37.87

with a range of 36.25 to 39.42 per cent. The mean per cent of the representative values for phosphorus was 17.24 with a range of 16.08 to 18.00 per cent.

Carpals.--The right carpals contained 44.10 per cent ash, and the left carpals contained 44.58 per cent. There were 39.56 per cent calcium and 17.79 per cent phosphorus in the ash of the right carpals and 39.88 per cent calcium and 17.90 per cent phosphorus in that of the left carpals.

Metacarpals and Phalanges

Part D of Table I contains the results of the metacarpals and phalanges of both hands of Primate 470. The metacarpals and phalanges of each digit were weighed and ashed together and analyzed as one sample.

The per cent ash in the bones of the digits ranged from 43.65 to 52.21 per cent with a mean value of 47.24 per cent. The per cent calcium in the bone ash values ranged from 37.08 to 40.92 per cent with a mean value of 38.65 per cent. The phosphorus content of the bone ash ranged from 16.89 to 19.12 per cent with a mean value of 17.68 per cent.

Leg Bones

Part E of Table I lists the long leg bones and the patellae.

Long Leg Bones.--The long leg bones had the largest percentages of ash of all of the types of bones in the skeleton of Primate 470, with a range of 56.14 to 59.32 per cent, with a mean value of 57.86 per cent. The calcium values within the ash of the long bones ranged from 38.03 to 39.75 per cent with a mean of 38.67, and the percentage of phosphorus ranged from 16.73 to 18.11 per cent, with a 17.53 per cent mean.

Patellae.--Although the patella ash percentages of 37.61 for the right and 34.34 for the left side were lower than those for the long bones, the mineral percentages in the ash were slightly higher, with 39.51 and 39.88 per cent for calcium and 17.42 and 18.43 per cent for phosphorus.

Foot Bones

Part F of Table I lists the foot bones.

Tarsals.--The Os calcis of each foot was ashed separately from the other foot bones. The tarsal percentages of ash ranged from 54.42 to 51.04 per cent with a mean value of 52.09. The percentage of calcium in the tarsal ash ranged from 36.03 to 38.93 per cent with a mean of 37.32 per cent. The percentage of the tarsal ash phosphorus ranged from 16.76 to 18.13 per cent with a mean per cent of 17.44.

Metatarsals and Phalanges.--The metatarsal and phalanges of each digit were considered as one sample and analyzed together. The ash content percentages ranged from 46.54 to 50.14 with a mean of 48.80 per cent. The calcium values in that ash were from 36.17 to 39.81 per cent with a mean of 37.80 per cent. The phosphorus in the ash ranged from 16.69 to 18.33 per cent with a mean of 17.84 per cent.

Comparison of Bones from Primate 470 with Those of Other Primates

Tables II through XV contain values for comparison of selected bones from the skeleton of Primate 470 and from skeletons of monkeys studied by other workers, including Varner[19] and Liu[20]. The value of any particular bone of Primate 470 is considered as value 100 per cent so as to establish a basis from which to discuss the differences between bones from Primate 470 and those from other Macaca Nemestrina monkeys.

Selected Bones

Table II contains the values for the dry weight, the weight of ash, and the weights of calcium and phosphorus for bones from the right side of the skeleton of Primate 470 to be compared with the mean and individual values of comparable bones of other primates of the same strain in Tables III, IV, and VIII through XV.

Mean Weights from Four Primates.--Table III contains the mean values of the bones from the four Macaca Nemestrina primates studied by Varner[19]. The purpose of this investigator had been to find the relationship between chemical quantitative analysis for calcium and radiographic bone densitometry. The coefficients of correlation to describe that relationship ranged from 0.9758 to 0.99986 denoting a high degree of correlation. The monkeys studied ranged in weight from 15 to 20 pounds and had undergone no specific treatment that would influence their calcium metabolism.

The mean dry weight values for Varner's monkey bones were similar, coming within 10 per cent of the weight of the same bones of Primate 470 except for the lower leg and foot bones. The mean value for Varner's primate for the Os calcis was 4.000 g., which was 26 per cent heavier than the 3.1822 g. for Primate 470. The mean tibia weight for Varner's primates was 20.5380 g., 20 per cent heavier than the 17.1785 g. weight for Primate 470. The fibula was 11 per cent heavier.

Ash Weight of Bones.--All differences in the bone ash weight values between the two series of bones fell within 10 per cent except for that of the tibia for which the difference was 11 per cent. Varner's mean tibia weight was 10.9767 g., and that for Primate 470 was 9.9019 g. The calcium values in Tables II and III were similar except the mean value for the humerus which was 6462.75 mg., 21 per cent larger than the 5362.89 mg. weight for Primate 470.

The pelvic area weights cannot be compared effectively because Varner's values included portions of tails and spines. The Table II value for the pelvic area for Primate 470 included only the ilium.

Values from Single Primate Tables.--Table IX, which contains the values for Primate V2 found by Varner, is representative of the individual primate values of Tables VIII through XI. In comparing Table IX with Table II, the arm bones of Primate V2 weighed less than those of Primate 470 while the lower leg bones weighed more.

The weights of the humerus and of the ulna of Primate V2, 21.5014 g. and 10.7305 g., respectively, were 12 per cent lighter in weight than were those of Primate 470, which were 24.5410 g. and 12.2615 g., respectively. The other dry weights fall within 10 per cent of those values found by Varner. The weight of the fibula, which was 4.9581 g. for Primate V2, was 33 per cent heavier than the 3.7204 g. of the corresponding bone of Primate 470.

The ash and calcium weights were similar for the two primates except for the tibia and fibula. The tibia ash weight for Primate V2 was 11.4544 g. which was 17 per cent greater than 9.9019 for Primate 470. The calcium weight was 4363 mg., 14 per cent greater than the 3832.60 mg. for Primate 470. The ash weight of the fibula of Primate V2 was 3.1471 g. which was 47 per cent greater than the 2.1430 g. of the fibula of Primate 470. The fibula calcium weight, 1255 mg., for Primate V2 also was 47 per cent greater than the 851.85 mg. of Primate 470.

Mean Weights Including Phosphorus Values.--Table IV contains the mean values of the bones from the four Macaca Nemestrina primates studied by Liu[20]. In addition to the quantitative analysis for calcium, which was similar to that done by Varner, Liu also analyzed the bone ash solutions for phosphorus. Although no weights for the animals were given in her report, the bone weights indicate the fact that the animals were larger than Primate 470 and larger also than those studied by Varner which suggests that these monkeys might have been more mature, or that they may have come from another geographic location.

The mean dry weights of the bones of Liu's primates ranged from 17 to 60 per cent heavier than did the dry weights of Primate 470. Similar to the pattern of the Table III values, the bones which were the heaviest when compared to those of Primate 470 were the lower leg and foot bones.

The mean tibia weight for Liu's primates was 24.5660 g. which was 43 per cent heavier than the 17.1785 g. weight of the tibia of Primate 470. The tibia ash and calcium weights were 35 per cent higher and the phosphorus weight was 26 per cent higher than the values for Primate 470. Although the mean value for the Os calcis, 4.3325 g., was 36 per cent higher than the 3.1822 Os calcis weight of Primate 470, the ash value was only 11 per cent higher. The calcium and phosphorus weights were within 10 per cent of the values for Primate 470.

The mean values for the phosphorus contents of the radius and ulna were 2850.50 mg. and 3206.00 mg., respectively, with the radius 179 per cent higher than 1020.12 mg. for Primate 470 and the ulna 177 per cent higher than the 1159.49 mg. for Primate 470. It can be noted that either of these bones was approximately one half the dry weight of the humerus, but they each contained about the same amount of phosphorus according to the mean values.

Values from Individual Primates Including Phosphorus.--Table XIV, listing the values of one of the smaller of Liu's monkeys, Primate 30, is used for comparative purposes. The phosphorus values of the radius and ulna were similar to those of Primate 470 with values that were 8 and 4 per cent respectively to those of Primate 470. The tibia, fibula and Os calcis followed the same pattern as that outlined in the earlier comparisons. The dry weights were 35, 39 and 50 per cent heavier respectively than the same samples from Primate 470, but the ash, calcium and phosphorus values were similar to those of Primate 470.

Relationships of Findings

Tables V, VI and VII contain percentages of ratios of the values given in Tables II, III and IV.

Ratio for Primate 470.--The per cent of ash in the dry bone is the ratio of the ash weight to the dry bone weight. The values for Primate 470 given on Table V ranged from 45.82 per cent for a lumbar vertebra to 58.91 per cent for the femur.

The per cent calcium in the dry bone is the ratio of the calcium content to the dry bone. The values for Primate 470 ranged from 16.77 per cent for the pelvic area to 23.02 for the fibula. The ratio of the calcium content to the ash weight ranged from 36.99 per cent of the pelvic area to 39.75 per cent of the fibula.

The phosphorus percentages ranged from 7.66 per cent of the dry bone weight of the lumbar vertebra 5 to 10.42 per cent of the fibula and ranged from 16.72 per cent of the ash in the vertebra to 18.55 per cent of the ash in the pelvic area.

Other Primate Bone Relationships.--Comparing percentages of the Varner primate bones in Table VI to those in Table V revealed that the values were within 3 per cent for each relationship.

The values in Table VII for the mean of Liu's four primates did not compare as well. The ash to bone ratios of Table VII were within 4 per cent to those in Table V except for the Os calcis and pelvic area values which were within 10 per cent. The calcium and phosphorus ratio values were within 4 per cent of those in Table V except for the Os calcis and pelvic area values which were within 10 per cent. The calcium and phosphorus ratio values were within 4 per cent of those in Table V except for the phosphorus ratios for the radius and ulna which were approximately 10 per cent greater in Table VII.

Summation Tables

Tables XVI through XIX contain the total values for the various parts of the skeleton of Primate 470. Table XVI lists the arms, hands, legs and feet of the skeleton and gives values for the total limbs. Table XVII gives the total values for the spinal column, the shoulder area, the rib cage and the pelvic area; the total trunk skeleton; the total limb bones; and the complete skeleton of Primate 470.

Table XVIII gives the percentages of the values listed in XVI, and Table XIX gives the percentages of the values listed in XVII.

The skeleton of Primate 470 weighed 438 g. and contained 223 g. ash, 82981 mg. calcium and 28693 mg. phosphorus.

Bone Densitometric Comparison

Table XX is the result of the bone density comparison study of Primate 470 and the flight control primate by Dr. Pauline Beery Mack[5], director of the Texas Woman's University Research Institute which shows the negative effects of the restraint and isolation of a space capsule on the skeletal density of both monkeys and of lift-off and weightlessness on that of Primate 470. Primate 470 lost 8.42 per cent of the bone density values taken over the 17 anatomic sites compared to the 6.47 per cent lost by Primate 264, the control monkey.

SUMMARY AND CONCLUSIONS

The purpose of this study was to analyze the skeleton of Primate 470 for concentrations of ash, calcium and phosphorus. The investigation was conducted at the Texas Woman's University Research Institute as a part of the autopsy of the flight subject of the Biosatellite III Project.

Summary of Primate 470 Analyses

The analysis of the bones of the skeleton of Primate 470 resulted in a variance of ash content from 24.58 per cent for the sternum to 59.32 per cent for each of the fibulae. The percentage of ash in the total skeleton was 50.85. The bones with the highest percentage of ash per dry bone weight were the long arm and the leg bones.

Relationship of Per Cent Ash to the Skeletal Site

Bones in the lower part of the body tended to be higher in ash content than those in the upper body. The pelvic area bones had a higher percentage of ash than the shoulder area bones. The long leg bones had a higher percentage than the arm bones, the tarsal bones had a higher percentage than the carpals, and the metacarpals and phalanges of the toes had a higher percentage of ash than did those of the fingers.

Statistical Correlations of Primate 470 Values

The coefficient of correlation between the weights of the dry bones and ash of those bones is 0.98982, which is highly significant, $P<.010$. The correlations between dry weights of bone and those of calcium and phosphorus are 0.98547 and 0.99072, respectively.

The coefficients of correlation between the weights of ash and the weights of calcium and phosphorus are 0.99934 and 0.99904, respectively. The correlation coefficient between the weights of calcium and the weights of phosphorus is 0.99807. Therefore the relationships between the weights of dry bone, ash, calcium and phosphorus are statistically highly significant, and the data can be considered homogeneous.

Formula Composition of Bone Ash

The major constituent of bone ash is calcium hydroxyapatite which is represented by the formula $[3Ca_3(PO_4)_2 \cdot Ca(OH_2)]$. The calcium content of the bone ash samples of Primate 470 ranged from 35.34 to 40.12 per cent with the larger values reported for the smaller bones; i.e. the carpals, the metacarpals and phalanges, and the patellae. The phosphorus content of the bone ash samples ranged from 16.08 to 19.12 per cent with no particular pattern of variance.

Comparison of Primate 470 with Other Monkeys

The seven bones of the right side of Primate 470 were either similar or proportionate to the same bones of the eight Macaca Nemestrina primates to which they were compared, except for the lower leg bones and the Os calces. The dry weight values for the bones of the means of the two groups of primates which were studied ranged from 10 to 49 per cent heavier than those of Primate 470, whereas the total weights ranged from 2.34 to 27.92 per cent heavier than the total seven bones of Primate 470.

Although the bone weights of the lower leg and foot bones were heavier, the mean per cent ash values, 53.45 and 57.22, were slightly lower than those of Primate 470 (57.60 and 57.64 per cent). The percentage of ash in the Os calcis of Primate 470, 54.43, was much higher than the percent ash reported for the means of the primates used for comparison (45.28 and 44.30 per cent). Therefore, although the tibia, fibula and Os calcis of Primate 470 were lighter in weight proportionately than the mean values of the other primates, those bones contained higher ratios of ash, calcium and phosphorus.

Statistical Comparisons and Conclusions

The bones of Primate 470, which had been preserved in a solution of formaldehyde and alcohol, when statistically compared with the bones of eight other monkeys which had been removed and analyzed immediately after sacrifice, yielded correlation coefficients approaching 1.00.

The correlation coefficients between Primate 470 and each of the other monkeys of the dry bone weights ranged from 0.96712 to 0.99942, of the ash weights ranged from 0.98659 to 0.99966, and of the calcium weights from 0.94077 to 0.99912. The correlation coefficients for Primate 470 and the other four animals for which phosphorus evaluations were made indicate that Primate 470, 25 and 30 were well correlated with coefficients of 0.99414, 0.99579 and 0.99491. These relationships were highly significant statistically ($P<.010$), which indicate that these were homogenous sets of data.

These statistical summations indicate that the placing of bones in a preservative such as formaldehyde and alcohol does not affect the calcium or phosphorus content. Thus, a preservative such as formaldehyde and alcohol may be used without altering the mineral content of the skeletal tissues when immediate analysis of these bones is not possible or practical.

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A P P E N D I X

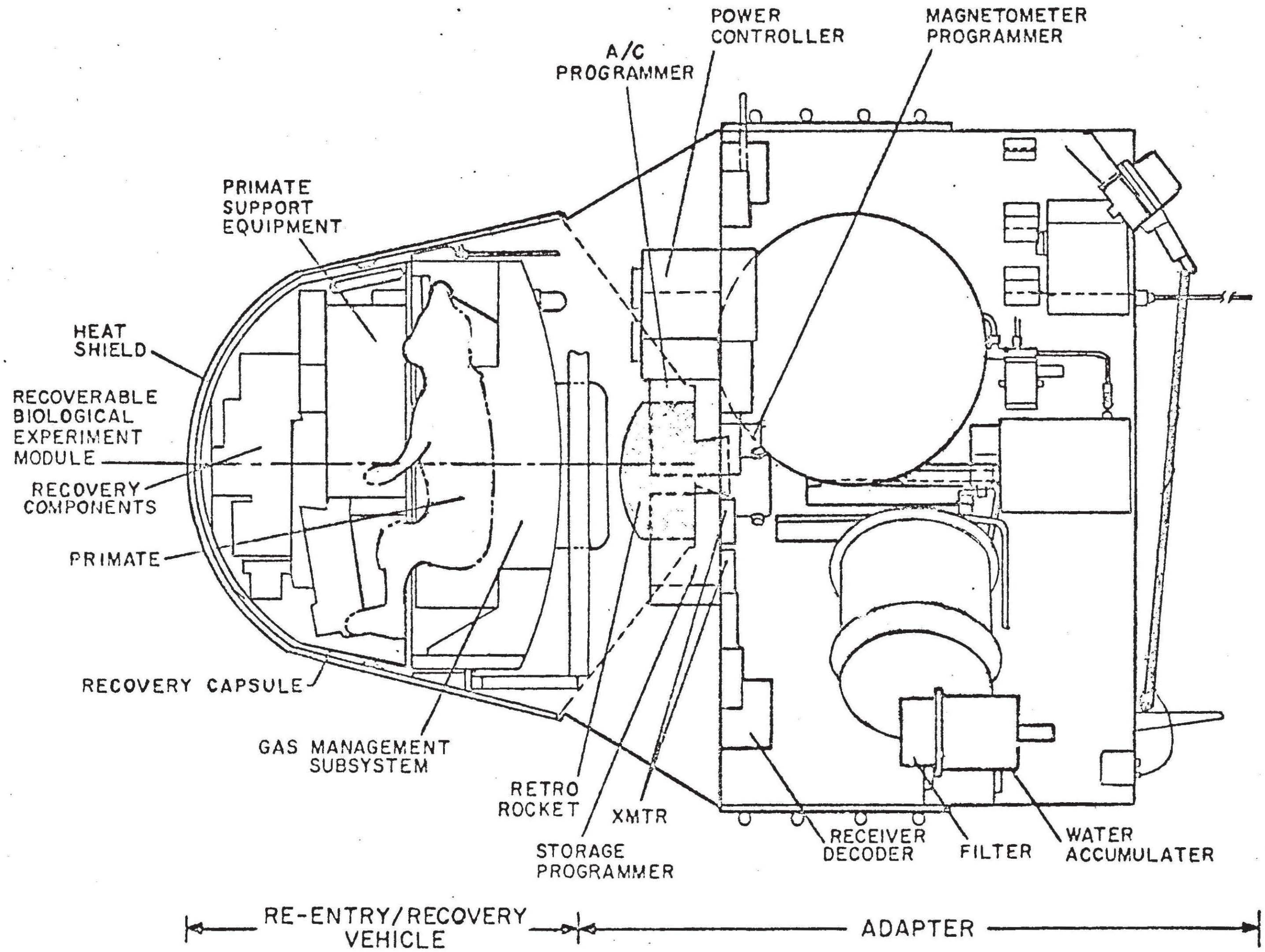


Figure 1. Biosatellite III orbiting vehicle cross section showing location of Primate 470.[1]

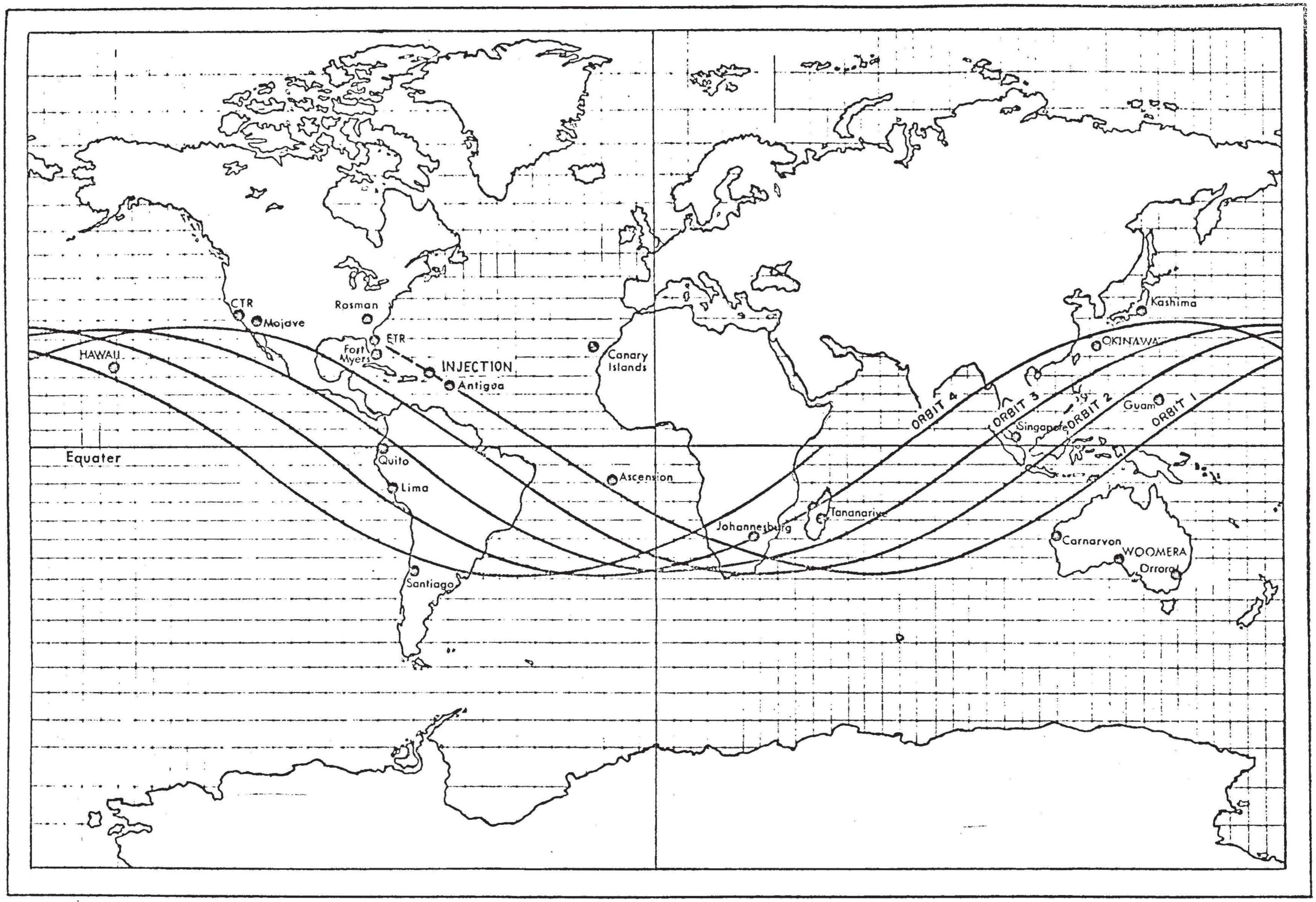


Figure 2. Orbital pattern of Biosatellite III. Locations of telemetry receiving stations are shown. The primary stations were Rosman, Fort Myers, Quito, Lima and Santiago.[1]

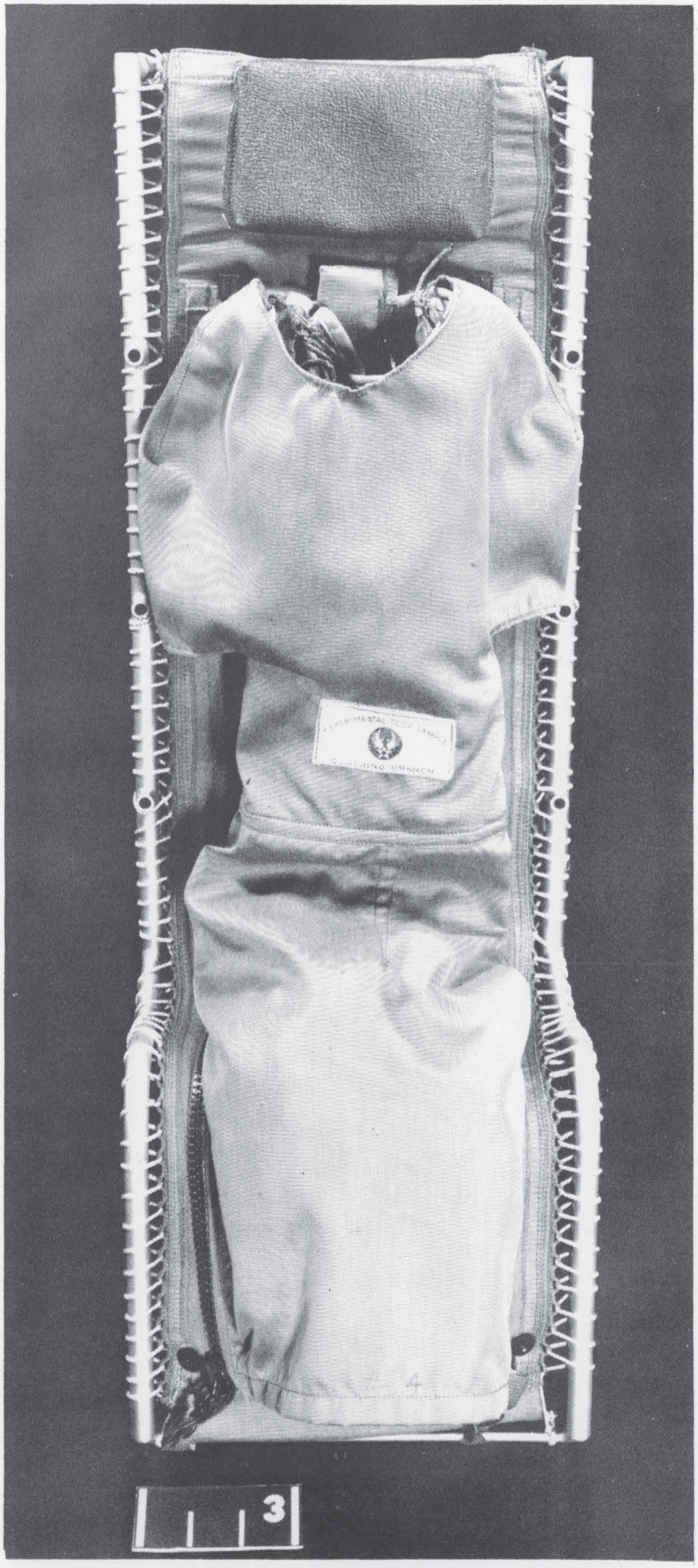
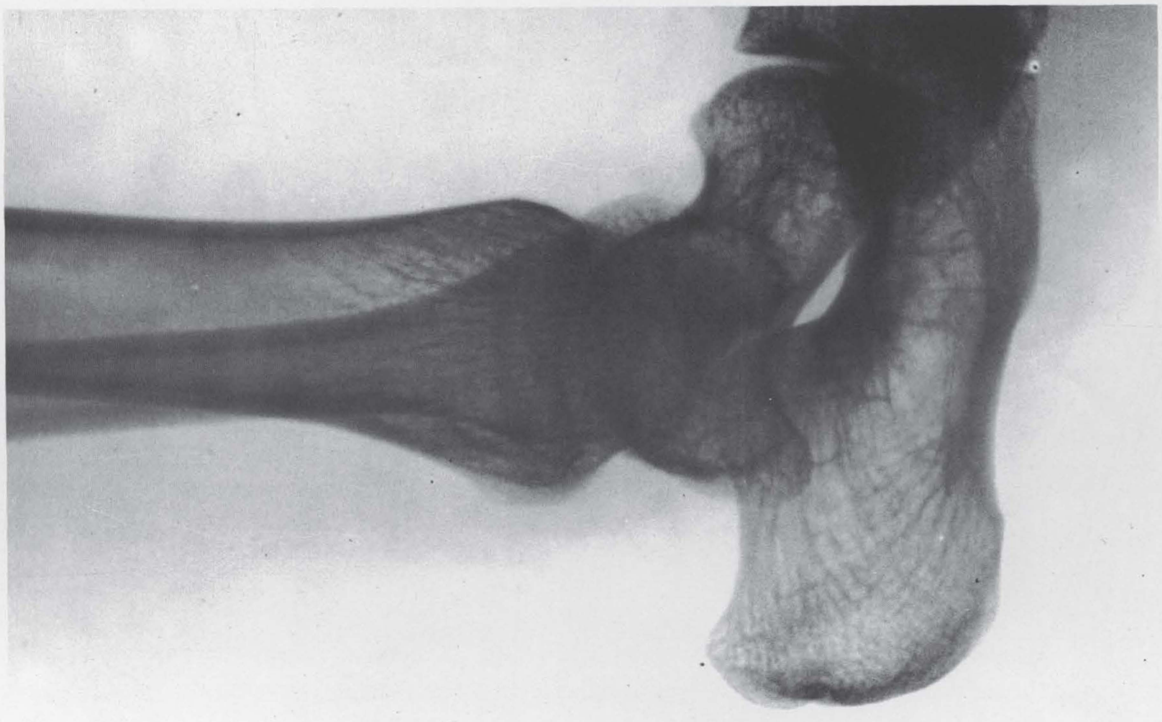


Figure 3. Space suit and couch frame used in Biosatellite III.

Figure 4. A Macaca Nemestrina monkey wearing space suit of the same type as worn by Primate 470 in Biosatellite III mission. Hands and arms were free to perform tasks and retrieve food pellets from a feeder by pressing a lever. He could move his head so that he could watch the task display window and suck water from the drinking nipple. This monkey was photographed by Dr. Ralph E. Pyke at the Texas Woman's University Research Institute Primate Laboratory.

Figure 5 (left)   Figure 6 (right)

(Left: Roentgenogram of lateral view of os calcis of Primate 470 (Biosatellite III, flight animal) on 6/16/69, and (right) same view on 7/8/69), showing an increase of 15.7 per cent in bone density in the disk between the epiphysis and the main bone of the os calcis between these dates. The figure on the left was made on June 16, 1969, twelve days before the launch of the flight animal and that on the right on July 8, 1969, at the close of the flight, following 8.8 days of weightlessness. (Enlargement 3X.)



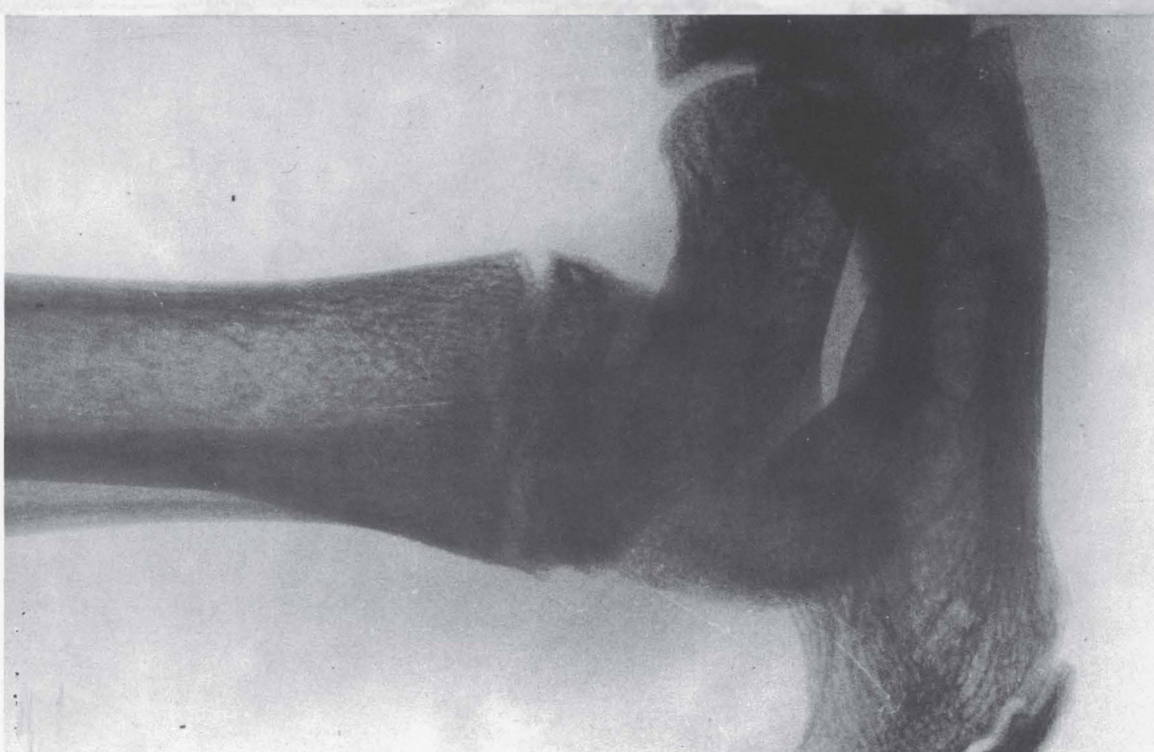


TABLE I

DRY WEIGHT, ASHED WEIGHT, CALCIUM AND PHOSPHORUS CONTENT OF BONE SAMPLES

PART A. VERTEBRAL COLUMN

Bone or Bone Group	Dry Wt. of Bone (g.)	Ash Wt. of Bone (g.)	Per cent Ash in Dry Bone	Calcium in Bone (mg.)	Per cent Calcium in Ash	Phosphorus in Bone (mg.)	Per cent Phosphorus in Ash
Cervical Vertebrae 5, 6, 7	4.3781	1.9951	45.57	759.25	38.06	330.13	16.55
Thoracic Vertebrae 1 through 6, partial 7	17.4623	6.9862	40.01	2584.46	36.99	1180.96	16.90
Thoracic Vertebrae Partial 7, 8 through 12	10.6973	4.5134	42.19	1753.42	38.85	815.94	18.08
Lumbar Vertebrae 1, 2, 3	13.9552	6.4092	45.93	2349.78	36.66	1041.39	16.25
Lumbar Vertebrae 4 (partial)	1.4126	.6433	45.54	240.95	37.45	111.72	17.37
Lumbar Vertebrae 5	7.0072	3.2106	45.82	1196.34	37.26	536.80	16.72
Lumbar Vertebrae 6	6.2314	2.8655	45.98	1073.06	37.45	488.49	17.05
Lumbar Vertebrae 7	5.3532	2.5145	46.97	964.12	38.34	416.02	16.54

T A B L E I CONTINUED

DRY WEIGHT, ASHED WEIGHT, CALCIUM AND PHOSPHORUS CONTENT OF BONE SAMPLES

PART B. SHOULDER, RIB AND PELVIC REGIONS

Bone or Bone Group	Dry Wt. of Bone (g.)	Ash Wt. of Bone (g.)	Per cent Ash in Dry Bone	Calcium in Bone (mg.)	Per cent Calcium in Ash	Phosphurus in Bone (mg.)	Per cent Phosphurus in Ash
Right clavicle	1.6319	0.8137	49.86	301.20	37.01	141.18	17.35
Left clavicle	1.6704	0.8096	48.47	304.30	37.58	146.01	18.03
Manubrium	0.9980	0.3386	33.93	128.39	37.92	55.82	16.49
Sternum (partial)	1.4132	0.3473	24.58	129.41	37.26	57.71	16.62
Ribs	27.0523	11.4102	42.05	4163.11	37.68	1971.29	17.33
Right scapula	9.2780	4.9034	52.85	1835.62	37.44	848.14	17.30
Left scapula	9.5566	5.0144	52.47	1814.98	36.20	866.93	17.29
Sacrum	7.8780	3.7079	47.07	1310.50	35.34	625.37	16.87
Ilium	51.9958	24.4798	47.08	9055.14	36.99	4542.67	18.55

TABLE I CONTINUED

DRY WEIGHT, ASHED WEIGHT, CALCIUM AND PHOSPHORUS CONTENT OF BONE SAMPLES

PART C. ARM AND WRIST REGIONS

Bone or Bone Group	Dry Wt. of Bone (g.)	Ash Wt. of Bone (g.)	Per cent Ash in Dry Bone	Calcium in Bone (mg.)	Per cent Calcium in Ash	Phosphorus in Bone (mg.)	Per cent Phosphorus in Ash
Right humerus	24.5410	13.6047	55.44	5362.89	39.42	2455.86	18.00
Left humerus	24.8744	13.8603	55.72	4886.80*	35.26	2113.65*	15.25
Right ulna	12.2615	6.8546	55.90	2630.22	38.37	1159.49	16.92
Left ulna	12.5046	6.8964	55.15	2593.60	37.61	1234.64	17.90
Right radius	10.3752	5.8840	56.71	2219.18	37.72	1020.12	17.34
Left radius	10.6969	5.8440	54.63	2118.72	36.25	939.58	16.08
Right carpals	2.5742	1.1351	44.10	449.05	39.56	201.97	17.79
Left carpals	2.5651	1.1435	44.58	456.00	39.88	204.65	17.90

*Portion of sample lost during analysis

T A B L E I CONTINUED

DRY WEIGHT, ASHED WEIGHT, CALCIUM AND PHOSPHORUS CONTENT OF BONE SAMPLES

PART D. HAND REGION

Bone Group	Dry Wt. of Bone (g.)	Ash Wt. of Bone (g.)	Per cent Ash in Dry Bone	Calcium in Bone (mg.)	Per cent Calcium in Ash	Phosphorus in Bone (mg.)	Per cent Phosphorus in Ash
Right metacarpals and phalanges 1	0.8058	0.3517	43.65	136.88	38.92	62.00	17.63
Left metacarpals and phalanges 1	0.8026	0.3538	44.08	141.96	40.12	67.63	19.12
Right metacarpals and phalanges 2	1.2723	0.5954	46.17	227.16	37.99	103.60	17.29
Left metacarpals and phalanges 2	1.4199	0.6592	46.43	248.88	37.75	120.44	18.27
Right metacarpals and phalanges 3	2.1853	1.1291	52.21	481.71	37.44	202.11	18.27
Left metacarpals and phalanges 3	2.3133	1.1484	49.64	469.90	40.92	202.69	17.65
Right metacarpals and phalanges 4	1.7258	0.8273	48.94	307.32	37.40	139.57	16.90
Left metacarpals and phalanges 4	1.9556	0.9534	48.75	379.65	39.82	163.05	17.10
Right metacarpals and phalanges 5	1.3746	0.6398	46.54	250.00	39.07	115.41	17.72
Left metacarpals and phalanges 5	1.3862	0.6376	46.00	236.42	37.08	107.70	16.89

TABLE I CONTINUED

DRY WEIGHT, ASHED WEIGHT, CALCIUM AND PHOSPHORUS CONTENT OF BONE SAMPLES

PART E. LEGS

Bone or Bone Group	Dry Wt. of Bone (g.)	Ash Wt. of Bone (g.)	Per cent Ash in Dry Bone	Calcium in Bone (mg.)	Per cent Calcium in Ash	Phosphorus in Bone (mg.)	Per cent Phosphorus in Ash
Right femur	30.4095	17.9132	58.91	6894.62	38.29	3113.45	17.38
Left femur	32.3622	18.1690	56.14	7006.75	38.56	3126.85	17.21
Right patella	1.3993	0.5263	37.61	208.15	39.51	91.80	17.42
Left patella	1.5693	0.5389	34.34	214.92	39.88	99.31	18.43
Right tibia	17.1785	9.9019	57.64	3832.60	38.71	1792.91	18.11
Left tibia	17.7801	10.0232	57.55	3875.90	38.67	1792.91	17.89
Right fibula	3.7204	2.1430	57.60	851.85	39.75	382.47	17.85
Left fibula	3.5136	2.0941	59.32	796.29	38.03	350.26	16.73

TABLE I CONTINUED

DRY WEIGHT, ASHED WEIGHT, CALCIUM AND PHOSPHORUS CONTENT OF BONE SAMPLES

PART F. 1. FOOT (OS CALCIS AND FIRST METATARSAL AND PHALANGES)

Bone Group	Dry Wt. of Bone (g.)	Ash Wt. of Bone (g.)	Per cent Ash in Dry Bone	Calcium in Bone (mg.)	Per cent Calcium in Ash	Phosphorus in Bone (mg.)	Per cent Phosphorus in Ash
Right Os calcis	3.1822	1.7322	54.43	659.19	38.06	295.22	17.04
Left Os calcis	3.2617	1.6991	52.09	616.00	36.25	307.99	18.13
Remaining right tarsals	5.2055	2.7500	52.83	990.86	36.03	460.84	16.76
Remaining left tarsals	5.0565	2.5806	51.04	1004.56	38.93	460.30	17.84
Right metatarsal and phalanges 1	1.7689	0.8691	49.13	332.19	38.22	153.66	17.68
Left metatarsal and phalanges 1	1.7729	0.8444	47.63	305.42	36.17	148.69	17.61

TABLE I CONTINUED

DRY WEIGHT, ASHED WEIGHT, CALCIUM AND PHOSPHORUS CONTENT OF BONE SAMPLES

PART F. 2. FOOT (SECOND, THIRD, FOURTH AND FIFTH METATARSAL AND PHALANGES)

Bone Group	Dry Wt. of Bone (g.)	Ash Wt. of Bone (g.)	Per cent Ash in Dry Bone	Calcium in Bone (mg.)	Per cent Calcium in Ash	Phosphorus in Bone (mg.)	Per cent Phosphorus in Ash
Right metatarsal and phalanges 2	1.6467	0.8109	49.24	299.78	36.97	144.93	17.87
Left metatarsal and phalanges 2	1.5797	0.7911	50.08	292.98	37.03	132.05	16.69
Right metatarsal and phalanges 3	2.3665	1.1533	48.73	444.45	38.54	209.35	18.15
Left metatarsal and phalanges 3	2.1903	1.0982	50.14	417.05	37.98	199.15	18.13
Right metatarsal and phalanges 4	2.2723	1.1279	49.64	449.05	39.81	202.64	17.97
Left metatarsal and phalanges 4	2.1421	1.0647	49.70	414.35	38.92	192.17	18.05
Right metatarsal and phalanges 5	1.4554	0.6773	46.54	259.05	38.25	124.13	18.33
Left metatarsal and phalanges 5	1.4250	0.6729	47.22	254.52	37.82	120.24	17.87

TABLE II

DRY WEIGHT, ASHED WEIGHT, CALCIUM AND PHOSPHORUS CONTENT OF DESIGNATED INDIVIDUAL BONES FROM PRIMATE 470

Bone	Dry Weight (grams)	Ashed Weight (grams)	Calcium in Bone (milligrams)	Phosphorus in Bone (milligrams)
Humerus	24.5410	13.6047	5362.89	2455.86
Ulna	12.2615	6.8546	2630.22	1159.49
Radius	10.3752	5.8840	2219.18	1020.12
Femur	30.4095	17.9132	6894.62	3113.45
Tibia	17.1785	9.9019	3832.60	1792.91
Fibula	3.7204	2.1430	851.85	382.47
Os calsis	3.1822	1.7322	659.19	295.22
Pelvic Area	51.9958	24.4798	9055.14	4542.67
Lumbar Vertebra 5	7.0072	3.2106	1196.34	536.80

TABLE III

MEAN DRY WEIGHT, ASHED WEIGHT, AND CALCIUM CONTENT OF DESIGNATED INDIVIDUAL BONES FROM FOUR PRIMATES

(VARNER[19])

Bone	Dry Weight (grams)	Ashed Weight (grams)	Calcium in Bone (milligrams)
Humerus	22.5117	13.1160	6462.75
Radius	11.1101	6.2782	2354.25
Ulna	11.8898	6.9236	2627.25
Femur	29.8446	16.9916	6462.72
Tibia	20.5380	10.9767	4129.25
Fibula	4.1571	2.9736	1131.00
Os calsis	4.0000	1.8111	650.75
Pelvic Area	80.5815	36.7908	13799.25

TABLE IV

MEAN DRY WEIGHT, ASHED WEIGHT, CALCIUM, AND PHOSPHORUS CONTENT OF DESIGNATED INDIVIDUAL BONES FROM FOUR PRIMATES

(LIU [20])

Bone	Dry Weight (grams)	Ashed Weight (grams)	Calcium in Bone (milligrams)	Phosphorus in Bone (milligrams)
Humerus	28.7674	17.1098	6633.75	2903.25
Radius	13.7356	7.9617	3445.75	2850.50
Ulna	14.7984	8.4834	3250.75	3206.00
Femur	37.9126	21.2164	8175.50	3643.75
Tibia	24.5660	13.3181	5189.25	2256.25
Fibula	5.9408	3.3712	1440.50	658.25
Os calsis	4.3325	1.9280	723.50	302.50
Pelvic Area	98.5815	38.0465	13001.25	6289.50
Lumbar Vertebra 4	7.7257	3.5377	1296.33	504.67

TABLE V

PER CENT CALCIUM AND PHOSPHORUS CALCULATED FROM THE DRY WEIGHT AND ASHED WEIGHT OF VARIOUS INDIVIDUAL BONES FROM PRIMATE 470

Bone	Dry Weight (grams)	Ashed Weight (grams)	Ash in Dry Weight (per cent)	Calcium in Dry Weight (per cent)	Calcium in Ashed Weight (per cent)	Phosphorus in Dry Weight (per cent)	Phosphorus in Ashed Weight (per cent)
Humerus	24.5410	13.6047	55.44	19.35	39.42	10.02	18.00
Radius	12.2615	6.8546	55.90	21.38	38.37	9.43	16.92
Ulna	10.3752	5.8840	56.71	21.34	37.72	9.81	17.34
Femur	30.4095	17.9132	58.91	22.68	38.29	10.24	17.38
Tibia	17.1785	9.9019	57.64	21.98	38.71	10.42	18.11
Fibula	3.7204	2.1430	57.60	23.02	39.75	10.34	17.85
Os calsis	3.1822	1.7322	54.43	20.60	38.06	9.23	17.04
Pelvic Area	51.9958	24.4798	47.09	16.77	36.99	8.74	18.55
Lumbar Vertebra 5	7.0072	3.2106	45.82	17.07	37.26	7.66	16.72

TABLE VI

MEAN PER CENT CALCIUM CALCULATED FROM THE DRY WEIGHT AND ASHED WEIGHT OF VARIOUS INDIVIDUAL BONES FROM FOUR PRIMATES

(VARNER[19])

Bone	Dry Weight (grams)	Ashed Weight (grams)	Ash in Dry Weight (per cent)	Calcium in Dry Weight (per cent)	Calcium in Ashed Weight (per cent)
Humerus	22.5117	13.1160	58.26	22.07	37.88
Radius	11.1101	6.2782	56.51	21.19	37.50
Ulna	11.8898	6.9236	58.23	22.10	37.95
Femur	29.8446	16.9916	56.93	21.65	38.03
Tibia	20.5380	10.9767	53.45	20.11	37.62
Fibula	5.1964	2.9736	57.22	21.76	38.03
Os calsis	4.0000	1.8111	45.28	16.27	35.93
Pelvic Area	80.5815	36.7908	45.66	17.12	37.51

TABLE VII

PER CENT CALCIUM AND PHOSPHORUS CALCULATED FROM THE DRY WEIGHT AND ASHED WEIGHT OF VARIOUS INDIVIDUAL BONES FROM FOUR PRIMATES

(LIU [20])

Bone	Dry Weight (grams)	Ashed Weight (grams)	Ash in Dry Weight (per cent)	Calcium in Dry Weight (per cent)	Calcium in Ashed Weight (per cent)	Phosphorus in Dry Weight (per cent)	Phosphorus in Ashed Weight (per cent)
Humerus	28.7674	17.1098	59.48	23.06	38.77	10.09	16.97
Radius	13.7356	7.9617	57.96	25.09	43.27	20.75	35.80
Ulna	14.7984	8.4834	57.33	21.97	38.37	21.66	37.79
Femur	37.9126	21.2164	55.96	21.56	38.53	9.61	17.17
Tibia	24.5660	13.3181	54.21	21.12	38.96	9.18	16.94
Fibula	5.9408	3.3712	56.75	24.25	42.73	11.08	19.53
Os calsis	4.3525	1.9280	44.30	16.62	37.53	6.95	15.69
Pelvic Area	98.5815	38.0465	38.59	13.19	34.17	6.38	16.53
Lumbar Vertebra 4	7.7257	3.5377	45.79	16.78	36.64	6.53	14.26

TABLE VIII

DRY WEIGHT, ASHED WEIGHT AND CALCIUM CONTENT OF DESIGNATED INDIVIDUAL BONES FROM PRIMATE V 1

(VARNER[19])

Bone	Dry Weight (grams)	Ashed Weight (grams)	Calcium in Bone (milligrams)
Humerus	19.2228	11.6394	4449
Radius	9.6950	5.8310	2185
Ulna	9.7937	5.9110	2262
Femur	22.4944	13.7930	5166
Tibia	15.2718	8.5858	3240
Fibula	4.5800	2.7285	1031
Os calsis	3.0895	1.5117	527
Pelvic Area	86.1832	33.4725	12345

TABLE IX

DRY WEIGHT, ASHED WEIGHT AND CALCIUM CONTENT OF DESIGNATED INDIVIDUAL BONES FROM PRIMATE V 2

(VARNER[19])

Bone	Dry Weight (grams)	Ashed Weight (grams)	Calcium in Bone (milligrams)
Humerus	21.5014	12.9591	4967
Radius	10.1390	6.3172	2423
Ulna	10.7305	6.7354	2570
Femur	28.0195	17.4982	6830
Tibia	18.5870	11.4544	4363
Fibula	4.9581	3.1471	1255
Os calsis	3.3226	1.8090	651
Pelvic Area	75.7822	38.9837	14748

TABLE X

DRY WEIGHT, ASHED WEIGHT AND CALCIUM CONTENT OF DESIGNATED INDIVIDUAL BONES FROM PRIMATE V 3

(VARNER[19])

Bone	Dry Weight (grams)	Ashed Weight (grams)	Calcium in Bone (milligrams)
Humerus	26.3383	14.0052	5396
Radius	12.7823	6.3264	2349
Ulna	13.7640	7.3846	2816
Femur	38.4036	17.9198	6727
Tibia	27.7761	12.1658	4539
Fibula	6.3610	3.1654	1191
Os calsis	4.8955	1.9909	725
Pelvic Area	87.4446	38.2774	14172

TABLE XI

DRY WEIGHT, ASHED WEIGHT AND CALCIUM CONTENT OF DESIGNATED INDIVIDUAL BONES FROM PRIMATE V 4

(VARNER[19])

Bone	Dry Weight (grams)	Ashed Weight (grams)	Calcium in Bone (milligrams)
Humerus	22.9843	13.8604	5059
Radius	11.8440	6.6382	2460
Ulna	13.2710	7.6634	2861
Femur	30.4610	18.7555	7128
Tibia	20.5171	11.7009	4375
Fibula	4.8866	2.8534	1047
Os calsis	4.6933	1.9329	700
Pelvic Area	72.9160	36.4297	13932

TABLE XII

DRY WEIGHT, ASHED WEIGHT, CALCIUM AND PHOSPHORUS CONTENT OF DESIGNATED INDIVIDUAL BONES FROM PRIMATE 21

(LIU[20])

Bone	Dry Weight (grams)	Ashed Weight (grams)	Calcium in Bone (milligrams)	Phosphorus in Bone (milligrams)
Humerus	30.7972	18.9783	7332	3257
Radius	15.0563	8.9106	3228	3103
Ulna	15.2484	9.3282	3551	3354
Femur	38.1065	22.0310	8429	3908
Tibia	24.4005	13.4687	5165	2286
Fibula	5.9100	3.4428	1714	1187
Os calsis	4.5130	2.1164	762	366
Pelvic Area	86.6272	38.3269	14618	6551
Lumbar Vertebra 4	7.7257	3.6643	1273	322

TABLE XIII

DRY WEIGHT, ASHED WEIGHT, CALCIUM AND PHOSPHORUS CONTENT OF DESIGNATED INDIVIDUAL BONES FROM PRIMATE 25

(LIU[20])

Bone	Dry Weight (grams)	Ashed Weight (grams)	Calcium in Bone (milligrams)	Phosphorus in Bone (milligrams)
Humerus	34.9164	20.4764	8104	3474
Radius	18.1310	10.2340	3354	1741
Ulna	17.7650	9.8127	3838	1746
Femur	48.5580	25.4396	10040	4329
Tibia	28.3348	15.1560	6050	2599
Fibula	7.9184	4.3590	1784	740
Os calsis	4.6580	2.0340	771	238
Pelvic Area	154.8368	51.4592	13360	8042
Lumbar Vertebra 4	—	4.5773	1757	790

TABLE XIV

DRY WEIGHT, ASHED WEIGHT, CALCIUM AND PHOSPHORUS CONTENT OF DESIGNATED INDIVIDUAL BONES FROM PRIMATE 30

(LIU 20)

Bone	Dry Weight (grams)	Ashed Weight (grams)	Calcium in Bone (milligrams)	Phosphorus in Bone (milligrams)
Humerus	24.8360	13.2740	5247	2250
Radius	11.4480	6.3710	2484	1106
Ulna	13.5950	6.9206	2726	1211
Femur	32.9233	17.1550	6771	2953
Tibia	23.2720	11.1135	4484	1895
Fibula	5.1552	2.7727	1197	467
Os calsis	4.7590	1.7004	664	296
Pelvic Area	69.3940	26.4814	10530	4466
Lumbar Vertebra 4	—	2.3715	859	402

TABLE XV

DRY WEIGHT, ASHED WEIGHT, CALCIUM AND PHOSPHORUS CONTENT OF DESIGNATED INDIVIDUAL BONES FROM PRIMATE 69

(LUI [20])

Bone	Dry Weight (grams)	Ashed Weight (grams)	Calcium in Bone (milligrams)	Phosphorus in Bone (milligrams)
Humerus	24.5199	15.7107	5852	2632
Radius	10.3070	6.3311	4717	5452
Ulna	12.5852	7.8723	2888	6513
Femur	32.0628	20.2399	7462	3385
Tibia	22.2568	13.5342	5058	2245
Fibula	4.7797	2.9105	1067	239
Os calsis	3.4800	1.8613	697	310
Pelvic Area	83.4681	35.9187	13497	5999

TABLE XVI

TOTAL BONE, ASH, CALCIUM AND PHOSPHORUS WEIGHTS OF LIMBS AND TOTAL LIMBS OF THE SKELETON OF PRIMATE 470

Bone	Dry Weight (grams)	Ashed Weight (grams)	Calcium in Bone (milligrams)	Phosphorus in Bone (milligrams)
Long Arm Bones	95.2536	52.9440	19811.41	8923.34
Carpals	5.1396	2.2786	905.05	406.62
Metacarpals Phalanges	15.2414	7.2957	2879.88	1284.20
Total Arm Limbs	115.6346	62.5183	23596.34	10614.16
Long Leg Bones	104.9643	60.2444	23258.01	10558.85
Tarsals	16.7059	8.7619	3270.61	1524.35
Metatarsals Phalanges	18.6198	9.1098	3468.84	1627.01
Patellas	2.9686	1.0652	423.07	191.11
Total Leg Limbs	143.2586	79.1813	30420.53	13901.32
Total Limbs	258.8932	141.6996	54016.87	24515.48

TABLE XVII

TOTAL BONE, ASH, CALCIUM AND PHOSPHORUS WEIGHTS OF TRUNK AND COMPLETE SKELETON OF PRIMATE 470

Bone	Dry Weight (grams)	Ashed Weight (grams)	Calcium in Bone (milligrams)	Phosphorus in Bone (milligrams)
Cervical Vertebrae	4.3781	1.9951	759.25	330.13
Thoracic Vertebrae	28.1596	11.4996	4337.88	1996.90
Lumbar Vertebrae	33.9596	15.6431	5824.25	2594.42
Total Spinal Column	66.4973	29.1378	10921.38	4921.45
Shoulder Area Bones	22.1369	11.5411	4256.10	2002.96
Ribs and Sternum Area	29.4635	12.0961	4420.91	2084.82
Sacrum and Ilium	59.8738	28.1877	10365.64	5168.04
Total Trunk Bones	176.9715	80.9627	28964.03	14177.27
Total Limbs (Table XVI)	258.8932	141.6996	54016.87	24515.48
Total Skeleton	437.8647	222.6623	82980.90	38692.75

TABLE XVIII

PER CENT ASH, CALCIUM AND PHOSPHORUS IN TOTAL LIMB SKELETON OF PRIMATE 470

Bone	Dry Weight (grams)	Ashed Weight (grams)	Ash in Dry Weight (per cent)	Calcium in Dry Weight (per cent)	Calcium in Ashed Weight (per cent)	Phosphorus in Dry Weight (per cent)	Phosphorus in Ashed Weight (per cent)
Long Arm Bones	95.2536	52.9440	55.58	20.80	37.42	9.37	16.85
Carpals	5.1396	2.2786	44.33	17.61	39.72	7.91	17.84
Metacarpals, Phalanges	15.2414	7.2957	47.87	18.90	39.47	8.43	17.60
Total Arm Limbs	115.6346	62.5183	54.07	20.41	37.74	9.18	16.66
Long Leg Bones	104.9643	60.2444	57.40	22.16	38.61	10.06	17.53
Tarsals	16.7059	8.7619	52.44	19.57	37.32	9.12	17.39
Metatarsals, Phalanges	18.6198	9.1098	48.93	18.63	38.08	8.74	17.86
Patellas	2.9686	1.0652	35.88	14.25	39.72	6.44	17.94
Total Leg Limbs	143.2586	79.1813	55.27	21.23	38.42	9.70	17.56
Total Limbs	258.8932	141.6996	54.73	20.86	38.12	9.47	17.30

TABLE XIX

PER CENT ASH, CALCIUM AND PHOSPHORUS IN TOTAL BONES OF TRUNK AND SKELETON OF PRIMATE 470

Bone	Dry Weight (grams)	Ashed Weight (grams)	Ash in Dry Weight (per cent)	Calcium in Dry Weight (per cent)	Calcium in Ashed Weight (per cent)	Phosphorus in Dry Weight (per cent)	Phosphorus in Ashed Weight (per cent)
Cervical Vertebrae	4.3781	1.9951	45.57	17.34	38.06	7.54	16.55
Thoracic Vertebrae	28.1596	11.4996	40.84	15.40	37.72	7.09	17.36
Lumbar Vertebrae	33.9596	15.6431	46.06	17.15	37.23	7.64	16.59
Total Spinal Column	66.4973	29.1378	44.48	16.66	37.48	7.40	16.89
Shoulder Area Bones	22.1369	11.5411	45.17	19.23	36.88	9.05	17.36
Ribs and Sternum Area	29.4635	12.0961	41.05	15.00	36.55	7.08	17.24
Sacrum and Ilium	59.8738	28.1877	47.08	17.31	36.77	8.63	18.33
Total Trunk	176.9715	80.9627	45.75	16.37	35.77	8.01	17.51
Total Limbs (Table XVIII)	258.8932	141.6996	54.73	20.86	38.12	9.47	17.30
Total Skeleton	437.8647	222.6623	50.85	18.95	37.27	8.84	17.38

TABLE XX

CHANGES IN BONE DENSITY OF FLIGHT PRIMATE DURING THE BIOSATELLITE ORBITAL MISSION, BASED ON LAST CORRESPONDING PRE-FLIGHT VALUE AT THE SAME ANATOMIC SITES AND THE RECOVERY VALUES, IN COMPARISON WITH THE STAND-IN CONTROL ANIMAL AT SIMILAR PERIODS OF TIME[5]

Anatomic Site	Flight Animal (Primate 470)			Control Animal (Primate 264)		
	Bone Density Values, Based on Integrator Counts from the Computer					
	Pre-Flight Bone Density	Recovery Bone Density	Change In Flight Primate (Per Cent)	Pre-Flight Control Bone Density	Recovery Control Bone Density	Change In Control Primate (Per Cent)
Central Section of Os Calcis	3,042	2,917	-4.11	2,557	2,312	-9.58
Central Section of Talus	1,352	1,253	-7.32	1,260	1,253	-0.56
Section across Patella	2,820	2,339	-17.06	2,736	2,701	-1.28
Hand Phalanx 4/2	4,790	4,753	-8.77	3,211	3,207	-0.12
Hand Phalanx 5/2	2,698	2,544	-5.71	2,256	2,160	-4.26
Diagonal Section across Capitate	1,501	1,238	-17.52	1,136	1,045	-8.01
Section across Distal End of Radius	1,984	1,701	-14.26	1,493	1,333	-10.72
Diaphysis of Radius	31,255	30,719	-1.71	33,819	30,887	-8.67
Section across Distal End of Ulna	1,192	1,069	-10.32	842	838	-0.48
Diaphysis of Ulna	29,908	28,844	-3.56	21,506	21,278	-1.06
Section across Elbow	1,350	1,250	-7.41	1,076	999	-7.16
Section across Olecranon	2,729	2,356	-13.67	2,350	2,162	-8.00
Lumbar Vertebra 4	90,448	81,748	-9.62	72,895	70,227	-3.66
Lumbar Vertebra 3	68,446	63,891	-6.65	64,620	62,350	-3.51
Lumbar Vertebra 2	60,835	54,425	-10.54	56,120	54,280	-3.28
Lumbar Vertebra 1	53,565	49,656	-7.30	47,833	46,580	-2.62
Thoracic Vertebra 12	47,096	43,131	-8.42	48,920	45,755	-6.47