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NASA Contract #NAS 9-13589

NASA CR-151421

(NASA-CR-151421) MODIFICATION OF OS CALCIS BONE MINERAL PROFILES DURING BEDREST (California Univ.) 12 p HC A02/MF A01 CSCL 06S G3/52 N77-25776 Unclas 30386

Title: Modification of os calcis bone mineral profiles during bedrest.

Principle Investigator: John Max Vogel, M.D.
Associate Professor of Radiology and Nuclear Medicine
University of California, Davis
Davis, California 94616

Objectives:

1. To apply the photon absorptiometric technique for estimating bone mineral content to a series of bedrest studies in progress at the USPHS Hospital, San Francisco, CA.

2. To compare local mineral content changes in a weight bearing bone (os calcis) with total body calcium balance changes.

Technical Description:

Instrumentation employed during the Apollo and Skylab missions was used in this study. The mineral content of the left central os calcis was determined using the photon absorptiometric technique modified for the space missions to permit area scanning. Therefore the mineral content for a significant volume of the bone could be quantitated. No commercial instrumentation has been available for this purpose. The instrument consists of a rectilinear scanner (Fig. 1) that is programmed by a specially designed control module to move a low energy X-ray emitting radionuclide (^{125}I) placed in opposition to a detector to scan the foot (os calcis) which is placed between them. The foot is placed in a plexiglas box filled with water to provide tissue equivalence and to compensate for irregularities in thickness of tissue cover that surrounds the bone. The mineral content of the central 2½ cm section of the os calcis is expressed as mg/cm^2 of hydroxyapatite. The mineral content is obtained from the basic attenuation equation $I = I_0^* e^{\mu x}$, where I_0^* is the unattenuated beam intensity, I the intensity through bone, μ the mass attenuation coefficient in cm^2/mg and x is the mineral content in mg/cm^2. Therefore the absorbance through the bone segment is proportional to the term $\ln I_0^*/I$ at each point in the bone. The mean of the sum of data points in the area of the os calcis being measured is compared to reference standards which have been calibrated in a number of laboratories. These included the Witt-Cameron standard which consists of three chambers containing depotassium hydrogen phosphate to simulate bone attenuation and the hydroxyapatite step wedge of Professor Heuck.

The heel measurement of John Vogel is shown on three attached pages as a profile, individual row data and the mean values for selected nine scan rows. The values for mineral content are given in mg/cm^2 of hydroxyapatite obtained by comparing with standards described above. The low I_0 values are the most accurate values. The Water I_0, and mean I_0 determinations are also calculated to permit evaluating the effect of alterations in soft tissue composition. They are useful for comparison with results obtained by others who do not make such corrections. The other data shown (Fat equivalent and Low/H_2O) permit the evaluation of changes in fat content during the longitudinal study.

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Progress Report:

Three studies were carried out during 1975 and 1976 which were directed at evaluating the effect of impact upon the os calcis mineral content. The first study (#10 and 11) consisted of two ambulatory controls who undertook no exercise and were essentially sedentary and 5 subjects who performed ambulatory vertical impact loading on the os calcis for 1 hour per day divided into four 15 minute segments. This consisted of rhythmicly raising on the toes and then impacting on the heel. Changes observed expressed as the mean of the 1st 4 weeks vs the last 4 weeks are shown in Table I. Nonsignificant changes were seen in the impacted group. The two control subjects however lost mineral 1½ to 2 standard deviations below the prestudy mean. This study was of limited value as a test of impact loading on os calcis mineral but did suggest that there was an effect when compared to the sedentary controls.

The second and third studies were bedrest studies in which acute compression was applied to the bottom of the feet, impact loading, by a device designed and built by C.A.L. Bassett, Division of Orthopaedics, Columbia University. The impact loader is an aluminum frame, which compresses an individual between the shoulders and heel and can be modified by both coarse and fine adjustments. The force applied between the soles of the feet and the acromial process of the shoulder equals approximately 2/3 of the body weight. An area is removed from the metal foot brace, allowing a 5.5 cm round rubber hammer to strike the firmly placed heel. The rubber hammer is attached to a spring which can be set between 10 and 50 lbs. In study #2 the spring was set for 20 lbs. and in #3, 35 lbs. of impact loading. A motor pulls the rubber hammer out 7 cm from the heel and then the rubber hammer is allowed to snap back hitting the heel sharply at a rate of 35 to 40 times a minute.

Five subjects were studied in study #2. After a baseline period all subjects remained on absolute bedrest for 5 weeks. Two received impact loading and three none. This was followed by an 11 week reambulation period and then another 5 weeks of bedrest with cross over of the study groups. Since the original study had been designed for a longer bedrest period the schedule for mineral studies was upset such that the data did not coordinate well with the change-over dates from bedrest to ambulation and visa versa. The data is shown in Table 2. No conclusions can be drawn. Very limited mineral losses have been observed during short 5 week bedrest studies in the past and it is not surprising that the results are so variable and inconclusive.

Study #3 consisted of 7 subjects, 2 controls and 5 with impact loading at 35 lbs. 6 hours per day during 8 weeks of bedrest. The results from this study are much more meaningful since the loss in os calcis mineral in the controls were -16.8 and 7.0% resp while the impacted subjects only had losses between 2 and 4.4%. Only one fell more than 1 S.D. outside the mean baseline. Since the mineral balance portion of the study failed to show any difference between the groups it is apparent that the observed changes were local. It is reasonable to conclude that the generation of pieso electric forces within the os calcis accounted for the local effect. Inadequate stimulation to the remainder of the axial and distal skeleton must be assumed since the net total body mineral loss was not affected.

These studies point out the need for studies of at least 8 week bedrest in order to draw firm conclusions and the need to adhere to rigid criteria and schedules.

In addition to the bedrest studies work has been in progress to modify and improve the hardware designed and built for Apollo and Skylab. Most of the equipment is now over 8 years old and requires major repair and replacement with state of the art electronics. Preliminary studies have also been undertaken to evaluate other detection systems. These have included the Cd Te solid state detector and a multiwire proportional chamber. The former can derive power from a battery pack and might be useful as an inflight detector.

Nature of Contracts with NASA:

Contracts have primarily been mission oriented during Apollo and Skylab which together with ground based bedrest simulations have formed a basis for evaluating counter measures.

Publications:

1. 1975 Vogel, J.M.: Bone mineral measurement, Skylab experiment M-078. Presented at the fifth Man in Space Symposium, Washington, D.C., November 29, 1973. Published in ACTA Astronautica 2(1-2):129-139.

2. 1975 Lockwood, D.R.; Vogel, J.M.; Schneider, V.S.; Hulley, S.B.: Effect of the Diphosphonate EHDP on Bone Mineral Metabolism During Prolonged Bed Rest. J.C.E.& M. 41:533-541.

3. 1976 Vogel, J.M.; Whittle, M.W.: Bone Mineral Changes: The Second Manned Skylab Mission. Aviation, Space and Environmental Medicine, April, pp. 396-400.

4. 1975 Rambaut, P.C., Smith, M.C., Mack, P.B. and Vogel, J.M.: "Skeletal Response: in the book Biomedical Results of Apollo, NASA-SP-368, 1975, pg. 303-322.

5. 1976 Vogel, J.M.: "Bone Mineral Measurement: Skylab Experiment M-078 in the book "Basic Environmental Problems of Man in Space", pg. 129-139, Pergamon Press Inc.

6. 1977 Vogel, J.M.; Ullman, J.; and Entine, G.: Use of Cd Te Detectors in Bone Mineral Measurements. Revue de Physique Appliquie. 12:375-378.

7. 1973 Lockwood, D.R.; Lammert, J.E.; Vogel, J.M.; and Hulley, S.B.: Bone Mineral Loss During Prolonged Bed Rest. Clinical Aspects of Metabolic Bone Disease 261-265. Int'l Congress Series No. 270, Excerpta Medica, Amsterdam.

Assessment:

Although the feasibility of short term manned space travel has been established, the risks associated with musculoskeletal deconditioning in weightlessness are paramount in establishing the limits as to the duration of such null gravity exposure. Two factors which our research has addressed over the past 8 years are of importance to NASA. First, the evaluation of counter measure bedrest simulations and secondly, the further validation of prediction profiles which have to date been found to be applicable to both bedrest and null gravity. These prediction profiles should receive further study to include older age individuals. It is possible that crew selection criteria could be established which when adoed to counter measures, not yet discovered, could result is safer extended missions.

Recommendations and Future Plans:

a) Modification of existing hardware to permit increased precision, simplicity in use and potential inflight application. Plans are currently being drawn and preliminary working drawings and specifications should be completed by July.

b) Expansion of bedrest studies to evaluate counter measures and crew selection criteria. It is anticipated that the diphosphonates should receive further trial (ref. 2). Older subjects should be studied using the bedrest study design. Prediction terms should be established for this group of subjects (ref. 7).

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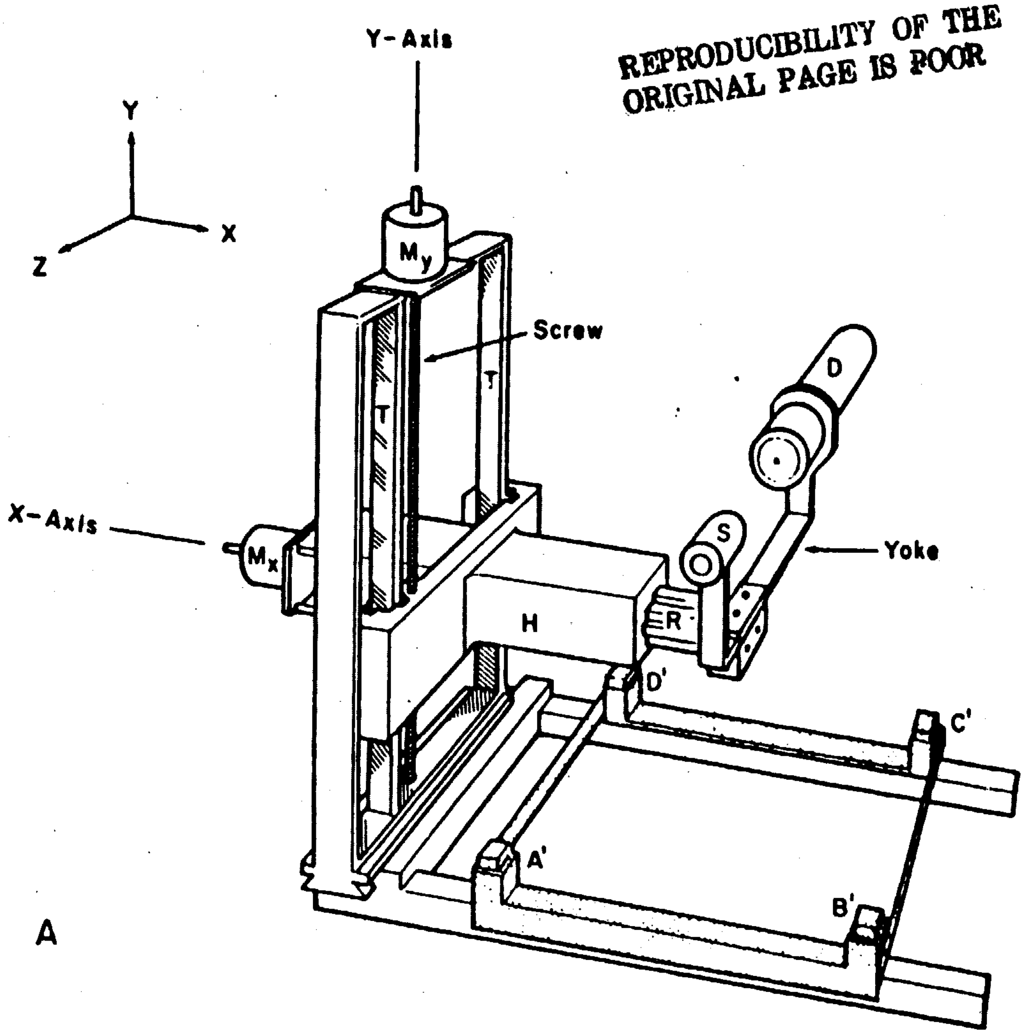


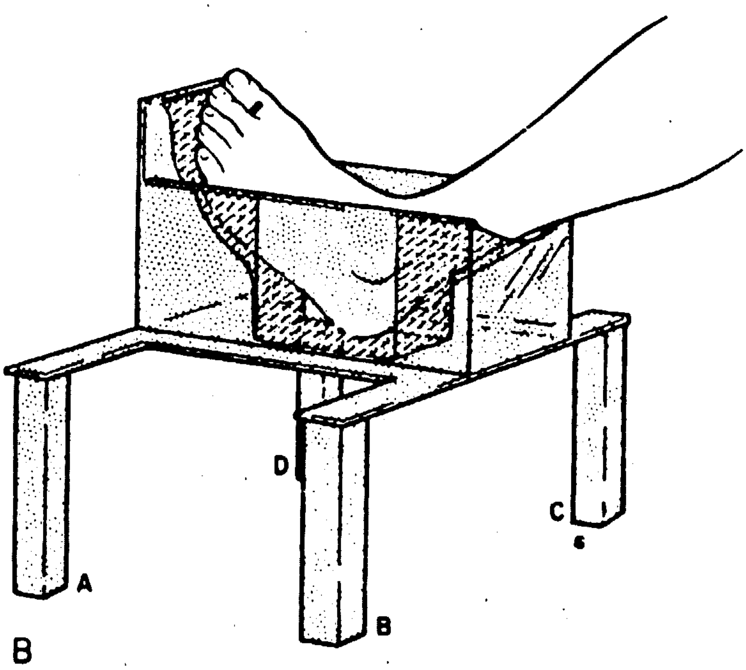
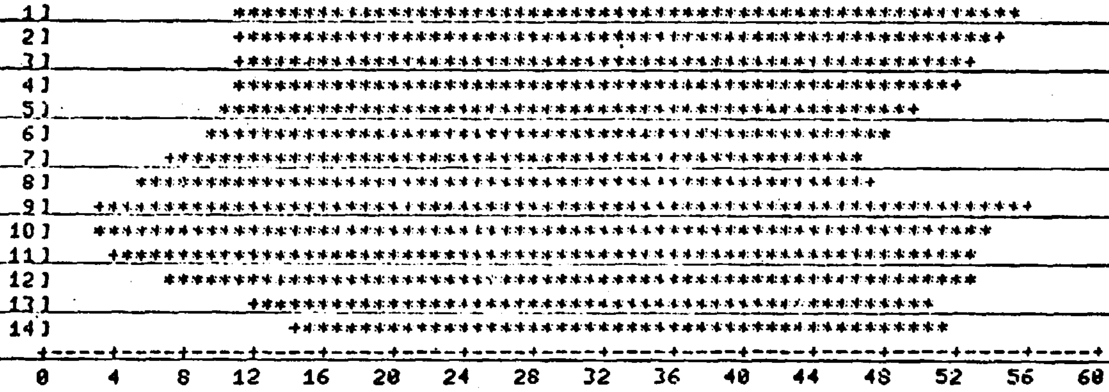


Figure 1

ROW	BCH	.ECH	LEAN SIDE
1	57	168	F
2	58	165	A
3	58	161	A
4	57	159	A
5	55	153	A
6	53	150	A
7	48	146	A
8	43	147	A
9	38	169	F
10	37	164	F
11	40	162	F
12	47	162	F
13	60	156	F
14	66	158	F

ROW JOHN VOGEL 7/21/75 L HEEL



WIDTH MM
ROW INTERVAL=3MM

JOHN VOGEL 7/21/75 L HEEL

HEEL SLOPE PROGRAM NOVEMBER 27,1973
PRE VOGEL 7/21/75 JV0721
POST VOGEL 7/21/75 JVP721
MG/SQCM SLOPE 0.25636421E-02 INTERCEPT -0.87159572E-02 WIO 422.25
GM/CM SLOPE 0.56143709E+02 INTERCEPT -0.15710115E+01

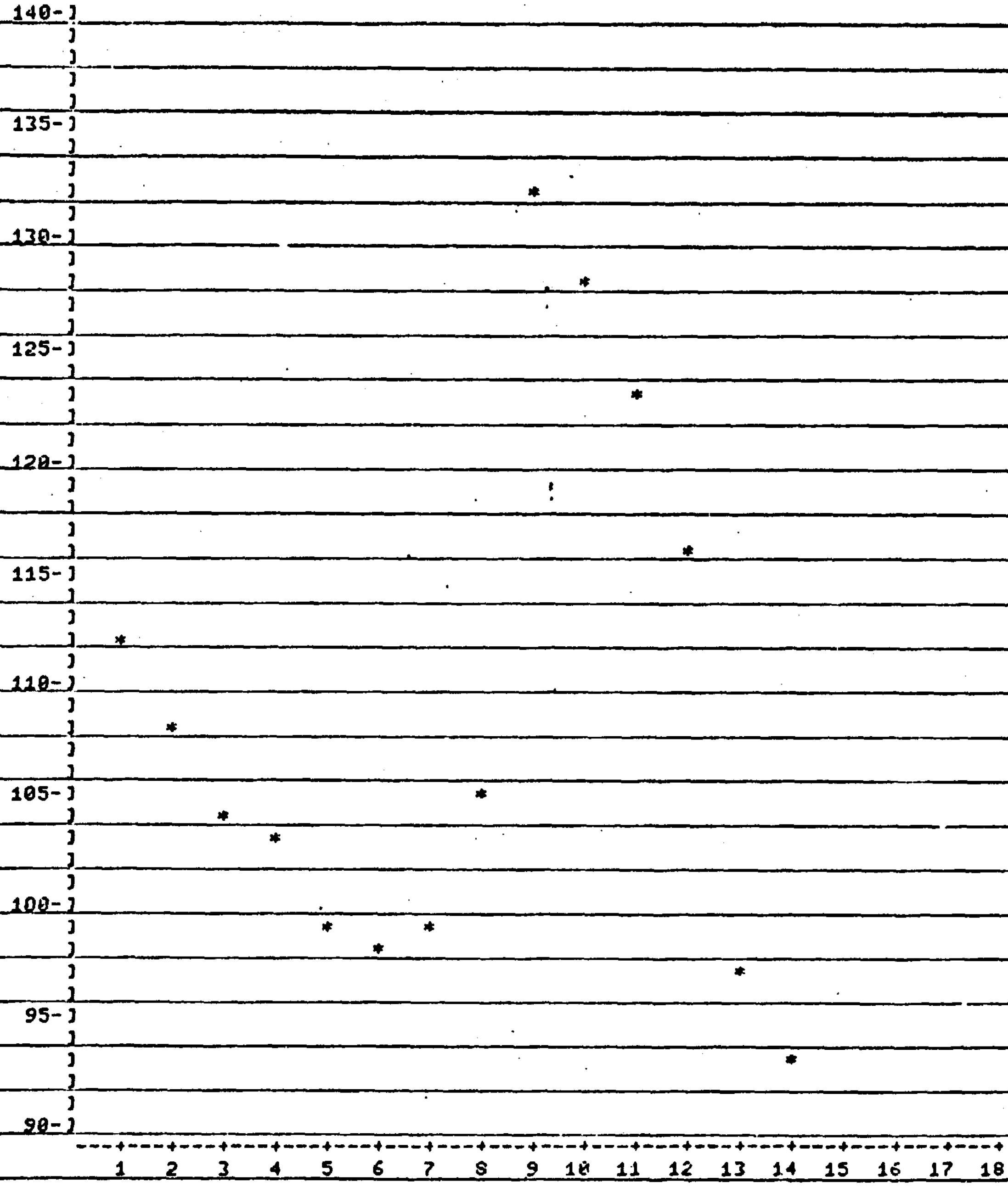
IZERO DATA

ROW	HIGH	LOW	MEAN	CN	FAT EQU	LOW:H2O
1	510.25	332.25	421.25	112	2.76	0.79
2	645.50	479.25	562.38	108	1.91	1.13
3	646.63	466.25	556.44	104	2.10	1.10
4	651.88	418.50	535.19	103	2.85	0.99
5	595.75	433.38	514.56	99	2.05	1.03
6	561.25	441.50	501.37	98	1.54	1.05
7	559.12	451.50	505.31	99	1.37	1.07
8	519.50	492.25	505.88	105	0.35	1.17
9	505.50	447.37	476.44	132	0.79	1.06
10	486.12	418.12	452.12	128	0.97	0.99
11	513.13	417.50	465.31	123	1.33	0.99
12	554.25	419.75	487.00	116	1.79	0.99
13	554.62	398.87	476.75	97	2.12	0.94
14	549.50	410.87	480.19	93	1.87	0.97
MEAN	560.93	430.53	495.73	108	1.70	1.02
SUM				1517		

BONE DATA

	LOW IO		H2O IO		MEAN IO	
ROW	CU	MG/SQCM	CU	MG/SQCM	CU	MG/SQCM
1	153.72	538.78	180.57	632.28	180.31	631.36
2	182.87	663.89	169.20	614.50	200.15	726.29
3	168.47	635.26	158.16	596.60	186.86	704.24
4	156.37	595.60	157.29	599.07	181.70	691.53
5	158.07	626.21	155.50	616.07	175.07	693.19
6	156.24	625.26	151.87	607.87	168.70	674.87
7	154.82	613.42	148.19	587.29	165.97	657.34
8	170.75	637.73	154.64	577.89	173.62	648.38
9	198.60	590.28	190.97	567.73	206.91	614.93
10	195.62	599.54	196.88	603.37	205.63	630.03
11	199.66	636.59	201.05	641.00	213.00	678.88
12	212.68	718.58	213.37	720.89	229.92	776.54
13	224.58	906.51	230.10	928.72	241.88	976.08
14	242.07	1018.70	244.61	1029.35	256.56	1079.51
SUM	2574.52	9406.35	2552.39	9322.65	2786.27	10183.07
MEAN	183.89	671.88	182.31	665.90	199.02	727.36

JOHN VOGEL 7/21/75 L HEEL



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JOHN VOGEL 7/21/75 L HEEL

HEEL SLOPE PROGRAM NOVEMBER 27,1973
PRE VOGEL 7/21/75 JV0721
POST VOGEL 7/21/75 JVP721
MG/SQCM SLOPE 0.25636421E-02 INTERCEPT -0.87159572E-02 WIO 422.25
GM/CM SLOPE 0.56143709E+02 INTERCEPT -0.15710115E+01

IZERO DATA

ROW	HIGH	LOW	MEAN	CN	FAT EQU	LOW:H20	ROW ID
1- 9	577.26	440.25	508.76	960	1.75	1.04	132
2-10	574.58	449.79	512.19	976	1.55	1.07	128
3-11	559.87	442.93	501.40	991	1.48	1.05	123
4-12	549.61	437.76	493.69	1003	1.45	1.04	116
5-13	538.81	435.58	487.19	997	1.37	1.03	97
6-14	533.67	433.08	483.37	991	1.35	1.03	93

BONE DATA

	LOW IO		H2O IO		MEAN IO	
ROW	CU	MG/SQCM	CU	MG/SQCM	CU	MG/SQCM
1- 9	1499.91	614.05	1466.38	599.92	1639.28	671.34
2-10	1541.81	620.80	1482.69	596.71	1664.60	671.19
3-11	1558.60	617.76	1514.54	599.65	1677.45	665.92
4-12	1602.81	627.02	1569.76	613.46	1720.51	673.95
5-13	1671.02	661.57	1642.57	650.09	1780.69	705.57
6-14	1755.02	705.18	1731.68	696.01	1862.18	748.50

Study #1 (#10 and 11)

Ambulatory control (sedentary)

	1st 4 wks	last 4 wks
RB	525.2 ± 9.2	511.0 ± 1.0
JV	616.0 ± 9.6	589.9 ± 3.2

Ambulatory Heel Strike

	1st 4 wks	last 4 wks
JC	616.9 ± 5.8	613.8 ± 1.8
BK	422.5 ± 8.2	420.2 ± 3.5
PD	512.6 ± 5.1	509.9 ± 3.7
NL	645.6 ± 5.1	640.3 ± 6.5
VS	584.5 ± 8.1	588.4 ± 3.5

Impact Loading

Study #2
20 lbs for 8 hrs/day
Central Os Calcis (mg/cm²)

	Baseline	Bedrest #1 5 wks Impact	Bedrest #2 5 wks Control
KB	464.5 ± 5.5	470.9 (+ 1.4%)	
SH	374.8 ± 3.2	382.6 (+ 2.1%)	413.1 (+ 10.2%)
		Control	Impact
JM	562.4 ± 8.4	573.3 (+ 1.9%)	596.7 (+ 6.1%)
DO	485.0 ± 13.8	497.2 (+ 2.5%)	490.7 (+ 1.2%)
RR	437.4 ± 4.5	436.5 (- 0.2%)	

Impact Loading

Study #3
35 lbs for 6 hrs per day
Central Os Calcis $(mg/cm)^2$

	Control	
	DJ	JH
Baseline	460.2 ± 8.1	516.6 ± 4.1
After 8 wks bedrest	383.0	480.5
Δ%	-16.8%	-7.0%
Prediction Term	20.0	27.9

	Impact Loading				
	SI	DT	RL	RV	MW
Baseline	593.6 ± 8.3	508 ± 13.1	515.5 ± 16.3	520.3 ± 2.9	475.7±11.3
After 8 wks bedrest	572.1	496.5	505.1	497.4	471.8
Δ%	-3.6%	-2.3%	-2.0%	-4.4%	-0.8%
After additional 3 wks bedrest without impact					451.7 -5.0%
Prediction Term	30.3	29.0	26.4	19.3	28.6