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DETERMINATION OF CARDIAC SIZE FROM CHEST ROENTGENOGRAMS FOLLOWING SKYLAB MISSIONS

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ABSTRACT

Decreased cardiothoracic transverse diameter ratios following Mercury, Gemini and Apollo space flights have been reported previously. To evaluate further changes in cardiac size, standard posteroanterior chest films in systole and diastole were obtained before flight and within a few hours after recovery on each of the Skylab astronauts. Postflight chest X-rays were visually compared to the preflight roentgenograms for possible changes in pulmonary vasculature, lung parenchyma, bony or soft tissue structures. From these roentgenograms the following measurements were obtained: cardiac and thoracic transverse diameters, cardiothoracic transverse diameter ratio, cardiac area from the product of both diagonal diameters, cardiac silhouette area by planimetry, thoracic cage area and cardiothoracic area ratio. The postflight frontal cardiac silhouette sizes were significantly decreased when compared with the respective preflight values ($P<0.05$ or 0.01). The observed changes are thought to be related to postflight decrease in the intracardiac chamber volume.

INTRODUCTION

Determination of size is a major factor in the clinical evaluation of the healthy or failing heart. Knowledge of heart size assists the interpretation of both electrocardiographic and hemodynamic information. The evaluation of changes in cardiac size has been important in the overall cardiovascular assessment of orthostatic intolerance observed among the majority of astronauts following space missions.

Decreased cardiothoracic transverse diameter ratios following Mercury, Gemini and Apollo flights have been reported earlier from our laboratory (1, 2). More recently similar data following space missions of

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longer duration have been presented (3). The majority of crewmembers who exhibited postflight decreases in the cardiac silhouette size also showed a decreased orthostatic tolerance to lower body negative pressure. Similar findings were also reported by the Soviet investigators following 30-day bed rest studies (4) and in cosmonauts upon return from space missions. This paper presents further radiological data from all three Skylab manned missions and discusses the physiological factors possibly involved in the cardiac silhouette changes.

METHODS AND MATERIALS

Standard posteroanterior chest films were obtained before and as soon as possible after flight on each of the Skylab astronauts following extended space flights of different durations: 28, 59 and 84 days. All X-ray exposures were 150 milliseconds in duration. Systolic and diastolic exposures were triggered electronically from the electrocardiographic R-wave peak by a special device interposed with the X-ray equipment control. The electronic trigger device delayed the roentgenographic exposures from the R-wave peak according to the instantaneous heart rate (the preceding RR interval). For systole the delays were 175 to 325 milliseconds, corresponding to heart rates ranging from 140 to 40 beats per minute, and for diastole 385 to 1165 milliseconds for heart rates ranging from 140 to 44 beats per minute.

Postflight chest X-rays were visually compared with the preflight films for possible changes which might have occurred in pulmonary vasculature, lung parenchyma, bony or soft tissue structures. One or two additional postflight films were taken several days following splashdown to assess trends. While many of the film pairs showed readily apparent postflight decreases in heart size (fig. 1), several measures have been adopted to determine this change quantitatively. Figure 2 shows the geometry utilized in determining thoracic and cardiac areas. The thoracic cage area was obtained by a modified method as described by Barnhard (5) and by Loyd (6). After the inner border of the ribs was outlined, the thoracic center was determined by drawing the line (CL) along the vertebral column. Next, perpendicular lines to (CL) were drawn at 2.5, 5.0 and 15.0 centimeters from the first thoracic intervertebral space - point of origin (a) creating three upper polygonal segments. A horizontal line (k-m) drawn halfway between the level of the apices of the right and left hemidiaphragms delineated the lower border of the fourth segment. The last segment was delimited by a horizontal line (n-p) drawn at mid-distance between the two costophrenic angles; actual area of this segment was modified by circular deductions for infra diaphragm space. The total thoracic area was summed from the computed area of each of the above five segments.

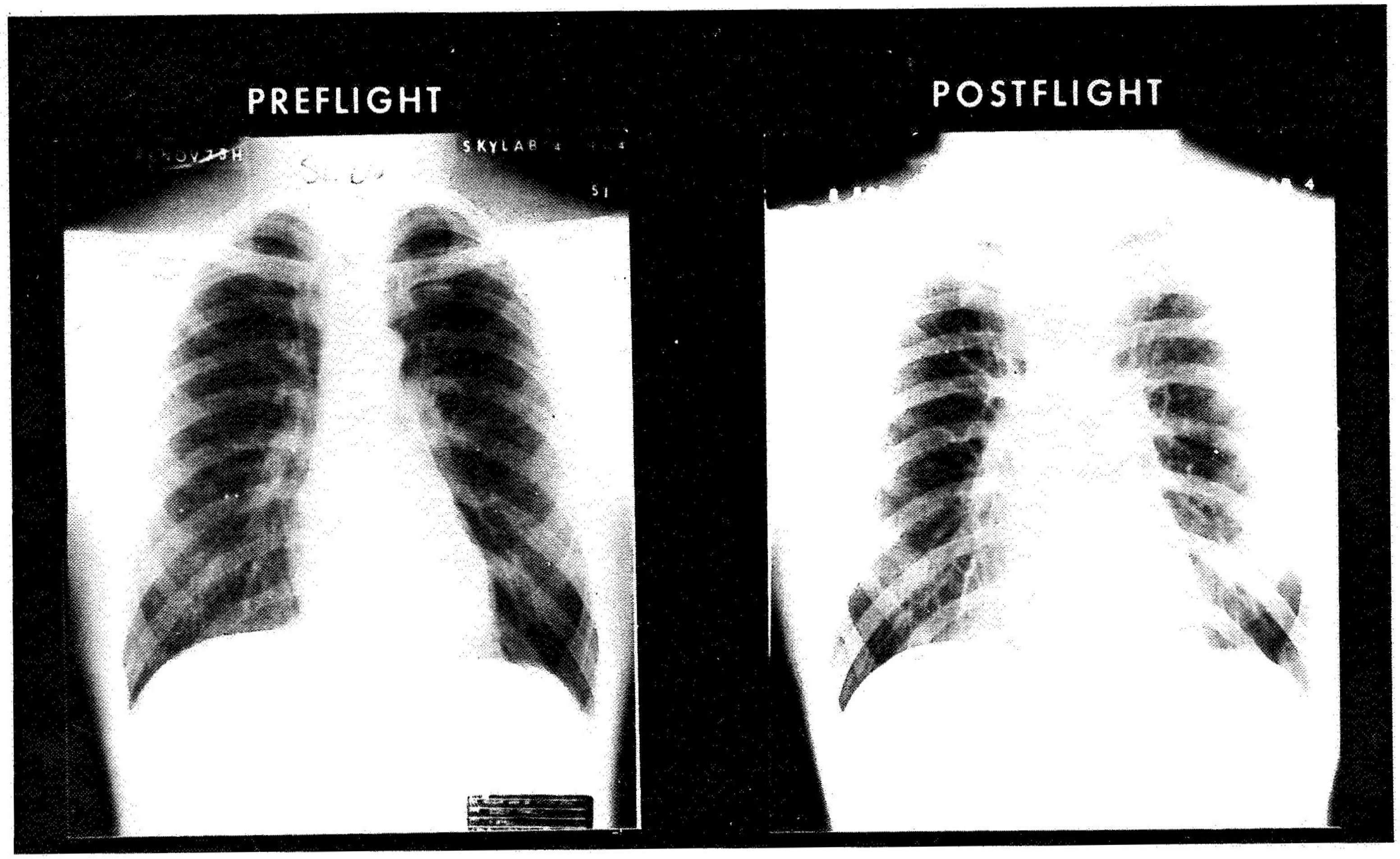

Figure 1. Systolic Chest X-ray of the Skylab 4 Scientist Pilot. (Preflight and on the day of Recovery)

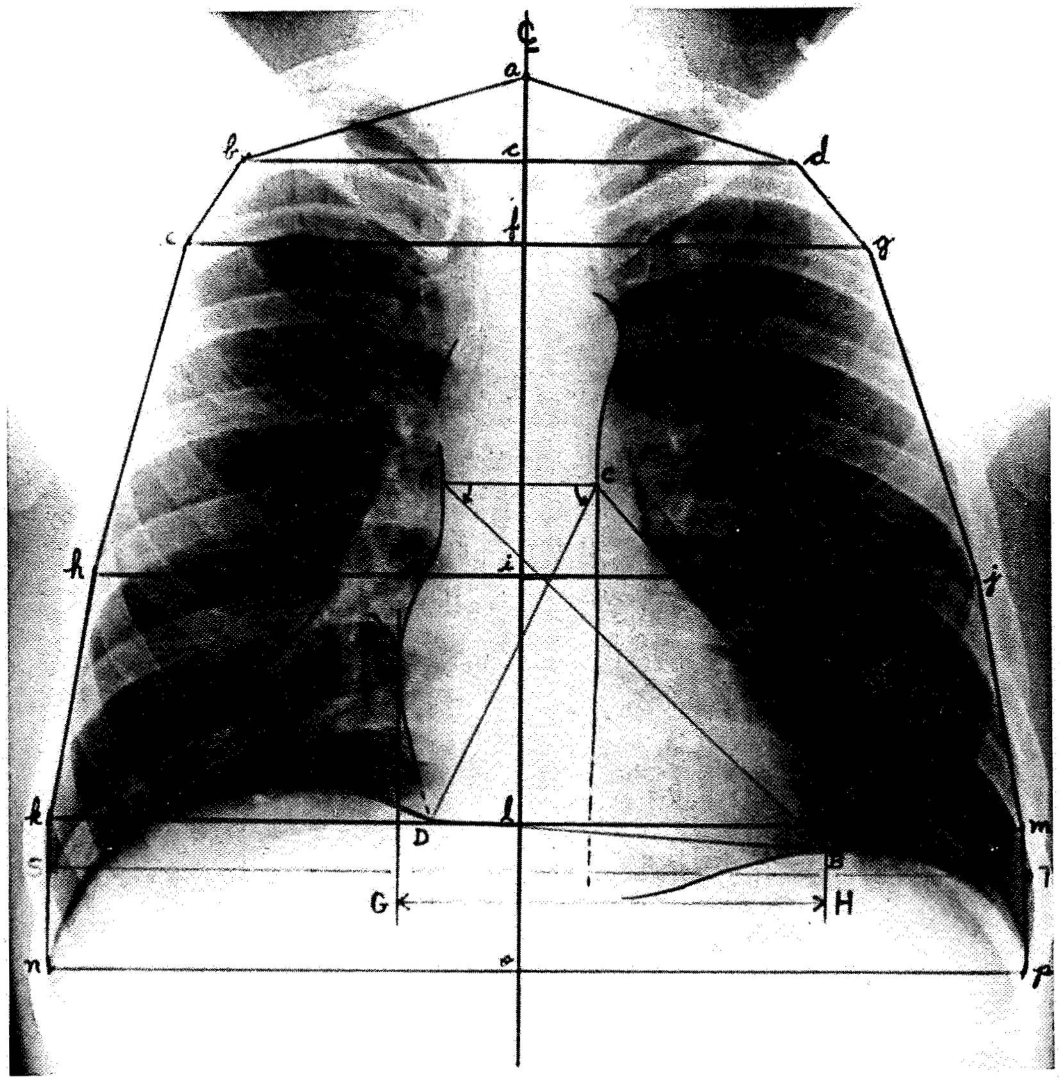

Figure 2. Geometry of cardiothoracic measurements.

To obtain uniform evaluation of the cardiac area, the heart silhouette was outlined in the following manner.

° The lower border of the heart was defined as the line (B-D) between the intersections of the right and left cardiac borders and the respective hemidiaphragms,

° the right cardiac border (A-D) followed the right atrium and superior vena cava,

° the left cardiac border (B-C) was completed by drawing a regression line of the left heart border intersecting with the left margin of the descending aorta,

° the upper cardiac border was outlined by a perpendicular (A-C) to the center line at the level of the upper left heart border.

The following parameters were measured and/or computed:

° Cardiothoracic transverse diameter ratio (C/T_D).

° Cardiac silhouette area, by planimetry.

° Cardiothoracic area ratio (C/T_A).

° Cardiac area from the product of long and short diagonal diameters.

It is hoped that the additional information inherent in this technique will reflect more accurate size values and help compensate for slight variations in body position and inspiratory level. All postflight data were compared to the respective preflight values using the Student's t-test and regression analysis.

RESULTS

No roentgenological abnormalities were observed on either preflight or postflight films. The chest X-rays of the Skylab 3 Pilot on the day of recovery were of poor quality and not amenable to analysis; all other X-rays were of acceptable quality. Differences between preflight and postflight systolic and diastolic cardiothoracic diameter and area ratios are presented in tables I and II. Both C/T_D and C/T_A showed a decrease in the individual values postflight. In general there was more variability in the C/T_D responses postflight, some cases in diastole showing a modest increase in the immediate postflight ratios. Comparison of the preflight and postflight cardiac silhouette area differences showed a fairly consistent decrease in the cardiac area on the day of recovery (tables III and IV). The Skylab 3 Commander, however, showed a postflight increase in the systolic cardiac area as determined from the products of minor and major diameters (19.76 cm^2) and a very slight increase in the diastolic cardiac area as measured by the planimetric method (0.30 cm^2).

TABLE I. SYSTOLIC CARDIOTHORACIC RATIO DIFFERENCES PREFLIGHT VERSUS POSTFLIGHT

		POSTFLIGHT ROENTGEN EXAMINATION								
		FIRST			SECOND			THIRD		
Skylab Mission	Crewman	Date (Days)	C/T_D*	C/T_A†	Date (Days)	C/T_D	C/T_A	Date (Days)	C/T_D	C/T_A
2	Commander	R+0	-0.003	-0.003	R+8	-0.020	-0.008			
	Scientist Pilot		0.000	-0.015		+0.004	-0.005			
	Pilot		-0.013	-0.011		-0.020	+0.004			
3	Commander	R+0	-0.040	-0.012	R+5	-0.014	+0.003	R+20	-0.001	+0.023
	Scientist Pilot		-0.040	-0.039		-0.043	-0.025		-0.007	-0.010
	Pilot		NA	NA		+0.012	+0.004		0.000	-0.004
4	Commander	R+0	-0.010	-0.011	R+5	-0.024	-0.015	R+11	-0.023	-0.007
	Scientist Pilot		-0.059	-0.020		-0.025	+0.002		-0.036	-0.006
	Pilot		+0.003	-0.004		-0.008	-0.019		+0.009	-0.017

*C/T_D = Diametral Ratio NA = Not available
†C/T_A = Areal Ratio R = Recovery

TABLE II. DIASTOLIC CARDIOTHORACIC RATIO DIFFERENCES PREFLIGHT VERSUS POSTFLIGHT

		POSTFLIGHT ROENTGEN EXAMINATION								
		FIRST			SECOND			THIRD		
Skylab Mission	Crewmembers	Date (Days)	C/T_D*	C/T_A†	Date (Days)	C/T_D	C/T_A	Date (Days)	C/T_D	C/T_A
2	Commander	R+0	+0.012	+0.002	R+8	-0.006	+0.003			
	Scientist Pilot		+0.003	-0.012		0.000	-0.007			
	Pilot		-0.008	-0.025		-0.003	-0.003			
3	Commander	R+0	-0.005	-0.006	R+5	+0.009	+0.012	R+20	+0.035	+0.027
	Scientist Pilot		-0.034	-0.022		-0.029	-0.015		-0.011	+0.006
	Pilot		NA	NA		+0.002	+0.005		+0.012	-0.007
4	Commander	R+0	+0.014	-0.018	R+5	+0.026	-0.010	R+11	+0.018	-0.003
	Scientist Pilot		+0.013	-0.006		+0.034	+0.014		+0.022	+0.012
	Pilot		+0.015	-0.013		-0.001	-0.017		+0.003	-0.010

*C/T_D = Diametral ratio NA = Not available
†C/T_A = Areal ratio R = Recovery

TABLE III. DIFFERENCES IN SYSTOLIC CARDIAC AREAS
PREFLIGHT COMPARED TO POSTFLIGHT

		POSTFLIGHT ROENTGEN EXAMINATION								
		FIRST			SECOND			THIRD		
Skylab Missions	Crewmembers	Date (Day)	D_1xD_2* (cm^2)	Plan.† (cm^2)	Date (Day)	D_1xD_2 (cm^2)	Plan. (cm^2)	Date (Day)	D_1xD_2 (cm^2)	Plan. (cm^2)
	Commander		-16.10	- 2.40		-19.00	- 9.50			
2	Scientist Pilot	R+0	-29.20	- 9.80	R+8	+10.70	- 2.10			
	Pilot		-15.50	- 9.80		+20.90	+ 6.00			
	Commander		+19.76	- 1.90		+21.20	+ 6.30		-72.00	+24.80
3	Scientist Pilot	R+0	-55.80	-26.70	R+5	-30.40	-15.50	R+20	-19.64	- 6.60
	Pilot		NA	NA		+ 7.35	+ 6.10		- 8.63	- 2.30
	Commander		-16.30	- 7.60		- 7.70	+ 6.30		-11.00	- 5.60
4	Scientist Pilot	R+0	-21.00	- 9.90	R+5	-10.50	- 5.60	R+11	-11.30	- 8.40
	Pilot		- 1.70	- 3.30		+ 1.30	- 7.70		- 0.30	- 6.90

*Cardiac area determined from the product of the major and minor diameters

†Cardiac area determined by planimetry

NA = Not available

R = Recovery

TABLE IV. DIFFERENCES IN DIASTOLIC CARDIAC AREAS
PREFLIGHT COMPARED TO POSTFLIGHT

		POSTFLIGHT ROENTGEN EXAMINATION								
		FIRST			SECOND			THIRD		
Skylab Missions	Crewman	Date (Day)	D_1xD_2* (cm^2)	Plan.† (cm^2)	Date (Day)	D_1xD_2 (cm^2)	Plan. (cm^2)	Date (Day)	D_1xD_2 (cm^2)	Plan. (cm^2)
	Commander		-14.20	- 2.70		- 4.80	- 5.10			
2	Scientist Pilot	R+0	-33.80	-12.00	R+8	- 3.00	- 5.60			
	Pilot		-40.70	-14.70		- 4.00	+ 1.40			
	Commander		- 2.10	+ 0.30		+18.00	+16.30		+46.90	+27.10
3	Scientist Pilot	R+0	-25.40	-16.50	R+5	-10.80	- 8.50	R+20	+30.00	- 5.00
	Pilot		NA	NA		-12.80	+ 2.20		-28.20	- 7.70
	Commander		-107.10	-17.30		-89.10	- 9.10		-78.30	- 6.90
4	Scientist Pilot	R+0	-41.20	- 1.70	R+5	- 0.00	+11.30	R+11	- 7.50	+10.30
	Pilot		-24.60	-15.60		- 4.60	- 7.60		+ 5.00	- 2.00

*Cardiac area determined from the product of the major and minor diameters

†Cardiac area determined by planimetry

NA = Not available

R = Recovery

Table V summarizes the determinants of cardiac sizes, their preflight and postflight means and standard deviation as well as the statistical significances. The mean differences, preflight versus postflight, of the cardiac areas, measured by planimetry, and of the derived measurement (C/T_A), were statistically significant ($P<0.01$ or $P<0.05$). Return to preflight values was quite variable for all crewmen, but most showed this directional trend by 4 to 5 days after splashdown. There was a significant correlation ($r = -0.91$) between postflight decrement in systolic heart size as measured by C/T_D, and the corresponding augmentation in heart rate responses registered during lower body negative pressure stress. There was no apparent correlation between the duration of orbital stay and the postflight change in heart size.

TABLE V. DETERMINANTS OF CARDIAC SIZE FROM ROENTGENOGRAMS

Cardiac Phase	Measurement	PREFLIGHT Mean	PREFLIGHT Standard Deviation	POSTFLIGHT (R+0) Mean	POSTFLIGHT (R+0) Standard Deviation	Statistical Significance
Systole	C/T_D*	0.416	0.029	0.390	0.018	P <0.05
	C/T_A†	0.180	0.019	0.166	0.018	P <0.01
	D_1xD_2‡	238.87(cm²)	38.13(cm²)	221.90(cm²)	40.82(cm²)	NS
	Plan.§	123.81(cm²)	13.31(cm²)	114.22(cm²)	12.74(cm²)	P <0.05
Diastole	C/T_D	0.403	0.018	0.399	0.021	NS
	C/T_A	0.177	0.015	0.164	0.020	P <0.01
	D_1xD_2	248.41(cm²)	28.28(cm²)	212.27(cm²)	34.09(cm²)	P <0.05
	Plan.	121.71(cm²)	7.74(cm²)	111.67(cm²)	12.20(cm²)	P <0.01

N = 8 (R+0 Film of Skylab 3 Pilot unsatisfactory)

*Cardiothoracic ratio based on the respective diameters

†Cardiothoracic ratio based on the respective areas

‡Cardiac area determined from the product of the minor and major diameters

§Cardiac area determined by planimetry

P = Probability

N.S. = Not significant

DISCUSSION AND CONCLUSIONS

Radiographic techniques for evaluating the size of the heart have the advantages of technical simplicity and widespread availability of equipment. Although the conventional cardiothoracic ratio has for many years provided a useful clinical standard (7) it carries a rather large variability due to body position, phase of respiration and other uncontrollable elements of thoracic configuration. In our practice the C/T_A and the associated cardiac area were found to compare well with the C/T_D, were easily obtained and quite adequate for serial comparisons on the same subject (3). In addition, the areal measurements provide more comprehensive information concerning the heart size than transverse diameters. The observed postflight decrease in frontal plane cardiac silhouette size could be attributed to a decrease in myocardial tissue mass and/or intrachamber blood content, anatomical reorientation or a combination of all of the above mentioned factors. Previous studies have shown that significant among determinants of cardiac size is the amount of blood returned to the heart (8). It is quite conceivable that caudad displacement of blood and other fluids together with an absolute decrease in the circulating blood volume (9) could account for the observed decreases in the cardiac silhouette size. At the present time there is certainly no indication that the Skylab crewmen exhibited a greater decrease in their cardiac size than that observed in the Apollo astronauts following shorter duration space missions, nor that the decrease in diastole heart size was of greater magnitude than that of the systolic phase of the cardiac cycle. A small diastolic size might more clearly delineate a deficit in blood return and chamber filling rather than loss of myocardial mass.

Further studies during the Shuttle era should be directed toward a better understanding of the intracardiac chamber and myocardial tissue components possibly involved in the reported X-ray findings.

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