Effects of High Gravity on Cardiac Dimensions in Trained Air Crew

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Significant acute hemodynamic changes occur in pilots upon transient exposure to high gravity forces (+G\textsubscript{z}). It is not well established, however, whether frequent repeated exposure to high values (up to 9) of acceleration stress may induce structural cardiovascular changes. A French study performed among 32 pilots flying high +G\textsubscript{z} revealed a statistically significant increase in left atrial dimension and ventricular septal thickness as assessed by echocardiography. A similar echocardiographic study was unable to reproduce these results. The present study examines the significance of repeated exposure to high +G\textsubscript{z} on cardiac dimensions and compares the measurements with those of air crew not exposed to high +G\textsubscript{z} (non +G\textsubscript{z}).

The study consisted of 2 parts: a cross-sectional study and a longitudinal follow-up study. The first part was a retrospective cross-sectional study in which the echocardiographic studies of 109 graduate air crew members (54 in the +G\textsubscript{z} group and 55 non +G\textsubscript{z} group) were reevaluated. These studies were recent consecutive studies performed as part of the routine follow-up program of the echocardiographic laboratory of the Israeli Air Force Aero-Medical Center. This part of the study compared various echocardiographic variables between the high +G\textsubscript{z} and the non +G\textsubscript{z} groups. Since not all high +G\textsubscript{z} members were actively flying, a subanalysis of echocardiographic variables from active aviators (n = 36) was performed for comparison with non +G\textsubscript{z} personnel.

The second part of the study was a retrospective longitudinal follow-up study in which echocardiographic parameters from 2 echocardiographic studies performed several years apart in the same air crew personnel were compared (16 high +G\textsubscript{z} members and 15 non +G\textsubscript{z} personnel).

Exclusion criteria were known cardiovascular or pulmonary disease, use of cardiovascular drugs, and unacceptable echocardiographic quality.

All echocardiographic studies were performed by the same cardiac sonographer, and the same procedures and techniques were used in all studies. Two-dimensional M-mode guided measurements were performed according to the recommendations of the American Society of Echocardiography. Left ventricular (LV) mass was determined by the cube formula, using the Penn convention as suggested by Devereux and Reichek. The formula used was: LV mass = 1.04 × (LVDD + LVPWD + VSD\textsuperscript{3}) \textsuperscript{0.667} \textsuperscript{0.333} - LVDD\textsuperscript{3} - 13.6, where LVDD is LV dimension at end diastole, LVPWD is left ventricular posterior wall thickness at end diastole, and VSD is ventricular septal thickness at end diastole.

Body surface area was calculated according to the standard manner (BSA = height\textsuperscript{0.725} × weight\textsuperscript{0.425}, 0.007184; height in cm and weight in kg) and M-mode indexes were calculated for all measured variables.

The unpaired 2-tailed t test was used to determine the significance of differences between patients’ baseline characteristics and means of M-mode measurements. For longitudinal measurements within the same patients, 1 factor analysis of variance (ANOVA) was used.

Baseline characteristics and M-mode measurements were similar in the high +G\textsubscript{z} and the non +G\textsubscript{z} air crew personnel (Table I). Although some significant differences existed between the active high +G\textsubscript{z} persons who were younger and thinner with a lower body surface area in comparison with the non high +G\textsubscript{z} group, no statistically significant changes could be detected in echocardiographic variables between the groups.

The 2 echocardiographic studies were performed 60 ± 25 and 47 ± 29 months apart in the high +G\textsubscript{z} and non +G\textsubscript{z} groups, respectively (Table II). Because this was a longitudinal study, baseline characteristics were significantly different between the sequential studies in both groups. The only echocardiographic measurements that were statistically significantly different between the echocardiographic studies were aortic root diameter index (16.2 ± 1.9 in the first study versus 17.2 ± 1.4, p < 0.05) and left atrial size in the high +G\textsubscript{z} group. After correcting the latter for body surface area, the left atrial index revealed no difference. The aortic root diameter, although significantly increased in the high +G\textsubscript{z} group during follow-up, was within normal limits. LV mass increased significantly during the follow-up period in both groups.

The present study showed no difference in cardiac chambers dimensions between aviators who fly advanced high +G\textsubscript{z} aircraft and those who fly other types of aircraft.

Repetitive exposure to high sustained G\textsubscript{z} causes marked changes in regional systemic and pulmonary
vascular pressures, resulting from both acceleration forces and respiratory straining maneuvers carried out to maintain blood pressure and cerebral perfusion. Therefore, concern arises as to whether long-term repetitive exposure might induce changes in cardiac structure, dimensions, and function. Such changes may be equivalent to changes of cardiac dimensions, secondary to physiologic stress such as hypertension and active sport performance; long-term athletic training leads to an increase in LV diastolic dimensions and wall thickness, resulting in an increase in LV mass.1

A decrease in cardiac dimensions had been observed in serial echocardiographic studies following deconditioning.2 Therefore, a subanalysis that included only active high +G, pilots was performed.
to avoid introduction of potential bias by including high $+G_z$ pilots not currently engaged in active flying duty.

A French study performed among 32 high $+G_z$ pilots revealed a statistically significant increase in left atrial dimension and interventricular septal thickness as assessed by echocardiography. This study also revealed a significant difference in right ventricular dimension between the high $+G_z$ and the non $+G_z$ groups (17.7 mm and 13.3 mm, respectively). Eight of the 32 high $+G_z$ group were found to have right ventricular enlargement, compared with 1 of 34 in non $+G_z$ personnel.

The results obtained in our study are in accord ance with 2 other echocardiographic studies which were unable to reproduce the results obtained by Ille et al. Celio could not detect any statistically significant difference between the 2 air crew groups (127 in the high $+G_z$ and 381 in the non $+G_z$), including right and left ventricular dimensions.

The increased aortic root diameter and index observed during follow-up of the high $+G_z$ group probably represents the normal increment that takes place during aging. Since the high $+G_z$ group was older than the non $+G_z$ group, both at baseline and in the follow-up echocardiographic study, these differences were not seen in the latter group.

One may argue that the calculated LV mass actually represents LV hypertrophy because it exceeds the indexed limits of 134 g/m² established for use with the modified cube formula. However, the study population represents a group of healthy young people who are highly motivated to perform physical activity, resulting in a mild form of athlete’s heart in many of them. LV mass and indexes increased in both groups during follow-up echocardiographic studies. These measurements are in accordance with the observation that age is positively correlated with LV mass.

We conclude that there is no difference in LV wall thickness, dimensions, or functional parameters between air crew members who fly high $+G_z$ aircraft and those who fly other types of aircraft. No differences were detected between high $+G_z$ air crew personnel and others in development of structural and functional changes over the short-term course of a flying career.