Cardiac responses to long duration and high magnitude +Gz exposure in pilots: An observational study

Pilotlarda kronik +Gz maruziyetinin kardiyak fonksiyonlara etkisi: Gözlemsel bir çalışma

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ABSTRACT

Objective: In military aviation, high performance aircraft pilots are exposed to +Gz acceleration at longer durations and higher magnitude than transport/helicopter pilots. The purpose of this study was to reveal the negative or positive cardiac responses to this occupational high +Gz exposure.
Methods: Our study design was cross-sectional and observational. We have evaluated 21 echocardiographic parameters of 63 pilots who applied for aircrew periodic medical examination. Of 63 pilots, 33 were grouped as high performance aircraft pilots group (Group A) and 30 were grouped as control group (Group B) whose aircraft type was transport or helicopter. Means of demographic and echocardiography parameters between two groups were compared statistically with Student's t-test, Mann- Whitney U or Chi-square test as appropriate.
Results: Among all echocardiographic parameters, mean TV A (tricuspid valve peak velocity during late diastolic filling) was significantly higher and TV E (peak velocity during early diastolic filling)/ A ratio was significantly lower for Group A pilots ($p<0.05$). In Group A pilots, mean TV A and TV E/A ratio were (52.12±13.85) and (1.36±0.30) respectively. In Group B pilots, mean TV A and TV E/A ratio were (42.61±6.42) and (1.53±0.20) respectively ($p=0.001$ for TVA and $p=0.005$ for TV E/A). Mean pulmonary artery pressure (PAP) of Group A pilots (32.04±9.09) was higher than Group B pilots (28.76±7.9) but it was not statistically significant ($p>0.05$).
Conclusion: We conclude that according to the results of our study, long term +Gz exposure has no effects on cardiac morphologic and systolic functions but has effects on right ventricular diastolic functions. We have considered that these effects may be a result of chronic +Gz adaptation or high PAP levels. *(Anadolu Kardiyol Derg 2012; 12: 668-74)*
Key words: Acceleration, echocardiography, diastolic function, pulmonary arterial pressure

ÖZET

Amaç: Askeri havacılıkta yüksek performanslı jet uçaklarını kullanan pilotlar, nakliye ve helikopter pilotlarına göre daha fazla miktarda ve sürede ivmelenme kuvvetlerine maruz kalmaktadırlar. Pilotlara uçuş esnasında bu ivmelenme kuvvetlerinden en fazla +Gz etki etmektedir. Çalışmamızın amacı bu mesleki faktörün uzun dönem kardiyak etkilerini ortaya çıkarmaktır.
Yöntemler: Çalışma gözlemsel-kesitsel nitelikte yapıldı. Periyodik muayeneler kapsamında başvuran 63 pilotun 21 ekokardiyografi parametresi değerlendirildi. Katılımcı pilotlardan 33'ü yüksek performanslı uçak pilotu grubu (Grup A) ve 30 nakliye ve helikopter pilotu ise kontrol grubu (Grup B) olarak ayrıldı. Grupların ekokardiyografik ve demografik parametreleri istatistiksel olarak Student t-test, Mann-Whitney U ve Ki-kare testlerinden uygun olanı ile karşılaştırıldı.
Bulgular: Ekokardiyografi parametre bulguları arasından Grup A pilotlarının TV A (triküspit kapağı geç diyastolik akım hızı) daha yüksek ve TV E (erken diyastolik akım hızı)/A oranı daha düşük ve anlamlı bulundu ($p<0.05$). Grup A pilotlarında, ortalama TV A ve TV E/A oranları sırası ile (52.12±13.85) ve (1.36±0.30) bulundu. Grup B pilotlarda ise ortalama TV A ve TV E/A oranları sırasıyla (42.61±6.42) ve (1.53±0.20) olarak bulundu (TVA için $p=0.001$, TV E/A için $p=0.015$). Grup A pilotların ortalama pulmoner arter basıncı (32.04±9.09) Grup B pilotlarınkinden (28.76±7.9) yüksek fakat istatistiksel olarak anlamlı değildi.
Sonuç: Uzun vadede şiddetli +Gz maruziyetinin kalbin anatomik yapısına ve sistolik fonksiyonlara bir etkisinin olmadığı, fakat sağ kalp diyastolik fonksiyonlarına etkisinin olduğu gözlenmiştir. Bu etkinin kronik +Gz adaptasyonu ya da yüksek PAP seviyelerinden kaynaklanmış olabileceği değerlendirilmiştir. *(Anadolu Kardiyol Derg 2012; 12: 668-74)*
Anahtar kelimeler: İvmelenme, ekokardiyografi, diyastolik fonksiyon, pulmoner arter basıncı

This study was presented at the 82nd Aerospace Medical Association Annual Scientific Meeting, 8-12 May 2011, Anchorage, AK-USA and named as a finalist in the Space Medicine Association Jeff Myers Young Investigator Award competition.
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Accepted Date/Kabul Tarihi: 19.07.2012 **Available Online Date/Çevrimiçi Yayın Tarihi:** 11.09.2012

doi:10.5152/akd.2012.219

Introduction

As a result of the improvements in aviation industry, high maneuverable aircraft were introduced to serve military aviation in the world. So the pilots of these aircraft are exposed to acceleration forces (especially +Gz) at higher magnitude and longer durations. "G" is a measure of the force experienced by a person due to acceleration. It is expressed in terms of multiples of the Earth's gravitational acceleration. +Gz is a description of G vector in which the vertical (z) axis is parallel to the long spinal axis of the body and the direction (+) is from head to foot. The G capability of modern aircraft is high but the G tolerance of human organism is limited. Against high acceleration forces, human body accommodates itself to this situation with physiologic compensation mechanisms. Besides, pilots perform anti-G measures like anti-G straining maneuvers (AGSM), positive pressure breathing and use of anti-G suits in order to resist G-induced stress and prevent themselves from being G-LOC (G-Induced Loss of Consciousness). Both exposures to +Gz and anti-G measures result in repetitive intrathoracic hydrostatic changes, which can cause significant changes in cardiac preload and afterload. In addition under high +Gz conditions, circulatory system is mostly affected. The response of cardiac functions and dimensions from exposing +Gz occupationally has always been a controversial issue.

Recent studies about this issue have focused generally on morphologic cardiac effects of high magnitude +Gz exposure. In 1979, Martin et al. (1) have revealed the relation between increased occurrences of cardiac valvular regurgitation with repetitive high G exposure. Whinnerey et al. (2) reported in 1982 that right ventricular pressure responses in swine against high +Gz forces. Ille et al. (3) reported right side cardiac morphologic defects in combat jet pilots with echocardiography in 1985. Another study in China showed no pathomorphological damage but some adaptive changes on the heart of retired fighter pilots with echocardiography examination (4). Unlike these findings, two studies showed that repetitive +Gz had no effect on cardiac dimensions and performance (5, 6). We considered not all these studies are adequate to clarify long term high +Gz effects on especially cardiac diastolic and systolic functions of pilots. Besides, in a study of Pantalos et al. (7) progressive reduction in both left ventricular end-diastolic volume index and stroke volume with entry into microgravity was documented with echocardiography. This could be due to the absence of a gravitational acceleration dependent, intraventricular hydrostatic pressure difference (Delta P) in microgravity that exists in the ventricle in normal gravity due to its size and anatomic orientation (7). Effects of +Gz magnitude between 0 and 1 on cardiac functions was reported in this study and so it can be thought that there should be a relationship between +Gz acceleration and cardiac functions.

The cabins of high performance aircraft are generally pressurized to a lower degree than transport or noncombat aircraft because they are more likely to sustain damage that may result in loss of pressurization and the pilots of these aircraft wear a mask of oxygen support system to be not hypoxic during the very rapid transients of altitude. Transport aircraft cabins are pressurized; they are not in ground conditions but in conditions like an altitude of 8.000-8.400 feet while the aircraft can operate up to approximately 40.000 feet. Helicopter cabins are not pressurized but the helicopters do not fly over 10.000 feet generally (8).

The objective of our study was to reveal the cardiac effects including morphologic, left and right heart systolic and diastolic functions of this occupational long duration and high magnitude +Gz exposure in military pilots. In addition, we considered smoking habits of pilots to eliminate controversial responses to these cardiac functions.

Methods

Study design

The study was designed as cross-sectional and observational study.

Study population

Subjects were selected from pilots who have applied for five yearly periodic medical examinations in a three months study period. From 240 military pilots, 63 pilots who were volunteers and met the criteria of 1000 or more total flight hours were selected as subjects. All subjects were currently active (not restricted from flight) male pilots. Female pilots were excluded from the study since their number was very few. Of 63 pilots, 33 were grouped as high performance aircraft pilots (Group A) since they had flown mostly and currently flying with aircraft like F-16, F-4, F-5 and T-38. 30 pilots were grouped as control group (Group B) since they had flown mostly and currently flying with aircraft like C-130, C-160, CN-235 and helicopters. Thirteen subjects in Group A pilots and seven subjects in Group B pilots have cited that they were regular smokers. Subjects who had one of the following criteria were excluded from this study: Less than 1000 total flight hours, cardiovascular or pulmonary disease, using regular drugs, age more than 45 years, not flown in the past 12 months.

The study protocol was approved in advance by local Ethical committee. Written informed consents of subjects were gained also.

Study protocol

Each subject was fully informed and provided written informed consent before participating. Information was collected from subjects with a standardized survey.

In order to evaluate pilots' cardiac morphology and functions, we used M-mode, 2D echo and Doppler echocardiography techniques. Smoking was not restricted for subjects, but there was not any time to smoke for at least one hour in the clinic during the procedures like taking blood sample, measuring hemodynamic parameters, height and weight measurements and completing questionnaire before the echocardiography.

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2012; 12: 668-74

Baseline variables

Demographic and biographic data included age, body mass index, smoking history, exercise habit, total flight hours and active flying years. Body mass index was defined as the subject's body mass divided by the square of his height. Hemodynamic parameters like heart rate (HR), blood pressure (BP) were measured after a five minutes rest.

+Gz acceleration criteria

Repetitive +Gz acceleration exposure for a long time was a predictor variable. The major factor that affects this variable was being a high performance aircraft pilot. Additional factors that affect +Gz acceleration exposure were active flying years and total flight hours of these pilots.

Echocardiography

Transthoracic echocardiography procedures were performed with a LOGIQ^{TM} 3 Expert device (GE Healthcare, Milwaukee, WI - USA) in Cardiology Clinic of Eskisehir Military Hospital. M-mode, 2-D (two-dimensional) echocardiograms and Doppler studies were completed on all pilots using standard techniques for obtaining images and measurements. All pilots were examined by the same cardiologist. All measured 21 parameters and their units were AOD- aorta diameter (mm), EDV-end-diastolic volume (mL), EF-ejection fraction (%), ESV-end-systolic volume (mL), FS-fractional shortening (%), IVST-interventricular septum thickness (mm), LAD-left atrium diameter (mm), LPWT-LV posterior wall thickness (mm), LVID-left ventricle diameter (mm), PAD-pulmonary artery diameter (mm), RAD-right atrium diameter (mm), RVD-right ventricle diameter (mm), MVA-mitral valve A (Atrial) velocity (cm/sec), MVE-mitral valve E (Early) velocity (cm/sec), MV(E/A)-mitral valve E/A ratio, PAP-pulmonary artery systolic pressure (mmHg), PAV-pulmonary artery velocity (cm/sec), TRV-tricuspid regurgitation velocity (cm/sec), TVA-tricuspid valve A velocity (cm/sec), TVE-tricuspid valve E velocity (cm/sec), TV(E/A)-tricuspid valve E/A ratio.

Echocardiography examination was performed to the subjects on left lateral decubitus position with a 3.5 MHz probe. Images were obtained from parasternal and apical view using 2D, M-Mode and Doppler echocardiographic techniques. The LV end-diastolic and end-systolic dimensions, IVST, LPWT measures were obtained from M-Mode echocardiography. EF was measured using biplane Simpson's method, left/right atrial and ventricular dimensions were determined via the biplane area length method from apical four and two chamber views according to recommendation of American Society of Echocardiography. Pulse wave Doppler 3 mm sample volume were taken from proximal to the mitral and tricuspid valve tips in the apical four chamber view to record LV and RV inflow, early diastolic peak flow (E), late diastolic peak flow (A) velocities were measured. E/A ratio were calculated. Pulmonary artery pressure (PAP) is pulmonary artery systolic pressure and it was estimated by means of using right atrium pressure and tricuspid insufficiency peak gradient. Right atrium pressure was taken as a constant value for all subjects for this calculation since they were all healthy adults (9, 10).

Statistical analysis

Statistical analysis was performed with SPSS 16.0 (SPSS Inc. Chicago, IL-USA) data analysis software, using the one sample Kolmogorov-Smirnov to assess the normality of data variance, Levene test to provide homogeneity of variances, Student's t-test or Mann-Whitney U test as appropriate to compare mean parameters between two groups. Chi-square test was used to compare the observed data between two groups. A value of $p<0.05$ was considered to be statistically significant. Correlation between total flight hours and echocardiography parameters were analyzed with Pearson correlation test.

Results

Basal characteristics

Demographic and clinical characteristics of both groups are shown in Table 1. Two groups were similar in aspect of multiple demographic parameters like age, body mass index, exercise habits, flight years, training - education history and health standards. Two groups differ from each other especially in pilots' +Gz exposure durations and magnitudes due to their aircraft types. Group B pilots had significantly higher mean total flight hours than Group A pilots. There were no statistically significant differences in other demographic or clinical data.

Among the hemodynamic parameters, diastolic blood pressure and mean arterial pressure values were significantly higher in Group A pilots. Calculated statistics were $t(61)=2.292$, $p=0.026$ for diastolic pressure, $t(61)=2.310$, $p=0.024$ for mean arterial pressure.

Table 1. Demographic and hemodynamic data comparisons between the groups

Variables	Group A (n=33)	Group B (n=30)	*p
Age, years	35.7±2.7	36.3±2.6	0.433
BMI, kg/m^2	25.8±2.2	25.6±2.6	0.716
Active smokers, n (%)	13 (39.39%)	7 (23.33%)	0.171
Exercise habit, n (%)	22 (66.66%)	18 (43.33%)	0.583
Total flight hours, hours	2212±683	2850±948	0.003
Active flying years, years	13.9±2.8	14.3±2.5	0.505
Systolic BP, mmHg	119.7±11.6 (160-110)	114.3±11.4 (130-90)	0.210
Diastolic BP, mmHg	79.1±6.8 (90-70)	74.3±9.4 (90-60)	0.022
MAP, mmHg	92.6±7.3	87.7±9.7	0.024
Heart rate, bpm	73.9±12.8	73.4±8.2	0.656

Data are presented as mean±SD, minimum and maximum values, and number (percentage)
*Student t-test for independent samples, Mann-Whitney U test and Pearson Chi-square test
BMI - body mass index, BP - blood pressure, MAP - mean arterial pressure

Table 2. Mean m-mode and 2-d echocardiographic parameters and comparisons between the groups

Variables	Group A	Group B	*p	Normal#
AOD, mm	29.6±3.3	28.7±2.3	0.192	20-37
LAD, mm	34.1±3.1	33.31±3.17	0.326	19-40
PAD, mm	22.8±2.7	23.2±3.2	0.660	24.2±2.2
RAD, mm	37.9±4.3	37.2±4.2	0.257	15-35
IVST (d/s), mm	10.3±1.4/ 13.2±1.4	10±1.1/ 13±1.7	0.278/ 0.695	6-11/ 8-13
LVID (d/s), mm	48.1±4/ 29.2±3.4	47.8±3.1/ 29.5±3	0.757/ 0.756	35-57/ 23-40
LPWT (d/s), mm	10.3±1.3/ 16.2±2.2	9.9±1.6/ 16.1±1.7	0.441/ 0.886	6-11/ 8-13
RVD (d/s), mm	36.5±5.3/ 26±4.3	35.5±4.9/ 26.3±4.4	0.428/ 0.784	19-38/ 9-26
EDV, mL	109±20.6	107±16.3	0.347	96-157
ESV, mL	32.8±8.4	34.1±8.5	0.865	33-68
EF, %	68.9±6.6	68±6	0.884	59±6
FS, %	38.9±5.3	38.3±4.6	0.639	28-44

Data are presented as mean±SD.
*Student t-test for independent samples
#For normal values of the measured parameters, see references 10 and 13.
AOD - aortic diameter, d - diastolic, EDV - end-diastolic volume, EF - ejection fraction, ESV - end-systolic volume, FS - fractional shortening, IVST - interventricular septum thickness, LAD - left atrial diameter, LPWT - left ventricular posterior wall thickness, LVID - left ventricular diameter, PAD - pulmonary artery diameter, RAD - right atrial diameter, RVD - right ventricular diameter, s - systolic

Effects of repetitive acceleration on cardiac chamber size and volumes

When participants were compared according to M-mode and 2-D echocardiographic parameters, there was no any statistically significant difference between these parameters of two groups (Table 2).

Effects of repetitive acceleration on systolic and diastolic functions

When Doppler echocardiographic parameters were analyzed, some statistically significant differences between two groups have been observed. In Group A pilots mean value of TV A was higher [t(61)=3.546, p=0.01] and TV E/A ratio was lower [t(61)=-2.507, p=0.015] than Group B pilots. The differences of other Doppler parameters between two groups were not statistically significant as shown in Table 3 (p>0.05).

Correlation between all echocardiography parameters and total flight hours of subjects were calculated and are shown in Table 4.

Effects of smoking on diastolic cardiac functions

Diastolic cardiac parameters in which there were significantly different (p=0.001 and p=0.005) parameters like TV A and TV E/A were also compared between two groups for both smoker subjects and non-smoker subjects as shown in Table 5.

Table 3. Mean Doppler echocardiographic parameters and comparisons between the groups

Variables	Group A	Group B	*p	Normal#
PAV, cm/sec	112.4±18.4	109.5±19.1	0.540	50-130
TRV, cm/sec	225.1±49.7	208.1±50.7	0.256	<250
MVE, cm/sec	78.9±12.3	79.3±15.1	0.905	72±14
MVA, cm/sec	60.3±12.4	57.2±10.6	0.281	40±10
MV(E/A)	1.34±0.27	1.40±0.27	0.400	1-3
TVE, cm/sec	68.4±12.7	64.6±7.3	0.140	50-70
TVA, cm/sec	52.1±13.8	42.6±6.4	0.001	20-40
TV(E/A)	1.36±0.30	1.53±0.20	0.015	0.7-3.1
PAP, mmHg	32±9.1	28.8±8	0.130	15-30

Data are presented as mean±SD.
*Student t-test for independent samples
#For normal values of the measured parameters, see references 10 and 13.
MVA - mitral valve A (atrial) velocity, MVE - mitral valve E (early) velocity, MV(E/A) - mitral valve E/A ratio, PAP - pulmonary artery systolic pressure, PAV - pulmonary artery velocity, TRV - tricuspid regurgitation velocity, TVA - tricuspid valve A velocity, TVE - tricuspid valve E velocity, TV (E/A) - tricuspid valve E/A ratio

At first, all subjects (63 pilots) were grouped as smokers and non-smokers and then diastolic parameters of Group A and Group B pilots were -compared both in smoker and non-smoker groups.

Discussion

Since the most important effects of exposing to high magnitude +Gz exposure are to circulation system, the cardiac functions are expected to be effected from this stress after a long period of time.

Our findings agreed with this thought and there were some significant differences between the high performance pilots who were to be exposed to repetitive high magnitude and long duration +Gz and other control pilots. Besides diastolic and mean arterial pressure, mean parameter differences between two groups there were especially a right heart diastolic function difference in aspect of TV A velocity. These differences are not thought to be defective but they may be a kind of adaptations against +Gz exposures. Adaptations of cardiovascular system against repetitive high +Gz exposure and AGSM during flights are expected to have effects on cardiac hemodynamics in the course of time (11, 12). Significant differences of some hemodynamic parameters between two groups were considered of less importance for being in normal limits. We thought this might be a result of blood pressure adaptation against repetitive +Gz exposure. A recent study suggested that repetitive exposure to +Gz results in an increased resting mean arterial pressure (MAP) and an elevated heart rate (HR) response to tilt test may provide G tolerance for fighter pilots (11).

The first significant difference between two groups was total flight hour means. Unsurprisingly the reason was that flight

Table 4. Correlation between total flight hours and echocardiographic parameters of all subjects

Flight Hours of Pilots (n=63)					
Variables	**Pearson r**	***p**		**Pearson r**	***p**
AOD	-0.003	0.983	PAV	0.028	0.825
LAD	0.174	0.172	TRV	-0.172	0.185
PAD	0.169	0.186	MVE	0.018	0.887
RAD	-0.062	0.631	MVA	0.073	0.570
IVST(d/s)	0.178/0.182	0.163/0.153	MV(E/A)	-0.084	0.514
LVID(d/s)	0.099/0.071	0.442/0.582	TVE	-0.117	0.362
LPWT(d/s)	-0.038/0.198	0.769/0.121	TVA	-0,106	0.408
RVD(d/s)	-0.065/-0.022	0.613/0.866	TV(E/A)	0.049	0.706
EDV	-0.009	0.945	PAP	-0.177	0.168
ESV	0.050	0.700	FS	-0.001	0.994
EF	0.020	0.876			

*Pearson correlation test

AOD- aortic diameter, d - diastolic, IVST - interventricular septum thickness, LAD - left atrium diameter, LVID - left ventricular diameter, MVA - mitral valve A (atrial) velocity, MVE - mitral valve E (early) velocity, MV(E/A) - mitral valve E/A ratio, PAD - pulmonary artery diameter, PAP-pulmonary artery systolic pressure, PAV-pulmonary artery velocity, RAD - right atrium diameter, TRV - tricuspid regurgitation velocity, TVA - tricuspid valve A velocity, TVE - tricuspid valve E velocity, TV(E/A) - tricuspid valve E/A ratio

Table 5. Relationship between smoking and mitral-tricuspid valve diastolic velocities

Variables	Group A Smokers (n=13)	Group B Smokers (n=7)	*p	Group A Non-Smokers (n=20)	Group B Non-Smokers (n=23)	*p
MV E, cm/sec	79.2	75.2	0.509	78.9	80.6	0.688
MV A, cm/sec	60.1	55	0.386	60.5	57.8	0.449
MV E/A	1.36	1.38	0.837	1.34	1.42	0.422
TV E, cm/sec	65.4	65.8	0.922	70.4	64.2	0.094
TV A, cm/sec	46.8	43.5	0.475	55.6	42.3	0.001
TV E/A	1.45	1.54	0.527	1.32	1.53	0.005

Data are presented as mean±SD.

*Student t-test for independent samples

#For normal values of the measured parameters, see references 10 and 13.

MVA - mitral valve A (atrial) velocity, MVE - mitral valve E (early) velocity, MV(E/A) - mitral valve E/A ratio, PAP - pulmonary artery systolic pressure, PAV - pulmonary artery velocity, TRV - tricuspid regurgitation velocity, TVA - tricuspid valve A velocity, TVE - tricuspid valve E velocity, TV(E/A) - tricuspid valve E/A ratio

duration of transport aircraft missions was much longer than high performance aircraft missions. We considered this was not important for transport aircraft or helicopter flights are not high maneuverable flights and can be neglected in aspect of exposing high +Gz. However there was a need to elucidate, the correlation between total flight hours and echocardiography parameters and there were no correlation as shown in Table 4. Subjects in Group A and Group B were similar in aspect of multiple demographic parameters like age, fitness, flight durations, training and education history, medical standards. They differ from each other especially with the type of aircraft that they had mostly flown. Former studies evaluating effects of this difference on cardiovascular system remained inconclusive. Findings from some of these studies suggest that occupational high performance aircraft piloting makes morphologic cardiac changes on heart (3, 4) on the other hand recent studies have not showed such an effect (5, 6). According to the results of our study, we also couldn't find any morphological cardiac difference for the high performance aircraft pilots with M-mode and 2-D echocardiography.

There are not many studies concerning functional effects of long durational acceleration forces on heart. In the study of Pantalos et al. (7), when 1-G upright, 1-G supine and micro-G conditions were evaluated with an artificial cardiovascular system in aspect of DeltaP, it was shown that additional atrial pressure (approximately 5 mmHg that is equal to DeltaP, between the base and the apex of the heart for the upright posture) was required in micro-G to obtain stroke volumes and flow rates similar to those measured in 1-G upright posture. From this, in the high +Gz conditions DeltaP could be expected to increase in proportion to the magnitude of +Gz and effect diastolic cardiac functions.

When we assess Doppler echocardiography data we see mean TV A velocity of Group A pilots was significantly higher than those of Group B pilots. As a result of TV A elevation, TV E/A ratios were significantly lower in Group A pilots. We observed these only significant differences in echocardiography of the high performance aircraft pilots. High levels of TV A could be a result of an adaptation against repetitive high G exposure. It could also be an early signal for a diastolic dysfunction. In the cardiac diastolic phase, TV E is known as the early filling peak velocity that comes out when blood passively passes from right atrium to right ventricle, while TV A is known as atrial peak velocity and it is resourced from atrium contraction. It is generally considered normal if TV E velocity is higher than TV A velocity.

Increased TV A velocity but not higher than TV E velocity which is common in Group A pilots indicates a non defective change. However, tricuspid or mitral E/A ratio, out of 1-3 range generally mean diastolic dysfunction (13). In our study, both mean TV A velocities were above normal range but increase in Group A was higher than Group B. So the mean E/A ratio of Group A was significantly lower than that of Group B nevertheless TV E/A remains in the normality range (0.7-3.1) for both groups.

The relationship between smoking and TV A increase in echocardiography has been reported in some studies (14, 15). In our study, since there were almost twice the numbers of smokers in Group A vs. Group B, we were in need of elucidating the effect of smoking on TV A increase. We compared the diastolic function parameters between two groups after all subjects divided as smokers and non-smokers as seen in Table 5. All differences were not statistically significant in smoker subjects' division and TV A was significantly higher and TV E/A was significantly lower in Group A in non-smoker subjects' division. So it could be said that TV A increase in Group A subjects was not related to smoking.

Most of the studies on diastolic dysfunctions have focused on the left ventricle functions. Studies concerning about the right ventricle dysfunctions are so few that the right ventricle is commonly known as "forgotten ventricle". According to the results of our study, early phase of right ventricle diastolic function wasn't effected by chronic +Gz exposure but there were some effects in the late phase of diastole, especially for mean TV A velocities and mean TV E/A ratios. It is also considered that TV A increases might be derived from high pulmonary artery pressure levels or augmented atrial contractions because of frequent tachycardia episodes during +Gz acceleration stress in Group A pilots. Despite the fact that the difference was not statistically significant, mean PAP of Group A pilots was higher than mean PAP of Group B pilots and than normal range. This increase might be a result of enhanced hypoxia due to the physically compelling condition like performing AGSM during +Gz exposure. +Gz induced drop in cardiac output and the consequences thereof in the lung (i.e., increased V_E-expired ventilation, ventilation/perfusion inequality, and reduced DL_{CO}-diffusing capacity) result in desaturation at higher increased +Gz (16). In addition, some studies showed relationship between exercise, hypoxia and PAP increase (17).

Results of our study were partially agreed with recent studies about cardiac response to chronic +Gz exposure (5, 6). We could not find evident cardiac defective signs between high performance aircraft and transport/helicopter pilots. However, some adaptive or predictive functional differences may be in question for high performance aircraft pilots. Finally incompatible with some previous studies, there were no morphologic cardiac differences between two groups (1, 3 and 4).

Clinical and practical implications

TV E/A ratio decrease in Group A pilots indicates that their right ventricle diastolic functions might have also been affected. We suggest that periodic screenings should include thorough echocardiographic examinations to accomplish early diagnoses. We expected these findings would be useful for flight safety and preventive aviation medicine.

Study limitations

Some differences may have been overlooked because of subjects who had cardiopulmonary diseases were excluded initially. Time needed to evaluate such number of parameters for a subject during echocardiography procedure was so long and persuading pilots to become volunteers was difficult. Therefore, the number of subjects was less than expected. Unable to use speckle tracking echocardiography and unable to follow up the pilots to check the variation of echocardiographic parameters in a year period were limitations of this study. Another limitation was pulmonary vascular resistance of subjects could have been measured echocardiographically.

Further studies concerning the effects of repetitive high +Gz exposure that focus on to right ventricle functions and pulmonary arterial pressure changes with large series can be done in order to reveal subtle effects of chronic +Gz exposure. Echocardiographic parameters of such studies should include tricuspid inflow tissue Doppler, myocardial performance index and strain rate.

Conclusion

We conclude that according to the results of our study, long term +Gz exposure has no effects on cardiac morphologic and systolic functions but has effects on right ventricular diastolic functions. We have considered that these effects may be a result of chronic +Gz adaptation or high PAP levels. All conditions that may give rise to incapacitation during flight should be investigated thoroughly. Discovering the adverse effects of long duration +Gz exposure on cardiac functions in pilots would be useful for contribution to aviation safety.

Acknowledgement

The authors wish to thank to Zeki Dulkadir, M.D., Assist. Prof. and Cengiz Han Açıkel, M.D., Assoc. Prof. for their assistance during statistical data analysis of this study.

Conflict of Interest: None declared.

Authorship contributions. Concept-S.İ., C.Ö.; Design - S.İ.; Supervision - A.A.; Resource - C.Ö.; Data collection&/or Processing - S.İ., C.Ö.; Analysis &/or interpretation - C.Ö.; Literature search - S.İ.; Writing - S.İ.; Critical review - C.Ö., A.A.; Other - A.A.

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