Echocardiographic dimensions and maximal oxygen uptake in elite soccer players

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ABSTRACT

Objectives: To assess cardiac dimensions in elite Saudi soccer players, and to correlate these measurements with maximal oxygen uptake.

Methods: Twenty-three soccer players representing the Saudi National soccer team, and 19 untrained males participated in this study. Cardiac dimensions were measured by M-mode echocardiography, and maximal oxygen uptake was assessed by open-circuit spirometry during treadmill running.

Results: When compared with age-matched untrained males, soccer players appeared to have significantly ($P<0.05$) greater values ($mm.m^{-2}$) in left ventricular end-diastolic dimension (28.8 ± 2.7 vs 26.5 ± 2.3), right ventricular cavity (14.1 ± 2.5 vs 11.8 ± 2.6), left atrial cavity (16.7 ± 1.6 vs 14.9 ± 2.2) and left ventricular mass (117.4 ± 21.2 vs 89.0 ± 16.0 $g.m^{-2}$). There was no significant difference between the 2 groups in left ventricular posterior wall (5.3 ± 0.77 vs 5.3 ± 0.61) or in interventricular septum (5.5 ± 0.65 vs 5.2 ± 0.59). When soccer players were grouped by playing position, there were no significant differences in cardiac dimensions between the players, though the midfielders and the full-backs showed the highest values for left ventricular cavity and maximal oxygen uptake. Further, maximal oxygen uptake relative to body mass ($ml.kg.^{-1}$ min^{-1}) exhibited a significant correlation with left ventricular cavity normalized to either body mass ($r = 0.62$; $P <0.01$), or to body surface area ($r = 0.53$; $P < 0.05$).

Conclusions: The elite Saudi soccer players appear to have significantly greater left ventricular cavity and mass than age-matched untrained males. Such cardiac adaptation seems to result from the highly dynamic nature of the soccer game.

Keywords: Cardiac dimensions, echocardiography, soccer, maximal oxygen uptake.

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Numerous cross-sectional and longitudinal echocardiographic studies have been, so far, reported for high-performance athletes from a variety of sports.[1-13] These studies demonstrated structural and functional adaptations in the cardiovascular system, which seem to be dependent on the duration and intensity of training. Athletes from sports such as rowing, canoeing, and cycling, who engage in strenuous and long-term endurance training, have been found to have a substantial left ventricular wall thickness, apart from their body size.[9] However, athletes training in isometric sports, such as weightlifting and wrestling, had high values for wall thickness relative to cavity dimension.[9] These physiological adaptations, nevertheless, were shown to be reversed with deconditioning.[14] Soccer is a considerably energy-demanding sport, and requires a high degree of skill, strength, agility, and

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endurance.[15-18] The total distance that is typically covered during a soccer game amounts to about 10km.[15,16,19] Furthermore, based on maximal oxygen uptake (VO_2max) values, soccer players, in general, seem to have good, but not outstanding aerobic power, something in the range of 55-65ml/kg. min.[15-18,20] According to the sports classification suggested by Mitchell et al,[21] soccer is largely considered a high dynamic sport with a low level of static load. However, there were few studies that have reported echocardiographic data for soccer players.[9,11,22] The findings of these studies indicated that a moderate level of impact for both left ventricular cavity and thickness was seen in players of sports such as soccer.[9,11] We had an opportunity to assess the cardiac dimensions of the Saudi National soccer team, and therefore, we are presenting in this paper the echocardiographic findings made on the Saudi elite soccer players, along with their relationships with maximal oxygen uptake in these elite soccer players.

Methods. ***Subjects.*** Subjects were comprised of 23 elite soccer players, representing the Saudi national team. They were in their early phase of preparation for the World Cup 1998, in France. In addition, 19 healthy untrained males, matched for age, were used as a reference group. The untrained subjects were recruited from King Saud University staff, as well as from the Sports Medicine Hospital, visitors who were accompanying patients. Body mass (kg) and height (cm) were measured using the Seca digital scale. Furthermore, subscapular and triceps skinfolds were measured using Harpenden caliper, on the right side of the body. Body fat percent was then estimated using a previously published prediction equation.[23]

Echocardiographic measurements. Echocardiograms were obtained in each subject using the Siemens Sonoline SL2 ultrasonograph, with a 3.5 MHz transducer. All examinations were performed by the same investigator with the subject in the left lateral decubitus position, and the transducer in the left intercostal space, 2 to 4 cm lateral from the left sternal border. The two-dimensional real-time pictures were obtained in the parasternal long-axis position, and then an M-mode picture was turned on to ensure the simultaneous visualization of the right ventricular cavity, inter ventricular septum, and the left ventricular posterior wall just below the mitral valve. Measurements were obtained with an on-line recorder, according to the recommendations of the American Society of Echocardiography (ASE),[24] using the leading edge methodology and the onset of the QRS complex of the electrocardiogram (ECG) as end-diastole. Cardiac dimensions included left ventricular internal end-diastolic dimension (LVIDd), defined as the distance between the left ventricular side of the septum and the posterior wall endocardium at the level of the posterior chorda; the interventricular septal wall (IVS), the left ventricular posterior wall (LVPW), defined as the distance between the endocardial and epicardial surfaces; the right ventricular cavity (RV), measured as the distance between the anterior right ventricular wall and the right septal echo; the left atrial cavity (LA), measured in endsystole. In addition, the left ventricular mass (LVM) was calculated according to the ASE cube formula of Devereux, et al.[25]

Maximal oxygen uptake testing. Maximal oxygen uptake (VO_2max) was determined within 3 days of echocardiographic measurement, using a continuous treadmill test. Following a 6 minute warm-up period, the soccer player began running on the treadmill while the speed was gradually increased until a velocity of 15.5 $km.h^{-1}$, after which the treadmill velocity was kept constant and the inclination was raised by 2% every 2 minutes until volitional exhaustion. All tests were conducted 2 hours after meals in a comfortable laboratory environment. Unfortunately, only the soccer players, not the untrained subjects, were tested for VO_2max. Expired air was collected and analyzed using an automated open-circuit spirometry, with 30-s sampling intervals [EOS-Sprint, Jaeger, Germany]. Gas analyzers were calibrated before each test with a known mixture of gases. Oxygen uptake was considered maximal when the respiratory exchange ratio exceeded 1.0, and heart rate level exceeded 90% of the predicted maximal heart rate. Heart rate was monitored continuously and recorded during the exercise test using CM5 lead and a single-channel ECG monitor and recorder (Helligi, Germany). In addition, ventilatory anaerobic threshold (VAT) was determined noninvasively through the use of gas exchange parameters.[26]

Statistical analysis. Descriptive statistics using the SPSS package were determined and data was presented as mean and standard deviations. The mean differences between the soccer players and the non-athletes for the cardiac dimensions were tested using a t-test for independent groups. In addition, the relationship of cardiac dimensions to VO_2max was determined for the soccer players using Pearson correlation coefficients. The level of significance was set at 0.05 or less. Furthermore, comparison of cardiac dimensions between soccer players and non-athletes was made relative to body surface area (BSA), since cardiac dimensions were shown to be related to body size and age. [9-11,27]

Results. Descriptive characteristics of the subjects are shown in Table 1. The soccer players are significantly taller and have larger surface area than the untrained group. However body mass and body mass index are similar in both groups. The soccer players in the present study have a fairly low fat content and a moderately high VO_2max level, in

Table 1 - Descriptive characteristics of the subjects (mean±SD (range)).

Variable	Soccer players (n=23)	Non-athletes (n=19)
Age (year)	25.2±3.3 (21-34)	25.1±4.1 (18-30)
Body mass (kg)	73.1±6.8 (64.3-90.3)	70.2±9.9 (53.5-84.0)
Body height (cm)	177.2±5.9** (163-189)	170.3±5.4 (158-178)
Body mass index ($kg.m^{-2}$)	23.3±1.4 (20.9-25.7)	24.2±3.2 (18.9-30.1)
Body surface area (m^2)	1.89±0.11* (1.72-2.18)	1.81±0.13 (1.58-2.0)
Body fat content (%)	12.3±2.7 (8.0-15.9)	-
VO_2 max ($ml.kg.^{-1}min^{-1}$)	56.8±4.8 (44.7-65.6)	-

SD - standard deviation
n = number
*Significantly different from non-athletes P<0.05; **P<0.01

Table 2 - Absolute echocardiographic measurements (mm) of Saudi soccer players and non-athletes (mean±SD (range)).

Variable	Soccer players	Non-athletes
LVPW	10.12±1.56 (8.3-14.0)	9.62±1.08 (8.1-11.0)
IVS	10.65±1.30** (8.3-14.0)	9.52±1.03 (7.6-12.0)
LVIDd	54.90±4.45** (47-62)	48.11±5.21 (40-57)
RV	26.95±4.53** (18-36)	21.47±5.06 (15-30)
LA	31.95±2.78** (28-39)	27.00±4.14 (20-36)
MWT	10.39±1.78* (8.65-14.0)	9.57±0.92 (7.95-11.50)
RWT (%)	38.13±6.11 (30.8-53.8)	40.23±6.09 (31.6-53.40
LVM (g)	224.45±44.46** (165.0-321.7)	162.01±35.33 (114.2-218.5)

LVPW: Left ventricular posterior wall; IVS:Interventricular septum; LVIDd:Left ventricular internal diastolic dimension; RV:Right ventricular cavity; LA:Left atrial cavity; MWT:Mean wall thickness [(LVPW+IVS)/2]; RWT: Relative wall thickness [(LVPW + IVS)/ LVIDd]; LVM:Calculated left ventricular mass. *P<0.05; **P<0.01

Table 3 - Echocardiographic measurements relative to body surface area ($mm.m^{-2}$) of Saudi soccer players and non-athletes (mean±SD (range)).

Variable	Soccer players	Non-athletes
LVPW	5.30±0.77 (4.26-7.45)	5.31±0.61 (4.40-6.63)
IVS	5.58±0.65 (4.45-7.45)	5.27±0.59 (4.43-6.48)
LVIDd	28.86±2.73** (23.98-33.54)	26.59±2.37 (22.42-31.89)
RV	14.17±2.58** (9.64-19.30)	11.86±2.69 (9.38-16.52)
LA	16.78±1.61** (14.29-20.18)	14.95±2.27 (11.61-20.00)
MWT	5.44±0.62 (4.64-7.45)	5.28±0.53 (4.61-6.48)
LVM($g.m^{-2}$)	117.42±21.23** (91.45-164.53)	89.03±16.00 (66.43-113.62)

LVPW: Left ventricle posterior wall; IVS: Interventricular septum; LVIDd: Left ventricular internal diastolic dimension; RV: Right ventricular cavity; LA: Left atrial cavity; MWT: Mean wall thickness [LVPW+IVS)/2]; LVM: Calculated left ventricular mass. **P<0.01

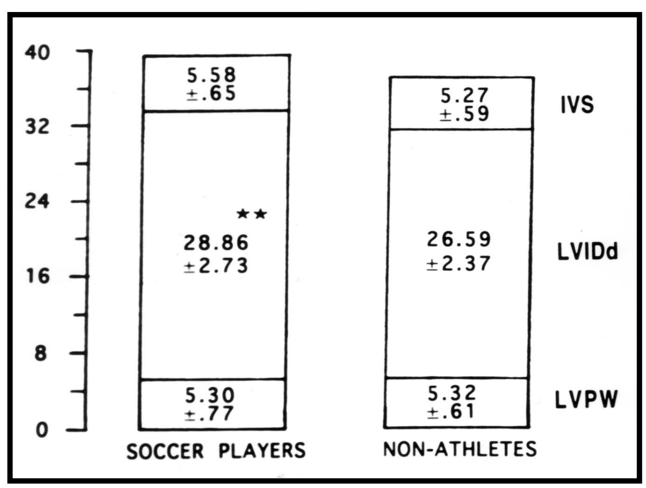

Figure 1 - Means (±SD) of left ventricular posterior wall thickness (LVPW), left ventricular end diastolic internal diameter (LVIDd), and interventricular septal thickness (IVS), relative to body surface area (mm.m-2) in Saudi soccer players and non-atheletes (**significant difference at 0.01 level).

Table 4 - Echocardiographic measurements relative to body surface area (mm.m^{-2}) of Saudi soccer players according to position (mean±SD).

Variable	Full-backs (n=6)	Center-backs (n=4)	Midfielders (n=6)	Forwards (n=7)
LVPW	4.98±0.44	5.46±0.70	5.9±0.89	4.86±0.63
IVS	5.47±0.64	5.40±0.55	5.89±0.89	5.49±0.40
LVIDd	29.66±3.70	26.40±0.83	29.78±2.54	28.65±1.76
RV	14.88±3.56	12.36±1.92	14.90±2.43	13.9±1.60
LA	16.49±1.53	16.79±2.62	16.84±1.20	17.03±1.70
MWT	5.23±0.54	5.43±0.63	5.89±0.88	5.18±0.51
RWT (%)	35.88±7.14	41.20±4.45	39.93±7.48	36.21±3.38
LVM(g.m^{-2})	112.98±16.7	117.75±35.6	127.25±28.3	114.58±11.90

LVPW: Left ventricular posterior wall; IVS:Interventricular septum; LVIDd:Left ventricular internal diastolic dimension; RV:Right ventricular cavity; LA:Left atrial cavity; MWT:Mean wall thickness [(LVPW+IVS)/2]; RWT: Relative wall thickness [(LVPW + IVS)/LVIDd]; LVM:Calculated left ventricular mass.
No significant difference was seen between players of differing positions.

comparison with values of soccer players elsewhere.[15-18,20] Results of absolute echocardiographic measurements for the soccer players and the untrained subjects are presented in Table 2. In comparison to the untrained group, the soccer players demonstrated significantly greater IVS, LVIDd, RV, LA, MWT and LVM. However there were no differences between the 2 groups in LVPW or relative wall thickness. Furthermore, soccer players exhibited a 38.5% greater LVM when compared to the untrained subjects. Looking at the absolute cardiac dimensions in the 2 groups, revealed that 10% of the soccer players exhibited values for LVPW or IVS greater than or equal to 13 mm, and about 50% of them showed values for LVIDd greater than or equal to 56 mm. However, none of the untrained subjects exceeded the above mentioned limits. Due to the differences in BSA between the 2 groups, it would be more appropriate to express values of cardiac dimensions relative to BSA. Table 3 and Figure 1 present the echocardiographic measurements (in mm.m^{-2}) for the 2 groups of subjects. In comparison with the untrained group, the soccer players significantly showed greater LVIDd, RV, LA, and LVM. The LVM relative to BSA in soccer players was approximately 32% greater than in the untrained group. Measures of left ventricular wall thickness were similar across the 2 groups. When the differences in cardiac dimensions within soccer players were examined, as shown in Table 4, there were no significant differences detected (at the 0.05 level) between the players of different positions. However, because of the small sample size in each position, we examined the magnitude of the differences between the midfielders and the other positions in standardized units, by calculating the effect size (ES) estimate. Effect size ranged from 0.55 to 2.0 units. These effect sizes are considered moderate to high. In other words, had the sample size in each position been larger, we would have detected significant differences between groups. The midfielders, thus, seemed to have the highest values, relative to BSA, for all cardiac dimensions that were examined. Calculated LVM was also the highest in the midfielders compared to the players from other positions. Table 5 presents the results of zero order correlation analysis between LVIDd and each of VO_2max and VAT. Because there were large differences in body mass among the soccer players, we also examined the relationships

Table 5 - Correlation coefficients of LVIDd with VO_2max indices and ventilatory anaerobic threshold (VAT) in Saudi soccer players.

Variables	LVIDd		
	mm	mm.kg^{-1}	mm.m^{-2}
VO_2max (L.min^{-1})	0.38	-0.04	-0.52*
VO_2max (ml.kg^{-1} min^{-1})	0.17	0.62**	0.53*
VO_2max (ml.kg$^{-0.75}$min^{-1})	0.25	0.52*	0.48*
VO_2max (ml.kg$^{-0.67}$ min^{-1})	0.27	0.47*	0.45*
VAT (ml.kg^{-1} min^{-1})	-0.09	0.44*	0.35

*P<0.05; **P<0.01

Table 6 - Comparison of cardiac dimensions for the Saudi elite soccer players with some previously published values in the literature.

Reference	Subjects	Age (year)	BSA (m^2)	LVPW (mm/m^2)	IVS (mm/m^2)	LVIDd (mm/m^2)	LVM (g/m^2)
Spirito et al, 1994*	62 Italian olympic soccer players	24.8±4.3	1.95±0.1		5.13	28.2	105±17
Urhausen et al, 1996	22 German national soccer players	20.3±3.4	1.96	5.2±0.7	5.1±0.7	27.8±1.9	111±21
Chukwuemeka & Al-Hazzaa,* 1995	Saudi athletes 10 weight lifters	22.0±2.5	1.89±0.3	6.2	6.5	25.3	114.1
	19 wrestlers	22.3±4.8	1.89±23	6.1	6.6	25.2	107.2
	10 endurance runners	23.6±2.9	1.72±0.1	6.3	6.8	27.8	116.1
Present study	Saudi national soccer players	25.2±3.3	1.89±0.1	5.30±0.77	5.58±0.65	28.8±2.7	117±2

*Data relative to body surface area (BSA) was not reported in the original papers and was calculated in this table.
LVPM - Left ventricular posterior wall; IVS -Interventricular septum; LVIDd - Left ventricular internal diastolic dimension; LVM - Calculated left ventricular mass.

between LVIDd and VO_2max scaled to 2/3rd or 3/4th of body mass. As shown in Table 5, VO_2max relative to body mass ($ml.kg.^{-1}min^{-1}$) demonstrated the highest correlation coefficient with LVIDd, expressed relative to body mass ($r = 0.62$; $p<0.01$) or relative to BSA ($r = 0.53$; $p<0.05$). When VO_2max values, scaled to 2/3rd or 3/4th of body mass, were related to LVIDd, the correlation became lower. Ventilatory anaerobic threshold, however, showed a much smaller correlation with cardiac dimensions than VO_2max relative to body mass.

Discussion. Soccer, which is classified as a dynamic sport with a low level of static load,[21] seemed, as the findings of this study indicated, to lead to structural and functional adaptations that are concurrent with the definition of the athlete's heart. The soccer players in this study were representing the Saudi national soccer team, who participated in the World Cup 1998, in France, and were mostly involved in soccer training for a considerable time. Previous local data on a Saudi junior soccer team indicated a significant cardiac adaptation when compared to a control group.[28] The differences between the soccer players and the untrained subjects in the present study were the largest in LVIDd, and were the smallest in wall thickness. Spirito et al,[11] using a multivariate linear model, calculated the effects of sport type on LVIDd and wall thickness in 947 Italian Olympic athletes representing 27 sports, and found that the impact of soccer ranked 9th on LVIDd and 15th on wall thickness. This means that soccer training had more impact on left ventricular cavity than on wall thickness. In our study, soccer players exhibited higher LVIDd but similar wall thickness compared with the untrained subjects. Two players (9%) in the Saudi soccer team exhibited a left-ventricular-wall thickness within the range compatible with the diagnosis of hypertrophic cardiomoypathy (≥ 13mm).[9] However, in a large scale study on Italian athletes from a variety of sports, it was reported that only 2% of the athletes had left ventricular wall thickness exceeding 13 mm,[9,11] and none were soccer players. Racial differences may have played a role in this regard, since the Italian athletes were all Caucasian whereas about one-third of the Saudi soccer players were black.

In the present study, the midfielders seemed to have the largest left ventricular internal cavity diameter, though not significantly different from the other players. The midfielders had also the highest values for VO_2max. It seemed therefore, that the larger the LVIDd in the midfielders enables them to better cope with the dynamic exercise task they undergo during the course of soccer game. Fagard,[5] in a meta-analysis study, concluded that endurance type sports, such as running and cycling, were showing the largest left ventricular cavity dimensions. Other studies have also reported endurance sports, namely cycling, rowing, canoeing, and swimming to exhibit the strongest effect on left ventricular cavity size and wall thickness. It appears that there are limited studies reporting echocardiographic findings for elite soccer players.[9,11,22] Comparison of our findings with these limited studies on soccer players are shown in Table 6. The values were reported relative to BSA. When compared to Italian or German soccer players, the Saudi soccer players seemed to have slightly greater

IVS and LVM, but comparable values for LVIDd. The increased cardiac dimensions of the Saudi soccer players may not be entirely the result of training. Genetic endowment could have been partially responsible for these differences. Comparison of the Saudi soccer players with some reported cardiac dimensions for other Saudi athletes,[28] revealed that LVPW and IVS were greater in weight lifters, wrestlers, and endurance runners. However, values of LVIDd for the soccer players and the Saudi endurance runners were similar. In healthy subjects, there is a close relationship between the heart size and the capacity for cardiorespiratory performance.[29] In the present study insignificant moderate correlation (r=0.38) was found between absolute LVIDd and VO_2max ($L.min^{-1}$). Other studies however had reported very weak relationships between VO_2max and LVIDd in moderately trained males,[27] and in trained oarsmen.[30] When both LVIDd and VO_2max values of the Saudi players were expressed relative to body mass, there was a significant positive relationship between the 2 variables ($r = 0.62$; $p < 0.01$). Soccer training is known to involve short bursts of intense activity.[15] Such interval type of training leads to increases in VO_2max and cardiac output.[15,17] Furthermore, the increase in stroke volume and blood volume as a result of training has a direct effect on the cardiac preload and on left ventricular chamber dilatation.[22] Anaerobic threshold, which is known to be more dependent on local muscle adaptation (rather than on central) had a lower correlation with LVIDd compared with VO_2max.

In conclusion, the elite Saudi soccer players in the present study appeared to have significantly greater LVIDd, RV, LA and LVM, and slightly larger IVS than age-matched untrained males. Such structural and functional adaptations are the results of the highly dynamic nature of the soccer game. In addition, VO_2max relative to body mass correlated significantly with LVIDd expressed relative to body mass or body surface area.

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