Doppler-echocardiographic findings in professional divers

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Stuhr LEB, Gerdts E, Nordrehaug JE. Doppler-echocardiographic findings in professional divers. Undersea Hyper Med 2000; 27(3):131–135.—To determine if professional diving leads to morphologic and/or functional cardiologic changes, Doppler-echocardiography was performed in 20 professional saturation divers (average 15 yr diving experience) and compared to 20 control persons (policemen) who were matched for age (35–45 yr) and number and duration of training sessions. The policemen were taller than the divers, therefore the echocardiographic dimensions but not the functional variables were normalized for body surface area. The groups were comparable for resting and maximal treadmill exercise heart rate, blood pressure, oxygen uptake, and respiratory exchange ratio. Thickness of left ventricular (LV) anterior and posterior wall in end diastole and end systole, and left ventricular mass were similar in the two groups. The systolic functional parameters, LV ejection fraction, and fractional shortening were on average normal in both groups, although one of the divers had low values. Their LV chamber dimensions, wall thickness, diastolic parameters, and exercise capability were normal. The diastolic functional parameters were equal in the two groups. These results suggest that professional divers have normal size and mass of the heart, no diastolic functional changes, and a normal average systolic function.

echocardiography, Doppler, left ventricular mass, systolic function, diastolic function, professional divers

Hyperbaric exposures have been shown to exert an acute stimulus on the mammalian heart, due partly to increased ambient pressure, increased breathing gas density, and/or increased partial pressure of the inert gas applied (1–3). Increased cardiac contractility (dP/dt) and left ventricular systolic pressure have been found in animal experiments regardless of what breathing gas was used (3,4). In vitro studies on human myocardial preparations have shown corresponding increase in the heart tension and tension development (5), which strongly indicates that similar effects can be expected in human studies. Simultaneously, an increased blood flow (20–50%) in the left ventricular myocardium was found in animals acutely exposed to 5 bar (6,7), indicating that the oxygen consumption of the heart is enhanced in hyperbaric conditions. As blood pressure and heart rate were found to be unchanged, the increase in myocardial blood flow cannot be explained by an increase in external work of the heart, but rather to an increased internal work (enhanced inotropy). A recent study in our laboratory has shown hypertrophy of the left ventricle of the rat heart after 40 exposures to 5 bar normoxic helium (1 h/day). Additionally, the study revealed necrotic areas in the left ventricle and indications of subvalvular aortic stenosis (8). There are few reports on human divers. An autopsy study has indicated higher left ventricular weight in 13 professional divers compared to 20 sport divers. However, the same study showed no pathologic changes in the myocardium in the two groups (9). Development of pathologic changes in the heart is indicated by a Swedish study on 269 professional divers, showing increased cardiovascular mortality in professional divers compared to the normal non-diving population with a standard mortality rate (SMR) of 1.37 and 1.51 for “circulatory system” and “ischemic heart disease”, respectively (10). The question is therefore whether professional diving leads to morphologic and/or functional changes in the heart, explaining the increased cardiovascular mortality reported from Sweden.

The aim of the present experiments was to assess left ventricular dimensions and systolic and diastolic function in professional divers compared to age-matched controls using Doppler-echocardiography (11).

SUBJECTS AND METHODS

Divers: Twenty professional saturation divers were included in a cross-sectional study of the heart. The divers were recruited by calling and asking divers in the region to participate. Their experience as divers averaged 15 yr
ments were done with the standard technique according to the guidelines given by the American Society of Echocardiography (12). The relative wall thickness was calculated as follows: \(2 \times \text{PWD}/\text{LVEDD}\). Left ventricular ejection fraction (LVEF) was calculated according to the cube method (13,14) and fractional shortening (LVFS) as \((\text{LVEDD-LVESD})/\text{LVEDD} \times 100\%\) (16). Calculation of the left ventricular mass (LVM) was performed according to Devereux et al. (15):

\[
\text{LVM} = (0.83)\left[(\text{LVEDD} + \text{IVS-EDD} + \text{LVPW-EDD})^3 - (\text{LVEDD})^3\right] + 0.6
\]

### Table 1: Baseline Characteristics

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Policemen</th>
<th>Divers</th>
</tr>
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<tbody>
<tr>
<td><strong>Age, yr</strong></td>
<td>39.7 ± 4.1</td>
<td>37.9 ± 4.7</td>
</tr>
<tr>
<td><strong>Height, cm</strong></td>
<td>184.8 ± 5.7</td>
<td>180 ± 5.2*</td>
</tr>
<tr>
<td><strong>Weight, kg</strong></td>
<td>86.3 ± 9.2</td>
<td>82 ± 8.1</td>
</tr>
<tr>
<td><strong>BSA, m²</strong></td>
<td>2.13 ± 0.14</td>
<td>2.03 ± 0.13*</td>
</tr>
<tr>
<td><strong>Smokers</strong></td>
<td>7</td>
<td>4</td>
</tr>
<tr>
<td><strong>Exercise, h/wk</strong></td>
<td>2.8 ± 2.0</td>
<td>2.7 ± 3.3</td>
</tr>
<tr>
<td><strong>VO₂max, liter·min⁻¹</strong></td>
<td>4.3 ± 0.6</td>
<td>4.0 ± 0.9</td>
</tr>
<tr>
<td><strong>VO₂max, ml·kg⁻¹·min⁻¹</strong></td>
<td>53.30 ± 11.1</td>
<td>51.06 ± 9.31</td>
</tr>
<tr>
<td><strong>V̇Emax, liter·min⁻¹</strong></td>
<td>127.3 ± 30</td>
<td>125.4 ± 22</td>
</tr>
<tr>
<td><strong>RER</strong></td>
<td>1.24 ± 0.09</td>
<td>1.24 ± 0.11</td>
</tr>
<tr>
<td><strong>BP systolic, mmHg</strong></td>
<td>132.0 ± 7.3</td>
<td>126.6 ± 10.4</td>
</tr>
<tr>
<td><strong>BP diastolic, mmHg</strong></td>
<td>86.1 ± 10.5</td>
<td>84.5 ± 9.3</td>
</tr>
<tr>
<td><strong>HR rest, beats·min⁻¹</strong></td>
<td>66.0 ± 10.8</td>
<td>65.9 ± 12.1</td>
</tr>
<tr>
<td><strong>HR max, beats·min⁻¹</strong></td>
<td>184.3 ± 2.0</td>
<td>183.3 ± 1.9</td>
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</tbody>
</table>

*Key: BSA = body surface area; VO₂max = maximal oxygen consumption; V̇Emax = maximal expired minute ventilation; RER = respiratory exchange ratio, BP = blood pressure, HR = heart rate.
* = Significantly different from corresponding control group, \(P<0.05\).
*At the time of the study; average of last 5 yr.
All examinations were performed in natural end expiration. The best three consecutive beats were chosen and the average of these was calculated. The ultrasound tracings were written out on a strip chart recorder (Mitsubishi color Copy Processor, Mitsubishi, Japan) on light-sensitive paper at a speed of 50 mm/s. All Doppler–echocardiographic examinations were performed by the same experienced echocardiographer who was unaware of the profession of the participants. The measurements obtained by this method have been shown to be accurate (16).

Exercise test: Exercise testing was performed on a Quinton treadmill system (Q-plex I, A.H. Robin Company, Washington), according to the Bruce protocol (17), starting at 1.7 mph and 10 grade (stage 1), with increasing workload every 3 min. $\text{VO}_2$ (liter $\cdot$ min$^{-1}$ STPD), maximal pulmonary ventilation (VE) (liter $\cdot$ min$^{-1}$ BTPS) and respiratory exchange ratio (RER) were measured and automatically calculated with a computerized pulmonary gas analyzer ($\text{O}_2$-zirconia, $\text{CO}_2$-infrared, Robin Company, Washington). The results were written out on an Epson writer (EX-800). Both $\text{VO}_{2\text{max}}$ and $\text{VE}_{\text{max}}$ were calculated from the last 30 s of the exercise, whereas RER was given as maximal value. Electrocardiogram (ECG) was continuously monitored from 12 chest-leads, recorded, and written out by a Hewlett Packard recorder (M 1700A connected to a PageWriter Xli, Hewlett Packard) at a speed of 50 mm/s. Volume and gas calibrations were done before each test. The drift of the gas analyzer was always below 0.05%.

Other measurements: The casual BP was measured in the sitting position with a standard mercury sphygmomanometer, and HR was recorded by ECG. BSA was estimated from height (H) and weight (W), $\text{M}^2 = \text{W}^{0.425 \times H^{0.725}} \times 71.84$ (18).

Interview: A standardized interview was done focusing on smoking habits, the amount of training performed by the subjects in their spare time, type of training, previous diseases, and a full diving history. All subjects gave informed consent, and the protocol was approved by the Regional Ethical Review Committee. Expenses were refunded, but no salary was paid.

Statistics: Data were stored and analyzed in SPSS/PC, version 6.1 (19) on an IBM personal computer. The subjects mean characteristic values and echocardiographic data were compared with independent Student's t test. Multivariate analysis was performed to find relevant correlations between echocardiographic data and age, BSA, $\text{VO}_2$, BP, and LVM. Results are presented as means $\pm$ SD. A $P < 0.05$ was considered statistically significant.

RESULTS

Baseline characteristics: All baseline characteristics are given in Table 1. No significant differences were found between the divers and controls regarding age, weight, BP, and resting or maximal HR. On average, the divers were slightly shorter ($P < 0.05$) and therefore had reduced BSA compared to controls. The echocardiologic data, which could be influenced by these parameters, were therefore corrected for these differences as shown below.

The treadmill exercise showed that the $\text{VO}_{2\text{max}}$, $\text{VE}_{\text{max}}$, and RER were similar in the two groups (Table 1) when correlated for BSA. The training duration each week was similar in the two groups.

Echocardiography: High quality Doppler–echocardiograms were obtained in all subjects.

- Left ventricular dimensions and systolic variables (Table 2): The heart dimensions were similar in the two

<table>
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<th>Table 2: M-Mode Echocardiographic Findings</th>
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<td>Policemen</td>
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<td>$n = 20$, mean $\pm$ SD</td>
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Left ventricular mass, g | 203 $\pm$ 43 | 192 $\pm$ 40 |
Left ventricular mass to body surface area, g $\cdot$ m$^{-2}$ | 95 $\pm$ 20 | 96 $\pm$ 20 |
Left ventricular mass to height$^{27}$, g $\cdot$ m$^{-2}$ | 40 $\pm$ 9 | 40 $\pm$ 9 |
Relative wall thickness, cm | 0.37 $\pm$ 0.08 | 0.38 $\pm$ 0.09 |
Left atrial dimension (systole), cm | 4.0 $\pm$ 0.4 | 3.8 $\pm$ 0.4 |
Left ventricular end-diastolic diameter, cm | 5.5 $\pm$ 0.4 | 5.4 $\pm$ 0.4 |
Left ventricular end-systolic diameter, cm | 3.6 $\pm$ 0.4 | 3.7 $\pm$ 0.3 |
Thickness of the inter-ventricular septum, cm | 0.9 $\pm$ 0.2 | 1.0 $\pm$ 0.2 |
Thickness of the left ventricular posterior wall, cm | 1.0 $\pm$ 0.2 | 1.0 $\pm$ 0.2 |
Left ventricular fractional shortening | 0.36 $\pm$ 0.05 | 0.31 $\pm$ 0.05$^*$ |
Left ventricular ejection fraction | 0.73 $\pm$ 0.06 | 0.66 $\pm$ 0.09$^*$ |

$^*$P < 0.01 between groups.
groups when compared to BSA. Average LVM was 192 ± 40 g in the diver group and 203 ± 43 g in the policeman group (not significant). When LVM was correlated to BSA there was still no significant difference between the two groups. Indices of systolic function LVFS and estimated LVEF were significantly lower (P < 0.01) in divers than in controls; however, they were within normal values.

- Left ventricular diastolic function (Table 3): Indices of diastolic function, A-wave, E-wave, A/E ratio, DT, and IVRT were comparable in the two groups. No significant differences were found between the two groups when corrected to height or BSA.

DISCUSSION

The aim of this study was to assess left ventricular dimensions and function in professional divers. Because of its ability to provide morphologic, functional, and hemodynamic information, Doppler–echocardiography was selected as a practical and reliable method (20).

Morphology: The LVM, according to the formula by Devereux and colleagues (20), was 192 g in divers and 203 g in policemen. The LVM was not significantly different between the two groups when corrected for height or BSA. As the groups differed in height, LVM was also indexed for height in allometric power (21). Thus, our findings are comparable with the Norwegian study of Mo et al. (22) where the LVM in the general normotensive population (average 44 yr) was 206 ± 65 and with Vos et al. (23) where the LVM was 188 ± 40.8 in controls (average 33 yr). However, an autopsy study on professional divers has shown an increased heart weight compared to recreational divers (9). This discrepancy in results is probably not due to methodologic differences, since autopsy studies have confirmed the validity of in vivo echocardiographic estimates of LVM (11,20). It is more likely a result of the difference in the diver materials. In the autopsy study, the heart weight was measured with little or no information on the divers previous BP and physical fitness data, whereas our study was performed on healthy divers still diving and with full physiologic background information. It is therefore possible that factors other than diving per se influenced the heart weight of the dead divers.

Heart morphology and function are related to age, BP, training, and body size (20,24). Since the echocardiographic dimensions are related to age, it was desirable that the two groups have identical age ranges. We therefore chose divers and policemen at the age range of 35–45 yr. We deliberately excluded individuals with high BP (>150/90), which might have influenced our data. Endurance training is also known to influence the muscle mass of both ventricles. The training amount, VO2max, and maximal HR were equal in the two groups, indicating comparable physical fitness levels. The most common way to standardize for body size is to divide the measure by BSA (20). The echocardiographic data: BSA ratios are given in Table 2. All the measurements in mass and size are normal in the divers as in the policemen. There was no development of hypertrophy of the heart as seen in a previous study on rats repeatedly exposed to 5 bar for 40 days (hypertrophy of the left ventricle including the intraventricular septum) (8). This discrepancy might be due to species differences.

The ejection fraction estimated by Doppler–echocardiography, usually above 55% in a normal population, is a relatively good index of left ventricular systolic function (25). The professional divers showed on average a normal EF and FS (22,23), though one of the divers had lower values. However, his LV chamber dimension, wall thickness, diastolic parameters, oxygen uptake, and exercise capacity were all normal.

A recent report indicated that the early functional alterations of the left ventricle are often diastolic rather than systolic (26). Doppler flow velocity provides relative accurate estimates of LV diastolic function, and was therefore measured. However, both the divers and the policemen had normal Doppler diastolic values (27).

In conclusion, despite development of left ventricular hypertrophy in rats after repeated ambient pressure and

<table>
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<tr>
<th>Table 3: Left Ventricular Diastolic Variables</th>
<th>Policemen n = 20, mean ± SD</th>
<th>Divers n = 20, mean ± SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Velocity of early diastolic filling wave-E, cm · s⁻¹</td>
<td>0.72 ± 0.15</td>
<td>0.71 ± 0.14</td>
</tr>
<tr>
<td>Velocity of late diastolic atrial filling wave-A, cm · s⁻¹</td>
<td>0.47 ± 0.12</td>
<td>0.55 ± 0.16</td>
</tr>
<tr>
<td>E/A ratio</td>
<td>1.6 ± 0.3</td>
<td>1.4 ± 0.4</td>
</tr>
<tr>
<td>Isovolumic relaxation time, ms</td>
<td>101.0 ± 18.8</td>
<td>101.5 ± 12.6</td>
</tr>
<tr>
<td>Deceleration time, ms</td>
<td>187.0 ± 46.8</td>
<td>177.5 ± 38</td>
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DIVERS' HEART: DOPPLER-ECHOCARDIOGRAPHIC FINDINGS

indication of increased cardiovascular mortality in divers, the present study shows that professional divers have a normal left ventricular mass, and normal diastolic and systolic function compared to age-matched control persons.

We are grateful to all the divers and the policemen for participating in this study. This work was supported by The Norwegian Research Council for Science and the Humanities. Council for Medical Research.—Manuscript received March 1999; accepted July 2000.

REFERENCES
