Large Lungs in Divers*
Natural Selection or a Training Effect?

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Background: Normal spirometry is required for medical clearance of professional divers in many countries. Divers frequently have unusually large lung volumes associated with a low ratio of FEV₁ to FVC (FEV₁%), suggestive of obstructive airways disease. We retrospectively analyzed the records of divers in the Israeli Navy with a low FEV₁% who fulfilled the criteria for large lungs, to determine whether this might be the effect of training or natural selection. We also investigated changes in pulmonary function in relation to diving experience.

Methods: A total of 171 divers with FEV₁% < 80% on simple spirometry were evaluated. We conducted a retrospective analysis of lung function data for those subjects who met the criteria for large lungs.

Results: One hundred nine of 171 divers with low FEV₁% met the criteria for large lungs and were included in the study. Their average age was 25 years (range, 18 to 44 years), and their mean diving experience was 7 years (range, 0 to 26 years). No difference was found in FVC values between experienced and inexperienced divers. The mean forced expiratory flow at 50% of vital capacity was significantly reduced in the most experienced group compared with the novice or less experienced divers. No difference was found in the diffusing capacity of the lung for carbon monoxide between experienced and inexperienced divers.

Conclusions: We suggest that large lungs may represent part of the natural selection for diving, rather than a training effect. Prolonged diving experience may result in the development of small airways disease.

Key words: diving; large lungs; long-term effects

Abbreviations: DLCO = diffusing capacity of the lung for carbon monoxide; FEF₅₀ = forced expiratory flow at 50% of vital capacity; FEV₁% = ratio of FEV₁ to FVC; RV = residual volume; TLC = total lung capacity

N
ormal pulmonary function is essential for divers, not only to ensure that they will be able to maintain high levels of physical activity, but also to avoid pulmonary barotrauma due to air trapping. Normal spirometry is a prerequisite for medical certification of nonrecreational diver candidates and is part of the annual medical examination of commercial divers.1,2

Several cross-sectional studies3–7 have shown that divers frequently have unusually large lung volumes and a low ratio of FEV₁ to FVC (FEV₁%), suggestive of obstructive airways disease or airflow limitation. However, when a low FEV₁% represents true airflow limitation, FEV₁ is reduced, and residual volume (RV) is often increased, also called air trapping. For a low FEV₁% to represent large lungs, FEV₁ must be at least normal, and RV has to be low.

Because a reduced FEV₁% might represent airflow limitation and/or air trapping, which increases the risk of pulmonary barotrauma and reduces exercise capacity during a dive, divers with reduced FEV₁% are required to undergo complete pulmonary function studies to exclude obstructive airways disease. Crosbie et al4,5 were the first to describe the phenomenon of large lungs in divers. Their lung function studies demonstrated a large FVC and increased FEV₁, as well as low FEV₁% with no other evidence of air trapping or obstructive airways disease. It is not known whether the considerable increase observed in FVC is the result of adaptation due to a training effect of diving on the respiratory muscles or whether it is an effect of selec-
Although there are data relating high vital capacity to diving history,\(^6\)\(^7\)

At the Israel Naval Medical Institute, we routinely perform spirometry as part of the annual medical fitness examination conducted on professional divers and as part of the prediving medical examination of diver candidates. Any diver or diver candidate with abnormal spirometry is required to undergo complete pulmonary function studies. We retrospectively analyzed the records of divers with a low FEV\(_1\)% who fulfilled the criteria for large lungs in divers, to determine whether this might be the effect of training or natural selection. We also investigated changes in pulmonary function in those divers who were found to have large lungs in relation to diving experience.

**MATERIALS AND METHODS**

One hundred seventy-one divers with FEV\(_1\)% <80% on simple spirometry (ST-250; Fukuda Sangyo; Chiba, Japan) during medical evaluation were referred for further investigation. Before testing, the spirometer was calibrated according to the recommendations of the American Thoracic Society.\(^8\) FVC, FEV\(_1\), and FEV\(_1\)% were measured. The best result of at least three tests was used for evaluation. All of the pulmonary function tests were conducted in a single pulmonary function laboratory by the same technicians. Lung volumes (vital capacity, total lung capacity [TLC], RV, and RV/TLC ratio) were measured and calculated using a body plethysmograph (Bodyscreen II; Erich Jaeger; Wurzburg, Germany). Volumes and flows were corrected to body temperature and pressure, saturated. Single-breath diffusing capacity of the lung for carbon monoxide (DLco) was measured according to the instructions of the manufacturer. Values were corrected for venous hemoglobin concentration. DLco is expressed in standard temperature and pressure, dry.

The criteria for large lungs were as follows: large FVC (FVC >100%), FEV\(_1\) ≥90%, and no evidence of air trapping, as manifested by a ratio of RV to TLC ≤0.3.\(^3\) We conducted a retrospective analysis of lung function data for the nonsmoking divers who met these criteria.

Comparison among groups was done by analysis of variance and linear regression analysis using SAS 6.03 (SAS Institute; Cary, NC). The scattergram was built with a 95% confidence interval.

**RESULTS**

Of the 171 divers with low FEV\(_1\)% 109 met the criteria for both large lungs and nonsmoking and were included in the study. The remaining 62 divers were excluded for the following reasons: 6 divers had large lungs but were smokers, and the other 56 divers had pulmonary function findings, suggestive of obstructive airflow limitation of unknown etiology. Twelve of these 56 divers were smokers.

Thus, the 109 divers included in the study were healthy, nonsmoking males with no history, symptoms, or other evidence of obstructive airways disease. Physical examination and chest radiograph findings were normal in all subjects. Their average age was 25 years (range, 18 to 44 years), and their mean diving experience was 7 years (range, 0 to 26 years). This group was further divided into three subgroups according to age and diving experience (novice, less experienced, and experienced), and the results of the pulmonary function tests were analyzed for each subgroup (Table 1). No difference was found in FVC values between experienced and inexperienced divers. The mean forced expiratory flow at 50% of vital capacity (FEF\(_{50}\)) was significantly reduced in the most experienced group compared with the novice or less experienced divers (p < 0.05) [Fig 1]. No difference was found in the DLco between experienced and inexperienced divers.

**DISCUSSION**

During diving, the respiratory system must deal with increased gas density, the effects of immersion, and the use of breathing apparatus, all of which increase respiratory mechanical load.\(^11\)\(^-\)\(^17\) Decompression stress and breathing high-oxygen concentrations can also have detrimental effects on pulmonary function.\(^11\)\(^-\)\(^13\)\(^,\)\(^18\) Therefore, one of the major concerns that must be addressed when assessing pulmo-

### Table 1—Results of Lung Function Tests in the Diver Population*

<table>
<thead>
<tr>
<th>Parameter</th>
<th>All Divers</th>
<th>Subgroup 1</th>
<th>Subgroup 2</th>
<th>Subgroup 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age range, yr</td>
<td>18–44</td>
<td>18–25</td>
<td>26–35</td>
<td>36–44</td>
</tr>
<tr>
<td>No.</td>
<td>109</td>
<td>67</td>
<td>28</td>
<td>14</td>
</tr>
<tr>
<td>Years diving</td>
<td>7.03 ± 7.2</td>
<td>2.10 ± 1.86</td>
<td>11.82 ± 3.99</td>
<td>21.07 ± 2.84</td>
</tr>
<tr>
<td>FVC</td>
<td>118.24 ± 13.6</td>
<td>120.31 ± 15.63</td>
<td>113.78 ± 7.90</td>
<td>117.28 ± 9.94</td>
</tr>
<tr>
<td>FEV(_1)</td>
<td>101.56 ± 9.6</td>
<td>102.86 ± 10.2</td>
<td>99.10 ± 6.64</td>
<td>100.28 ± 8.74</td>
</tr>
<tr>
<td>FEF(_{50})</td>
<td>69.15 ± 15</td>
<td>70.60 ± 17.28</td>
<td>68.92 ± 10.78</td>
<td>62.71 ± 8.38</td>
</tr>
<tr>
<td>TLC</td>
<td>110.75 ± 12.93</td>
<td>112.95 ± 13.64</td>
<td>105.6 ± 11.32</td>
<td>110.64 ± 9.94</td>
</tr>
<tr>
<td>RV</td>
<td>113.25 ± 31.16</td>
<td>114.86 ± 31.68</td>
<td>109.57 ± 32.5</td>
<td>113.00 ± 27.02</td>
</tr>
<tr>
<td>ITGV</td>
<td>113.54 ± 22.06</td>
<td>115.18 ± 20.55</td>
<td>111.62 ± 23.8</td>
<td>109.50 ± 26.10</td>
</tr>
<tr>
<td>D(_{LCO})</td>
<td>94.68 ± 16.89</td>
<td>95.84 ± 15.5</td>
<td>84.75 ± 18.39</td>
<td>84.81 ± 20.7</td>
</tr>
</tbody>
</table>

*p < 0.05.

All values are percentage of predicted of normal. Values are given as mean ± SD, unless otherwise indicated. ITGV = intrathoracic gas volume.
nary fitness to dive is whether specific lung diseases might predispose the diver to injuries unique to the diving environment. Lung function testing is a useful tool to discover clinically occult pulmonary abnormalities. This is the rationale for screening professional divers by referring those with abnormal spirometry results (FEV₁, FVC, and FEV₁% below predicted values) for further evaluation to exclude pulmonary disease.¹⁹

Obstructive lung disease and, in particular, asthma are the most common lung diseases that must be excluded in divers,²⁰ due to concern about the possible occurrence of pulmonary barotrauma and arterial gas embolism as a result of air trapping.²¹⁻²³ Moreover, breathing cold, dry air during diving, as well as the greater demands made on the respiratory system underwater due to the physical exertion required, can lead to bronchospasm.¹⁴ In our diving population, asthma and other obstructive airways disease associated with air trapping are contraindications to commence or continue diving. However, an earlier study by Crosbie et al.⁵ described a diver population in whom, despite abnormal spirometry manifesting as a low FEV₁%, further evaluation revealed no evidence of obstructive airways disease. These divers had elevated FVC and TLC, a normal FEV₁, and no air trapping (normal RV/TLC). Crosbie and colleagues⁴,⁵ named this phenomenon divers’ “large lungs.” It was shown that in divers up to the age of 30 years, FVC increased with years of diving and with increased diving depth.⁴,⁵ In contrast to this, there was no change in FEV₁. This resulted in a large FVC and a decrease in the FEV₁%, with no evidence of air trapping. It was noted, however, that in divers >30 years old, FVC declined despite continued diving, even when age was taken into account.⁴,⁵ This decrease may be related to diving-induced structural changes in the lung beyond the reduction in the elastic recoil of normal lungs due to aging.

The phenomenon of increased FVC in divers may be attributed to a number of factors. Breathing dense air via breathing apparatus during diving results in increased inspiratory and expiratory resistance, leading to an increase in the work of breathing. The physical stress imposed by the underwater environment, together with the increased work of breathing, produces a breathing pattern characterized by high tidal volumes, which is maintained for prolonged periods.¹⁴ A previous study⁹ demonstrated that inspiratory muscle strength training near TLC and conditioning of the accessory muscles of the neck and chest wall may be important in expanding the chest at large lung volumes, and can cause a shift in the optimal length of the inspiratory muscles such that larger forces can be generated at a shorter muscle length. A change in lung compliance and an increase in alveolar size can lead to a shift of the volume-pressure curve of the lung and chest wall and an increase in TLC.²⁴ As opposed to those studies,⁴,⁵,⁹,²⁴ others raised the question whether the considerable increase observed in FVC is indeed the result of adaptation due to a training effect of diving on the respiratory muscles, or whether it is advantageous for the novice diver, helping him in the selection process toward becoming a professional diver.
diver. Divers quickly learn that breathing with high tidal volumes enables them to work for a longer time when using self-contained gas supplies. It is possible that large lungs (an increased FVC at the expense of a reduced RV) may be due to hypertrophy of the thoracic wall and diaphragm muscles. This might be a training effect of breathing against an increased respiratory load. In turn, the stronger respiratory muscles might facilitate overcoming the increased work of breathing during diving.

The characteristics of our diver population are similar to those reported in the literature. But in contrast to others, we did not find a correlation between large FVC and diving experience. This supports the notion that there is a natural selection for professional divers, and that the increase in FVC is not due to a training effect on the respiratory muscles.

The present study indicates that increased diving experience correlates with reduced expiratory flows at low lung volumes, possibly indicating pathological changes in the lung periphery, suggesting small airways disease. This is in agreement with previous investigations of the long-term effects of diving on pulmonary function. Tetzlaff et al found that divers had lower midexpiratory flow values at 25% of vital capacity than control subjects, and that their midexpiratory flows at 25% and 50% of vital capacity were inversely related to years of diving. Skogstad et al demonstrated that professional divers initially belong to a selected group having a large FVC, and that exposure to the diving environment mostly affects small airway conductance. These changes were related to breathing hyperbaric air, venous gas microembolism during decompression, and hypoxic exposure, and they may lead to small airways disease in experienced divers. To test whether the development of small airways disease is correlated with morphologic abnormalities, Reuter et al found that divers had lower midexpiratory flow values at 25% of vital capacity than control subjects, and that their midexpiratory flows at 25% and 50% of vital capacity were inversely related to years of diving.

Our results show that there was no significant change in diffusion capacity between the experienced diver populations compared with novice divers. The average depth and bottom times for our diver population were 25 to 35 m of seawater for 30 to 40 min, respectively, occurring mostly during dives using compressed air. Because the decompression requirement and the inert gas load are low, and the exposure to relatively high oxygen partial pressures in these dives is too short to result in lung injury, this may explain our findings.

In summary, our findings lead us to concur with previous authors that in a diving population, a low FEV₁% does not necessarily indicate obstructive airways disease, but may simply reflect the phenomenon of divers’ large lungs. We suggest that large lungs represent part of the natural selection for diving, rather than a training effect. Prolonged diving experience may result in the development of small airways disease.

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