Divers with large or normal lungs: is the difference justified?

Pieter-Jan AM van Ooij[1,2], Robert A van Hulst[3]

[1] *Diving Medical Centre, Royal Netherlands Navy, Den Helder, the Netherlands*
[2] *Department of Respiratory Medicine, Amsterdam University Medical Centre (AUMC), University of Amsterdam, Amsterdam, the Netherlands*
[3] *Department of Anesthesiology and Hyperbaric Medicine, Amsterdam University Medical Centre (AUMC), University of Amsterdam, Amsterdam, the Netherlands*

Corresponding author: *Dr Pieter-Jan van Ooij, Diving Medical Centre, Royal Netherlands Navy. PO Box 10,000 1781 ZX Den Helder, the Netherlands*
ORCiD: *0000-0002-2108-320X*
pjam.v.ooij.01@mindef.nl

Keywords
Fitness to dive; Lung function; Medical conditions and problems; Military diving; Pulmonary barotrauma; Risk factors

Abstract
(van Ooij PJAM, van Hulst RA. Divers with large or normal lungs: is the difference justified? Diving and Hyperbaric Medicine. 2025 31 March;55(1):18–26. doi: 10.28920/dhm55.1.18-26. PMID: 40090022.)
Introduction: Measurements of forced vital capacity (FVC) have shown that divers have larger lungs than members of the general population. Bullae or decompression illness (DCI) secondary to pulmonary barotrauma is more likely to occur in large lungs (LLs) than in normal lungs (NLs). This study retrospectively compared lung function, high-resolution CT (HRCT) scan anomalies, the unfit-to-dive rate, and the prevalence of DCI in groups of divers with LLs and NLs.
Methods: The results of fitness examinations of divers with LLs (FVC z-score > 1.96) and NLs (FVC z-score ≤ 1.96) from 2011 to 2020 were retrospectively evaluated. Data were obtained from lung function tests, HRCT results, fitness examination outcomes, and whether the diver did or did not have DCI.
Results: The study included 1,069 divers, with 65 subjects, all male, fulfilling the requirements for LLs. Subjects with LLs had a significantly higher z-scores for FVC and FEV_1 but a significantly lower FEV_1/FVC ratio, than subjects with NLs. The rates of bullae, DCI, and unfit-to-dive did not differ significantly in the two groups.
Conclusions: Although FEV_1/FVC ratio was significantly lower in the LL than in the NL group, there were no between-group differences in the rates of bullae and DCI. These findings suggest that subjects with LLs are not at a higher risk of bullae and DCI than are subjects with NLs.

Introduction

Divers have large lungs (LLs), with a much higher forced vital capacity (FVC) than subjects in the general population.[1–5] Subjects with LLs have a disadvantage, however, as their forced expiratory volume in one second (FEV_1) often increases to a lesser degree than the increment of FVC. This may result in a lower FEV_1/FVC ratio. Although this could be interpreted as an obstructive airway disease, it is merely an effect of dysanapsis.[6]

Divers with obstructive lung diseases are at a higher risk for pulmonary barotrauma (PBt), which may cause arterial gas embolism (AGE).[7,8] Air trapping was found to be more frequent in divers with LLs,[9] suggesting the need for caution when assessing these divers. Yet, we must remember that 'trapped air' in that article was measured at a lower lung volume than may be relevant during ascent from a dive, where trapped lung gas cannot be exhaled from a large lung volume close to total lung capacity (TLC). Besides, the lower FEV_1/FVC ratio in subjects with LLs may not have a pathological cause,[10] but can be a physiological phenomenon, known as dynamic airway compression.[11]

Between 2009 and 2011, the Royal Netherlands Navy's Dive Medical Center (DMC) encountered six subjects with PBt. A retrospective analysis of their medical files revealed that all six had LLs based on the reference values at that time. Post-injury CT scans showed abnormalities, including air trapping, bullae and blebs in all six subjects, suggesting that the risk of PBt is higher in divers with LLs than NLs.[12] Since 2011, therefore, every diver found to have LLs has undergone additional lung function tests, such as body plethysmography and high-resolution computed tomography (HRCT) scans. Although divers with LLs are comprehensively assessed, it is unclear whether testing mitigates the risk of PBt in divers with LLs or results in a higher rate of diver rejection, with rejected subjects labelled as unfit to dive (UtD).

These findings suggested that divers with LLs would have higher rates of HRCT anomalies and UtD, but, a similar rate of decompression illness (DCI) when compared with divers with NLs. The primary objective of this retrospective study was therefore to compare the results of spirometry, body plethysmography, and HRCT, as well as the rates of DCI, defined as both decompression sickness (DCS) and PBt in divers with LLs and NLs.

Methods

As this study was a retrospective analysis of anonymous data gathered during divers' annual assessments, approval from a Medical Ethical Committee was not required. However, the Surgeon General of the Netherlands Armed Forces evaluated and granted permission for this study (reference number DOSCO 2024010072).

Divers belonging to the Netherlands Armed Forces undergo annual medical assessments. These assessments include biometric data, spirometry, and exercise testing, along with an interview and physical examination by the dive medical officer. Fitness-to-dive was assessed according to the European Diving Technology Committee (EDTC) guidelines.[13] Large lungs were defined as those with a FVC > 120% of the European Community for Steel and Coal (ECSC) reference value.[14] Since 2015, the ECSC reference value was replaced by the Global Lung Function Initiative (GLI) reference values, which use z-scores to compare the measured data to the reference value. The z-scores are corrected for height, age, sex and ethnicity; LLs were defined as those with FVC z-scores > 1.96.[15,16]

SPIROMETRY AND PLETHYSMOGRAPHY

Until 2005, the FVC, FEV_1, FEV_1/FVC ratio, and forced expiratory flow rate at 75% of FVC (FEF_{75}) were measured using the Vmax Legacy (SensorMedics, Milan, Italy); after 2005, these parameters were measured using the Vmax Encore (Care-Fusion, Houten, the Netherlands). Residual volume (RV) and functional residual capacity (FRC) were measured, and total lung capacity (TLC) plethysmography was performed, in a V62J Body box using the Vmax Encore. Current GLI reference values and their z-scores were used.[15,17] All measurements were performed by qualified respiratory technicians according to European Respiratory Society / American Thoracic Society task force guidelines. Instruments were calibrated before each test, according to the manufacturer's instructions.

HRCT IMAGING

As stated before, all divers classified as LL were referred to the respiratory physician of our military hospital for extensive lung function testing and HRCT imaging. When we switched from the ECSC reference value to the GLI reference value, some LL subjects were now classified as NL. Furthermore, when NL subjects had a decreased FEV_1/FVC ratio with normal FVC and FEV_1 reference values, and HRCT imaging was performed to exclude air trapping, parenchymal abnormalities or ventilation inhomogeneity.

DATA GATHERING

Demographic and respiratory data from all annual assessments of all divers who visited our centre between January 2011 and January 2021 were obtained from the Diving Medical Centre database. These medical files included HRCT results, as determined by radiologists, and determinations of any DCI, including DCS or PBt, during the study period. All data were anonymised prior to analysis. We divided the included subjects into two groups: those with normal lungs (NLs), defined as having FVC z-scores ≤ 1.96, and those with LLs, defined as having FVC z-scores > 1.96. Ex-smokers were considered non-smokers if they had abstained from smoking ≥1 year.[18]

STATISTICAL ANALYSIS

All data were tested for normality using the Shapiro-Wilk test. Normally distributed continuous data were expressed as mean and standard deviation (SD) and compared in the NL and LL groups using Student's *t*-tests. Non-normally distributed data were reported as median and interquartile range (IQR) and compared using Wilcoxon rank-sum tests. Dichotomous and categorical data were expressed as frequencies (%) and compared using Fisher's exact tests. Differences in successive z-scores of FVC, FEV_1, and FEV_1/FVC were compared by one-way ANOVA with Scheffé correction. All statistical analyses were performed using Stata BE software (version 18, StataCorp, USA), with P-values < 0.05 considered statistically significant.

Results

TOTAL GROUP

This study included 1,069 subjects, 21 (2%) women, and 1,048 (98%) men; of these subjects, 14.5% were smokers, and 85.5% were non-smokers or ex-smokers (Table 1). Sixty-five subjects (6.1%) were identified as having LLs (see Figure 1). Based on the reference population, this percentage was more than the expected 2.5%. All 65 subjects with LLs were male, constituting 6.2% of the male subjects in this study. The FVC z-scores of the study subjects obtained during their first assessment (median FVC z-score 0.422) were higher than those of the reference population (Figure 2). The UtD rate for the whole population was 10.9%, affecting 10.8% of male and 14.3% of female subjects. DCIs were observed only in male subjects. The overall DCI rate was 2.0%, including 1.1% of subjects with type 1 DCS, 0.2% with Type 2 DCS, and 0.7% with PBT.

'LARGE LUNG' VERSUS 'NORMAL LUNG'

A comparison of the 65 subjects with LLs and the 1,004 with NLs showed that subjects in the LL group were significantly older. Unsurprisingly, FVC, FVC z-score, FEV_1, and FEV_1 z-score were significantly higher, and FEV_1/FVC ratio and FEV_1/FVC z-score significantly lower, in the LL group

Table 1

Demographic characteristics of all included subjects and of males and females. Normally distributed data reported as mean (standard deviation) and non-normally distributed data reported as median (interquartile range). * = $P < 0.05$; † = $P < 0.01$; DCI – decompression illness; FVC – forced vital capacity; zFVC – z-score for FVC; FEV_1 – forced exhaled volume in one second; $zFEV_1$ – z-score for FEV_1; FEV_1/FVC – FEV_1/FVC ratio; $zFEV_1/FVC$ – z-score for FEV_1/FVC ratio; $FEF_{75\%}$ – forced expiratory flow rate at 75% of FVC; $zFEF_{75\%}$ – z-score for $FEF_{75\%}$

Parameter	Total group (*n* = 1,069)	Male (*n* = 1,048)	Female (*n* = 21)
Age (yrs)	28.2 (24.8–33.8)	28.2 (24.8–33.9)	28.1 (5.5)
Height (cm)	182.7 (6.6)	182.9 (6.4)	172.5 (6.6)†
Weight (kg)	84 (79–91)	84 (79–91)	69 (7)†
Fat (%)	14.6 (11.5–17.7)	14.5 (11.5–17.7)	25.0 (20.7–27.2)†
Smoking (%)	14.5	14.4	19
FVC (L)	6.22 (5.70–6.68)	6.24 (5.73–6.70)	4.55 (0.67)†
zFVC	0.637 (0.022–1.200)	0.639 (0.023–1.210)	0.409 (0.771)
FEV_1 (L)	4.80 (0.63)	4.83 (0.61)	3.67 (0.52)†
$zFEV_1$	0.144 (0.911)	0.146 (0.910)	0.067 (1.008)
FEV_1/FVC (%)	78 (74–82)	78 (74–81)	80 (7)*
z FEV_1/FVC	0.776 (0.057)	-0.734 (0.818)	-0.593 (0.935)
$FEF_{75\%}$ ($L.s^{-1}$)	1.8 (1.5–2.3)	1.8 (1.5–2.3)	1.8 (0.7)
$zFEF_{75\%}$	-0.296 (0.790)	-0.299 (0.781)	-0.138 (1.190)
Unfit to dive (%)	10.9 (*n* = 116)	10.8 (*n* = 113)	14.3 (*n* = 3)
DCI (%)	2.0 (*n* = 21)	2.0 (*n* = 21)	0.0

Figure 1

Data flow diagram; HRCT – high-resolution computed tomography

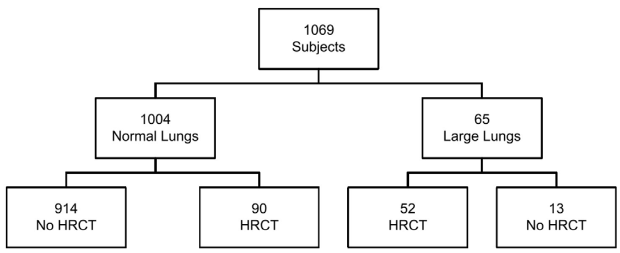
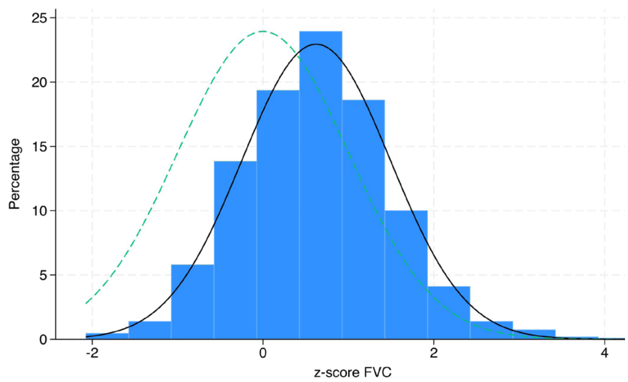


Figure 2

Histogram and normality curve of the z-score of the forced vital capacity (FVC) in the study population (black line) compared with the normality distribution curve (dashed green line); Percentage – percentages of subjects in a specific bin



than in the NL group (Table 2). The rates of UtD, DCS, and PBt did not differ significantly in these two groups. The predominant reasons for UtD in the NL group were based on lung function results (72.3%), followed by HRCT anomalies (19.6%) and other non-respiratory reasons (8.1%). For the LL group, it was 60%, 40% and 0%, respectively (see Table 3). The differences between the NL and LL groups were not significant.

‘LARGE LUNGS’ VERSUS ‘NORMAL LUNGS’ WITH HRCT IMAGING

Of these divers, 142 underwent HRCTs, 90 in the NL group and 52 in the LL group (Figure 2). Body plethysmography data were also available for 120 of these subjects. Age, height, weight, fat percentage and smoking rate did not differ significantly in NL and LL subjects who underwent HRCT. Similar to findings in the total male population, FVC, FVC z-score, FEV_1, and FEV_1 z-score were significantly higher, while FEV_1/FVC ratio and FEV_1/FVC z-score were significantly lower, in LL than in NL subjects who underwent HRCT (Table 4). Plethysmography showed that TLC, TLC z-score, and FRC z-score were significantly higher in subjects with LL, whereas RV, RV z-score, RV/TLC ratio and RV/TLC ratio z-score did not differ in the two groups. Surprisingly, the UtD rate was significantly lower

Table 2

Demographic characteristics of male subjects with normal and large lungs. Normally distributed data reported as mean (standard deviation) and non-normally distributed data reported as median (interquartile range). * = $P < 0.01$; FVC – forced vital capacity; zFVC – z-score for FVC; FEV1 – forced exhaled volume in one second; $zFEV_1$ – z-score for FEV_1; FEV_1/FVC – FEV_1/FVC ratio; $zFEV_1$/FVC – z-score for FEV_1/FVC ratio; $FEF_{75\%}$ – forced expiratory flow rate at 75% of FVC; $zFEF_{75\%}$ – z-score for $FEF_{75\%}$; DCS – decompression sickness; PBt – Pulmonary barotrauma

Parameter	Normal lungs (*n* = 983)	Large lungs (*n* = 65)
Age (yrs)	28.0 (24.8–33.7)	30.2 (25.8–38.7)*
Height (cm)	183.0 (6.3)	182.0 (7.2)
Weight (kg)	84 (79-91)	87 (9)
Fat (%)	14.5 (11.5–17.7)	14.8 (4.2)
Smoking (%)	14	16
FVC (L)	6.16 (0.70)	7.37 (0.67)*
zFVC	0.559 (-0.014–1.088)	2.320 (2.105–2.686)*
FEV_1 (L)	4.78 (0.59)	5.44 (0.59)*
$zFEV_1$	0.054 (0.839)	1.469 (0.864)*
FEV_1/FVC% (%)	78 (74–82)	74 (6)*
z FEV_1/FVC	-0.698 (0.812)	-1.248 (0.734)*
$FEF_{75\%}$ ($L.s^{-1}$)	1.8 (1.5-2.3)	1.9 (0.7)
$zFEF_{75\%}$	-0.310 (0.781)	-0.144 (0.763)
Unfit to dive (%)	11.1 (*n* = 109)	6.2 (*n* = 4)
DCS (%)	1.2 (*n* = 12)	3.1 (*n* = 2)
PBt (%)	0.7 (*n* = 7)	0.0

Table 3

Reason for unfit to dive decision for normal and large lung groups; 'HRCT' are bullae, blebs, emphysematous change, air trapping, and other pulmonary HRCT findings; 'Lung' is lung function reasons, such as insufficient spirometry, positive bronchoprovocation test, etc; 'Other' is non-pulmonary reasons. There were no significant between-group differences. HRCT – high resolution computed tomography

Group	HRCT	Lung	Other	Total
Normal lungs	*n* = 22 (19.6%)	*n* = 82 (72.3%)	*n* = 8 (8.1%)	*n* = 112
Large lungs	*n* = 2 (40%)	*n* = 3 (60%)	0%	*n* = 5
Total	*n* = 24 (20.5%)	*n* = 85 (72.6%)	*n* = 8 (6.9%)	*n* = 117

in LL than in NL subjects who underwent HRCT, a result ascribed to the larger number of HRCT anomalies in the NL group (Table 5). Rates of bullae and blebs, however, did not differ significantly in these two groups, nor did the rates of DCS and PBt (Table 4).

'LARGE LUNGS' AND 'NORMAL LUNGS' OVER TIME

Divers undergo medical assessments once per year, with z-scores for spirometric data corrected by sex, age, and ethnicity. Over time, the FVC z-score decreased minimally in the NL group, but showed a greater decrease in the LL group (Figure 3). The FEV_1 z-scores decreased minimally in both groups (Figure 4), accompanied by increases in their z-scores for the FEV_1/FVC ratio (Figure 5). The $FEF_{75\%}$ z-scores did not differ significantly in the LL and NL (Figure 6). One-way ANOVA with Scheffé correction for multiple comparisons showed that neither group's changes were statistically significant.

Discussion

To our knowledge, this is the first study to compare HRCT anomalies, UtD rates, and the prevalence of DCI in groups of divers with LLs and NLs. The percentage of divers with LLs was higher than that of the GLI reference population. Although the FEV_1/FVC ratio was significantly lower in the LL group, the number of HRCT anomalies in the LL group was also significantly lower than in the NL group. In addition, rates of DCS and PBt did not differ in these two

Table 4

Demographic characteristics of male subjects with normal and large lungs evaluated by high resolution computed tomography (HRCT) imaging; normally distributed data are reported as mean (SD) and non-normally distributed data reported as median (IQR). * n = 80; † n = 40; ¶ = $P < 0.05$; ‡ = $P < 0.01$; FVC – forced vital capacity; zFVC – z-score for FVC; FEV_1 – forced exhaled volume in one second; $zFEV_1$ – z-score for FEV_1; FEV_1/FVC – FEV_1/FVC ratio; $zFEV_1/FVC$ – z-score for FEV_1/FVC ratio; $FEF_{75\%}$ – forced expiratory flow rate at 75% of FVC; $zFEF_{75\%}$ – z-score for $FEF_{75\%}$; FRC – functional residual capacity; zFRC – z-score for FRC; TLC – total lung capacity; zTLC – z-score for TLC; RV – residual volume; zRV – z-score for RV; RV/TLC – RV/TLC ratio; zRV/TLC – z-score for RV/TLC ratio; DCS – decompression sickness; PBt – pulmonary barotrauma

Parameter	Normal Lungs (n = 90)	Large lung (n = 52)
Age (yrs)	30.5 (26.7–39.5)	30.2 (25.3–38.7)
Height (cm)	184.1 (6.5)	182.5 (9.2)
Weight (kg)	87 (9)	87 (9)
Fat (%)	15.1 (12.2–17.7)	15.0 (3.8)
Smoking (%)	14	16
FVC (L)	6.57 (0.71)	7.42 (0.66)‡
zFVC	0.559 (0.695–1.528)	2.325 (2.122–2.686) ‡
FEV_1 (L)	4.98 (0.68)	5.44 (0.55) ‡
$zFEV_1$	0.392 (-0,412–1.277)	1.172(0.862–1.957) ‡
FEV_1/FVC (%)	76 (6)	73 (5)¶
z FEV_1/FVC	-0.668 (-1.579– -0.183)	-1.312 (0.678) ‡
$FEF_{75\%}$ ($L.s^{-1}$)	1.8 (1.4–2.3)	1.9 (0.6)
$zFEF_{75\%}$	-0.273 (0.946)	-0.182 (0.710)
FRC (L)	3.73 (0.73)*	3.91 (0.72) †
zFRC	0.018 (0.738)*	0.393 (0.664) †,¶
TLC (L)	8.21 (0.90)*	8.86 (0.86) †,‡
zTLC	0.534 (0.658)*	1.468 (1.145–1.767) †,‡
RV (L)	1.62 (1.36–2.10)*	1.74 (0.29) †
zRV	-0.043 (0.663)*	0.127 (0.528) †
RV/TLC	0.21 (0.05)*	0.20 (0.04) †
zRV/TLC	-0.239 (0.625)*	-0.382 (0.502) †
Unfit to dive (%)	27.7 (n = 25)	3.8‡ (n = 2)
HRCT anomaly (%)	23.3 (n = 21)	3.8‡ (n = 2)
DCS (%)	1.1 (n = 1)	3.8 (n = 2)
PBt (%)	3.3 (n = 3)	0.0

Table 5

Comparison of high-resolution computed tomography (HRCT) anomalies in subjects with normal and large lungs. There were no significant between-group differences

Pulmonary finding	Normal lungs (n = 21)	Large lungs (n = 2)
Bullae and blebs	33.3% (n = 7)	100% (n = 2)
Emphysematous change	19.0% (n = 4)	0%
Air trapping	9.5% (n = 2)	0%
Cysts	9.5% (n = 2)	0%
Other	28.6% (n = 6)	0%

Figure 3

Time courses of z-scores for forced vital capacity (FVC)

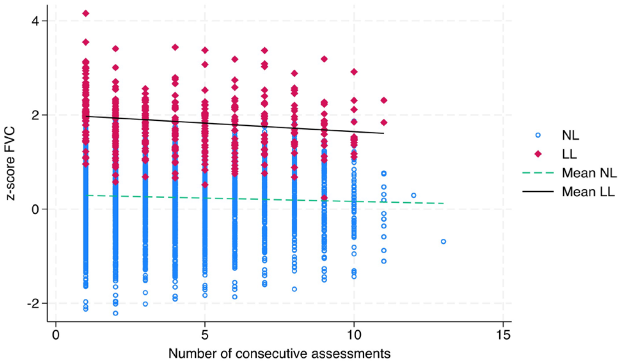


Figure 4

Time courses of z-scores for forced exhaled volume in one second (FEV_1)

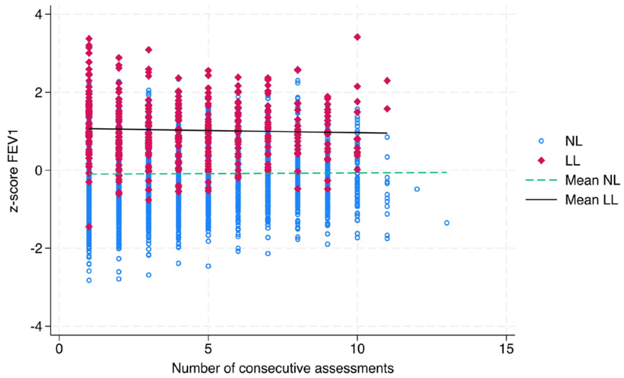


Figure 5

Time courses of z-scores for forced exhaled volume in one second to forced vital capacity (FEV_1/FVC) ratio

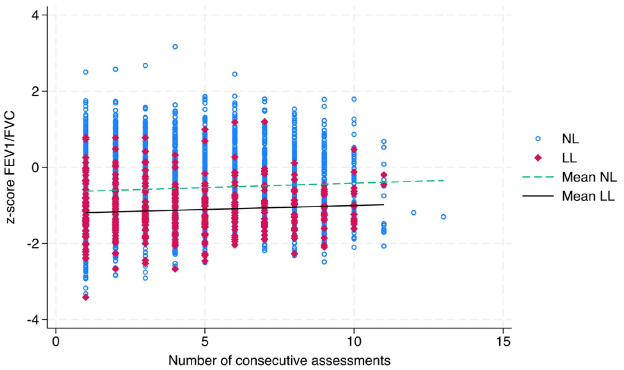
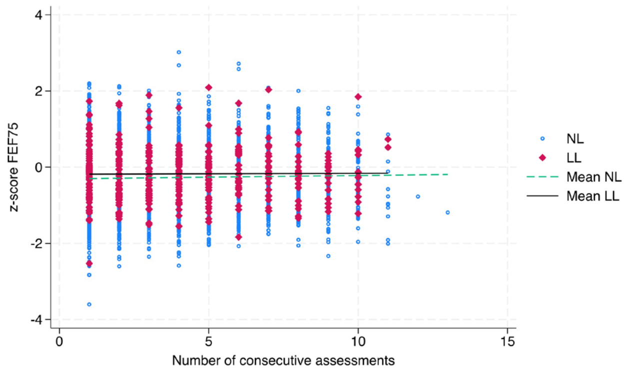


Figure 6

Time courses of z-scores for forced expiratory flow rate at 75% of FVC ($FEF_{75\%}$)



groups, suggesting that subjects with LL group were not at higher risk than those with NL.

Over the assessment period, the FVC, FEV_1, and FEV_1/FVC z-scores showed little change in both groups, in agreement with previous findings.[10,19] Although evaluations of older subjects showed significant changes over time,[20] the GLI introduced better age-corrected reference values, resulting in non-significant changes. This strongly supports the importance of using correct reference values.[21]

An international consensus conference in 1993 concluded that diving could affect pulmonary function by increasing the FVC and reducing the FEV_1/FVC ratio.[22] This is different from the results of the present study. Large lungs may not be a diving-related physiological phenomenon but rather a selection bias.[23,24] The median FVC z-score obtained during the first assessment of the subjects in the present study was 0.422, shifting the normality curve of the population to the right and supporting the likelihood of selection bias. Alternatively, it could also be that within the LL group, more subjects had already dived before being assessed as military divers, leading to higher FVC values. Indeed, 49.8% of the divers with large lungs had some diving experience, varying between one to 80 dives. However, we found that 77% of the subjects in the NL group had also been diving before the first assessment, ranging between one and 30 dives. Thus, we do not think that this biased our results.

Two results surprised us. First, the UtD rate did not differ significantly in males with LLs and NLs. The five subjects rejected in the LL group included two with anomalies on HRCT and three with abnormal lung function testing results. The predominant reasons for rejection in the NL group were mainly based on insufficient lung function values compared to the reference value. Although the reasons for this difference are not clear, the results of lung function tests may be more strictly interpreted in the NL group. Large lungs are not necessarily considered a pathological phenomenon, but an anatomical imbalance between the upper and lower airways, resulting in differences in FVC and FEV_1, also called dysanapsis.[10,11] Subjects with LL may undergo additional lung function testing to confirm this anatomical imbalance, which resulted in a lower UtD rate.

By contrast, subjects with NL may undergo lung function testing to exclude pathological bronchoconstriction, resulted in a higher rejection rate for diving.

Second, the percentage of subjects with HRCT anomalies was significantly higher in the NL (23.3%) than in the LL (3.8%) group. This difference was mainly due to the rates of anomalies other than bullae and blebs, as rates of bullae and blebs were similar in the two groups. However, the prevalence of bullae and blebs in the NL group (7.8%) was higher than previously reported (4.7%).[25] Other studies, however, have reported higher rates of bullae in healthy subjects aged ≤ 40 years (7.2%)[26] and in a population of military divers (7.0%).[27]

Despite the 'Large Lung Protocol', 13 subjects in the LL group did not undergo HRCT. All 13 subjects had z-scores for the FEV_1/FVC ratio within the normal range, which may explain the lack of HRCT in these subjects. Performing an HRCT may have increased the number of bullae detected. The exact rates of bullae and blebs in a military population and in subjects with LLs are unclear, but they could range between 2.3% and 7.8%. More importantly, these findings showed that subjects with LLs were not at higher risk of having bullae and blebs than those with NLs.

In contrast to the present findings, another study showed air trapping rates were higher in divers with LLs than NLs.[9] The amount of trapped air was calculated by subtracting total lung capacity (TLC), as measured by a helium dilution test, from TLC as measured by plethysmography. The volume of trapped air was found to increase when vital capacity (VC) was > 122% of reference. In the present study, subjects in the LL group had z-scores > 1.96, or > 123% of reference. Only two of these subjects had bullae, with none of the others having trapped air. Despite improvements in the resolution of HRCT, small areas of air trapping may be missed. A post-mortem study using high-dose total body CT found that the prevalence of bullae in a general population without any lung diseases was > 30%,[28] indicating that the current HRCT technique is not sufficiently sensitive to show all areas of trapped air. Further developments in HRCT techniques and models may enable the exact volume of trapped air to be measured. Yet, when assessing air trapping by comparing end-inspiratory to end-expiratory HRCT, one assesses at a lower lung volume than what may be relevant during ascent from a dive, as a diver will never breathe at expiratory reserve volume while diving. This raises the question of whether the methods used to detect air trapping, specifically end-inspiratory and end-expiratory HRCT imaging, are appropriate tools. Especially when air trapping diagnosed through HRCT could result in UtD, as was the case at our centre due to the interpretation of the former EDTC guidelines.[13]

Furthermore, in the Wuorimaa et al.[9] and the present studies, the RV was not significantly different between the LL and NL groups. This implies an increased functional capacity but no increase in RV to suggest air trapping, which may be reassuring when assessing a LL dive candidate. This might explain the present study's lack of abnormalities in HRCT.

STRENGTHS AND LIMITATIONS

The strengths of the present study include the size of the study population and its being the first study to compare pulmonary function, chest HRCT results, and UtD and DCI rates in military divers with LLs and NLs. Nevertheless, this study had several limitations. First, most of the study population was male. Only 2% were females, and none of these had LLs. Thus, the results of the present study are inapplicable to female divers. Furthermore, military diving differs from off-shore, in-shore and saturation diving. Thus, male military divers with LLs and NLs do not differ in UtD rate, the number of bullae and the risk of diving accidents. Research on other categories of professional divers, including off-shore and in-shore divers, may clarify whether findings in these divers are similar to those in military divers. Second, despite the longitudinal evaluation of some subjects, data on the exact diving exposure of each subject were not available. Although all of these divers had to dive for at least 360 minutes per month, information on dive depth and the diving gas used could not be determined, thus precluding the determination of any relationship between diving and changes in lung function parameters. Yet, as shown in Figure 3, the diving methods used in our military setting did not increase FVC over time in both LL and NL. Therefore, we do not think the missing diving data biased our study. Nevertheless, future studies could include these diving data to determine whether diving experience and diving gas have any effect on LLs in non-military diving settings. Third, few subjects had diving accidents during the 10-year study period. Although DCI rates did not differ significantly in the LL and NL groups, the numbers of diving accidents may have been too low to show any significant effect. *A posteriori* power analyses showed that the minimum number of DCI events in each arm required to show a significant between-group difference was > 1,000, a number too large for a single centre study. Multi-centre trials in allied countries are therefore needed to study the effects of NLs and LLs on DCI events (particularly PBt).

Conclusions

Previously, subjects with LLs were regarded as being at higher risk for bullae and DCI than subjects with NLs. The present study compared HRCT anomalies and UtD and DCI rates in military divers with LLs and NLs. Although the FEV_1/FVC ratio was significantly lower in the LL group, the number of bullae in the NL and LL groups did not differ. In addition, with the caveat that the study was underpowered to show a difference, rates of DCS and PBt did not differ in these two groups, suggesting that divers with LLs are not at higher risk of DCI.

References

1 Reuter M, Tetzlaff K, Steffens JC, Glüer CC, Faeseke KP, Bettinghausen E, et al. Functional and high-resolution computed tomographic studies of divers' lungs. Scand J Work Environ Health. 1999;25:67–74. doi: 10.5271/sjweh.385. PMID: 10204673.

2 Konarski M, Klos R, Nitsch-Osuch A, Korzeniewski K, Prokop E. Lung function in divers. Adv Exp Med Biol. 2013;788:221–7. doi: 10.1007/978-94-007-6627-3_32. PMID: 23835982.

3 Watt SJ. Effect of commercial diving on ventilatory function. Br J Ind Med. 1985;42:59–62. doi: 10.1136/oem.42.1.59. PMID: 3965017. PMCID: PMC1007418.

4 Crosbie WA, Clarke MB, Cox RA, McIver NK, Anderson IK, Evans HA, et al. Physical characteristics and ventilatory function of 404 commercial divers working in the North Sea. Br J Ind Med. 1977;34:19–25. doi: 10.1136/oem.34.1.19. PMID: 843459. PMCID: PMC1008167.

5 Crosbie WA, Reed JW, Clarke MC. Functional characteristics of the large lungs found in commercial divers. J Appl Physiol Respir Environ Exerc Physiol. 1979;46:639–45. doi: 10.1152/jappl.1979.46.4.639. PMID: 457539.

6 McGinn EA, Mandell EW, Smith BJ, Duke JW, Bush A, Abman SH. Dysanapsis as a determinant of lung function in development and disease. Am J Respir Crit Care Med. 2023;208:956–63. doi: 10.1164/rccm.202306-1120PP. PMID: 37677135. PMCID: PMC10870865.

7 Mebane G. The coincidence of asthma and morbidity or mortality in recreational scuba divers involving United States citizens and reported to Divers Alert Network (DAN). In: Elliott DH, editor. Are asthmatics fit to dive? Kensington, Maryland: Undersea and Hyperbaric Medical Society; 1996. p. 3–5.

8 Tetzlaff K, Reuter M, Leplow B, Heller M, Bettinghausen E. Risk factors for pulmonary barotrauma in divers. Chest. 1997;112:654–9. doi: 10.1378/chest.112.3.654. PMID: 9315797.

9 Wuorimaa T, Haukka J, Tikkinen J, Parkkola K, Piirilä P. Large lungs may predict increased air trapping in navy divers. Physiol Rep. 2022;10:e15153. doi: 10.14814/phy2.15153. PMID: 35212176. PMCID: PMC8874342.

10 Voortman M, van Ooij PJAM, van Hulst RA, Zanen P. Pulmonary function changes in Navy divers during their professional careers. Undersea Hyperb Med. 2016;43:649–57. PMID: 28768392.

11 O'Donnell CR, Litmanovich D, Loring SH, Boiselle PM. Age and sex dependence of forced expiratory central airway collapse in healthy volunteers. Chest. 2012;142:168–74. doi: 10.1378/chest.11-2361. PMID: 22194588. PMCID: PMC3418856.

12 van Hulst RA, van Ooij PA. Large lungs in divers: a risk for pulmonary barotrauma? Diving Hyperb Med. 2024;54:225–9. doi: 10.28920/dhm54.3.225-229. PMID: 39288928. PMCID: PMC11659061.

13 Wendling J, Elliot D, Nome T. Medical assessment of working divers. Fitness to dive standards of European Diving Technology Committee. 1st ed. Biele-Biene: Hyperbaric Conditions; 2004.

14 Standardized lung function testing. Report working party. Bull Eur Physiopathol Respir. 1983;19(Suppl 5):1–95. PMID: 6616097.

15 Quanjer PH, Stanojevic S, Cole TJ, Baur X, Hall GL, Culver BH, et al. Multi-ethnic reference values for spirometry for the 3-95-yr age range: the global lung function 2012 equations. Eur Respir J. 2012;40:1324–43. doi: 10.1183/09031936.00080312. PMID: 22743675. PMCID: PMC3786581.

16 Wingelaar TT, van Ooij PA, Endert EL. The lower limit for FEV_1/FVC in dive medical assessments: a retrospective study. Diving Hyperb Med. 2021;51:368–72. doi: 10.28920/dhm51.4.368-372. PMID: 34897602. PMCID: PMC8920896.

17 Hall GL, Filipow N, Ruppel G, Okitika T, Thompson B, Kirkby J, et al. Official ERS technical standard: Global Lung Function Initiative reference values for static lung volumes in individuals of European ancestry. Eur Respir J. 2021;57:2000289. doi: 10.1183/13993003.00289-2020. PMID: 33707167.

18 Wetter DW, Cofta-Gunn L, Fouladi RT, Cinciripini PM, Sui D, Gritz ER. Late relapse/sustained abstinence among former smokers: a longitudinal study. Prev Med. 2004;39:1156–63. doi: 10.1016/j.ypmed.2004.04.028. PMID: 15539050.

19 Sames C, Gorman DF, Mitchell SJ, Zhou L. Long-term changes in spirometry in occupational divers: a 10-25 year audit. Diving Hyperb Med. 2018;48:10–16. doi: 10.28920/dhm48.1.10-16. PMID: 29557096. PMCID: PMC6467824.

20 Pougnet R, Pougnet L, Lucas D, Uguen M, Henckes A, Dewitte JD, et al. Longitudinal change in professional divers' lung function: literature review. Int Marit Health. 2014;65:223–9. doi: 10.5603/IMH.2014.0042. PMID: 25522707.

21 Wingelaar TT, Clarijs P, van Ooij PJAM, Koch DA, van Hulst RA. Modern assessment of pulmonary function in divers cannot rely on old reference values. Diving Hyperb Med. 2018;48:17–22. doi: 10.28920/dhm48.1.17-22. PMID: 29557097. PMCID: PMC6467825.

22 Hope A, Lund T, Elliott DH, Halsey MJ, Wiig H, editors. Long term health effects of diving. Bergen, Norway: Norwegian Underwater Technology Centre; 1994.

23 Tetzlaff K, Thomas PS. Short- and long-term effects of diving on pulmonary function. Eur Respir Rev. 2017;26(143):160097. doi: 10.1183/16000617.0097-2016. PMID: 28356403. PMCID: PMC9489140.

24 Adir Y, Shupak A, Laor A, Weiler-Ravell D. Large lungs in divers: natural selection or a training effect? Chest. 2005;128:224–8. doi: 10.1378/chest.128.1.224. PMID: 16002939.

25 Weaver LK, Calderone P, Perez A, Schneider M, Deru K. Prevalence of underlying gas cavities/cysts, emphysematous changes, and bronchiectasis by chest computed tomography. Undersea Hyperb Med 2022;49:134–5. doi: 10.22462/01.02.2022.9.

26 Bresser MF, Wingelaar TT, Van Weering JAF, Bresser P, Van Hulst RA. An observational study ascertaining the prevalence of bullae and blebs in young, healthy adults and its possible implications for scuba diving. Front Physiol. 2024;15:1349229. doi: 10.3389/fphys.2024.1349229. PMID: 38420621. PMCID: PMC10899502.

27 Bonnemaison B, Castagna O, de Maistre S, Blatteau J-É. Chest CT scan for the screening of air anomalies at risk of pulmonary barotrauma for the initial medical assessment of fitness to dive in a military population. Front Physiol. 2022;13:1005698. doi: 10.3389/fphys.2022.1005698. PMID: 36277200. PMCID: PMC9585318.

28 de Bakker HM, Tijsterman M, de Bakker-Teunissen OJG, Soerdjbalie-Maikoe V, van Hulst RA, de Bakker BS. Prevalence of pulmonary bullae and blebs in postmortem CT imaging with potential implications for diving medicine. Chest. 2020;157:916–23. doi: 10.1016/j.chest.2019.11.008. PMID: 31759963.

Conflicts of interest and funding: nil

Submitted: 21 July 2024
Accepted after revision: 13 January 2025
