Relation of alveolar size to forced vital capacity in professional divers

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ABSTRACT Eight cases have been studied in which both lung function and histological morphometric data was available on divers' lungs. A correlation was found between the increase in forced vital capacity measured at routine annual medical examination and the morphometric measurement of alveoli by mean cord length. The results suggest that reduction of forced expiratory volume in one second may be due to narrowing of small airways by distention of the alveoli.

The effects of a hyperbaric environment have long been recognised in certain target organs especially bone¹ and the spinal cord.² It is becoming increasingly apparent, however, that the effects are total body and multiorgan, of which only some may be clinically detectable. Lung function tests, using a Vitalograph, form part of routine diving medical examinations and vital capacity has been shown to be one of the parameters that increase. It has been suggested that this change may be due to increase in accessory respiratory muscle, development of more lung units, or narrowing of airways due to loss of lung elastic tissue.³

It has been possible to establish a relation between vital capacity and alveolar size by a comparison of clinical and histological data.

Materials and methods

In a series of necropsies on professional divers 37 cases were suitable for detailed examination of the lungs. Of these, it was possible to obtain the details of the clinical history, including lung function, in only eight. These have been used as the basis of the present study and the data, together with causes of death, are recorded in table 1.

LUNG MORPHOMETRY

All the lungs were inflated through the trachea at a standard pressure of 25–30 cm water from 10% formal saline using the technique described by Heard *et al.*⁴ As part of the routine necropsy protocol the fixed lungs were sliced into sections about 1.5 cm

thick by the method of Kleinerman and Cowdrey.⁵ Whole lung sections were randomly selected from each of the eight cases and laid flat. On the upper cut surface of the slice a transparent plastic sheet was laid on which was superimposed a rectangular lattice 1.5 × 2.5 cm, a method employed by Weibel.⁶ Each field was numbered consecutively and continuously over all the slices and the fields for sampling were selected by a method of random numbers. This fixed the location of the blocks which were marked on the lung tissue by inserting headless pins through the perforated corners of the squares. The blocks were paraffin wax embedded, cut at 5–7 µm, and stained with reticulin.

The histological preparations were examined through a Vickers binocular microscope, fitted with an image splitter, that was coupled to a Cambridge Instruments model 720 Quantimet image analysis system. This gave a display of the histological image on a monitor screen and allowed the electronic image to be definitively identified by independent observation through the light microscope. An electronic pencil allowed each alveolus to be accurately outlined. The quantimet program could then resolve from the area of the individual alveoli the mean cord length. The machine was calibrated to resolve this into micrometres.

The field of the sections were examined by blind random displacement of the mechanical stage without observing through the tube. To eliminate bias the horizontal and vertical stage micrometers were set each time at an integer millimetre position. This procedure was repeated until 100 alveoli had been counted.

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Table 1 Clinical and necropsy data

Case No	Age	FVC	³ /FVC	Period between medical exam and death (months)	Years of experience in diving	Greatest depth dived (m)	Cause of death	Interval between death and necropsy (h)
1	25	74	4.2	6	5	50	Hypothermia	36
2	23	123	4.97	1	2	100	Head injury	24
3	28	79	4.29	4	9	50	Acute anoxia	12
4	33	131	5.08	8	14	150	Hypothermia	48
5	28	125	5.0	6	8	185	Asphyxia (drowning)	36
6	31	147	5.28	4	8	200	Asphyxia (drowning)	24
7	26	106	4.73	5	6	50	Acute anoxia	18
8	31	113	4.83	8	12	150	Asphyxia (drowning)	24

Table 2 Quantimet results

Case No	MCL (μ)	Standard deviation	Alveoli per field	Alveoli counted	No of fields	Standard error
1	184.9	97.59	17	107	7	9.42
2	218.3	63.59	10	105	11	6.21
3	184.8	59.28	25	100	4	5.93
4	222.7	71.75	9	107	11	6.24
5	218.9	74.88	21	104	5	4.56
6	231.2	65.85	16	110	7	6.24
7	167.1	65.17	21	101	5	6.49
8	212.3	85.85	11	101	10	6.54

FORCED VITAL CAPACITY (FVC)
Forced vital capacity is one of the parameters required as part of the annual medical examination under the "Diving Operations at Work Regulations."⁷ This had been measured in all cases using an R Model Vitalograph and had been repeated at least twice to obtain reproducible tracings.

Results

QUANTIMETRIC MEASUREMENT
The Quantimet 720 was programmed to print out

Forced vital capacity plotted against mean cord length. Aberrant case 7 is only smoker in series.

mean cord length, standard deviation, alveoli per field, number of alveoli counted, number of fields, and standard error (table 2).

FORCED VITAL CAPACITY
The FVC measurements were abstracted from the clinical records and checked against the available Vitalograph flow charts. The FVC and ³/FVC interval between medical and death, years of diving experience, and greatest depth of diving are shown in table 1.

The ³/FVC were plotted against the mean cord length on linear scale, shown in the figure.

Discussion

Morphometry with respect to lung has been extensively exploited by several workers.^{6,8,9} The present study is the first in which it has been possible to compare accurate clinical and specially prepared histological data in human subjects.

Considerable attention has been paid to lung function in commercial divers.^{3,10} Clinical evidence from these groups of workers has shown that a significant association exists between the maximal depth the subjects had experienced and FVC, but independent of age, stature, and smoking habits. There is, however, some evidence from these workers that the ratio of forced expiratory volume in one second (FEV₁) to FVC was reduced, suggesting that there was narrowing of airways secondary to diving induced loss of elastic tissue. Morphometric evidence considered here

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suggests that the changes of FVC are related to an increase in alveolar volume.

The rationale for measuring the MCL as an overall reflection of increase in alveolar volume is based on the well established theoretical consideration of Crofton.¹¹ The principle of MCL is simple and reliable in application and does not depend on any geometrical pattern of the system. This is an important consideration in view of the concept that the shape of the alveolus is a complex of a double cone and a dodecahedron.

In the past some investigators had used questionable methods for determining mean cord length but those of Tomkeiff⁹ and Hennig⁸ are considered to be the most reliable. This basic principle was exploited by using the Quantimet 720. Kulenkampff attributed errors to poor fixation methods, which allowed uneven distention as formalin was inserted while the lungs were still in the cadaver.¹²

The well established inflation technique⁴ meant that all the lungs carefully dissected from cadavers were inflated at a pressure of 25–30 cm water. The actual measurements shown in table 2 agree with the results of other experimental workers, which range from that of 254 μm ¹³ to the more recent figures of 250–300 μm .^{14 15}

Although these figures are slightly higher than those of the present series there is little information on the methods used to inflate the lungs; these could have caused overdistention. The present cases were all inflated at the same pressure and could therefore be considered as comparable. There was also a set but random protocol for sampling the lungs.

All the measurements of FVC were made within eight months of death and should give a reasonable reflection of the value at this time. The one aberrant result is for case No 7 who was the only smoker in the series (25 cigarettes a day).

In a different dimension there is some correlation between FVC and the greatest depth dived which is in accord with earlier observers.⁶ Years of experience in diving did not relate to FVC changes.

Examination of the curve of the graph in this series shows that the increase in vital capacities is closely related to the increase in mean cord length which in turn reflects the alveolar volume. This lends support to the supposition that in this particular group of divers there is an actual increase in alveolar size and it is not merely due to an increase in accessory respiratory muscle power giving a physiological effect.

It has to be considered that the distention of alveoli may be locally at the expense of small airways. As a result, the airways may be narrowed by the outside physical pressure of the distended alveoli, which is reflected in the reduction of the FEV₁.¹⁰

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