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Forced Expiration and Inspiration under Hyperbaric Conditions

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Summary

Assessment in 37 healthy volunteers (aged 23 to 53 years) provided evidence that in a hyperbaric environment (0.4 MPa) a significant decline of expiratory and inspiratory dynamic indicators of pulmonary ventilation occurs, as compared with normobaric conditions (0.1 MPa). This phenomenon has a physical basis and it should be a contraindication for subjects with bronchopulmonary obstruction to dwell in a hyperbaric environment.

Key words
Respiratory resistance – Hyperbaric environment

Introduction

Some people occasionally spend some time in an environment where the pressure is well above the atmospheric pressure. These in particular include divers, caisson workers, some tunnelers, subjects treated in hyperbaric chambers and staff operating these chambers (Kindwall 1988, King 1989). In conjunction with these conditions, they may develop health problems caused either by excessive pressure alone (e.g. nitrogen anaesthesia and oxygen intoxication) or by pressure changes (e.g. barotraumas, meteorism or decompression sickness) (Bennett and Elliott 1982, Kindwall 1988). Moreover, subjects exposed to hyperbaric pressure may suffer from increased flow resistance of the airways which develops on physical grounds (Bennett and Elliott 1982, Burnet *et al.* 1990, Hrnčíř 1996).

The decisive proportion of activities implemented under hyperbaric conditions takes place at pressures which are not higher than 0.4 MPa. This corresponds to a pressure of 30 m below the water level. Greater depths are not recommended, e.g. for sports diving, as there is the risk of manifestations of nitrogen anaesthesia and other medical complications during inspiration of compressed air. For practical purposes, it is important to ascertain to what extent the dynamic indicators of pulmonary ventilation change at a pressure of 0.4 MPa and the possible practical impact of these changes. This is the subject of the present paper.

Material and Methods

In 37 healthy men, aged 23 to 53 years (mean 36.1 years ± 7.1 S.D.), the forced expiration after a maximal inspiration and the immediately following forced inspiration were evaluated, both during normal atmospheric pressure (0.1 MPa) and in a hyperbaric chamber at a pressure of 0.4 MPa. The assessments were made by means of a Chiradat spirometer (made by Chirana, Stará Turá), the low-tension flow recorder of which was adapted for measurements inside the hyperbaric chamber under hyperbaric conditions (Hrnčíř *et al.* 1990). In every subject the following spirometric values were obtained:

– forced expiratory vital capacity (FEVC in litres),
– one-second expiratory pulmonary capacity (FEV_1 in litres),
– ratio of one-second and vital capacity (FEV_1/FEVC in percentage),

– peak expiratory flow (PEF in litres per second)
– expiratory flow at the moment when in the lungs 75 %, 50 % or 25 % of FEVC remain (FEF_{75}, FEF_{50} or FEF_{25} in litres per second) and analogous inspiratory variables (FIVC, FIV_1, FIV_1/FIVC, PIF, FIF_{75}, FIF_{50} and FIF_{25}). (Note: In the case of FIF the numerals 75, 50 and 25 indicate what percentage of FIVC remains to be inspired.)

For illustration, the arithmetic means and standard deviation of the assembled values were calculated. For statistical evaluation, however, non-parametric methods were used – Wilcoxon's test – as it was not certain that all groups have a normal (Gaussian) distribution (Kubánková and Hendl 1987).

The spirometer was programmed in such a way that it evaluated and recorded, besides repeatedly forced expirations (or inspirations), a value where the highest FEVC (or FIVC) was attained in every examined subject. Calibration of the spirometer for the assessment at a pressure of 0.4 MPa was performed by means of a gravitational generator with a precisely defined volume and shape of the flow curve, supplied by the manufacturer. There were doubts whether this calibration is quite accurate as it had to be made at a higher pressure than the prescribed range. Control measurements of the flow with a known volume at pressures of 0.1 MPa and 0.4 MPa proved that at a higher pressure and during inspiration the spirometer records somewhat higher values than the normobaric expiratory ones. Differences of FEVC and FIVC recorded at pressures of 0.1 MPa and 0.4 MPa ($FEVC_{0.1MPa}$, $FEVC_{0.4MPa}$, $FIVC_{0.1MPa}$ and $FIVC_{0.4MPa}$) were consistent with this phenomenon. These differences were considered as errors of the method. Although in individual cases they did not exceed 5 %, they were eliminated by multiplying all recorded hyperbaric and inspiratory values except FEV_1/FEVC and FIV_1/FIVC by factor which was defined as $FEVC_{0.1MPa}$ to $FEVC_{0.4MPa}$ ratio (or to $FIVC_{0.1MPa}$ or to $FIVC_{0.4MPa}$, depending which measurement was involved).

Table 1
Dynamic indicators of pulmonary ventilation at pressures of 0.1 MPa and 0.4 MPa

Dynamic indicator of pulmonary ventilation	At pressure 0.1 MPa	At pressure 0.4 MPa
FEV_1 (l)	4.481 ± 0.753	3.802 ± 0.613
FEV_1/FEVC (%)	85.735 ± 5.285	73.108 ± 8.508
FIV_1 (l)	4.711 ± 0.967	3.305 ± 0.853
FIV_1/FIVC (%)	90.146 ± 12.131	63.541 ± 15.455

Data are means ± S.D., FEVC = FIVC = 5.226 ± 0.796 l, n = 37

Results

It is obvious that a decline of all dynamic indicators of pulmonary ventilation had occurred under hyperbaric conditions (Fig. 1, Table 1). The difference of various variables recorded at pressures of 0.1 MPa and 0.4 MPa are statistically highly significant (in all instances $p<0.001$, Wilcoxon's test).

Discussion

The results indicate that a significant decline of dynamic indicators of pulmonary ventilation occurs in a hyperbaric environment. This corresponds to the increase of flow resistance in the airways in conjunction with increased environmental pressure. It is assumed that this phenomenon is due to physical causes. It is associated in particular with the extension of turbulent flow into larger portions of the airways during increased pressure and with the fact that during turbulent flow the flow resistance is proportional to the density of the gas and thus also to the surrounding pressure (Hrnčíř 1993, 1996). It is remarkable that dynamic indicators of pulmonary ventilation which correspond to higher flow rates (e.g. FEF_{75}) are depressed more during hyperbaric conditions than those which correspond to lower flow rates (e.g. FEF_{25}). A future report will deal with this phenomenon and its interpretation.

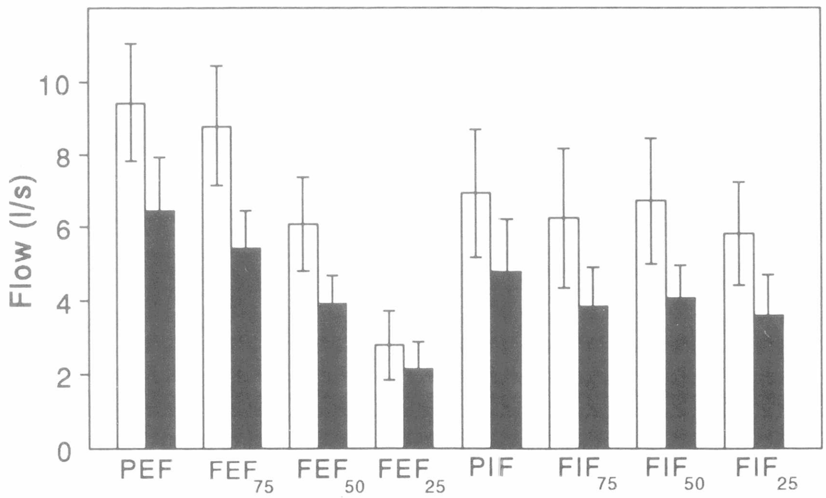

Fig. 1

Dynamic indicators of pulmonary ventilation at pressures of 0.1 MPa (open columns) and 0.4 MPa (full columns). Data are means ± S.D.

The increase of flow resistance in the airways under hyperbaric conditions can become the limiting factor of pulmonary ventilation. For this reason, subjects with obstructive pulmonary disease are not suited for dwelling or working in a hyperbaric environment even when this impediment is only slight. The flow resistance of the airways, which in these subjects is already higher even under normobaric conditions than in the healthy population, may increase during hyperbaric conditions to such an extent that it can lead to inadequate pulmonary ventilation.

References

BENNETT P.B., ELLIOTT D.H.: *The Physiology and Medicine of Diving and Compressed Air Work*. Bailliare Tindall, London, 1982, 532 pp.

BURNET H., LUCCIANO M., JAMMES Y.: Respiratory effects of cold-gas breathing in humans under hyperbaric environment. *Respir. Physiol.* **81**: 413–423, 1990.

HRNČÍŘ E., HYKEŠ P., DOLEŽAL V.: Changes of some ventilation parameters in hyperbaric environment (in Czech). *Pracov. Lék.* **42**: 311–313, 1990.

HRNČÍŘ E: Why pulmonary functions change in a hyperbaric environment. *Stud. Pneumol. Phtiseol.* **53**: 58–63, 1993.

HRNČÍŘ E.: Flow resistance of the airways under hyperbaric conditions. *Physiol. Res.* **45**: 153–158, 1996.

KINDWALL E.P.: Medical aspects of commercial diving and compressed-air work. In: *Occupational Medicine,* Second Edition, C. ZENZ (ed), Year Book Med. Publ., Chicago, 1988, pp. 383–425.

KING J.: Health effects of hyperbaric environments. In: *Occupational Health Practice,* H.A. WALDRON (ed.), Butterworths, London, 1989, pp. 415–429.

KUBÁNKOVÁ V., HENDL J.: Statistics for physicians (in Czech). Czech Ministry of Health, Prague, 1987, 278 pp.

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