RESPIRATORY INDUCTANCE PLETHYSMOGRAPHY: *AN* EVALUATION FOR USE IN NORMOBARIC AND HYPERBARIC ENVIRONMENTS

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INTRODUCTION

This laboratory is evaluating Respiratory Inductance Plethysmography (RIP), commercially known as Respitrace[R], for the measurement of ventilation in diving and non-diving applications where direct connection to the airway is impracticable. RIP is based on the assumption that the respiratory system has two degrees of freedom of movement: one is the rib cage (RC), the other the abdomen (AB). Two independent self-inductance coils supplied by a small oscillator unit are used to monitor changes in the moss-sectional area of the RC and AB components respectively during respiration. Following calibration against known volume changes (in this study using a spirometer, SP), the demodulated output from each coil is summed to give the corresponding changes in lung volume.

This paper presents results taken from trials in which the minute volume by RIP (V_{RIP}) was compared with simultaneous measurement by a pneumotachograph (V_{PN}) or dry gas meter (V_{GM}) during exercise on a cycle ergometer. An accuracy of $\pm$ 10% or better was generally considered necessary for the use of RIP to measure minute volume in diving experiments. The experiments were carried out in the laboratory and in a dry compression chamber at 1,3 and 5 bar during trials of other equipment. Calibration was routinely carried out at 1 bar (normobaric). An important part of this work was to determine if calibration needed to be carried out under hyperbaric conditions for experiments at 3 and 5 bar.

Various methods are available for calibrating RIP. Work carried out in this laboratory (Garside 1984; unpublished) indicated that the original simultaneous equation method of calibrating RIP was unsuitable for diving applications. Therefore a multiple linear regression calibration technique (MLR) used successfully by Stradling et al.[1] for resting subjects was tested in this study. Segadal et al.[2] have used RIP during shallow and deep simulated dives, calibrated by means of a least squares technique.

METHOD

3-4 male subjects with diving experience took part in the experiments. 32 experiments compared V_{RIP} with V_{PN}. Each gave 1 measurement of minute volume during steady-state cycling. 4 experiments compared V_{RIP} with V_{PN}, covering workloads from rest to moderate or heavy. All measurements were of 60s duration. The transducers were modified by sewing the coils into neoprene bands since they were more stable and easier to put on than commercial transducers. Transducers and oscillator were held in place by a close fitting elasticated net. Outputs from the RIP calibrator/ demodulator were sampled and analysed using an Acorn Archimedes 310 computer with ± 15 bit A/D converter (CIL PCI 6480). Sample rates were 13.4 Hz and 19.4 Hz for calibration (RC, AB, SP) and test (RC, AB) signals respectively.

A Fleisch pneumotachograph was used to measure inspiratory minute volume (V_{PN}). A dry gas meter (Parkinson Cowan CD4) was used to monitor expiratory minute volume (V_{GM}). The spirometer, pneumotachograph and gas meter were calibrated with a 1 litre syringe. Volumes were expressed as BTPS (spirometer and gas meter) or BTP with 60% RH (pneumotachograph).

RIP calibration procedure: The subject breathed on a closed-circuit rolling-seal spirometer for 20s or 30s (0.8-3.6 litres tidal volume) while changes in cross-sectional area of chest and abdomen were measured by RC and AB transducers. The MLR technique was used to determine the two volume-motion (V-M) coefficients (MRC and MAB) and their standard errors (SE). The procedure was repeated up to 8 times before and after cycling. Calibrations in which either MRC or MAB were negative were rejected. In each experiment, an average value of V_{RIP} was calculated from the remaining calibrations. In one study the effect of additional selection criteria for calibrations was also tested. These criteria were the SE of MRC <5.0%, the ratio of tidal volume for RIP/SP between 0.95 and 1.05 and the standard deviation of the ratio <0.05. Since preliminary experiments using commercial bands confirmed the observation that MLR is posture dependent [1], calibration was carried out with the subject resting on the ergometer. The volume of CO, removed when soda lime was present in the spirometer had little or no effect on the value of V_{RIP}.

RESULTS

The main results of the RIP-pneumotachograph studies obtained in 4 experimental conditions are summarized in the Table. Columns 2 - 5 give the linear regression analysis for the relationship of V_{RIP} upon V_{PN}. Mean-RIP (column 6) is the mean of the percentage difference between V_{RIP} and V_{PN}, defined as $(V_{RIP}-V_{PN})100/V_{PN}$. The relationship between V_{RIP} and V_{PN} was not significantly different from the line of identity at the 5% level, irrespective of the pressure during cycling (cyc), the calibration pressure (cal) or whether the experiment was carried out in the laboratory (L) or the compression chamber (CC). Mean-RIP ranged from -3.07 to 9.84% and was not significantly different from zero in any condition shown (p>0.05). Thus although mean values of V_{RIP} were within ±10% of V_{PN}, the variation was such that individual measurements of V_{RIP} were not necessarily accurate to this level.

The slope of the regression line for V_{RIP} upon V_{GM} in 4 subjects (4 experiments) was significantly greater than 1. The slope was 1.08 ± 0.01 ($n=76$, $p_1 < 0.001$). The intercept (-0.49 ± 1.83 l/min) was not significantly different from zero ($p_2 = 0.7 - 0.8$).

When mean-RIP was recalculated for one set of conditions using the additional selection criteria given in Methods, the standard deviation was reduced by 34% . (Mean-RIP ± SD was $9.97 \pm 5.85\%$ and $9.84 \pm 8.83\%$ with and without the use of the criteria, respectively). This suggests that one important source of error in individual values of V_{RIP}, is the reliability of individual calibrations.

When minute volume was measured during cycling at 3 bar, there was no significant difference in the calculated values of V_{RIP} based on calibration at 3 bar (before and after cycling) relative to calibration at 1 bar (before and after hyperbaric exposure). The mean difference ± SD was $-3.01 \pm 3.68\%$ ($n=5$, p>0.1). At 5 bar, the mean difference in V_{RIP} based on calibrations at 5 bar compared to 1 bar was more marked ($-6.26 \pm 1.32\%$, $n=2$), however more data is *required* to confirm this result

TABLE   Comparison of minute volume by RIP and Pneumotachograph during exercise

Experimental Conditions (1)	Slope ± SE (2)	p_1 (3)	Intercept ± SE (litres/min) (4)	p_2 (5)	Mean-RIP ± SD (%) (6)	n (7)	Range (l/min) (8)
1 bar cyc, 1 bar cal, L	0.99 ± 0.11	>0.9	3.34 ± 3.01	0.2-0.3	9.84 ± 8.83	10	21- 49
1 bar cyc, 1 bar cal, CC	1.06 ± 0.29	0.8-0.9	-3.18 ± 6.65	0.6-0.7	-3.07 £18.61	12	22- 45
3 bar cyc, 1 bar d, CC	0.98 ± 0.03	0.5-0.6	2.81 ± 2.86	0.3-0.4	4.37 ± 4.52	5	28-134
3 bar cyc, 3 bar cal, CC	0.95 ± 0.03	0.1-0.2	3.04 ± 2.51	0.2-0.3	1.26 ± 5.37	5	28-134

p_1 & p_2 are probabilities that the slope and intercept equal 1 and 0, respectively. n = no. of observations

CONCLUSIONS

The RIP technique described here is able to measure the mean minute volume during cycling to an accuracy ± 10%. However, individual measurements of minute volume by RIP (each based on a one minute sample) may be in error by more than ± 20%. The use of preset criteria for the selection or rejection of calibrations is one method of improving reliability. Calibration at pressure is not required for hyperbaric experiments in dry conditions up to 3 bar. Further work is needed to investigate higher pressures and wet environments.

REFERENCES

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