Method for analysing multiple-breath nitrogen washouts

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Abstract—A method of analysing multiple-breath nitrogen washouts is described and discussed. The method is objective and introduces no weighting into the results. The necessary raw data are obtained from a computer-assisted nitrogen washout test. During the analysis, objective parameters which characterise the alveolar ventilation in terms of nitrogen elimination pattern and gas-mixing efficiency are calculated, together with estimates of functional residual capacity (FRC), tidal volume, dead space, and effective part of the tidal volume. The elimination pattern is described through linear fitting of exponential models to the obtained washout course and is determined by using the $z$-transform. The dead space and the effective part of the tidal volume are estimated from a gas-mixing model. The applied estimation procedure defines a dead space which is larger than the corresponding single-breath dead space and has been designated ‘effective dead space’. The gas-mixing efficiency is described by two indices, one describing the efficiency within an idealised breath and the other the overall efficiency of the lungs. The calculation algorithms are fast and the results are easy to interpret, which makes the method suitable for clinical online applications. The method has been evaluated in a group of 24 healthy newborns at about 26 hours of age, but the application is not restricted to this category of patient.

Keywords—Computer analysis, Dead space calculation, Distribution of ventilation, Gas mixing, Linear estimation of exponentials, Multiple breath nitrogen washout, Nitrogen elimination pattern, Ventilatory efficiency, $z$-transform

1 Introduction

THROUGHOUT LIFE, adequate lung volumes, optimum distribution of the inspired gas and efficient gas mixing are prerequisites for an effective gas exchange in the lungs. The multiple-breath nitrogen washout test is a clinically practical method for investigating these aspects of lung performance, and has the advantage of being applicable even to non-co-operating patients. Various techniques for the analysis have been proposed to determine nitrogen elimination pattern (distribution of ventilation) and to estimate dead space $V_D$, functional residual capacity $FRC$, and ventilatory efficiency, e.g. ARAJAN et al. (1967), BECKLAKE (1952), BOUHUYS and LUNDIN (1959), CUMMING and SEMPLE (1973), FOWLER et al. (1952), HANSON and SHINOZAKI (1967), HASHIMOTO (1967), ROSSH (1966) and SHINOZAKI et al. (1966). Most of these techniques, however, suffer from one or more drawbacks. By using semilogarithmic representation in the estimation procedure, a weighting of the nitrogen values at the end of the washout is introduced. Using nitrogen concentration as the variable makes the calculations very sensitive to variation in tidal volume as well as to how the value is chosen. Finally, it is impossible to keep the manual curve-fitting procedures utilised in some techniques free from subjective influences.

Therefore, to deal with these problems, we developed the method presented in this paper. To avoid unwarranted weighting the analysis is based on linearly represented washout data, and to reduce the problems connected with using nitrogen concentration as variable the reduction in initial lung nitrogen volume is used instead. Furthermore, to eliminate subjective influences and increase calculation speed, all results are based on objectively determined parameters calculated by computer. The results describe the observed nitrogen elimination in terms of elimination pattern, gas mixing efficiency and ventilatory volumes, i.e., $FRC$, $V_D$, mean tidal volume $V_T$ and effective tidal volume $V_{reff}$. The method has been developed to investigate ventilation in healthy and sick newborn infants, but its application is not restricted to this category.

2 Method and theory

The measuring system consists of a specially designed face-out volume displacement body plethysmograph (HJALMARSON, 1974), a minicomputer, and equipment to measure ventilatory flow and breathing gas nitrogen concentration (Figs. 1 and 2). The ventilatory flow is measured by a pneumotachometer, Fleisch No. 1, connected to a small aperture in the plethysmograph wall, and a differen-
the breathing system. The nitrogen concentration is measured by a Hewlett-Packard 47302A fast nitrogen analyser, which has a sample flow rate of 30 ml min⁻¹, a risetime of 30 ms and a delay time to the 10 per cent point of less than 50 ms. The analyser probe and a Rendell-Baker facemask are connected to a modified Ambu valve, through which a gas flow of 6–8 l min⁻¹ is maintained. To diminish the dead space and to make the system airtight, the facemask is partly filled with grease (Macrogol). The dead space of the system and its behaviour, and the ventilation volumes are calculated directly from the original data. The models are selected by using available mathematical models. By introducing mathematical models it is possible to test how well the observed data fit one model or another, and also to estimate various model parameters. The models are selected by using available a priori knowledge of the system and its behaviour, and the ventilation description is made from the estimated model parameters and parameters calculated directly from the original data.

All calculations and the sampling are performed by a PDP-11/40 minicomputer with the software written in Fortran. Details, including software and derivation of the equations presented below, are described in Sjöqvist (1984). The analysis method has been evaluated in a group of 24 healthy newborns, having a median gestational age of 39 weeks and a median age of 26 h. Together with these results, four infants illustrating extremes of the calculated variables are presented. Two of these are from the examined group of healthy newborns and two are infants with neonatal lung disease (pulmonary maladaptation).

2.1 Determination of nitrogen elimination pattern

The nitrogen elimination pattern is determined by using...