

Title: THE DYNAMIC MEASUREMENT OF EFFECTIVE IMPEDANCE IN ANESTHESIA APPARATUS

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A patient breathing spontaneously through an anesthesia circuit is exposed to respiratory resistance which requires increased respiratory work. Previous studies of breathing apparatus and its components usually consisted of determining flow resistance ( $R=P/V$ ) at various constant gas flows. This is a static method which describes the characteristics of breathing equipment under conditions substantially different from those which obtain during the pulsatile flow of actual breathing and indeed may be misleading with respect to differences in performances of various pieces of apparatus. On the other hand a dynamic method for evaluating respiratory apparatus in which the tidal nature of respiratory air flow is reflected can provide information about relative changes (increases) in respiratory work imposed on the patient when breathing spontaneously during anesthesia through various systems of apparatus. It is suggested that useful comparative information is provided by the measurement of effective impedance ( $I_e$ ), which is the work required to displace 1 L of respired gas through the breathing circuit (work per liter ventilation -  $W/L$ ) expressed as a function of minute volume ( $V_e$ ). The purpose of this study was: 1) to test the usefulness and applicability of the measurement of  $I_e$  and 2) to compare the information derived from the standard static measurement of resistance to flow through apparatus with that obtained by the measurement of  $I_e$ .

**Method.** The study was divided into 3 parts:

- 1) a mechanical lung analog was used to simulate breathing through various circle absorption systems. The circuits were a) two commonly used adult circle systems for carbon dioxide absorption (one standard, one disposable). Tidal volume ( $V_T$ ) was varied from 50 ml to 400 ml and respiratory frequency ( $f$ ) from 15 to 45 breaths per minute; b) two infant circles (Bloomquist and Ohio) at  $V_T$  from 50 to 100 ml and  $f$  from 17 to 50 per minute. Using differential pressure transducers and a Fleisch pneumotachograph, pressure, flow and tidal volume (obtained as an integral of flow) were continuously recorded on a Gilson polygraph and simultaneously utilized for plotting of pressure-volume loops on an X-Y recorder. The measured areas of the loops were used to calculate both the total work and the inspiratory work per breath against the flow impedance of the circle. Each of these values was divided by the corresponding  $V_T$  to obtain  $W/l$  which in turn was plotted against the corresponding  $V_e$  to obtain  $W/l$  at various minute volumes ( $I_e$ ).
- 2) Compressed air at continuously increasing flow rates from 0 to 28 l/min was directed through the inspiratory limb of each circle (from the attachment of the breathing bag to the outflow of the Y-piece). Using the same transducers, polygraph and X-Y recorder, the flow was continuously plotted against the pressure gradient

across each system of apparatus. Analysis of the obtained curves provided values of flow resistance ( $R$ ) for each circle at various flow rates.

- 3) The adult circles were then modified by addition of a Revell circulator into the inspiratory limb of each, using the same recording equipment as in (1) and (2), pressure-volume loops were recorded with the circulator consecutively off and on, either in the closed circle with no fresh gas flow, or in the semi-closed circle with fresh oxygen inflow at a rate of 5 l/min using the open tail of the bag for overflow. The circulating flows were measured with a pneumotachograph and were adjusted to equal 1/1 and 2 times the measured peak inspiratory flow rate of the analog.

#### Results

- 1) The work per breath rose with increases in the  $V_T$  and  $f$  but when calculated per liter ventilation it becomes a parabolic function of  $V_e$  independent of the  $V_T$  and  $f$ . Plots of the  $W/l$  against  $V_e$  demonstrated considerable differences in the performance of various circles. The differences detected by the study of  $R$  using the continuous flow method were qualitatively similar but quantitatively substantially smaller than seen with the measurement of  $I_e$ . The ability to discriminate and appreciate the differences in effect during usage between two systems of apparatus is much greater with the information provided by the dynamic method.
- 2) Analysis of the pressure-volume loops plotted from the study of two adult circles as modified by the addition of the Revell circulator showed that at a circulating flow approximately equal to 1/2 of the peak inspiratory flow rate the inspiratory work of breathing through an anesthetic circle can be entirely eliminated.

**Discussion and Conclusion.** The commonly used method of evaluating the performance of breathing apparatus does not reflect the conditions of pulsatile flow produced in the circuit by a breathing patient. The data presented indicate that study of pressure-volume relationships of a tidal (pulsating) air flow generated in the circle by a mechanical lung is a useful method for study of impedance of anesthesia apparatus since the conditions closely resemble those which obtain in actual clinical use. Analysis of the P-V loops indicates the amount of work required to breathe through the system and the relative increase in respiratory workload imposed upon a spontaneously breathing patient. Plotting of the calculated amount of respiratory work per liter ventilation against the corresponding minute volumes provides graphic representation of the dynamic changes occurring because of the apparatus and permits a comparison of the adverse characteristics of such circuits and the potential beneficial effect of any introduced modifications.