

# A SYSTEM OF EQUATIONS FOR COMPUTATIONS ABOUT PULMONARY MECHANICS

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## INTRODUCTION

A mathematical description of the mechanical system of a person's lungs can be analogous to the description of an electrical circuit with pulmonary resistance (electrical resistance), compliance (capacitance), and inertance (inductance). However, to be useful and realistic, computations about respiratory equipment or work of breathing in unusual environments should recognize the limits of attainable forces and volumes and should account for several mathematical complications; the limitations and complications can be of crucial importance in exercise or in persons with pulmonary disease. One complication is that resistance is far from a simple constant; the pressure to cause air flow depends on lung volume, gas density and the flow itself. Furthermore, there can be a mathematical discontinuity -- when a person exhales rapidly, airways may become "choked"; when it occurs, this "dynamic airway compression" causes a step increase in pressure for flow.

## METHOD

With a system of equations which are solved by a numerical method on a Macintosh IIcx microcomputer, I estimate the total pressure generated by the respiratory musculature, as a function of time, from the flow-resistance, elastic-recoil, and inertance components; calculate the instantaneous pressure-flow product (power); and integrate the power to estimate work of breathing and oxygen requirement for a breath (1).

## RESULTS

Figure 1 shows sample computations for a normal person who is exercising vigorously in a normal environment. The top panel shows volume during a breath. The second panel shows total pressure, composed of pressures to cause air flow and to overcome elastic recoil. Note that total pressure is not in phase with either volume or rate of change of volume (flow), and that during the expiratory phase, choking of otherwise open airways causes a sudden increase (downward) of flow pressure and total pressure. The next panel shows flow pressure divided by flow (= resistance); it varies by a factor of 5 during the breath. The lowest panel shows instantaneous power and work for the breath. The oxygen cost of the breath is expected to be proportional to the height of the work curve reached by the end of the breath; it includes a ramp-like rise during the choked-airway phase of expiration.

## DISCUSSION

Literature about pulmonary mechanics tends to focus on one or another isolated aspect; this computer model allows one to develop an overview of how the parts fit together. Application of the system of equations to a person without breathing apparatus in a hyperbaric environment has predicted that the very high pressure necessary to cause air flow overshadows the small pressure needed for overcoming inertia of the dense gas (1), and that in hyperbaric environments, an exercising person's ventilation and breathing pattern are limited by the muscular forces which can be exerted; mechanical work accomplished is inversely related to ambient pressure. Non-linearity of compliance is important for large breaths, and inertance is negligible except when the subject breathes very dense gas.

Although Fig. 1 illustrates the consequences of choked airways, exercising people may sometimes sense the approach to a choked condition and avoid it by decreasing the airflow; this would save energy but would require adjustments in other parts of the breath if decrease of overall ventilation is to be avoided (2).

Those concerned with ergonomics of utilizing respiratory apparatus would be well advised to calculate the total work done by a person (work done on the person's body structures plus work occasioned by the apparatus) rather than just the work of breathing through the apparatus divorced from the person. The phase of maximum pressure to move gas through the apparatus will depend on elastic, resistive and inertial properties of the apparatus. The phase relations of the apparatus could interact favorably or unfavorably with the phase relations that are intrinsic to the human body.

REFERENCES

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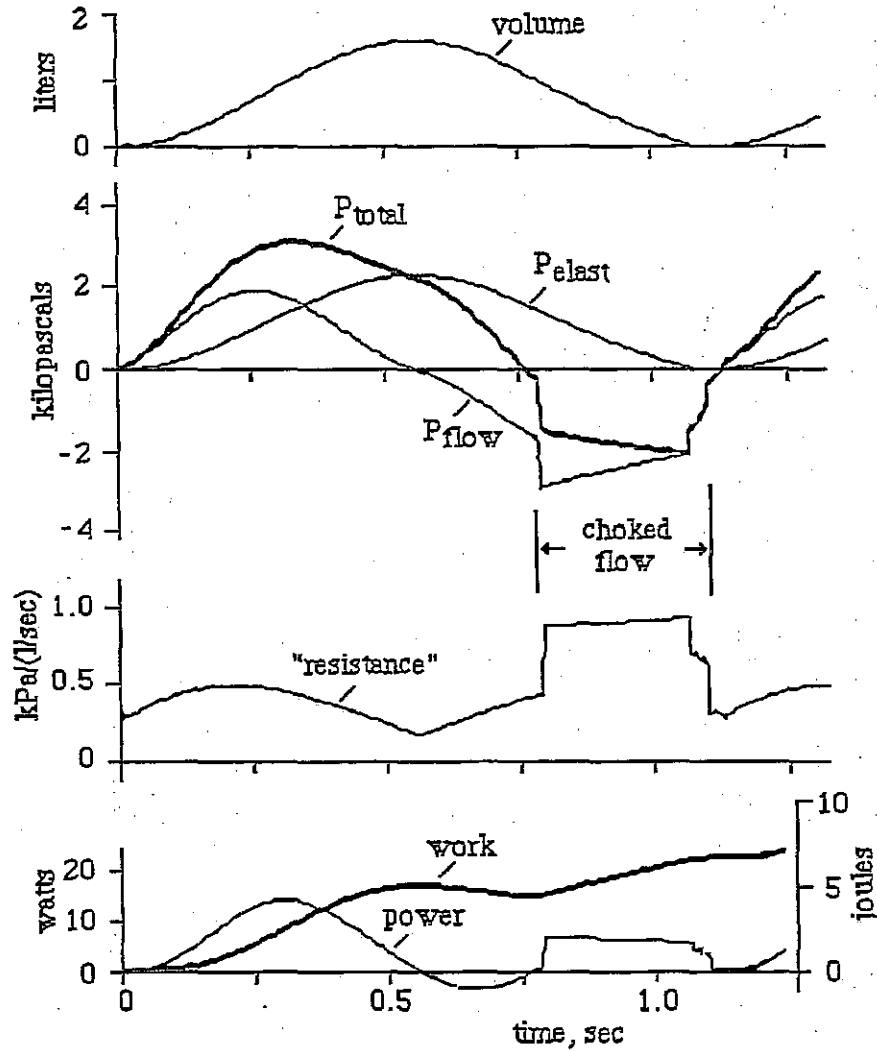


Figure 1. Breath variables vs time during strenuous exercise. For convenience, inflating pressures are shown as positive, as would be the case if the breaths were imposed on a person by a positive-pressure ventilator pump.