

## Impedance in Anesthesiology

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The purpose of this report is to develop for the clinician an appreciation of the concept of impedance and to link its physiologic and clinical meanings pertinent to the practice of anesthesiology. Impedance may be defined as the total opposition to volume flow of gas into the lung-thorax system due to: a) elastic resistance, b) flow-resistive forces such as airway, tissue and chest-wall resistance, including skeletal muscle, bone and tissue opposition to inflation, and c) inertance of the respiratory system. Inertance is defined as the ratio of pressure required to produce acceleration of the system to the volume acceleration ( $\dot{V}$ ) measured simultaneously. In man  $\dot{V}$  normally is not significant, constituting an estimated 0.5 per cent at rest and up to 5 per cent on effort of the total applied pressure.<sup>1</sup> The term "impedance" has been used previously in anesthesia,<sup>2</sup> but it has not gained popularity, probably because as a physiologic term it is not applied with facility to the anesthetized human being.

When the anesthetist diagnoses decreased compliance or bronchoconstriction based on the feel of the rebreathing bag, the difficulty in inflating the bag may be due to: a) lowered compliance, b) raised resistance, c) increased inertance, or d) various combinations of the foregoing. When any or all of these forces opposing inflation occur, impedance has increased. The term "compliance" occasionally has been misused and misunderstood in anesthesia, one concept relating it to the force required to compress the rebreathing bag. Thus, when the bag feels tight, compliance is said to be low.<sup>3</sup> A decrease in compliance may

also be labeled "bronchospasm" when another factor is the true cause.<sup>4</sup>

Ventilators with volume meters of limited accuracy and pressure manometers have also been utilized to provide information about compliance. One popular ventilator labels the volume meter a "patient compliance monitor." When the patient is unrelaxed the airway pressure rises, and the inference is that compliance has fallen. Unless certain conditions prevail, volume-pressure measurements during anesthesia, although they are related to compliance, may be more accurately described within the concept of impedance. First, erroneous volume information due to lack of compensation for expansion of elastic tubing lying between the ventilator and the mouth of the patient may be obtained.<sup>5</sup> Second, pressure in the ventilator and not at the mouth is frequently measured. Third, the patient may be apneic but unrelaxed. Fourth, he may be breathing spontaneously with poorly-phased assisted ventilation; therefore, higher pressures must be developed to inflate the lung-thorax system to overcome skeletal muscle tone and even frictional resistance during flow of gas. Pressure-volume changes here do not refer simply to compliance but may be described more accurately within the concept of impedance. When impedance is high, one or a combination of these elements opposing inflation may be acting. The anesthetist's hand may sense this as a tight bag. A pressure-guaranteed ventilator will deliver less volume and a volume-guaranteed ventilator will deliver the same volume at the expense of a rise in airway pressure.

In the lung-thorax system which includes volume compliance and frictional flow resistances, the volume inertance may be considered the inertial property of this system, which opposes changes in volume flow without dissipation of energy.<sup>6,7</sup> Inertance is designated by the symbol  $Z$  and calibrated in the same units as resistance,  $\text{cm H}_2\text{O/l/sec}$ .

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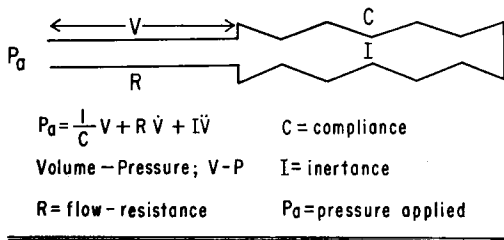


FIG. 1. Mechanical linear system with one degree of freedom and equation of motion.

Use of the equations of motion bridges the gap between theoretical pulmonary mechanics and clinical medicine. These equations express relationships between motion of mechanical systems and the forces applied to them.<sup>1</sup> The equation of motion of a rectilinear mechanical system with one degree of freedom and linear elements is:

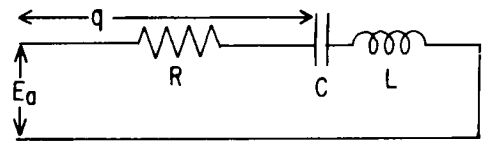
$$F_a = Kl + R_v + M_a$$

Here  $F_a$  is force applied;  $l$ ,  $v$  and  $a$  represent rectilinear distance, velocity, and acceleration, respectively, and  $K$ ,  $R$  and  $M$  are constants representing linear elastance, frictional resistance and inertia forces. A three-dimensional system from which a model has been constructed consisting of a bellows (elastic) and a tube containing fluid may be built and equations of motion written. Here the inertance is distributed between the moving parts of the fluid and the wall of the bellows (fig. 1). This equation (fig. 1) in essence states that instantaneous pressures applied to the respiratory system or its parts are equally opposed by pressures developed within the respiratory system. Such opposing pressures are the sum of pressures dependent on the physical properties of these parts. These physical properties include elasticity, flow-resistance and inertia. Opposing pressures related to these properties are unspecified functions, respectively, of volumes, rates of volume change (flow) and volume acceleration.

An electrical analogy to this mechanical system may be constructed. It consists of a series circuit including ohmic resistance, capacitance and inductance. This is analogous to flow resistance, compliance and inertance (fig. 2).

A bellows-type model was built (fig. 3). Any or all three components of impedance may be added or subtracted from this system, which is inflated by a rebreathing bag. The bellows moves horizontally along a rack and pinion. An airway pressure tap leading to a manometer provides objective evidence of change in: a) resistance—tightening the screw clamp increases frictional flow resistance; b) compliance—substituting heavier springs decreases compliance; c) inertance—substituting a larger flywheel increases inertance. All (a, b and c) represent increased “airway pressure” and more difficult bellows inflation—increased impedance. The screw clamp, compliance springs and flywheel may be removed, a circumstance in which, theoretically, no impedance is present.

In recent years the attention of anesthesiologists has been directed toward atelectasis and shunting which may occur during the administration of anesthesia with constant tidal volume. Lower lung volumes may be simulated on the model and used for teaching purposes. A one-liter or five-liter bottle attached to this system, as seen in figure 3, may be removed to resemble this clinical condition. This effectively changes the lung volume history and, if other factors stay constant, corresponding changes in airway pressure and feel of the bag will be noted. A pneumotachograph, airway pressure taps and appropriate electronic measuring devices may be incorporated into the model to provide pressure, flow and volume



$$E_a = \frac{1}{C} q + R \dot{q} + L \ddot{q}$$

$$E_a = \frac{1}{C} \int i dt + R i + L \frac{di}{dt}$$

Electric (charge-Voltage;  $q-E$ )

$R =$  Ohmic resistance     $L =$  Inductance

$C =$  Capacitance     $E_a =$  Voltage applied

FIG. 2. Electrical linear system with one degree of freedom and equation of motion.

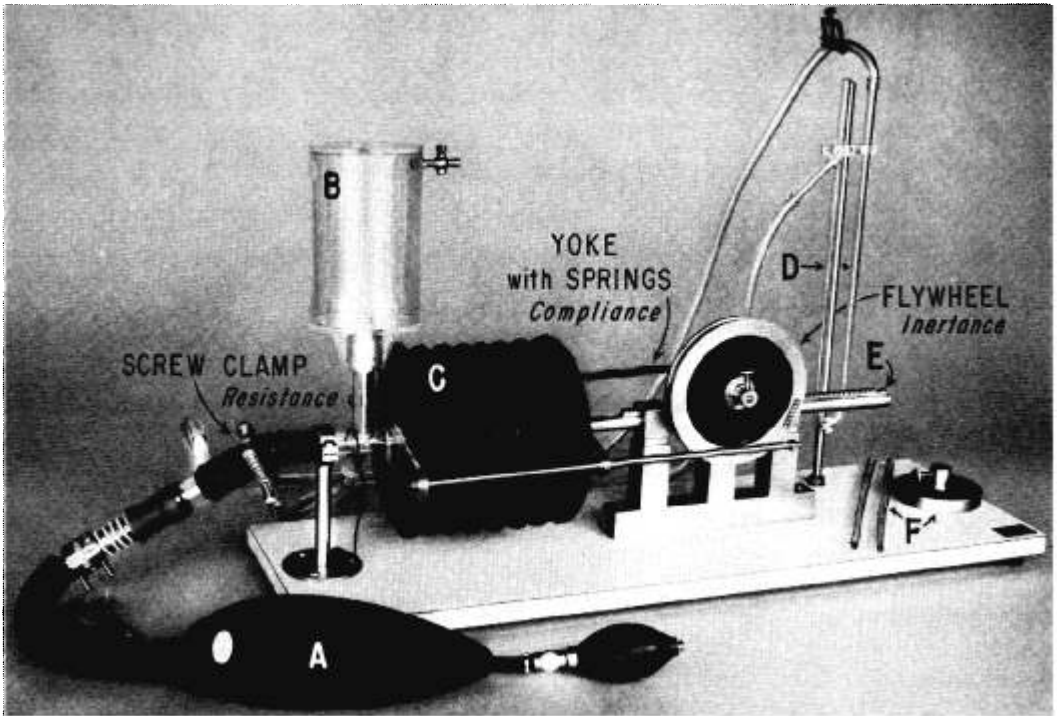


FIG. 3. Model of bellows with three components of impedance. A = bag, B = 1-l bottle, C = bellows, D = manometer, E = rack and pinion, F = changeable springs and flywheel.

traces which correspond with various simulated impedance changes which are introduced deliberately.

In conclusion, impedance, a physiologic term, is suggested as an all-inclusive description of difficulty in inflating the lung. Use of the term represents a move towards increased physiologic accuracy. Impedance is less confusing and includes three components; compliance, resistance and inertance. When any or all of these three factors change in the direction of increased opposition to inflation, impedance has increased. This has an unfavorable connotation; it corresponds clinically to the bag feeling tight or the ventilator meeting more opposition to inspiration—inflation is impeded. Since neither decreased compliance nor bronchospasm is usually the sole cause, the inclusive term “impedance” is recommended. Clinically, “increased impedance” would be substituted for the physiologic concepts “decreased compliance” (elastic resistance) and “bronchoconstriction,” referring to increased flow resistance.

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