A Pattern to Evaluate Airway Resistive Phenomenon Using Rohrer’s Equation

The phenomenon of airway resistance to inflow is complex and has different behaviors as the fluid flows. The physiopathology of main respiratory diseases shows alterations in the resistive component. The complete description of the phenomenon requires more robust mathematical tools of the mechanics of fluid physical science. The pattern presented below simplifies these observations, evidences in didactic form the main elements related to the resistive phenomenon, and uses basic mathematics to describe the observations done.

A fluid moves through a conduit due to the pressure difference ($\Delta P$) that overcomes the attrition after the flow ($V$) (3). Thus, $V$ depends on the existence of $\Delta P$ between the extremities of the conduit, as follows:

$$P_i - P_f = \Delta P$$  \hspace{1cm} (1)

where $P_i$ is initial pressure and $P_f$ is final pressure.

The larger or smaller difficulty to the passage of this flow is understood as larger or smaller resistance ($R$), which is directly proportional to $\Delta P$ and inversely proportional to $V$, as demonstrated in the following equation (2, 3):

$$R_{wa} = \Delta P/V$$  \hspace{1cm} (2)

where $R_{wa}$ is airway resistance.

When the phenomenon is observed with low flows, the tendency is that molecules move in concentric layers with increasing speeds from outside the tube inward. This is called laminar flow, an occurrence that can be described by a first-grade equation (3). If the flow is increased, the composition is altered, or if the internal part of the conduit is modified, the flow will become turbulent, and the equation to describe this phenomenon will be the following second-grade equation (1, 4), as described by Rohrer in 1915 (4):

$$P_i - P_f = K_1 \times V$$  \hspace{1cm} (3)

$$P_i - P_f = K_1 \times V + K_2 \times V^2$$  \hspace{1cm} (4)

where $K_1$ is the linear coefficient and $K_2$ is the angular coefficient of the straight line.

By dividing all the terms of Eq. 4 by $V$, the following equation to be used during the experiment can be obtained:

$$\frac{(P_i - P_f)}{V} = K_1 + K_2 \times V$$  \hspace{1cm} (5)

By substituting Eq. 2 into Eq. 5, one can observe that system $R$ is linearly related to $V$, as follows:

$$R_{wa} = K_1 + K_2 \times V$$  \hspace{1cm} (6)

The experiment aims to observe pressure variations with the administration of constant and variable flows in cannulas. The pattern is composed of a gas source, a pressure generator that supports constant flows, a pressure gauge, connections, and hospital cannulas of various standards and lengths. It is connected to the compressed air pressure generator. A 2-mm-internal diameter, 10-cm-long cannula is connected to the generator. Initially, a 5 l/min flow is offered, and the intake pressure is measured using the pressure gauge connected to the part that inserts the pressure generator into the cannula. This gives $P_i$ and, because the cannula is open to the environment, $P_f$ is zero. Then, the inflow is increased and reduced in 1-l/min increments up to amounts convenient enough to describe the phenomenon. The pressure is measured as previously described in each of these flows, and a graph is built considering $R$ ($\Delta P/V$) as the dependent variable and $V$ as the independent variable. A software program is used to calculate the linear regression, which gives $K_1$ and $K_2$. Thus, one can obtain, respectively, the laminar and turbulent flow coefficients. One can also prolong the experiment to observe the main components that may influence $R$ when $V$ is constant, namely, cannula length ($l$), internal diameter ($r$), and fluid viscosity ($\eta$). These factors are easily identified by Poiseuille’s law, as described in the equation below:

$$R = (8\eta l)/(\pi r^4)$$  \hspace{1cm} (7)

For these observations, it is suggested to use an inflow of 5 l/min in a 10-cm-long, 2-mm-internal diameter cannula and to measure the intake pressure. Then, change the cannula with other cannulas of the same length but with variable internal diameters of 1, 4, 6, or 8 mm. Intake pressures are measured once again, and the phenomenon of resistance reduction can be observed, which is now a nonlinear phenomenon. In the next phase, a 2-mm-internal diameter cannula is used with varying lengths of 20, 30, 40, and 50 cm. In each modification described above, $P_i$, $P_f$, and $V$ will be constant, and, consequently, the characteristics of the phenomenon will be known. This is a very didactic pattern in the study of resistive phenomenon, which needs only basic mathematics and is low cost.

REFERENCES


Eduardo Gaio
César Melo
Laboratory of Respiratory Physiology, University of Brasilia,
SQN 311 DI D apto 103, Norte Brasilia 70757-040, Brazil
E-mail: eduardogaio@unb.br
doi:10.1152/advan.00082.2006