3. The small volume of dialyzate (only 3 liters) and the opportunity for using the usual non-sterile saline solution as the dialyzate increase the independence of dialysis equipment, simplify its clinical application, and improves the physiological background of dialysis. Dialysis with dialyzate regeneration allows the use of acetate to be avoided, and it can be considered as an alternative for bicarbonate dialysis.

LITERATURE CITED


ANALYSIS OF THE ACCURACY OF RESPIRATORY IMPEDANCE MEASUREMENTS ON TUBES AND IN MAN

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UDC 615.471.03:616.24-008.4-073.731

1. Introduction

The forced oscillation technique has been widely used in recent years for studying lung mechanics [4, 9]. Such studies are usually conducted on locally made devices [8, 9]. Therefore, the problem of calibration and verification of the devices is of great importance. The calibration and verification can be fulfilled by comparing the theoretically calculated and experimentally measured values of impedance of pneumatic elements. A theory for calculating impedance of tubes of finite length is given in the present work. The theory has already been applied to calculation of the complex transfer function (i.e., in fact, for calibration) of the device developed in our laboratory [3].

Results of impedance measurements, like of any other parameter, are subjected to random spread caused by unstable operation of measuring instruments. If the properties of the object itself may vary during the measurements, it is important to distinguish between the spread of parameters caused by unstable operation of measuring device and by lability of the object of measurements. This is particularly important for measurements of physiological parameters. Such verification and calibration of devices for forced oscillation technique can be performed by measuring the impedance of their pneumatic elements. Previously, the procedure was performed by calibrating several tens of various pneumatic elements, each of the elements requiring several measurements [3]. Average error in the impedance of the element, connected to the pneumatic center of the device, was then estimated.

It is seen from the functional diagram of the device described in [3] (see Fig. 2 therein) that the impedance connected to the pneumatic center includes the impedance of a standard tube, the impedance of a mouthpiece and the sought impedance. In addition, the pneumatic center itself contains a certain amount of gas, and it is also characterized by a certain capacitive impedance. The software of the device contains programs for calculating the sought impedance from the measured values of the impedance connected to the pneumatic center. The programs are rather sophisticated, and they operate with complex variables. Therefore, additional evaluation of the sought impedance error is required.

The goals of the present work were: 1) estimation of the accuracy of the developed device by comparing calculated and measured values of the impedance; 2) determination of random error in parameters of pneumatic elements connected to the mouthpiece of the device; 3) comparison between errors in parameters of these pneumatic elements and parameters of the human respiratory system.

2. Theory (substantiation of method for calculating tube impedance)

Acoustic equations for round tubes with elastic walls and conditions of their application have been considered in [2]. The equations were derived on the basis of formulas for three-dimensional movement of gas under small perturbations. The equations have been shown to be valid over the considered frequency range (from 7 to 19 Hz) for all the available diameters and lengths of tubes (from fractions of a millimeter to tens of centimeters). In the present work we consider a simplified case of rigid tubes of finite length. Expressions for infinitely long tubes are similar to those derived in [6].

Acoustic properties are usually specified by the acoustic impedance $Z_c$ (ratio of pressure to mass gas flow) of an infinitely long tube and by the propagation constant $\Gamma$ describing the instantaneous pattern of spatial distribution of the acoustic wave. Both values are complex variables. For a direct wave:

$$Z_c = (Z/Y)^{1/\iota}, \quad (1)$$

$$\Gamma = (Z/Y)^{1/\iota}, \quad (2)$$

the following definitions were used:

$$Z(i\omega) = \frac{i\omega S}{\iota} \cdot \left[ 1 - \frac{2}{\iota a} \cdot \frac{J_1 \left[ \frac{i\omega a}{v_0} \right]}{J_0 \left[ \frac{i\omega a}{v_0} \right]} \right]^{-1}, \quad (3)$$

$$Y(i\omega) = \frac{i\omega S \rho_0}{\iota \rho_0} \cdot \left[ 1 + \frac{2(\gamma - 1)}{\iota a} \cdot \frac{J_1 \left[ \frac{i\omega a}{v_0} \right]}{J_0 \left[ \frac{i\omega a}{v_0} \right]} \right], \quad (4)$$

where $a$ is the radius of the tube, $S$ is the cross sectional area of the tube, $\omega$ is the angular frequency of oscillations, $\rho_0$ and $\rho_0$ are the non-perturbed values of density and pressure, $v_0$ is the coefficient of kinematic viscosity of the gas, $\gamma$ is the adiabatic constant, $\sigma_0$ is the Prandtl constant, $i$ is imaginary unity, and $J_1$ and $J_0$ are complex Bessel functions.

Wave resistance is often used instead of characteristic impedance to describe acoustic properties:

$$W_1 = \rho_0 S Z_c. \quad (5)$$

Let $Z_l$ to be the output impedance of a tube of the length $l$. In other words:

$$p(l, t) = Z_l V(l, t), \quad (6)$$

where $V(l, t)$ is the volume gas flow in the tube, and $p(l, t)$ is the pressure at the outlet of the tube. The input impedance of the tube is:

$$Z = \frac{p(0, t)}{V(0, t)} = Z_0 \frac{Z_ch(\Gamma l) + Z_{\sigma_0} sh(\Gamma l)}{Z_{ch}(\Gamma l) + Z_{\sigma_0} sh(\Gamma l)}, \quad (7)$$

where $ch$ and $sh$ are the hyperbolic cosine and sine of complex arguments, respectively.

By defining $Z$ through wave resistance $W_1$, we obtain:

$$Z = \frac{W_1}{S} \cdot \frac{Z_ch(\Gamma l) + (W_1/S)sh(\Gamma l)}{Z_{ch}(\Gamma l) + (W_1/S)sh(\Gamma l)}. \quad (8)$$

Equation (8) allows calculation of impedance of a round tube of finite length. Propagation constant, wave resistance, and some other parameters of Eq. (8) are calculated from Eqs. (1-5).