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A Method for Functional Evaluation of External Respiration by Pressure Chamber Recording (Plethysmography)

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From the Russian

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A METHOD FOR FUNCTIONAL EVALUATION OF EXTERNAL RESPIRATION BY PRESSURE CHAMBER RECORDING (PLETHYSMOGRAPHY)

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The problem of functional evaluation of the lungs in children of young age presents a number of difficulties. In examining children, we cannot depend on help from the patients; also, all manipulations and the recording process itself must disturb the child as little as possible. For infants, contactless methods, not requiring attachment of anything which might hinder respiration to the body of test subject for recording of the physiological processes, are most desirable.

The essence of the method which we suggest is that the child be placed in a steel chamber (whole body plethysmograph) and a manometer records changes in pressure as the child breathes.

The principle of manometric recording of respiration in a plethysmograph has been used repeatedly by physiologists. The earliest work of which we know was written by the 19th century physiologist P. Bert, who placed laboratory animals beneath a glass bell connected to a Marey's tambour and recorded the fluctuations in pressure as the animal breathed through a kymograph. The simple experiment of Bert is of interest in connection with the recent development of new and sometimes very complex methods for the determination of the volume of the lungs and resistance of the respiratory tract (Du Bios et al.; Bargeton et al.; Polgar; Jaiger et al.).

Our method allows to obtain certain indexes of the functional state of the lungs, under physiological conditions, for patients of any age, regardless of the severity of their condition. As our plethysmograph, we used the chamber of an artificial respirator with a volume of 200 l, after assuring the required tightness of seal (time constant of leads 5-10 sec). The pressure measuring device was a low-inertia capacitive manometer, the recording device was a VKS-4 type device. If we consider that in one minute 10 ml/kg oxygen are absorbed and 9 ml/kg CO_2 are evolved, we see that after fifteen minutes a chamber with a volume of 200 l will contain 20.6 % oxygen and 0.38 % CO_2 for a child weighing 5 kg and 20.2 % oxygen and 0.72 % CO_2 for a child weighing 10 kg. Therefore, it can be considered that the composition of the air breathed by the child remains practically unchanged during the time of investigation (2-3 min). Usually, a child could stay in the plethysmograph for about an hour.

Analysis of physical processes on which method is based. In order to illustrate the first factor causing a change in pressure in the chamber, we can draw an analogy with a syringe (Fig. 1). As the piston is withdrawn (inhalation), air enters the syringe through the narrow apperture (respiratory tract), the presence of which causes a rarefaction in the syringe while the pressure in the chamber increases. The pressure in the chamber (p) is determined by the pressure in the syringe (p_a) and the ratio of the volume of the chamber (V) and the syringe (V_a);

$$PV = P_a V_a \tag{1}$$

Applied to the method being described, this means that the dynamics of pressure in the plethysmograph depend on the pressure changes in the lungs.

The second principal factor influencing the pressure within the chamber is the hygrothermal factor. As it enters the lungs, air is heated and saturated with water vapor, causing an increase in the total pressure within the chamber. During exhalation, the pressure drops. This factor can be quantitatively estimated using the equation of Bargeton:

$$PV = \left[P_0 - h - \frac{T}{T_0}(P_0 - h_0)\right] V_T. \tag{2}$$

where P is the excess pressure in the plethysmograph; T is the absolute temperature in the plethysmograph; h is the water vapor pressure in the plethysmograph; T_a is the absolute temperature in the lungs; h_a is the water vapor pressure in the lungs; P_0 is the atmospheric pressure; V_T is the respiratory volume; V is the volume of the chamber.

Changes in chamber pressure as a result of the hygrothermal factor reflect the volumetric changes during filling of the lungs with air (V_T). Therefore, their graphic representation can be looked upon as a spirogram. The closer the chamber temperature to body temperature, the less the thermal effect and the more the changes in pressure in the chamber depend on the alveolar pressure. However, in order to avoid the overheating of the organism, the ambient temperature must be somewhat lower than body temperature. Attempting to perform the method under the best physiological conditions, we performed our investigations with a temperature difference between chamber and body of child of 11-13°C. The absolute moisture content of the air during the investigation was 18-24 mm Hg. Under these conditions, the manometric curve shows the sum of two processes: the dynamics of alveolar pressure and the hygrothermal effect.

This method should be used with diseases accompanied by increased resistance in the respiratory tract. In these cases, the significant increase in fluctuations of alveolar pressure should be clearly reflected on the pressure in the plethysmograph. Under normal conditions, the thermal, spirographic factor predominates. For a quantitative evaluation of certain aspects of the pulmonary function, we can use the PV indicator, the product of the volume of the chamber (in l) less the volume of the body of the test subject (V), and the total fluctuation in pressure in the chamber in one respiratory cycle, in centimeters of water (P).

Using this method, we studied 92 children, ranging in age from two weeks to four years. Of these 50 were examined during various forms of pneumonia, 16 of the children showing pulmonary pathology accompanied by phenomena of acute respiratory insufficiency resulting from obstruction of the respiratory tract (exudation in the bronchi, edema, asthmatic syndrome). The control group included 6 healthy children and 36 children without pulmonary pathology, who were in the clinic in connection with hypotrophy, anemia, chronic tonsillitis and certain other diseases, frequently encountered in children with pneumonia as accompanying diseases. The work was preceeded by studies on adults and animal experimentation.

Preliminary Results

The method in question is a highly sensitive method for recording respiration in general. It is little subject to the distorting influence of, for example, muscular motion. During normal respiration, the curve shows the difference in relationships of inhalation and exhalation, difference in amplitude between respiratory cycles, etc. Under normal respiratory conditions, the manometric pneumogram is similar to a spirogram; an increase in respiratory volume causes a proportional increase in the amplitude of the variation in chamber pressure. If a child cries or screams, the amplitude of the manometric curve increases by 5 to 8 times, sometimes decreasing the similarity to a spirogram, a result of the compression of the alveolar gas due to the constriction of the larynx.

Figure 2[1] shows a chamber pneumogram (bottom) and a pneumogram from the thorax (top curve). The curves are characteristic for normal at rest respiration; they were recorded from a child six months in age during sleep. The rise in both curves near the end of the recording resulted from a short, deep inhalation. The P indicator averages 3 cm water · ℓ, or 24 cm water · ℓ with the deep inhalation.

When pneumonia is not complicated by an acute disorder in the bronchial passages, the plethysmograms are similar to spirograms measured for children without pulmonary pathology. With extreme dyspnea, when there is a great deal of mucus in the respiratory tract or when an asthmatic syndrome is present, the manometric curve changes: the amplitude increases by 5-10 times, and the curve has peaks unrelated to even changes in air flow.

Figure 3 shows a plethysmogram and an ordinary pneumogram of a child one and one-half months of age with pronounced dyspnea, resulting from a severe state of acute respiratory insufficiency. The patient was suffering from hypertoxic pneumonia, complicated by atelectasis of two segments, the lungs presented an abundance of rales, the upper respiratory tract and bronchi contained a good deal of mucus. The PV averaged 16 cm water · ℓ. During crying

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[1] The oscillograph was connected so that its beam was deflected upward when the pressure in the chamber increased, downward as it decreased. The polarity of the pneumogram is the same: inhalation-upward, exhalation-downward. The time marks correspond to 0.05 sec; 1 mm amplitude of the plethysmogram corresponds to 0.004 cm water · ℓ.

(beginning of recording), PV reached 30 cm water · ℓ. Similar plethysmograms were recorded for this patient for four days, during the most acute period of the process. Then, parallel with improvement in the condition and a reduction in dyspnea, the amplitude of the plethysmogram dropped, and the curves became similar to those shown on figure 2.

Figure 4 shows the pneumogram and plethysmopneumogram of a child three months of age with acute expiratory asthmatic dyspnea. Beginning of curve: pneumogram reduced, exhalation long and stepped-dyspnea with groaning -- downward waves on curves strongly developed, indicating difficulty in exhalation; this is followed by an increase in the amplitude of the pneumogram and a sharp increase in the amplitude of the manometric curve, caused by marked respiratory movements during a spasm of the larynx. Subsequently, on the pneumogram the respiratory waves are absent, while the increases and decreases in pressure on the plethysmogram indicate expansion and contraction of the alveolar gas with blockage of the respiratory tract. Respiration is then gradually normalized. Figure 5 shows a fragment of the same recording 15 seconds later, when respiration was less labored.

Pathological, "nonspirographic" plethysmograms, similar to figures 3 and 4, were observed in 16 patients with acute dyspnea resulting from an increased pulmonary pressure variation amplitude due to increased resistance in the respiratory tract. As this condition was eliminated, the pathologically altered curve assumed greater similarity to the spirographic curve.

The amplitude of the nonspirographic curves best reflects the pressure in the lungs, so that, by subtracting the hygrothermal component from the PV value, we can estimate the alveolar pressure and the resistance of the respiratory tract. Differentiation of nonspirographic plethysmograms is possible only during simultaneous recording of ventilation. In our experiments, this was achieved by a simultaneous recording of an impedance pneumogram, calibrated in units of volume. Nevertheless, the recording of a chamber plethysmogram alone is of great interest for charactization of the respiratory function of a patient, as can be seen from the examples presented.

During normal at rest respiration, a spirographic plethysmogram shows primarily the hygrothermal component; therefore, using equation 2 we can calculate the respiratory volume rather accurately from the PV value. For example, on figure 2 the volume of a typical respiratory cycle is about 40 ml, the volume of a deep inhalation is on the order of 300 ml/volume of the plethysmograph -- 200 ℓ, temperature 25°C, moisture content 19 mm Hg; the atmospheric pressure was 760 mm Hg; the minute volume in this study was about 1.5 ℓ.

Conclusions

1. The method of plethysmopneumography is technically simple and safe, allows external respiration to be studied under most physiologic conditions. This method is suitable for examination of children of any age, beginning with the first days of life, regardless of the severity of their condition.

2. With a significant temperature difference between plethysmograph and body of patient (on the order of 10° C), plethysmopneumography can be used to obtain a spirographic characteristic of the respiration.

3. There is particular interest in the use of this method for infants with severe pneumonia. The increase in pressure within the lungs resulting from obstruction of the respiratory tract changes the nature of the manometric curve. In these cases, the method allows the increased resistance of the respiratory tract to be estimated. The method is an aid to diagnosis and reflects the changes in the dynamics of the respiratory function.

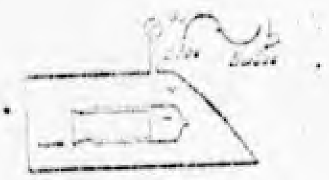

Fig. 1. a, inhalation; b, exhalation.

Fig. 2. Chamber pneumogram (bottom) and pneumogram of thorax (top).

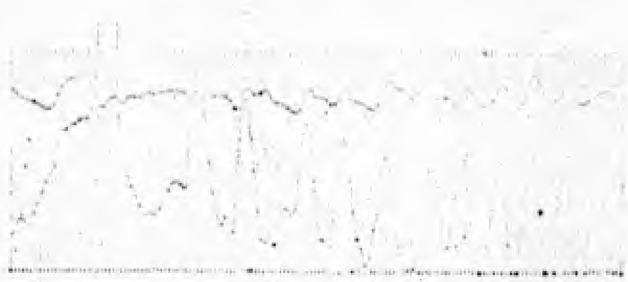

Fig 3. Plethysmogram and ordinary pneumogram of child one and one-half months in age with pronounced dyspnea.

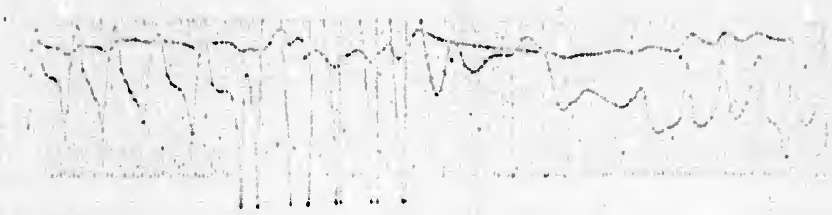

Fig. 4. Pneumogram and plethysmopneumogram of child three months in age with acute expiratory dyspnea of asthmatic type.

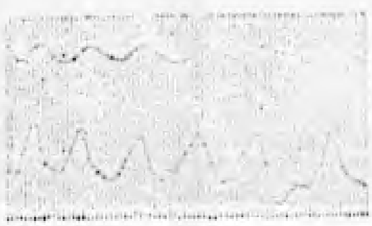

Fig. 5. Fragment of pneumogram and plethysmopneumogram of same child after attack.