

Recording Methods and the Capabilities of Modern Respiratory Rate Monitoring Devices (literature review)

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Determination of respiratory rate is a necessary task in assessing the state of health in humans. This review provides a description of modern devices used for recording and monitoring respiratory rate. The advantages and disadvantages of the principles of operation of these devices are discussed.

Introduction

Respiratory rate is an indicator that reflects the physical condition of a person and his/her health in general. Pauses in breathing lasting from a second to a minute are characteristic of sleep apnea, and breathing too rapidly at rest can be an important predictor of cardiac arrest. In addition, athletes rely on their breathing rate as an indicator of fitness, preferring slow but deep breathing during exercise. Respiratory rate is one of the criteria in determining the severity of the condition of patients with acute respiratory infection caused by SARS-CoV-2 coronavirus (COVID-19). Interestingly, several methods are available for determining respiratory rate beyond simply counting the rise and fall of the chest. This article discusses the main advantages and disadvantages of the two main diagnostic methods for measuring respiratory parameters: pneumography (pneumometry) and spirometry. The goal of many researchers is to create wearable devices capable of continuously monitoring respiratory activity in natural physiological conditions.

Respiration is a set of processes that ensure the supply of oxygen to the body, its use for the oxidation of organic substances, and the removal of carbon dioxide from the body [1]. Breathing is a periodic process and, by its nature,

has a certain similarity with oscillatory mechanical processes, in particular in having the characteristic termed respiratory rate [2, 3].

Respiratory rate (RR) is a dynamic indicator of pulmonary ventilation. This indicator is expressed as the number of respiratory movement cycles per unit of time. Measurements of RR are used in the following fields of application [4]:

1) diagnostics:

- detection of objective changes in the functional state of the lungs, including those influenced by diseases;
- during initial examination when certain clinical signs are present (shortness of breath, changes in percussion tone and breathing pattern, wheezing, etc.);
- prognosis of the course of disease;

2) during dynamic observation (monitoring):

- evaluation of the effectiveness of therapeutic measures;
- assessment of the course of disease (pulmonary, cardiovascular, neuromuscular system);

3) expert assessment:

- temporary disability;
- suitability for work in certain conditions.

Most pathological conditions associated with breathing are characterized by particular clinical manifestations [5-8]. Accurate diagnosis depends both on the clarity of the clinical picture and the doctor's qualifications, as well as the diagnostic technologies used for confirmation [9-13]. The present study is relevant because there is currently an increasing awareness among physicians of the value of correct diagnosis of RR [14, 15].

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The frequency of respiratory movements is one of the criteria for determining severity in patients with acute respiratory infection caused by the SARS-CoV-2 coronavirus (COVID-19) [16]:

- mild COVID-19 (outpatient treatment, all signs): $T_{\text{body}} < 38.0^{\circ}\text{C}$; $\text{RR} \leq 22/\text{min}$; no shortness of breath with usual physical activity; $\text{SpO}_2 \geq 95\%$;

- moderately severe COVID-19: hospitalization if two of the following four main criteria are met: $T_{\text{body}} \geq 38.0^{\circ}\text{C}$; $\text{SpO}_2 < 95\%$; $\text{RR} > 22/\text{min}$;

- severe COVID-19: emergency admission to the ICU if two of the following three main criteria are met: $T_{\text{body}} \geq 39^{\circ}\text{C}$; $\text{RR} \geq 30/\text{min}$; $\text{SpO}_2 \leq 93\%$;

- extremely severe COVID-19: emergency admission to the ICU if two of the three following main criteria are present: impaired consciousness; $\text{SpO}_2 < 92\%$ (on the background of O_2 therapy); $\text{RR} > 35/\text{min}$.

The use of specific instruments for recording RR is becoming increasingly important. Although the class of such devices is quite extensive and diverse, the functionality and reliability of many are open to question. The Russian medical devices market has recently seen an increase in demand for devices of this class [17-26].

Before proceeding to the development of a device for measuring respiratory rate, the main methods used to record respiratory rate need to be investigated to determine their basic principles, advantages and disadvantages [4].

There are two main diagnostic methods for measuring respiratory parameters: pneumography (pneumometry) and spirometry [27-33].

Pneumography is a method for studying external respiration using graphic or digital recording of respiratory movements [27, 28]. The principle of pneumography is that the mechanical energy of the respiratory movements of the chest is converted into an electric current by a conductive sensor and is then transformed by a recording device [30-33]. Pneumograph devices include transducers (sensors) consisting of rubber tubes (one or more) filled with a conductive powder or solution, attached to the surface of the patient's chest with an elastic bandage or vest. There are also other types of pneumographs, where electrodes attached to the chest are used instead of rubber tubes [30].

Spirometry is a method of studying external respiratory function, which includes the measurement of the volume and rate of respiration [32]. The principle of spirometry is that the air flow recorded by the sensor is recorded and analyzed in an electronic device. In other words, spirometer devices are digital devices that consist of an air flow sensor and an electronic device that converts the sensor readings into digital form and performs the necessary calculations [32].

Advantages of pneumography: the principle of recording measurements is simple; there is widespread use of pneumograph devices on the market.

Disadvantages of pneumography:

- bulky equipment ($500 \times 100 \times 500$ mm, excluding chest belt, vest or electrodes);

- small number of measurable parameters compared with spirometry;

- time-consuming preparation for and running of the procedure;

- relatively high measurement error – up to 10%;

- contraindications to the procedure (children under 5 years old, people with heart disease).

Advantages of spirometry:

- small size of equipment;

- multifunctionality and multitasking;

- short duration of signal recording and information processing;

- diagnostic procedures can be run in animals.

The disadvantage of spirometry is the high cost of spirometers.

This comparison leads to the conclusion that there is a need to develop a device for measuring RR based on the spirometry method

The following devices for recording RR are currently on the market and are briefly described below.

1. Respiratory rate sensor (JSC MEDIUS, Russia).

This digital sensor records human respiratory rate based on measuring the temperature difference between inhaled and exhaled air. A thermistor placed in the external nasal passage is used as the sensory element to determine the temperature difference between inhaled cold air and exhaled warm air.

The RR measurement range is from 0 to 30 cycles/min. Measurements can be made at rest and during exercise. The sensor is connected to a computer via a USB connector. Specialized software outputs data as the relationship between RR and time [34].

2. Releon respiratory rate sensor (Russia). The sensor measures the frequency of respiratory movements (inhalation-exhalation cycles) per unit of time and analyzes the number of contractions of the chest and anterior abdominal wall [35]. The sensor kit includes a set of hygienic disposable nozzles that are attached tightly to the breathing tube.

3. PASCO PS-2187 digital breath rate sensor (with mask). This device is not a medical device and is intended for educational use only. The RR sensor measures RR by detecting the change in pressure in a standard disposable dust mask. It ensures measurement stability even during physical exertion. The kit includes (Fig. 1):

- a disposable barometric digital pressure sensor with a clamp and a tube for connection to a measuring device;



Fig. 1. PS-2187 PASCO digital respiratory rate sensor (USA).



Fig. 2. Rainbow digital USB respiratory rate sensor (Russia).

- disposable dust mask;
- data recorder.

The measurement range is from 5 to 60 breaths/min. The device provides two modes of operation:

- 1) measurement of respiratory rate as a value inversely proportional to the time between two successive breaths;
- 2) measurement of the average respiratory rate, calculated from the durations of four inhalation-exhalation cycles.

These measurements are transmitted digitally to a computer or data logger for further analysis [36].

4. “PASCO” (USA) digital respiratory rate sensor (chest). This digital sensor records RR before and after exercise. It measures the change in pressure that occurs in the chest cavity as it expands and contracts during breathing.

Typical applications are: comparison before and after exercise, calculation of possible correlations between RR and heart rate, determination of the effect of altitude on breathing [36]. The system includes a PASCO digital relative pressure sensor and a belt, i.e., the RR sensor. Addi-

tionally, an interface from the *Data collection and processing systems* section is used to collect, display and analyze data. It should be noted that the chest RR sensor is not a medical instrument and should not be used to determine a person’s state of health or fitness [36].

5. Digital USB respiratory rate sensor. This sensor is an electronic unit that connects directly to a personal computer. The primary transducer of the sensor is based on a thermistor and is built into a breathing mask (Fig. 2). The mask is designed to be attached to the subject’s face and allows measurements to be taken during various physical activities and at rest. The thermistor converts the temperature of the inhaled and exhaled air into an electrical signal [37]. Software presents data on the monitor and provides data storage and the ability to transfer data to other programs, such as Excel.

6. GDX-RB wireless respiration belt for measuring respiratory rate (Vernier Software & Technology, USA). The effectiveness of training, the rate of stabilization of breathing after sports exercises, breath-holding, and effects of chest volume can be measured using the wireless breathing belt. The cordless respirator uses a force sensor and an adjustable nylon chest strap to measure breathing effort and breathing rate. The LED indicator provides feedback so belt tension can be improved [38].

The respiration sensor for determination of RR is an adjustable belt with a wireless sensor that can also be operated via USB (Fig. 3).

Conclusions

This review provides a description of modern devices used for recording and monitoring respiratory rate. The advantages and disadvantages of the principles of operation of these devices are discussed. Existing device models are not autonomous: values are interpreted using a computer (smartphone) or software.

A promising direction for further research may be the development of an autonomous device (mask) for regis-



Fig. 3. GDX-RB wireless respiration belt (Vernier Software & Technology, USA).

tering and monitoring RR with the ability to visualize the measurements without auxiliary equipment.

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