Spirometry: Use and Construction Of a Simple Classroom Device

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The biology of the human lung has become increasingly interesting to the layman and student. This may be due, in part, to news about smoking and lung cancer, the effect of high altitude on athletes, the rising incidence of respiratory diseases (emphysema, tuberculosis, bronchitis), and air pollution. This new-found interest in the respiratory system calls for a response in the biology classroom.

Spirometry experiments usually require the use of special instruments, which are generally beyond the purchasing power of the typical science department. This paper discusses spirometry in general and describes a simplified wet spirometer that can be used as a teaching aid in the study of the human respiratory system.

The response of my students to the experiments outlined here was encouraging. I found that 10th-grade boys were interested in measuring their vital capacity (defined below), and they actually competed for maximum displacement. At times they exhaled with such vigor that the better judgment of a teacher was required to restrain any superhuman efforts. Male athletes were always inquisitive.

Spirometry Theory

The lung-capacity device discussed here may be classified as a wet spirometer. (See fig. 1. Construction details are given later in the article.) The air, exhaled through a large-bore rubber tube, displaces the water; this forces the smaller tank to rise to a level proportional to the volume of air within.

The procedures described in this paper were developed when the author was teaching at Walkersville High School and Frederick Community College, Frederick County, Md. He is presently assistant professor of biology, Virginia Commonwealth University, Richmond 23220.

J. Hutchinson is credited with the development of the spirometer, before the turn of the century. He conducted many studies of the vital capacity of normal and diseased individuals. Later, G. Dreyer and H. F. West investigated the vital capacity and noted correlations between vital capacity and stem height (height of the body from the chair in a sitting position), body surface area, and total height (Dreyer, 1919; West, 1920). The vital capacity of a male, in cubic centimeters, was reported at that time to be 25 times the height of the subject, in centimeters. It was also reported to be 20 times the height for females and 29 times the height for athletes (Best and Taylor, 1945). Dreyer developed a series of classifications based on human physical characteristics and their respective associated vital capacities. He found that a vital capacity 15% below the expected class value usually indicated a pathologic condition. These early works are the basis for most of the spirometric techniques in common use today in both physiologic research and medical diagnosis.

Lung Volumes

Natural breathing—eupnea—is a quiet process, accomplished with ease. The air that the human being exchanges in normal breathing is known as tidal air. Tidal air represents a small percentage (about 10%) of the air that can be inhaled during deep breathing. The normal tidal volume (TV) is about 500 cc at a breathing rate of 12 exchanges a minute in the adult. At birth, the breathing rate is very rapid: 40 to 70 times a minute. At age one it has decreased to 35 to 40 exchanges a minute. At five years of age it is 25 a minute; at age 10 years, about 20 a minute; at 25 years of age, 16 to 18 times a minute (Pace, McCashland, and Landolt, 1965). Women breathe a little

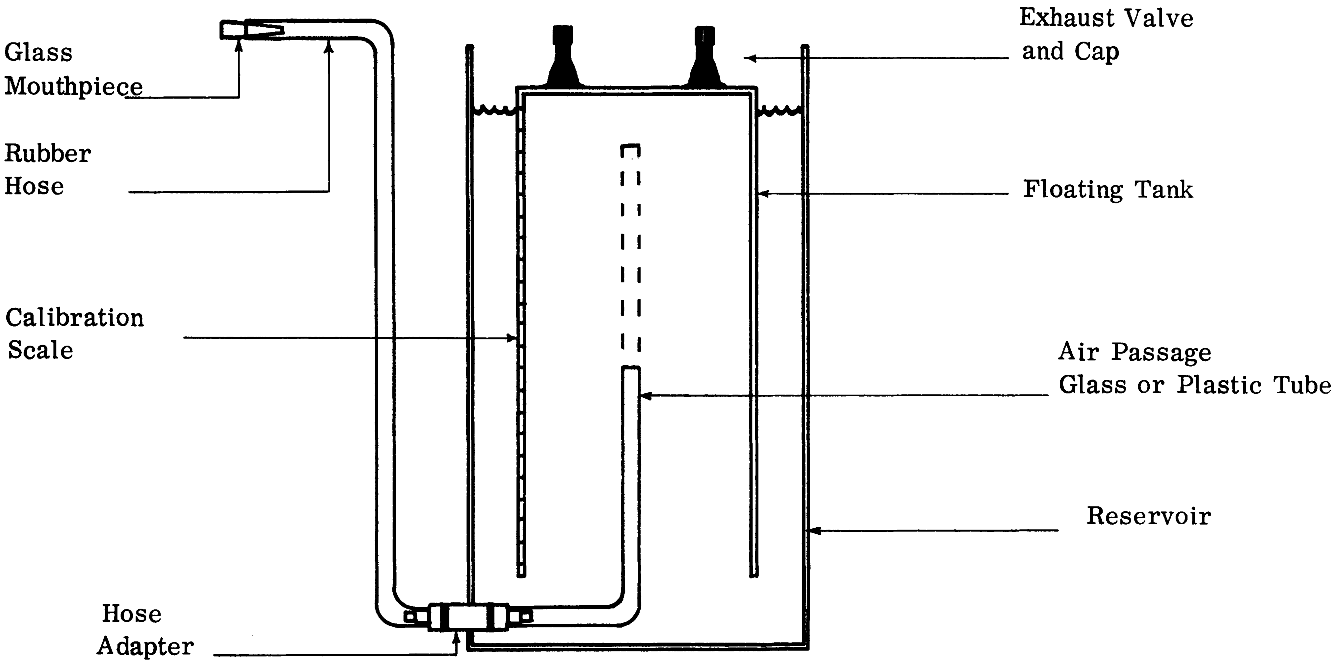

Fig. 1. Diagram of the wet spirometer. Ragged line near top of drum indicates water level.

more rapidly than men—approximately 2 to 4 more respirations a minute—but the tidal air of the female is less than that of the male: in a given period the male breathes more air than the female.

Inspiration capacity (IC) is defined as the volume of air the subject strenuously breathes inward following a normal expiration. This is normally determined after the subject has taken three normal breaths (tidal exchanges). IC includes only the amount of air pulled into the lungs from the beginning of the third breath and excludes the volume of air already in the lungs at the beginning of this breath. Therefore IC consists of the tidal volume (TV) and the inspiration reserve volume (IRV). The following equation summarizes the components of IC: IRV + TV = IC. In other words, IRV, which is approximately 3,000 cc for the typical adult, is the reserve capacity of the lungs, over and above their capacity for tidal air. At times the term complemental air is used to designate the inspirational air (Guyton, 1964).

After several normal respirations the subject expires as much as possible beyond a normal expiration. This volume is normally 1,100 cc in adults and is known as the expiratory reserve volume (ERV).

The most strenuous expiration will not remove all the residual air in the lungs. The residual volume (RV) amounts to 1,200 cc in adults. This air remains in the lungs because the alveoli cannot collapse as long as the intrathoracic pressure is negative. If the chest cavity is penetrated the lungs collapse, but some of the residual air will still remain in the air sacs. This is the minimal air, which is evidenced by buoyancy of the lung tissue in water. Because the lungs of a dead animal will float in water they are popularly known as the "lights." This is important in forensic medicine: it provides a test of whether an infant was stillborn or died after having breathed (Best and Taylor, 1945).

The sum of the expiratory reserve volume (ERV) and the residual volume (RV) is called the functional residual capacity (FRC). This is the air remaining in the respiratory system at the end of a normal expiration (FRC = ERV + RV). It is this air that allows the transfer of oxygen into the blood and of carbon dioxide out of the blood to be maintained at a continuous rate between inspirations.

From the spirogram (fig. 2) the maximum inhalation and maximum expiration may be noted. The total change in pulmonary volume between these two extremes is the vital capacity (VC)—in other words, the volume of air that can be forcefully expelled after forcefully filling the lungs to their greatest capacity (VC = IRV + TV + ERV). This volume in the normal person is about 4,500 cc. A well-trained athlete may have a vital capacity of 6,500 cc; a frail woman may have a vital capacity no greater than 3,000 cc (Guyton, 1965).

Vital capacity is a measure of the subject's overall ability to breathe. In breathing, two important factors are (i) the strength of the respiratory muscles and (ii) the resistance of the thoracic cage and lungs to expansion and contraction (Guyton, 1964). If the expanded chest is measured with a tape measure, the reading may bear a minimal relationship to the vital capacity. A subject with powerful chest muscles is capable of enlarging his thoracic cavity to a volume greater than his lungs are able to fill. At this time his diaphragm is drawn upwards and the viscera move into the thoracic cavity, due to a strong contraction of the abdominal muscles (Langley and Cheraskin, 1965). Altogether, the value of vital-capacity mea-

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surements in assessing the functional ability of the lungs is evident.

Spirometry in the Classroom

Each of my students was allotted, if he wished, three attempts to expel the air in his lungs into the wet spirometer. These attempts were made within a 15-minute period, and the values attained—distances the floating drum moved, indicating the volumes of air in the drum—were averaged.

We also compared the mean vital capacity of each class and of groups within each section. For example, we compared boys and girls, varsity and nonvarsity athletes, boys over and under 5 feet 10 inches in height, and smokers and nonsmokers. Comparisons of VC in the lying, sitting, and standing positions were attempted.

It was usually during this class activity that vital capacity was explained and the possible meanings of the measurement were discussed. The four definite divisions of lung volume (TV, IRV, ERV, RV) were presented. The relationship of physique and conditioning to vital capacity—for example, the change in VC over a period of time in members of the basketball team as they strengthened their physical condition through training—was either discussed or demonstrated.

Students designed short- or long-term experiments in which they tabulated data and attempted to draw conclusions or to indicate tendencies observed from the graphic representation of their data. Some students proceeded to compare their average, experimental VC with the value predicted by the following formula (Best and Taylor, 1945), which is based on the expected, standard VC for their body weight: $VC = \frac{W^n}{K}$, where VC is the vital capacity in cubic centimeters, W is the weight of the body in grams, K is a constant, always equal to 0.690, and n is always equal to 0.72. Therefore, to determine vital capacity, simply substitute the body weight in grams for W and the calculated answer will be the VC in cubic centimeters: $VC = \frac{W^{0.72}}{0.690}$.

Students were also told about diseased conditions that can alter the vital capacity: emphysema, pneumonia, poliomyelitis (in which the chest muscles may be weakened) and tuberculosis (which reduces the expansibility of the lungs). Other conditions, in-

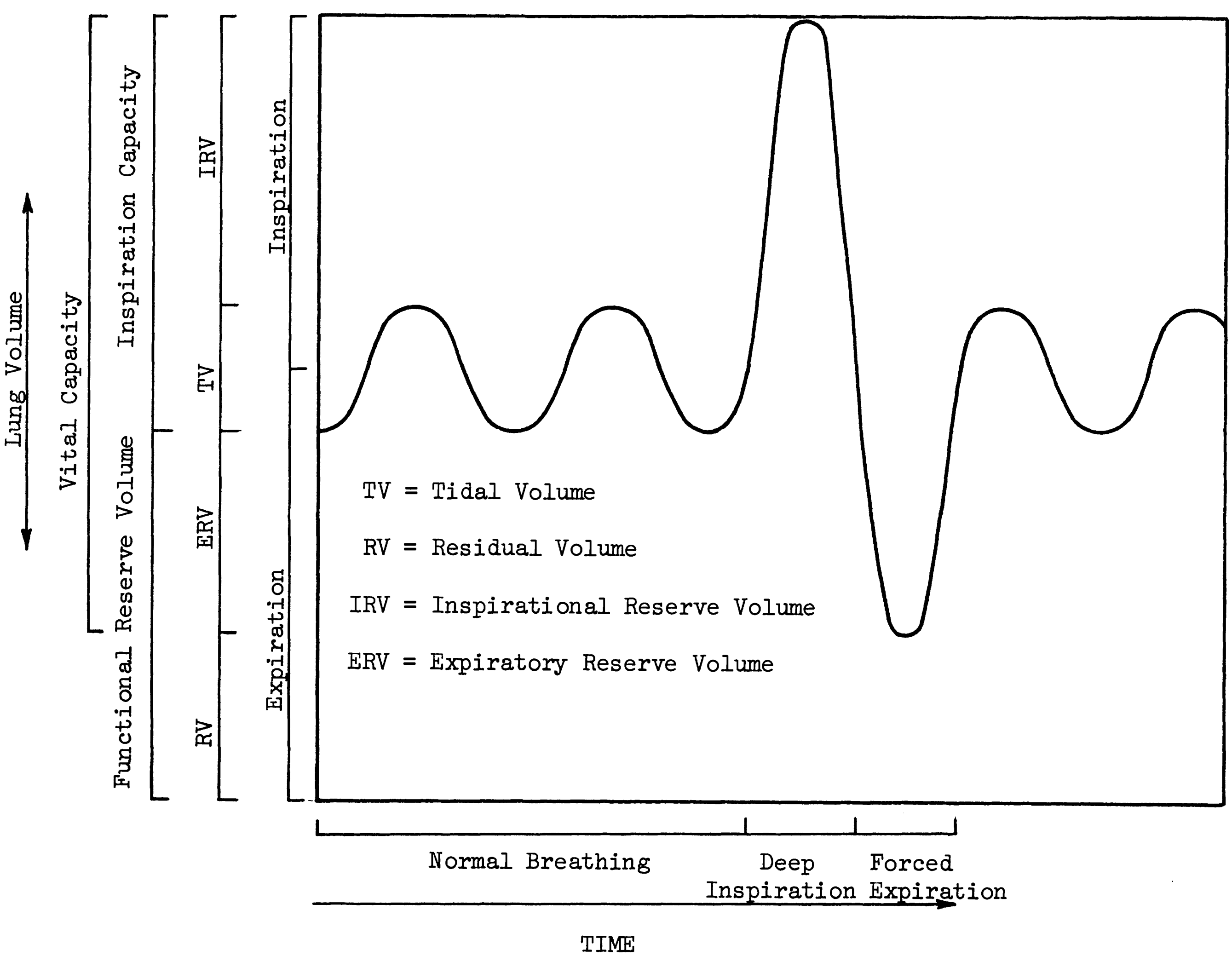

Fig. 2. A spirogram, with indicators of volume designations commonly used in spirometry.

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Fig. 3. A wet spirometer calibrated with meter sticks and used to determine vital capacity. The hose is fitted with a sterile glass mouthpiece.

cluding tumors and heart disease, have been found to reduce the vital capacity (Smith, 1935).

Construction Details

Most of the major equipment-supply companies sell both the water-displacement and direct-read, or proper, spirometer (respirometer). They are well constructed and accurate, but their price may be much greater than the cost of this do-it-yourself instrument, which is quite satisfactory for classroom needs. Mine cost less than $6.

The primary materials include two metal or plastic trash cans commonly sold in department stores. Their dimensions should be at least 28 cm deep by 21 cm in diameter. They should be nearly the same size. The difference in diameter should be such that the first, when inverted, will fit loosely within the second, with minimal clearance. Cylindric containers are easier to calibrate for volume than slightly tapered containers. The containers should be lightweight and free of leaks. The metallike coating commonly found on these containers usually inhibits rusting, but a coat of paint could be advantageous; or, of course, one might choose an aluminum container. Plastic aquarium cement, applied to the seams and joints, provides additional protection against leaks.

Drill a suitable hole for the air hose near the bottom on the side of the larger container, which is the reservoir drum. Place the rubber-tubing adapter in this opening and seal it. Now add the air-passage tubes to both sides of the rubber-tubing adapter and fill the drum with tap water. Local availability of materials will determine hose size, glass-tubing size, and air-tube connections. You may want to consider using plastic pipe or copper tubing, available from plumbing suppliers, as the air passage.

Invert the smaller container, the floating drum, and place it within the reservoir drum. The floating drum should be prepared with holes in the top to accommodate two automobile tubeless-tire valve stems, from which the caps and pressure valves (cores) have been removed.

The valve stem caps with their fine threads will serve to seal the valve openings. They are easy to unscrew, in order to exhaust the air which accumulates in the floating drum after each vital-capacity determination. Valve stems and caps may be obtained without charge from an automobile tire center or service station, because at times the stems become slightly damaged and must be replaced to maintain pressure in the tire.

Many construction modifications are possible. For example, you may want to exhaust the floating drum with stopcocks or even rubber stoppers.

The apparatus may be calibrated by various means. In general the "instrument" will be consistent and all measurements will be standard to that particular device. To take measurements for comparison with values given in the literature is beyond the intended capability of this device. The smaller tank may be calibrated by simply adding a known volume of water and marking the approximate level externally on this drum. Or meter sticks may be attached (fig. 3) and calibrated for volume change as the floating drum rises; or, more simply, the distance that the rising drum moves upward can be taken as a relative measurement.

If the air-flow tube is larger than 2 cm in diameter and extends above the water level, the tidal volume may be determined by breathing in and out. Sterile glass tubes 10 cm long serve as mouthpieces for each subject. Glass tubing with fire-polished ends may be autoclaved and will remain sterile in paper or aluminum foil; or it may be soaked in 95% ethanol for several minutes. Each person should have his own glass mouthpiece.

Only two individuals who used the apparatus had a vital capacity exceeding its measurement capacity. One was a well-known adult athlete, the other an outstanding high school basketball player.

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Two-Year-College . . . from p. 227

of excessive teaching loads and of inadequate technical and secretarial assistance take their toll of the teacher's time and energy. Many such biologists simply do not have the time and energy to devote to reading the latest journals (if, indeed, they are available) or to involvement in professional scientific societies. Their time is devoted to keeping abreast of the usual day-to-day operations of their classes.

To make matters worse: some biologists do not know that there are ways of improving their academic environment. They are not aware that many two-year colleges provide student assistants, technicians, and a reasonable teaching load. I think it behooves all of us, and especially organizations such as the National Task Force of Two-Year-College Biologists and the National Association of Biology Teachers, to inform these two-year-college biologists that there is a better way; and we must assist them in obtaining it. In order to increase the professional participation of two-year-college biologists and to upgrade the profession in general, each one of us must address himself to this need. Success in this task will bring about great rewards for all—especially for students. The challenge is great, the job is difficult, and time is short; so let's get on with it.

EXPERIMENTAL SCHOOLS BOOSTED

The idea of experimental schools, long advocated by the Nixon administration but only recently given grudging support by Congress, got a new boost when reports of two "forums" of authorities and laymen studying the nation's schools came up with the same idea.

The plea for experimental schools was made by two groups that had conducted preliminary studies for the recent White House Conference on Children —one chaired by Dwight Allen, dean of the University of Massachusetts School of Education, the other headed by John I. Goodlad, dean of UCLA's Graduate School of Education.

The Allen group, dealing with "Myths of Education," proposed a more imaginative use of existing resources rather than a reliance on vast sums to bring about reform. One of the myths it identified is the belief that "you can't change education without more money."

But the Goodlad forum, exploring "The Future of Learning," called for a "massive infusion" of government funds to develop experimental schools, reconstruct existing schools to apply known innovations, and create learning options outside of the present education systems. "In a diverse, complex society, our schools demonstrate almost monolithic conformity and enormous resistance to change," they said. "The schools have been great sorting machines, labeling and certifying those who presumably will be winners and losers as adults," the Goodlad group said. "The winners are disproportionately white and affluent. The losers, too often, are poor, and brown or black or red."

Report on Education Research

AFRICAN ECOLOGY TOUR

Six quarter-credits in ecology may be earned this summer by taking a four-week African ecology study tour offered by Colorado State University. The tour, limited to 20 participants, will visit game reserves and national parks in east, central, and southern Africa. Professional ecologists and park managers will lead field trips and conduct evening seminars concerned with the ecology and management of their respective areas. The participants will have an opportunity to observe and discuss African ecology in the field with eminent authorities of the areas visited. Detailed information concerning the tour (Aug. 10 to Sept. 6) may be obtained from the tour leader, Eugene Decker, College of Forestry, Colorado State University, Fort Collins 80521.

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