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PULMONARY FUNCTION TESTING IN OCCUPATIONAL MEDICINE

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PULMONARY FUNCTION TESTING IN OCCUPATIONAL MEDICINE

I. INTRODUCTION

The routine assessment of ventilatory capacity for pre-employment evaluation and periodic medical surveillance is becoming an increasingly common practice in occupational medicine. Combined with a careful history and physical examination, such pre-placement screening can identify the job applicant with pre-existing functional impairment or unusual susceptibility to airborne substances. Follow-up studies can facilitate the early detection of respiratory impairment at a stage when corrective measures may still be beneficial. The utility of screening spirometry has been recognized by the federal government. The passage of the Federal Coal Mine Health and Safety Act and the Occupational Safety and Health Act have lead to an increase in pulmonary function evaluation.

Nonetheless, not all employers have established screening programs or even identified workers at risk. Occupational Safety and Health Administration (OSHA) standards for general industry currently require such screening only for exposure to asbestos and coke oven emissions. However, Criteria Documents formulated by the National Institute of Occupational Safety and Health (NIOSH) assure it will eventually be required for numerous other substances as well. Presently, the U.S. Navy has mandated pulmonary function studies for asbestos, berrylium and isocyanates, but it too can be expected to adopt any future OSHA regulations.

Facilities that have instituted screening programs are beset by a multitude of problems. Technicians have been inadequately trained and tests are performed or calculated incorrectly. Spirometers may be inaccurate or technically unsatisfactory. Within any large organization methodology may lack standardization, rendering difficult the comparison of results obtained at different locations. Information derived under these circumstances may be worse than no information at all.

II. TECHNIQUE

Much attention has been focused on the specific tests of pulmonary function and the type of spirometer, but relatively little thought has been given to the single most important factor in successful spirometry - the skill and training of the technician. As Dr. Hans Weill stated in an article appearing in the September, 1973 issue of Journal of Occupational Medicine, "the personality, patience and perserverance of the pulmonary function technician will often determine the difference between a successful and unsuccessful program of pulmonary function examination." Such technician training can be accomplished at special courses, or through the direction of a knowledgable physician or senior

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technican, preferably in a well-equipped pulmonary function laboratory.

During the actual performance of spirometry, meticulous attention to detail is essential. The procedure should be explained to the patient in simple terms. A statement that you wish to test "how hard and how fast he can breathe" may not be physiologically precise, but it may be the only explanation necessary. At least one hour should have elapsed between the subject's last smoke or the administration of aerosolized bronchodilators. Pulmonary function studies should not be performed within two hours of the main meal. They should be postponed if the subject is acutely ill from any cause or has experienced an upper or lower respiratory tract infection during previous three weeks.

The subject should then be instructed to remove any tight clothing or dentures. He should sit or stand in front of the spirometer. The chin should be slightly elevated with the neck slightly extended. Under normal circumstances there is little difference in pulmonary function values whether the patient is standing or sitting. An exception is the grossly obese subject where the sitting value may be significantly lower. The use of a nose clip is recommended.

The subject should then be instructed to take the deepest possible inspiration from a normal breathing pattern, close his mouth firmly around the mouth piece and without further hesitation blow into the apparatus as hard, fast and completely as possible. Common errors at this point include failing to maintain an air tight seal around the mouth piece, pursing the lips as with a musical instrument or obstructing the mouth piece with the tongue.

After two practice attempts, three further tracings should be recorded and assessed for acceptability. (If) the technican believes the patient has not made a full inspiration prior to the forced expiration, has not put forth a maximal effort, (or) has not continued expiration for at least five seconds (or until an obvious plateau in the volume-time curve has occurred) that particular tracing should be repeated. Attempts marred by coughing should also be rejected. (Fig. 1). The variation between the largest and smallest forced vital capacity (FVC) of the three satisfactory tracings should not exceed 10%. (Fig. 2). From the three satisfactory tracings, the forced vital capacity and forced expiratory volume in one second (FEV_1) should be measured. The largest FVC and FEV_1 should be used in the analysis regardless of the curve(s) on which they occur. For example: in the calculation of $FEV_1/FVC\%$, the FEV_1 and FVC need not be from the same curve.

III. SELECTION AND CALCULATION OF SPECIFIC TESTS

Numerous criteria are available to assist one in the choice of appropriate pulmonary function tests. Briefly, the ideal test should be able to distinguish "normal" from "abnormal" with sensitivity, safety and reproducibility. The test should be effort independent, or if not,

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subject motivation should be assessable by a trained observer.

None of the usual spirometric tests available are "ideal" in the sense described, but certain indices have proven useful. These include the forced vital capacity (FVC), forced expiratory volume in one second (FEV_1), forced expiratory volume in one second as a percent of the total forced vital capacity ($FEV_1/FVC\%$), and forced expiratory flow during the middle half of the FVC ($FEF_{25-75\%}$).

FVC (Forced Vital Capacity)

The FVC is the maximal volume of air which can be exhaled forcefully after a maximal inspiration. (Fig. 3). For all practical purposes, the VC (vital capacity without forced effort) and the FVC are identical in most individuals. In patients with severe bronchopulmonary disease, however, the FVC is often smaller than the VC because of expiratory slowing, air trapping and hyper-inflation. In the absence of airways obstruction, an abnormal FVC is seen in "restrictive" disease - those conditions characterized by a decrease in lung volume. Extrapulmonary factors can contribute to the inability to achieve a full inspiration including chest wall deformities (kyphoscoliosis) or respiratory muscle weakness (polio, muscular dystrophy). Actual replacement of lung tissue by tumor or inflamatory exudate decreases lung volume thereby lowering the FVC. Stiffening of the lungs by either excess fluid or fibrosis interferes with full inspiration. Pulmonary fibrosis can be due to connective tissue disease (rheumatoid arthritis, lupus erythematosis) or the pneumoconioses (asbestosis, silicosis, berylliosis). It can also exist without apparent cause (idiopathic pulmonary fibrosis). With regard to the early detection of pneumoconiosis, the FVC is of variable utility. In asbestosis, the FVC has been regarded as the most sensitive indicator of early disease and is frequently impaired before there are radiographic abnormalities. Conversely, X-ray changes may be evident in the silicotic while the FVC is still normal.

FEV_1 (Forced Expiratory Volume in One Second)

The FEV_1 is that volume of air which can be forcibly expelled during the first second of expiration (Fig. 3). In those instruments where the chart recorder or kymograph is activated prior to expiration, the zero point for timing the FEV_1 must be determined by extrapolating the steepest portion of the volume curve back to the maximal inspiration volume (Fig. 4). The FEV_1 has been regarded as the most useful overall spirometric measurement and is abnormal in obstructive disease. In emphysema, resistance to airflow in the bronchial tree can result from airway collapse secondary to intrinsic airways disease and/or loss of elastic support from surrounding lung tissue. In asthma and chronic bronchitis, the bronchial lumen is narrowed by retained mucus and/or spasm of the bronchial musculature.

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FEV_1/FVC% (Forced Expiratory Volume in One Second as a percent of the Total FVC)

The FEV_1 can be expressed as a percent of the predicted normal value for FEV_1 or as a percent of the total FVC. (Fig. 3). By routinely calculating FEV_1/FVC% one can avoid a common mistake. This occurs in severe pulmonary restrictive disease where a reduction in FVC alone may falsely suggest airways obstruction. Normally one should be able to expire 70-80% of the FVC in one second, depending upon age and sex. For example, a patient with pulmonary fibrosis may have a significantly reduced FVC of only two liters; but in the absence of airways obstruction he should expire 80% of this forced vital capacity in one second. However, this volume would be only 1.6 liters or 50% of his predicted FEV_1 of 3.2 liters. Therefore, one could erroneously assume he has obstructive disease, when in fact only pulmonary restriction is present. The calculated FEV_1/FVC% (1.6/2.0) in this case is a normal 80%.

If ventilatory obstruction is present, an assessment of reversibility may be desirable. The patient is asked to inhale a nebulized bronchodilator such as isoproterenol. After five minutes the FEV_1 is repeated. An increase of 15% or more from the baseline value indicates an element of reversibility. Such information can have both diagnostic and therapeutic implications. Reversibility, particularly if it is complete or nearly so, favors a diagnosis of asthma (a disease more likely to be of occupational origin) rather than chronic bronchitis or emphysema. Reversibility is also indicative of probable improvement with bronchodilators.

Conversely, an individual with asthma may have normal pulmonary function studies on a given day. Inhalation of the cholinergic drug methacholine, can induce mild bronchospasm in asymptomatic asthmatics, allowing the correct diagnosis to be made. A decrease of 15% or more in the FEV_1 as compared to the baseline value is regarded as a positive test. However, to perform this procedure in the face of spirometrically obvious airways obstruction is not only unnecessary, but also potentially hazardous. Although neither isoproterenol nor methacholine inhalation are regarded as routine screening procedures, they can provide further useful information with little additional risk. Under no circumstances should either be performed without the supervision of an experienced physician.

$FEF_{25-75\%}$ (Forced Expiratory Flow during the middle half of the FVC)

The $FEF_{25-75\%}$ can be defined as the average rate of flow during the middle two quarters of the forced expiratory effort, i.e., from 25-75% of the vital capacity (Fig. 5). It was previously known as the MMF or maximal mid-expiratory flow rate. Compared to the FEV_1, it is more sensitive in detecting early airways obstruction and tends to reflect changes in airways less than 2 millimeters in diameter. It is in these smaller bronchi and bronchioles that airborne substances are thought to

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exert their initial deleterious effects; yet because they contribute only 15% to total airway resistance, considerable disease may be present in them without being reflected in the FEV_1. A diminished $FEF_{25-75\%}$ is frequently the only abnormality noted in the asymptomatic asthmatic or young cigarette smoker.

The $FEF_{25-75\%}$ has been regarded as less dependent on voluntary effort than the FEV_1, but unfortunately it is less reproducible. It is more susceptible to instrumental artifacts and its coefficient of variation (variability in the same individual) may be as great as 25% compared to 2-6% for the FEV_1 and FVC.

Due in part to this variability, the $FEF_{25-75\%}$ has not been designated by OSHA or the Navy as a required screening test. Although it can be easily calculated from the forced expiratory tracing, it must be interpreted only by a physician qualified to evaluate chest disease. No individual should be denied employment, transferred or referred for an exhaustive pulmonary evaluation solely on the basis of a decreased $FEF_{25-75\%}$.

The "normal" values for $FEF_{25-75\%}$ are age dependent. For individuals under 50 years of age, less than 75% of the predicted value may be abnormal. In those over 50, the "lower limit of normal" is 70% of predicted. In follow-up studies, where the individual functions as his own control, comparison must be made to the previously recorded highest value for that individual. A decline in $FEF_{25-75\%}$ of 20% or more may be significant.

Several additional tests should be mentioned primarily to discourage their use. The $FEF_{200-1200}$ is the flow between 200 and 1200cc of the vital capacity. Formerly known as MEFR or the maximal expiratory flow rate, it reflects changes in the large airways, but has little further to add to that information obtained from the FEV_1. Peak expiratory flow rates are significantly influenced by patient effort, are quite variable and provide less information than the FEV_1 or FVC. The MVV (maximum voluntary ventilation) is unpleasant, exhausting and very effort dependent. In addition, it cannot be performed adequately on some spirometers. Although sometimes required by law in the evaluation of pulmonary disability, it is not a useful screening test.

Correction to BTPS (body temperature, ambient pressure, saturated with water vapor) is an important step in the calculation of spirometric tests. This is necessary because the patient exhales the gas at body temperature (37°C) while the volume recorded by the spirometer is at a somewhat lower ambient temperature. This volume of gas recorded by the spirometer must then be multiplied by a factor to convert it to what it should be at normal body temperature (Table I). This usually increases the gas volume recorded by the spirometer by approximately 8%, but it may vary from 4-10% depending upon ambient temperature. This correction is particularly important in field studies where ambient temperature may

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vary considerably. Some manufacturers build in an automatic correction factor, either into the apparatus itself (electronic spirometer) or in the recording paper. The latter is acceptable, but less desirable than direct calculation of the conversion to BTPS.

IV. INTERPRETATION OF BASELINE AND FOLLOW-UP SPIROGRAMS

After the population at risk has been identified, baseline studies should be obtained, ideally prior to any work-related exposure. The decision as to whether baseline studies are "normal" is usually made by comparison with a set of published predicted normal values. Many physicians still use data derived by Kory and his associates from the 1960 VA - Army Cooperative Study of Pulmonary Function. This group contained a large proportion of smokers and its values generally run lower than those of Morris and co-workers published in 1971 by the American Review of Respiratory Disease. These were derived from a population of healthy, non-smoking men and women with relatively little exposure to air pollution. They are regarded by many as the preferred set of predicted normals (Figs. 6 and 7).

Abnormal functions are present when the:

1. FEV_1 or FVC is less than 80% of predicted; or
2. FEV_1/FVC% is less than 70%.

If a qualified physician is available for assessment of the $FEF_{25-75\%}$, its interpretation should be done according to the guidelines on page 4.

It must be pointed out the FVC and FEV_1 of non-Caucasians is approximately 15% lower than in whites of the same age and height; differences in the FEV_1/FVC% are not significant, however. Allowances for these ethnic differences must be made during pre-employment evaluations to avoid serious errors in interpretation. In non-Caucasians (blacks, Orientals), the predicted FEV_1 and FVC for any given individual should be multiplied by 0.85 to adjust for this 15% difference. No such correction is necessary for the FEV_1/FVC%. Before labelling any baseline or pre-employment studies as abnormal, they should be repeated in two weeks.

More sensitive than comparing the spirometric values of a particular worker with a set of predicted normals, is the longitudinal or repeat testing of the same worker over a period of time. Here he serves as his own control and follow-up values can be compared to changes in pulmonary function which might normally be expected with aging. In males, a 30 milliliter annual decline in FEV_1 and 25 milliliters in FVC can be attributed to normal aging. In females, it is 25 milliliters for both the FEV_1 and FVC.

In addition to the effects of age and disease, other sources of

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variability exist. The coefficient of variation, the change in any given subject repeatedly tested over a period of time, may be 2 - 6% for the FEV_1 and FVC. This variation includes both biological (fluctuating patient effort) and instrumentation (changes in calibration) factors. Comparing follow-up values obtained on different spirometers can be an additional source of error. This is a particularly serious problem in any large organization like the Navy where different spirometers are in use and where the work force is relatively mobile. There seems to be no solution to this problem at present; the ideal situation, the use of a single type of spirometer, is simply not feasible. An alternate approach would be utilization of appropriate "conversion factors". This would allow pulmonary function values obtained on different instruments to be expressed as if they had been done on one standard type of spirometer, e.g., a water-sealed Stead-Wells. Whether a compilation of such conversion factors will ever be published is presently a matter of conjecture. One of the references at the end of this manual, "Assessment of Ventilatory Capacity", describes the procedure for determining conversion factors.

The predictable pattern of daily and seasonal variation must also be considered. Measurements of pulmonary function are highest in the afternoon, and decline slightly during the evening hours. Values are also higher during the summer than the winter. If annual follow-up studies are contemplated, ideally they should be scheduled during the same shift and month.

In addition to accelerating the normal effects of aging, cigarette smoking may transiently alter certain pulmonary function tests, particularl. the forced expiratory flow rates. This effect may be particularly pronounced for an hour after smoking and one should wait this long prior to the performance of spirometry. Fixed airways obstruction eventually occurs in many smokers and hence one can generally expect to find lower values for FEV_1 and FEV_1/FVC% as well.

Given these variables and technical considerations what criteria should be used to decide if a given change is due to disease? For follow-up studies, comparison should be made with the previously recorded <u>highest</u> value for each test. This highest value may not necessarily have occurred during baseline or pre-employment testing. If the following changes are not clearly attributable to the effects non-disease related variables, they should be considered abnormal:

1. decline in the FEV_1 or FVC greater than 8%;

2. decrease in the FEV_1/FVC% greater than 6%; or,

3. FEV_1/FVC% less than 70% at <u>any</u> time.

Any abnormalities of either baseline or follow-up pulmonary functions should be verified by repeating spirometry in two weeks. If abnormali-

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ties persist, clinical assessment by a physician qualified to evaluate chest disease is essential.

It should be re-emphasized that pulmonary function tests are non-specific; one can seldom make a diagnosis based on spirometric findings alone. The total clinical presentation must be considered including the medical history, physical examination, chest X-ray and appropriate laboratory studies. Similarly, medical management in the occupational setting must be tempered by clinical judgment. It is seldom justifiable to deny an individual employment or transfer him to another job solely on the basis of minimally abnormal spirometry (Table II). Most abnormalities on these screening tests are not due to work-related disorders. Smoking, non-occupational lung disease, and variation in technique are more common causes of alterations in pulmonary function.

The necessity of maintaining complete medical records should also be underscored. Both pre-employment (baseline) and follow-up values must be inscribed on a flow sheet (Fig. 8). It is also advisable to incorporate the spirographic tracing itself into the worker's record.

V. INSTRUMENT SPECIFICATIONS

Various types of spirometers are available; many are technically satisfactory, but a significant minority are not. The following general guidelines on what constitutes an acceptable spirometer have been derived from currently available sources, including the NIOSH-ALOSH (Appalachian Laboratory for Occupational Safety and Health) Pulmonary Function Standards submitted to OSHA in 1977.

Volume - The volume capacity of the instrument should be 7 liters at BTPS. This is the chief inadequacy of the Air Shields Vitalor, an instrument designed primarily for monitoring hospitalized patients. It is not recommended for screening healthy young males. In addition, spirometers should be capable of accumulating volume for at least 8 seconds.

Accuracy-linearity - For measuring FEV_1 and FVC, the instrument should be accurate within 50 milliliters or within 3% of reading, whichever is greater.

Inertia + resistance - The instrument should have low inertia and offer low resistance to air flow. The combined effect of inertia and resistance may be assessed by measuring the back pressure in the tubing during the performance of the test. In a subject with a FEV_1 of at least 3.5 liters, back pressure at the mouthpiece should not exceed 10 cm of H_2O for longer than 0.5 seconds and 2 centimeters of water during the remainder of the maneuver.

Timing - The timing units of instruments so equipped should be accurate to within 3%, be capable of calibration in the field, and be actuated by exhalation of 50 milliliters or after an expiratory flow of 200 milli-

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liters per second has been achieved.

If a chart recorder or kymograph is used in the determination of FEV_1, it must be activated at least one second prior to the forced expiration to ensure operation at the proper speed.

Conversion to BTPS - The instrument or user of the instrument must have a means of correcting volumes to BTPS under conditions of varying ambient temperature.

Provision of a written tracing - The instrument should provide a tracing or display of either flow versus volume or volume versus time during the entire forced expiration. This is necessary to determine whether a patient has performed the test properly. The tracing should be of sufficient size such that hand calculations can be made (7.5 millimeters of chart per liter of volume and 20 millimeters of chart per second of time).

Calibration - The instrument should be capable of calibration in the field with respect to FEV_1 and FVC. Periodic recalibration of the instrument should be performed using a syringe or other known volume source of at least 2 liters. The frequency of such calibration will vary with the use of the spirometer. Instruments that provide electrical outputs proportional to volume and/or flow (electronic spirometers) should be calibrated at least daily according to the manufacturer's instructions.

VI. SPECIFIC TYPES OF SPIROMETERS

The water-seal spirometers, such as the Stead-Wells and Collins, are time-tested instruments and are frequently used as a standard to which other devices are compared (Fig. 9). Although they provide a high degree of accuracy and reproducibility, they require more technician sophistication, and are larger and more expensive than the commonly used bellows instruments. This latter group of spirometers replaces the water-sealed drum with a bellows apparatus. They include among others, the Vitalograph* by Vitalograph Ltd. (Fig. 10) and the Jones Pulmonar (Fig. 11). In most respects they compare reasonably well with the water-sealed instruments. Their advantages include portability, simplicity of operation and reasonable cost.

Recent years have witnessed the proliferation of several types of electronic spirometers (Fig. 12). These are of two basic designs. One type employs a turbinometer, the rotational speed of its blades being proportional to the flow of expired air. The other uses a thermistor, a hot wire which is kept at a constant temperature by an electric current. Expired air cools the wire and the current required to re-estab-

*The use of manufacturer's names does not constitute endorsement of a specific instrument by either the author or the Department of Defense.

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lish the original temperature is proportional to the flow rate. These electronic spirometers offer many conveniences including ease and rapidy of operation, digital readout of results and automatic conversion of values to BTPS. Inadequacies in certain models have been documented, however, and include alinearity, variability, lack of a written record, necessity of frequent calibration and relatively high cost. These weaknesses should not be taken as a general condemnation of electronic spirometers, however, and each instrument should be evaluated on its own merits.

Another innovation in the field was the introduction of the dry, rolling seal spirometer manufactured by Ohio Medical Products and Warren E. Collins, among others. A U-shaped silastic device is the method of sealing between the piston and the cylinder (Fig. 13). This plastic seal rolls freely upon itself during function testing and is responsible for the low resistance of these spirometers (Fig. 14).

The wide variety of available spirometers poses problems in deciding which one is right for your particular facility and purposes. Financial considerations are oftentimes of paramount importance, although a sub-standard spirometer at any price is no bargain. Acceptable instruments can be purchased for approximately $1,000. Prior to ordering any spirometer, one should review currently recommended standards for equipment specifications.

VII. CONCLUSION

The foregoing recommendations represent the essentials of a valid, practical pulmonary function screening program. Along with industrial hygiene practices, biological monitoring such as spirometry, comprise the core of any effective occupational health endeavor. Properly implemented, they will help fulfill the intent of the Occupational Safety and Health Act, "to assure safe and healthful working conditions for working men and women".

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APPENDIX A

PROCEDURE AND INTERPRETATION - A SUMMARY

1. Screening spirometry should not be performed if the subject:

   a. is acutely ill from any cause;
   b. has smoked or used an aerosolized bronchodilator within the past hour;
   c. has ingested a heavy meal within the previous two hours;
   d. has experienced an upper or lower respiratory tract infection during the past three weeks. (For example: influenza, severe "cold", "bronchitis", or pneumonia).

2. The procedure should be adequately explained to the subject.

3. The subject should be instructed to remove any tight clothing or dentures and to sit or stand comfortably in front of the spirometer. The chin should be slightly elevated with the neck slightly extended. The use of a nose clip is recommended.

4. The subject should be told to take the deepest possible inspiration, close his mouth firmly around the mouthpiece and without further hesitation, blow into the apparatus as hard, fast and completely as possible. Active coaching throughout the entire duration of the forced expiration is desirable to elicit maximum subject effort. Positioning of the lips around the mouthpiece should be checked.

5. After two practice attempts, three further tracings should be recorded. If the technician believes that the subject has not made a full inspiration prior to the forced expiration, not put forth a maximal effort or not continued expiration sufficiently long, that particular tracing should be repeated. Attempts marred by coughing should also be repeated. The variation between the largest and smallest FVC of three satisfactory tracings should not exceed 10%.

6. From the three satisfactory tracings, the FVC, FEV_1, and $FEV_1/FVC\%$ should be determined. The largest FVC and FEV_1 should be used in the calculations regardless of the curve(s) on which they occur. Transcribe results on the "Pulmonary Function Record" sheet under "observed" (Obs.). The tracing itself should also be maintained as part of the medical record.

7. If the tests are baseline studies, determine the predicted values from Morris et. al. and calculate the subject's percent of the predicted normal, and transcribe results on the record sheet. In non-Caucasians, the predicted FEV_1 and FVC should be multiplied by 0.85 to adjust for

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ethnic differences. No correction factor is necessary for the FEV_1/FVC%.

Abnormal functions are present when:

FEV_1 or FVC is less than 80% of predicted: or,

FEV_1/FVC% is less than 70%.

8. If the tests are follow-up studies, comparison should be made with the previously recorded highest value for each test. This highest value may not necessarily have occurred during baseline testings. If the following changes cannot clearly be attributed to the effects non-disease related variables or to the effects of aging*, they should be considered abnormal:

a. decline in the FEV_1 or FVC greater than 8%;

b. decrease in the FEV_1/FVC% greater than 6%.

9. Any abnormalities in either baseline or follow-up pulmonary functions, should be verified by repeating spirometry in two weeks. If abnormalities persist, clinical assessment by a physician qualified to evaluate chest disease is essential.

10. In those circumstances where screening spirometry is performed and interpreted without direct physician supervision or review, referral of the subject is mandatory when:

a. the baseline or follow-up values are abnormal as defined in 7. or 8. above and remain so after repeat studies in two weeks; or,
b. respiratory symptoms are present, regardless of pulmonary function values.

* In males, a 30 millimeters annual decline in FEV_1 and 25 millimeters FVC can be attributed to normal aging. In females, it is 25 millimeters in both the FEV_1 and FVC.

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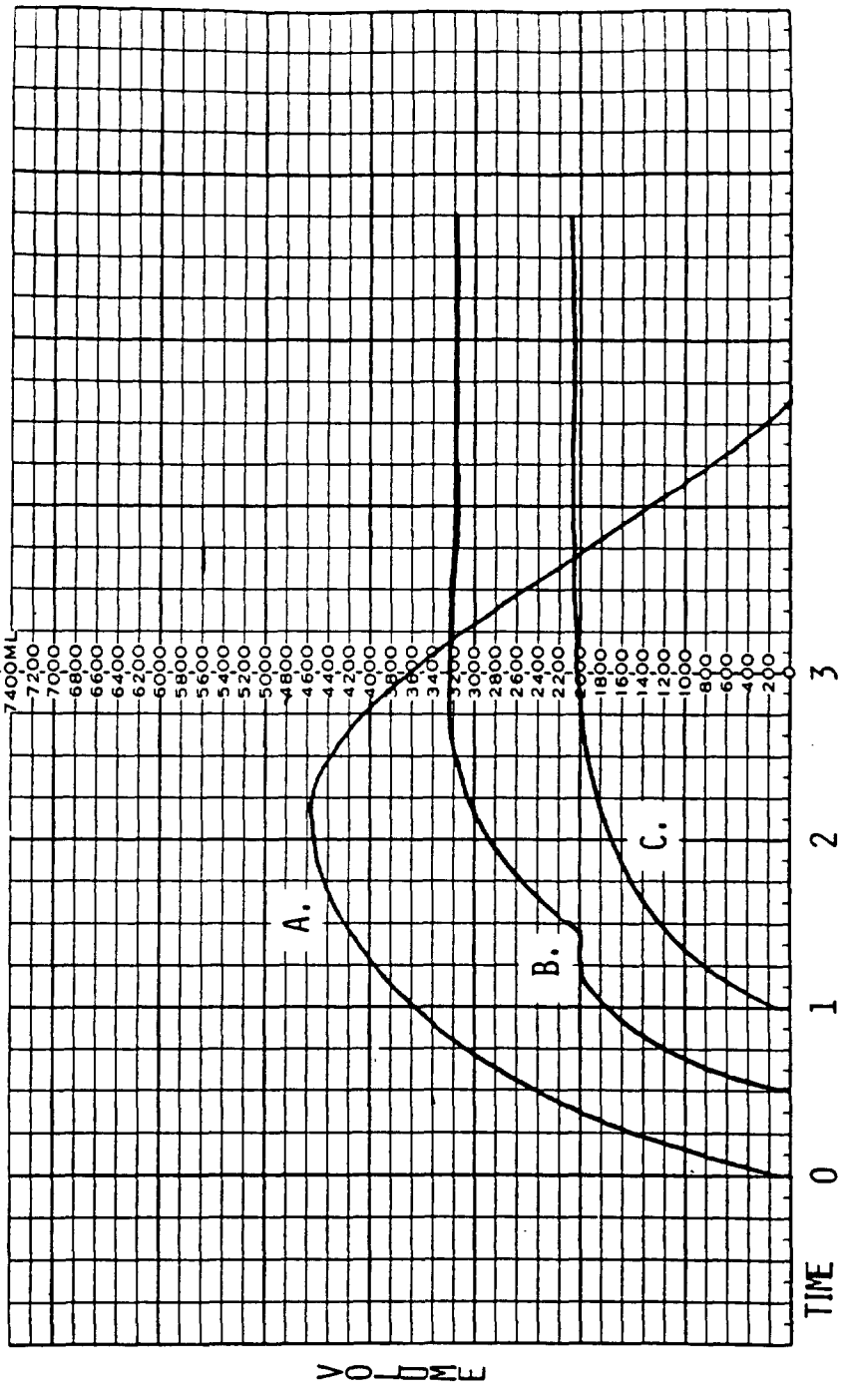

Figure 1. Three unacceptable tracings. A. Expiration too brief.
B. Cough. C. Inadequate effort.

FIGURE 1

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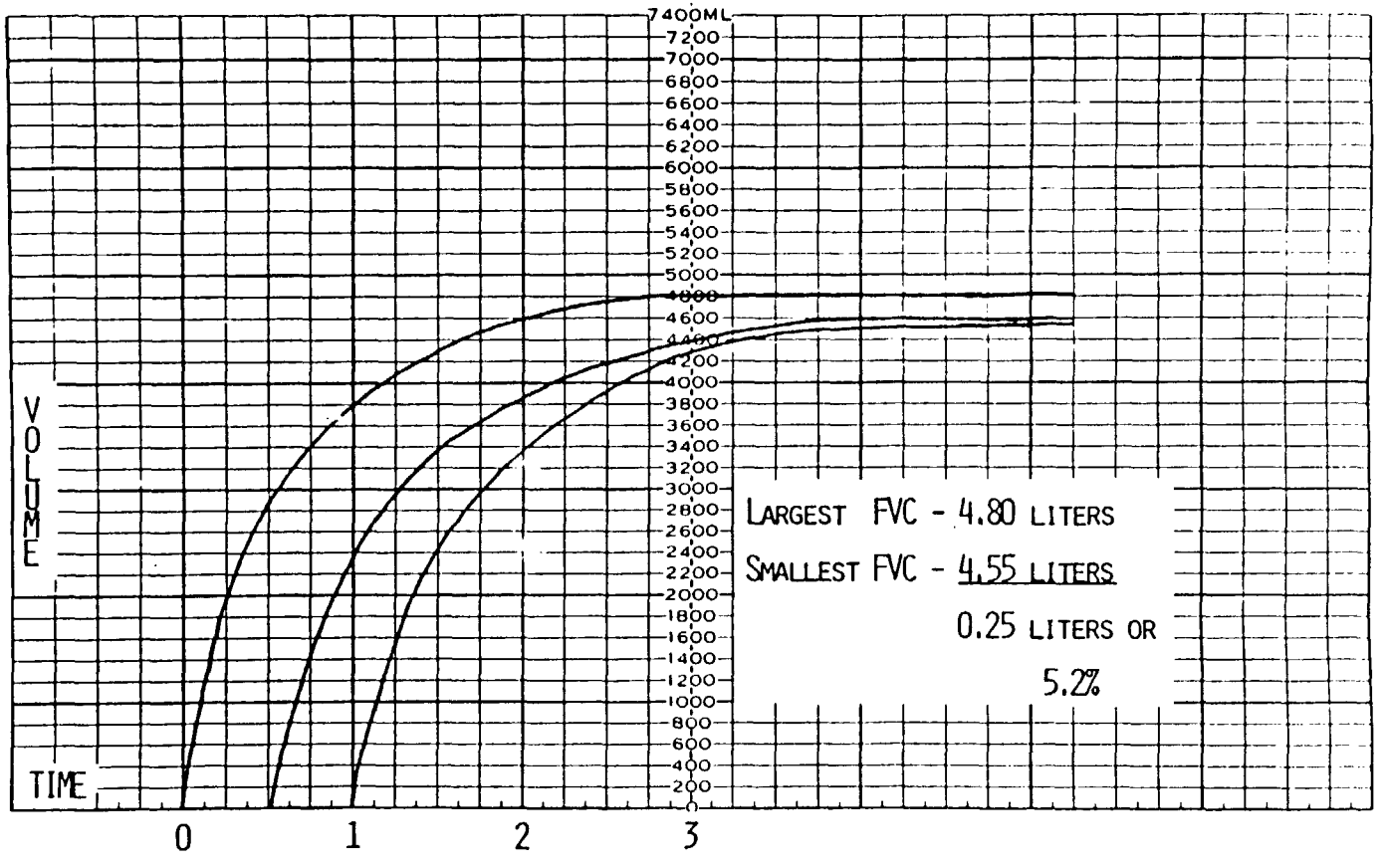

Figure 2. Three acceptable tracings. The variation between the largest and smallest FVC is less than 10%.

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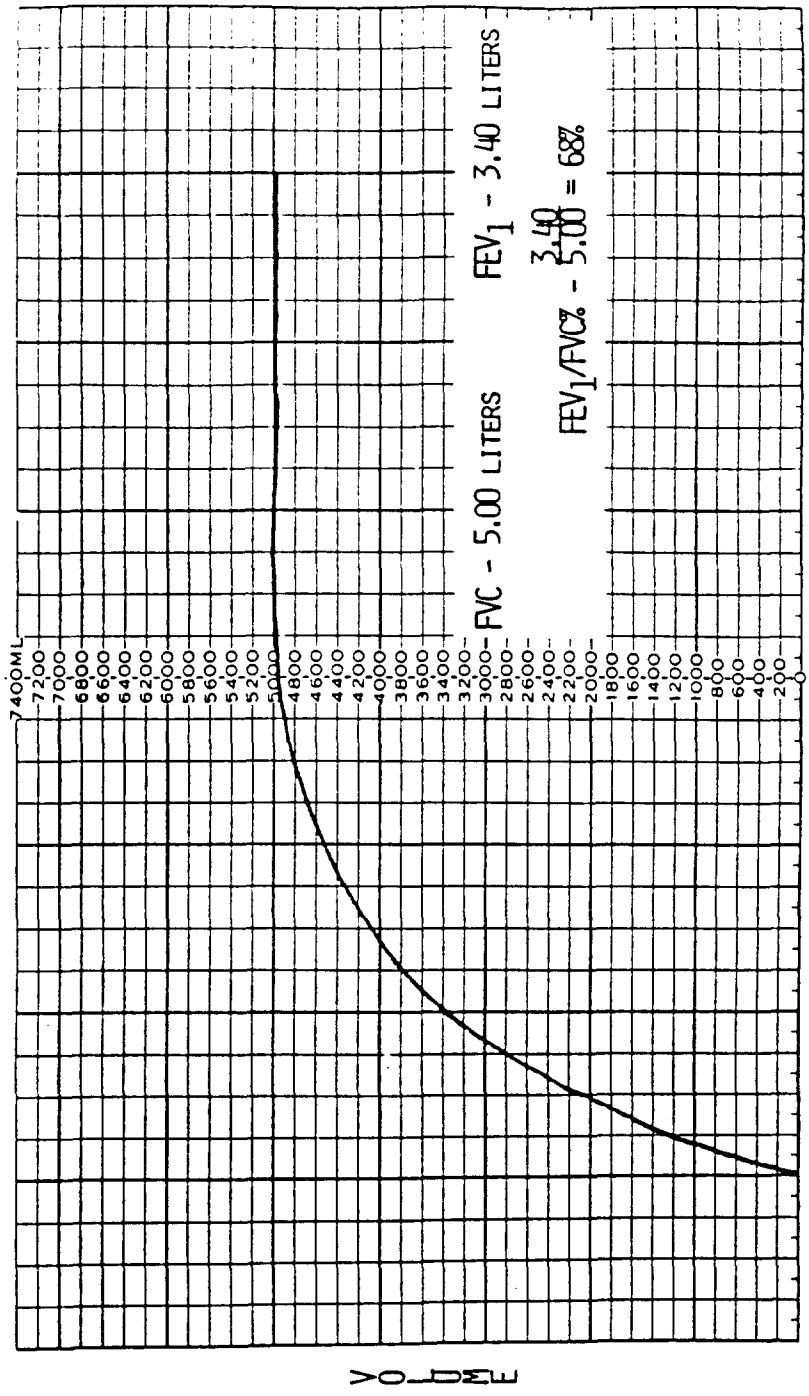

Figure 3. Determination of the FEV_1, FVC, and $FEV_1/FVC\%$.

FIGURE 3

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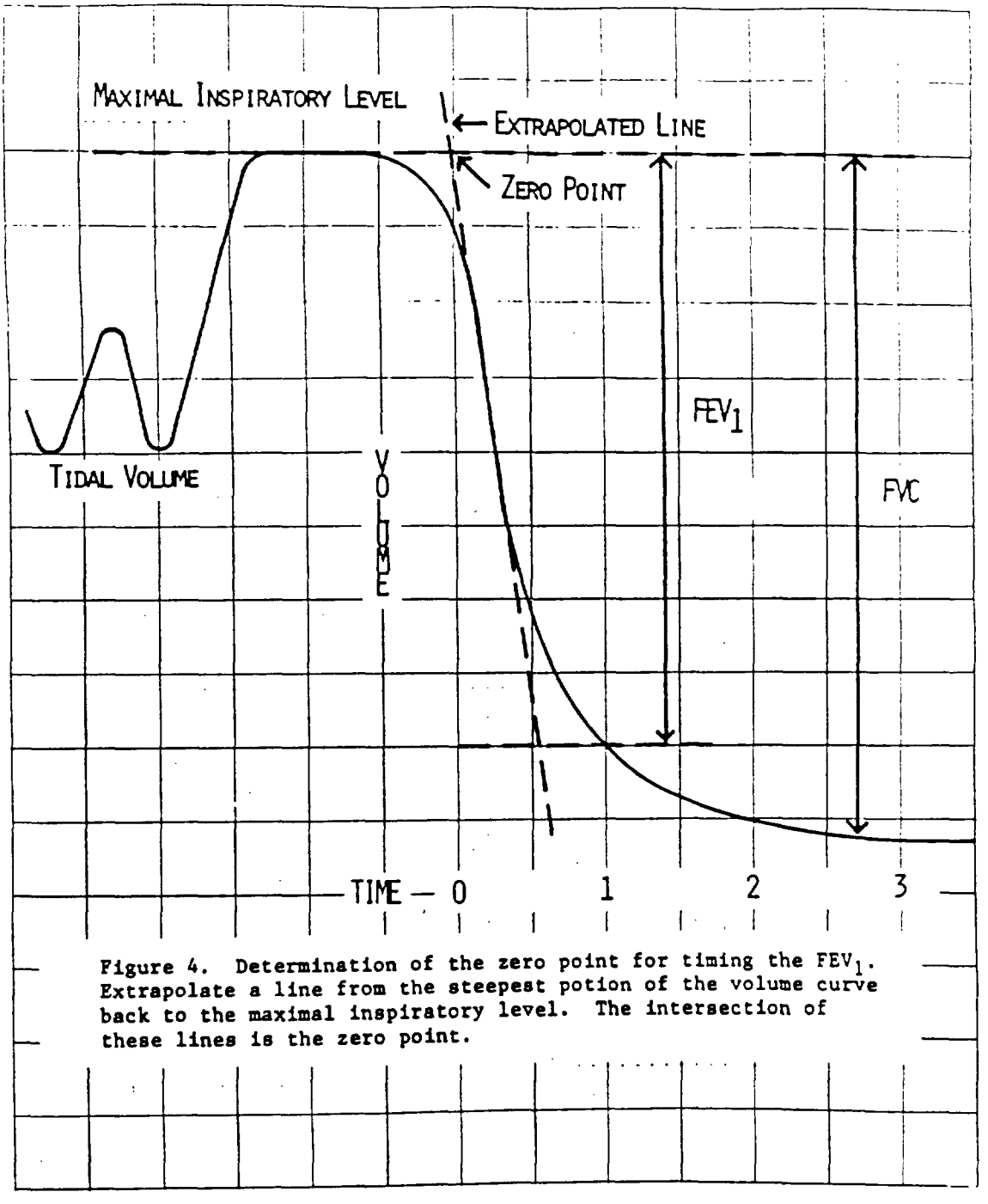

Figure 4. Determination of the zero point for timing the FEV_1. Extrapolate a line from the steepest potion of the volume curve back to the maximal inspiratory level. The intersection of these lines is the zero point.

FIGURE 4

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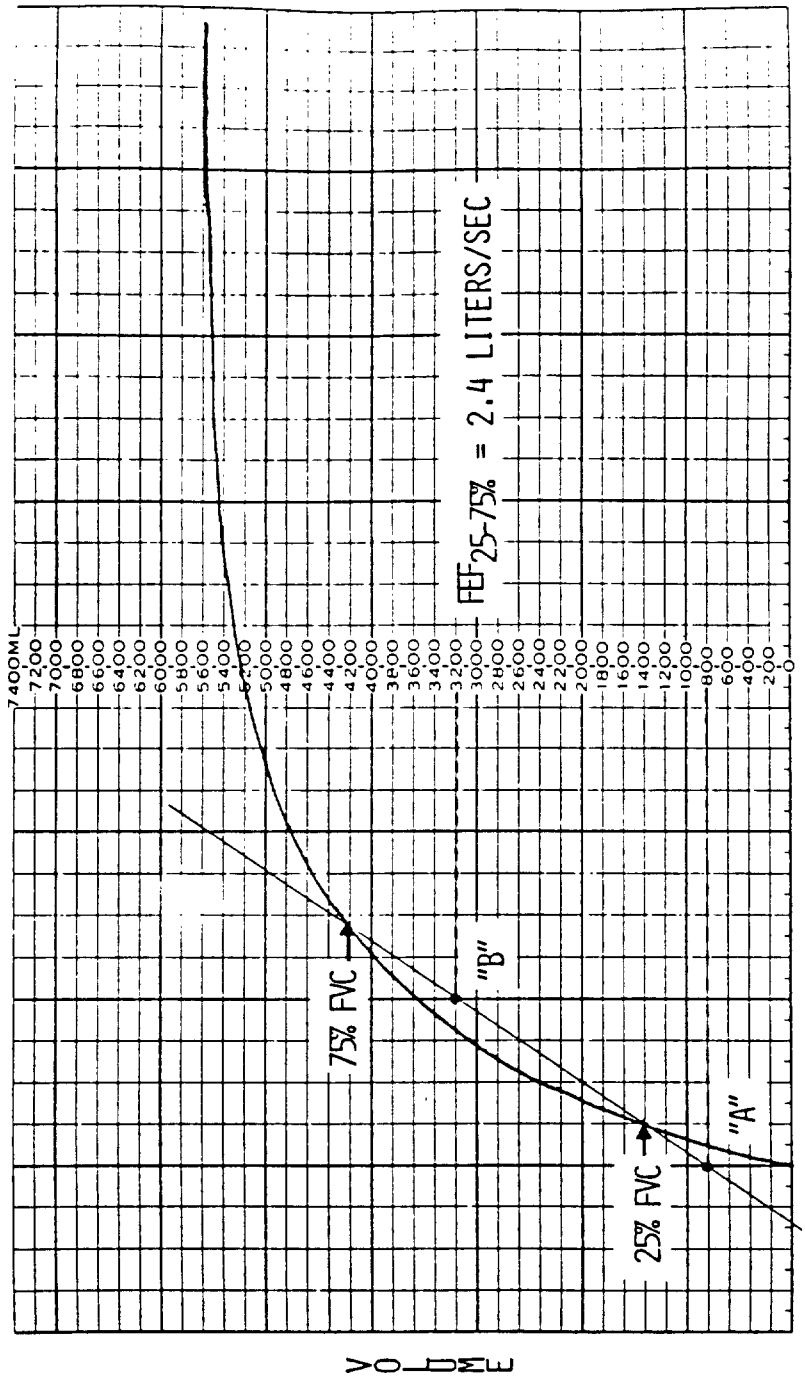


Figure 5. Determination of the $FEF_{25-75\%}$. Locate points on the tracing representing 25% and 75% of the FVC. Draw a line connecting these points and extend it to intersect adjacent time lines one second apart, points "A" and "B". The flow rate in liters per second can be read as the vertical distance between two points, in this case 2.4 liters/second.

FIGURE 5

APC 003557

Table I
FACTORS FOR CONVERTING GAS VOLUMES
FROM ROOM TEMPERATURE TO BTPS

Conversion factor	Gas temperature (centigrade)
1.114	18
1.111	19
1.102	20
1.096	21
1.091	22
1.085	23
1.080	24
1.075	25
1.068	26
1.063	27
1.057	28
1.051	29
1.045	30
1.039	31
1.032	32
1.026	33
1 20	34
1.014	35
1.007	36
1.000	37

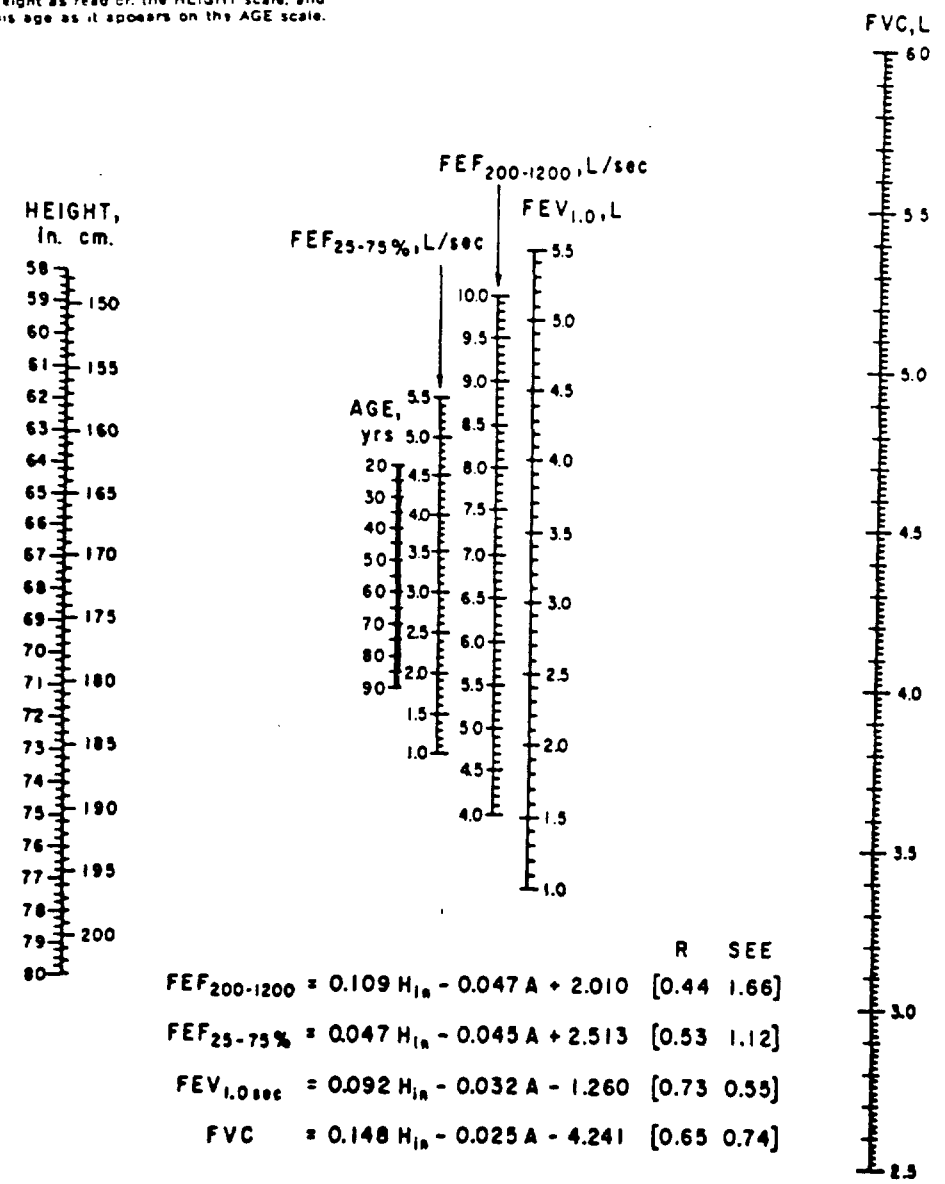
$$^{\circ}C = \frac{5(^{\circ}F-32)}{9}$$

TABLE 1

APC 003558

Spirometric Standards for Normal MALES (BTPS)

TO USE NOMOGRAM:
Lay a straight edge between the patient's height as read on the HEIGHT scale, and his age as it appears on the AGE scale.



		R	SEE
$FEF_{200-1200}$	= 0.109 H_{in} - 0.047 A + 2.010	[0.44	1.66]
$FEF_{25-75\%}$	= 0.047 H_{in} - 0.045 A + 2.513	[0.53	1.12]
$FEV_{1.0\,sec}$	= 0.092 H_{in} - 0.032 A - 1.260	[0.73	0.55]
FVC	= 0.148 H_{in} - 0.025 A - 4.241	[0.65	0.74]

Morris, J.F., et. al.: Amer.Rev.Resp.Dis., 103:57, 1971

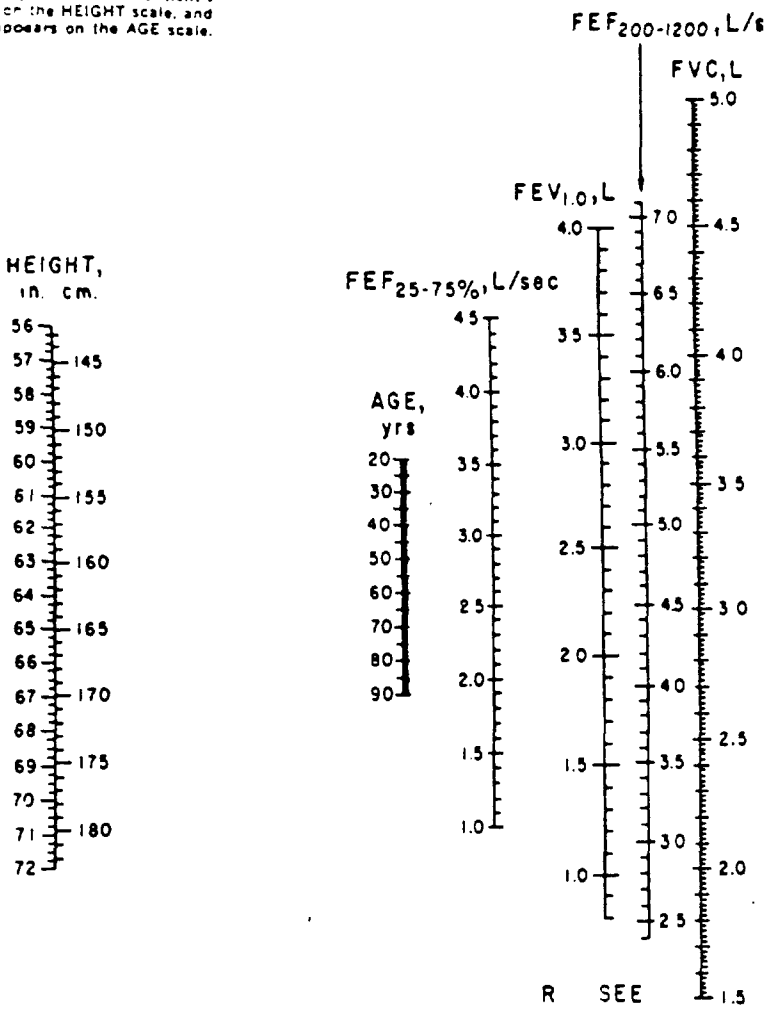
Note: The predicted FEV_1 and FVC in non-Caucasians must be multiplied by 0.85.

Figure 6.

APC 003559

Spirometric Standards for Normal FEMALES (BTPS)

TO USE NOMOGRAM:
Lay a straight edge between the patient's height as read on the HEIGHT scale, and his age as it appears on the AGE scale.



$FEF_{200-1200} = 0.145\,H_{in} - 0.036\,A - 2.532$ [0.53 1.19]

$FEF_{25-75\%} = 0.060\,H_{in} - 0.030\,A + 0.551$ [0.56 0.80]

$FEV_{1.0sec} = 0.089\,H_{in} - 0.025\,A - 1.932$ [0.73 0.47]

$FVC = 0.115\,H_{in} - 0.024\,A - 2.852$ [0.71 0.52]

Morris, J.F., et. al.: Amer.Rev.Resp.Dis., 103:57, 1971

Note: The predicted FEV_1 and FVC in non-Caucasians must be multiplied by 0.85.

Figure 7.

APC 003560

Table II
SPIROMETRIC GUIDELINES FOR THE
ASSESSMENT OF RESPIRATORY IMPAIRMENT

	Obstructive Disease $FEV_1/FVC\%$	Restrictive Disease $\frac{FVC}{FVC\ Pred.}\ \%$
Normal	≥ 0.70	≥ 0.80
Mild	0.61 - 0.69	0.66 - 0.79
Moderate	0.45 - 0.60	0.51 - 0.65
Severe	≤ 0.45	≤ 0.50

APC 003561

PULMONARY FUNCTION RECORD SHEET

Name _____ Date of Birth _____ Social Security No. _____ Race* _____

Sex _____

	Date	Spiro. type	Amb. temp. °C	Age	Ht. cm.	FEV_1 L	FVC L	FEV_1 % FVC	FEF 25-75% L/SEC
Obs.									
Pred.									
% Pred.									
Diff. (±%)									
Obs.									
Pred.									
% Pred.									
Diff. (±%)									
Obs.									
Pred.									
% Pred.									
Diff. (±%)									

	Date	Spiro. type	Amb. temp. °C	Age	Ht. cm.	FEV_1 L	FVC L	FEV_1 % FVC	FEF 25-75% L/SEC
Obs.									
Pred.									
% Pred.									
Diff. (±%)									
Obs.									
Pred.									
% Pred.									
Diff. (±%)									
Obs.									
Pred.									
% Pred.									
Diff. (±%)									

(Figure 3)

* Note: The predicted FEV_1 and FVC in non-Caucasians must be multiplied by 0.85.

APC 003562

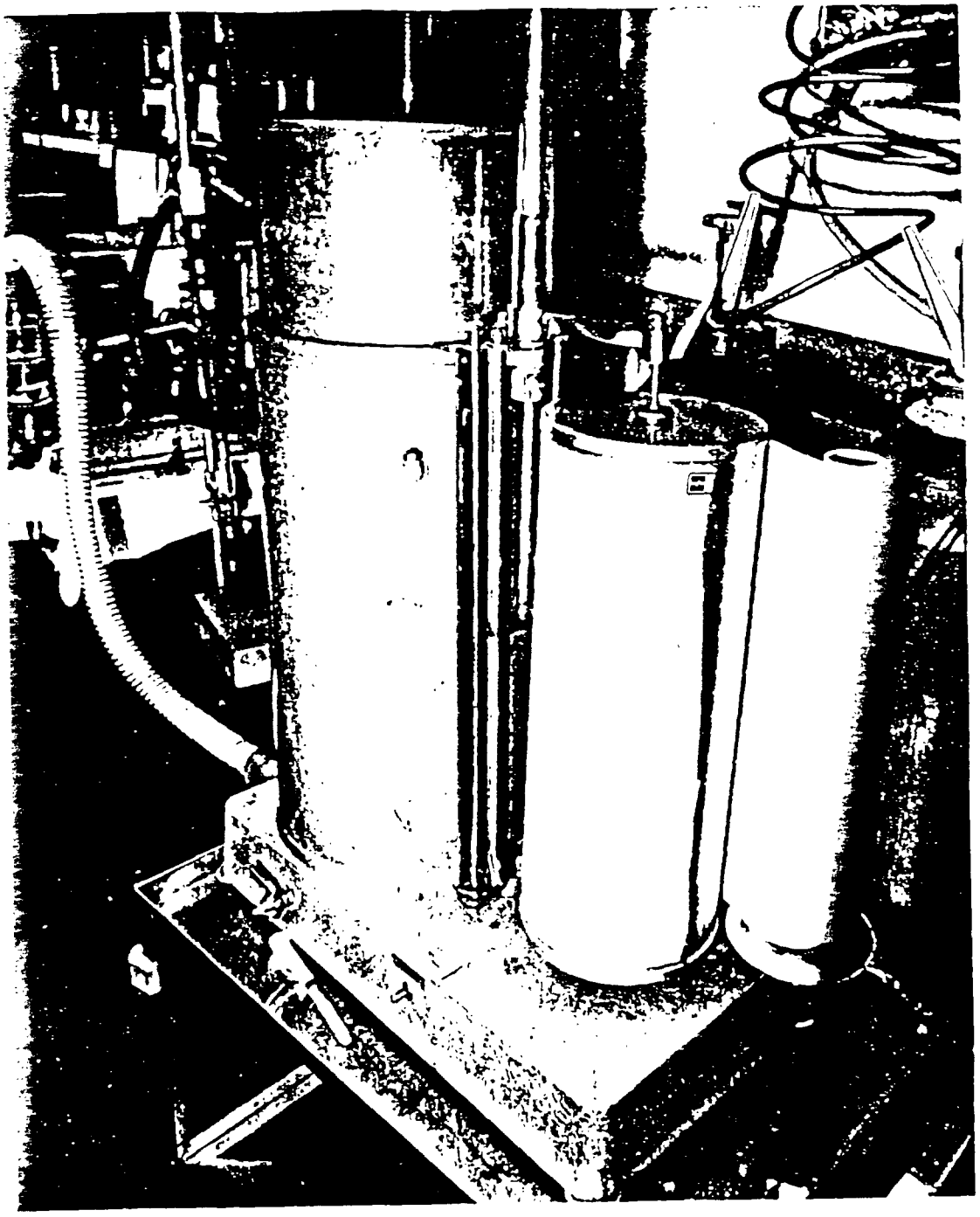


FIGURE 9

Collins water-seal spirometer.

non-Cauca ns must be mu lied by 0.85.

APC 003563

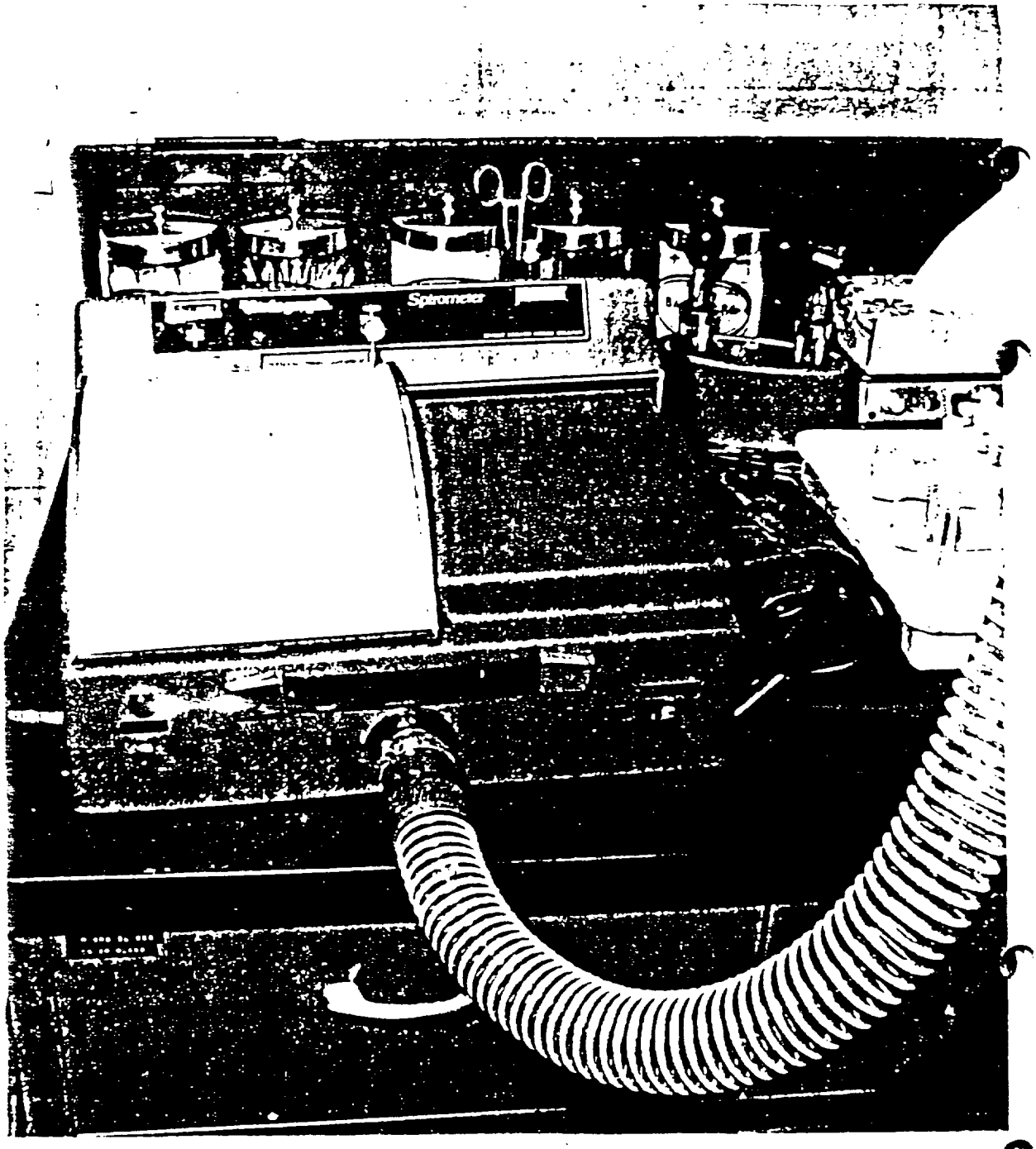


FIGURE 10

Vitalograph bellows spirometer.

APC 003564

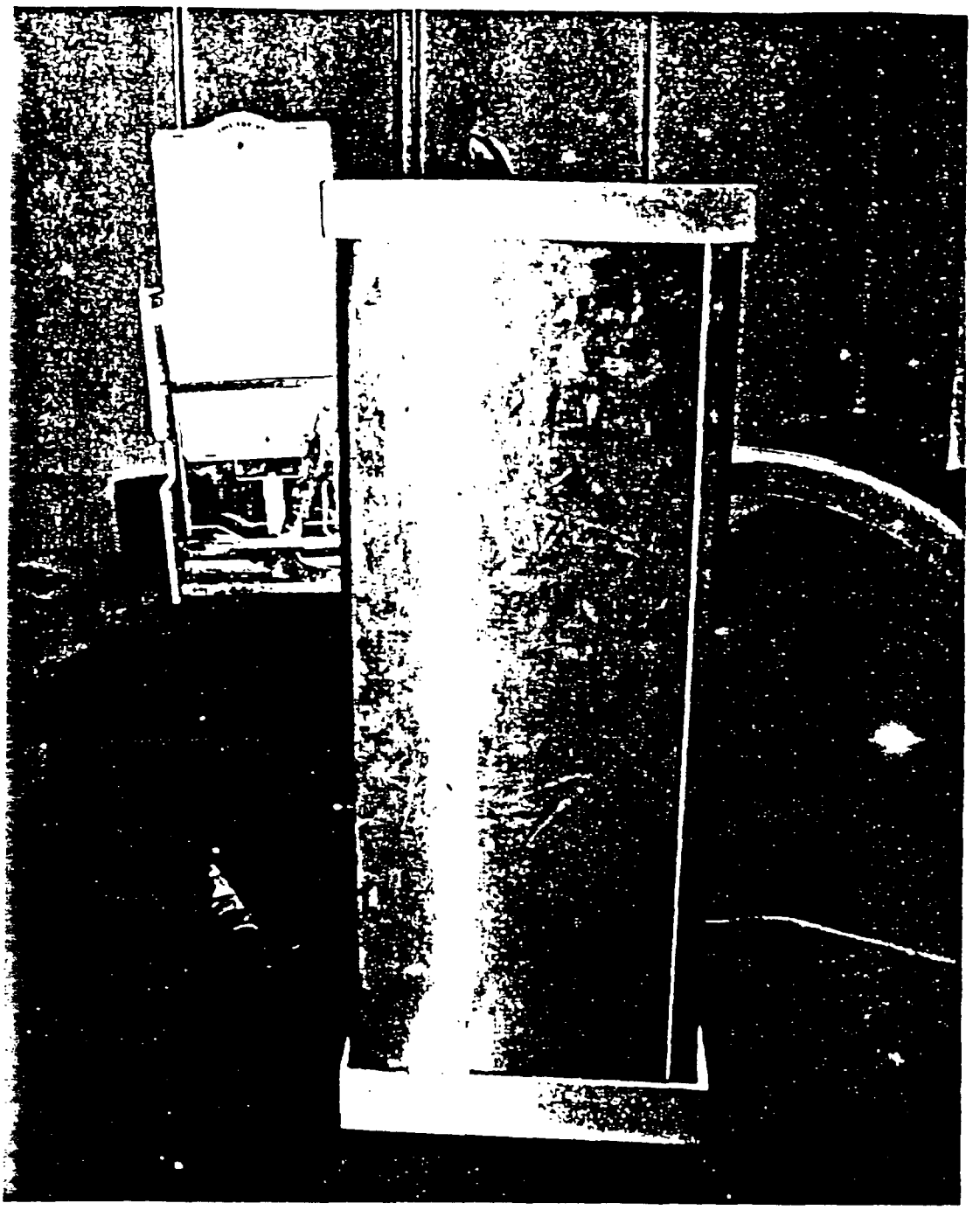


FIGURE 11

Jones Pulmonar.

APC 003565

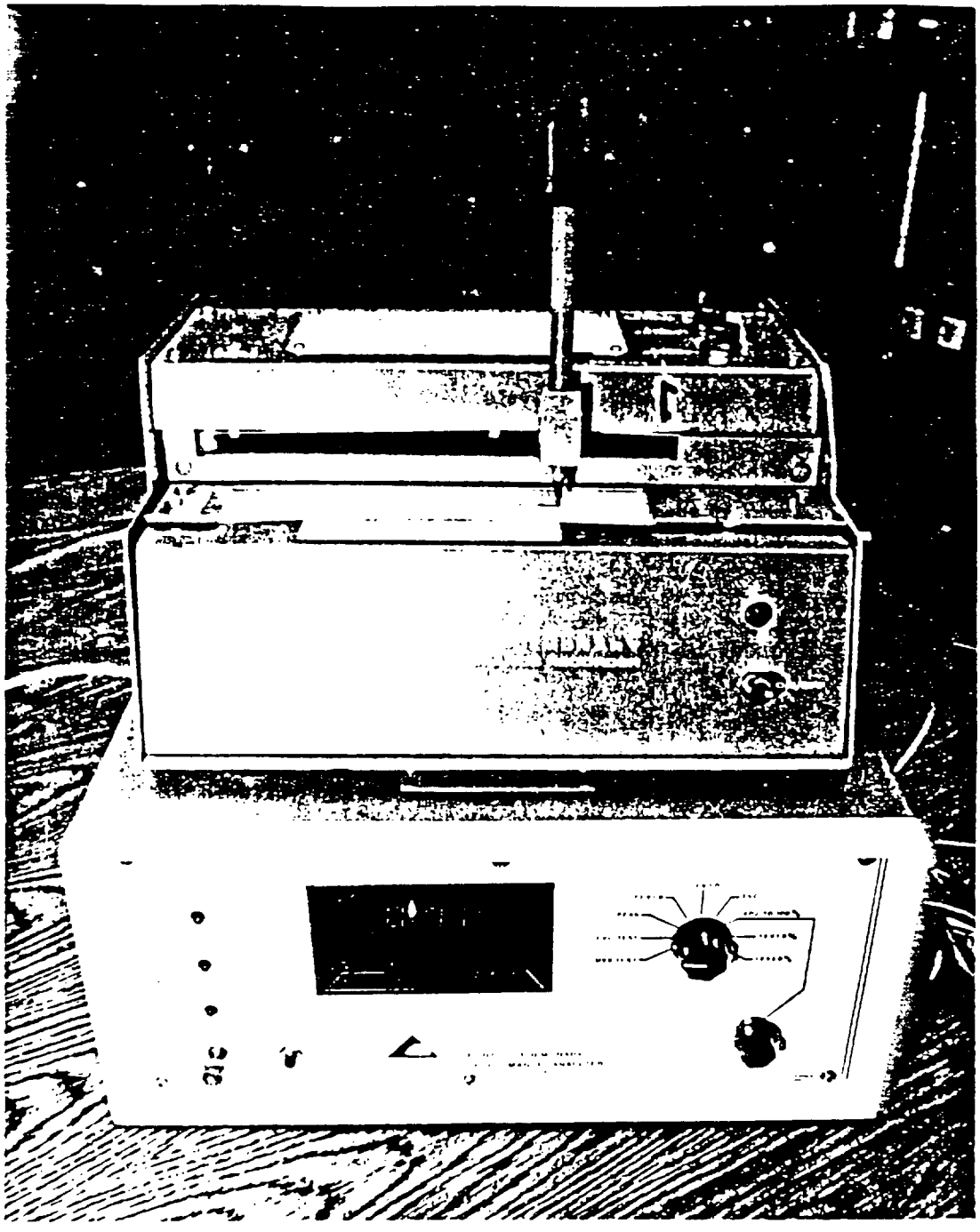


FIGURE 12

Donti electronic spirometer.

APC 003566

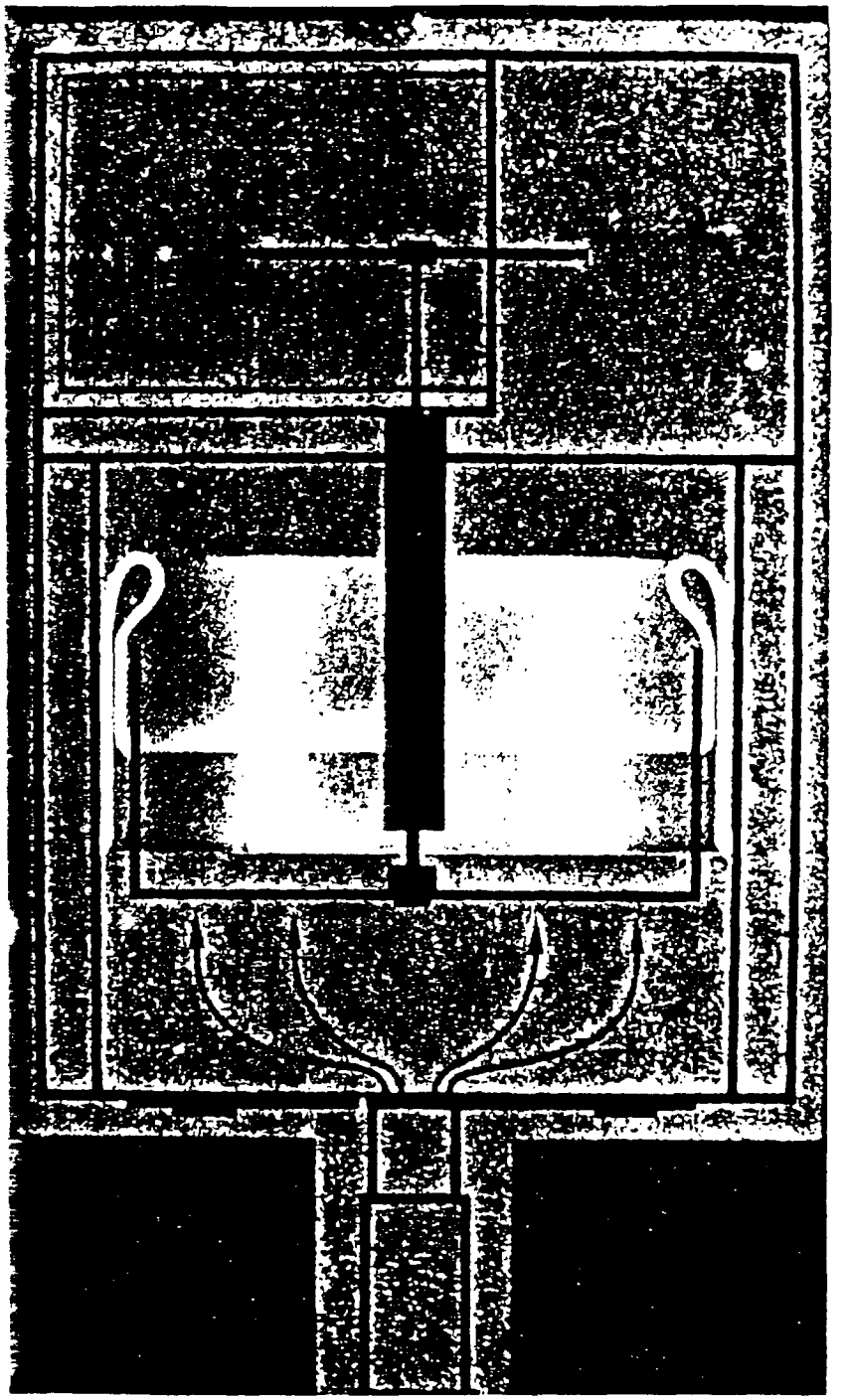


FIGURE 13

Dry rolling seal spirometer. Cutaway view demonstrating the U-shaped silastic seal between the piston and cylinder.

APC 003567

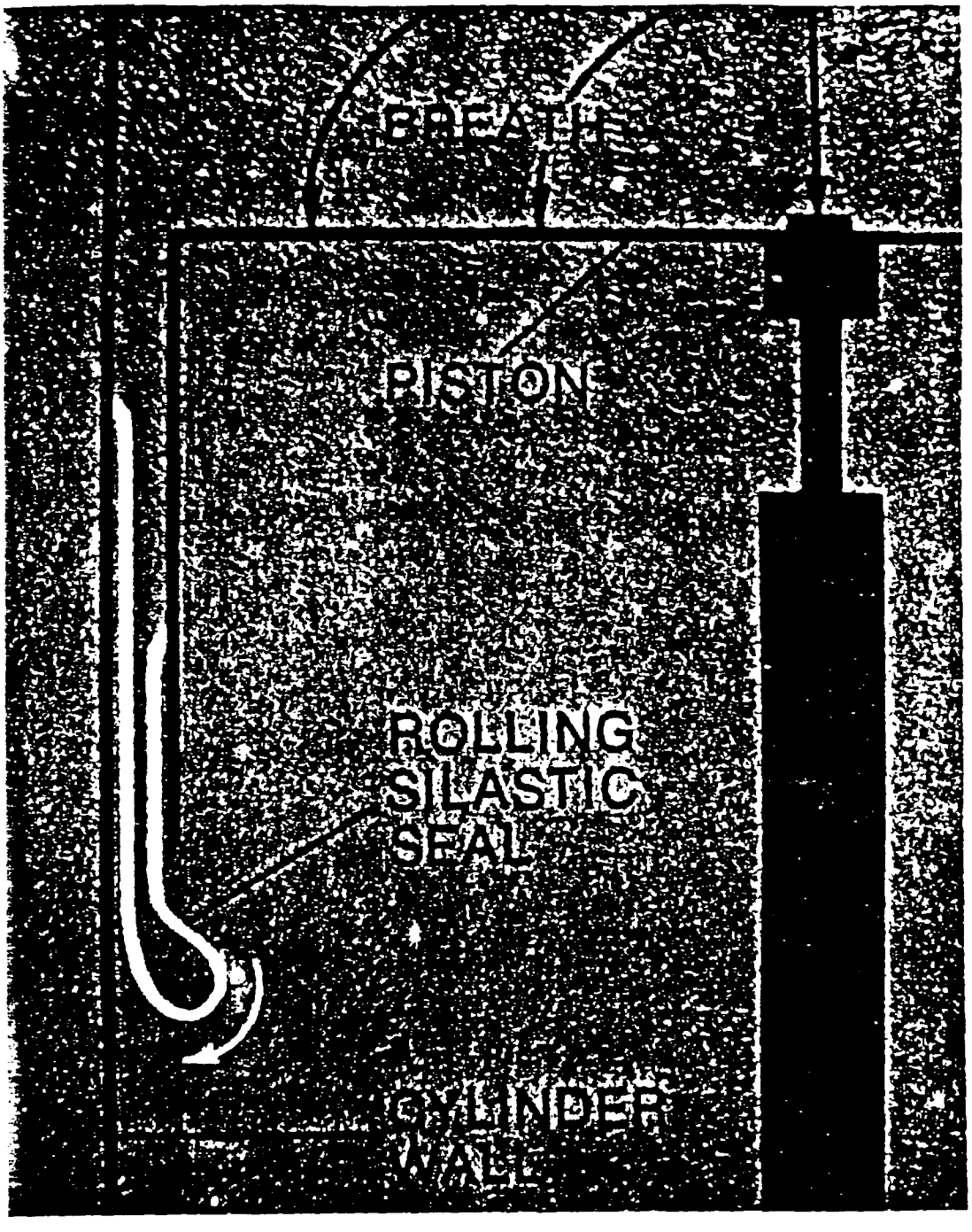


FIGURE 14

Plastic seal rolling freely upon itself during performance of spirometry.

APC 003568