Maximum Voluntary Ventilation Prediction from the Velocity-Volume Loop

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O f all the pulmonary function tests used to assess the mechanical capacity of the chest-lung complex, the maximum breathing capacity (MBC), or perhaps more correctly the maximum voluntary ventilation (MVV), test is one of the most useful tests of ventilatory capacity. Its usefulness as a diagnostic tool is somewhat compromised by the strenuous nature of the test procedure. There have, therefore, been a number of attempts to devise tests which are less demanding and which still provide as meaningful a measure of functional mechanical capacity. In this search for a substitute for the demanding MVV test, it is not surprising that there have been attempts to predict the MVV from less strenuous procedures. Bernstein and Kazantzis used both the inspiratory and the expiratory fast vital capacity curves to predict the MBC with considerable reliability. We here report a technique for predicting the MVV from a maximum velocity-volume (V-V) loop. Not only is the reliability of prediction good, but from this same simple test procedure a number of other measures of pulmonary function may also be ascertained.

Procedure

Apparatus

The V-V loop may be constructed by plotting temporally aligned values from any simultaneously recorded breath velocity and volume patterns. The construction of the loop is accomplished by feeding the signals from the velocity and volume transducers into the two axes of the cathode ray oscilloscope from which a loop may be recorded photographically. The apparatus used in the present studies and details of the techniques are described elsewhere. In brief, the Servospirometer (or Wedge spirometer) provides both velocity and volume transduction. These two signals are fed into the y and x of the cathode ray oscilloscope respectively. For permanent records, the trace is photographed.

Testing Procedure

Measured MVV: The tests were performed by inspiring from the atmosphere through a full face mask fitted to a low resistance Hans Rudolph valve and expiring into a 50 L. Douglas bag. The volume of air exhaled into the bag was measured by evacuating, to a constant negative pressure, into a Tissot spirometer or through a dry gas meter. Because the MVV varies with a number of factors, considerable care must be exercised in any experiment where MVV data are to be used quantitatively. The precautions which we observe have been detailed in a previous publication and will, therefore, not be repeated here. In the present experiments, the MVV was determined at a number of breathing frequencies. Details for assuring maximum performance with regulated breathing frequencies are also included in this previous publication. MVV was measured at 20, 40, 60, 80, 120, 150 and 200 breaths per minute.

V-V Loop: The subject was asked to inspire maximally from and expire maximally into the Servo- or Wedge spirometer as rapidly as possible. Complete lung filling and emptying during these inspiratory and expiratory vital capacity maneuvers was assured by asking the subject to "strain" at both ends of the breathing cycle. If this precaution was not taken, the loop was frequently not closed due to a difference in the inspiratory and expiratory volumes. In actuality more than a single breath was usually used. It was observed that there
was occasionally a difference between these loops and a loop from the first breath. Usually, therefore, two breaths were used and the photographic record was made of the second breath. A typical forced vital capacity (maximum) V-V loop from a normal subject is shown in Fig. 1.

![Figure 1: Trace of velocity volume (V-V) loop from forced inspiratory and forced expiratory vital capacity. In this and subsequent figures the horizontal straight line is zero velocity and the loop envelopes have been carefully traced from original photographs. Original photographs do not reproduce well.](image)

If a maximum V-V loop is recorded and the subject, without removing the mask, performs a series of maximum breaths such as are used in a routine MVV test, the resultant MVV loop may be subsequently photographically superimposed on the maximum V-V loop.

Two such superimposed loops are shown in Fig. 2. As seen in these reproductions, there was a frequent overshoot of the maximum V-V envelope by the MVV loop. For the purpose of the following presentation of the prediction technique, this overshoot will be ignored. Its possible cause and relationship to the predicted MVV will be treated in the discussion below as extensively as present knowledge of the phenomenon permits.

**The V-V Loop and MVV Prediction**

**Rationale:** If V is constant over a volume interval, V1 - V2, then the corresponding time interval may be calculated from

\[ T_1 - T_2 = \frac{(V_1 - V_2)^2}{A} \]  

where A is the area under the curve. If V is not constant, the application of (1) will yield an approximation to the true value. The equation (1) above, for simplicity, may be stated

\[ T = \frac{V^2}{A} \]  

where T is the time for both inspiratory and expiratory phases of a breath, V is twice the volume of the breath because the breath is moved both in and out of the lungs, and A is the area of the V-V loop of the breath. It should be stressed that this formula is true only when V is constant and is a reasonable approximation only when V is reasonably constant. For our purposes in MVV prediction from the V-V loop, described below, the approximation, judging from the congruence of predicted and measured MVV values, would appear to be quite good enough.

The relationships between breath velocity, breath volume and "time" make possible a prediction of the MVV for any breathing frequency from the single maximum inspiratory and expiratory efforts recorded in the maximum V-V loop. The V-V for these predictions is described below.

As in the method of Bernstein and Kazantzis it is assumed that air exchange is made over that portion of the vital capacity yielding the highest ventilation. In the use of the V-V loop what this means, of course, is that when a tidal volume is assumed it must be ascertained as to where on the vital capacity axis this volume can be
moved in the shortest time, thus yielding the highest breathing frequency and largest predicted MVV for this tidal volume. This minimum time is found by finding the location of the assumed tidal volume on the vital capacity axis where perpendiculars at the inspiratory and expiratory ends of the tidal volume embrace the largest combined inspiratory and expiratory areas. That this need not include the largest inspiratory or expiratory area is shown diagrammatically in Fig. 3. Also shown here is the large difference in area (and therefore time and predicted MVV) that may be obtained by placing the tidal volume at different positions on the vital capacity axis. There is the obvious necessity, then, of placing the tidal volume at the optimum position on the vital capacity axis.

From previous experimentation and from superimposition of the maximum V-V loop and MVV loops at several different breathing frequencies there is justification for the above rationale in MVV prediction. As seen in Fig. 2, ignoring for a moment the envelope overshoot, the MVV loop follows the contour of the envelope and then breaks away abruptly and follows a course almost perpendicular to the volume axis until intercepting the envelope limits of the other breath half cycle. The placement of the tidal volume on the volume axis to provide for delimiting the largest area is also apparent. The procedure for determining the optimum placement of the assumed tidal volume on the vital capacity axis in the MVV prediction is shown below.

**Family of Curves Showing Optimum Limit of Inspiration for Each Tidal Volume**

The maximum V-V loop is recorded on a grid to facilitate velocity and volume measurements. To measure area, the loops were enlarged to provide a 20 cm. distance for the vital capacity. This was most easily done by placing the polaroid picture in a photographic enlarger and changing the focal distance till the desired size was obtained. The dim loop outline was then traced directly on coordinate paper. The vital capacity was divided into 20 volume units and the area subtended by each volume unit estimated by multiplying the volume unit by the average breath veloc-

![Diagram](image_url)

**Figure 3:** Diagrammatic sketches showing difference in area subtended by perpendiculars drawn at inspiratory and expiratory ends of a given tidal volume placed at different levels on vital capacity volume axis.
ity over the lung volume change. For simplicity, unit values were used and then, after addition of the areas from the several volume units representing the tidal volume used, the unit areas were corrected to true V-V values by means of a conversion factor relating the 20 volume units to the actual vital capacity. Once the areas delimited by the 20 volume units were estimated, the remainder of the MVV prediction procedure went very rapidly, for now a series of 20 area figures was used and those included in the specific volume range under consideration simply added to find the total area subtended by that assumed tidal volume.

The optimum limit of inspiration (i.e., the percentage of full inspiration at which an inspiration must cease to yield the largest tidal volume) or, as it has been previously referred to in this discussion, the optimum placement of the tidal volume on the vital capacity axis, is found for a progression of tidal volumes. Tidal volumes of 20 per cent, 30 per cent, 40 per cent, 60 per cent and 80 per cent of vital capacity were used. A tidal volume is selected and then placed on the vital capacity axis with the limit of inspiration sequentially at 100 per cent, 95 per cent, 90 per cent, 80 per cent, 70 per cent, and 50 per cent of full inspiration. At each limit of inspiration, perpendiculars to the volume axis are drawn at each end of the tidal breath and the enclosed area found. Actually as described above, this is much simplified when the total area is represented by 20 area values for the 20 units of vital capacity. Using the formula developed above (2) the time for moving the breath at this limit of inspiration is calculated. From this information the maximum number of breaths possible for the tidal volume at this limit of inspiration is obtained. These data are plotted as shown in Figs. 4 and 5. The limit of inspiration is then moved to another point and the procedure repeated. Thus for each tidal volume one curve of a family of curves

![Figure 4: Family of curves showing swept fraction as related to limit of inspiration and breathing frequency.](image-url)
is plotted. As seen in Figs. 4 and 5 a family of curves shows the optimum limit of inspiration for each tidal volume.

For the data reported here a family of curves was constructed for each experiment. Actually, for normal subjects the curves are so similar that for routine testing the limits of inspiration to use for each tidal volume in MVV prediction may be obtained from a single average family of curves with negligible error involved.

Predicting the MVV: Having determined the optimum limit of inspiration for each breathing frequency it becomes possible to construct a predicted MVV breathing rate curve. One of a series of tidal volumes is selected and by interpretation from the optimum limit of inspiration curves, placed on the vital capacity axis with the inspiratory end at the proper limit of inspiration. Perpendiculars are erected at either end of the tidal breath and the embraced area measured and the time for the complete breath and the MVV calculated. This procedure is repeated for each of the selected tidal breaths in the series. When plotted on MVV-breathing rate coordinates the predicted MVV curve over a wide range of breathing frequencies is constructed.

RESULTS AND DISCUSSION

Predicted and Observed MVV Relations

The V-V Loop is, in a sense, another form of the forced inspiratory and expiratory fast vital capacity curves used by Bernstein and Kazantzis1 for predicting the MVV. However, because volume is plotted against velocity, rather than time as in the fast vital capacity curves, several additional pulmonary functions parameters may be assessed from the V-V loop.

Typical relationship of the predicted and observed MVV breathing rate curves are shown for three subjects in Figs. 6, 7 and 8. For all subjects for breathing rates of 80 and over the predicted MVV was larger than the measured MVV. This same re-
relationship was found using another MVV prediction technique. Also observed in these and the previous experiments, whereas the predicted MVV continued to increase with increasing breathing frequencies, the measured MVV at breathing rates in excess of 100-120 breaths per minute was universally observed to fall with increasing breathing frequencies. As pointed out previously and as observed in the present experiment (see Figs. 6-8, for examples), however, at the higher breathing frequencies (80-120) the observed and predicted MVV values bear a rather constant relationship to each other. It is seen, therefore, that the measured MVV may be estimated with considerable accuracy from the predicted values to obtain MVV values to compare with those customarily obtained.

However, there seems no real reason why the predicted values themselves should not be used. It has been our experience that a satisfactory maximum V-V loop is much more easily obtained than a satisfactory MVV measured by conventional techniques. Whereas a satisfactory maximum V-V loop was usually obtained in the first try if the subject had been properly instructed, this was not true for the MVV measurements. When MVV values for a number of breathing frequencies are obtained it is obvious when the value at one breathing frequency is too low. To obtain smooth MVV breathing rate curves the MVV test at a given breathing frequency sometimes had to be repeated several times. In previous experiments with trained subjects we obtained very good reproducibility in MVV measurements made at different times. With untrained subjects as used in the present experiments such reproducibility is not easily obtained. We have found it much easier to reproduce V-V loops than MVV measurements. It seems reasonable therefore, to use the predicted MVV value per se since it is usually a more reproducible value than the measured MVV.
**MBC V-V Loop Overshoot:** As seen in Fig. 2 the MVV V-V loop frequently somewhat overshoots the maximum V-V loop. Since by the method of its production the maximum V-V loop should represent the highest velocity attainable at all lung volumes it follows that the MVV V-V loop should not show velocities in excess of those shown in the maximum loop. In Fig. 9 are shown the results of an interesting experiment which bears upon this point. A maximum V-V loop is recorded and then during the expiratory portion of the second breath the breath is expelled by forced coughing. These cough velocities are seen to occur consistently somewhat overshoot the maximum envelope.

**Figure 9:** Trace of maximum V-V envelope and velocity volume relation of forced coughing during expiratory phase of breath.

In Fig. 10 are shown the results of another pertinent experiment. An MVV effort was made with midposition (end expiration) intentionally moved from near residual to near full inspiratory volume. At every volume range there was significant overshoot of the expiratory portion of the maximum V-V loop. Although this trace shows only expiratory velocity overshoot, it also occurs with slower maximum efforts on the inspiratory side of the V-V loop (Fig. 10). The experiment shown in Fig. 10 differed from that shown in Fig. 9 in that the chest-lung complex was in "oscillation," as it were, and the overshoot is seen to be considerably greater.

From the limited data available to us it appears that the maximum V-V loop does not necessarily represent the maximum velocity attainable at the various lung volumes. Moreover, it appears that when the chest-lung complex is "oscillated," as in breathing frequencies of 150 per minute and above, the overshoot of the maximum V-V envelope is greater. It should be pointed out that breathing frequencies of even 250-300 breaths per minute are still somewhat below the suspected resonate frequency of the chest-lung complex of 6-10 cycles per second. The overshoot, it appears then, is probably not related to resonating frequencies but rather to the approach to a given velocity-volume point on the envelope from a zero or low velocity point.

The relation between the maximum V-V loop and the loop overshoot observed during MVV maneuvers, coughing, and rapid forced breathing, may be explained by the relationship between transmural (intrathoracic-intrabronchial difference) pressure and bronchiolar diameter. Fry et al. have explained in detail the contribu-
tion of this relationship to the markedly decreased expiratory flows in patients with emphysema. With forced breathing, intrathoracic pressure is increased during expiration. As explained by Fry et al., this increased pressure, if it is not countered by a similar increase in intrabronchial pressure, presses upon the thin terminal bronchiolar ducts and constricts them. There is ample experimental evidence of such bronchiolar attenuation with forced breathing in emphysema. From the observations of maximum V-V loop overshoot it appears that in normal subjects the terminal airways must be somewhat constricted by increased transmural pressure during the forced expiratory vital capacity maneuver. In coughing, in the MVV breaths and in fast forced breathing, the distortion of the terminal airways by increased transmural pressure is apparently less than in the forced vital capacity maneuvers. This might be due to a relatively long time course of tissue distortion so that rapid increases in transmural pressure are not accompanied by corresponding changes in terminal airway caliber. Whatever the explanation, it appears certain that the maximum V-V envelope does not delimit maximum attainable expiratory velocities at varying lung volumes for all circumstances.

While an increased transmural pressure and attenuated terminal airways may explain the lesser expiratory velocities of the maximum V-V loop as compared to expiratory velocities during the other breathing maneuvers, it apparently cannot explain the loop overshoot of inspiratory velocities. Here an increased transmural pressure gradient should enlarge the caliber of the terminal airways if an increased negative pressure has opposite effects to an increased positive pressure.

Considering purely physical principles, however, the inspiratory velocity overshoot might be explained as follows: With a forced total inspiratory effort the high velocities of air movement in the terminal thin walled airways may produce a narrowing of these airways due to the Bernoulli effect. With shorter breaths the velocity at a given lung volume might well be higher if a long time course for tissue distortion and lumen narrowing delayed response to the Bernoulli effect.

If the above suggestions for maximum V-V loop overshoot are correct then one should see the overshoot only at the beginning of a relatively long breath. In point of fact the observations bear out such a hypothesis. The greatest overshoot is certainly at the beginning of the breath and if the breath is long (50 per cent capacity) the velocity falls to the level of the maximum V-V envelope.

It is possible, of course, that the overshoot might be explained on the basis of a greater alveolar pressure during the shorter forced breath. It has been previously demonstrated\(^9\) that in the normal subjects the MVV is limited by speed of muscle contraction. In the patient with markedly increased airway resistance the MVV is apparently limited by the strength of muscle contraction. In the normal subjects, then, as used in the presently reported study, the velocity of air movement at the higher lung volumes would appear to be limited by speed of muscle contraction. At lower lung volumes (which are not utilized in the usual MVV testing) where expiratory resistance is high, the maximum velocity might well be limited by the strength of muscle contraction. In any event, it appears that at the higher lung volumes (above midposition) if there is a greater pressure during fast short breaths than during the forced vital capacity breaths, the increased pressure must be related to a more rapid rate of muscular shortening.

From the present evidence it is not possible to tell if one of the above mechanical alterations accounts for the maximum V-V loop overshoot. The constant temperature, constant humidity whole body plethysmograph might be used for clarification. This plethysmograph permits the use of any breathing pattern.
**MBC V-V Loop Overshoot and MVV Prediction:** On first inspection, the fact that the MVV loop overshoots the maximum V-V loop presents a paradox. If the increased velocities in the MVV loop resulted in a larger area for the MVV loop than the area subtended by perpendiculars drawn at the end of the tidal volume of the MVV breath as used in the MVV prediction described above, the time for the measured MVV breaths (from MVV V-V loop) would be less than the time obtained from the prediction technique, indicating that the measured MVV would be larger than the predicted MVV. It never is. In all subjects the measured MVV has been less at higher breathing frequencies than the predicted MVV. At lower breathing frequencies they are essentially the same.

Although the MVV loop overshoots the maximum V-V loop, as shown diagrammatically in Fig. 11, the area of the MVV V-V envelope is less than the envelope of the simulated MVV envelope produced by erecting perpendiculars at the end of the tidal volume. Thus it is seen that the "rounding" of the MVV loop approaches to the maximum envelope accounts for a greater area loss than the area increase produced by the overshoot. A comparison of the MVV V-V loops and maximum V-V loops, then, indicates that the predicted MVV will be higher than the measured MVV. As seen in Figs. 6-8, this relationship obtains at all breathing frequencies. Also, it appears to be universal for all subjects.

**Pulmonary Function and MVV Prediction**

In considering the usefulness in pulmonary function evaluation of an MVV prediction, one tends to think of the reliability of the predicted MVV in relation to the measured MVV. Such an approach is perhaps well taken in view of the fact that all of our values for the MVV are from actual measurements. However, when considering the reliability and reproducibility of the predicted and measured MVV, there may be a justification for preferring the predicted value to the measured one. In experimental work, it has been our experience that with the usual untrained subject it is difficult to obtain the peak MVV effort for each test. There is much less difficulty in consistently obtaining a usable maximum V-V loop (from which the MVV is predicted). It seems reasonable that a maximum effort for one or two breaths should be easier to obtain from a subject than a sustained maximum effort. In view of the improved reliability and reproducibility, the predicted value might be used in lieu of the measured value. If a predicted value were to be used, however, one might just as well use a direct time-volume value from the V-V loop. Such a value would be more meaningful than the timed vital capacity because both the inspiratory and expiratory breath phases are represented in the V-V loop.

![Diagram](image)

**FIGURE 11:** Diagrammatic sketch showing relative area of simulated and actual MVV V-V loops. Note that increased area from overshoot is less than area loss due to "rounding" as MVV envelope approaches maximum envelope.
able to establish conversion factors and to provide baseline values.

**Summary**

1. When an MVV V-V loop is superimposed on a maximum (forced vital capacity) V-V loop, it follows the maximum envelope during the major portion of a breath half cycle until it breaks away abruptly, transects the zero velocity abscissa, and joins the maximum envelope for the other breath half cycle.

2. Because of the relationship of the MVV V-V loop to the maximum V-V loop, it is possible to simulate the MVV V-V loop by erecting perpendiculars at either end of the tidal volume. If this is done for a variety of assumed tidal volumes, MVV V-V loops at a number of breathing frequencies are simulated.

3. By use of the equation Time-V²/Area, the calculated time for moving each assumed tidal volume in and out of the lungs is found. From the tidal volume and the time necessary for its movement, breathing frequency and MVV are calculated.

4. The "correct" (optimum) placement of the tidal volume on the vital capacity axis is found by use of a family of curves (breathing frequency-limit of inspiration) which are evolved from the maximum V-V loop.

5. The predicted MVV values over a wide range of breathing frequencies calculated from a single maximum V-V loop compare favorably with MVV values obtained with the usual 15-second MVV test.

**Resumen**

1. Cuando una curva MVV V-V se sobrepone a una curva de capacidad vital forzada máxima (V-V), se cubren al máximo durante la mayor parte de la mitad del ciclo respiratorio hasta que se separan de pronto, la primera corta la abscisa de la velocidad en cero y se une a la cobertura máxima de la otra mitad del ciclo.

2. A causa de la relación de MVV V-V con el máximo de la curva V-V es posible simular la curva MVV V-V levantando perpendiculares al término de cualquier volumen de aire corriente. Si se hace esto para una variedad de supuestos volúmenes de aire corriente, se simulan curvas MVV V-V a ciertas frecuencias respiratorias.

3. Por el uso de la ecuación: Tiempo = V²/Area el tiempo calculado para mover cada volumen de corriente hacia dentro o hacia fuera del pulmón se encuentra. Del volumen del aire corriente y el tiempo necesario para su movimiento se calculan la frecuencia respiratoria y la MVV.

4. La correcta colocación (óptima) del volumen del aire corriente sobre el eje de la capacidad vital se encuentra por el uso de una "familia" de curvas (frecuencia respiratoria-límite de la inspiración) que se desprenden de la curva V-V.

5. Los valores esperados de MVV sobre un número grande de frecuencias respiratorias calculadas a partir de una curva única de máximo V-V se compara favorablemente con MVV obtenidos con la prueba habitual de MVV de 15 segundos.

**Resumé**

1. Quand un tracé "en boucle" de la ventilation maxima volontaire (MVV) est superposé à une capacité vitale forçée au cours de la mesure de la vélométrie des volumes pulmonaires (V. V. Loop), il suit l'enveloppe maximum pendant la plus grande partie d'un demi-cycle respiratoire jusqu'à ce qu'il tombe abruptement, croise le zéro de l'abscisse de vélométrie, et joint l'enveloppe maximum pour l'autre moitié du cycle respiratoire.

2. En raison des rapports existants entre la courbe MVV V-V et la courbe maximum V-V, il est possible de simuler une courbe MVV V-V en dressant des perpendiculaires à chaque extrémité du volume courant. Si on le fait pour une variété de volumes courants présumés, les courbes MVV V-V sont simulées pour un nombre de fréquences respiratoires.

3. En utilisant l'équation Temps = V²/surface, on trouve le temps calculé pour mobiliser chaque volume courant présumé entrant et sortant des poumons. De ce volume courant et du temps nécessaire à sa mobilisation, la fréquence respiratoire et la VMM sont calculés.

4. L'emplacement correct du volume courant dans l'axe de la capacité vitale est déterminé par l'emploi d'une famille de courbes (fréquence respiratoire, limite de l'inspiration) qui sont développées à partir de la "MVV loop."

5. Les valeurs de la MVV déduites sur une large échelle de fréquences respiratoires calculées à partir d'une seule courbe "en boucle" de vélométrie pulmonaire sont favorablement comparables aux valeurs obtenues par le test usuel de la ventilation maxima volontaire en 15 secondes.

**Zusammenfassung**

1. Wird eine Kurve der freiwilligen Maximalatmung überlagert auf eine solche der forcierten Vitalkapazität, so folgt diese der maximalen Umhüllungskurve während des größeren
Teile der Atemhalbphase, bis sie plötzlich abbricht, die Abszisse der Null-Geschwindigkeit überquert und den Maximalwert für die andere Atem-Halbphase berührt.

2. Im Hinblick auf die Beziehung der Kurve der freiwilligen Maximalatmung zu der forcierten Vitalkapazität ist es möglich, letztere nachzuhaken. Man findet dazu eine Vielzahl angenommener Atemvolumina, also werden Kurven für die forcierte Vitalkapazität für eine Anzahl von Atemfrequenzen nachgezogen.


REFERENCES

NEUROPATHY IN BRONCHOGENIC CARCINOMA

A case is presented of a sensorimotor peripheral neuropathy in a patient with bronchogenic carcinoma. An additional 24 cases of bronchogenic carcinoma associated with peripheral neuropathy were analyzed. The pathologic changes within the nervous system were characterized by two processes: demyelination and neuronal degeneration. The former may involve peripheral nerve, posterior root, and posterior column. The latter has involved anterior horns and dorsal root ganglia. Why the nervous system is peculiarly affected in certain malignant states remains an enigma. A number of hypotheses have been offered, but none has been substantiated. Denny-Brown's original suggestion that the tumor releases a substance which competes with or inhibits an enzyme or coenzyme necessary to maintain the integrity of myelin and neurones remains to be proved. Although carcinoma of the lung is most frequently inerminated in this association, it was stressed that the reaction is not tumor specific and further that the neurologic signs may precede those of the carcinoma.


PULMONARY ATELECTASIS CAUSED BY ASPERGILLUS FUMIGATUS

The various types of pulmonary aspergilllosis are discussed. The case of a 26-year-old woman who had two episodes of atelectasis due to an aspergillus infection is presented. This patient's episodes occurred three years apart and the second one is described in detail. A short time after bronchoscopy, the patient coughed up a dark brown mass which, on culture, yielded pure Aspergillus fumigatus. The atelectasis cleared completely in six days.