Atelectasis and Pneumothorax:

Effect on Lung Function and Shunting

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Lung mechanics and physiologic shunting were measured before and after experimentally-produced atelectasis and pneumothorax in dogs breathing air or oxygen. Atelectasis of the left lung was accomplished with an endobronchial blocker; pneumothorax by injecting an amount of air equal to the functional residual capacity of the dog. Increases in physiologic shunting following atelectasis and pneumothorax were less than expected from the amount of collapsed lung involved, indicating that the measurement of shunt is an insensitive index of atelectasis. Reductions in lung compliance, however, were related directly to the amount of induced atelectasis confirmed by postmortem examination. Functional residual capacity was found to be related linearly and inversely to the degree of shunting during breathing of air but not during inhalation of oxygen. Thus, maintenance of an optimal state of resting lung volume seems necessary to minimize shunting whenever the inspired gas is not oxygen.

Changes in lung compliance and/or physiologic shunting frequently have been assessed as indices of atelectasis. Data correlating changes in lung compliance and shunting with the actual amount of atelectasis present are lacking, however. Changes in lung compliance also may reflect changes in functional residual capacity (FRC), surface tension or cycling dynamics during controlled ventilation without development of atelectasis. Accordingly, spontaneously-breathing dogs were studied to determine the effect of a known amount of atelectasis produced by bronchial blockage or pneumothorax on lung compliance, FRC and physiologic shunting, and to assess the relative contributions of ventilation-perfusion defects to the observed shunts.

Methods

Twenty-six dogs were anesthetized with a 50:50 mixture of sodium pentobarbital and sodium thiopental, administered intravenously. An initial dose of 16 mg./kg. was followed by supplementary doses of pentobarbital, as required. The dogs were placed in the supine position and an esophageal balloon was passed into the stomach, withdrawn to the lower third of the esophagus, and 0.5 ml. of air was added. A large double-cuffed endotracheal tube was passed and attached to a modified T piece. Thirteen dogs breathed air and 13 breathed oxygen throughout the study. Either oxygen or air was admitted through the sidearm at 6-8 liters per minute, a flow more than sufficient to eliminate rebreathing. Denitrogenation was assessed by analysis of end-tidal samples for O₂ and CO₂. Measurements of FRC and compliance were made in duplicate approximately 30 minutes after induction of anesthesia. Femoral arterial blood and expired gas samples were obtained for gas analysis between the duplicate FRC determinations. In 12 dogs a catheter for sampling mixed venous blood was inserted through the jugular vein into the pulmonary artery, using the method of Fife and Lee.

Atelectasis

Atelectasis was produced in the following manner: following collection of control data, the trachea was extubated and a McCarthy double-lumen bronchial blocker passed through a #10 Jackson bronchoscope into the left
main-stem bronchus. The bronchoscope was
removed and reinserted beside the bronchial
blocker, and the blocker withdrawn slowly
until the proximal end of the cuff was just
visible below the carina. The cuff was in-
flicted under direct vision following expiration,
so that the blocked lung contained an amount
of gas equal to its normal contribution to the
total FRC. The tightness of the block was
tested by gentle tugs after which the endo-
tracheal tube was reinserted. As much gas as
possible was removed from the blocked lung
by gentle aspiration through the blocker tubing
opening distal to the balloon. This was usually
less than half the expected left lung vol-
ume. A period of at least ten minutes then
was allowed, to permit complete absorption
of the remaining oxygen from the blocked lung.11,12
All measurements made in the control
period were repeated 30 minutes after in-
stitution of atelectasis, since shunting is max-
imal during the first hour.11 At this point eight
dogs were sacrificed immediately with intra-
venous pentobarbital, the endotracheal tube
clamped, and the extent of atelectasis deter-
mined by postmortem examination. In the
remaining dogs the endobronchial blocker was
removed and the lungs were hyperinflated ac-
tively several times by sustained pressures of
40 cm. H₂O for 15–20 seconds, to re-expand
them adequately. Spontaneous respiration
was permitted for 30 minutes to allow the lungs
to attain their normal resting volume fol-
lowing inflation, after which control mea-
surements were repeated.

PNEUMOTHORAX

Pneumothorax was produced with injection
into the left chest of air in a volume equal to
the control FRC, using a syringe and an 18-
gauge needle. Care was exercised to avoid
puncturing the lung. Following measurements
made 30 minutes after pneumothorax, four
dogs were sacrificed and examined to deter-
mine the extent of lung collapse. In the re-
mainng dogs the gas was aspirated from the
chest and repeat measurements were made 30
minutes later. Finally, inflation of the lungs
was accomplished in a manner similar to that
following atelectasis, and after the resump-
tion of spontaneous respiration for 30 minutes the
measurements were repeated.

FRC determinations were made using the
closed-circuit helium-dilution technique. Hel-
umeter readings were corrected for changes in oxygen concentration which oc-
curred during the determinations, by a method
described elsewhere.12 The per cent change
in helium concentration was measured at 30-
second intervals during helium equilibration
to assess the efficiency of intrapulmonary mixing.
When plotted on semilog paper, a straight line results if mixing is normal. If the
lung contains poorly-ventilated components, the plot is represented best by two or more
exponential equations, as suggested by Nye,14
and observed clinically.15,16

Dynamic lung compliance was computed as
the change in lung volume per unit change in
transpulmonary pressure measured from the
beginning of inspiration to the end of inspira-
tion. Transpulmonary pressure was repre-
sented as the difference in pressure between
airway and esophageal pressure. Tidal vol-
ume was determined by integrating the flow
signal from a Fleisch #1 pneumotachograph
attached to the endotracheal tube. All blood
gas analyses were done with a Beckman 160
Analyzer or an Instrumentation Laboratories
Analyzer.

Calculations

Alveolar oxygen tension during inspiration
of oxygen was calculated from the equation:

\[ P_{A\text{O}_2} = P_B - P_{H_2O} - P_{ACO_2} \] \hspace{1cm} (1)

When air was inspired, the alveolar air equa-
tion was used:

\[ P_{A\text{O}_2} = F_{IO_2}(P_B - P_{H_2O}) \]

\[ - P_{ACO_2}\left[F_{IO_2} + \frac{1 - F_{IO_2}}{R}\right] \] \hspace{1cm} (2)

The respiratory exchange ratio (R) was deter-
mained from analyses of the inspired and ex-
pired air, the latter collected at the time of
femoral arterial blood sampling. Both equa-
tions were solved assuming that \( P_{ACO_2} = P_{CO_2} \).
Actually, there is a CO₂ gradient of less than
2 mm. Hg in right-to-left shunts of less than
20 per cent, and it can be ignored. The exis-
tence of a 5-mm. Hg gradient in the presence
of a 40 per cent shunt during air inhalation
would lead to an underestimation of the shunt by less than 1 per cent.

The total physiologic shunt was calculated from the shunt equation:

\[
\dot{Q}_s / \dot{Q}_t = \frac{C_{\text{CO}_2} - C_{\text{aO}_2}}{C_{\text{CO}_2} - C_{\text{vO}_2}}
\]  

(3)

where \( \dot{Q}_s \) represents that portion of the total blood flow (\( \dot{Q}_t \)) which is shunted past non-ventilated alveoli, blood coming from regions with low ventilation-perfusion ratios, as well as blood flowing through anatomical shunts. \( C_{\text{CO}_2}, C_{\text{aO}_2}, \) and \( C_{\text{vO}_2} \) represent the oxygen contents of pulmonary capillary, arterial and mixed venous bloods, respectively. \( C_{\text{aO}_2} \) during oxygen breathing was calculated from the hematocrit and addition of the amount physically dissolved—a method found to give results similar to the direct Van Slyke technique.\(^{17}\) When air was inspired, \( C_{\text{aO}_2} \) was determined utilizing the nomogram of Rossing and Cain, which determines saturation of dog’s blood from \( P_{\text{A}O_2}, pH, \) and temperature.\(^{18}\) During inhalation of oxygen when pulmonary capillary blood reaches full equilibration at the observed \( P_{\text{A}O_2} \) only anatomical shunting and shunt past non-ventilated alveoli are measured. During inhalation of air, pulmonary capillary blood fails to achieve equilibration at the observed \( P_{\text{A}O_2} \). The difference between the \( C_{\text{CO}_2} \) predicted from full equilibration and that actually achieved (\( C_{\text{aO}_2} \)), represents the total physiologic shunt. Therefore, \( C_{\text{CO}_2} \) was calculated assuming full equilibration of pulmonary capillary blood at the observed \( P_{\text{A}O_2} \). Oxygen consumption was measured spirometrically and the cardiac output determined by the Fick principle:

\[
C.O. (l/min.) = \frac{\dot{V}_O_2}{C_{\text{aO}_2} - C_{\text{vO}_2}}
\]  

(4)

Since \( C_{\text{aO}_2} - C_{\text{vO}_2} \) did not change significantly in twelve dogs following atelectasis, whether air or oxygen was inhaled, the observed mean value of 3.2 volumes per cent was used in estimating shunt in the remaining 14 dogs.

Results

Experimental data are summarized in tables 1 and 2. Lung compliance and FRC during quiet breathing in anesthetized dogs exhibited a loosely dependent relationship \((r = 0.50)\). The regression equation expressing this relation was \( FRC = 0.37 + 4.78 C_t \). The mean \( C_t \) was 0.056 ± 0.02 1/cm. H\(_2\)O and mean FRC of the group was 0.633 ± 0.19 l. The coefficients of variation for \( C_t \) and FRC were 36 per cent and 30 per cent, respectively.

The relationship of helium-mixing time to respiratory minute volume and FRC was determined by analysis of 42 simultaneous measurements of these parameters during the control periods. No correlation was found between mixing time and minute volume \((r = 0.06)\). A positive correlation \((r = 0.38)\) was found between mixing time and FRC, which is significant at the 1 per cent level. The formula expressing the relationship was: mixing time (min.) = 1.27 + 1.6 FRC\(_t\). During the control periods and with atelectasis produced by lung blockage and pneumothorax, the mixing times required for complete helium dilution were less than three minutes. Only following pneumothorax did mixing time differ significantly \((P < 0.05)\) when air or oxygen was inhaled because of the marked difference in FRC. In all situations, however, the slopes of the helium-dilution curves, when plotted semilogarithmically, were straight, indicating absence of poorly-ventilated areas of the lung.

Atelectasis

The large A-a\(_{\text{O}_2}\) gradient present during inhalation of oxygen in the control period suggested significant atelectasis when dogs are allowed to breathe spontaneously during anesthesia. During breathing of air or oxygen, 27 per cent or 23 per cent, respectively, of venous blood was shunted. When the left lung was made atelectatic following bronchial occlusion, tidal volume was reduced approximately 17 per cent, but a 23 per cent increase in respiratory rate also occurred and the minute volume remained virtually unchanged. The loss of approximately 40 per cent\(^{14,19}\) of the total lung tissue was reflected by a decrease in lung compliance of equal magnitude (42 per cent and 46 per cent) in both groups of dogs. The FRC was reduced by 41 per cent in the group breathing air and 23 per cent in the group breathing oxygen. Shunting...
increased to 43 per cent during breathing of air and 34 per cent during breathing of oxygen following atelectasis. No significant change in cardiac output occurred following institution of atelectasis, whether oxygen or air was inhaled (table 2). In all eight dogs, examination of the lung following inhalation of oxygen and bronchial blockage revealed that the left lung was completely livid in both color and consistency. The right lungs appeared fully inflated without evidence of atelectasis in the dependent portions. In each dog, correct positioning of the bronchial blocker in the left main-stem bronchus and the catheter within the pulmonary artery was confirmed.

PNEUMOTHORAX

Introduction into the thorax of air equal in volume to the FRC of the dog resulted in a reduction in tidal volume and almost doubling of the respiratory rate. Minute volume increased approximately 50 per cent. A 53 per cent reduction of the FRC during breathing of air and a 67 per cent reduction during breathing of oxygen also occurred. The difference between the two groups was significant at the 1 per cent level. Larger reduction in FRC were not expected, since some oxygen is absorbed from the pneumothorax and the thoracic volume actually increases somewhat with the introduction of air. The negative intrapleural pressure resulting from the elastic retractive force of the lung was reduced, allowing the rib cage to enlarge.21

Pneumothorax decreased lung compliance by 52 per cent and 44 per cent of control values when air and oxygen, respectively, were inspired. For dogs breathing oxygen, the physiologic shunt following pneumothorax, which presumably represents shunting past nonventilated alveoli, was also the same as that observed following bronchial blockage. The total shunt was again higher when air was breathed, suggesting that ventilation-perfusion abnormalities of patent alveoli contribute a significant amount to the total physiologic shunt. Both lungs of four dogs sacrificed

| Table 1. Respiratory and Blood Gas Changes Due to Induced Atelectasis and Pneumothorax in Dogs Breathing Either Air or Oxygen (Mean values and standard deviations. Significant differences between the air versus oxygen groups: *P < 0.05; **<0.01.) |
|-----------------|-----------------|-----------------|-----------------|-----------------|
|                 | Control         | Atelectasis     | Control         | Pneumothorax    | Aspiration      |
|                | Air            | O2              | Air            | O2              | Air            | O2              | Air            | O2              | Air            | O2              | Air            | O2              | Air            | O2              |
| **CL (l/min. H2O)** | 13 dogs 13 dogs | 9 dogs 9 dogs | 13 dogs 13 dogs | 9 dogs 9 dogs   | 7 dogs 7 dogs  | 7 dogs 7 dogs  | 7 dogs 7 dogs  | 7 dogs 7 dogs  | 7 dogs 7 dogs  | 7 dogs 7 dogs  | 7 dogs 7 dogs  | 7 dogs 7 dogs  | 7 dogs 7 dogs  | 7 dogs 7 dogs  |
|                 | 0.035 ± 0.021  | 0.032 ± 0.018  | 0.067 ± 0.022  | 0.035 ± 0.021  | 0.032 ± 0.021  | 0.066 ± 0.023  | 0.032 ± 0.021  | 0.066 ± 0.023  | 0.032 ± 0.021  | 0.066 ± 0.023  | 0.032 ± 0.021  | 0.066 ± 0.023  | 0.032 ± 0.021  | 0.066 ± 0.023  |
| **FRC (l.)**    | 0.583 ± 0.053  | 0.412 ± 0.111  | 0.727 ± 0.192  | 0.584 ± 0.103  | 0.347 ± 0.191  | 0.529 ± 0.136* | 0.353 ± 0.083* | 0.529 ± 0.136* | 0.353 ± 0.083* | 0.529 ± 0.136* | 0.353 ± 0.083* | 0.529 ± 0.136* | 0.353 ± 0.083* | 0.529 ± 0.136* |
| **FRC** (ml./kg.) | 25.4 ± 4.9     | 17.0 ± 3.7     | 26.7 ± 2.8     | 12.5 ± 2.2     | 19.7 ± 2.2     | 13.0 ± 3.7**   | 6.2 ± 1.6      | 17.5 ± 5.1*    | 6.2 ± 1.6      | 17.5 ± 5.1*    | 6.2 ± 1.6      | 17.5 ± 5.1*    | 6.2 ± 1.6      | 17.5 ± 5.1*    |
| **Vt (ml/kg.)** | 9.2 ± 7.8      | 7.8 ± 2.5      | 6.6 ± 2.5      | 5.7 ± 1.5      | 6.3 ± 3.6      | 6.1 ± 3.2      | 6.2 ± 1.6      | 6.0 ± 3.0      | 6.2 ± 1.6      | 6.0 ± 3.0      | 6.2 ± 1.6      | 6.0 ± 3.0      | 6.2 ± 1.6      | 6.0 ± 3.0      |
| **Rate (resp./min.)** | 13 ± 4       | 13 ± 4        | 17 ± 7         | 30 ± 14        | 32 ± 10        | 25 ± 7        | 25 ± 7        | 25 ± 7        | 25 ± 7        | 25 ± 7        | 25 ± 7        | 25 ± 7        | 25 ± 7        | 25 ± 7        |
| **Minute volume (ml./kg./min)** | 121 ± 112 | 125 ± 112 | 118 ± 112 | 104 ± 94 | 118 ± 112 | 104 ± 94 | 118 ± 112 | 104 ± 94 | 118 ± 112 | 104 ± 94 | 118 ± 112 | 104 ± 94 | 118 ± 112 | 104 ± 94 |
| **Mixing time (min.)** | 2.8 ± 0.5     | 2.1 ± 0.8      | 2.6 ± 0.7      | 2.7 ± 0.6      | 2.1 ± 0.5      | 2.7 ± 0.6      | 2.1 ± 0.5      | 2.7 ± 0.6      | 2.1 ± 0.5      | 2.7 ± 0.6      | 2.1 ± 0.5      | 2.7 ± 0.6      | 2.1 ± 0.5      | 2.7 ± 0.6      |
| **pH** | 7.34 ± 0.06 | 7.32 ± 0.05 | 7.32 ± 0.05 | 7.32 ± 0.05 | 7.32 ± 0.05 | 7.32 ± 0.05 | 7.32 ± 0.05 | 7.32 ± 0.05 | 7.32 ± 0.05 | 7.32 ± 0.05 | 7.32 ± 0.05 | 7.32 ± 0.05 | 7.32 ± 0.05 | 7.32 ± 0.05 |
| **Paco2 (mm. Hg.)** | 43 ± 7 | 43 ± 7 | 43 ± 7 | 43 ± 7 | 43 ± 7 | 43 ± 7 | 43 ± 7 | 43 ± 7 | 43 ± 7 | 43 ± 7 | 43 ± 7 | 43 ± 7 | 43 ± 7 | 43 ± 7 |
| **Pao2 (mm. Hg.)** | 70 ± 7 | 70 ± 7 | 70 ± 7 | 70 ± 7 | 70 ± 7 | 70 ± 7 | 70 ± 7 | 70 ± 7 | 70 ± 7 | 70 ± 7 | 70 ± 7 | 70 ± 7 | 70 ± 7 | 70 ± 7 |
| **Qs/Qt X 100** | 27 ± 22 | 27 ± 22 | 27 ± 22 | 27 ± 22 | 27 ± 22 | 27 ± 22 | 27 ± 22 | 27 ± 22 | 27 ± 22 | 27 ± 22 | 27 ± 22 | 27 ± 22 | 27 ± 22 | 27 ± 22 |
after pneumothorax were partially collapsed, with patchy atelectasis in the dependent portions. Lung volume was estimated visually to have been reduced to 50–60 per cent of normal volume by the pneumothorax.

Aspiration of pneumothorax air produced no increase in compliance in either group, and since no decrease in shunting occurred in the oxygen-breathing group, presumably there was no reduction in atelectasis. FRC did increase in both groups, however, and the increase in resting lung volume in the air-breathing group was associated with a reduction in the total shunt from 43 per cent to 36 per cent of the cardiac output. Compliance values and shunting returned to control levels only in the period following vigorous hyperinflation.

Discussion

It is well documented that if anesthetized dogs are allowed to breathe spontaneously, atelectasis is present, usually in the dependent portions of the lung. Hyperventilation, whether spontaneous or artificially produced, may lead to elimination or marked reduction in shunting and significant increase in compliance. Invariably, however, these changes are followed by return to prehyperinflation levels. When air is breathed, the total shunt is considerably greater than during inhalation of oxygen, presumably because of abnormalities in ventilation relative to perfusion, since an appreciable diffusion gradient has not been demonstrated in dogs. 

LUNG COMPLIANCE, FRC, AND ATELECTASIS

The present study shows that, following an increase in the amount of atelectasis caused by bronchial blockage or pneumothorax, a proportional decrease in lung compliance can be expected, whether air or oxygen is inspired. Factors other than atelectasis, such as changes in respirator pressure and cycling dynamics during controlled respiration, can influence compliance measurements, however. During spontaneous respiration, changes in frequency and depth of respiration as well as changes in alveolar surface tension, bronchial tone, and position, can alter compliance significantly. The observations of Williams et al. suggest that during controlled respiration, reductions in lung compliance can be expected in hypoventilated alveoli on the basis of increasing surface tension alone, without atelectasis. Whether these changes occur during spontaneous respiration is not known. In our animals alveoli undoubtedly were hypoventilated during the control periods, and particularly during bronchial blockage and pneumothorax, as evidenced by the increased shunt during breathing of air. It is unlikely, however, that changes in surface tension played a significant role in reducing compliance values, since increases in FRC following aspiration of pneumothorax air, while effecting major increases in alveolar volume, left compliance unchanged. Measurement of lung compliance, then, should be considered a sensitive method for assessing changes in the amount of atelectasis, provided other factors known to influence lung compliance remain relatively unchanged.

Reduction in FRC also occurred after atelectasis. However, changes in resting intrapleural pressure or tone of musculature of the chest wall, quite apart from atelectasis, may affect the resting lung volume, also. That changes of this nature occur is evident from the responses to aspiration of pneumothorax air: following aspiration, dogs breathing oxygen experienced no reduction in shunting and atelectasis but a marked increase in FRC. In spite of this increase, lung compliance remained unchanged, reflecting the persistence of atelectasis. Only following the high sustained inflation pressures required to overcome
the surface tension forces involved in atelectasis did compliance values and reduction in shunting reflect the reopening of collapsed alveoli. Thus, lung compliance, unlike the FRC, consistently reflects the amount of underlying atelectasis, regardless of whether air or oxygen fills the lungs.

Resting lung volume following bronchial blockage also is influenced by the presence or absence of nitrogen in the lung distal to the block. We found, as did Dale and Rahn, that no significant change occurred in the FRC of the unblocked lung if the other lung contained air before blockage. When oxygen was present in the blocked lung, however, absorption of the trapped oxygen occurred, causing mediastinal shift and a larger resting lung volume for the unblocked lung. Presumably this explains the smaller decrease in FRC following bronchial blockage during oxygen inhalation (23 per cent) than during air inhalation (41 per cent).

**ATELECTASIS AND SHUNTING**

We were unable to explain why the shunt only increased from a control value of 27 per cent to 43 per cent during breathing of air following blockage of the left lung and from 28 per cent to 34 per cent during inhalation of oxygen unless some pulmonary blood was shunted towards the unaffected lung. Both shunting and FRC were greater when air rather than oxygen was breathed following pneumothorax. Hypoxygenated alveoli containing air, although contributing significantly to the total physiologic shunt, may sustain a greater volume than O₂-filled alveoli because of the “nitrogen scaffold” and may account for the larger FRC's measured during air breathing throughout the study.

Changes in the amount of shunting were observed to be closely related to changes in FRC during breathing of air. When changes in shunt, determined from table 1 data, are plotted against changes in FRC, physiologic shunting increases about 5 per cent with each 100-ml. decrease in FRC (fig. 1). We observed that a reduction in shunting can be accomplished without a reduction in atelectasis by increasing the resting lung volume, as occurred following aspiration of pneumothorax air. When the lung contains air, partially-collapsed alveoli are maintained patent by slowly-absorbed nitrogen and are more readily re-expanded when pneumothorax air is aspirated. When the lung contains only oxygen, partially-collapsed alveoli are more likely to become completely atelectatic. Aspiration of pneumothorax air leads only to overexpansion of the remaining lung without reopening completely atelectatic alveoli. The V/Q ratio of ventilated alveoli was noted to improve with increases in FRC during breathing of air, suggesting that changes in resting lung volume, quite apart from the presence or absence of atelectasis, may play a significant role in determining the overall efficiency of respiration.

How resting lung volume influences the V/Q ratio is not altogether clear. We were unable to demonstrate a distribution defect in ventilation during atelectasis and pneumothorax. The possibility exists that the helium-mixing time may be too insensitive to ventilation defects in normal but hypoventilated lung, yet its value in the presence of lung disease is well chronicled. Alterations in perfusion may be affected by resting lung volume, however. Rahn has shown that in anesthetized supine spontaneously-breathing dogs, even though more ventilation occurs in dependent portions of the lung, considerably
more blood per unit volume of lung tissue flows through the dependent portions, more than offsetting any increase in ventilation. With some shunting of blood toward unaffected lung tissue following institution of atelectasis, the increase in the total physiologic shunt would be less than predictable from the amount of induced atelectasis. Yet a further reduction in the V/Q ratio of nonatelectatic lung, now relatively overperfused, would occur, partially offsetting the reduction in shunt due to redistribution. Additional reduction in resting lung volume in such a situation will enhance the shunt further. An optimal lung volume must exist, below which increases in shunting can occur during air inhalation. Thus, the achievement and maintenance of this volume seems necessary to minimize shunting whenever the inspired gas is not oxygen.

Conclusions

Judging from our results, it seems unlikely that a sensitive assessment of atelectasis can be made from measurement of the physiologic shunt alone. Increases in shunting were less than expected from the loss of nearly half the functioning lung, and these changes probably reflected blood shunting towards unaffected lung tissue. Still further changes in shunting can be produced by altering the state of inflation (FRC) of nonatelectatic lung without changing the degree of atelectasis, when air is inspired. Changes in lung compliance during spontaneous respiration, however, consistently reflected the degree of atelectasis (determined by postmortem examination), regardless of changes in the FRC or the calculated shunt, whether air or oxygen was inhaled.

The data also suggest that FRC determinations may be helpful in suspected cases of atelectasis. Reductions in FRC may suggest atelectasis but, more important, may foretell significant ventilation–perfusion defects. In such a situation measurement of shunt during both inhalation of oxygen and breathing air would allow assessment of the relative contributions of atelectasis and ventilation–perfusion defects to the total shunt.
Drugs

NARCOTICS The pulmonary and systemic hemodynamic effects of meperidine and hydroxyzine, individually and in combination, were investigated. The preparation consisted of intact, unanesthetized dogs in which pulmonary artery, left atrial and aortic catheters and an electromagnetic flowmeter had been implanted at operation. Meperidine produced significantly increased computed pulmonary and systemic vascular resistance. Hydroxyzine produced significantly increased systemic vascular resistance, but had little effect on the pulmonary circulation. A combination of meperidine and hydroxyzine produced considerably fewer changes than meperidine alone. Both agents individually and in combination produced hemodynamic changes which could alter the interpretation of a cardiac catheterization.