RADIOLOGICAL MANIFESTATIONS
OF
ENDOBRONCHIAL OBSTRUCTION

EXPERIMENTAL STUDY

A Thesis
Presented in Partial Fulfillment of the Requirements
for the Degree Master of Medical Sciences

By
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# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>INTRODUCTION</td>
<td>1</td>
</tr>
<tr>
<td>EXPERIMENTATION</td>
<td>5</td>
</tr>
<tr>
<td>Experiment 1</td>
<td>8</td>
</tr>
<tr>
<td>Experiment 6</td>
<td>26</td>
</tr>
<tr>
<td>Experiment 8</td>
<td>29</td>
</tr>
<tr>
<td>Experiment 17</td>
<td>39</td>
</tr>
<tr>
<td>Experiment 20</td>
<td>51</td>
</tr>
<tr>
<td>Experiment 14</td>
<td>66</td>
</tr>
<tr>
<td>Experiment 15</td>
<td>80</td>
</tr>
<tr>
<td>CONCLUSIONS</td>
<td>87</td>
</tr>
<tr>
<td>BIBLIOGRAPHY</td>
<td>89</td>
</tr>
</tbody>
</table>
INTRODUCTION

Atelectasis has been treated extensively in medical literature long before 1895 when Roentgen rays were discovered and the use of bronchoscope, which was popularized by Chevalier Jackson, was known.

Preoperative atelectasis especially, known in old times as "ether pneumonia" was always a serious and acute problem. We use the terms atelectasis and collapse as synonyms connoting incomplete expansion of the lung tissue. This can be referred to a small anatomical unit, to a lobe, or to an entire lung.

There are two kinds of atelectasis as we see them in the everyday medical practice. The one which is the result of compression of the lung such as in cases of large masses or massive pleural effusions and the other is the type of atelectasis which results from an obstruction of a bronchus by an intrinsic lesion such as bronchogenic carcinoma or secondary to the aspiration of a foreign body which might lodge into a bronchus. Therefore, from the etiological standpoint we can call the first kind
compressive atelectasis while the second one should be called by virtue of its mechanism obstructive atelectasis. In both mechanisms we have the same final result as far as lung parenchyma is concerned, namely a smaller lung volume brought about by decreasing the normal excess of internal intrapulmonary pressure over the external. In the case of obstructive atelectasis the positive intrapulmonary pressure is converted into a negative one due to absorption of air. In the case of compression of the lung by effusion, pneumothorax or large tumor masses the effects of the intrapleural negative pressure are abolished.

Whereas compression atelectasis is relatively easy to diagnose by means of routine chest x-ray examinations, obstructive atelectasis presents not infrequently several problems which demand careful consideration of several factors in order to reach the proper diagnosis. Even more it is important the fact that delay in prompt diagnosis might result in serious consequences for the patient. The difficulties are present mainly during the early stages of
obstruction at which time the Roentgenogram may not
give pathognomonic features. This has been time and
again the experience of several people including our
own. In postoperative cases the significance of the
same is also obvious. Some fatalities following
chest or upper abdominal operative procedures believed
to be secondary to postoperative shock proved actually
to be the result simply of an acute extensive
obstructive atelectasis secondary to large amount of
secretions and poor ventilation and abolishment of
the coughing reflex. We think that at least a number
of patients could be saved if a correct diagnosis is
made in time.

In an attempt to further investigate this problem
primarily from the radiological point of view we
carried out an experimental study in dogs in most of
which we used a method of endobronchial obstruction
which we personally developed.

We hope that in the future we might further pur-
sue this study for further investigation of the dynamic
physiopathologic and particularly from the hemodynamic
points of view. We consider this problem as one of
the important ones not only from the everyday clinical standpoint of view but also because of the implications of the pathologic physiology of bronchial obstruction.
EXPERIMENTATION

It is known that the tension of gases within the alveoli is in an approximate equilibrium with the tension of gases in the arterial blood. This does not happen in the case of gaseous tension in the venous blood. This fact is explained by the change of the oxygen tension by approximately 60 mm. Hg. Since oxygen represents 14.5 per cent of the gas mixture in the alveolar air, it is under a partial pressure of 103 mm. Hg. \( \frac{14.5}{100} = \frac{103}{706-47} \). In venous blood oxygen is present in approximately 5 per cent and therefore the partial pressure is only 35 mm. Hg.

On the other hand, the carbon dioxide, being approximately 5.6 per cent in the alveoli, has a partial pressure of 40 mm. Hg., whereas in the venous blood it is approximately 6.7 per cent which represents a partial pressure of 47 mm. Hg. The percentage of the partial pressure of the nitrogen is the same in the alveoli and in the venous blood (60 per cent-570 mm. Hg.). These facts explain why the venous blood has a total gas tension of about 66 mm. Hg., lower
than the alveolar air. The significance in this pressure difference as related to the absorption of the alveolar air for the development of atelec-
tasis following occlusion of a bronchus is obvious.

<table>
<thead>
<tr>
<th>MEDIUM</th>
<th>$P_{O_2}$ (mm Hg)</th>
<th>$P_{CO_2}$ (mm Hg)</th>
<th>$P_{N_2}$ (mm Hg)</th>
<th>$P_{H_2O}$ (mm Hg)</th>
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</tr>
</thead>
<tbody>
<tr>
<td>Ambient Air (Dry)</td>
<td>160</td>
<td>0.4</td>
<td>600</td>
<td>0</td>
<td>760</td>
</tr>
<tr>
<td>Alveolar Air</td>
<td>103</td>
<td>40</td>
<td>570</td>
<td>47</td>
<td>760</td>
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<tr>
<td>Arterial Blood</td>
<td>102</td>
<td>40</td>
<td>570</td>
<td>47</td>
<td>760</td>
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<tr>
<td>Venous Blood</td>
<td>25</td>
<td>47</td>
<td>570</td>
<td>47</td>
<td>700</td>
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1. Differences between ambient and alveolar air due to:
   - Saturation with water vapor in respiratory passages, ($P_{H_2O}$, saturated at 37°C = 47 mm Hg, always).
   - Mixture of inspired air with "dead air" residual air.
   - Constant loss of $O_2$ and gain of $CO_2$ in alveoli.

2. Pressure differentials across alveolar membrane:
   - $P_{O_2}$ (alv.) MINUS $P_{O_2}$ (ven.) = 103-35 = 68 mm Hg $P_{O_2}$.
   - $P_{CO_2}$ (ven.) MINUS $P_{CO_2}$ (alv.) = 47-40 = 7 mm Hg $P_{CO_2}$.

3. Identical figures for alveolar air and arterial blood show that diffusion of respiratory gases goes to complete equilibrium, essentially.

4. And, incidentally, the lower gas pressures (except CO₂) in venous blood as compared with air provides a pressure gradient favoring absorption of gas from any closed cavity in the body.

EXPERIMENTATION

For reasons of space the most pertinent experiments will be mentioned in detail. Intravenous anesthesia was used using Surital (sodium Thiamylal 8 mg. per pound). Preliminary radiograms routinely were made as usual in the ventrodorsal and lateral projections. The dogs were positioned in the routine fashion on the surgical table for bronchoscopy. The instruments used included: 1) a bronchoscope, No. 6/45 cm. with long foreign body forceps which we borrowed from the thoracic surgery department, 2) a dental speculum 3) a suction tube, 4) a modified Foley bag catheter, No. 12. The orifice communicating with the free end of the Foley bag catheter was obstructed. A five cc.
syringe with a nozzle adaptable to the orifice communicating with the balloon was used for the injection of the radiopaque contrast medium. This served a dual purpose, to inflate the balloon for the purpose of obstruction of the bronchus and to render radiopaque the site of obstruction. Routine inspection of the orifices of the bronchi of the site to be obstructed was routinely made. This was done in order to accurately estimate the distance of the bronchus to be obstructed and also to rule out the possibility of any significant inflammatory disease or possible anomaly before the establishment of the obstruction. Details of the method which we developed for the purpose of inducing bronchial obstruction without the complications and physiological implications of an open thoracotomy will be published, we hope sometime in the future. Suffice to say here that this method which we developed with trial and error is a simple one and necessitates minimal instrumentation.

Experiment 1: February 17, 1956, 5:00 p.m., female dog, weighing approximately 25 pounds was used. 200 mg. of Surital were introduced intravenously through
the femoral vein. Satisfactory anesthesia was induced immediately. Preliminary radiograms were made in the ventrodorsal and lateral projections. Under fluoroscopic control the diaphragmatic excursion was inspected and bilateral expansion of the lungs was noted. The dog was breathing normally. No cyanosis or any other signs of ill effects were manifested. (Figure 1A and 1B.)

5:30 p.m. Following the fluoroscopic inspection the dog was brought back to the surgical table for the introduction of the bronchoscope and through the bronchoscope, following inspection of the orifices the insertion of the long foreign body forceps was made. The distal end of the deflated Foley bag catheter was grasped on the outside of the distal end of the bronchoscope by the protruding and moveable distal end of the foreign body forceps. The system, therefore, of the bronchoscope with the foreign body forceps and the deflated Foley bag catheter secured by the grasping end of the foreign body forceps was introduced on block. Following this 3 cc. of hypaque 50% were introduced. However, the balloon did not inflate adequately and some coughing was precipitated. Subsequently, it was realized that the
balloon was accidentally ruptured. Therefore, the contrast medium leaked into the bronchial tree.

It was realized that this was the result of the accidental puncture of the Foley bag by the grasping end of the forceps. The whole system was removed and the bronchus was aspirated with available suction tube. Fluoroscopic inspection fifteen minutes later indicated that no contrast medium was left in the bronchial tree. The dog was brought again on the surgical table and the obstruction of the bronchus this time was attempted with a cotton plug the size of a peanut which was well compressed and adequately soaked with lipiodol in order to be rendered radiopaque. This was placed safely with the foreign body forceps, following inspection of the orifice at the intermediate bronchus which thus was obstructed. (Figure 2A and 2B).

6:15 p.m. A pair of radiographs in the ventrodorsal and lateral projection were made. Fluoroscopically there was evidence of equal illumination of the lung fields. There was some question, however, of some decrease of the illumination of the left lung in relation to the right at the end of the expiratory phase. No indication of any abnormality distal or
adjacent to the obstructing foreign body was present.

8:30 p.m. Radiograms in the ventrodorsal and right lateral projections showed no evidence radiographically of any pathologic process. Fluoroscopically, however, there was noted lack of expansion distal to the obstructing foreign body and lack of change in the degree of illumination between the phases of deep inspiration and expiration. Radiograms at this time are indicated in Figure 3A and 3B.

11:30 p.m. Radiograms in the ventrodorsal and right lateral positions showed no increase in the pulmonary markings and no definite evidence of collapse of any of the lobes or segments of the right lung. (Figure 4A and 4B)

4:00 p.m., 2/16/56. The dog was fluoroscoped and a distinct area of increased density corresponding to the intermediate lobe was seen. The adjacent lobes showed normal expansion and aeration. Radiograms taken 22 hours following the obstruction showed an area of airlessness corresponding to the region of the intermediate lobe. This is better seen in the lateral view (Figure 5A and 5B). There was no evidence
of any shift of the heart appreciated during the
fluoroscopy nor in the radiograms which were sub-
sequently made. The right hemidiaphragm showed no
particular elevation nor any narrowing of the rib
interspaces was noticed. This should be explained
on the basis of the relatively small lung volume
involved in this obstruction. The intermediate lobe
is a relatively small one and definitely smaller in
to the adjacent diaphragmatic lobe and
therefore the dynamic changes due to this segmental
obstruction were not reflected by any shift of the
mediastinum or elevation of the diaphragm. It is
worth noticing in these radiograms (Figure 5A and 5B)
that most of the lipiodol which was soaked into this
compressed cotton plug was eliminated. This raised
the question of possible dislodgement of the obstruct-
ing foreign body as also happened in several of the
dogs in our preliminary experimentation, however,
the autopsy findings indicated that the obstruction
was well maintained as indicated below.
4:20 p.m. The dog was sacrificed following a five
fold dose of Surital intravencously (approximately 1
gram). Following careful dissection of the thorax,
the lungs were separated in toto and inspected and photographed. The color of the obstructed and atelectatic intermediate lobe was dark red and its volume was markedly decreased as indicated in the Figure 6A. The hue of this lobe was like the one of the liver. Inflation of both lungs with a hand operated elastic bulb demonstrated good inflation and distension of all the lobes of the left lung and also of the right lung with the exception of the intermediate lobe. This demonstrated also the effectiveness of the obstruction. Subsequently, the trachea and both main bronchi were dissected and the cotton plug was found at the origin of the intermediate bronchus. This is well illustrated in the Figure 6B. A considerable amount of mucous secretions were found when the obstructing foreign body was removed distal to the obstructed bronchus and a smaller amount was also present in the region immediately proximal to the obstruction.

It should be noted that the use of this well compressed cotton plug soaked in lipiodol was used in this particular case because of the accidental rupture of the balloon during the insertion into the
DOG  I
10 MINUTES

FIGURE 2A
DOG 1
22 HOURS

FIGURE 5A
bronchus we had no availability of a second Foley bag catheter at that particular time in our laboratory so that we decided to use this less reliable, however successful in this particular case, of obstruction. Only a small lobe, however, was obstructed in this way while in the majority of our other experiments more than one lobe were obstructed simultaneously with a more reliable and effective method of the balloon as already described.

Experiment 6

April 8, 1956, 10:30 a.m. Male dog weighing 31 pounds was used. The animal was placed under general anesthesia on the surgical table following the administration of approximately 200 mg. of Surital. Routine preliminary radiograms in the ventrodorsal and right lateral projections were made and showed that both lungs are well expanded without evidence of any infiltration or pleural disease. Subsequently the dog was fluoroscoped and showed equal bilateral expansion and normal movement of both hemidiaphragms. The orifices of the lobar bronchi on both sides were inspected and appeared normal. A marker was placed on the proximal part of the bronchoscope to indicate the distance of
the orifice to be obstructed. Subsequently the bronchoscope was removed and with the introduction of a long foreign body forceps the distal end of the deflated, modified Foley bag catheter was grasped and the system en block was slowly and carefully introduced into the right lower lobe bronchus. The bronchoscope and the foreign body forceps were carefully removed while the modified Foley bag catheter was left in place following the introduction of approximately 3 cc. of 50% hypaque. Fluoroscopic examination subsequently indicated good positioning of the balloon. The lung field distal to the visualised balloon showed no evidence of atelectasis or any increased density. Subsequently radiograms were made in the routine ventrodorsal and lateral projections and the dog was returned to its cage.

3:00 p.m. Approximately four hours following the obstruction fluoroscopic examination demonstrated no evidence of atelectasis. However, there were some increased lung markings in the area of the lung just distal to the radiopaque balloon. There was some decrease in the excursion of the diaphragm noted probably as a result of the larger volume of lung obstructed
distal to the balloon in contra distinction to experiment Number 1 where only the diaphragmatic lobe was obstructed. No evidence of diaphragmatic displacement was present. Radiograms made in the ventrodorsal and right lateral projection at this time demonstrated a slight elevation of the right hemidiaphragm with no evidence, however, of any distinct opacification to indicate the presence of atelectasis nor any shift of the mediastinal structures.

3:30 p.m. Approximately five hours following the bronchial obstruction, the dog was sacrificed with an overdose of Surital intravenously. This relatively early termination of the experiment was done on purpose in order to evaluate the pathologic findings during this interval of time. The overall volume of the diaphragmatic and intermediate lobes was definitely decreased however, not collapsed and this probably explains the difficulty in identifying the atelectatic changes in the plain radiogram as the obstructed lobes still contained part of the original air. A routine inflation of both lungs through the intact trachea was made to ascertain the effectiveness of the obstruction. Following the inflation of air the left lung was well
distended as well as the apical and the cardiac lobes on the right side. No air, nor any indication of inflation, was present in the intermediate and diaphragmatic lobes confirming the impression of adequate obstruction. Subsequently, dissection of the trachea and bronchi was made. The inspection indicated again the exact location of the balloon obstructing the orifices of the adjacent intermediate and diaphragmatic lobes. Mucous secretions were present distal to the balloon. There was some discoloration of the bronchial mucosa seen when the balloon was removed most likely the result of the extrinsic pressure exerted on the bronchial wall by the inflated balloon.

Experiment 8

April 22, 1956, 10:30 a.m. Female dog, weighing 27 pounds was used. A satisfactory general anesthesia was obtained by the use of 175 mg. of Surital. Routine preliminary radiograms in the ventrodorsal and right lateral projections were made (Figures 7A and 7B). These showed some increase in the bronchopulmonary markings in the lower lung fields which were thought to be due to bronchitis. Fluoroscopically both lungs
were well aerated and both hemidiaphragms moved normally. There was no indication of any consolidation or any atelectatic changes.

11:00 a.m. Bronchoscopy showed somewhat hyperemic mucosa but no other changes were present. All the main bronchi were patent. A No. 12 Foley catheter was introduced with bronchoscopic guidance and with the help of the long foreign body forceps. Following the placement of the deflated balloon approximately 2.5 cc. of 50% hypaque were introduced and the orifice of the right diaphragmatic bronchus was obstructed. This was verified fluoroscopically. The vital signs of the dog were within normal limits. No evidence of any shift of the mediastinum was present and the diaphragmatic excursion was not remarkable. Radiograms which were obtained at 20 minutes following the obstruction (Figure 8A and 8B) showed some increase in the bronchopulmonary markings in the right lower lung field close to the cardiophrenic angle which were interpreted as congestion of the vessels and probably some increase in retained secretions. It was already mentioned that mucosal changes compatible with chronic bronchitis were present in the preliminary
bronchoscopic evaluation.

7:40 p.m. Eight and one half hours following the obstruction, radiograms in the ventrodorsal and right lateral projections showed an area of airless lung in the right lower lung field obliterating the adjacent right heart border (Figure 9A and Figure 9B). There was some elevation of the right hemidiaphragm and shift of the heart toward the right side. Interestingly enough, some narrowing of the 7th and 8th intercostal spaces was also noted. Fluoroscopically the right hemidiaphragm showed restriction in diaphragmatic excursion. The lung parenchyma distal to the balloon showed lack of aeration. No change in the degree of density of this particular part of the lung parenchyma was noted during the phases of inspiration and expiration. The surrounding lung parenchyma was well aerated. Subsequently, the dog was sacrificed with an overdose of Surital. The thorax was carefully dissected and both lungs were removed with the trachea intact. The color of the diaphragmatic lobe was dark red. Inflation through the trachea showed that all the lobes with the exception of the diaphragmatic on the right side and the left lung were well distended. Rather marked hyperemia
DOG 8
8 1/2 HOURS

FIGURE 9A
and an abundance of secretions was present in all the bronchi in the area adjacent to the site of obstruction. Radiogram of the specimen is shown in Figure 10. This experiment demonstrated that atelectatic changes as well as radiological manifestations might well be established as early as eight hours. Underlying bronchial inflammatory process (bronchitis) is probably a contributing factor. Microscopic examination of the specimen of the mucosa from the bronchi of the cardiac and intermediate lobes, which were not obstructed, did demonstrate inflammatory changes.

Experiment 17

November 3, 1956, 3:00 p.m. Female dog, weighing 35 pounds was used. General anesthesia was obtained following intravenous administration of 250 mg. of Surital. Satisfactory anesthesia was induced. Preliminary radiograms were obtained in the ventrodorsal and right lateral projections (Figures 11A and 11B). The lungs were well expanded and there was no evidence of pleural or parenchymal disease process. Fluoroscopically the diaphragm and mediastinum showed no abnormalities. There was equal bilateral expansion of both lungs.
3:40 P.M. Bronchoscopy indicated patent bronchi bilaterally. Some hyperemia of the bronchial mucosa was noted. No appreciable change in the appearance of the bronchial mucosa however was noted between the left and right side of the bronchial tree. Following the preliminary bronchoscopy, a Foley catheter, No. 12, was introduced and 3 cc. of 50% hypaque were injected. The orifice of the diaphragmatic and intermediate lobes were obstructed. The dog continued to breathe quietly. Radiograms in the ventrodorsal and right lateral projections showed no appreciable changes in comparison with the pre-obstruction radiograms. (Figure 12A and 12B).

6:00 P.M. Fluoroscopically there was some diminution in the excursion of the right hemidiaphragm, however there was no indication, whatsoever, of any infiltration or atelectatic changes. Radiograms in the ventrodorsal and right lateral projection at this time (more than two hours following the obstruction) showed no radiographic evidence of any appreciable change since the preliminary examination.

8:40 P.M. Under fluoroscopic examination both lungs showed equal, practically, density. The diaphragmatic
excursion, however, was distinctly limited on the right side. Radiograms in the ventrodorsal and right lateral projection at this time, and almost five hours following the obstruction, showed no evidence of any significant radiographic changes when compared with the preliminary preobstruction examination. (Figures 13A and 13B).

11:00 p.m. Fluoroscopic examination demonstrated a localized area of infiltration like underaeration particularly adjacent to the right cardiophrenic angle area. Radiograms in the ventrodorsal and right lateral projection approximately eight hours following the bronchial obstruction demonstrated rather subtle changes in the region of the right cardiophrenic angle with no definite evidence of atelectasis. (Figures 14A and 14B).

11:30 p.m. The dog was sacrificed. The thorax was entered after the trachea was clamped, as was also done in the previous cases. The obstructed lobes showed a reddish pink color. Through the trachea both lungs were inflated. The apical and cardiac lobes on the right side were inflated while the diaphragmatic and intermediate did not show any communication with the outside air. The left lung was also
DOG 17
Preliminary

FIGURE 118
FIGURE 13A

DOG 17
5 HOURS
FIGURE 14A
DOG 17
8 HOURS

FIGURE 24B
well inflated. The radiogram of the specimen (Figure 15) showed that there was some under-aeration of the obstructed lobes. The balloon was removed, mistakenly, before the radiogram of the specimen was made. However, the location of the balloon is indicated by the arrow. One can notice the slight dilatation of the bronchus at the level of the obstruction. This experiment shows that earlier radiographic findings seven hours and 50 minutes following the obstruction did not, conclusively, demonstrate evidence of atelectasis. The adequacy of the obstruction of these two bronchi, it should be noted, was tested by means of the inflation through the trachea which demonstrated that even under pressure no air entered into these two bronchi.

Experiment 20

November 6, 1956, Male dog, weighing 30 pounds was used.

9:45 A.M. Satisfactory anesthesia was obtained following intravenous injection of 225 mg. of Surital. Bronchoscopic routine examination showed patent
bronchi on both sides. The bronchial mucosa was not remarkable.

11:30 a.m. Preliminary radiograms in the ventro-dorsal and right lateral projections were obtained (Figures 16A and 16B). Fluoroscopic examination was also conducted and showed equal expansion of both lungs without evidence of mediastinal shift. Both hemidiaphragms showed equal excursion. Following the determination of the distance of the orifice of the diaphragmatic and intermediate lobes, the bronchoscope with long foreign body forceps and the Foley bag catheter were introduced in the routine fashion. The balloon was subsequently distended with 2,8 cc. of 50% hypaque. Radiograms in the ventrodorsal and right lateral projections (Figures 17A and 17B) showed that the inflated hypaque balloon was in good position at the level of the adjacent orifices of the above mentioned lobes. The lung parenchyma distal to the obstruction showed no indication of underaeration.

4:00 p.m. Four and one half hours after the obstruction the dog was placed on the fluoroscopic table and showed a few patches of underaeration in the right
lower lung field. The right hemidiaphragm showed a distinct decrease of its excursion, more evident when compared with the left one. Radiograms obtained in the ventrodorsal and right lateral projection showed underaeration of the right lower lung field medially and close to the cardiophrenic angle. The adjacent heart border, however, was sharply delineated. (Figure 18A and Figure 18B).

6:00 p.m. The fluoroscopic examination demonstrated decreased excursion of the right hemidiaphragm and more evident atelectatic changes than in the previous examination of four and one half hours following the obstruction. However, there was no evidence of definite atelectasis. The radiograms obtained in the ventrodorsal and right lateral projections (Figures 19A and 19B) confirm the above mentioned findings.

7:00 p.m. The dog was sacrificed. The trachea was routinely clamped before the chest was entered. There was a slight diminution in the volume of the obstructed two lobes. The color of these lobes was reddish. The unobstructed lobes had a light pink color. (Figure 20)
Insufflation through the trachea showed no evidence of air leak nor any inflation of the obstructed lobes. The remaining lobes of the right lung and the left lung showed normal distension following the insufflation.

Radiogram of the specimen (Figure 21) showed a fairly well aerated (air-containing parenchyma distal to the obstruction). Histological sections showed (Fig. 21A) the presence of partially collapsed alveoli. Irregular scattered spaces were noted microscopically which were smaller in size than in the sections of the normal lung, taken from the unobstructed lobes. The apparently greatly thickened septa were, in fact, made up of opposed septa of collapsed alveolar spaces. The capillaries of the alveolar septa were markedly congested and rows of erythrocytes could be seen in the congested capillaries. This experiment shows that after seven hours and 30 minutes following the obstruction the earlier radiographic findings indicated the presence of underaeration, however no complete collapse of the obstructed lobes was demonstrated radiologically or pathologically.
FIGURE 103

DOG 20
6 1/2 HOURS
Experiment 14

August 20, 1956, female dog, weighing 40 pounds. General anesthesia was obtained using 300 mg. of Surital. 3:00 p.m. Preliminary radiograms were made in the ventrodorsal and right lateral projections (Figures 22A and 22B). A mild scoliosis of the dorsal spine with the convexity to the right was noted. Fluoroscopic examination showed that both lungs were well expanded and both hemidiaphragms demonstrated a normal excursion.

4:10 p.m. Under continuous Surital anesthesia, the dog was placed in the ventrodorsal position and was bronchosoped in the routine fashion. There was slight bilateral hyperemia, however no indication of any inflammatory process was present. The distance of the orifice of the diaphragmatic and adjacent intermediate lobar bronchi was noticed and marked on the bronroscope. Subsequently, the Foley bag catheter with a long foreign body forceps was used and the deflated catheter was introduced at the level of the orifices of the above mentioned bronchi. Dispension of the balloon was accomplished by the injection of 3 cc. of 50% hypaque.
10:40 P.M. Six and one half hours after the obstruction the dog was re-examined. Fluoroscopy indicated well delineated atelectasis in the right lower lobe obliterating the right cardiophrenic angle. There was some loss of definition of the right heart border and slight narrowing of the intercostal spaces of the lower rib cage on the right side. Heart rate as well as the rate of respirations were within normal limits. The radiologic findings were recorded in the ventrodorsal and right lateral views (Figures 23A and 23B). The atelectatic changes of the right lower lobe, some elevation of the right hemidiaphragm and decrease in the adjacent intercostal spaces are demonstrated.

6:00 a.m., 8-21-56. Fourteen hours following the obstruction the animal was re-examined fluoroscopically following general anesthesia with Surital. There was further elevation of the right hemidiaphragm and also distinct narrowing of the intercostal spaces in the right lower hemithorax. The atelectatic lobes - diaphragmatic and intermediate - were rather sharply delineated. There was marked diminution in the excursion of the diaphragm and some shift of the mediastinal structures and the heart towards the right side. Ne
evidence of paradoxical movement of the diaphragm or the mediastinum was present. Radiograms were made in the ventrodorsal and right lateral projections. In these radiograms one could easily notice the narrowing of the intercostal spaces and elevation of the left hemidiaphragm as well as the shift of the heart and mediastinal structures to the right side. The obstructing balloon is overlapped in the PA view by the heart silhouette. However, it is clearly delineated in the lateral view. The overall effect of the atelectasis, however, is less well outlined in the lateral view due to the effect of the left lung which is modified by the projection in the same direction of the well expanded left lung.

12:10 p.m. Twenty hours following the obstruction the dog was examined fluoroscopically. There was a sharp delineation of the medial part of the right lower lung field due to the atelectatic lobe. The adjacent somewhat overdistended cardiac segment was well aerated. The associated findings of decreased diaphragmatic excursion, narrowing of the intercostal spaces and the further shift of the heart and
mediastinal structures to the right side indicate very clearly the atelectatic changes secondary to endobronchial obstruction. Subsequently, radiograms in the ventrodorsal and left lateral projection were obtained (Figures 24A and 24B). These radiograms represent accurate recording of the above mentioned fluoroscopic findings. The heart rate as well as the rate of respirations were slightly increased and were recorded.

5:00 P.M., August 21, 1956. Twenty five hours following the obstruction the dog was again anesthetized with Surital and was placed on the fluoroscopic table. The previously mentioned findings were again noted without any significant changes except that the diagnosis of endobronchial obstruction was clearly and unquestionably present. The above mentioned classical findings of shift of the heart and mediastinal structures, decrease of the intercostal spaces, elevation of the right hemidiaphragm and sharp delineation of the atelectatic part of the lung were easily seen. Subsequently, radiograms were made in the ventrodorsal and right lateral projection (Figures 25A and 25B). Notice that in spite of the well
established atelectasis the right heart border is still outlined. This is well explained by the autopsy findings which are described subsequently. 6:30 p.m. The dog was sacrificed by an overdose of Surital. The trachea was clamped and a careful dissection of the thorax was made. The cardiac lobe, adjacent to the right side of the heart had a normal color. Inflation of the lungs through the intact trachea was made. The unobstructed segments of the right lung and the left lung were inflated to the approximate volume assumed during inspiratory phase. It was obvious that the cardiac lobe was adjacent to the surface of the right side of the heart for a distance (thickness) between 2.5 and 4 cm. This explains the fact that in spite of the adjacent atelectatic changes of the diaphragmatic and intermediate lobes the heart border was still delineated as the cardiac silhouette was surrounded by a part of the lung parenchyma which was still aerated thus permitting the advantage of differential absorption between the heart muscle and the air containing lung parenchyma adjacent to the heart, (absorption coefficient).
It is worth noticing, on the other hand, that in the 25 hour follow-up examination (Figure 25A) the right hemidiaphragm is not outlined. This is obvious when this examination is compared with the preliminary one (Figure 22A). The lack of definition of the right hemidiaphragm is attributed to the fact that the lung parenchyma adjacent to the diaphragm (diaphragmatic lobe) is atelectatic. Consequently, the differential absorption of the x-ray beam through this particular area and between the diaphragm and adjacent liver on one hand and the overlying atelectatic lung on the other are for practical purposes very similar. Therefore, the basic principal of the differential absorption due to the difference in the absorption coefficient which is so fundamental in diagnostic x-ray examinations is abolished. This finding was also verified in this experiment as well as in others in which the diaphragmatic lobe was found to be completely atelectatic. Needless to say that similar radiologic findings regarding the diaphragm are commonly seen in cases of large amounts of pleural fluid or consolidation of the adjacent lung parenchyma in which cases the adjacent diaphragm
DOG 14
Preliminary
is not defined. This again is the function of the same fundamental principal of differential absorption coefficient required for the delineation of adjacent structures.

Experiment 19

October 20, 1956. Male dog, weighing 35 pounds.

General anesthesia was induced following the intravenous injection of 275 mg. of Surital.

8:00 a.m. Routine bronchoscopic examination showed no evidence of abnormalities. The lobar bronchi, bilaterally were patent and the bronchial mucosa was within normal limits. Subsequent fluoroscopy demonstrated equal bilateral excursion of the diaphragms.

9:00 a.m. The Foley bag catheter was introduced in routine fashion and both the diaphragmatic and intermediate lobes were obstructed with the introduction of 3 cc. of 50% hypaque. Fluoroscopic examination following the obstruction demonstrated a bilateral radiability of the lung fields. No indication of disease process was noted. The heart rate and respiratory movements showed no particular abnormality.

Radiograms obtained subsequently showed findings similar to the previously described with no indication
of atelectasis or any infiltration in the lung field.

5:00 p.m. Following the induction of general anesthesiawith Surital the dog was again fluoroscoped (approximately nine hours following the obstruction) and showed a distinct atelectasis involving the lung field adjacent to the left heart border and above the diaphragm. The right heart border adjacent to the area of atelectasis could still be delineated fluoroscopically while the right hemidiaphragm adjacent to the atelectatic area could not be clearly outlined. This observation which was made in other cases was discussed previously (see description of Experiment 14).

9:00 a.m. Approximately 24 hours following the obstruction, the dog was anesthetized with intravenous administration of Surital. Fluoroscopically it was obvious that the right hemidiaphragm, the medial part of which was obliterated, showed some elevation. Shift of the mediastinal structures and some narrowing of the intercostal spaces was noted as in previous cases. The balloon was seen through the cardiac silhouette just to the right of the dorsal spine.
Diaphragmatic excursion on the right side was markedly limited. The apical and cardiac lobes were well illuminated as well as the left lung. The above mentioned hallmarks of atelectasis therefore were well established. Subsequently, the proximal end of the catheter was grasped with a hemostat and a partial incision was made. This produced the flow of some of the contrast medium resulting in deflation of the balloon. Grasping the partly incised proximal end, the entire catheter was removed without any difficulty. Coughing was initiated which was partly attributed to the probable irritation by the hypertonic solution of the hypaque which escaped following the incision.

9:20 a.m. Approximately 10 minutes following the removal of the obstructing balloon the dog was fluoroscoped and showed that the previously present classical signs of atelectasis were no longer evident. Instead there was fluoroscopic evidence of a few patches of underaeration in the right lower lung field.

11:00 a.m. The dog was again fluoroscoped and it was noted that none of the abnormal findings of atelectasis were present. The rib interspaces were normal and the
right hemidiaphragm, including its medial part, were well outlined. The mediastinal structures were well in the midline and the right lower lung field was well ventilated. Radiographic examination in the ventrodorsal and right lateral projections demonstrated radiological findings practically identical to the preliminary radiogram. It should be mentioned that prior to this examination and following the relatively short acting Surital anesthesia rather vigorous coughing was noted. This probably contributed to the expulsion of some of the retained secretions distal to the obstruction which were noted rather constantly in the previous experiments. It was rather impressive to us that while the manifestations of the atelectasis following the endobronchial obstruction were noted fluoroscopically as well as radiographically several hours later, the restitution of the normal ventilation following the removal of the obstruction resulted in rather immediate aeration of the lung and abolishment of the previously present radiological findings of atelectasis. The lack of any even localized areas of infiltration, as a result of the previous endobronchial obstruction, might be
attributed to the fact that the lung parenchyma, prior to the obstruction, was not infected and that the time interval from the time of obstruction was not long enough to precipitate significant inflammatory process.

1:00 p.m. Approximately four hours following the release of the obstruction the dog was sacrificed with an overdose of Surital. Careful opening of the thoracic cavity, following occlusion of the bronchus with ligation and double clamping with hemostats, showed no evidence of atelectatic changes. The color of the previously obstructed lobes was practically normal with a light pink hue. Dissection of the bronchi showed a mild degree of hyperemia of the previously obstructed bronchi when compared with the nonobstructed ones. Microscopic examination by the pathologist of the previously obstructed bronchi indicated a mild degree of mucosal edema in the region just distal to the area where the diaphragmatic and intermediate lobe bronchi were obstructed.

No indication of local inflammatory process in the lung parenchyma distal to the previously produced
obstruction were present nor any indication of bronchiectasis or dilatation of the bronchi was precipitated by the temporary bronchial obstruction. One would seriously doubt that such a relatively short bronchial obstruction of approximately 24 hours could ever produce any permanent bronchial changes such as bronchiectasis. While bronchial obstruction is one of the important contributing factors to the pathogenesis of bronchiectasis, bronchial infection undoubtedly with subsequent destruction due to infection, of the bronchial mucosa, smooth muscle elastic fibers and cartilage appears to be the main etiologic mechanism. Bronchial obstruction may act only as a precipitant of the infection if the mechanical obstruction lasts long enough. Longer lasting bronchial obstructions with pre- and post-obstruction bronchographic studies would probably be a reliable way to more accurately study the significance of the obstruction and the time interval required for the establishment of bronchiectasis. It is only logical to assume that the first stage of the bronchial changes will be reversible ones as the inflammatory process of the bronchial mucosa which will be first
to be effected will return to normal in most cases, particularly if treatment with antibiotics and proper bronchial toilet is established. This has been shown in clinical cases and we hope that our experience in this subject will be published in some details in the near future.
CONCLUSION

1. The radiographic and fluoroscopic observations during endobronchial obstruction by our method of bronchial obstruction were observed and described in detail.

2. The radiographic diagnosis of atelectasis is practically impossible for several hours following endobronchial obstruction. One should be aware of this possibility and avoid the exclusion of the possibility of bronchial obstruction at least a few hours following the obstruction.

3. It is important to remember that although atelectasis is indication of bronchial occlusion, radiologically speaking, absence of atelectasis is not always conclusive evidence of a patent bronchus.

4. Observations related to the silhouette sign, both positive and negative, were made with the diaphragmatic surface and heart border and confirmed by autopsy findings.
5. The results of a bronchial obstruction of a relatively short duration do not result in bronchiectasis or bronchial dilatation particularly when the most significant pathogenetic factors of bronchiectasis, i.e. is absent.
BIBLIOGRAPHY


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