ON

EXPIRATORY CERVICAL EMPHYSEMA,

THAT IS,

EMPHYSEMA OF THE NECK OCCURRING DURING LABOUR
AND DURING VIOLENT EXPIRATORY EFFORTS.

AN EXPERIMENTAL INQUIRY.

BY

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IN spite of the fact that emphysema of the neck, face, and other adjacent parts is an accident of labour which is not extremely rare, its pathology has hitherto been the subject of various hypotheses, amounting to little more than guesses, and even at the present time has never, hitherto, been the subject of accurate investigation.

The present paper is an effort to place the pathology of this affection on a firmer basis, and the investigations here detailed suggested themselves by way of corollary to experiments concerning the subject of artificial respiration in newborn children and kindred subjects related in the 'Med.-Chir. Transactions,' vol. lxiv, 1881, pp. 41—101, and vol. lxy, 1882, pp. 75—86. But the latter

investigation, concerning mediastinal emphysema and pneumothorax after tracheotomy (in which the route followed by the air was proved to be from the tracheotomy wound, beneath the deep cervical fascia and so into the tissue of the anterior mediastinum beneath the pleura), suggested that emphysema of the neck during labour might follow the same route in an opposite direction. This it was determined to test by experiment on the foetus, for the reasons that although it is true that the affection does not concern foetuses but adult women, yet (1) fresh foetuses have usually fairly healthy lungs; (2) their nearly identical age makes them a nearly uniform material; (3) the experiments could in any case only be illustrative, and therefore could only possess value in proportion to the amount of correspondence which they showed to the known phenomena. In this way adult subjects could only serve in the same manner as foetuses. With these considerations it was determined to choose foetuses as the subjects of experiment. Two children only who had breathed for a very short time (Experiments 9 and 10) were also used.

Frequency of occurrence of emphysema.—*Johnston and Sinclair*¹ (p. 517) had seven cases in the course of seven years (13,748 labours) in the Dublin Hospital, or less than 1 in 2000 cases.

Ætiology.—It is generally agreed that emphysema of the neck occurring during labour is due to bearing down. This will be seen on reference to almost any case on record (see table of references). Thus in the Dublin Hospital all the patients affected were primiparæ, and in all the cases severe bearing-down efforts are noted; it is obvious that any cause of obstruction to labour must so far favour it.

The time of its occurrence tells the same story. It never occurs before the second stage of labour, though it may not show itself till the third stage or altogether after labour (see *Dunn's* first case). In any case, how-

¹ For the list of works quoted in this paper see p. 67.

ever, it is no doubt produced during the second stage, even if it does not appear till later.

It need not occur, however, in connection with parturition at all, but may follow violent coughing (as in *Roche's* case, in which there was a foreign body in the trachea), or perhaps straining at stool (see remarks by *Dr. Otis* on *McLane's* case). Indeed the bearing down in labour has nothing special about it except that straining is maintained for a longer time than under other conditions.

Clinical course.—It will perhaps be well to quote one or two recent cases. Those of *Dunn* and *McLane* are selected as amongst the latest recorded.

Dunn records four cases of emphysema during labour; with two of which no details are, however, given. These are obviously cases of emphysema beginning below, and probably in connection with rupture of the uterus. Both ended fatally. This subject is alien to the present inquiry. The other two cases are more to our purpose.

(1) The first of these occurred in a primipara, who had an "ordinary labour" (whatever that may mean). During a violent effort to expel the placenta the right side of the face became swollen and crepitant. (N.B.—It came out in the discussion that the swelling was first noticed by the patient, and not till half an hour after the expulsion of the placenta, which throws considerable doubt on the time of the occurrence.) The swelling seemed to begin on the lower part of the right sub-maxillary region, and extended upwards on the nose and cheek as far as the zygoma; it gradually extended to the neck; no other symptoms were noticed. After some hours, the swelling, which was puffy and moveable, extended to the upper side of the chest and right arm. There was no cough, pain, or dyspnoea, and no change in the respiration. In the next two days the emphysema extended lower on the chest. The air remained four days and then gradually disappeared.

(2) The emphysema in the second case began (?) on the upper part of the right side of the chest under the

clavicle, and extended upwards as far as the zygoma and down to the middle third of the chest; also to the shoulder and upper part of the arm.

The details are so meagre that the order of the appearance of the emphysema is open to considerable doubt, but the localities affected may be accepted as correct.

McLane's case was that of a primipara, æt. 21. The first stage was very painful, the pains being long and very severe, lasting two hours, and necessitating the use of chloroform.

During the second stage there was violent straining; during one of these efforts the face became congested and purple, a swelling appeared on the right side near the trachea, and became much larger during the next three or four pains, which followed each other rapidly. The swelling extended to the right cheek. As soon as the patient recovered from the chloroform she complained of a constriction in the throat, and had some difficulty in swallowing. "Her neck, previously slender, was now thick and cedematous; her face so puffed that on the right side the eyelids were closed, as if by dropsical effusion, and the features effaced." The swelling crackled on touch. There was no emphysema below the clavicle. The whole swelling had disappeared in a week.

We learn from this and other cases that the swelling appears during the second stage of labour, generally during some violent straining effort, that it first appears in or about the suprasternal notch, extends rapidly upwards along the neck, and may reach the face; it may also extend down over the chest and down the arms. Its course reminds us of that of extravasation of urine affecting the opposite sex in a different part of the body, except that in the latter case the urine is unable to travel down the limbs. To trace the possible course of the air or the urine would be waste of time, since air easily travels all over the surface of the body in the subcutaneous cellular tissue—a fact practically useful in the skinning of animals—and urine for its part may do the same. All varieties

of its extension may be found in the appended references. The other points of interest are that the air is all absorbed in a week or so, without any ill-consequences, and never ends fatally (a fact partly explaining the doubt as to its pathology).

The last, but perhaps most important, fact is that there is no disorder of respiration, and *never pneumothorax*.

Pathology.—We now come to the chief subject of our investigation.

The theories to account for the phenomena are various.

Cloquet (p. 33) gives a good account of a case which of course recovered. He says, "It would be impossible for me to define here precisely in what spot the bronchi or their branches were ruptured."

Ménière quotes *Cloquet*.

Blundell (p. 473) attributes it to "*rupture of the trachea and bronchi*." He saw it twice in the same patient, a vociferous Hibernian, and in no other case.

Depaul (p. 689) gives two post-mortem accounts in which there was interlobular emphysema of the lung, but not of the neck.

Watson (vol. ii, p. 176) says, "Air passes into the mediastinum, and so into the neck."

Johnston and Sinclair do not explain it.

Roché (p. 252) in a case in which a foreign body had got into the trachea, found air in the mediastinum, and double interlobular emphysema, especially on the left side.

Soyre refers to *Cloquet's* case, and says, "*The rupture of the trachea* was situated a little above the bifurcation of the bronchi."

Oppolzer (p. 582) says that the commonest site of interlobular emphysema is the anterior edges of the upper lobes. "Serious consequences may ensue, if the air advances towards the hilum of the lung and the mediastinum, and from thence ascends into the subcutaneous cellular tissue of the neck and face. This is, however, on the whole a rare event."

Traube (p. 89) quotes *Roché*.

Mackenzie (p. 205) quotes *Watson*.

Whitney (p. 350) relates a case, but does not speculate on the pathology.

Haultcœur (p. 420) refers to *Depaul*.

Schroeder (p. 455) simply says it is due to "rupture of the air-vesicles."

Prince relates a case only.

Worthington does the same.

Atthill refers to *Depaul*.

Alexeef refers to *Depaul* and *Haultcœur*.

Nelson relates a case.

Spiegelberg (p. 419) mentions it only as an evidence of the force of bearing down.

Dunn (p. 397) remarks that in his second case interlobular emphysema due to laceration of the air-vessels or of the bronchial tissue was possible. This rupture generally causes emphysema of the pleura, which may extend to the subcutaneous tissue of the thorax and body generally. He remarks that *Jones* and *Sieveling* say that the same condition may arise from laceration of the trachea. I have repeatedly searched for this reference but failed to find it.

McLane (p. 582) believed the lesion in his case to have been rupture of the trachea. He had seen but one other case, and in that there was rupture of the pulmonary vesicles.

We have thus a variety of theories :

(1) Rupture of the bronchi.

(2) Rupture of the trachea.

(3) Rupture of the lung.

The *post-mortem records* bearing at all on the subject are meagre in the extreme ; they comprise two autopsies, showing interlobular emphysema of the lung, but not of the neck (*Depaul*), one case of interlobular emphysema, and air in the mediastinum (*Roché*) ; the other theories are not supported by any actual observations that I have been able to find.

It became necessary then to put these theories to the test.

Mode of experiment.—It was obviously impossible to exactly imitate bearing down, but on considering the conditions it appeared that they would be best imitated by putting pressure on the lungs filled with air and within the thorax. If any encouraging results followed it would then be advisable to study the behaviour of the lungs removed from the chest, so as to estimate the influence of the thoracic box.

The desideratum was *to produce emphysema of the neck without pneumothorax*. If pneumothorax should occur in some cases and not in others it would remain to eliminate its influence by a consideration of the cases.

Apparatus.—The apparatus consisted of a simple mercury manometer marked in millimetres, attached to a tube ending in a tracheal cannula. A T-piece answered the purpose of a mouth-piece for the operator, connected on one side with the manometer, and on the other with the trachea of the fœtus through the tracheal cannula.

Some experiments were performed with the lungs *in situ*, others with the thorax open, others with the lungs removed from the chest. In one experiment an attempt was made to trace the course of the air in former experiments by means of a coloured gelatine mass.

EXPERIMENT 1.—March 24th, 1882. Male child, born March 23rd.

Experiment March 24th, 3 p.m. (about thirty-six hours). Tracheotomy was performed, a cannula tied into the trachea and connected with a V tube filled with mercury, to the india-rubber tube of which was connected a T-piece, through which inflation was practised.

On blowing through the T-piece the chest expanded, then two small projections appeared below the third rib on each side in the nipple line; shortly afterwards the skin along the right sterno-mastoid became swollen; the

swelling was tympanitic; on pressure air escaped from the tracheotomy wound.

The extreme height of the manometer = 50 mm., *i. e.* height of mercurial column = 100 mm.

Autopsy.—Thorax opened under water. Double pneumothorax. Air bubbles beneath pulmonary pleura at the reflection of the pleura from the root of the right lung over the anterior mediastinum. Some diffuse subpleural emphysema.

On inflating the lungs again after opening the thorax, air distends the reflection of the pleura over the root of the right lung still more, and on the left side in the same manner, raising the pleura from the pericardium, and following the whole course of both phrenic nerves, dissecting up the pleura.

On plunging the foetus again under water and blowing, air escapes from two small holes in the anterior inferior part of each lung, but in larger bubbles from the reflection of the pleura over the root of the right lung (? were the small holes in the lungs punctures or ruptures).

The region of the cervical emphysema was next dissected; the air was found along the course of the right internal jugular vein:

(a) A bubble could be pressed into this collection from that in the anterior mediastinum.

(b) A bubble could be pressed the reverse way.

The air seemed to have passed from the anterior surface of the right lung—near and in front of its root—into the anterior mediastinum, behind the vena cava superior, and so along the right internal jugular vein.

Remarks.—The object of the experiment was to see in what direction air would escape from the lungs if overblown. This succeeded, the air passing from the lung substance near the root, behind the pleura, and along the great vessels of the neck.

Pneumothorax was, however, produced on both sides.

EXPERIMENT 2.—March 31st, 1882. Foetus born March 29th, after placenta prævia (? full time).

Experiment March 31st, 3 p.m. Tracheotomy was performed and a cannula tied into the trachea as before.

Inflation was then practised intermittently, so as to imitate, as far as possible, bearing down during labour.

The maximum height of the mercury column = 60 mm., *i. e.* whole column = 120 mm.

Autopsy.—On opening the thorax, air escaped from both pleuræ. Universal subpleural emphysema. Air occupies the anterior mediastinum and spreads in front of the root of each lung into the anterior mediastinum. No emphysema in right side of neck. Air extends along the course of the left internal jugular vein and can be pressed into the collection in front of the root of the right lung, to and fro; it passes under the left innominate vein.

On reinflating the lungs, air is distinctly seen to pass from beneath the pleuræ near the root of the right lung, in front of the right lung into the anterior mediastinum. Similarly on the left side, where the air chose the same path upwards along the left phrenic nerve. Air escaped from several ruptures in the pulmonary pleuræ.

Remarks.—The object and results practically the same as in Exp. 1.

EXPERIMENT 3.—April 4th, 1882. Full-time male child, born after turning, April 2nd, 2 a.m.

Experiment April 4th, 3 p.m. An incision was made from the ensiform cartilage to the pubes. Part of the right fourth rib was excised, the pleura exposed, and a cannula tied into the pleural sac, and then connected with the manometer as before.

Inflation was then practised, and the mercurial column raised to 50 mm., *i. e.* the column = 100 mm. in height; at this height air escaped through a hole made in dissection at the junction of the diaphragm and right lower

ribs, wounding the diaphragm but not the pleura, but leaving the pleura unsupported and therefore weak at this point; from this spot the air travelled behind the peritoneum, stripping it up. The cannula was quite secure. On the left side the same condition was found.

Remarks.—The object was to compare the strength of the lung and pleura, or rather of the lung and pulmonary pleura, with that of the parietal pleura. The experiment failed, but it showed the extreme ease with which air travels beneath the pleura and peritoneum.

EXPERIMENT 4.—April 5th, 1882. Full-time male child, born April 2nd, 1882.

Experiment April 5th, at noon. The same apparatus was used as before, except that the india-rubber tube, instead of passing directly to the tracheal cannula, passed to a Wolff's bottle filled with a warm solution of coloured gelatine, which was therefore to be driven into the lungs.

On blowing at the T-piece the gelatine solution passed into the lungs.

The maximum height of the mercurial column = 30 mm., *i. e.* the height of the whole column = 60 mm.

Autopsy.—Coloured gelatine in both pleuræ. The pleuræ universally œdematous with the same fluid, but most has collected in front of the root of each lung, in the anterior mediastinum, but not along the great vessels of the neck. On blowing air through the tracheal tube, air escapes and forms emphysema on the front of the left lung in one place, and on the front of the root of the right lung, but in no other part. The most œdematous parts are perfectly air-tight.

Remarks.—The object was to produce, if possible, emphysema of the neck with some coagulable injection, to allow of a leisurely dissection. The gelatine, however, simply transuded almost as if through a filter. I had observed this in the case of water in an experiment not here recorded. The most remarkable fact is that the

lungs are simple filters to fluid when they are still absolutely air-tight. The bearing of this is wide, but need not here be enlarged upon.

EXPERIMENT 5.—April 5th, 1882. Female child, born April 13th, weight 4 lbs., length $17\frac{1}{2}$ in.

N.B.—Manometer was broken at the beginning of the experiment and could not be used.

Tracheotomy, cannula tied into trachea. Lungs inflated intermittently to imitate intermittent bearing down during labour.

Autopsy.—Double pneumothorax.

General subpleural emphysema, *especially in front of both roots of the lungs*; no emphysema of the neck.

On inflating the lungs again, air slightly escaped from a few places.

Remarks.—In the absence of the manometer an attempt was made to repeat the production of emphysema of the neck, but without success. The foetus was probably immature.

EXPERIMENT 6.—April 17th, 1882. Male child, born April 15th, 9 a.m. (hand presented), full time. Length $20\frac{1}{2}$ inches, weight 7 lbs.

Experiment April 17th, 11 a.m., *i.e.* fifty hours after death, continued for an hour and a half. Tracheotomy, cannula tied into trachea, inflation intermittent.

An escape of air from the incision was noted, ? from trachea. Cannula was tied in again.

Escape of air continued. The skin incision was prolonged to the sternum, the trachea was opened as low as possible and the cannula tied in again.

Escape of air continued, apparently not from trachea but from right side of it, in the region of the large vessels.

N.B. The escape of air is only occasional, and does not prevent the mercurial column from rising to 40 mm. (*i.e.* column=80 mm.).

Autopsy.—Double pneumothorax.

Both lungs show subpleural emphysema, the right more than the left.

A large collection of air-bubbles existed on either side in front of the root of each lung, the air having got beneath the reflection of the visceral pleura over the mediastinum nearly everywhere on the right side. Another collection of bubbles on each side where the phrenic nerves reach the diaphragm. A large collection in front of the base of the right lung. The *right* half of the anterior mediastinum is one huge bubble; there are no bubbles on the left half.

The right side of the neck was very carefully dissected.

Air is present beneath right sterno-mastoid muscle, corresponding to the place from which it escaped during the experiment. A continuous chain of air-bubbles extends from the anterior mediastinum to the collection along the vessels of the neck on the right side, following the course of the phrenic nerve. Air can be pressed from collections on the upper part of the diaphragm, along the course of each phrenic nerve to the collection in front of the root of each lung.

On the left side a few small bubbles are found in the neighbourhood of the incision, and seem to have come from the incision.

On reinflating the lungs, air can be seen to pass behind the pleural reflection into the mediastinum as above, and to escape freely from the surface of both lungs.

Remarks.—The object was still the same, and the experiment succeeded in showing plainly the route taken by the air from the lung to the neck, but pneumothorax was also produced

EXPERIMENT 7.—June 26th, 1882. Small foetus, obviously premature, born June 24th.

Experiment June 26th, 5 p.m. Weight of foetus $2\frac{3}{4}$ lbs., length $15\frac{1}{2}$ inches. Tracheotomy, cannula tied into trachea. Intermittent inflation. Maximum rise of mercurial column = 40 mm. (*i. e.* height of whole column = 80

mm.) Air escaped eventually from the right side of the incision.

Autopsy.—On opening the chest one or two doubtful bubbles escape from the right pleural sac, *none from the left.*

Anterior mediastinum airless in most parts. Along the great vessels on both sides (especially the right) there is a continuous chain of air-bubbles, passing behind the innominate vein towards a collection in front of the root of each lung.

Subpleural emphysema (slight) in one or two patches in front of each lung, but especially on their inner surface near the root.

Remarks.—The object was the same as that of the preceding experiments, and the result very instructive. On the right side the air had taken the usual route, but there was a little doubtful pneumothorax. On the left side, however, the air had passed into the neck without escaping into the pleural sac.

EXPERIMENT 8.—November 3, 1883. Male, full-time foetus, quite fresh.

Experiment at 3 p.m. Thoracic viscera with the trachea were removed *en masse*. The lungs showed a few superficial lobules expanded, mostly at the apices.

The trachea was attached to the manometer, and a looking-glass arranged so as to show the side of the lungs away from the experimenter.

The pressure was begun at a rise of 5 mm. (*i. e.* the height of the mercury column = 10 mm.), and the order of expansion of the different parts observed. It was as follows :

- (1) Left apex.
- (2) Right apex.
- (3) Vertical strip along costal angles behind.
- (4) Extension downwards over both back and front, most extensive on the right side, a few isolated patches refusing to expand.

- (5) Slight bubbling below front of root of left lung.
- (6) " above " "
- (7) " below " right lung.
- (8) " to outer side of " "

One patch of subpleural emphysema the size of a hemp-seed on the inner surface of the right upper lobe.

(Up to this time the rise of the mercury column did not exceed 10 mm [*i. e.* the height of the whole column=20 mm.]).

Bubbling continued all round the root of the right lung, especially below, the spot of emphysema increased, and one or two smaller ones formed near it.

Pressure was now increased to a rise of 15 mm. (*i. e.* height of whole column=30 mm.).

A large patch of emphysema formed at once on the inner side of each upper lobe, as large as half a marble.

(N.B.—These patches spread when the pressure only causes a rise of 5 mm., *i. e.* under a column of 10 mm.).

One or two very small patches of emphysema were seen at the sides of the lungs, but none in front.

A large patch formed on the under surface of the right upper lobe, also in the fissures of the right lung.

The left lower lobe was then treated separately, the cannula was thrust into the lung substance and secured, the lung was then inflated. Immediately, a large bubble rose on the surface, disappearing as soon as pressure was relaxed, and reappearing instantly when it was resumed. It was found impossible to burst this even when 100 mm. pressure (*i. e.* a rise of 50 mm.) was steadily and repeatedly produced.

The bronchi being tied, it was found impossible to burst them under the greatest expiratory force available (=a rise of a 50 mm., or a column of a height=100 mm.).

Remarks.—The object was to see the behaviour of the lungs themselves uninfluenced by the thorax, (1) with regard to the order of expansion of different parts, (2) with regard to the comparative tenacity of different parts of the lungs, (3) of the pulmonary pleura, (4) of the bronchi.

(1) The order of expansion is given above. It is curious that the vertical strip along the costal angles, which is one of the last places to be expanded when the lungs are within the thorax, should have been one of the first to expand here.

(2) The weakest part of the lung was seen to be about its root, which gave way (subpleural emphysema) under the pressure of a column = 20 mm.

(3) The strength of the pulmonary pleura was seen to vary immensely; here it could not be ruptured, in former experiments the pleura was ruptured by far less pressure.

(4) The bronchi could not be ruptured by the strongest expiratory effort.

Emphysema, once formed, was seen to spread at a comparatively small pressure (column = 10 mm.).

EXPERIMENT 9.—November 8th, 1882. Fœtus female, born November 6—7 (midnight) and lived eight hours. Artificial respiration had been performed.

Experiment November 8th, 10 p.m. Thorax opened, but lungs not removed. No pneumothorax; a few small subpleural ecchymoses, lungs partly expanded.

Tracheotomy, cannula tied in trachea. Inflation (to a rise = 10 mm., or a column = 20 mm.) caused no emphysema.

The pressure was increased to a rise of 15 mm. (or a column = 30 mm.). Slight scattered interlobular subpleural emphysema followed, most marked in the left lung.

On repeating inflation under the same pressure, emphysema spreads, especially in the fissures.

The pressure was increased to a rise of 20 mm. (or a column = 40 mm.), and a bubble of subpleural emphysema on the inner side of the right middle lobe gave way.

After several repetitions, a large bubble was seen to occupy the posterior mediastinum, extending below and in front of the root of the left lung, and gradually extending upwards thence into the anterior mediastinum between the thymus and pericardium.

Although pressure was repeatedly increased to a rise of 25 mm. (or a column = 50 mm.) and although the posterior mediastinum was full of air as far as the diaphragm, no air rose into the neck.

Remarks.—The object was to observe the behaviour of the lungs *in situ*, but with the thorax opened.

(1) No emphysema took place till a rise of 15 mm. (or a column = 30 mm.), *i. e.* the lung substance gave way at this pressure.

(2) The first emphysema was between the lobules at the surface of the lung.

(3) Emphysema appeared very early between the lobes.

(4) The pleura gave way at a rise of 20 mm. (or a column = 40 mm.)

(5) The air did not rise into the neck.

EXPERIMENT 10.—November 9th, 1882. Male, seven months child, born midnight November 6th—7th, died 12.30 p.m. November 8th (thirty-six hours).

Thorax opened. Tracheotomy, cannula in trachea.

On inflating the lungs, a leak is seen in the inner edge of the left upper lobe (the lung had probably been pricked in opening the chest). The leak cannot be stopped.

Experiment failed.

EXPERIMENT 11.—December 29th, 1882. Full-time stillborn male child, of somewhat doubtful freshness (date of birth unknown).

Thorax opened, cannula tied into trachea.

Lungs entirely airless, very watery.

Slight expiration inflates patches of the lungs, especially on the posterior surface.

Additional inflation produces increased expansion of the same parts, least behind.

Eventually the lungs became almost entirely expanded.

The pressure was increased to a rise of 10 mm. (or a column = 20 mm.). No emphysema.

The pressure was increased to a rise of 15 mm. (or a column = 30 mm.). Considerable emphysema of the front

of the root of the right lung occurred, extending into the fissure in front between the right upper and middle lobes, and also (but less) emphysema of the anterior and inner aspects of the upper and middle lobes. It began most markedly between the lobules. A bubble burst on the inner and anterior surface of the right upper and middle lobes.

Numerous leaks having occurred through the pleura the root of the right lung was tied.

Pressure producing a rise of 10 to 15 mm. (or a column = 20 to 30 mm.) produced well-marked emphysema of the front of the root of the left lung, extending in the anterior mediastinum and $\frac{1}{2}$ inch along the course of the left phrenic nerve.

On repeating this, the inner surface of the upper lobe became emphysematous, and a bubble in that situation burst. Emphysema extended into the fissure between the upper and middle lobes.

The pressure was increased to a rise of 20 mm. (or a column = 40 mm.), and produced much escape of air from subpleural bubbles and extension of the emphysema from the root of the lung downwards into the posterior mediastinum.

The *bronchi were then tied*, and the greatest possible expiratory force exerted, causing a rise of 75 mm. (or a column = 150 mm.).

No escape of air took place.

Remarks.—(1) Emphysema (= rupture of the lung) took place at a pressure = a column 30 mm. high.

(2) The pleura eventually gave way at this pressure.

(3) The front of the root of each lung was the first place to give way.

(4) The spaces between the lobules and lobes (*i. e.* the interlobular spaces and fissures) were weak places.

(5) The bronchi and trachea could not be ruptured by the greatest expiratory effort.

EXPERIMENT 12.—December 30th, 1882. Large full-

time female child, stillborn (placenta prævia), about twenty-four hours.

Thorax opened ; lungs unexpanded and very sodden.

Tracheotomy, cannula tied into trachea. Inflation was begun at a rise of 10 mm. (or a column = 20 mm.), and produced scattered inflated patches on the anterior and internal edges of all the lobes of both lungs, most marked inferiorly.

Second inflation at the same pressure produced an increase of the same, plus slight subpleural emphysema of the left base posteriorly.

The third inflation at the same pressure fully inflated the lungs and slightly increased the emphysema.

The pressure was increased to a rise of 15 mm. (or a column = 30 mm.), and produced a leakage of air from the left base.

The left base, seeming to be unusually frail, was tied off, and the experiment resumed.

On repeating the inflation at the same pressure a large patch of emphysema occupied the tip of the lingula. A large bubble formed in front of the root of the left lung, and smaller ones on the inner surface of the left upper lobe, mostly interlobular. The emphysema, still mostly interlobular, extended over the left lung.

The left lung was next tied at the root, and the experiment continued with the right lung.

Inflation was continued with a rise of 15 mm. (or a column = 30 mm.), which produced interlobular emphysema of the right base. Large bubbles occupied the fissures between the middle and lower lobes.

The pressure was increased to a rise of 20 mm. (or a column = 40 mm.) ; the emphysema extended over the front of the middle lobe, and a bubble burst, probably in one of the fissures.

The root of the right lung was tied and the strongest expiratory force exerted. No leak was produced at a rise of 80 mm. (or a column = 160 mm.).

Remarks.—The order of inflation was unlike the

former experiments, perhaps in consequence of the sodden state of the lungs.

(1) The left lung gave way (emphysema) under a column 20 mm. high, the right under a column 30 mm. high.

(2) The left pleura gave way under a column 30 mm. high, the right under a column 40 mm. high.

(3) The spaces between the lobules and lobes (interlobular spaces and fissures) were weak places.

(4) The bronchi and trachea could not be burst by the greatest expiratory effort.

EXPERIMENT 13.—January 1st, 1883. Full-time still-born child (craniotomy), born twenty-four hours previously.

Thorax not opened. Tracheotomy, cannula tied into trachea and attached to mercury manometer as before.

The lungs were inflated at a rise not exceeding 10 mm. (or a column 20 mm. high), then the thorax was compressed (the escape of air being prevented), causing an increased rise of 30 mm. (or a column 60 mm. high).

This was several times repeated, to imitate as far as possible the effect of bearing down.

A projection is seen above each clavicle, apparently from the apices of the lungs.

After several repetitions the left side of the neck was seen to be full, and on pouring water on the tracheotomy incision bubbles were seen to escape from the left side of the wound.

The initial pressure was now increased, so as to produce a rise of 15 mm. (or a column = 30 mm.), and then a rise of 20 mm. (or a column = 40 mm.).

Autopsy.—Considerable emphysema was found round the root of left lung, extending into the fissures and posterior mediastinum. Interlobular emphysema of whole of left lung, air escaping from several places. Slight diffused subpleural and interlobular emphysema of right lung, especially in front of its root.

No emphysema of neck.

The bronchi being tied, the greatest possible expiratory efforts, producing a rise of 80 mm. (or a column = 160 mm.), produced no escape of air.

Remarks.—(1) The dissection threw doubt on the escape of air from the neck, at least no air was found along the great vessels on dissection.

(2) The emphysema was seen to occupy the interlobular spaces, fissures, and the front of the root of the right lung.

(3) The bronchi and trachea could not be burst by the greatest expiratory effort.

EXPERIMENT 14.—February 22nd, 1883. Full-time still-born male child (face presentation), born February 19th.

Experiment February 22nd, noon. Thorax not opened. Tracheotomy, cannula tied into trachea.

The lungs were then inflated by intermittent inflations, the pressure causing a rise not exceeding 15 mm. (or a column = 30 mm. high), and these inflations were continued half an hour.

Autopsy.—Lungs completely inflated, no emphysema. Inflation was then continued at same pressure; no further result.

Pressure was then increased so as to produce a rise of 20 mm. (or a column = 40 mm.), producing a small spot of *subpleural emphysema* on the anterior surface of the internal inferior angle of the right middle lobe, and in several *interlobular* spaces on the inner surface of the right upper and middle lobes.

On repeating the inflation, the emphysema spread and extended in front of the root of the right lung, from which air then escaped.

The emphysema extended to the left lung and in front of its root, markedly between the lobules and in the fissures.

The emphysema then extended slightly into the right side of the *anterior mediastinum*, above and in front (from the front of the root of the right lung), and into the left side of the *posterior mediastinum* behind and below.

The emphysema then occupied all the fissures of both lungs.

The right side of the posterior mediastinum then became emphysematous.

Both lungs eventually showed great emphysema behind all pleural reflections.

Remarks.—The lungs were unusually air-tight; it was not till a rise of 20 mm. (or a column of 40 mm.) was produced that any emphysema appeared.

(1) The lung tissue gave way at a rise of 20 mm. (or a column of 40 mm.).

(2) The pleura gave way at the same pressure when prolonged.

(3) The pleural reflections and the interlobular spaces were the weakest. (These include the fissures and the reflection of the pleura over the root of the lung to the anterior mediastinum.)

EXPERIMENT 15.—February 27th, 1883. Male stillborn child (premature labour at end of eighth month), born February 26th, 2 p.m.

Experiment February 27th, noon.

Tracheotomy, cannula tied into trachea. Lungs were inflated at a pressure causing a rise not exceeding 15 mm. (or a column = 30 mm.). This was repeated intermittently for fifteen minutes, when the pressure was increased to a rise of 20 mm. (or a column = 40 mm.).

No signs of emphysema of the neck.

Autopsy.—No emphysema except a small spot on the inferior edge of the front of the right middle lobe (? produced in opening thorax), from which air escapes. On holding this, the emphysema spreads widely over all surfaces of the right lung. The right lung was then tied at its root. The left lung sustained a pressure causing a rise of 20 mm. (or a column = 40 mm.). On increasing the pressure to a rise of 40 mm. (or a column = 80 mm.), diffuse subpleural emphysema formed over posterior and inferior surface of back of left base.

Remarks.—The lung tissue only yielded to a pressure equal to a column of mercury 80 mm. high.

EXPERIMENT 16.—March 17th, 1883. Stillborn male child, born evening of March 15th.

Experiment at 11 a.m., March 17th. Thorax not opened. Tracheotomy, cannula tied into trachea.

The lungs were inflated intermittently, the pressure being gradually increased from a rise of 15 mm. (or a column = 30 mm.) to a rise of 40 mm. (or a column = 80 mm.), at which pressure the column sank as if from a leak.

Autopsy.—Air in both pleuræ, a good deal of fluid; lungs very œdematous. One or two very small patches of subpleural emphysema on both lungs. In front of the root of the right lung is a large patch extending into the anterior mediastinum in front, into the posterior mediastinum (which is greatly distended) behind, and into the fissure between the right middle and lower lobes.

On the left side the root of the lung is simply surrounded with emphysema, raising the reflection of the visceral and parietal pleura along the inner edge of the lung in its whole length, thus filling the posterior and left half of the anterior mediastinum. From the front of the root of the right lung bubbles extend to the phrenic nerve and along its course to the diaphragm, where there is a large collection of bubbles. No collection of bubbles is seen on dissection on either side of the neck, but they can be pressed from the anterior mediastinum upwards and escape alongside of the great vessels on the left side, passing behind the left innominate vein.

Summary.—Rupture of both lungs about their root at a pressure of 80 mm. of mercury; escape of air into both mediastina, on the left side following the phrenic nerve to the diaphragm. Pneumothorax (double), probably from escape of air from a rupture of the mediastinum.

Remarks.—The weak parts were the reflections of the pleura as before, especially the large ones in front of the root of the lungs and in the fissures.

Although air was not actually found in the neck, a free communication between the neck and the anterior mediastinum was demonstrated. The passage of air along the phrenic nerve to the diaphragm has already been noted in other cases and also in the experiments on artificial respiration ('Med-Chir. Trans.,' vol. lxxv, 1882, pp. 77 and 80).

EXPERIMENT 17.—March 20th, 1883. Full-time stillborn male child (second of twins) born March 19th, 3 a.m.

Experiment March 20th, noon. Thorax not opened. Tracheotomy, cannula tied into trachea.

Lungs were inflated at a pressure producing a rise not exceeding 15 mm. (or column = 30 mm.)

Pressure was gradually increased to a rise not exceeding 20 mm. (or column = 40 mm.), giving twenty inflations at each rise of 5 mm. (or increase of column = 10 mm.).

On reaching this pressure, the *left side of the neck became distended, and air escaped from the left side of the incision.*

Autopsy.—No pneumothorax. The lungs on being inflated after opening the thorax are found perfectly air-tight.

Left side.—Air extends along the large vessels of the neck on the left side, and can be traced behind the left innominate vein to the anterior mediastinum, where a large collection is continuous with one in front of the root of the left lung and extending into the fissures of the lung. Air distends the posterior mediastinum and runs beneath the whole reflection of the visceral into the parietal pleura, along the inner edge of the left lung, and from thence along the diaphragm to the termination of the phrenic nerve; a few scattered spots of subpleural emphysema, especially on the "lingula."

Right side.—No emphysema of neck. Emphysema in front of root of lung and upwards a little way along phrenic nerve towards neck (N.B.—The middle lobe was not separated from the upper) and along the inner side of

the middle lobe following an intralobar fissure; also (as on left side) in posterior mediastinum, extending forwards to the ending of the phrenic nerve in the diaphragm, along the reflection of the pleura over the adjacent sides of the anterior mediastinum, diaphragm, and pericardium; also upwards along the phrenic nerves.

No other emphysema.

Remarks.—Emphysema of the left side of the neck was produced without pneumothorax. The air as usual had escaped from the front of the left lung near its root, into the mediastinum and along the great vessels to the neck. The fissures were also occupied by emphysema.

The pleura (though not the lung) withstood a pressure producing a rise = 20 mm. (or a column = 40 mm.).

Consideration of the experiments.—The production of emphysema of the neck was effected in the very first experiment, but it was not till Exp. 7 that it was produced without pneumothorax (left side). This result was also achieved in the last experiment, No. 17 (left side).

The difficulty was to find the necessary pressure.

The question of the significance of the cases in which pneumothorax was produced will be discussed hereafter.

The route selected by the air was exactly the same as in emphysema of the mediastinum after tracheotomy (after entering the mediastinum), but in a contrary direction.

The source of the air was rupture of the lung tissue producing interlobular emphysema near the anterior aspect of the root of the lung.

The question *why this spot is especially prone to rupture* was capable of two answers: (1) it might be due to inherent weakness in this part of the lung, (2) it might be due to the relation between the lung and the thoracic box.

This question was investigated by experiments on the lungs with the chest open, or after their removal from the chest. The results obtained showed that in lungs removed from the pressure of the chest wall, the weakest parts are the spaces between the lobules and lobes.

This is easily intelligible when it is remembered that the pleura invests the lung with hardly any adhesion to its surface, and that it can be stripped up with almost inappreciable force by air beneath it. The strength of the pleura is simply that of an independent investing elastic bag. If the air escapes from a lobule it finds no resistance from the pleura except on the surface of the lung, and may easily lie between the lobules without any pressure from the pleura.

With regard to the fissures of the lung, the same is true ; the pleura is here, so to speak, slack and offers little or no resistance to air once escaped from the air-cells.

But experiments showed that the root of the lung was a specially weak spot with the thorax closed, though not with the thorax open. In other words, when the thorax was open it merely shared the weakness common to all the pleural reflections.

This point requires some discussion. What is the physical condition of the lung during inflation within the closed thoracic walls ? The thorax is distended, the diaphragm depressed, the sternum, clavicles, and ribs elevated.

Is the thorax or the lung the more distensible ? To this it must be answered that the lungs can easily be ruptured within the thorax.

But it nevertheless cannot be doubted that, up to this point, the thorax supports its contents.

Does it do so equally in all directions ? Below, we have the unbroken plane of the diaphragm ; behind, in front, and at the outer side we have the ribs and muscles. But at the inner side we have the compressible mediastinum, whose easy penetrability was proved in the experiments already alluded to dealing with the subject of mediastinal emphysema after tracheotomy. This side then seems to be the direction of least resistance.

When once in the mediastinum, the air is already within the track of easy penetrability or of slight resistance, leading into the neck, and which probably owes

this quality partly to the fact that the upper aperture of the thorax is the weakest spot in the thoracic box, not being directly defended by muscles, which pass obliquely from the neck to the upper ribs, clavicles, and sternum. It must also be remembered that this upper aperture of the thorax is enlarged on inspiration.

The above reasons show that the mediastinum may be considered to be within the area of diminished resistance.

What happens in a bearing-down effort? First a deep inspiration, which (among other things) raises the upper ribs and clavicles, and increases the size of the upper aperture of the thorax. Next the glottis is closed. Lastly the whole of the expiratory muscles, essential and accessory, put forth their strength.

The least resistance is offered to pressure at the upper aperture of the thorax.

Thus then, on the *anterior surface of the root of the lung is the pleural reflection least supported externally.*

We have now to consider the question of the significance of the occurrence of pneumothorax in some of the experiments.

Is the pneumothorax in these cases a link in the chain ending in emphysema of the neck?

A very little consideration will suffice to put such an idea aside.

Let us consider the course of the air on this hypothesis. It escapes from the air-vesicles beneath the pleura; bursts through the pulmonary pleura; must then distend the pleural cavity; then bursts through the parietal pleura, and so gets beneath the deep cervical fascia.

First of all, the autopsies entirely contradict such an assertion; they show the course of the air to be different.

Secondly, the air beneath the pulmonary pleura finds practically no resistance in travelling beneath the pleura, but the pulmonary pleura is rather tougher than the lung. The experiments show the tenacity of both lung and pleura to vary very greatly in the foetus (whatever they do in the adult), as the following table shows:

Lowest force required to burst the lung :—

Experiment No. 8	.	.	20 mm.
„ „ 12	.	.	20 „

Lowest force required to burst the pleura :—

Experiment No. 11	.	.	30 mm.
„ „ 12	.	.	30 „

Highest force required to burst the lung :—

Experiment No. 15	.	.	80 mm.
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Highest force required to burst the pleura :—

Experiment No. 8 (N.B., locally)			100 mm.
„ „ 9	.	.	40 „
„ „ 14	.	.	40 „

An attempt was made (Exp. 3) to test the tenacity of the parietal pleura, but it was unsuccessful. It must, however, be remembered that the tenacity of a membrane like the pleura must be very different when raised from the subjacent structures (pulmonary pleura), and when subjected to force, which only presses it the more firmly on its supports. It can easily be imagined that a film of collodion might add great strength to a membrane if force was applied in such a direction as to press the film against the membrane, while its strength would probably be very small if it had to resist a force from below, that is, raising it from its supporting membrane.

We therefore conclude that pneumothorax, when it occurred, had nothing to do with the production of emphysema of the neck.

We have avoided speaking of the clinical phenomena which form the actual subject of our consideration, but it must not be forgotten that pneumothorax never occurs either with emphysema of the neck during labour, or as the result of expiratory efforts.

We have not hitherto spoken of the theories that regard

emphysema of the neck as due to rupture of the trachea or of the bronchi.

This may be dismissed in a word: *The strongest expiratory effort failed to burst the trachea or bronchi of a fœtus.*

The experiment was repeatedly tried, and amounts to a "reductio ad absurdum" of the hypothesis.

It cannot be alleged that in the cases in which this accident occurs during labour the patients have had disease or fistula of their bronchi or trachea, for the patients may in all cases be, and are nearly always, expressly described as perfectly healthy, and moreover they suffer no ill-effects.

To the question whether a lung can be ruptured with impunity we must answer in the affirmative; if the air is all absorbed within a week from the subcutaneous cellular tissue, why not from beneath the pleura?

Again, the collection beneath the pleura must be small or it would give physical signs, or at least marked symptoms, which, however, are always absent.

What actually happens is probably as follows: During a violent expiratory effort an air-cell near the front of the root of the lung gives way, and the air lies beneath the pulmonary pleura. With the next effort this becomes larger, and part of it moves in the direction of least resistance, namely, towards the mediastinum, next time towards the neck, and so on, until a bubble emerges beneath the deep cervical fascia. A channel will thus be formed along which bubbles will pass as quickly almost as they escape from the lung. They may form a large collection in the neck, beneath the deep cervical fascia, where the pressure is small; eventually they may find their way into the superficial fascia, and so all over the body.

The gelatine injection (Exp. No. 4) gave us the interesting fact that a lung which is quite air-tight is quite permeable for fluids. I had previously proved this as regards water, and it is seen to be true also of a colloid mass. This fact has various and important bearings, which this is not the place to enlarge upon. It may,

however, be remarked that the air-cells are lined with an epithelium not much removed from an endothelium, such as that which lines serous cavities which are lymph-sacs and highly permeable to fluids.

The experiments are thus seen to illustrate the clinical facts of emphysema of the neck during labour, and during violent expiratory efforts.

The emphysema is essentially *expiratory* in its nature, and due to a cause entirely opposite to that which is answerable for emphysema of the mediastinum after tracheotomy. In saying this it is conceivably possible that expiratory emphysema might occur after tracheotomy, though the conditions under which the operation is performed are well known to obstruct inspiration rather than expiration. In this case the operation would have nothing to do with the emphysema. Emphysema of the lung may occur from over-distension of a part due to obstruction in other parts. This is a well-known clinical fact, and was also illustrated in the experiments quoted above ('Med.-Chir. Trans.,' vol. lxx, 1882, p. 78, Exp. 19 (L.)). In such a case the air which had escaped beneath the pulmonary pleura might conceivably be forced into the mediastinum. But the burden of proof in any case of tracheotomy rests with the observer who asserts that the emphysema which he finds, is due to expiratory rather than inspiratory causes. The mediastinal emphysema of tracheotomy is *inspiratory*; the mediastinal emphysema of violent expiratory efforts is *expiratory*. Mediastinal emphysema without subpleural emphysema cannot be expiratory. Subpleural emphysema without mediastinal emphysema may be inspiratory as well as expiratory. Subpleural, together with mediastinal, emphysema is probably altogether expiratory, but the former may be due to inspiratory over-distension of part of the lung with obstruction elsewhere; the latter may conceivably be due to the expiratory forcing of the air thus escaped into the mediastinum. We are now only speaking of cases of tracheotomy in which the derivation of the air from a cervical

wound is a possibility, and the source of the air is therefore so far debateable.

But while allowing the above possibilities, we wish to repeat that the emphysema of tracheotomy occurs under conditions which obstruct inspiration, and is therefore essentially *inspiratory*, the air being derived from the cervical wound.

The following conclusions are offered :

1. The cause of emphysema of the neck during labour is rupture of the lung tissue, the air escaping near the root of the lung, passing beneath the pulmonary pleura into the anterior mediastinum, and so beneath the deep cervical fascia into the neck. The route thus marked is the same by which air sometimes passes into the anterior mediastinum after tracheotomy (see 'Med.-Chir. Trans.,' vol. lxy, 1882, p. 75, *et seq.*, and p. 85).

2. The weakest parts of the lung are opposite the pleural reflections (that is the fissures) and the interlobular spaces. The anterior surface of the root of the lung is the weakest spot while the lungs are within the thorax, being that pleural reflection lying within the comparatively unsupported area near the upper aperture of the thorax.

3. Pneumothorax, when it occurred during experiment, had nothing to do with the production of emphysema of the neck, and in two experiments was not associated with this emphysema, which thus exactly imitated that occurring during labour.

4. The healthy bronchi and trachea are able to resist the greatest possible expiratory efforts.

5. The lungs and pleuræ when quite air-tight are freely permeable to fluids.

6. The usual rules of practice to restrain bearing down and accelerate labour after the production of emphysema of the neck are sound.

7. The accident would seem to be noted in about 1 case in 2000, but it is not improbable that slight cases are overlooked.

8. The air emerges from the thorax along the great vessels, but may not become superficial till it has travelled higher up.

9. The emphysema of the lower part of the trunk, usually connected with rupture of the uterus, belongs to quite a different category and is generally associated with a fatal result.

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[See also *Chahbazian*. Arch. de Tocologie, Juillet, 1883.]

[For discussion on this paper see 'Proceedings of the Royal Medical and Chirurgical Society,' New Series, vol. i, p. 285.]