THIRD COMMUNICATION
ON
ARTIFICIAL RESPIRATION IN STILL-
BORN CHILDREN.
MEDIASTINAL EMPHYSEMA AND PNEUMOTHORAX
IN CONNECTION WITH TRACHEOTOMY.
AN EXPERIMENTAL INQUIRY.

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THE occurrence of emphysema in the anterior mediastinum, and pneumothorax, in the course of a series of experiments on artificial respiration in stillborn children, has seemed a matter of sufficient interest to justify a short communication on the subject.

The series of experiments concerned twenty-six subjects who had never breathed, and extended over a period of two and a half years, from January, 1878, to July, 1880, in the laboratory of Dr. Lauder Brunton. They are related in detail in 'Med.-Chir. Trans.,' for 1881, pp. 41—101.

Five of the experiments do not concern the present branch of the inquiry, but in the others the following was the course pursued:—Tracheotomy was performed, a cannula was tied into the trachea and connected to an india-rubber tube, which in its turn was attached to a water manometer in twenty cases and to a mercury manometer in one case. When this was done, the effects of various methods of respiration by manipulation were tried, and the height of the column of water noted by the manometer.

In each case the height noted is the height above zero or the line of original level, so that the actual height of the column of water is represented by double the height indicated.

As the object was that of comparing the relative inspiratory forces of the various methods, this was quite correct as a means of comparison, though the above fact would have to be remembered in calculating the actual inspiratory force.

In the latter case the fact that the manometer would not register more than 6 or 7 inches, and had to be readjusted in the middle of the experiment when the effect exceeded this, would have to be remembered.

The accompanying table shows in the first column the number of the experiment for reference, in the second column the methods of artificial respiration employed, in the third column the maximum inspiratory effect of each method; the fourth column contains the account of the dissection and remarks.

No. of experiment.	Method employed.	Maximum respiratory effect.	Autopsy and remarks.
8	Marshall Hall Silvester (forcible) Schroeder Schultze No inflation.	0 5 in. 0 3 in.	Loud whistling heard at the root of the neck during the Schultze manipulations. Air in both pleural sacs; thymus embedded in large air-bubbles, which filled the anterior mediastinum, and on pressure escaped from the tracheotomy wound. Left lung airless. Right lung: middle lobe, and upper and inner edge of the lower lobe inflated. No wound in any of the air-passages discoverable.
11	Marshall Hall Silvester (forcible) Schultze Schultze-Silvester No inflation.	$\frac{3}{4}$ in. 11 in. 7 in. 7 in.	Gurgling and whistling heard during Schultze and Schultze-Silvester manipulations. Air in right pleural sac, none in left. Large bubbles of air in anterior mediastinum, embedding thymus, and extending along course of left phrenic nerve as far as diaphragm, and along right phrenic vein about half way to the diaphragm; on pressure air escapes at tracheotomy wound. Both lungs float, and are generally fairly expanded. No wound in any of the air-passages discoverable.
12	Marshall Hall Silvester (forcible) Schultze Schultze-Silvester No inflation.	$\frac{1}{8}$ in. 8 in. 7 in. 7 in.	Whistling heard at root of neck during Schultze manipulations. Air in left pleural sac, none in right. Anterior mediastinum full of air-bubbles, some of which escape on pressure at the tracheotomy wound. Left lung slightly inflated. Right lung better inflated, but only partially.
14 (G)	Silvester (forcible) Marshall Hall Schultze Inflation.	6 in. $\frac{1}{8}$ in. 2 in.	Whistling heard during Schultze manipulations. No air in pleural sacs; mediastinum full of air-bubbles, embedding thymus. Both lungs fully inflated.
16 (I)	Pacini Bain Schultze Silvester (forcible) Unsuccessful attempt at inflation.	6 in. 6 in. 5 in. 6 in.	Whistling heard during manipulations (during which is not noted). Air in right pleural sac. Anterior mediastinum full of air-bubbles, which partly escape on pressure into right pleura. Both lungs partly inflated.

No. of experiment.	Method employed.	Maximum respiratory effect.	Autopsy and remarks.
18 (K)	Bain-Pacini Schüller Schultze No inflation.	5 in. 0 3½ in.	Sucking noise heard during Schultze manipulations, the amount of inspiratory effect diminishing as this increased. Air in right pleural sac, none in left. Anterior mediastinum full of air-bubbles. Right lung airless. Left lung partly inflated.
19 (L)	Bain-Pacini Silvester (forcible) Schücking Schultze No inflation.	4 in. 5 in. 5 in. 5 in.	Sucking noise heard at root of neck during Schultze manipulations. No air in either pleural sac. Anterior mediastinum full of air-bubbles, covering right auricle of heart. Left lung airless. Right lung airless, except middle lobe and anterior internal part of lower lobe. At this point is a patch of subpleural emphysema.

Remarks.—It will be seen that mediastinal emphysema was observed in seven out of twenty-one experiments, *i.e.* in one out of three, or 33·33 per cent.

The first time the phenomena were observed, it occurred for a moment that the emphysema might be due to post-mortem changes, but the freshness of the subject contradicted this.

The next impression was that the air had escaped from one of the bronchi or the trachea, but careful examination and inflation through the trachea with the extremities of the bronchi clamped failed to discover any leak.

It was not long before the appearances could be satisfactorily traced to their cause.

Pneumothorax was often associated with mediastinal emphysema, but never occurred without emphysema; on the contrary, the emphysema occurred without pneumothorax. Therefore the pneumothorax was probably a later sequel of the emphysema.

Air was observed to escape from the mediastinum into the pleural sac.

Air could be pressed from the anterior mediastinum and emerged at the tracheotomy wound.

A whistling or sucking noise was observed during the experiments at the root of the neck.

It appeared, then, that the air travelled from the tracheotomy wound into the mediastinum, which in some cases it ruptured, producing pneumothorax.

Pneumothorax occurred in five out of seven cases of mediastinal emphysema, in one case into both pleural sacs, in three into the right, in one into the left sac.

In every case but one (16 (1), in which both lungs were about equally inflated), the pneumothorax occurred on the side on which the lung was less expanded.

Experiment.—By way of confirmation a foetus was taken, and the tissues down to the trachea were divided, the trachea being left intact; the skin was raised so as to form a funnel or pouch, and into this coloured injection was poured. Silvester's method was then employed; the coloured injection was found in the anterior mediastinum.

The following is the explanation offered :

When by the manipulations for respiration the thoracic cavity is expanded, the intra-thoracic air is rarefied (which is relatively the same thing as the extra-thoracic pressure being increased).

When all the air apertures of the thorax are closed the only way in which the intra- and extra-thoracic pressures can be equalised is by suction through the blood-vessels; the lungs become hyperæmic, and transudation of serum into the air-passages may occur, causing œdema.

If all the air passages are not closed the pressure will be equalised through the route of least resistance—the trachea.

This is what occurs in ordinary breathing :

When a manometer is tied into the trachea, the air enters by the trachea until the column of fluid equalises the pressure, when equilibrium is established.

But the weight of a column of fluid is equivalent to an obstruction of the air passages; and in this case the

same phenomena may be observed in the subject as are observed in a living child which is making violent inspiratory efforts, its air passages being obstructed, viz. the pressure of the external air depresses the weakest points.

In a living child these include the supra-clavicular fossæ and supra-sternal notch, the abdomen, and hypochondria.

In a dead child the effect of the diaphragm (which is practically not much affected by any artificial mode of respiration) is eliminated, and the hypochondria are not retracted, but the abdomen and parts above the sternum and clavicles are depressed.

But if a potential passage to the thoracic cavity exists, this becomes a *locus minoris resistentiæ*, and the pressure will act through it.

The tracheotomy wound establishes this potential passage by piercing the deep cervical fascia. This fascia, as is well known, runs behind the sternum and becomes continuous with the sheaths of the great vessels and the pericardium.

It is through this passage that air penetrates into the mediastium.

Whether it goes further than this is determined by the question whether a sufficient quantity can be contained there to equalise the pressure; if not it will go farther.

In one case it followed the course of the phrenic nerves, on one side to the diaphragm.

In the majority of cases it burst the mediastinum and distended the pleural sac.

It was observed that in most cases one lung was better expanded than the other, and it was on the less expanded side that the pneumothorax occurred.

This is what we should have expected from the above-named physical conditions.

No case occurred in which it burst into the better expanded side, though in one case, the lungs being (as far as could be seen) about equally expanded, pneumothorax occurred on one side only. (A thickened pleura,

however, might determine rupture into the opposite or better expanded side.)

In one case (19 L) it was noted that with mediastinal emphysema there was one patch of subpleural emphysema on the solitary expanded portion of either lung.

With emphysema in connection with partial collapse, solidification, &c., we are familiar; it is but an illustration of the same physical laws as preside over mediastinal emphysema.

It was observed that the noise at the root of the neck in six cases out of the seven was found to occur during the Schultze manipulations; in the seventh case it was heard, but its exact time of occurrence is not noted.

This coincides with what we know of the suddenness and violence of the action of this method noted elsewhere; it was the sudden jerk caused by this method which produced the sudden blast at the tracheotomy wound which burrowed into the anterior mediastinum.

It is to be remarked that the presence of a large mediastinal emphysema, even with pneumothorax, does not necessarily prevent considerable inspiratory effect.

I have looked through the post-mortem records of St. Bartholomew's Hospital from 1868 and find records of twenty-seven cases of autopsies after tracheotomy for various causes.

Mediastinal emphysema is recorded in three cases, or 11.1 per cent.

In two out of these three cases pneumothorax is noted, and in one it was the cause of death. In one case in which pneumothorax was probably bilateral, both lungs were collapsed; in another, the right-sided pneumothorax corresponded with right-sided collapse.

In one case there was emphysema of the tissues about the neck. In one case the air channel was traced down from the wound into the anterior mediastinum.

I have also examined the post-mortem records of the Hospital for Sick Children since 1860, and find records of eighty-two cases of autopsies after tracheotomy for various causes.

Mediastinal emphysema is recorded in five cases, or 6·09 per cent.

In no case is pneumothorax noted.

The state of the lungs was as follows :

CASE 1. Both lungs collapsed.

2. No collapse.

3. Both lungs partly hepatised.

4. Anterior parts of lungs emphysematous, posterior parts less expanded than anterior.

5. Upper lobe and posterior part of lower lobe of right lung solid and airless.

Emphysema of the neck is noted in three out of the five cases.

I do not imagine that these numbers represent the actual facts ; indeed, in the cases in which mediastinal emphysema is recorded, it is almost invariably mentioned by the way as if an unimportant fact ; and one recent case was only recovered from oblivion by personal inquiries.

This is not to be wondered at, considering that, as far as I have been able to discover, the matter is not even hinted at in any of the books dealing with tracheotomy ; indeed, the following passage is the only mention of the subject which I have been able to find :

Wilks and Moxon, 'Lectures on Pathological Anatomy,' second edition, 1875, p. 308 :

"We believe we have seen two cases of pneumothorax arise from tracheotomy, and we mention the circumstance because we are not aware that it has ever been alluded to. In one case where, after tracheotomy, death occurred without sufficient reason, both lungs were found contracted in the chest, and the cellular tissue in the posterior mediastinum was filled with air, producing large bubbles, which we think had burst through the pleura into the chest.

"In another case, where most extensive superficial emphysema followed the operation, the breathing became laborious before death, and the lungs were found con-

tracted in the same manner; the emphysema had penetrated the mediastinum."

The latter of these two cases, together with my experiments, may illustrate the production of emphysema of the tissues of the neck, &c., during labour.

With regard to pneumothorax, any small amount of air in the pleura is liable to escape observation unless the thorax is opened under water.

Still, thus much is proved:

1. That mediastinal emphysema does occur after tracheotomy.
2. That it is sometimes accompanied by pneumothorax.
3. That it sometimes exists apart from emphysema of the neck.

The route which the air takes was proved by experiments to be behind the deep cervical fascia.

It remains to discuss the relation of mediastinal emphysema to emphysema of the neck.

It would appear, *à priori*, probable that these would be due to a common cause.

The experiment in which coloured injection penetrated beneath the deep cervical fascia to the anterior mediastinum, without tracheotomy; and all the experiments in the table (in which no escape of air from the trachea was possible) prove that the air does not penetrate from the tracheal wound.

But if the above views are correct the two sorts of emphysema are obviously due, not only to different but to opposite causes, mediastinal emphysema being due to the diminished pressure in the thorax during inspiration, emphysema of the neck, on the contrary, being produced during expiration.

Emphysema of the neck may indeed run beneath the skin and fascia upwards to any extent, and downwards over the thorax, but the air cannot be forced by the expiratory force into the thorax, for the simple reason that the *vis a tergo* of the air issuing from the tracheal

wound is at once met by the equally powerful *vis a fronte* of the intra-thoracic pressure.

The production of anterior mediastinal emphysema and the route taken by the air need not be again explained.

It is not to be denied that air blown from the tracheal wound beneath the cervical fascia may be subsequently sucked into the anterior mediastinum (though air in the subcutaneous cellular tissue could hardly do so), but what is insisted on is that, whether the air travels directly from the wound or indirectly, as explained above, the mechanism of the production of the two sorts of emphysema is entirely different, and, indeed, opposite.

The following case shows that blood or, indeed, any other fluid, effused beneath the deep cervical fascia, may subsequently be drawn into the thorax, a fact which perhaps deserves attention with regard to the after treatment of operations near the root of the neck and of deep cervical abscesses. In view of the above observations, strong or sudden inspiratory efforts (*e.g.* in vomiting) must greatly increase the risk of thoracic complications from the inspiration of pus or other fluids into the thoracic cavity.

The case is briefly as follows:—Induction of premature labour for flat pelvis; turning; delay of after-coming head at brim; child stillborn, with heart beating; artificial respiration by direct inflation and the methods of Silvester and Schultze for three hours, after which child breathed naturally; death six hours after birth.

Autopsy showed separation of fifth and sixth cervical vertebræ without fracture, blood extravasated in all directions, among others into the tissues of the neck, including deep cervical fascia, from whence it extended downwards to the apices of the lungs and along the sheath of the vessels on the left side to the level of the third dorsal vertebra. Bloody fluid in both pleuræ.

It is of some consequence to consider the exact moment at which the danger of mediastinal emphysema occurs.

The conditions favouring its production are two—a

wound of the deep cervical fascia, and obstruction to the air passages; the moment of its production is inspiration.

To apply this: the danger begins as soon as the operator has divided the deep cervical fascia. The lower this is divided the more easily emphysema of the anterior mediastinum is produced.

Supposing obstruction to exist in the larynx, the period of greatest danger is the interval between the division of the deep cervical fascia and the establishment of efficient patency of the trachea.

Elevation of this fascia away from the trachea renders the entry of air beneath it more easy.

Bungling in inserting the tube increases the danger by prolonging the dangerous period.

Insertion of the tube beneath the deep cervical fascia instead of into the trachea (of which instances are on record) renders the entrance of air easy above all other conditions.

The following practical conclusions are offered:

1. Emphysema of the anterior mediastinum occurs in a certain number of tracheotomies.

2. It is often associated with pneumothorax, to which it stands in causal relation, and which may be the cause of death after tracheotomy.

3. The air is most likely to burst into that pleura of which the lung is the less expanded. On the other hand, pneumothorax, of course, helps to collapse the lung.

4. The route selected by the air is the space beneath the deep cervical fascia.

5. Emphysema of the anterior mediastinum may or may not be associated with emphysema of the neck; but their causes are different, and the conditions of their production are opposite.

6. The conditions favouring the production of mediastinal emphysema are division of the deep cervical fascia, obstruction to the air passages, and inspiratory efforts.

7. The dangerous period during tracheotomy is the

interval between the division of the deep cervical fascia and the efficient introduction of the tube.

8. The incision in the deep cervical fascia should not be longer than necessary in the direction of the sternum. It should on no account be raised from the trachea, and this should be particularly remembered during inspiratory efforts.

9. It will probably be found that the frequency of occurrence of emphysema of the anterior mediastinum depends much on the skill of the operator, especially in inserting the tube.

10. If artificial respiration should prove necessary the tissues should be kept in apposition with the trachea, and any manipulations performed steadily and without jerks.

11. Schultze's method (which is not otherwise suitable for the above purpose) is especially prone to produce emphysema of the anterior mediastinum.

12. These observations illustrate the fact that, apart from the question of tracheotomy, the inspiratory force of the thorax should be remembered in all operations near the root of the neck, whether dealing with vessels or not, and in the case of all collections of pus beneath the deep cervical fascia. In these cases quiet respiration is essential for the safety of the patient, and vomiting, which begins with a sudden inspiration, is dangerous.

13. These observations may serve to illustrate the production of emphysema of the neck, &c., during labour.