IX. *On the ultimate distribution of the Air-passages, and the formation of the Air-cells of the Lungs.* *By* William Addison, *Esq., F.L.S., Member of the Royal College of Surgeons, and of the Council of the Worcestershire Natural History Society.* *Communicated by* Robert B. Todd, *M.D., F.R.S.*

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The opinions of anatomists have been much divided as to the manner in which the bronchial tubes terminate; whether the cells composing a lobule of the lungs have free communication with each other, or whether each cell, without any such communication, receives the inspired air by a single bronchial ramification only.

The latter opinion, derived from the results of Reisseissen's investigations, prevails.

Malpighi was the first to describe the *air-vesicles* of the lungs, and the *air-tubes* ending in them*.

Helvetius attempted to prove that these *Malpighian vesicles* were nothing more than common cellular tissue, diffused without order through the lungs, and that the air proceeding thither through the minute air-tubes, not only passes easily from cell to cell, but likewise from the lobules into their interstices, and finally diffuses itself through the whole lung.

Haller adopted the opinions of Helvetius. "The vesicles of the lungs," he says, "do not receive the air by a single orifice from the windpipe as into an oval grape or phial, but the air exhaling from the least branches freely spreads from any one part of the lungs into all the rest, and returns again in like manner; neither is the cellular fabric of the intervals between the lobules shut up from the vesicles of the lungs, nor are the lesser lobes surrounded by any peculiar membrane†."

Reisseissen, in his work *De Fabrica Pulmonum*, discourses of the labours of his predecessors, and refers particularly to the opinions entertained by Helvetius and Haller; and then, aided in his researches by a microscope, and by various methods of inflation and injection, he attempts to controvert them, and to prove that the cells in each lobular subdivision have no communication with those of the adjoining ones, in the manner of cellular tissue. "The air-cells," he says, "are the *culs de sac* terminations of the air-tubes, and are perfectly independent of one another‡."

* M. Malpighi de Pulm. Epistol. 1 and 2, ad A. Borellum, 1661. Epistola 1. de Pulm. Published at the end of the Exercit. de Visc. Struct. p. 220, &c.

† Haller (Von Albert), Elementa Physiologiæ: Cap. De Respiratione.

‡ "Inde jam facile colligitur, singulas per pulmonum faciem vesiculas, cellulasve aëriferas, cæcos esse extremorum canaliculorum fines, easque ingenti numero distributas, massam illam conficere quæ spumosa ut est plurimis contextus cellulosus videbatur."—*Op. citat.*, p. 56.

CRUVEILHIER and MAJENDIE, however, describe the air-cells as freely communicating with each other, in the interior of each lobule; but I am not aware that either of these authors has given any detailed or minute description of the aëriferous structure of the lung*.

Having been engaged in investigating by the microscope the seat and nature of tubercles in the lungs, and having examined the structure, recent and dry, in every possible way I could devise, I nevertheless always failed to discover any *tubes* ending in *culs de sac*; on the contrary, I always saw air-cells communicating with each other in every section I made.

I therefore repeated several of REISSEISSEN's experiments, and instituted others, from which I derived ample evidence that *the bronchial tubes,* after dividing into a multitude of minute branches which take their course in the cellular interstices of the lobules, *terminate* in their interior *in branched air-passages, and* freely *communicating air-cells.*

In a fœtal lung the bronchial ramifications in the interior of a lobule, or the *intralobular ramifications*†, have a regular branched arrangement, subdividing in all directions, somewhat dichotomously, and terminating at the boundary of the lobule in closed extremities. It is not, however, at the boundary of the lobule only that these closed extremities or *culs de sac* terminations of the intralobular bronchial ramifications are placed, many of them may be seen in the interior of a lobule, lying against and pressing upon the sides of the adjoining branches (*a*), Plate XII. fig. 8.

It is important to remark, that there are *no anastomoses* to be seen between the intralobular bronchial branches; each branch pursues its own independent course, until it terminates in a closed extremity.

Anatomical writers generally use the terms *air-vesicles* and *air-cells* synonymously, so that they are convertible terms; but strictly speaking, an air-vesicle is an air-bubble, and may exist either in or out of a pulmonary air-cell. It is not necessary to the existence of an air-bubble, that it should be contained in a membranous envelope; hundreds of them may not only exist, but in any slightly viscous liquid may even press against each other, without losing their figure or globular isolation.

In a fœtal lung neither air-bubbles nor air-cells exist; but when an animal respires, the entrance of the air into the lungs inflates all the lobules to twice or three times their fœtal dimensions, and the *intralobular bronchial ramifications* experience a great and important change both in figure and character. The delicate membrane composing them opposes an unequal degree of resistance to the pressure of the air, which is very considerable, and it is consequently distended into little globular inflations, forming a series of communicating cells, which are immediately and perma-

* CRUVEILHIER's Anatomy, by A. TWEEDIE, M.D., F.R.S., p. 552. MAJENDIE's Lectures.

† I have adopted the appropriate and now universally received terms of Mr. KIERNAN, which exactly express a very necessary distinction between the bronchial ramifications in the cellular interstices of the lobules, which are always tubes, and those in the interior of the lobules, which are tubular only in the fœtus.

nently occupied by air-bubbles, in the mass of which all trace of the symmetry of their branched arrangement is entirely lost or obscured. The rounded inflations of one branch meeting on all sides those of the adjoining branches, are moulded by pressure into pentagonal or hexagonal forms, which are the figures of the air-cells, fig. 9.

Branched passages, however, still exist, and form a communication between the cells; but these passages are now neither tubular nor cylindrical. It is therefore necessary to distinguish them, and I have called them Lobular Passages, an appropriate term suggested to me by Dr. R. B. Todd.

The air-cells have not an indiscriminate and general intercommunication throughout the interior of a lobule. I have before observed that there are no anastomoses between the intralobular bronchial ramifications; hence the air-cells formed along the branch (*b*), fig. 8, do not communicate with those in the branch (*c*), except by means of their common opening into a larger branch at (*d*), and so on for each branch respectively.

Experiment 1.—Take a very thin section of inflated and dried lung, and submit it to an examination by the microscope. A great number of large and well-defined Oval Foramina, (*a*, *a*) fig. 1, with a sharp and delicate edge, will be seen thickly distributed among the cells. Frequently three, four, or five of them (*b*, *b*) may be seen close together, and whichever way the section be made, they are equally numerous and conspicuous. These foramina are evidently not portions of bronchial tubes, for they have no uniform cylindrical wall, which is necessary to constitute a tube. By gently altering the focus of the microscope you may look down through the uppermost foramina into the interior of air-cells situated laterally below them, and several foramina and cells may thus be brought successively into view (*c*, *c*).

These foramina are portions of the *lobular passages*, and if the section be taken from the surface of the lung, including the pleura, they are smaller, and placed at more equal distances from each other, than when made from the interior of the organ, fig. 2; which is exactly the result that would accrue from a division of branched passages, in the former case (fig. 2.) approaching their terminations, and in the latter (fig. 1.) nearer the point whence the branches emanate.

Experiment 2.—I injected with mercury a small bronchial tube in the lung of an Ox, leading towards the thin margin of the organ; the metal appeared at the surface, forming a mass of minute globules. Having made an incision in the interval between two lobules and inflated the cellular tissue, I was enabled carefully to dissect away the pleura, and I then observed through a lens that the globules were contained in delicate membranous sacs, forming rounded eminences projecting from the tissue. I then separated several lobules from each other, and saw the mercury at the surface of every lobule, presenting rounded eminences similar to those observed at the surface of the lung. On examining these rounded eminences or globules in the microscope, I perceived that the mercury was not inclosed in a simple sac or cell, but in a divided

or multilocular cavity. Nor is it difficult to comprehend the character of these multilocular cells at the surface, when we conceive the nature of the structure of a lobule, consisting of numberless small branches of a ramified tube, which the atmosphere at birth distends into cells. The extremities of these branches, evolving or shooting forth under the pressure of the air, meet with resistance and support from the adjoining lobules, and being as it were thrown back upon themselves, form the multilocular cavities or cells I have described (b, c') fig. 8. WAGNER's figure represents these terminal cells only*.

Experiment 3.—Having inflated a recent lung, I cut off a small portion, and examined it as an *opake object* by the microscope; I found all the oval foramina occupied by large air-bubbles, other bubbles of various sizes occupying the surrounding cells. I then placed *a very small* piece between two slips of glass, which were so arranged under the microscope that I could gently and gradually press them together, still keeping the object (*now viewed transparent*) in focus. I then observed the air-bubbles changing their situation, not by moving equably through any tube or cylindrical passage, but by sudden starts from cell to cell. I frequently saw a large bubble of air become compressed for a moment in passing from one cell to another, and sometimes divide into two smaller bubbles, one of which passed on to another cell, the other retiring to the spot from which a momentary pressure had removed it. I have frequently watched a bubble of air pass through three or four cells in succession, the communication between them not being through a tubular passage, but by limited openings (oval foramina) leading from cell to cell.

It does occasionally happen that a small portion of bronchial tube may be included in the object thus submitted to examination, and if so, when the glasses are pressed together, the air-bubbles glide easily and readily through it. The bubbles of air formed in the lungs are of all dimensions, some large, some small, and others so minute as not to measure more than $\frac{1}{1000}$th or $\frac{1}{800}$th of an inch in diameter; hence three, four or more may occupy a single cell, and the heterogeneous adhesion between them and the tissue is so strong, that it is impossible to expel all of them by pressure. They may, however, be removed from very thin sections of recent lung by two or three days' maceration in water, and the pulmonary network is by this means rendered very distinct; and if such sections be carefully examined by a lens, *lobular passages may be seen partially laid open, disclosing a series of communicating cells* (a, a, b, fig. 3.).

Experiment 4.—If the lungs of a Rabbit be allowed to macerate for two or three days, all the air-bubbles at the thin edge of the organ will be removed, and this portion assimilated to a fœtal state. Having prepared a lung in this way, I poured mercury into the trachea, and allowed the metal by its own weight to traverse the air-tubes and passages; it appeared at the surface of some of the lobules in the form of little globules (a, fig. 4.), in others *as beaded* or *nodulated branches* (b.). By press-

* Icones Physiologicæ, tab. xv. fig. 8, 1839.

ing the mercury onward, these beaded branches became more and more numerous, smaller ones proceeding not only from the extremities of those first seen, but shooting out from them laterally in all directions; by continuing a little gentle pressure, all symmetrical arrangement was lost in a mass of minute globules (*c*). These beaded branches evidently combine the character both of cells and passages; each bead or globular inflation is an air-cell, communicating with others on either side in such manner as to form branched passages*.

If the pleura be stripped off from the lung of a fœtal Calf, the lobules may be readily separated from each other, and their subdivisions are carried to a great extent. I have measured several from $\frac{1}{20}$ to $\frac{1}{30}$th of an inch only. The smallness of the ultimate lobular subdivisions may also be seen by removing a small strip from the thin margin of a lung, and slightly compressing it between two slips of glass, figs. 5 and 6.

The lobules have an irregular polygonal figure of from four to six sides: after respiration the sides are flatter, and the angles sharpened by the pressure of the adjoining lobules.

Experiment 5.—I poured mercury into the lungs of a fœtal Calf by the trachea,

* Reisseissen was the first who noticed the globular distentions or nodules formed on the extreme bronchial branches when a lung is injected with mercury; but he appears to have looked upon them as unnatural or abnormal, produced by the weight of the metal, not considering that the weight or pressure of the air rushing into a fœtal lung is much greater than the weight of any column of mercury that would usually be employed to inject a lung. Speaking of a lobule injected with mercury, he observes, "Hæc fabrica clarius etiamnum perspicietur, lobulo ejusmodi intra duas laminas vitreas comprehenso, ac microscopio subjecto. Laminæ autem quadamtenus sunt comprimendæ ut hydrargyrum, ab aëre intus residuo usque repulsum extremos in fines impellatur. Sic apparebit, canaliculos ad extremum usque marginem certo quodam ordine, eoque constantissime servato in ramulos excurrere, horumque diametros ad rationem procedentis ramificationis decrescere, ipsam vero in ramulos divisionem ad finem adeo increbrescere, ut ex singulis cujusque ramuli locis novi circumquaque proveniant, qui, hydrargyro impleti, quasi nodulos referunt; denique extremos illorum fines tam breves evadere, ut speciem tantum globulorum dimidiatorum exhibeant instar brassicæ botrytidos stipatorum.

"Ne quis autem objicere posset, partes per se tenerrimas hydrargyri pondere extendi, idque ipsum, in globulos discedere valde pronum, illusionibus opticis occasionem dare, aliud institui experimentum, quod, quum tales præcidat dubitationes, viarum spiritalium fines clarius etiam armato oculo repræsentat. Statui itaque illas spiritu tantum impletas, nec ulla adhibita vi novo examini submittere. Pulmonem vero quam recentissimum, eumque teneriori ex animali exemptum (vitulinus opinor optimus est) aquæ submergi deindeque seponi jussi. Tum, sublatum post aliquot dies, quum demisso spiritu maxima quidem ex parte collapsus est, nonnulli tamen lobuli aërem inclusum etiamnum retinerent, calida curavi perfundendum, sic ut rarefacto per calorem spiritu, distenti ramuli in subjecta rubicunda bullarum collapsarum massa facile adspectui se præberent. Deinde, aëris columella scalpelli ope extremos ad fines promota, eandem vidi, ut antea distributionem, præterquam quod canaliculi minus intenti cylindros exactiores referebant. Evidentissime autem cognosci potest, canaliculos ad extremum productos cæcos in fines, sive vesiculas pulmonales abire, lobulo tali intra lamellas vitreas microscopio ita subjecto, ut a spectro reflexorio pelluceat, et illis subinde leviter agitatis, aër modo antrorsum, modo laterales in ramos impellatur. Neque tandem vesicularum forma fallere quenquam potest, pro distentis sacculis illas habentem, vel bullulis globosis, quæ extremis canalibus sint adnexæ, quum ambitum ipsarum ad ramulos, unde prodeunt relatum, perinde se habere, atque ramos ad truncum clarissime perspiciat.

"*Hæc experimenta abunde, ut videtur, ostendunt, vias pulmonum spiritales canales teretes esse ad finem cæcos, membranaceos, ex tunica videlicet tracheæ mucosa conformatos, aëri, ut supra commemoratum est, planè impermeabiles.*"

and allowed it by its own weight to trickle down the bronchial tubes which were filled with the metal, and were very conspicuous at the thin margin of the organ. I placed a portion of the injected thin margin of the lung between two plates of glass, and on using slight pressure, the mercury at the extremities of the injected branches was forced into still smaller nodulated branches, which divided and subdivided in an unvaried branched order, (*a*) figs. 5 and 6; by using a little more pressure their numbers increased, the symmetry of the branches being readily detected by the microscope; but ultimately, by continuing the pressure, all symmetry was lost in a mass of minute globules (*a*). The same effects were produced by pressing the mercury in the bronchial tubes onward between the finger and thumb without using the plates of glass.

With a good light and a power magnifying 120 times linear, the globules of mercury are seen to be inclosed in cellular cavities formed laterally on branched passages. In the small branches the metal appears in round globules; it is less globular in the larger branches, and a disposition to the formation of cells may be detected by the depressed lines seen on the column of mercury in branches of still greater magnitude.

I have in my possession a preparation containing lobules from the thin margin of a fœtal lung which were partially distended by air, sufficient to show the regular branched symmetry of the air-tubes to their ultimate terminations; establishing a perfect analogy between them and the secreting tubes of glandular organs. The air with which the tubes were partially distended has been absorbed by the fluid in which the preparation is preserved, and membranous septa are everywhere visible in their interior. The pulmonary cells are evidently formed by the pressure of the air against the sides of the tubes in the intervals between these folds (fig. 8.). A careful examination of the membranes of the air-cells by the microscope in a thin section of dried inflated lung will be sufficient to convince any one that they do not form round nor even rounded cells, but that they are perfectly flat membranous plates, circumscribing polyhedric spaces. When healthy and recent they are exceedingly tough and elastic. I have often found that the tissue of the lungs may be stretched to twice its dimensions without rupturing them. They will bear the scrutiny of the highest powers of the microscope, and are characterized by several peculiar ovate bodies which form a part of their structure. They are also marked by numerous delicate lines, which are, no doubt, uninjected vessels of the capillary network. They possess an epithelium in the form of large round nucleated scales, and from one to fifteen or more nuclei may be counted in a single scale. A great many nuclei without any epithelium envelope may be seen upon them, but I have never satisfied myself that they possess the ciliated cylinder epithelium so abundant in the trachea and the bronchi.

The dimensions of the air-cells, as might be expected from the preceding details of their structure and formation, gradually increase with age, but in healthy women they are always smaller than in healthy men at the same period of life. Taking the recent lung of a healthy man, aged forty-five, as the mean between the small cells of

Fig. 1.

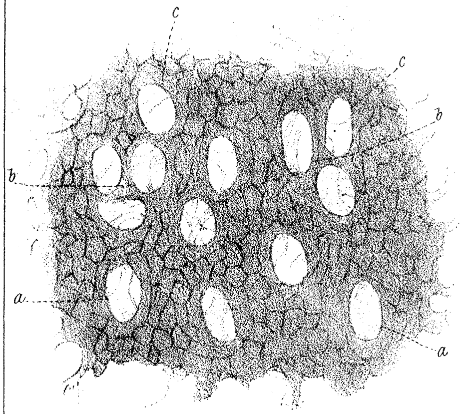


Fig. 2.

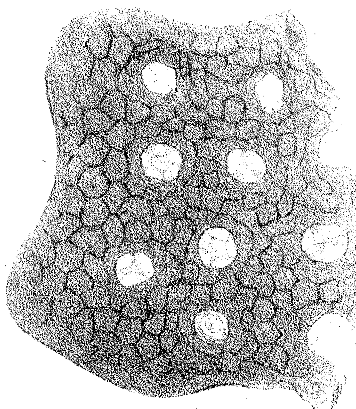
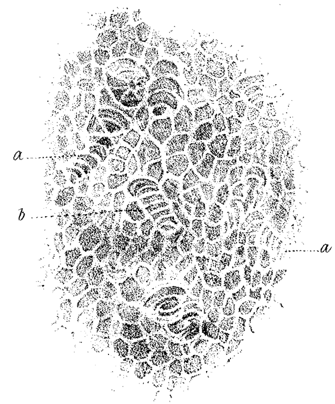


Fig. 3.



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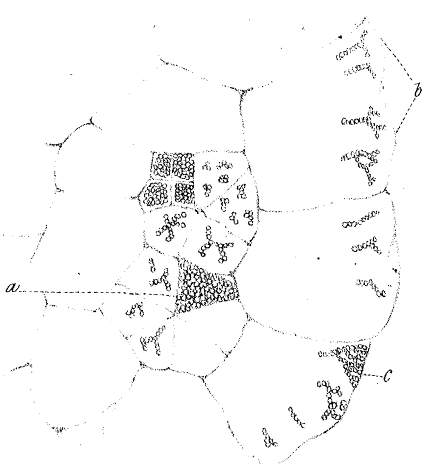
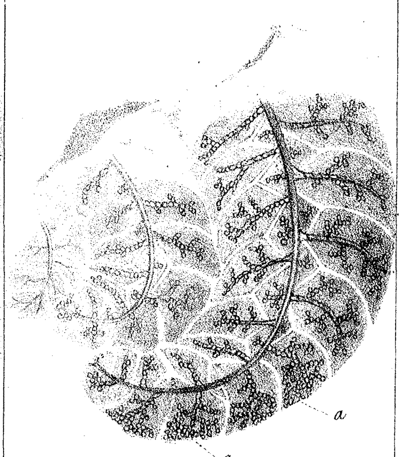


Fig. 5.

Fig. 6.



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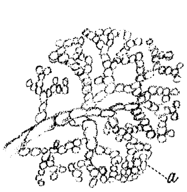


Fig. 8.

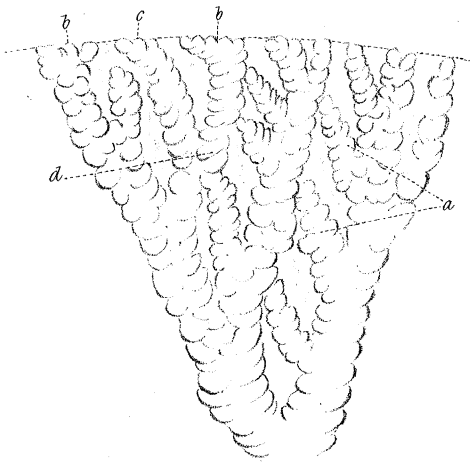
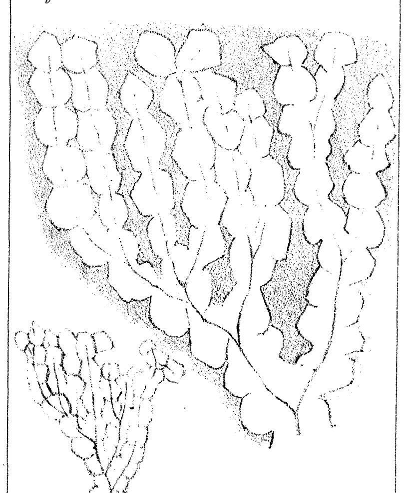


Fig. 9.



youth and the large cells of old age, I found them varying from $\frac{1}{200}$th to $\frac{1}{500}$th of an inch; the largest oval foramina were from $\frac{1}{60}$th to $\frac{1}{80}$th of an inch, some were from $\frac{1}{100}$th to $\frac{1}{150}$th of an inch, and there were others less. In dried and inflated preparations, the cells and foramina being fully distended with air, measure more than when the preparations are fresh and recent. On the other hand, in injected preparations, the vessels being distended, the cells and foramina measure less.

Explanation of the Plate.

PLATE XII.

Fig. 1. A thin section of dried and inflated lung, showing large oval foramina produced by dividing the lobular passages; (*b*, *b*) several oval foramina close together, the section having passed very near to the point whence the passages branch off. Subjacent cells and foramina are seen by looking down through the uppermost foramina (*c*, *c*).

Fig. 2. Oval foramina seen in a section of inflated and dried lung made at the surface and including the pleura; they are somewhat smaller, and placed at more equal distances from each other than in the preceding figure.

Fig. 3. A thin section of recent and macerated lung, slightly extended, showing sections of cells and lobular passages; (*a*, *a*, *b*) a series of communicating cells.

Fig. 4. A small portion of the thin edge of a lung of a Rabbit injected partially with mercury, showing a mass of minute globules in a fully injected lobule (*a*), and nodulated or beaded branches in others (*b*). The nodules being cells communicating with each other by lobular passages; the branched symmetry is lost in a mass of globules at *c*.

Figs. 5 and 6. Small sections from the thin margin of the lung of a fœtal Calf, magnified about three diameters. The lobules are compressed and spread out by pressure between two plates of glass. Several bronchial tubes are filled with mercury; they *gradually* assume a nodulated appearance, and at length in the interior of the lobules terminate in cells and lobular passages.

Fig. 7. A more magnified view of the branchings of the intralobular bronchial ramifications. The mercury has been urged on by increased pressure, so as to fill a greater number of ramifications, which at (*a*) have become so numerous that their symmetry is lost in the multitude of globules.

Fig. 8. Intralobular bronchial ramifications, partially inflated and highly magnified. (*a*). *Culs de sac* terminations lying against the lateral inflations of adjoining branches. (*b*, *b*, *c*). The multilocular *culs de sac* at the surface of a lobule.

Fig. 9. Shows the cells formed upon the intralobular bronchial branches, with polyhedric figures formed by pressure.