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THE HISTO-PATHOLOGY OF MASTOIDITIS.*

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THE theme of this paper is by no means a new one, the first comprehensive article on the subject being published by Scheibe in 1903. His opinion was unchallenged for over twenty years until Krainz wrote his monograph on "Mastoiditis." This author presented the subject from an entirely different aspect, and since then numerous papers have been published upon it.

Up to the "'nineties" all forms of mastoid disease were included together in the general term "caries," as comprehensive and as convenient a term as that of the present day, "influenza." Politzer broke away from this and divided the cases into "acute" and "chronic." Bezold further subdivided the acute forms into "genuine" and "those complicating a general disease" (secondary). Scheibe, on the foundations of his researches, renamed the conditions forming the latter subdivision, "genuine empyema" and "empyema complicating general diseases," empyema in his mind being the nucleus of the disease. By the term "empyema" Scheibe understands an accumulation of pus under pressure originating from one or more eccentrically dilated pneumatic cells, *i.e.*, from a preformed cavity lined by epithelium. Max Mayer substitutes the designation "bone abscess" for "empyema," as he main-

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tains that the purulent exudate accumulates in a cavity formed by the disintegration of tissue and, therefore, not preformed.

Since then, great progress has been made in the pathology of diseases of the mastoid process.

The factor of pneumatisation has been investigated by Arthur Cheatle, Wittmaack, and Mouret. A study of the structure of the lining of the mastoid cells was ably embodied in a paper by Krainz. The effect of the closure of the Eustachian tube and its consequences on the mastoid process were related by Scheibe and further elaborated by Krainz.

The result of work directed towards elucidating the pathogenicity of the various micro-organisms met with in mastoiditis has been disappointing and the problem has yet to be solved.

Lately, Krainz has maintained that mastoiditis is the only correct designation of this disease since the pathological changes originate in the bone itself (Haversian canals) and only spread secondarily to the muco-endosteum. Scheibe refuted this on the ground that the disease originates in the mucous membrane of the pneumatic cell before affecting the bone, and is primarily of the nature of an "empyema"; the term "mastoiditis" was misleading. Considering the nomenclature from the operative standpoint, Schlitter prefers the term "empyema" or "bone abscess." The "throbbing symptom" due to the retention of the pus under pressure is one on which he places great reliance for diagnostic purposes.

In the Edinburgh Clinic, the present disease has always been spoken of as "mastoiditis," and thus we shall continue to designate it.

In this paper, the clinical, bacteriological and histological conditions in 50 cases have been reviewed; of these, 30 were "genuine" and 20 "secondary." On comparison, no distinctive histological differences have been found between the two groups, and hence all the cases have been considered together.

Of the "secondary" cases, 13 occurred after and two during influenza, one after pneumonia, one in the course of subacute nephritis, and three during scarlet fever. The "genuine" ones complicated a local lesion of the nose or throat.

The material was obtained at the time of operation from bone chips of diseased tissue, and hence it represents the state of the tissues removed at the Schwartze operation. On its removal, the material was placed in fixative (Pick, Jores,

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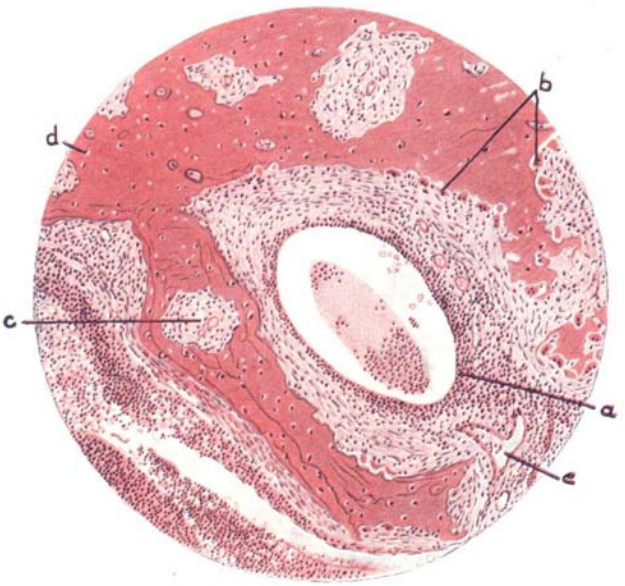


FIG. 1.—Pneumatic Cell. × 100.

Section shows great inflammatory expansion of the muco-endosteum of a pneumatic cell, the narrowed lumen of which contains pus.

a, Epithelium. *b*, Osteoclasts. *c*, Medullary space filled with fibrous tissue and showing osteoclasts. *d*, Old bone. *e*, Blood space.

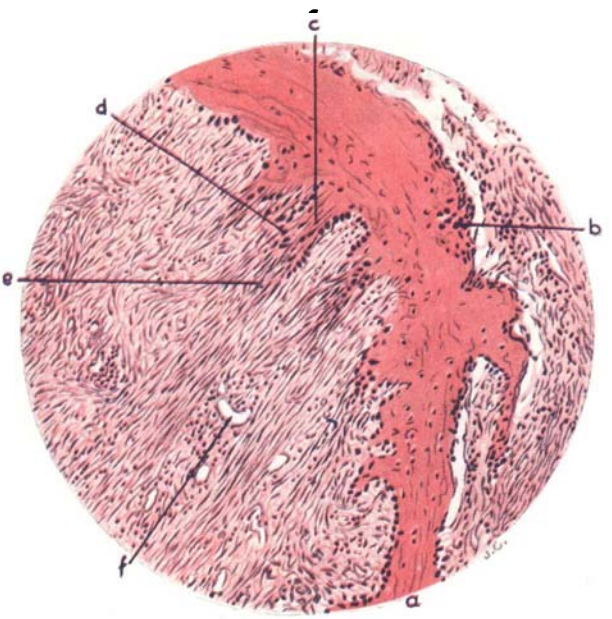


FIG. 2.—Bone Formation in a Former Pneumatic Cell. × 100.

a, Old bone. *b*, Apposition bone (note irregularity of bone-cells). *c*, Reticular formed bone. *d*, Osteoblasts becoming embedded in the forming bone. *e*, Condensation of the fibrous tissue prior to its transformation into new bone. *f*, Blood space.

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Zenker, or picric acid), and later into Perreny's decalcifying fluid. When decalcification was complete, some of the tissue was used for frozen sections and the remainder was embedded in paraffin. Sections were stained by hæmatoxylin and eosin and by the methods of van Gieson and Schmorl, and by Heidenhain's "azan" modification of Mallory's stain.

At the time of operation a specimen of pus was taken from the mastoid cells and submitted to bacteriological examination. Considerable effort was made to demonstrate the micro-organisms in sections of the diseased bone, but, except in one case, the attempt failed. The decalcifying fluid seems to destroy the staining properties of the micro-organisms.

The subject will be considered from the following standpoints:—

A. **Anatomical:**	Development of the Mastoid Process.
	Pneumatisation of the Mastoid Process.
	Arrested Pneumatisation.
	The Lining of the Pneumatic Cell.
B. **Pathological:**	Changes in the Bone-Marrow.
	Œdema *ex vacuo*.
	Changes in the Muco-Endosteum.
	Bone Removal.
	Necrosis.
	Fistulæ.
	New Bone Formation.
C. **Clinical:**	Bacteriology.
	Incidence of Mastoiditis.
	Clinical Manifestations.
	Mastoiditis in Scarlet Fever.
	Mastoiditis in Influenza.

A. **Anatomical: Development of the Mastoid Process.**— The mastoid process is developed from two bones; the anterior part is derived from the squamous, and the posterior part from the petrous, portion of the temporal bone. Between these two bones there is the mastoid fissure which forms the site of predilection of a fistula. The lateral wall of the mastoid bone often contains, in its early stages, islets of cartilage which facilitate fistulous formations (Keith).

The squamous portion develops directly from membrane to bone, the petrous part from membrane to cartilage and

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thence to bone. Absence of the tympanic antrum has been described (Mouret, Ruttin), but is rare. The mastoid process only takes shape from the commencement of the second year onwards. It develops in response to static conditions associated with the neck muscles to which it gives attachment. The period of its greatest growth is at puberty.

Pneumatisation of the Mastoid Process.—Eckert-Möbius divided the development of the mastoid process into three periods.

The first is the development of the lumen of the recessus and antrum, which takes place during the first year of life.

The second period is the development of the pneumatic cells, which normally takes place during the second and third year of life—at latest, the end of the fourth year. If after the fifth year an incompletely pneumatised process is present, disturbance of the pneumatisation has occurred. Alexander of Vienna, and Stenger come to the same conclusions, although the former states that in exceptional cases normal pneumatisation may take place up to the sixth year. Incidentally, Alexander is strongly of the opinion that, as the Eustachian tube is responsible for the ventilation of the middle-ear cleft and therefore plays a very important rôle in the pneumatisation of the mastoid process, adenoids, if present, should be removed before this age.

The process of pneumatisation is as follows: Those marrow spaces which open towards the antrum are pressed upon by the ingrowing epithelial sac, thus producing a collateral œdema whereby the parenchymatous element of the bone-marrow atrophies, leaving only its framework of endosteal tissue. This becomes myxomatous, and is later transformed into loose fibrous tissue which then becomes pressed in a very thin layer on the osseous trabeculæ. It is surmounted by a single layer of flattened epithelium. Simultaneously, widening of the bony walls of the pneumatic cell takes place either by osteoclasts or by perforating vessels (Fig. 3).

The third period of development is the further distribution of the pneumatic cells in later life.

The pneumatic cells diverge into the marginal zones and neighbouring compact bone surrounding the labyrinthine capsule; the process takes place by the development of small marginal medullary spaces in the immediate neighbourhood of a blood-vessel. In the air-cells contiguous to medullary bone

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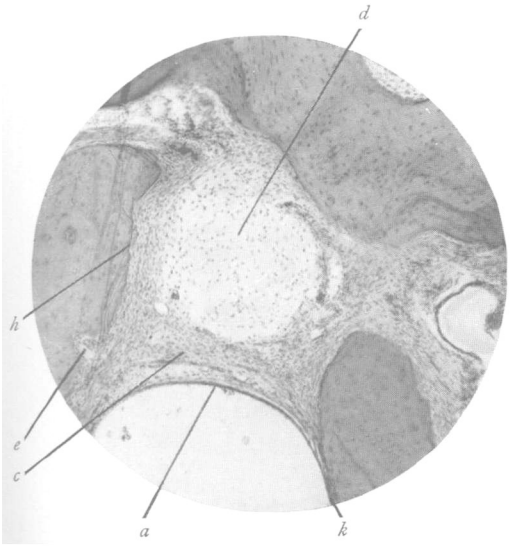


FIG. 3.—Formation of a Pneumatic Cell. × 50.

a, Epithelial sac. *c*, Fibrous marrow. *d*, Myxomatous change occurring in the marrow. *e*, Perforating vessel. *h*, Osteoclasts. *k*, Fully formed muco-endosteum.

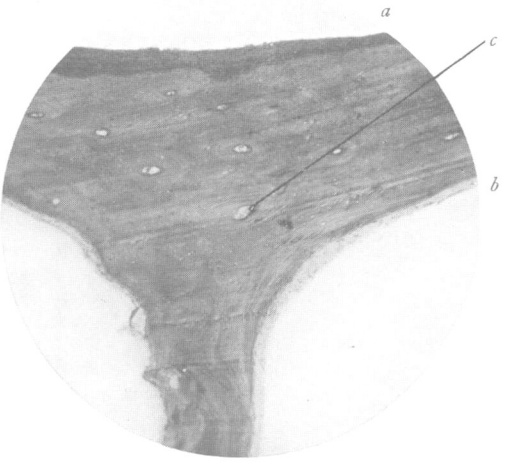


FIG. 4.—Normal Pneumatic Cell. × 100.

a, Dense bone laid down under periosteum at cortex. *b*, Muco-endosteum. *c*, Haversian systems.

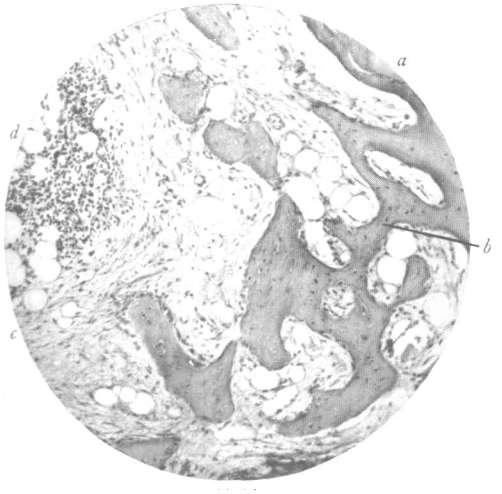


FIG. 5.—Original Marrow Space. × 75.

a, Bone wall. *b*, New-formed reticular bone. *c*, Fibrosis of marrow reticulum with disappearance of fat-cells and parenchyma. *d*, Marrow with fat-cells; the marrow reticulum contains round-celled infiltration.

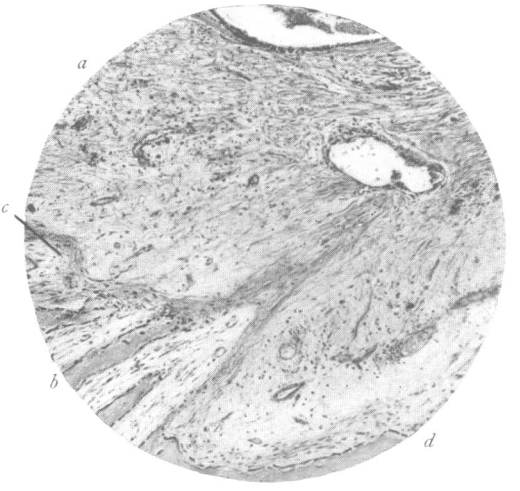


FIG. 6.—Formation of a Secondary Marrow Space. × 70.

a, Enormously thickened muco-endosteum of a pneumatic cell. *b*, Trabecula of new formed bone. *c*, Arching over of a trabecula to enclose the future marrow tissue. *d*, Active osteoblasts lining bony wall of pneumatic cell.

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spaces (occiput, squamous portion of temporal bone and zygomatic process, etc.), the pneumatisation is the same as described under the second period of development.

In a perfectly pneumatised mastoid process the cells are regular and laid down in definite arrangement; thus we can distinguish the various cell groups which are constant. The following anatomical grouping of the cells is according to von Neumann:—

1. Zygomatic cells;
2. Cells bordering the floor of the middle fossa;
3. Angle or petrosal cells;
4. Marginal cells lying posterior to the sigmoid sinus plate;
5. Cells overlying the sinus plate;
6. Retrofacial cells;
7. Sub-labyrinthine cells;
8. Tip cells; and
9. Very rarely cells in the bony part of the Eustachian tube—peritubal cells.

The cortex of a well-pneumatised mastoid process is of thin compact bone, while the blood spaces in the bone throughout it are few.

There are comparatively few completely pneumatised mastoid processes (Ruttin gives about 25 per cent. as his figure), and all types may be met with between the completely pneumatised and the acellular. J. Beck found in his series of cases that 58 per cent. of the mastoid processes were incompletely pneumatised. A. Cheatle states that 15 per cent. of mastoid processes are of the "acellular type" and 2 per cent. of the "dense infantile type."

Arrested Pneumatisation.—The normal development of the mastoid air-cells may be interfered with at any stage by the presence and effects of local inflammation. Wittmaack in his extensive researches gives us valuable information on this point. In the presence of disease, new connective tissue is formed beneath the epithelial layer of the advancing sac. Consequently, adhesions are formed and growth of new bone takes place encapsulating the antrum from the spongy mastoid, and thus by a mechanical process further pneumatisation is prevented. The adhesions form loculi in which the inflammatory process may continue although in a quiescent form, while the affected mucous membrane may be left in a state of chronic

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phlegmasia. Staphylococcal infection seems to favour the chronicity and also the slow course of the condition.

Cheatle's views on pneumatisation are briefly as follows. He differentiates two main types, infantile or acellular, and cellular. The infantile group is subdivided into the "diploëtic infantile type" and the "dense infantile type," according to the consistence of the mastoid bone. In the infantile group the outer antral wall consists of an external layer of compact bone and an internal layer of cells. The mastoid mass is diploëtic and separated from the cavity of the antrum by a thin layer of dense bone which forms the antral walls. As growth progresses, the outer dense wall and the walls separating the cavity of the antrum from the diploëtic mastoid mass become thicker, and so cellular development never takes place.

This condition of affairs would be, according to Wittmaack, the results of a previous otitis media; what Cheatle interprets as being developmental is in Wittmaack's opinion a pathological new bone formation.

Mouret asserts that a dense mastoid process has remained acellular not as the result of a suppuration which might be supposed to conduce to a progressive sclerosis of the bone and gradual disappearance of the pneumatic cells, but because pneumatic and non-pneumatic processes are natural, anatomical forms, which rather order the course of the suppuration and are not in themselves caused by it. In this matter the views of Cheatle and Mouret appear to be in agreement. As regards the relationship to chronicity of the two types, diploic and dense, all are agreed.

In the writer's view it is possible however that, after repeated attacks of mastoiditis not severe enough to be operated upon, a completely pneumatised mastoid process could be converted again into a partly or wholly spongy bone (Fig. 22).

The Lining of the Pneumatic Cell.—The recent researches of Krainz have left no doubt as to the structure of the lining membrane of the air-cells.

During fœtal life a double row of ciliated columnar epithelial cells bud off from the nasopharyngeal mucous membrane and by active growth, aided no doubt by intrauterine pressure, hollows out and lines the Eustachian tube. At birth, when breathing commences, pressure is produced by the act of swallowing, which forces air into the Eustachian tube; this in

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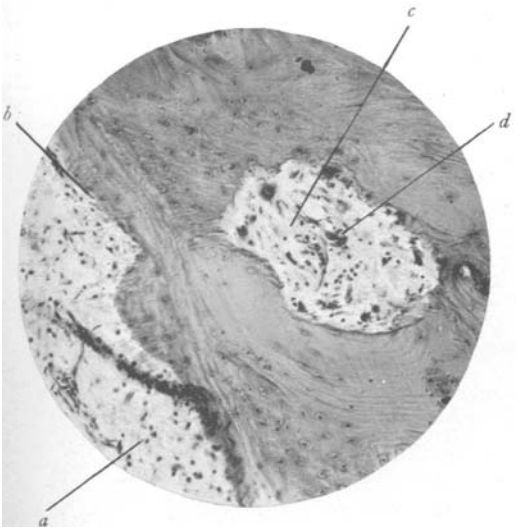


FIG. 7.—Bone Wall of a Pneumatic Cell. × 100.

a, Pneumatic endosteum. *b*, Halisteresis occurring in bone edge. *c*, Haversian space showing well-marked osteoclasis. *d*, Endothelial cell from central vessel making its way to periphery to attach itself to an osteoclast.



FIG. 8.—Pneumatic Endosteum. × 350.

a, Blood-vessel. *b*, Capillary budding off from present vessel. *c*, Marked congestion of a blood space.

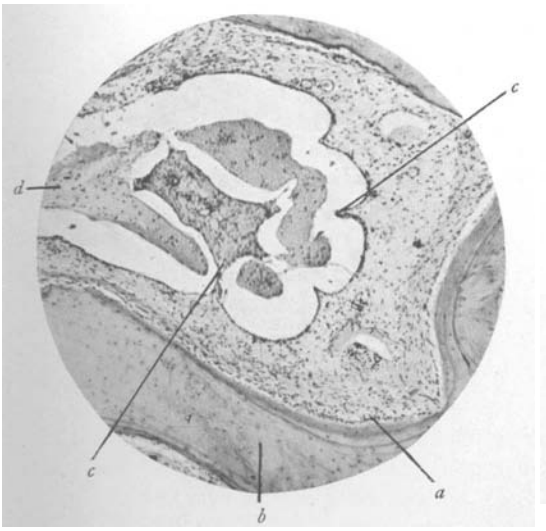


FIG. 9.—Plastic Changes in Air-Cell Lining. × 100.

a, Osteoblasts lining bony wall. *b*, Old bone. *c*, Bridge of fibrous tissue covered by epithelium growing into organised exudate. *d*, Unorganised exudate.

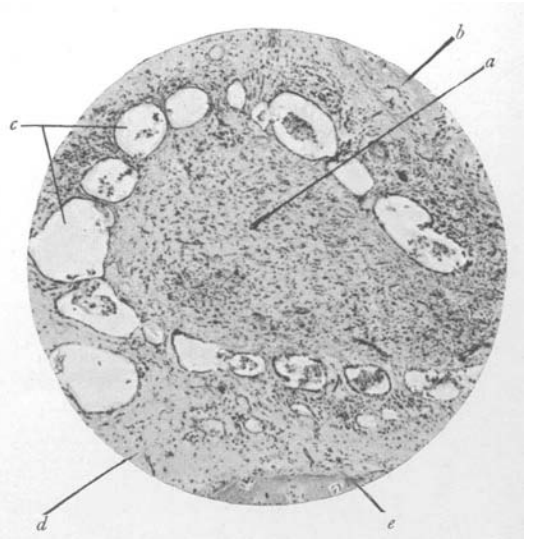


FIG. 10.—Original Pneumatic Cell showing "Pearl Necklace." × 100.

a, Organised exudate. *b*, Reticular bone surrounded by osteoblasts. *c*, Epithelial lined lumina—"Pearls"—some contain exudate. *d*, Endosteum. *e*, Reticular bone set on cell wall.

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turn forces the spreading epithelium into the middle-ear and its spaces. As it grows in more deeply, the epithelium tends to lose its ciliated character, so that finally only the Eustachian tube and anterior part of the tympanum are lined by it. The epithelium of the mastoid air-cells, on the other hand, is flattened in type, structurally resembling endothelium, the intermediate parts being lined by epithelium of the various transitional types between these two extremes.

This characteristic of the epithelium is analogous to that of the main respiratory tract; in the trachea it is ciliated, and in the air-cells or alveoli it is flattened and has often been compared to a serous membrane.

Thus the structural lining of the mastoid air-cells consists of an external, single layer of flattened epithelium with its basement membrane lying directly on a substratum of residual endosteal tissue, devoid of sensory nerves and glands, and closely applied to the underlying bone (Fig. 4). It is yellow in colour from the underlying bone, but during acute disease it becomes red through the dilatation of the endosteal vessels.

B. **Pathological: Changes in the Bone-Marrow.**—The marrow of the mastoid process is of the red variety; it differs from the yellow in having fewer fat-cells and more hæmopoietic elements.

When the marrow in the mastoid process is the site of inflammation, the reticulum swells up into a semitransparent substance in which are a few, delicate, fibrous tissue cells, having long, thin processes and faintly staining nuclei. The change starts at the periphery of the space and progresses centrally. The blood-forming cells disappear, the fat-cells atrophy and degenerate into a homogeneous mass. This mass is then replaced by protoplasmic cells possessing tufts of fine fibrillar processes; later, the cells become spindle-shaped and form connective tissue. This process is a typical one of reversion to myxomatous elements.

The next stage consists in a transformation of the myxomatous tissue into fibrous tissue, which begins at the periphery and spreads centrally, following in the wake of the primary myxomatous change.

This fibrosis of the marrow results from a passive circulation in the presence of an irritant (Cone).

The third stage in the metamorphosis of the marrow is new

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bone formation (Fig. 5). But this does not occur to anything like the same extent as in the pneumatic cells. This supports Sharpey-Schafer's statement that in regeneration of bone in the adult, participation of the marrow is much less than that of the bone itself.

The various stages in the transformation of marrow spaces into spongy bone having been defined above, attention must now be directed to the reverse process by which new marrow spaces are developed (Fig. 6).

The trabeculæ of bone arch over, meet and fuse together, forming a space lined by osteoblasts and containing fibrous tissue and vessels. The fibrous tissue changes into one which is myxomatous in structure and from which are developed a reticulum and fat-cells. With the development of these new elements, hæmopoietic cells derived from blood-vessels appear in their meshes. Marrow formed in this way, however, always remains of the fibrous type.

In none of the present series of cases has pus been found in the marrow spaces (*cf.* primary acute osteomyelitis). This agrees with the experience of other observers.

The changes observed in the marrow are the following :—

1. Marrow tissue.
2. Myxomatous-like tissue.
3. Fibrous tissue.
4. New bone: and

1. Fibrous tissue.
2. Myxomatous tissue.
3. Marrow tissue.

The marrow space can be transformed either into a cancellous space or into one containing fibroid marrow.

Œdema *ex Vacuo*.—In order to understand fully the various processes involved in mastoiditis, a brief review of the condition of œdema *ex vacuo* is important.

Air plays a very important rôle in the absorption of exudate from the middle-ear spaces and its exclusion and absorption render the individual more liable to disease. This is well seen in children, where the air content of the middle-ear cleft is very small, and in the incompletely pneumatised mastoid where, on exclusion, air is more quickly resorbed; on the other hand, a well-pneumatised mastoid process containing more air than the antrum and middle-ear, becomes infected

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less frequently, but when infection occurs it is of a more dangerous character, owing to the comparatively small number of blood-vessels.

When the blockage of the Eustachian tube or of a group of cells occurs, an œdema *ex vacuo* results. The muco-endosteum, which normally is pressed flat against the bony wall of the cell, expands to many times its original thickness; the endosteum is spread out into a looser or thicker network, according to whether it is healthy or has been the seat of previous infection; owing to the decreased tension of the supporting tissues, the vessels dilate and extravasation of plasma occurs. Where the supporting tissue of the blood-vessels consists of a large amount of well-formed fibrous tissue the œdema will not be so intense, as the tension will be better maintained; on the other hand, pressure effects will more quickly supervene.

The patency to the passage of air of the Eustachian tube has a bearing therefore on the course of the disease, in ventilating the cavities and so favouring re-absorption.

Changes in the Muco-Endosteum.—Under the stimulus of an irritant, hyperæmia and resulting transudation of fluid into the soft tissues are produced, whereby the lining of the pneumatic cell becomes swollen and thickened (Fig. 1). According to Scheibe, the swelling may be so great that the muco-endosteum becomes eighty times its original thickness. This swelling is due principally to the back pressure and consequent transudation from the vessels in the neighbouring Haversian systems, and the œdema *ex vacuo* is only of minor degree.

Thus, as in other tissues of the body, the initial stage of mastoiditis is an increased blood-pressure. The Haversian canals are rigid, bony tubes and the vessels in them first feel the effects of the increased pressure. A certain degree of liberation of pressure can be obtained through the medium of the lining of the pneumatic cell and up to a point this acts as a safety-valve: but soon the effects of pressure, as evidenced by the presence of osteoclasts, manifest themselves. Even three days after the onset of the inflammatory process, the effects of pressure may be seen quite plainly (Fig. 7).

Although the fibrous tissue in the endosteum is small in amount, it is not dense in character and can therefore contain considerable œdema in its meshes. But in the incompletely pneumatised mastoid, although the fibrous tissue is more

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abundant, it is denser in structure and cannot expand to contain the same amount of fluid. On the other hand, the blood supply of the perfectly pneumatised mastoid is scanty, while in the partially pneumatised mastoid it is good. This factor more than balances the lesser capacity for œdema possessed by the latter type, since the raised blood-pressure can be more readily stabilised and the infection more readily combated, as evidenced by the greater cellular infiltration. The single layer of flattened epithelium becomes cubical and swollen without any corresponding increase in the size of its nucleus. The epithelium may assume a mammiform or wavy outline, due to being pushed outwards by the accumulation of infiltrating cells beneath it. These cells make their way into the lumen of the air cavity either by passing through the interstices or by erupting through the epithelium.

The capillaries in the muco-endosteum become engorged and, by a process of active budding, new ones are formed (Fig. 8). Polymorphonuclear leucocytes make their way through the vessel walls, giving a perivascular infiltration; meanwhile, a transudation of fluid from the blood into the tissues takes place. The lumen of the air-cell contains at first a serous and later a purulent cellular exudate. The inflamed muco-endosteal surfaces may meet, thus occluding the ostium of the cell or series of cells; the consequent increase of pressure may be shown by the presence of osteoclastic activity or other phenomena. This constitutes the empyema of Scheibe, "the danger zone," and is a condition seen mostly in the second and third week of the disease. Air-cells containing pus not under pressure, Scheibe designates "simple cell suppuration." This condition may occur, for example, in the peripheral smaller mastoid cells.

All the air-cells are not affected to the same degree. One cell may be in a state of acute inflammation, while the adjoining cell is only slightly affected. The zone of reaction occupies a greater radius than that of the actual inflammation. Thus an area in which destruction is advanced is surrounded by one in which constructive processes are occurring. In almost every case examined, new bone, or at least active osteoblasts, have been demonstrated, and as the latter predominate, mastoiditis has come to be considered a sclerosing disease.

The conditions necessary for commencing organisation obtain, when the exudate becomes "stagnant," less fluid and

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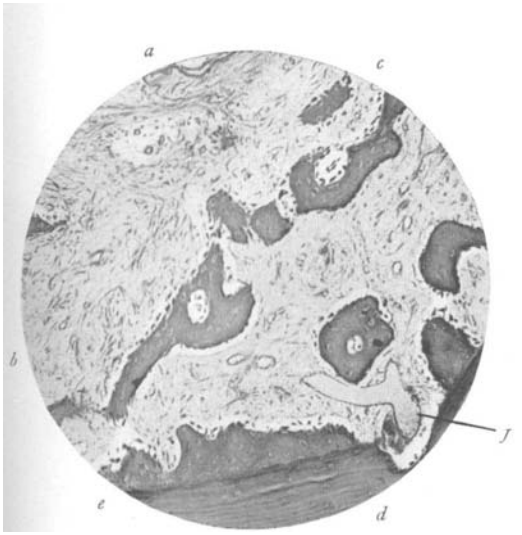


FIG. 11.—Pneumatic Cell. × 100.

a, Mammiform appearance of epithelium. *b*, Proliferated muco-endosteum. *c*, New reticular bone formation, reaching almost to the epithelium. *e*, New apposition bone. *d*, Set on cell wall. *f*, Blood space.

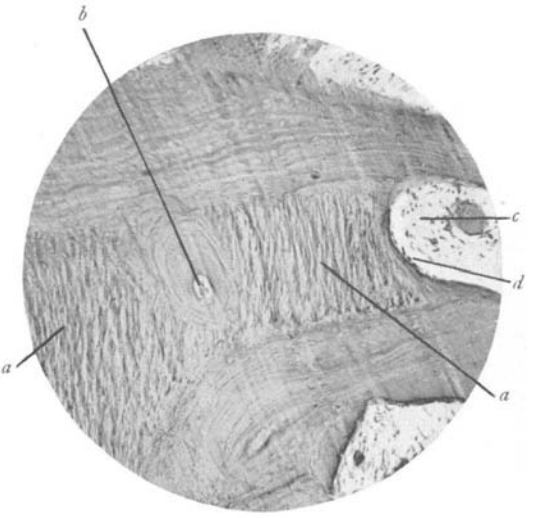


FIG. 12.—Bone-removal by Halisteresis. × 100.

Shows Sharpey's fibres with solution of the ground substance. *a*, Sharpey's fibres. *b*, Haversian canal. *c*, Medullary space. *d*, Proliferated endosteal cells and osteoblasts. Note the sharp definition between the altered softened bone and the healthy bone. Haversian lamellæ are unaffected.

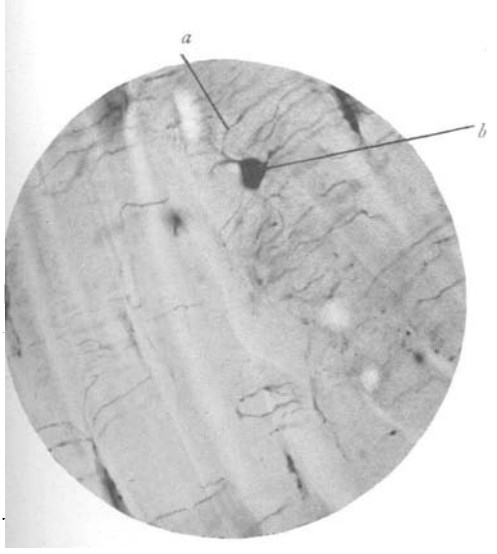


FIG. 13.—Normal Bone Cells. × 1000.

a, Canaliculi. *b*, Bone cell.

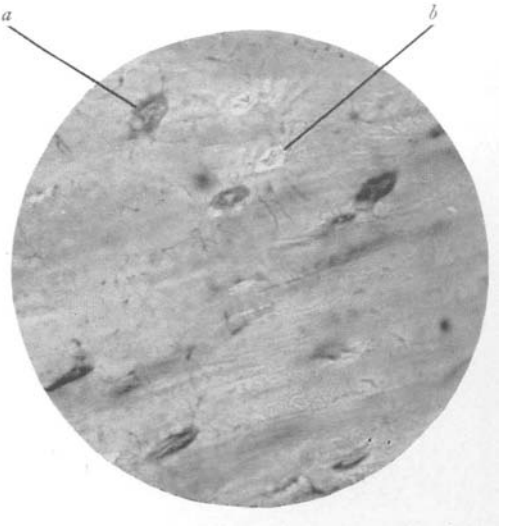


FIG. 14.—Changes in Bone Cells. × 1000.

a, Granular degeneration of bone cells with loss of canaliculi. *b*, More advanced stage of degeneration.

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fibrinised. At many points, through gaps in the epithelium, young blood-vessels sprout out from the muco-endosteum and together with elongated fibroblasts form tissue bridges. The formation of granulation tissue thus proceeds from all sides (Fig. 9). As organisation progresses, the zone of granulation tissue advances further into the exudate and the fibroblasts become shorter and thicker as they are converted into connective tissue. The stage of organisation at any place can be made out by observing the degree of differentiation reached by the fibroblasts.

The epithelium is stimulated to proliferate by the process of organisation, and grows along the tissue-bridges, its chief aim being to conserve as much as possible of the original lumen of the air-cell. These bridges may connect together by sending out lateral shoots and thus enclose a space which is rapidly clothed by epithelium. These spaces lined by epithelium are termed pseudocysts (Döderlein) or, from their resemblance to a string of pearls, designated "pearls" (Fig. 10). If these "pearls" are in direct communication with spaces containing air, they remain and so conserve a portion of the original lumen. Further, if the "pearl" contains exudate and this is not absorbed, it remains as a true cyst. Lastly, if an attempt be made to organise the exudate in the pearl, it becomes obliterated in the process.

In the process of organisation of the exudate, new tissue is formed and the total mass increases in bulk, but when fibrosis is complete a shrinkage takes place (*cf.* scar tissue). In each case, pressure is exerted on the "pearls"; these may become flattened out and appear as "epithelial ropes," or the epithelium may degenerate and the space be filled completely by fibrous tissue. It should be noted that before the pneumatic space can be completely obliterated as such, the epithelium must disappear, and this can quite easily take place in the manner outlined above.

Once the epithelium is destroyed the power of resorption is lost. In regard to chronicity, this is of much greater importance when occurring in the middle-ear than in the mastoid air-cells.

It must not be forgotten that this process of organisation is one of proliferation of endosteal tissue, that is, of potential bone-forming tissue; new bone formation, therefore, is one of the most striking structural features of the disease (Figs. 6, 11, 22).

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When owing to the reduction of pressure the conditions become favourable, new bone is formed. This is principally reticular in character and in many cases reaches almost to the epithelium, if remaining. Therefore, one of the possible end-results of mastoiditis is a spongy bone transformation (Fig. 22).

Bone Removal.—There are three methods by which bone may be removed, namely by halisteresis, by osteoclasts, and by perforating blood-vessels.

(1) *By Halisteresis.*—Halisteresis signifies a decalcification of bone through the agency of the body fluids.

Scheibe found that the spongy transformation of bone took place only in the fundamental and interstitial but not in the Haversian lamellæ; further, that the spongy converted bone always formed a sharp line of demarcation at its junction with normal bone; this is well illustrated in Fig. 12.

On investigation, in several of the sections, especially in those taken from cases of short duration, a want of sharp definition of the edges of the bone is found. This is not uniform, however, but varies; in some places the lack of definition merges into and even beyond the cement line. This shows that the process is one of absorption since, if it were one of deposition, the new bone formed would be in front of the cement line and added to it.

Fibrillation of the bone margins without the presence of any cells to account for it is in support of halisteresis. Further, many of the bone-cells become vesicular and surrounded by a clear zone, with loss of their canalicular processes, a picture which is strongly suggestive of halisteresis. (Compare Fig. 13 with Fig. 14.) Their vitality becomes affected and consequently the bone under their immediate control loses its vitality and becomes more vulnerable to the attacks of the resorbing processes.

Halisteresis takes place early and is confined to the first ten days of the disease. The absorption of mineral salts causes the bone to be softened and its tissue components are then removed by osteoclasts or by perforating blood-vessels (see later).

Halisteresis is present in 14 per cent. of the cases in the series.

(2) *By Osteoclasts.*—The removal of bone by osteoclasts is a phenomenon so commonly seen that a brief description of the process will suffice.

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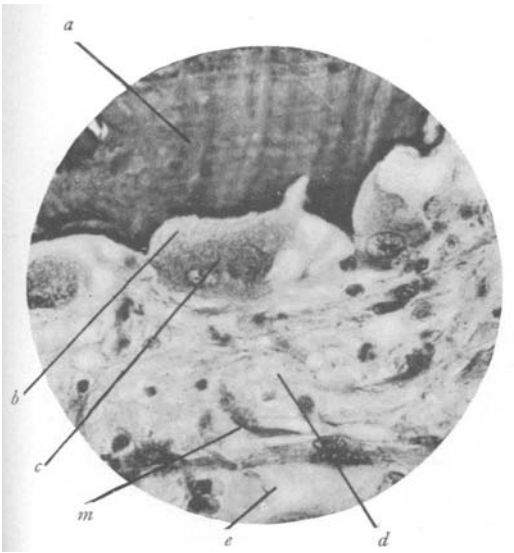


FIG. 15.—Bone-removal by Osteoclasts in Pneumatic Cell. ×400.

a, Bone wall. *b*, Syncytial border of giant cell. *c*, Osteoclast lying in Howship's lacuna. *d*, Proliferated endosteum. *e*, Blood-vessel. *m*, Endothelial cell detaching itself from blood-vessel wall and making its way to join the osteoclast.

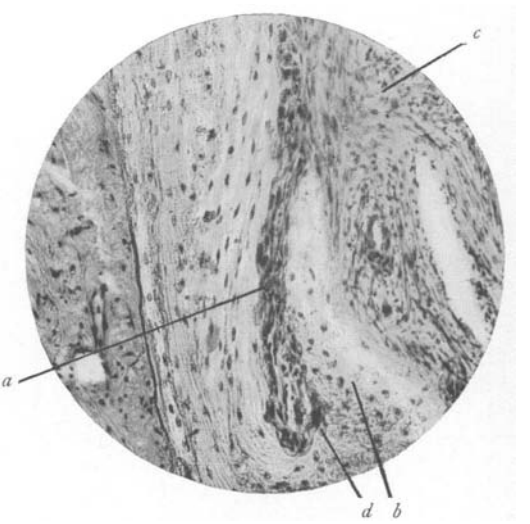


FIG. 16.—Bone-removal by Perforating Vessels. ×100.

a, Perforating vessel growing into—*b*—old bone *c*, Proliferated endosteum. *d*, Osteoclastic surface o resorption of the capillary wall.

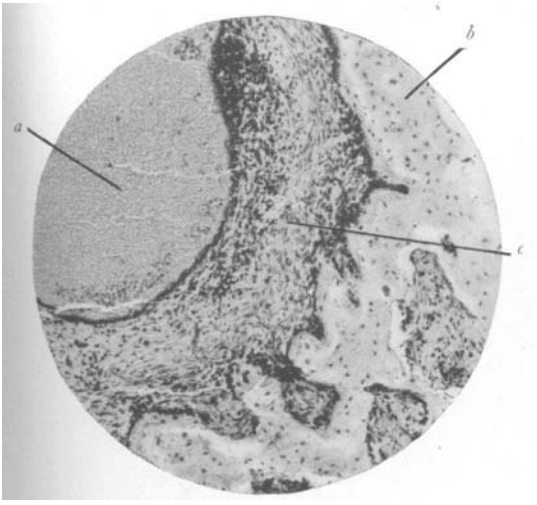


FIG. 17.—Bone Necrosis in Pneumatic Cell. ×100.

a, Pus. *c*, Degenerated proliferated fibrous endosteum. *b*, Bone remains with the calcium groundwork practically all dissolved away, leaving framework of Sharpey's fibres.

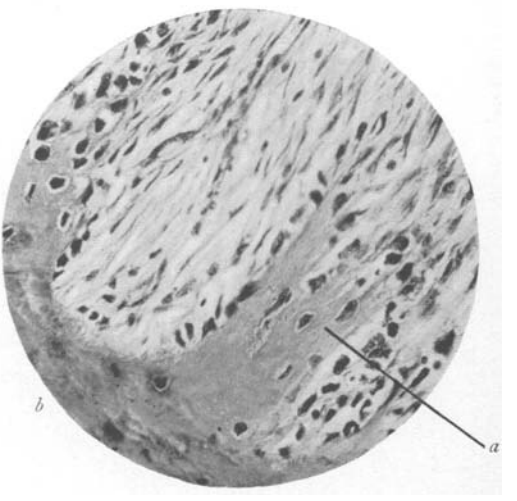


FIG. 18.—Intramembranous bone-formation occurring in Original Pneumatic Cell. ×300.

a, Trabecula of bone. Note irregular arrangement of osteoblasts. *b*, Bone wall of original pneumatic cell.

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Osteoclasts are not specific formations, but are commonly formed by the fusion of endothelial cells. The various stages of their formation from the budding off of the cell from the wall of the capillary to the fully formed giant cell in its scalloped-out space—Howship's lacuna—may be followed in Fig. 15.

The activity of the osteoclast is not to be measured by the number of its nuclei but by the surface relation which these bear to the total volume of the cytoplasm. When the osteoclast shows double-outlined fine borders and disappearance of its nucleus, it is waning in activity and on the verge of disintegration. The actual structure of the osteoclast and its mode of action is well brought out in Fig. 15. The syncytial cytoplasm of the cells has a striated border which is fused to the bone. In its close approximation to the bone, this border may be transformed into fine cilia-like processes which interdigitate with the minute bone fibrils (Dawson).

The action of the osteoclast appears to be biochemical in nature. According to Nicholson, "Oxidation in such a tissue (osteoclast) is rapid and a large amount of CO_2 is given off by it. CO_2 is, according to Hofmeister, the great solvent of lime salts within the body. The solution of bone is therefore rapidly effected in the immediate vicinity of the osteoclasts."

The functions of the osteoclast are said to persist longer in secondary cases and they are active under a pressure in which apposition bone is formed in a more resistive organism.

Rarefaction of bone takes place at the end of the first week and is well advanced during the second week; it diminishes after this, although in one of the cases of the present series it was well marked three months after the onset of the disease.

Evidence of osteoclastic activity is found in 74 per cent. of our cases.

(3) *By Perforating Blood-Vessels.*—The third method of bone removal is by perforating blood-vessels (Fig. 16).

In mastoiditis the perforating vessel appears to be the dominating factor in bone resorption. Almost every section examined has given evidence either of the process actually taking place, or the structural changes have been such as to show that it had occurred. The perforating vessel acts not so much by its own powers of resorption as by exposing a new and greater area of the bone to osteoclastic activity.

Perforating vessels take an active part in the inflammatory process from almost the very start of the disease, since their

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presence is well seen as early as the third day. Their actual presence, or indubitable evidence that they had been present, is seen in 90 per cent. of the cases of the series.

Necrosis.—Necrosis in genuine cases of mastoiditis is very rare. Krainz reports one case only out of a series of 100, and Otto Mayer's series of cases does not provide a single example of this condition. When present, necrosis generally occurs in cases of mastoiditis complicating a systemic wasting disease such as diabetes, tuberculosis, etc., and, in such, is found in the very young or in old age.

In this series of cases there is no occurrence of necrosis, but one illustration (Fig. 17) is shown, a specimen presented by Dr J. S. Fraser.

Fistulæ.—Fistulæ form only when peripheral pneumatic cells are present, that is, when they are in close proximity to a free surface, either cortex or cranium. When the natural paths for drainage become occluded either by osteoplastic changes or by a plug of granulation tissue, the pus in a cell or collection of cells which have been converted into one common cavity cannot escape. Consequently pressure conditions are much more acute and, following the line of least resistance, an outlet to the surface is excavated and the pus escapes under the periosteum or dura mater. In the case of the former the canal is narrow, whereas in the latter it is much larger. A thick outer bony cortex predisposes the fistula to open inwardly. Fistulæ never lead from the antrum and the cells immediately adjacent. Apart from infants, where an obstruction to the aditus ad antrum may take place, there can be no retention of pus in the antrum and the cells immediately adjacent to it; this is due to free drainage into the middle-ear and thence through a perforation in the tympanic membrane, if present, or by the Eustachian tube; hence fistulæ from these air-cells never occur.

In infants a fistula is more liable to pass outwards, as the antrum is placed against the cortex, which often contains islets of cartilage; or, secondly, the sutures may be still open.

It is usual to get only one fistula in the cortex, and when two or more are present the case is probably one of the "secondary" group. Macroscopically, the fistula is often filled with granulation tissue; microscopically, its edges are deeply eroded by active osteoclasts—indicating a persistence of the pressure—and the lumen is filled with proliferating endosteum.

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The formation of the fistula does not seem to influence the pre-existing vascular pressure.

In the present series, a subperiosteal abscess was present in 17 cases (7 male, 10 female). Of these, 15 occurred in genuine and the remaining 2 in secondary cases; 14 took place after the third week of the disease; and in 9, an intracranial infection was a complication.

New Bone Formation.—New bone may be laid down in lamellar (apposition bone) or in reticular formation. After infancy, the former process normally takes place within the body; the latter is of a primitive type and, apart from occurring in embryonic and infantile tissues, is seen only in pathological processes.

It is interesting to note that Robison and Soames have found evidence of a special enzyme in bone which brings about an orderly precipitation of the calcium salts of the blood within newly-formed bone matrix.

Lamellar Bone.—The osteoblasts arrange themselves in one or more rows along the original margin of the bone; there they secrete osseo-mucin, and becoming embedded in this are converted into bone corpuscles. Calcium salts are then deposited. The relation between the calcified and uncalcified portions gives one some indication of the rate of growth of the particular bone.

Reticular Bone.—As already stated, this is an embryonic type of bone formation and is analogous to bone developed in membrane.

Vascular dilatation is indicative of waning resorption, and the first signs of new bone formation is a grouping together of the osteogenic fibre-bundles (Figs. 18, 2). Later, active osteoblasts are found around the fibre-bundles and within their meshes, and as a result of the secretion of osseomucin, the bundle is transformed into a homogeneous mass. At the growing points of the bony trabeculæ thus formed, the fibres are continued into the general mass of fibrous tissue surrounding the area, while at the base they are continuous with the parent bone and thus acquire permanent vitality.

These bony trabeculæ may reach almost to the epithelium of the pneumatic cell (Fig. 11), and thus the cell, though lined by epithelium, can never return to its former dimensions. The part the trabeculæ take in the formation of secondary marrow spaces has been already considered (Fig. 6).

By the general laws of development, imperfect forms are

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gradually replaced by those more perfect so that the trabeculæ become transformed into lamellar bone.

The formation of reticular bone is a response by the organism to the great stimulus of the disease; apposition bone cannot be formed quickly enough, and therefore the more quickly growing and primitive type is produced.

In the present series of cases no evidence has been found of new bone formation taking place within the first few days after onset of the inflammation. The osteoid edges which Mayer and Beck claim to be new bone formation, are a zone of decalcification; from its arrangement, its irregularity and the inactive cells which line it, there is no doubt that the changes here are the result of halisteresis.

Great hyperæmia is induced beyond the limits of the actual infection and this stimulates the osteoblasts to rapid proliferation. The area of bone formation is greater, therefore, than that of bone destruction. The new bone formed more than compensates for the eroded portion and this has an important bearing on pneumatisation.

The cement line is an important guide to the condition existing before new bone has been formed. By following its outline, evidence of past osteoclastic activity and of perforating vessels can be obtained. On the other hand, if the cement line is regular, with new bone set on it, the new bone is a response to an irritant and not reconstructive after erosion.

In two cases of the present series, formation of new bone (one apposition, one reticular) had occurred by the seventh day of the disease; during the second and third weeks the production is progressively commoner, while during the fourth week it occurs most abundantly.

C. **Clinical: Bacteriology.**—Bezold maintained that the kind of micro-organism had no influence on the liability of the bone to be affected, nor on the subsequent course of the disease, but this statement must be modified in the light of present-day knowledge; probably Gradenigo's dictum that the clinical symptoms are not in direct relationship to the kind of micro-organism would be more correct.

The figures for the present series are as follows: in 11 cases *Streptococcus pyogenes*; in 14 *Streptococcus hæmolyticus*; in 4 *Pneumococcus*; in 1 *Staphylococcus aureus*; in 1 *Pneumococcus mucosus*; in 1 *Streptococcus mucosus*; in 3 *Streptococcus pyogenes*

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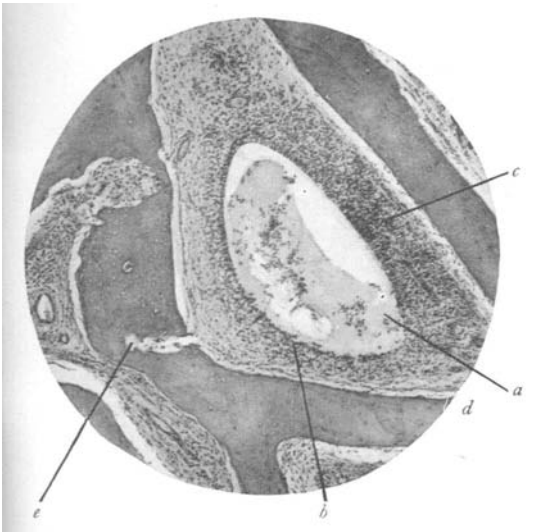


FIG. 19.—Pneumatic Space. Scarlet Fever. × 100.

a, Unorganised exudate. *b*, Epithelium, being cast off into the lumen. *c*, Proliferated endosteum, with round-cell infiltration. *d*, Inactive elongated osteoblasts lining cell wall. *e*, Perforating vessel.

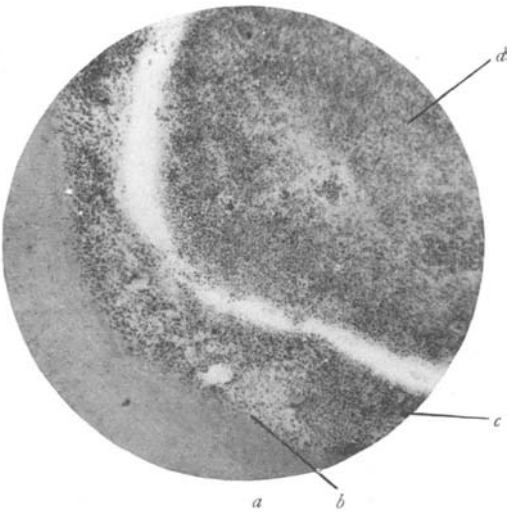


FIG. 20.—Pneumatic Cell. Influenza. × 150.

a, Bone wall. *b*, Hazy outline of bone edge. *c*, Slightly thickened muco-endosteum containing hæmorrhages. *d*, Cell lumen, containing pus cells and red blood corpuscles.

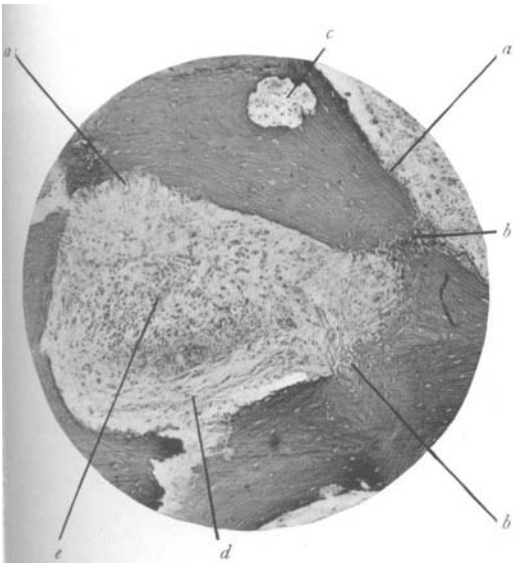


FIG. 21.—Original Pneumatic Cell. × 100.

a, Fibrillation of bone margin. *b*, Active osteoclasis. *c*, Haversian space showing osteoclasis. *d*, Proliferated endosteum. *e*, Organised exudate.

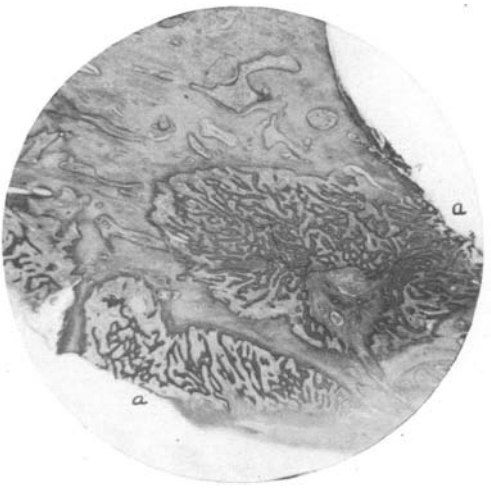


FIG. 22.—Tip of Mastoid Process. × 8.

a, Former pneumatic cell filled with new bone.

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and *Pneumococcus*; in 2 *Streptococcus pyogenes* and *Staphylococcus aureus*; in 2 a *Gram-negative cocco-bacillus.* No micro-organisms were isolated from the remaining 11 cases owing to the length of time which elapsed before the material could be examined bacteriologically.

The intracranial complications associated with these micro-organisms were as follows: Of the 11 cases associated with *Streptococcus pyogenes*, 1 developed perisinus abscess; of the 14 with *Streptococcus hæmolyticus*, 4 developed perisinus abscess; 1 extradural abscess of middle fossa, 1 acute purulent lepto-meningitis, 1 Gradenigo's syndrome, and 1 septicæmia; of the 4 with *Pneumococcus*, 1 developed perisinus abscess and 1 died of cerebral œdema; the 1 with *Streptococcus mucosus* was complicated by perisinus abscess; of the 3 with *Streptococcus pyogenes* and *Pneumococcus*, 1 had perisinus abscess and 1 died from exhaustion following pneumonia; of the 2 with a Gram-negative cocco-bacillus, 1 developed perisinus abscess; of those cases associated with *Staphylococcus aureus* (1), with *Pneumococcus mucosus* (1), and with *Staphylococcus pyogenes* and *Staphylococcus aureus* (2), no intracranial complications developed.

It is thus seen that the *Streptococcus hæmolyticus* is the most dangerous micro-organism as regards intracranial complication, and is practically always met with in scarlet fever and to a lesser extent in influenza.

The pus from a case of acute mastoiditis is odourless: its consistence depends upon the type of the infecting micro-organism and has an important bearing, therefore, on the drainage or stagnation and subsequent organisation. Thus *Streptococcus mucosus* gives a thick, glairy pus, which is apt therefore to be retained and "stagnate"; further, the quiet course of the disease also favours retention of the pus. In contrast to this type is the violent, profuse, pulsating discharge in an acute otitis media due to *Streptococcus pyogenes.*

In this connection it is of interest to notice that Urbantschitsch maintains that *Streptococcus mucosus* can present morphologic variations. He indicates that the coccus may pass into transitional forms or forms which are recognised as definite types, *e.g. Streptococcus pyogenes.* In certain cases he has isolated the *Diplococcus mucosus* at one time, *Streptococcus hæmolyticus* at another, and finally has recovered *D. mucosus* in a third culture.

General Incidence.—The series consisted of 50 cases, 29 being females and 21 males.

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Ear affected—Right ear, 30; left ear, 20.

Age in decades—1st, 15; 2nd, 8; 3rd, 7; 4th, 11; 5th, 2; 6th, 4; 7th, 3.

According to Heine, on account of the osteosclerotic character of the mastoid process in patients over 40 years of age, mastoiditis occurs with more difficulty; in sucklings, on the other hand, in consequence of the anatomical structure of the middle-ear spaces and of the delay of spontaneous perforation through the membrana tympani, extension of the inflammation from the middle-ear to the mastoid process is greatly favoured.

Operation in relation to the period of the disease—

In 1st week, 7 cases;	2nd week, 12 cases;	3rd week, 8 cases.
„ 4th „ 6 „	5th „ 4 „	6th „ 5 „
„ 7th „ 1 case	8th „ 3 „	9th „ 2 „
„ 3 months, 1 „	6 months, 1 case	

The earliest operation took place on the 3rd day. Subperiosteal abscess occurred in 17 cases. Intracranial complications occurred in 17 cases.

Deaths.—1 from meningitis; 1 from cerebral œdema; and 2 from general exhaustion—one in an old man, in his convalescence from pneumonia, who failed to rally after operation, and the other in a female patient, the subject of nephritis, some weeks following the operation, the wound having healed.

The actual mortality from the mastoid disease was, therefore, 2 per cent.

Seasonal Incidence—

January 1 case.	February 10 cases.	March 4 cases.
April 8 cases.	May 10 „	June 2 „
July 3 „	August 3 „	September 0 „
October 1 case.	November 1 case.	December 7 „

Clinical Manifestations.—The time at which operation was indicated was fixed by one or more of the following conditions:—

1. When the discharge continues for more than five weeks and is pulsating and profuse. If the discharge persists for some time after an acute otitis should ordinarily have cleared up, it is coming from the mastoid cells (Bezold). In any case it is a generally recognised form of treatment to drain the middle-ear through the mastoid, but the question is outside the scope of the present paper.

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2. Continuous pain behind the ear; this denotes an involvement of the periosteum and occurs later than the onset of the mastoiditis, since the inflammatory process extends from within outwards. Pain may be present early, but is not intense; it is due to a slight tension in relation to the periosteum and disappears after one or two days when the existing blood-pressure becomes adjusted.
3. Sensitiveness to pressure over certain points:—(*a*) over the antrum; (*b*) over the posterior border of the mastoid; (*c*) over the posterior border of the tip of the mastoid process.
4. Œdema and redness of the external soft parts (erection of the auricle) and subperiosteal abscess.
5. Sagging of the posterior meatal wall.
6. Throbbing or "beating" noises which do not clear up in two weeks.

   Scheibe explains these noises thus:—They are worse at night on account of the passive hyperæmia due to the low position of the head when in bed. The inflammatory phenomena occur in both the mucous membrane and the medullary tissues; these structures communicate with each other by vessels and both of them are surrounded by bone, a tissue which is not compressible; thus resistance to the pulse wave is exerted and this is manifested by a sensation of pulsation or beating.

   Pus under pressure in any part of the body exhibits this "throbbing" (*cf.* whitlow), and it is one of the most valuable and absolute signs in the diagnosis of empyema. As these "beatings" are synchronous with the pulse, the patient's statements on this point can be easily checked.
7. Intracranial symptoms.
8. Continued fever: in the adult, an ordinary case of mastoiditis is unaccompanied by fever; when fever is present, great care must be taken in the examination. In children, however, it is not uncommon to find fever in the first few days of the illness. Alexander gives 101° F. as the limit for a temperature of an uncomplicated mastoiditis.

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9. X-ray picture: a negative plate is not reliable and only positive results are to be regarded. Positive results are obtained in only 58 per cent. of cases (Krainz).

10. Some authorities consider that migraine occurring in a patient who has recently developed discharge from the ear is an indication for operation.

It must be remembered that a normal tympanic membrane does not exclude disease of the outlying mastoid cells which may lead to a fatal termination (*vide* Brock's case).

The time to operate is of great importance. Naturally, it is decided on clinical grounds and according to the opinion of the operator; hence there is not much uniformity in this matter. The figures of the present series show the greatest number (52 per cent.) were operated upon in the first three weeks, the majority of those (24 per cent.) being performed in the second week.

Mastoiditis in Scarlet Fever.—In this exanthema, mastoiditis presents two types. The one is of a comparatively mild nature and really belongs to the "secondary" division of the classification made at the beginning of this paper. It rarely occurs before the sixth day of the fever and is ushered in by a sharp rise of temperature; otherwise the clinical symptoms are similar to those cases which constitute the main group (Fig. 19).

The microscopical changes are the same as those observed in all the cases of the series under review. The prognosis and the mortality rate also do not differ.

While the above is the commonest form in which mastoiditis occurs in scarlatina, there is an aggravated type, "mastoiditis necrotica scarlatinosa." It is distinguished by commencing about the second day of the disease and, according to Manasse, is associated invariably with tonsillitis and pharyngitis necroticans. The patient is in a profoundly toxæmic state and the aural conditions which are often bilateral (potential deafmutism) may be masked by the general symptoms. The microscopical changes are in keeping with the severity of the condition as indicated by the nomenclature.

Three cases obtained from scarlatina are included in the present research. They fall into the first or mild type, and the only features in which they differ from the rest of the cases

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of the type are in the destructive processes being more advanced and the reparative process slower.

It is interesting to quote Nager's statistics on this subject: he examined 750 scarlatinal patients and found 59 per cent. of them with normal ears and 41 per cent. with diseased ears. In only 30 per cent. of the last group was the ear condition directly due to scarlatina. Therefore 13 per cent. of the total number of patients had purely scarlatinal ear affections.

Mastoiditis in Influenza.—As in scarlatinal cases, so in influenzal cases a distinction must be made between mastoiditis occurring in the course of the disease and mastoiditis directly due to influenzal influences. Here again, the former cases fall into the category of those "secondary" cases and call for no further description.

The genuine influenzal cases are met with in the first days of the disease and are of a severe nature. The usual symptoms of acute mastoiditis are very intense and the case often comes to operation early.

Macroscopically, at operation the lining of the pneumatic cells is swollen, dark red or purple in colour, and a small amount of purulent secretion is present. The bone is hard and the tissues bleed readily and profusely.

Microscopically, in the endosteum of the pneumatic cell are hæmorrhages so large that they mask the structure, but the membrane is not thickened to the same degree as in the "genuine" type (Fig. 20).

The epithelium may be stripped off by the extravasation of blood, and again in some fulminating cases it may be partially necrosed. The lumen of the air-cells contains free hæmorrhage and shortly afterwards pus-cells make their appearance.

The further progress of the condition is characteristic of a "secondary" type.

Summary.

Mastoiditis is a broad term with no strict anatomical basis. It includes not only an inflammation of the pneumatic cells in the mastoid bone proper, but also all the extensions of these cells into neighbouring bones (zygoma, occipitalis, etc.).

From this it will be understood that the anatomical distribution of the pneumatic cells plays an important part in the course of the disease. Brock's case illustrates the point. In this a fatal meningitis ensued from a pneumatic cell placed in

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the wall of the internal auditory meatus. According to this author's investigations on pneumatised temporal bones of all ages, 11 per cent. had normally such an extension to this site. Even *if diagnosed, the utter impossibility of opening up such* a cell can be appreciated.

In the present paper, the various stages of acute mastoiditis are described and illustrated:—

I. The initial change in the directly infected zone is a local rise of blood-pressure whereby the vessels in the Haversian systems are caused to dilate and the muco-endosteum to become hyperæmic.

II. The next stage is characterised by osteoclasis occurring in the Haversian systems.

III. Coincident with the above changes, softening or halisteresis occurs in the bone and a few perforating vessels make their appearance.

IV. This stage is the period of active rarefaction of the bony wall of the pneumatic space by osteoclasts and perforating blood-vessels.

V. The next stage consists in the regeneration of the destroyed tissue by new bone formation.

The whole inflammatory condition is subject to phase-change which can turn it from one of exudation accompanied by increase of intravascular pressure into a more proliferative one (Krainz). The latter phase is introduced by a transudation of œdema and tissue-fluid back into the veins (Körner). This process is essential for the decrease of the local pressure since the only outflow of the tissue-fluid from the bones is by the veins (von Recklinghausen). Thus is explained the occurrence of the proliferative process in those cases in which no eruption through the covering occurs.

VI. In the regenerative stage the remnants of epithelium subserve the function of preserving portions of the original pneumatic cell lumen.

It thus becomes apparent, firstly, that a certain number of the pneumatic cell spaces must be converted into spongy bone and, secondly, that this conversion will be most pronounced in a very cellular mastoid process since it contains outlying cells in which pus stagnates and in which organisation will eventually take place.

The change in the bone removed at operation depends upon the time at which the operation is carried out. If late, new

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formed bone, organised tissue and diseased tissue are taken away, and macroscopically no differentiation can be made between them; hence a complete clearance is necessary.

The infecting micro-organism has some effect on the course of the disease, the most dangerous being *Streptococcus hæmolyticus*.

The disease is not influenced directly by age, provided that the patient is healthy, but its course is dependent on the acuteness and severity of the infection.

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