INCIPIENT OTOSCLEROSIS*

AS SEEN IN THE "CUPOLA" OF THE FENESTRATED HORIZONTAL CANAL

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THE portion of the bony wall of the horizontal semicircular canal which was removed during the fenestration operation on the horizontal canal affords a view of the progressive advance of otosclerosis into normal bone, with a clarity impossible to observe elsewhere.

For many years biopsies were taken by J. Lempert of the "cupola" or bony covering of the membranous canal. This was removed at operation when "creating a fenestra novovalis in the surgical dome of the horizontal canal". These minute bits of tissue, some scarcely larger than the head of a common pin (if fractured in handling), were embedded in celloidin and serially sectioned. Through the years 500 of these "cupolas" were examined. The present study is the result of the microscopic observations on 200 of these biopsies, taken in consecutive series.

The specimens came from 130 females and 70 males. One hundred and sixteen of the biopsies came from the right side, eighty-four from the left. Among the 200 cupolas 34 or 17 per cent. were found to be definitely positive for otosclerosis. An additional group of 19 "cupolas" in the 200 were termed "incipient otosclerosis" because the microscopic picture, although not that of frank otosclerosis, presented either an altered staining reaction, diffuse blue mantling, hypervascularity or necrotic areas of bone, to such a degree that invasion of this area by the pathological process, appeared to be imminent.

The specimens came from patients ranging in age from 11 years to 62 years. Two cases fell in the 11th year. One of these was a case of malformed ear and the other of generalized bone disease.

Technique

Specimens were fixed either in 20 per cent. formalin or in Heidenhain-Susa solution. When formalin was used the specimen was next put into formalin and formic acid where it was left for 6-8 days, unchanged. It was then washed in tap water by decanting the fixative and pouring tap water into the bottle. This was done two or three times, then the usual dehydra-

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tion was started. If Heidenhain-Susa was used the specimen was decalcified, usually 5 days in trichloracetic acid. It was then washed as above and dehydrated for celloidin embedding.

The average number of sections procured from each "cupola" was 22. The smallest number was two. The largest number from a single "cupola" was 45. Occasionally a "cupola" would cut well but would fall out of the celloidin while being stained. It is possible, however, to stain such isolated "cupolas", using tiny stender dishes with only a few drops of hæmatoxylin and knowing exactly how many bits of tissue have been put into each dish. If the tissues cannot be retrieved with fine eye forceps they can be recovered on filter paper and passed to the next solution.

The advantage in using celloidin rather than paraffin lies in the fact that the tissue can always be seen and therefore cut in the best plane; also it is never "cooked" but always maintained at room temperature. Sections should be cut at 6-8 mu. Too thin sections will lead to the false observation of too many empty lacunae, and interpretation of necrotic bone when the osteocyte was really there, but at a different level than a given section.

Histologic Observations

The bone of the otic capsule covering the so-called "surgical dome" of the horizontal semicircular canal consists usually of three characteristic layers of bone. These are described as (1) endosteal, a thin layer of lamellar bone immediately surrounding the membranous canal, (2) enchondral, a layer containing globuli interossei and occasional spaces with a fibrous type of marrow, once hæmopoietic in infancy, and (3) a superficial layer of lamellar bone of periosteal derivation. In some instances the enchondral layer is not distinguishable in the "cupola" sections as we do not always see globuli interossei in this area. Marrow, of any type, is practically never seen in this region.

The area of the "cupola" removed at fenestration surgery is normally well supplied with inconspicuous blood vessels. This fact is well illustrated in Figure 40, page 81 of *Microscopic Anatomy of the Temporal Bone* by Wolff, Bellucci and Eggston. The illustration comes from a routine serial section of non-otosclerotic temporal bone. It is believed that the vessels supplying this area come primarily from the submucosa of the middle ear. In the presence of otosclerosis the number of vascular channels in the involved area is always augmented. Throughout viable biological tissue injury is always followed by hypervascularity to the site.

We present in Fig. 1 A, B, C, D and E, five different "cupolas" from five different patients ranging in age from 31 to 43 years, all female and all with clinical otosclerosis but not with frank otosclerosis in the "cupolar" area.

The elaborate hypervascularity seen in Fig. 1A occurred near the

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so-called "blue line" of the surgical "cupola", that is, near the approach to the membranous canal. The vessels within the Haversian canals were constricted. This could conceivably have been the autonomic reaction to the use of the drill in the proximity. Showers of small round cells were present in the perivascular tissue.

Fig. 1B presents a slightly more enlarged vascular area of a "cupola" with early evidence of "blue mantling" and strands of necrotic endothelial cells within the Haversian canals. Some viable osteocytes are present.

Egg-shell fragility is indicated in Fig. 1C in the bony walls of these vascular channels which appear to be devoid of vascular content and yet the bone in the area contains many viable osteocytes. Early blue mantling is also seen here.

In Fig. 1D we have patent vascular channels running through viable bone. Many endothelial cells are needle-shaped suggesting early necrosis. A toxic substance seems to be diffusing not only through the walls of the



FIG. 1A.

Elaborate hypervascular pattern near the so-called "blue line" of a surgical "cupola" removed from the bony wall of the horizontal semi-circular canal at fenestration surgery of the canal. Vessels within the Haversian canals are constricted. Showers of small round cells are present in the tissue. 43 years. W.F.

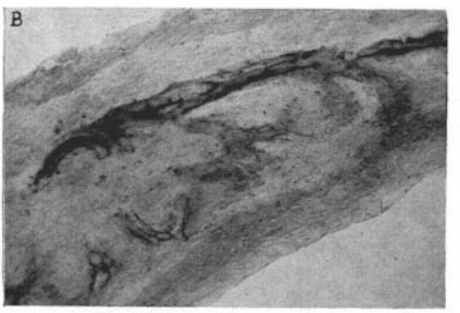


FIG. 1B.

Haversian canals frequently appear to be empty save for strands of necrotic endothelial cells. The bone here is partly viable, partly necrotic. 32 years. W.F.

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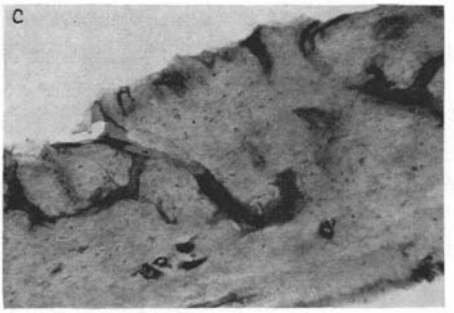


FIG. 1C.

Egg-shell fragility of bone is sometimes manifest along the blue mantled vascular channels of a "cupola" showing hypervascularity. Both viable and necrotic osteocytes are present. Note spread of blue mantles in lower centre and left fields. 40 years. W.F.

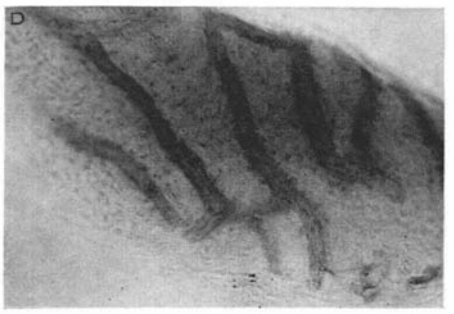


FIG. 1D.

Hypervascularity of a surgical "cupola" showing loops of more or less parallel blue-mantled vessels. Note the needle-shaped endothelial cells. The bone exhibits viable osteocytes. 31 years. W.F.

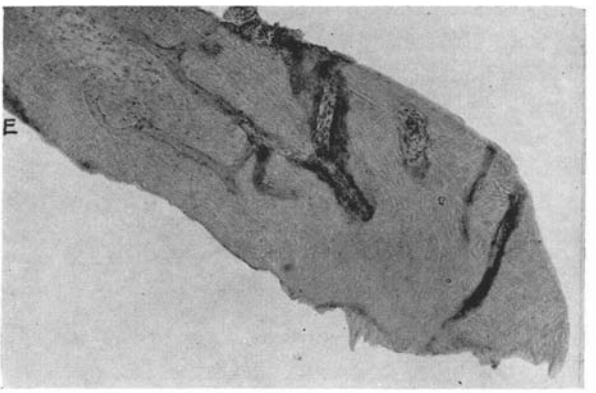


FIG. 1E.

Note the widening of vascular channels and concomitant blue mantling. No osteoclasts are present. 32 years. W.F.

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vessels but also through the bony walls of the Haversian canals, altering the staining reaction to the hæmatoxylin.

Widening of the vascular channels appears to occur concomitantly with blue mantling as demonstrated in the centre field of Fig. 1E and in the lower right field. The impression is that a decalcifying agent such as a degradative enzyme or a hormone is producing aseptic necrosis and breakdown of the bone adjacent to the blood vessels. Since the blue mantling may be apparent prior to the widening of the vascular channel (Altmann would consider this Grenz scheide), one cannot assume that the blue mantling is always produced by the formation of new bone. Occasionally the disease process is not completely aseptic since even polymorphonuclear cells have been found in the area. Their presence might, of course, be due to some completely secondary invasion.

In Fig. 2 Series A, Series B and Series C, we present three "cupolas" from three patients. Each "cupola" is cut in serial sections to show the appearance of the tissue at different levels, as the endosteal wall of the bony semicircular canal is approached. In Series A the first section shows the area of the so-called "blue line". The bone in this "cupola" is still normal. Numerous vessels traversing the region are evident. The second section in this series shows the actual lumen of the bony semicircular

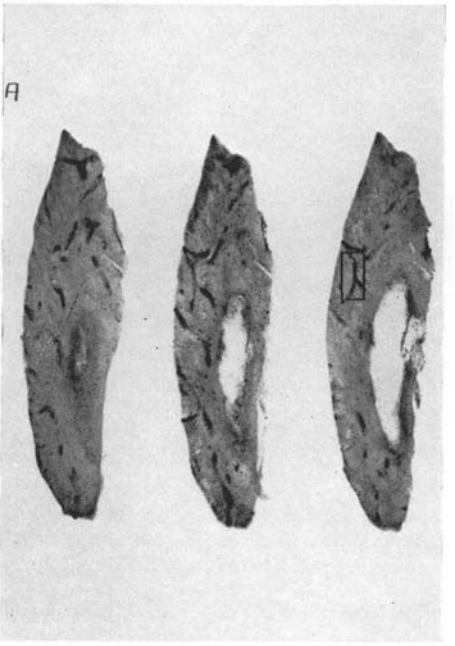


FIG. 2A.

Series A. Three serial sections through one "cupola" of normal appearing bone but with pathology in the vascular channel. See Fig. 3. 48 years. W.F.

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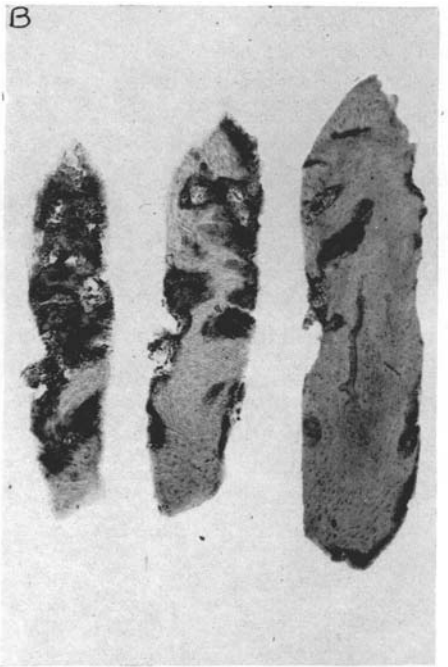


FIG. 2B.

Series B. Three serial sections through one "cupola" which exhibits otosclerosis peripherally but the deeper layers of bone are less involved. 32 years. W.F.

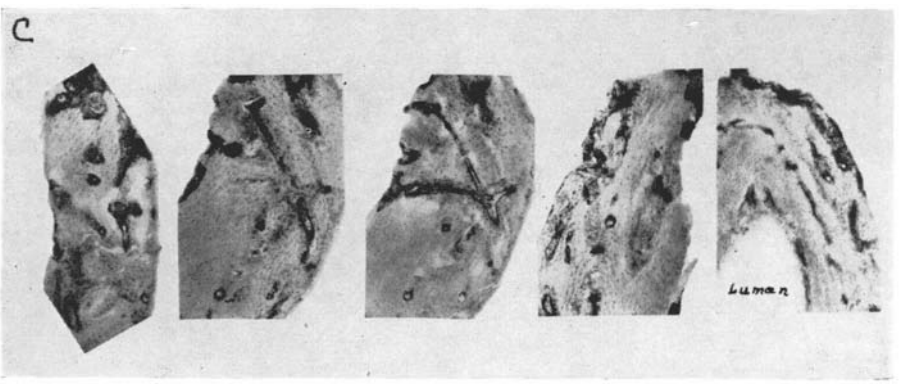


FIG. 2C.

Series C. Five levels from an otosclerotic "cupola" showing vascular involvement with blue mantling and occlusion of the lumen of the vessels with decalcifying bone. W.M. 28 years.

canal. Approximately twenty different cuts of vascular channels appear in this section. Several of these undoubtedly pass through the same vessel as it ramifies through the bone of the area. As noted from the dotted appearance, the bone at this specific level is viable, the dots being the

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osteocytes present in their lacunae. The third section shows a larger view of the lumen. Along the lower left contour globuli interossei can be seen.

Although the bone *per se* is still normal in this area the capillary-sized vascular channels already reflect pathological changes in the rectangular enclosure presented in higher magnification in Fig. 3. Here we see that the lumen of the vessel is completely occluded at the bifurcation of the vessel. Endothelial cells are aggregated and necrotic in this region. The blood



FIG. 3.

Detail of Section 3 in Fig. 2, Series A. Necrotic endothelial cells occluding vascular lumen at the bifurcation. Note decalcification around osteocyte lying in bifurcation. Surrounding bone is devoid of viable osteocytes.

supply has been constricted. An apparently toxic fluid has been disseminated through the canaliculi to neighbouring lacunae, necrotizing their contained osteocytes. Consequently at this specific level the bone has lost its osteocytes, only nine remaining visible and viable in a field containing 30 lacunae. No diffusion can any longer be traced through the canaliculi which themselves have now broken down, the whole area being necrotic. Not every lacuna in normal bone contains a viable osteocyte but this proportion of empty lacunae is pathologically high. Furthermore if we examine carefully the area to the right of the bifurcation we observe a large oval decalcified area around a viable osteocyte. Note the globular, foamy or "soapy" nature of the biochemical surrounding the osteocyte. A similar smaller more rounded area lies nearby but over the other branch of the vessel. These conditions suggest the possibility of acidified tissue fluids in the presence of stagnated blood-supply with consequent

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decalcification of the bone. This appears to be aseptic chelation of bone. Since we know this patient had an otosclerotic lesion at a lower level in the petrosal bone it seems reasonable to assume that we may be observing the incipient stages of otosclerosis in an as yet slightly involved area. A toxic decalcifying biochemical fluid is evidently being dispersed from the vessel through the ground substance of the bone. This degredative enzymatic substance undoubtedly possesses an organic-free radical which enables it to latch onto some metallic crystallites of bone. This chelating agent loosens the casually attached mineral calcium crystals or crystallites from their moorings to the double or triple coils of collagen fibres composing bone. Not only does this biochemical loosen and dissolve the bone minerals but it also necrotizes the endothelial cells of the blood vessel walls as it disseminates, thus compounding the injury (Fig. 3).

The different series in Fig. 2 clearly demonstrate the varied degrees of involvement of the "cupolar" area in different cases having received a clinical diagnosis of otosclerosis. Series B, in contrast to that of Series A exhibits a full-blown otosclerotic lesion already present in the outer wall (first small section) of the canal. The spongy hypervascular bone with enlarged vascular channels is apparent. The next section shows occlusion of the vascular channels with decalcified bone. The third section reveals the spread of the lesion along "blue mantled" blood vessels as the cutting microtome approaches, but does not attain, in this illustration, the level of the lumen of the canal. The bone in the area is viable.

Fig. 4 is a detail of this case taken at the level of the membranous canal. A leakage of fluid from the vessel has evidently occurred into the surrounding tissue. The hæmatoxylin dye has accentuated the chemical change of the ground substance of the bone along the wall of the vascular channel as the pathological substance flows in a cumulative mass. This illustration depicts the "finger-like" extensions of the pathological process as described by earlier observers. Attempted repair of the widened vascular channel by perivascular fibrosis has already been initiated in this area of early invasion into normal bone. Undoubtedly this patient will develop or has developed the type of otosclerosis characterized by fibrotic replacement of bone.

Series C, like that of Series B, exhibits the greatest degree of pathology superficially or on the periphery of the bony wall of the horizontal canal rather than near the endosteal lining. We have five sections at successive levels approaching the inner wall. In the first section we see the heavy blue mantling, particularly at the top of the section. Here also is a cross-section of a vessel, the lumen of which is completely occluded with fragments of decalcified bone. In the second section we see more blue mantling and the longitudinal cut of a blood vessel is clearly discerned passing diagonally across the field. In the next section this same vessel plus another joining it are clearly observed. It is quite apparent that the

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pathology of this bone also is being disseminated along the vascular channels and by numerous different routes. In the fourth section we see the oval contour of the so-called "blue line" or outer cap of the underlying endosteal area. It is notable that this area is being attacked from two vascular sources, observed in Sections 2 and 3 where the intersecting vessels cross paths. Blue mantling is not only present but also occlusion of the vascular channels both by precipitated calcium and by decalcified bone, as seen in the first section. The specimen comes from a white male of 28 years.

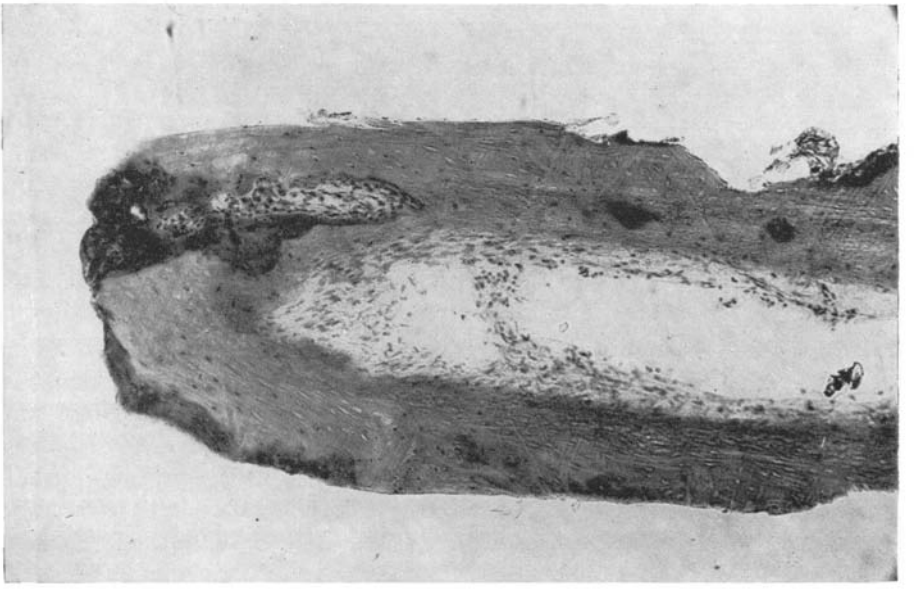


FIG. 4.

Detail from a section taken at a lower level than those illustrated in Fig. 2 Series B but from the same "cupola". The lesion almost borders on the endosteum. Evidence of cumulative bulbous flow or spread is seen in the deeply stained mass along the lower border of the vessel. 32 years. W.F.

The tissues presented herewith in photographs were placed in fixative as promptly as any surgical specimens could possibly have been so placed. We therefore believe the histopathological picture to be as representative as possible of the condition *in situ*.

We must recognize that in the process of repair of any pathological lesion, there is a tendency on the part of nature, to multiply the vascular supply to the area. Thus we have our "inflammation" and our "granulation tissue" (certainly a misnomer) of soft tissues.

Anatomically, we do not believe the area of the site of predilection of otosclerosis to have a paucity of blood supply. Nor does the area herewith described have a paucity of blood supply, normally. The neuroepithelium

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of the inner ear is supplied by the internal auditory artery, a branch of the basilar artery. The vessels which traverse the otic capsule terminate for the most part in that bone and nourish it through canaliculi where they cannot be terminal. How vessels can multiply as seen in Fig. 1A, in solid bone, we are not prepared to state. We do observe occlusion of vessels once multiplied for a given area, thus producing a lesion of osteoporosis. We have not included this pathology in these illustrations as we would consider the condition no longer incipient. Such conditions have been observed by us in relatively young individuals (26 and 34 years of age) and these people have exhibited blue sclera. See Lempert, 1951, *Transactions A.A.O.O.*

Nor have we presented the classical type of otosclerosis with congestion, stasis, osteoclasts and new bone deposition. This also could no longer be considered incipient. Incidentally very few such specimens were found in this area of the horizontal canal bony wall.

Of course we must remember that arterial supply to the otic capsule and inner ear arrives through vessels that are of the calibre of capillaries for any other part of the anatomy.

Summary

Presented as incipient otosclerosis the advance of otosclerotic or spongy pathological bone into normal areas of the surgical "cupola" or bony covering of the horizontal semicircular canal is described and illustrated. No osteoclasts are to be seen in these early stages. Decalcification occurs along the course of vascular channels, thence through canaliculi. Hypervascularity develops as an early phenomenon. The process appears to be aseptic although mononuclear cells and even polymorphonuclear cells are occasionally observed. A toxic, probably acidic fluid is disseminated from the blood vessels, producing necrosis of the endothelial cells of the vessels as well as destruction of the bone.

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