J. Anat. (1976), **122**, 2. pp. 389–401
With 12 *figures*
Printed in Great Britain

The root surface in human teeth: a microradiographic study

P. D. A. OWENS

Department of Anatomy, Queen's University of Belfast, Belfast, BT7 1NN, N. Ireland

(*Accepted* 23 *October* 1975)

INTRODUCTION

The human cemento-dentinal junction has been investigated by a variety of techniques, but there is still little agreement about where dentine ends and cementum begins. Most frequently it is implied that the granular layer of Tomes represents the outer limit of dentine (Soni, Van Huysen & Swenson, 1962; Yamamoto, Masuda, Toeda & Suzuki, 1962; Furseth, 1965, 1967; Anneroth, Bergman & Welander, 1966; Orban, 1972; Ten Cate, 1972). However, other studies have suggested that some of the matrix *external* to the granular layer may be of dentinal origin (Owens, 1972, 1973; Kawasaki, 1975) indicating the need for further investigations of root development.

In the present study, ground sections of human teeth with incompletely formed and fully formed roots were studied histologically and in microradiographs in the hope of determining the boundary between dentine and cementum.

MATERIALS AND METHODS

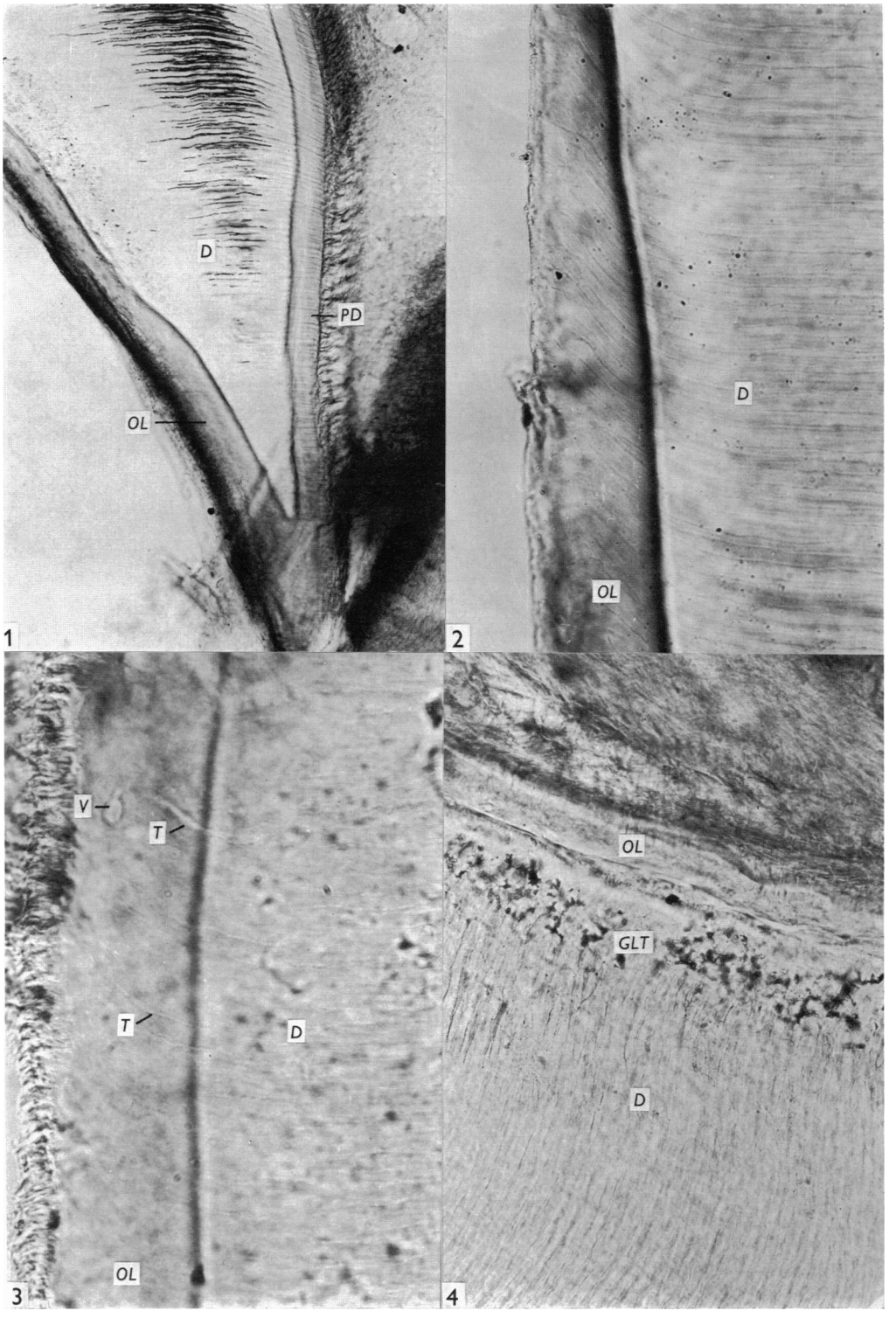
Twenty three extracted human permanent molar and premolar teeth were used, all of which were free from dental caries. These were divided into two groups, those with incomplete roots (9 teeth) and those with completed roots (14 teeth). Longitudinal, mid-root axial ground sections, ranging in thickness from 100 to 275 cm, were prepared in routine manner and examined by light microscopy. Microradiographs of the same sections were made on Kodak experimental film V 6028 with a Philips' X-ray diffraction unit, type PW 1010, operated at 20 kV and 20 mA. Nickel-filtered copper radiation was used, exposure times varying from 12 to 30 minutes. The distance between target and film was 20 cm in all cases.

Tracings of the photographs and microradiographs were made and compared.

RESULTS

Incompletely formed teeth

In most ground sections a single distinct layer was present along the root surface and this was continuous with the predentine layer at the forming apex (Fig. 1). This outer layer varied in width from section to section, being sometimes as thin as 15 μm and sometimes as thick as 35 μm. However, in any one specimen its width was fairly constant. In most cases some follicular connective tissue remained attached to its outer surface.


D
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1
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4

In many areas this outer layer contained tubules which were continuous with those in the undoubted dentine. This feature was most evident and uniform in the coronal region of the root (Fig. 2): in more apical regions the number of tubules in the layer was fewer, and they often showed varicose endings (Fig. 3).

The granular layer of Tomes was not demonstrable in all areas of the root (Fig. 5A), but when present it lay beneath the outer layer (Fig. 4). In such regions tubules were not observed to cross from the dentine into the outer layer.

Superimposition of tracings of ground sections and microradiographs enabled the conclusion to be drawn that the outer layer was radio-lucent (Figs. 5A, B and C).

Nearer to the apex, and in the inter-radicular region, several sections showed irregular areas where the histology was not typical of either dentine or cementum. Such areas were bounded externally by the outer layer and internally by the granular layer of Tomes (Fig. 6A). The areas contained irregular outlines, and their radio-density varied, being sometimes less than that of the dentine (Fig. 6B) and sometimes nearly equal to it. However, in all but a very few cases the overlying outer layer was radio-lucent (Fig. 6C): in the remaining cases some of the films showed the outer layer to be faintly radio-opaque, but not more so than the predentine in the same section (Fig. 7).

Teeth with completed roots

The results varied considerably, and on re-examination of the records some of the variations appeared to be age-related.

Ground sections of teeth from younger patients whose roots had completed shortly before extraction showed an apparently single layer on the root surface nearest the crown (Fig. 8A). Higher magnification revealed that there were not one but two layers – an inner which contained tubular extensions from the dentine and an outer devoid of recognizable structures (Fig. 8B). The microradiographs did not reveal any differential radio-densities at the root surface (Fig. 8C) and on comparing outlines with those of ground sections, both the outer layers were shown to be radio-lucent (Fig. 8D).

In the same specimens, areas of cellular cementum were present around the apical region. These were sometimes overlaid by a structureless layer which was continuous with the outer of the two layers in the coronal region (Fig. 9A). The cellular cementum was less radio-dense than dentine (Fig. 9B) while the structureless layer was radio-lucent (Fig. 9C).

Fig. 1. Section of the root of an incompletely formed molar tooth showing a distinct outer layer (*OL*) on the periodontal surface of the dentine (*D*), which is continuous with the predentine (*PD*). ×260.

Fig. 2. Section of the cervical region of an incompletely formed molar tooth showing tubules in the outer layer (*OL*). *D*, dentine. ×415.

Fig. 3. Section of the mid-root region of an incompletely formed molar tooth showing a few tubules (*T*) in the outer layer, one of which has a varicose ending (*V*). ×415.

Fig. 4. Section of the inter-radicular region of an incompletely formed molar tooth showing the granular layer of Tomes (*GLT*) beneath the outer layer (*OL*) in which tubules are not seen. *D*, dentine. ×260.

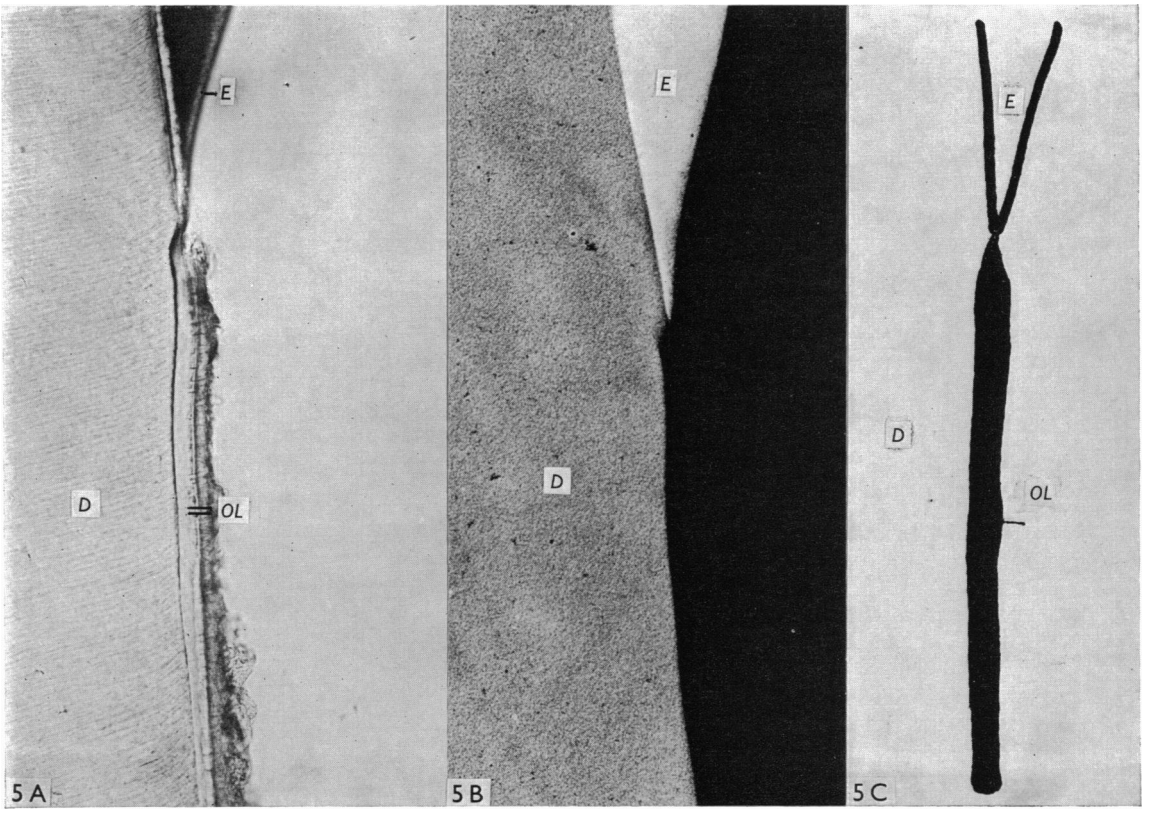

Fig. 5. The cervical region of an incompletely formed molar tooth showing (A) the ground section appearance, (B) the microradiograph and (C) the tracing of outlines of (A) and (B) superimposed. The shaded area on (C) represents an area seen on the ground section only and corresponds exactly to the outer layer. *D*, dentine; *E*, enamel; *OL*, outer layer. ×135.

In teeth from older patients, ground sections of the coronal root region showed a distinct granular layer of Tomes overlain by a layer of what appeared to be acellular cementum (Fig. 10A). The granular layer was less radio-dense than the subjacent dentine and immediately external to it was a thin radio-dense line (Fig. 10B). The acellular cementum-like layer was marginally less radio-dense that the dentine (Fig. 10B).

In the apical regions, cellular cementum was usually separated from the granular layer by a homogeneous zone of variable width whose radio-density lay between that of the dentine and the cementum (Figs. 11A, B). Occasionally, however, other areas were noted which contained irregular spaces, and sometimes extensions of dentinal tubules, which were bounded by the granular layer of Tomes internally and a cementum layer externally (Fig. 12).

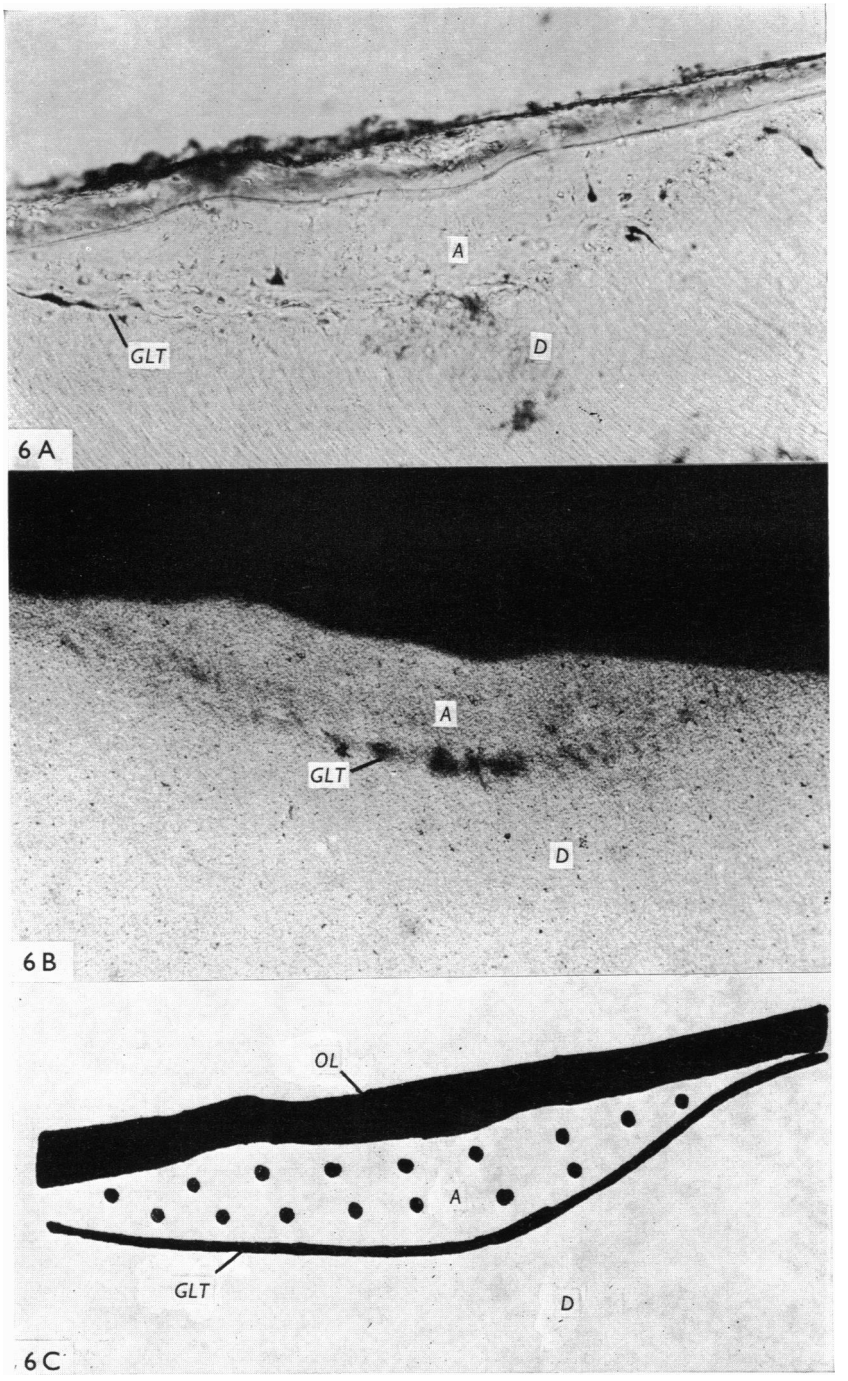

Fig. 6. Near the apex of an incompletely formed molar tooth, showing (A) the ground section appearance of an irregular area(*A*); (B) the microradiographic appearance and (C) the superimposed tracings. The irregular area, *A* (stippled), is common to both ground section and microradiograph but the outer layer (*OL* shaded) is seen only in the ground section. *D*, dentine; *GLT*, granular layer of Tomes. × 135.

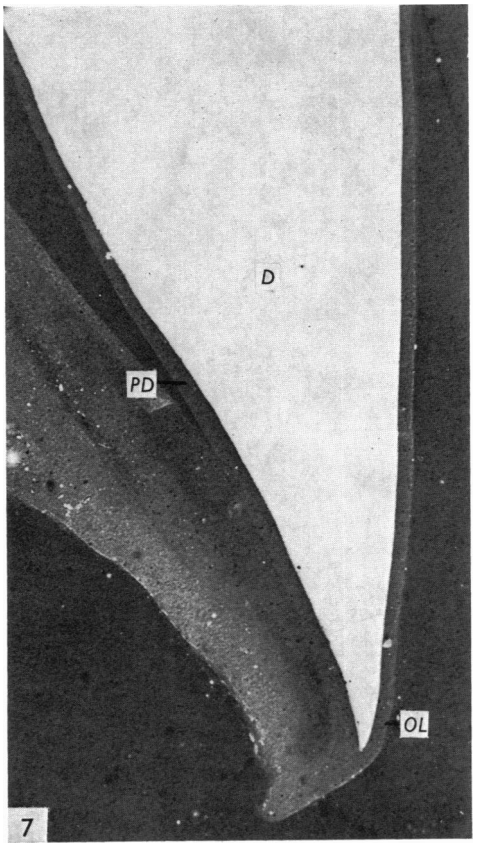

Fig. 7. Microradiograph from near the apex of an incompletely formed molar tooth showing the slight radio-density of the outer layer (*OL*) which corresponds with that of predentine (*PD*). *D*, dentine. × 135.

DISCUSSION

Incompletely formed teeth

The presence of a distinctive outer layer along the root surface has been noted previously (Owens, 1972). At that time it was concluded, on the basis of its tubular content and continuity with predentine, that the layer was of dentinal origin, and probably unmineralized. The present results strongly support this conclusion and appear to confirm that the layer was unmineralized. Even in those films where the outer layer appeared faintly radio-opaque, its opacity was no greater than that of the predentine, and indeed of the dental pulp (Fig. 7). This indicates that the opacity of the outer layer was not due to its mineralization but was probably a result of section thickness or some slight variation in technique. Hereafter the layer will be referred to as the outer dentine layer.

In the same previous study (Owens, 1972) the outer dentine layer appeared to have mineralized when the roots of the teeth were two thirds to three quarters formed, whereas in the present investigation the layer appeared to have remained unmineralized in some of the specimens at the equivalent stage of root formation. It therefore

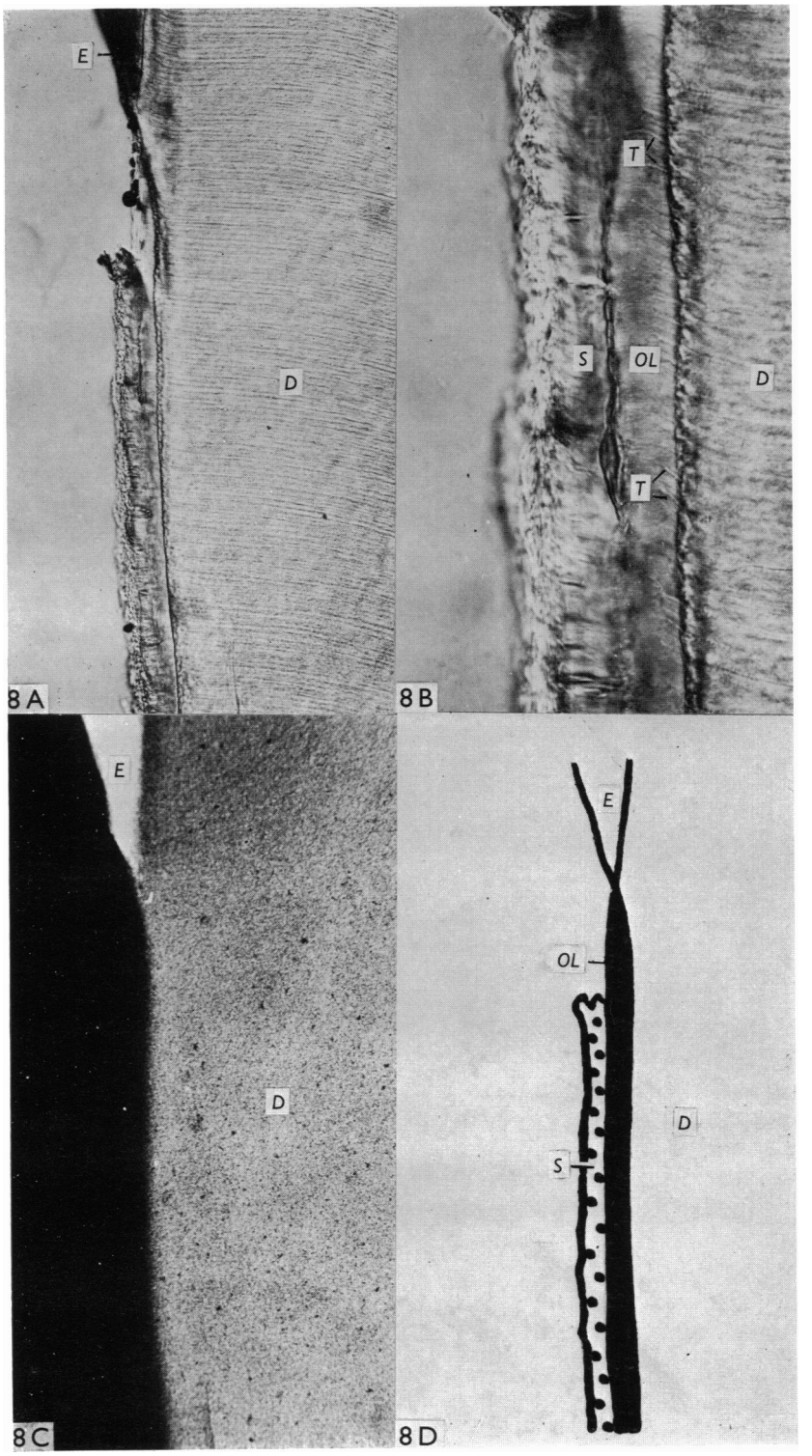

Fig. 8. Near the cervical region of a molar tooth whose roots had formed shortly before extraction showing (A) the ground section appearance, (B) magnification of the surface layers (×415) showing a two-layered appearance (the inner layer (*OL*) contains tubules (*T*), the surface layer (*S*) is amorphous), (C) the microradiograph and (D) the superimposed tracings of the area. Both the *OL* (shaded) and the layer *S* (stippled) do not appear on the microradiograph. E, enamel. ×135.

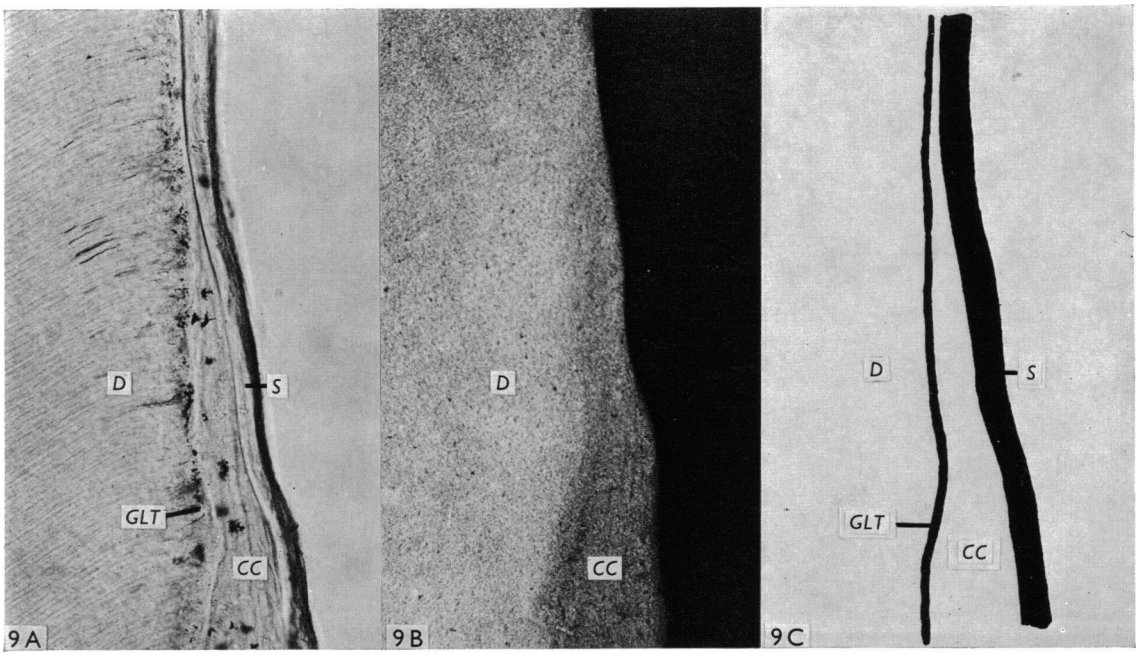

Fig. 9. Near the apical region of a specimen similar to that in Fig. 8. In the ground section (A) cellular cementum is present, overlaid by a surface layer (*S*). When compared with the micro-radiograph (B) and the combined tracings (C), the layer *S* is seen to be radio-lucent. *D*, dentine; *CC*, cellular cementum; *GLT*, granular layer of Tomes. × 135.

seems probable that the rate of mineralization of the outer layer varies from tooth to tooth: it is also possible that it varies likewise in initial thickness. These possibilities require further investigation.

As the outer layer appeared to be of dentinal origin, the tissue in areas exhibiting irregular histology must also have been some form of dentine. The reasons for the irregularities are unknown, but their presence supports a previous suggestion that growing dentine may modify its surface histology quite considerably (Owens, 1973). Furthermore, it seems reasonable to suggest that these irregular areas correspond to what has been termed 'intermediate cementum' (Blackwood, 1957) as they contain irregular spaces and lie external to the granular layer of Tomes. Osborn (1965) proposed a dentinal origin for intermediate cementum, but, as far as can be determined, the present results are the first to support this possibility on developmental grounds.

The presence of the outer dentine layer and the irregular areas external to the granular layer of Tomes means that the latter cannot represent the external boundary of dentine. The relationship of the granular layer to these overlying dentinal layers is still uncertain, but the results suggest that there may be an inverse relationship between the tubular content of the outer dentine layer and the presence of the granular layer.

The absence of a mineralized layer equatable with acellular cementum was noteworthy. According to widely accepted views on the site and timing of initial

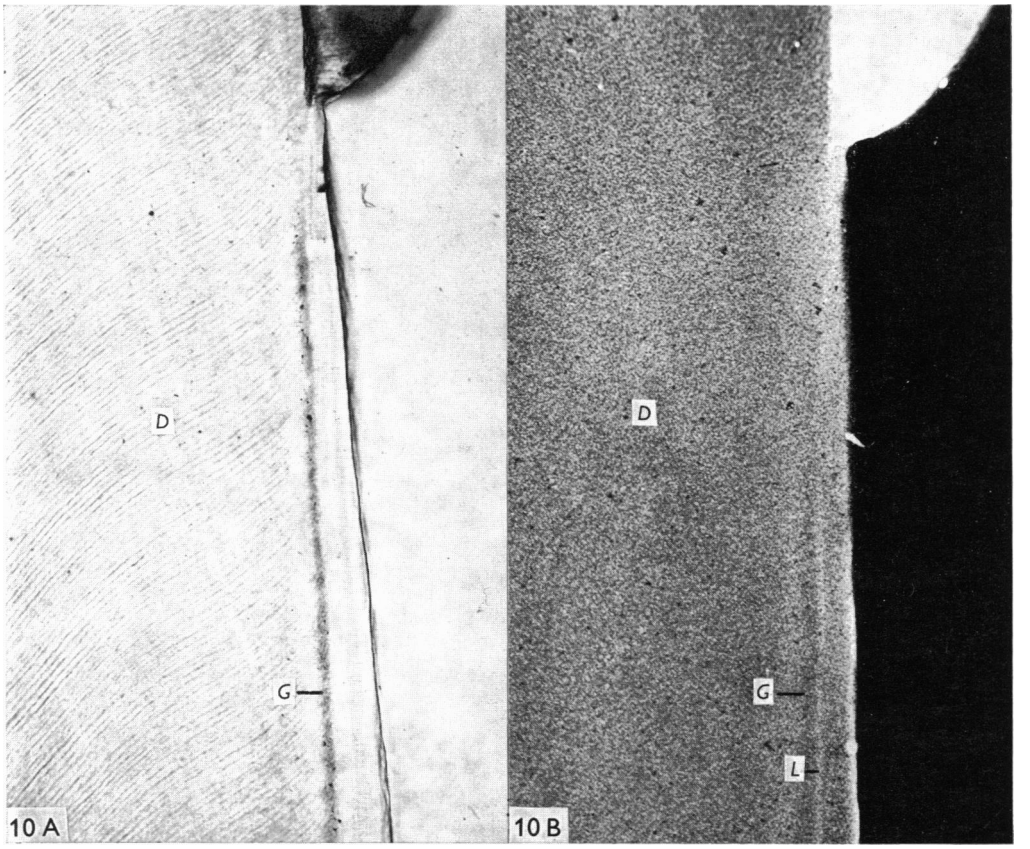

Fig. 10. From the cervical region of a molar tooth from an older patient showing (A) the ground section appearance and (B) the microradiograph. The layers external to the granular layer (*G*) are radio-dense. *D*, dentine; *L*, radio-dense line. ×135.

cementogenesis, surface mineralization was to be expected in the most coronal region of the root, certainly in cases where the roots were three quarter formed. Absence of mineralization, therefore, suggests that, in human teeth as in dogs' premolar teeth, cementum is not formed initially in the coronal region of the root (Owens, 1974, 1975).

Teeth with completed roots

In the specimens from younger patients a surprising find was the presence of two radio-lucent, and therefore unmineralized, surface layers in the coronal root region. The inner layer, which contained dentinal tubules, appeared to represent a persistent outer dentine layer. The superimposed structureless layer was therefore interpreted as newly formed cementum, but, not being mineralized, it must be regarded as precementum or cementoid rather than acellular cementum.

This latter finding was again unexpected, as the same roots showed quite thick deposits of cellular cementum around their apices. It suggests that in these teeth

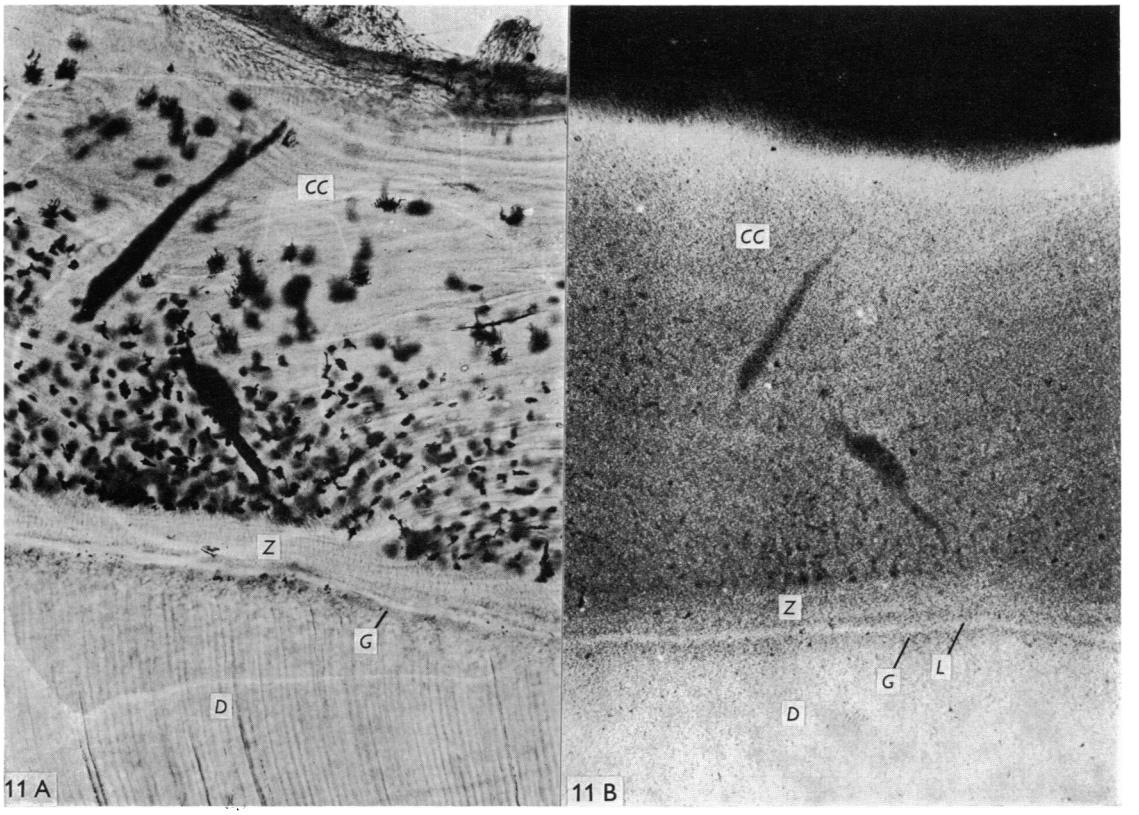

Fig. 11. From the apical region of a molar tooth of an older patient showing (A) the ground section appearance and(B) the microradiograph. The homogeneous zone (*Z*) beneath the cellular cementum (*CC*) is quite wide and more radio-dense that the cementum. *D*, dentine; *G*, granular layer of Tomes; *L*, radio-dense line external to the granular layer. × 260.

cellular, and not acellular, cementum was the first to be formed, conflicting with the more widely held view of cementogenesis that the reverse order applies (Orban, 1972; Scott & Symons, 1974). The present conclusion is, however, supported by the previously noted absence of acellular cementum in teeth with incompleted roots. In the more general context of mammalian root formation this would indicate that cementogenesis begins first in the more apical regions at a time when the roots are nearing completion. This suggestion is supported by previous results in dogs (Owens, 1974, 1975) and in the molar teeth of mice (Cohn, 1957). Furthermore, in the present work the presence of a pre-cemental layer investing both cellular cementum apically and the outer dentine layer coronally in the same tooth supports the view that cementogenesis spreads from the apical region towards the coronal region (Owens, 1974, 1975), rather than in the reverse direction.

Interpretation of boundaries in the teeth of older patients was more difficult, as mineralized tissues lined the entire root surface. In the coronal region, for example, it was not easily determined how much of the matrix external to the granular layer of Tomes was originally of dentinal origin and how much was of cemental

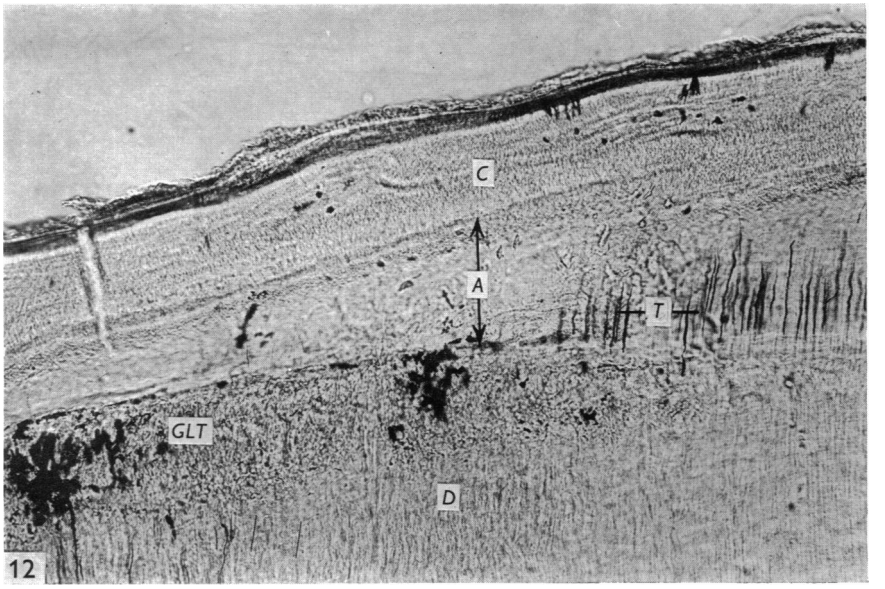

Fig. 12. From the apical region of a molar tooth of an older patient showing an area (*A*) bounded by the granular layer of Tomes (*GLT*) and cementum (*C*). The area *A* contains some irregular spaces and dentinal tubules. × 260.

origin. Most previous workers have concluded that the radio-dense line immediately external to the granular layer represents the true cemento-dentinal junction (Soni *et al.* 1962; Yamamoto *et al.* 1962; Furseth, 1965, 1967; Anneroth *et al.* 1966). The present studies, on the other hand, suggest that the true junction almost certainly lies further out from the granular layer, although they do not indicate the precise location of the junction.

However, it seems reasonable to suggest that the homogeneous zones noted between cellular cementum and the granular layer of Tomes represent mineralized versions of the outer dentine layer, and to equate these zones with the homogeneous or hyaline layer of Hopewell-Smith (1903, 1919). On this basis the true cemento-dentinal junction in Figure 11 would not be represented by the radio-dense line, but by the boundary between the homogeneous zone (*Z*) and the cellular cementum. It also appears consistent with observed developmental histology to suggest that clearly defined irregular areas between cementum and the granular layer of Tomes may represent areas of modified dentine rather than irregular forms of cementum. The presence of these areas, also, is consistent with the view that the cemento-dentinal junction lies further away from the granular layer of Tomes than is usually believed.

The findings and interpretations indicate that further investigations of root development are required. In particular the suggestion made here that cemento-genesis begins when the roots are nearing completion obviously has important implications for the development of attachment systems in mammalian teeth; Clearly however, the facts must be investigated in other species before general conclusions can be drawn.

SUMMARY

In an attempt to clarify the nature of the human cemento-dentinal junction, ground sections of incompletely formed and fully formed extracted teeth were prepared and their histology compared with their microradiographic appearances.

The results showed that incompletely formed teeth possess distinctive surface layers outside the granular layer of Tomes. The evidence indicates that these layers are of dentinal origin; their presence during development supports previous explanations by the author of the hyaline layer of Hopewell-Smith and of so-called intermediate cementum. The results also indicate that the granular layer of Tomes does not represent the outer limit of root dentine.

The relationship of these surface layers to the definitive cementum which is present in fully formed teeth was studied in both young and older patients. From the results it was concluded that cementum formation begins in the more apical region of the teeth at a time when root formation is well advanced, and that it spreads towards the crown rather than in the generally accepted reverse direction.

Thanks are due to Professor J. J. Pritchard for his assistance with the text. The technical assistance of Messrs G. Bryan and S. McKearney is gratefully acknowledged. The microradiographic work was made possible by the kindness and the assistance of Dr D. Adams, Dr T. Tranter and Mrs J. Davies at the Dental School, Heath, Cardiff. The work was supported by a grant from the Eastern Area Health and Social Services Board, Northern Ireland.

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