Cementum is the thin layer of calcified tissue covering the dentine of the root (Fig. 11.1). It is one of the four tissues that support the tooth in the jaw (the periodontium), the others being the alveolar bone, the periodontal ligament and the gingivae. Although many of these periodontal tissues have been extensively studied, cementum remains the least known. Indeed, it is the least known of all the mineralised tissues in the body. For example, very little is known about the origin, differentiation and cell dynamics of the cementum-forming cell (the cementoblast).

Although restricted to the root in humans, cementum is present on the crowns of some mammals as an adaptation to a herbivorous diet. Cementum varies in thickness at different levels of the root. It is thickest at the root apex and in the inter-radicular areas of multirooted teeth, and thinnest cervically. The thickness cervically is 10–15 µm, and apically 50–200 µm (although it may exceed 600 µm).

Cementum is contiguous with the periodontal ligament on its outer surface and is firmly adherent to dentine on its deep surface. Its prime function is to give attachment to collagen fibres of the periodontal ligament. It therefore is a highly responsive mineralised tissue, maintaining the integrity of the root, helping to maintain the tooth in its functional position in the mouth, and being involved in tooth repair and regeneration.

Cementum is slowly formed throughout life and this allows for continual reattachment of the periodontal ligament fibres – some regard cementum as a calcified component of the ligament. Developmentally, cementum is said to be derived from the investing layer of the dental follicle. Like dentine, there is always a thin layer (3–5 µm) of uncalcified matrix on the surface of the cellular variety of cementum (see page 346). This layer of uncalcified matrix is called precementum (Fig. 11.2). Similar in chemical composition and physical properties to bone, cementum is, however, avascular and has no innervation. It is also less readily resorbed, a feature that is important for permitting orthodontic tooth movement. The reason for this feature is unknown but it may be related to:

- differences in physicochemical or biological properties between bone and cementum;
- the properties of the precementum;
- the increased density of Sharpey’s fibres (particularly in acellular cementum);
- the proximity of epithelial cell rests to the root surface.

The arrangement of tissues at the cement–enamel junction is shown in Figs 11.3–11.5. In any single section of a tooth, three arrangements of the junction between cementum and enamel may be seen. Pattern 1, where the cementum overlaps the enamel for a short distance, is the predominant arrangement in 60% of sections. Pattern 2, where the cementum and enamel meet at a butt joint, occurs in 30% of sections. Pattern 3, where the cementum and enamel fail to meet and the dentine between them is exposed, occurs in 10% of sections. Although
one of these patterns may predominate in any individual tooth, all three patterns can be present.

**PHYSICAL PROPERTIES**

Cementum is pale yellow with a dull surface. It is softer than dentine. Permeability varies with age and the type of cementum, the cellular variety being more permeable. In general, cementum is more permeable than dentine. Like the other dental tissues, permeability decreases with age. The relative softness of cementum, combined with its thinness cervically, means that it is readily removed by abrasion when gingival recession exposes the root surface to the oral environment. Loss of cementum in such cases will expose dentine.

**CHEMICAL PROPERTIES**

Cementum contains on a wet-weight basis 65% inorganic material, 23% organic material and 12% water. By volume, the inorganic material comprises approximately 45%, organic material 33%, and water 22%. The degree of mineralisation varies in different parts of the tissue; some acellular zones may be more highly calcified than dentine. The principal inorganic component is hydroxyapatite, although other forms of calcium are present at higher levels than in enamel and dentine. The hydroxyapatite crystals are thin and plate-like and similar to those in bone. They are on average 55 nm wide and 8 nm thick. Their length varies, but values derived from sections cut with a diamond knife are underestimates due to shattering of the crystals along their length. As with enamel, the concentration of trace elements tends to be higher at the external surface. This, for example, is true of fluoride levels, which are also higher in acellular than in cellular cementum. The organic matrix is primarily collagen. The collagen is virtually all type I. In addition, the non-collagenous elements are assumed to be similar to those found in bone (see page 206). However, because of the difficulties of obtaining sufficient material for analysis, less information is available. Nevertheless, among the important molecules known to be present are bone sialoprotein, osteopontin and possibly other cementum-specific elements that are conjectured to be involved in periodontal reattachment and/or remineralisation.

**CLASSIFICATION OF CEMENTUM**

The various types of cementum encountered may be classified in three different ways: the presence or absence of cells, the nature and origin of the organic matrix and a combination of both.

**Classification based on the presence or absence of cells – cellular and acellular cementum**

Cellular cementum, as its name indicates, contains cells (cementocytes); acellular cementum does not. In the most common arrangement, acellular cementum covers the root adjacent to the dentine, whereas cellular cementum is found mainly in the apical area and overlying the acellular cementum (Fig. 11.6). Deviations from this arrangement are
common and sometimes several layers of each variant alternate. Being formed first, the acellular cementum is sometimes termed primary cementum and the subsequently formed cellular variety secondary cementum. Cellular cementum is especially common in interradicular areas.

Acellular cementum appears relatively structureless (Fig. 11.7). In the outer region of the radicular dentine, the granular layer (of Tomes) can be seen and outside this the hyaline layer (of Hopewell-Smith). These layers are also described on page 136. A dark line may be discerned between the hyaline layer and the acellular cementum; this may be related to the afibrillar cementum that is patchily present at this position. The usual arrangement at the apical region of the root is of a layer of cellular cementum overlying acellular cementum (Fig. 11.8). Many of the structural differences between cellular and acellular cementum are thought to be related to the faster rate of matrix formation for cellular cementum. Indeed, a major difference is that, as cellular cementum develops, the formative cells (the cementoblasts) become embedded in the tissue as cementocytes. The different rates of cementum formation are also reflected in the presence of a precementum layer and in the more widely spaced incremental lines in cellular cementum.

Although the usual relationship between acellular and cellular cementum is for the cellular variety to overlie the acellular, the reverse may occur (Fig. 11.9). Furthermore, it is also common for the two variants of cementum to alternate (Fig. 11.10), probably representing variations in the rate of deposition.

Fig. 11.6 The distribution of acellular (A) and cellular (B) cementum.

Fig. 11.7 The appearance of acellular cementum (A). B = Hyaline layer (of Hopewell-Smith); C = granular layer (of Tomes); D = root dentine. Note that the dark layer arrowed between the hyaline layer and the acellular cementum may be related to the afibrillar cementum patchily present at this position (Ground section; × 200).

Fig. 11.8 Cellular cementum (B) overlying acellular cementum (A). Note the greater thickness of the cellular layer (Ground section; × 50).

Fig. 11.9 Acellular cementum (A) overlying cellular cementum (B) (Ground section of the root; × 50).

Fig. 11.10 Alternating acellular (A) and cellular cementum (B) (Ground section; × 60).
The spaces that the cementocytes occupy in cellular cementum are called lacunae, and the channels that their processes extend along are the canaliculi (Fig. 11.11; see also Fig. 11.2). Adjacent canaliculi are often connected, and the processes within them exhibit gap junctions. In ground sections (Fig. 11.11), the cellular contents are lost, air and debris filling the voids to give the dark appearance. In thicker layers of cellular cementum, it is highly probable that many of the lacunae do not contain vital cells. Compared with osteocytes in bone, cementocytes are more widely dispersed and more randomly arranged. In addition, their canaliculi are preferentially oriented towards the periodontal ligament, their chief source of nutrition. Unlike bone, the cementocytes are not arranged circumferentially around blood vessels in the form of osteons (Haversian systems). In decalcified sections (Fig. 11.2), the cellular contents of the lacunae are retained, albeit in a shrunken condition.

Fig. 11.12 illustrates the ultrastructural appearance of a cementocyte within a lacuna. Although derived from active cementoblasts, once they become embedded within the cementum matrix cementocytes become relatively inactive.

This is reflected in their ultrastructural appearance. Their cytoplasmic/nuclear ratio is low and they have sparse, if any, representation of the organelles responsible for energy production and for synthesis. Some unmineralised matrix may be seen in the perilacunar space. The cementocyte processes can extend for distances several times longer than the diameter of the cell body.

Cementum is deposited in an irregular rhythm, resulting in unevenly spaced incremental lines (of Salter; Fig. 11.13). Unlike enamel and dentine, the precise periodicity between the incremental lines is unknown, although there have been unsuccessful attempts to relate it to an annual cycle. In acellular cementum, incremental lines tend to be close together, thin and even. In the more rapidly formed cellular cementum, the lines are further apart, thicker, and more irregular. The appearance of incremental lines in cementum is mainly due to differences in the degree of mineralisation, but these must also reflect differences in composition of the underlying matrix since, as shown in Figure 11.13, the lines are readily visible in decalcified sections. Table 11.1 summarises differences between acellular and cellular cementum.

**Classification based on the nature and origin of the organic matrix**

Cementum derives its organic matrix from two sources: from the inserting Sharpey’s fibres of the periodontal ligament, and from the cementoblasts. It is therefore possible to classify cementum according to the nature and origin of the fibrous matrix. When derived from the periodontal ligament, the fibres are referred to as the extrinsic fibres. These Sharpey’s fibres continue into the cementum in the same direction as the principal fibres of the ligament (i.e. perpendicular or oblique to the root surface; see page 182). When derived from the cementoblasts, the fibres are referred to as intrinsic fibres. These run parallel to the root surface and approximately at right angles to the extrinsic fibres. Where both extrinsic and intrinsic fibres are present, the tissue may be termed mixed fibre cementum.
### Classification based on the presence or absence of cells and on the nature and origin of the organic matrix

This classification, which is becoming more widely used, contains a number of types of cementum. For human teeth, two main varieties of cementum are found – acellular extrinsic fibre cementum (AEFC) and cellular intrinsic fibre cementum (CIFC). AEFC is located mainly over the cervical half of the root and constitutes the bulk of cementum in some teeth (e.g. in premolars). AEFC is the first formed cementum (see pages 340–345) and layers attain a thickness of approximately 15 µm.

#### Acellular extrinsic fibre cementum (Fig. 11.14)

For this type of cementum all the collagen is derived as Sharpey’s fibres from the periodontal ligament (the ground substance itself may be produced by the cementoblasts). This type of cementum corresponds with primary acellular cementum and therefore covers the cervical two-thirds of the root (Fig. 11.7). It is therefore formed slowly and the root surface is smooth (Fig. 11.4). The fibres are generally well mineralised. As shown in Fig. 11.15, however, the extrinsic fibres seen in ground sections may have unmineralised cores. These may be lost during preparation of a ground section and replaced with air or debris. This results in the total internal reflection of transmitted light, giving the appearance of thin black lines.

#### Cellular intrinsic fibre cementum (Figs 11.16, 11.17)

This type of cementum is composed only of intrinsic fibres running parallel to the root surface. The absence of Sharpey’s fibres means intrinsic fibre cementum has no role in tooth attachment. It may be found in patches in the apical region. It may be a temporary phase, with extrinsic fibres subsequently gaining a reattachment, or may represent a permanent region without attaching fibres. It generally corresponds to secondary cellular cementum and is found in the apical third of the root and in the interradicular areas. Although intrinsic fibre cementum is generally cellular due to the rapid speed of formation, sometimes intrinsic fibre cementum is formed more slowly and cells are not incorporated (acellular intrinsic fibre cementum).

### Table 11.1 Summary of differences between acellular and cellular cementum

<table>
<thead>
<tr>
<th></th>
<th>Acellular cementum</th>
<th>Cellular cementum</th>
</tr>
</thead>
<tbody>
<tr>
<td>No cells</td>
<td></td>
<td>Lacunae and canaliculi containing cementocytes and their processes</td>
</tr>
<tr>
<td>Border with dentine</td>
<td>Not clearly demarcated</td>
<td>Border with dentine clearly demarcated</td>
</tr>
<tr>
<td>Rate of development</td>
<td>Relatively slow</td>
<td>Rate of development relatively fast</td>
</tr>
<tr>
<td>Incremental lines</td>
<td>Relatively close together</td>
<td>Incremental lines relatively wide apart</td>
</tr>
<tr>
<td>Precementum layer</td>
<td>Virtually absent</td>
<td>Precementum layer present</td>
</tr>
</tbody>
</table>

**Fig. 11.14** SEMs of fractured surface of root illustrating acellular extrinsic fibre cementum (AEFC). PLFB = inserting periodontal ligament fibre bundles; CIFC = underlying cellular intrinsic fibre cementum (a and b × 630; inset × 1650). Courtesy of Professor H.E. Schroeder and the editor of Schweizer Monatsschrift für Zahnmedizin.
Towards the root apex, and in the furcation areas of multi-rooted teeth, the acellular extrinsic fibre cementum and the cellular intrinsic fibre cementum commonly may be present in alternating layers known as cellular mixed stratified cementum (see Fig. 11.18).

**Mixed-fibre cementum** (Fig. 11.19)

For this third variety of cementum, the collagen fibres of the organic matrix are derived from both extrinsic fibres (from the periodontal ligament) and intrinsic fibres (from cementoblasts). The extrinsic and intrinsic fibres can be readily distinguished. First, the intrinsic fibres run between the extrinsic fibres with a different orientation. Indeed, the fewer the number of intrinsic fibres in mixed fibre cementum, the closer the extrinsic fibre bundles (Fig. 11.19). Second, the fibre bundles are of different sizes: the extrinsic fibres are ovoid or round bundles about 5–7 µm in diameter; the intrinsic fibres are 1–2 µm in diameter (Fig. 11.19).

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**Fig. 11.15** Extrinsic fibres in ground sections. The arrows indicate that the core of the extrinsic fibre bundle has been lost during preparation of the ground section and replaced with air or debris (Ground section; × 100). Courtesy of Dr P.D.A. Owens.

**Fig. 11.16** SEM showing the appearance of intrinsic fibre cementum at the surface of the root apex. Note the absence of Sharpey’s fibres and the parallel distribution of the bundles of mineralised intrinsic fibres (Anorganic preparation; × 150). Courtesy of Professor S.J. Jones.

**Fig. 11.17** SEMs of fractured surface of root showing the appearance of cellular intrinsic fibre cementum (CIFC). Note the absence of Sharpey’s fibres and the parallel distribution of the bundles of mineralised intrinsic fibres (a and b × 470; inset × 1650). Courtesy of Professor H.E. Schroeder and the editor of Schweizer Monatsschrift für Zahnmedizin.
Fig. 11.18  (a) The appearance of mixed fibre cementum. A light micrograph to show the alternating distribution of acellular extrinsic fibre cementum (AEFC) and cellular intrinsic fibre cementum (CIFC), forming cellular mixed stratified cementum (CMSC). (Ground section; × 80). (b, c, d) SEMs illustrating mixed fibre cementum; (c) and (d) are highlighted areas provided by the boxes in (b). (SEM; (b) × 900; c and d × 2450). Courtesy of Professor H.E. Schroeder and the editor of Schweizer Monatsschrift für Zahnmedizin.
If the formation rate is slow, the cementum may be termed **acellular mixed-fibre cementum** and is generally well mineralised. If the formation rate is fast, the cementum may be called **cellular mixed-fibre cementum** and the fibres are less well-mineralised (especially their cores).

Fig. 11.20 shows the fibre orientation in acellular and cellular cementum as seen in polarised light, the different colours reflecting different orientations of the collagen fibres. The acellular cementum contains primarily extrinsic fibres arranged perpendicular to the root surface. The overlying cellular cementum contains mainly intrinsic fibres running parallel to the root surface. Thus, there is a colour difference between the two layers.

**Afibrillar cementum**

The extrinsic, intrinsic and mixed fibre cementum types all contain collagen fibres. However, there is a further type of cementum that contains no collagen fibres. This afibrillar cementum is sparsely distributed and consists of a well mineralised ground substance that may be of epithelial origin. Afibrillar cementum is a thin, acellular layer (difficult to identify at the light microscope level), which covers cervical enamel or

![Fig. 11.19](image1.png) **Fig. 11.19**  SEM of the surface of a root showing the appearance of mixed fibre cementum. A = Mineralised intrinsic fibres (present here in small amounts); B = mineralised extrinsic fibres. Note the smaller dimensions of the intrinsic fibre bundles (Anorganic preparation; × 3000). Courtesy of Professor S.J. Jones.

![Fig. 11.20](image2.png) **Fig. 11.20**  Fibre orientation in acellular and cellular cementum. The root surface is seen in polarised light, the different colours reflecting different orientations of the collagen fibres. A = Acellular cementum; B = cellular cementum (Ground, longitudinal section; polarised light; × 50).

![Fig. 11.21](image3.png) **Fig. 11.21**  Attachment of the periodontal ligament fibres to cementum. The fibres of the periodontal ligament (B) are seen to run into the organic matrix of precementum (A) (Decalcified section; Masson's blue trichrome; × 200).

![Fig. 11.22](image4.png) **Fig. 11.22**  Electronmicroscopic appearance of the insertion of Sharpey's fibres into cementum. (a) Ground section showing that the inserting collagen fibres darken as they enter the cementum due to their partial mineralisation. (b) Decalcified section showing the grouping of collagen into a bundle and collagen cross banding. C = Cementum; D = periodontal ligament (TEM; (A) × 8000; (B) × 15 000). Courtesy of Dr D.K. Whittaker.
intervenes between fibrillar cementum and dentine. Afibrillar cementum is thought to be formed at this site following the loss of the reduced enamel epithelium (see page 345).

ATTACHMENT OF THE PERIODONTAL LIGAMENT FIBRES TO CEMENTUM

The fibres of the periodontal ligament run into the organic matrix of pre cementum that is secreted by cementoblasts. Subsequent mineralisation of pre cementum will incorporate the extrinsic fibres as Sharpey’s fibres into cementum (Figs 11.21, 11.22).

THE CEMENT–DENTINE JUNCTION

The nature of the cement–dentinal junction is of particular importance, being of interest biologically because it forms an interface (a ‘fit’) between two very different mineralised tissues that are developing contemporarily. It is also of clinical importance because of the processes involved in maintaining tooth function whilst repairing a diseased root surface.

It is often reported that an ‘intermediate layer’ (Fig. 11.23) exists between cementum and dentine and that this layer is involved in ‘anchoring’ the periodontal fibres to the dentine. A variety of names has been given to the ‘intermediate layer’ (including ‘innermost cementum layer’, ‘superficial layer of root dentine’ and ‘intermediate cementum’). Indeed, it appears that the term has even been used to describe the hyaline layer of dentine (see page 136).

The intermediate layer is said to be characterised by wide, irregular branching spaces (Fig. 11.24) and is most commonly found in the apical region of cheek teeth. The spaces may interconnect with dentinal tubules. The nature and origin of the spaces is controversial; they may be related to entrapped epithelial cells (cell remnants containing filaments characteristic of epithelial cells have been described in this region). Alternatively, they may be enlarged terminals of dentinal tubules.

There appears to be marked species differences with respect to the intermediate layer. In rat molars, a distinct intermediate layer exists that is rich in the glycoproteins sialoprotein and osteopontin (both these glycoproteins being normally bone-related), although the role of these glycoproteins remains unclear. The origin of this layer in rat molars is also unclear, some believing that it is derived from the epithelial root sheath that lines the developing root (see page 340), while others claim that it is cementoblast-derived. Indeed, there are reports suggesting that, in humans, the region between the cementum and the root dentine contains enamel matrix protein and is a product of the epithelial root sheath. However, it has been claimed that, for many human teeth, the collagen within the AEFC layer intermingles with the dentine matrix, there is no sialoprotein and osteopontin, and there is no obvious zone between dentine and cementum.

Where an intermediate layer exists, it has been suggested that this functions as a permeability barrier, that it may be a precursor for cementogenesis, and that it is a precursor for cementogenesis in wound healing. These potential functions remain speculative. If, however, there is doubt about the very presence of an intermediate zone in human teeth then either human teeth do not require such functions (which is highly unlikely) or too much is being conjectured with too little experimental evidence.

The clinical significance of the interface between cementum and dentine relates to regeneration of the periodontium following periodontal surgery. Although a layer of cementum may regenerate, subsequent histological examination may show a ‘space’ between regenerated cementum and surface dentine, perhaps indicating an absence of a true union.

THE ULTRASTRUCTURAL APPEARANCE OF CEMENTUM

This varies with the level of the tissue examined. Near the periodontal surface (Fig. 11.25) cementum is not homogeneous, due to ongoing calcification and the presence of Sharpey’s
fibres. The calcification of precementum is probably initiated in the early phases by the presence of the underlying root dentine mineral, and continues on and around the collagen fibres (both those formed by the cementoblasts and those included as attachment fibres from the periodontal ligament). The outer part of the cementum, where Sharpey’s fibres predominate, may be considered as calcified periodontal ligament. Unlike dentine, no calcospherites are present within precementum. At deeper levels (Fig. 11.26), closer to the cement–dentine junction, acellular cementum resembles peripheral dentine and a demarcation is often difficult to see. The small channels seen at this level may be canaliculi derived from more superficial cementocytes, but some may be the terminals of dentinal tubules that traverse the border between the two tissues.

**RESORPTION AND REPAIR OF CEMENTUM**

Although cementum is less susceptible to resorption than bone under the same pressures (e.g. with orthodontic loading), most roots of permanent teeth still show small, localised areas of resorption (Figs 11.27–11.29). The cause of this is not known, but may be associated with microtrauma. The resorption is carried out by multinucleated odontoclasts (see page 351) and may continue into the root dentine.

Resorption deficiencies may be filled by deposition of mineralised tissue. Indeed, a line known as a reversal line may be seen separating the repair tissue from the normal underlying dental tissues (repair of cementum following a localised...
region of root resorption is illustrated in Fig. 11.28). In this section, odontoclasts have resorbed through the thin layer of acellular cementum and penetrated into the root dentine. Repair is occurring and a layer of formative cells (cementoblasts) have deposited a thin layer of matrix (precementum) in the deficiency. An irregular, and dark-staining, reversal line separates the repair tissue from the underlying dental tissues. Fig. 11.29 shows an infilled area where dentine had been resorbed.

The repair tissue resembles cellular cementum. The formative cells have a similar ultrastructure to cementoblasts. Lines resembling incremental lines may be seen and there is a zone of uncalcified repair tissue homologous to precementum. However, differences can be noted between the repair tissue and cementum: the width of the uncalcified zone of reparative cementum (15 µm) is greater than that for precementum (5–10 µm); its degree of mineralisation is less (as judged by electron density); its crystals are smaller; and calcific globules are present, suggesting that mineralisation is not proceeding evenly.

These differences may be related to the speed of formation of the repair tissue. Where this is very slow, the repair tissue cannot be distinguished histologically, or in its mineralisation pattern, from primary cementum. However, where the repair tissue is formed rapidly (as in resorbing deciduous teeth), it closely resembles woven bone.

### CLINICAL CONSIDERATIONS

Root fractures may, on some occasions, repair by the formation of a cemental callus. Unlike the callus that forms around fractured bone, the cemental callus does not usually remodel to the original dimensions of the tooth.
Cementicles (Fig. 11.30) are small, globular masses of cementum found in approximately 35% of human roots. They are not always attached to the cementum surface but may be located free in the periodontal ligament. Cementicles may result from microtrauma, when extra stress on the Sharpey’s fibres causes a tear in the cementum. They are more common in the apical and middle third of the root and in root furcation areas.

Cementum continues to be deposited slowly throughout life, its thickness increasing about threefold between the ages of 16 and 70, although whether this proceeds in a linear manner is not known. Cementum may be formed at the root apex in much greater amounts as a result of compensatory tooth eruption in response to attrition (wear) at the occlusal surface. Where there has been a history of chronic periapical inflammation, cementum formation may be substantial, giving rise to local hypercementosis (Fig. 11.31). This may cause problems during tooth extraction. Hypercementosis affecting all the teeth may be associated with Paget’s disease.

Where the root canal exits at the apex of the tooth, cementum is deposited not only over the apex but also for a short distance (usually 0.5–1.5 mm) from the anatomical apex. This results in a narrowing of the canal at this point, the apical constriction. This represents the junction of the pulp and periodontal tissue (although there is no visible demarcation in the soft tissue). In clinical procedures of root canal therapy that call for the removal of a diseased or decayed pulp, this is the point to which the cleansing should be extended.