LINDHE'S

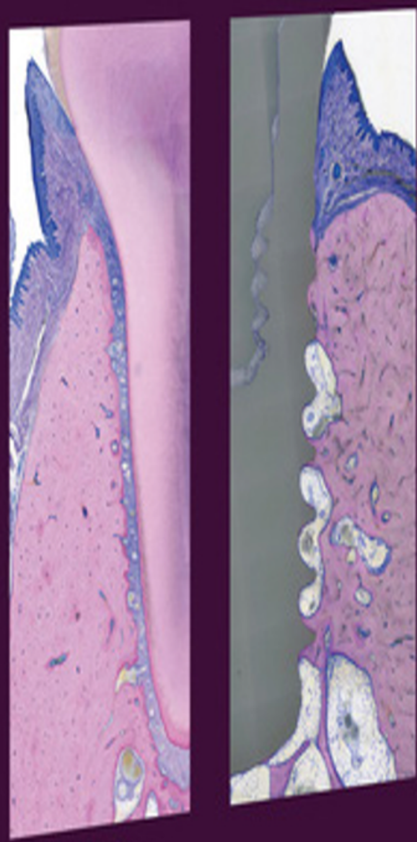
SEVENTH EDITION

Clinical Periodontology and Implant Dentistry

VOLUME 1

EDITED BY

Tord Berglundh, William V. Giannobile, Niklaus P. Lang, and Mariano Sanz



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Lindhe's Clinical Periodontology and Implant Dentistry

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Seventh Edition

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Preface

In 1983, Professor Jan Lindhe, University of Gothenburg, Sweden, published the first edition of *Clinical Periodontology*. This was only 2 years after the publication of a textbook on clinical periodontology in Scandinavian languages. It was a pioneer enterprise and began a new era in the study of periodontology. Up to this point, the profession was predominantly oriented towards a treatment philosophy that was based on *deductive thinking*, and very little scientific evidence had been presented.

In this light, the publication of a textbook that was based on *inductive thinking* and hypothesis testing was a true milestone and represented a novelty in teaching undergraduate and graduate students. As the field of clinical periodontology evolved, and more evidence arose from both clinical and preclinical studies, the textbook had to be revised on a regular basis. By and large, every 5 to 8 years a new edition of *Clinical Periodontology* was put together. With every edition, efforts were made to expand the circle of authors in order to obtain more information on evidence-based concepts. The textbook thus became the most internationally recognized source of information in the periodontal community.

About 20–30 years ago, implant dentistry had become an integral part of clinical periodontology. Hence, the fifth edition of *Clinical Periodontology* was substantially expanded to incorporate biological and clinical aspects of implant dentistry. As teeth and implants are to function together as separate or connected units in the same dentition, a profound knowledge of the biology of the tissues surrounding the tooth and the dental implant is of utmost importance. Owing to the large volume of new information, the fifth edition of the now titled *Clinical Periodontology and Implant Dentistry* was split into two volumes, one on *basic concepts* and another on *clinical concepts*. This division into two volumes was maintained for the sixth edition and is also maintained for this, the seventh edition.

In the last 35 years, during which the textbook evolved into the most popular source of reference, periodontology and implant dentistry have become clinical disciplines based on sound scientific evidence. As a new classification of periodontal and peri-implant diseases and conditions emerged after a world workshop staged by the American Academy of Periodontology and the European Federation of Periodontology, it was time, again, to update the textbook.

In this edition, over 90% of the content has been thoroughly revised and condensed for better understanding. Some less essential chapters have been eliminated and others merged to make the text more cohesive. A new and younger generation of authors of international reputation have been invited to contribute. Moreover, the team of Editors has been enlarged to four.

It is our hope that *Lindhe's Clinical Periodontology and Implant Dentistry* remains the key book of reference to guide treatment planning according to sound biological and evidence-based principles rather than opinions based on trial and error philosophies.

Tord Berglundh
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March 2021

Part 1: Anatomy

Chapter 1

Anatomy and Histology of Periodontal Tissues

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Introduction

This chapter provides a brief description of the characteristics of the normal periodontium. It is assumed that the reader has prior knowledge of oral embryology and histology.

The periodontium (peri = around, odontos = tooth) comprises the following tissues: (1) *gingiva*, (2) *periodontal ligament*, (3) *root cementum*, and (4) *alveolar bone proper* (Fig. 1-1). The latter lines the alveolus of the tooth and is continuous with the alveolar bone; on a radiograph it can be called *lamina dura*. The *alveolar process* that extends from the basal bone of the maxilla and mandible consists of the alveolar bone and the *alveolar bone proper*.

The main function of the periodontium is to attach the tooth to the jaw bone and to maintain the integrity of the surface of the masticatory mucosa of the oral cavity. The periodontal ligament, root cementum, and alveolar bone proper, may together be called "the attachment apparatus" or "the supporting tissues of the teeth", constituting a developmental, biologic, and functional unit which undergoes certain changes with age and is, in addition, subjected to morphologic changes related to functional alterations and alterations in the oral environment.

The development of the periodontal tissues occurs during the development and formation of teeth. This process starts early in the embryonic phase when cells from the neural crest (from the neural tube of the embryo) migrate into the first branchial arch. In this position, the neural crest cells form a band of *ectomesenchyme* beneath the epithelium of the stomatodeum (the primitive oral cavity). After the uncommitted neural crest cells have reached their location in the jaw space, the epithelium of the stomatodeum releases factors which initiate epithelial–ectomesenchymal interactions. Once these interactions have occurred, the ectomesenchyme takes the dominant role in the further development. Following the formation of the *dental lamina*, a series of processes are initiated (bud stage, cap stage, bell stage, and root development) which result in the formation of a tooth and its surrounding periodontal tissues, including the alveolar bone proper. During the cap stage, condensation of ectomesenchymal cells appears in relation to the dental epithelium (the dental organ), forming the *dental papilla* that gives rise to

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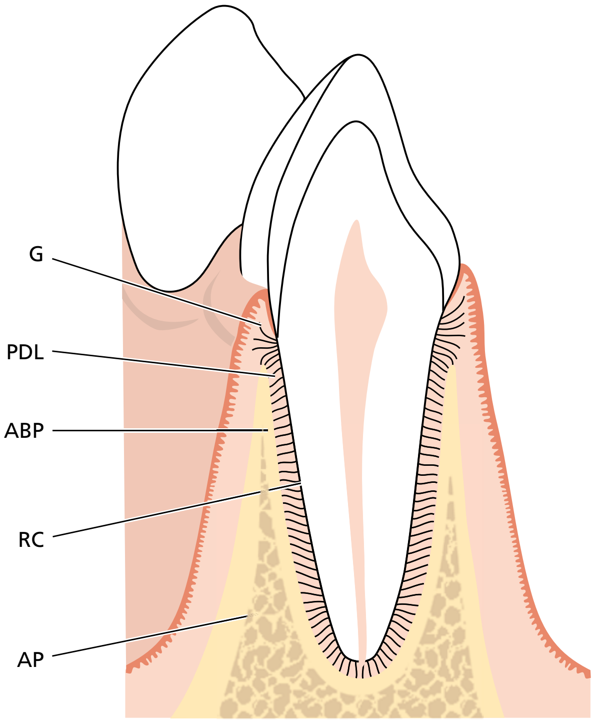

Fig. 1-1 A tooth and its periodontal tissues consisting of gingiva (G), periodontal ligament (PDL), alveolar bone proper (ABP), and root cementum (RC). AP, alveolar process.

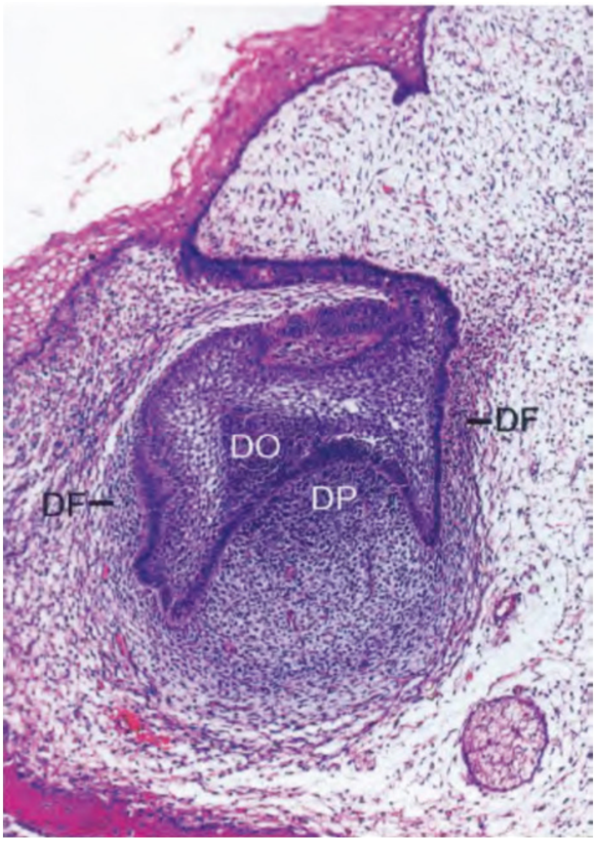

Fig. 1-2 Light micrograph of a tooth germ at the cap stage with the dental organ (DO), the dental papilla (DP), and the dental follicle (DF).

the dentin and the pulp, and the *dental follicle* that gives rise to the periodontal supporting tissues (Fig. 1-2). The decisive role played by the ectomesenchyme in this process is further established by the fact that the tissue of the dental papilla apparently also determines the shape and form of the tooth.

If a tooth germ in the bell stage of development is dissected and transplanted to an ectopic site (e.g. the connective tissue of the anterior chamber of the eye), the tooth formation process continues. The crown and the root are formed, and the supporting structures (i.e. cementum, periodontal ligament, and a thin lamina of alveolar bone proper) also develop. Such experiments document that all information necessary for the formation of a tooth and its attachment apparatus resides within the tissues of the dental organ and the surrounding ectomesenchyme. The dental organ is the formative organ of enamel, the dental papilla is the formative organ of the dentin–pulp complex, and the dental follicle is the formative organ of the attachment apparatus (cementum, periodontal ligament, and alveolar bone proper).

The development of the root and the periodontal supporting tissues follows that of the crown. Epithelial cells of the external and internal dental epithelium (the dental organ) proliferate in an apical direction, forming a double layer of cells called *Hertwig's epithelial root sheath*. The odontoblasts forming the dentin of the root differentiate from ectomesenchymal cells in the dental papilla under the inductive influence of the inner epithelial cells (Fig. 1-3). The dentin continues to form in an apical direction, producing the framework of the root. During formation of the root, the periodontal supporting tissues including the acellular extrinsic fiber cementum (AEFC) develop. Some of the events in cementogenesis are still unclear, but the following concept is now generally accepted.

At the start of root dentin formation, the inner cells of Hertwig's epithelial root sheath may synthesize and secrete enamel-related proteins, some of which belong to the amelogenin family. At the end of this process, the epithelial root sheath becomes fenestrated and ectomesenchymal cells from the dental follicle penetrate through these fenestrations and contact the root surface. The ectomesenchymal cells in contact with the root surface differentiate into cementoblasts and start to form cementoid. This cementoid represents the organic matrix of the cementum and consists of a ground substance and collagen fibers, which intermingle with collagen fibers in the not yet fully mineralized outer layer of the dentin. It is assumed that the cementum becomes firmly attached to the dentin through these fiber interactions followed by mineralization of this interface (Fig. 1-4). The formation of the CIFC, which often covers the apical third of the dental roots, differs from that of AEFC

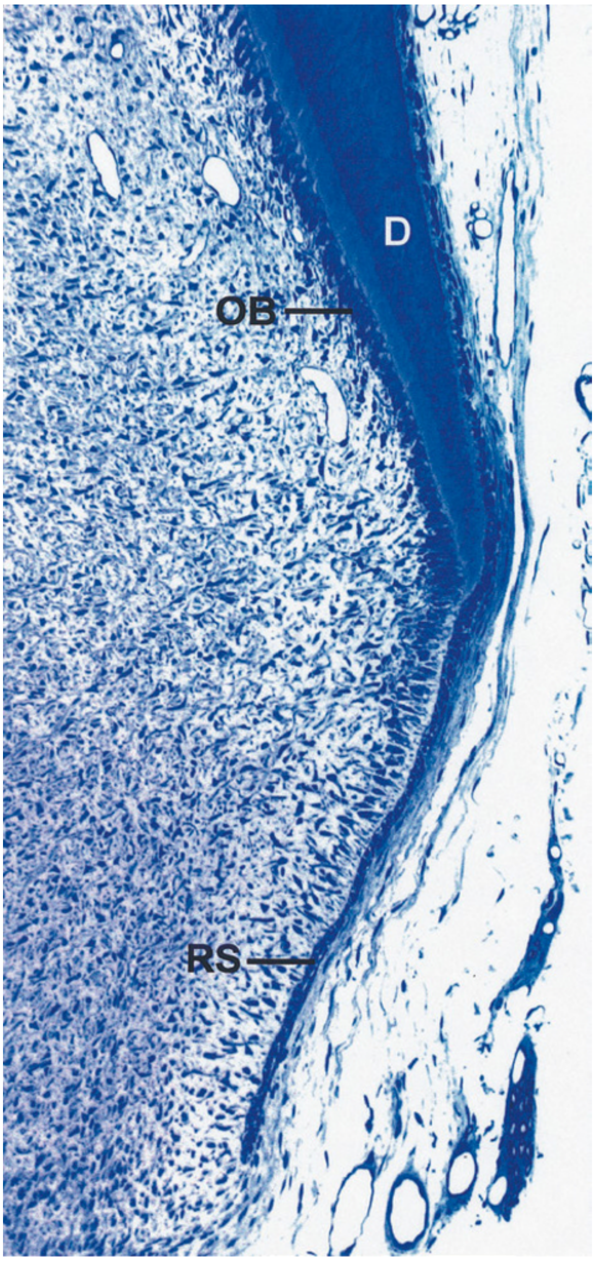

Fig. 1-3 Light micrograph illustrating the edge of a developing tooth root with the Hertwig's epithelial root sheath (RS), odontoblasts (OB), and dentin (D).

as some of the cementoblasts become embedded in the cementum.

The remaining parts of the periodontium are formed by ectomesenchymal cells from the dental follicle lateral to the cementum. Some of them differentiate into periodontal ligament fibroblasts and form the fibers of the periodontal ligament, while others become osteoblasts and form the alveolar bone proper in which the periodontal fibers are anchored. This bony structure has also been term "*bundle bone*". In other words, the bundle bone is also an ectomesenchymal product. It is likely, but still not conclusively documented, that ectomesenchymal cells remain in the mature periodontium and take part in the turnover of this tissue.

Gingiva

Anatomy

The oral mucosa is continuous with the skin of the lips and the mucosa of the soft palate and pharynx. The oral mucosa consists of: (1) the *masticatory mucosa*, which includes the gingiva and the covering of the hard palate; (2) the *specialized mucosa*, which covers the dorsum of the tongue; and (3) the remaining part, called the *lining mucosa*.

The gingiva is that part of the masticatory mucosa which covers the alveolar process and surrounds the cervical portion of the teeth (Fig. 1-5). It consists of an epithelial layer and an underlying connective tissue layer called the *lamina propria*. The gingiva obtains its final shape and texture in conjunction with eruption of the teeth.

In the coronal direction, the coral pink gingiva terminates in the *free gingival margin*, which has a scalloped outline. In the apical direction, the gingiva is continuous with the loose, darker red *alveolar mucosa* (lining mucosa) from which the gingiva is separated by a usually easily recognizable border called either the mucogingival junction, sometimes termed the mucogingival line (Fig. 1-5, arrows). As the hard palate and maxillary alveolar process are covered by a keratinizing mucosa of similar clinical appearance, no mucogingival junction is macroscopically recognizable (Fig. 1-6).

Two parts of the gingiva may be identified (Fig. 1-7): (1) the free gingiva and (2) the attached gingiva. The free gingiva is coral pink, has a dull surface and a firm consistency. It comprises the gingival tissue at the vestibular and lingual/palatal aspects of the teeth. On the vestibular and lingual sides of the teeth, the free gingiva extends from the gingival margin in an apical direction to a structure named *free gingival groove*, which is only observable in approximately one-third of the cases. The attached gingiva is demarcated by the mucogingival junction in the apical direction.

The free gingival margin is often rounded in such a way that a small invagination or sulcus is formed between the tooth and the gingiva. When a periodontal probe is inserted into this invagination and, further apically, towards the cementoenamel junction (CEJ), the gingival tissue is separated from the tooth and a "*gingival pocket*" or "*gingival crevice*" is artificially opened (Fig. 1-8). Thus, in clinically healthy gingiva, there is in fact no "gingival pocket" or "gingival crevice" present, but the gingiva is in close contact with the enamel surface. After complete tooth eruption, the free gingival margin is located on the enamel surface approximately 1.5–2 mm coronal to the CEJ.

The shape of the *interdental gingiva (the interdental papilla)* is determined by the contact relationships between the teeth, the width of the approximal tooth

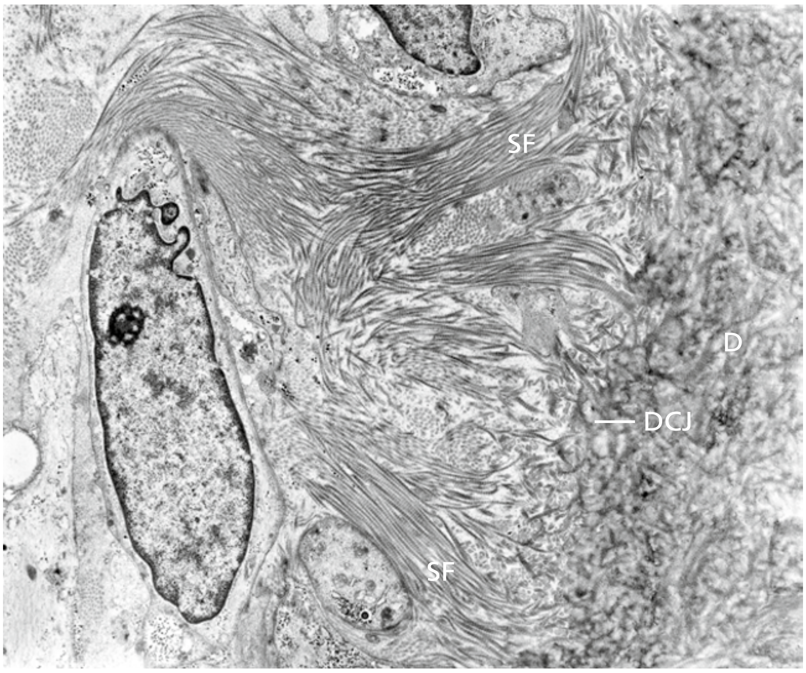

Fig. 1-4 Transmission electron micrograph illustrating the attachment of the future Sharpey's fibers (SF) to the root dentin (D) at a time where the mineralization has reached the dentinocemental junction (DCJ).

Fig. 1-5 Frontal view of the masticatory and lining mucosa. The arrows indicate the mucogingival junction, sometimes also called the mucogingival line.

Fig. 1-6 Masticatory mucosa lining the hard palate. There is no mucogingival line present in the palate, because the hard palate and the maxillary alveolar process are covered by the same type of masticatory mucosa.

surfaces, and the course of the CEJ. In anterior regions of the dentition, the interdental papilla is of pyramidal shape (Fig. 1-9a), while in the molar regions, the papillae are flatter in the buccolingual direction (Fig. 1-9b). Due to the presence of interdental papillae, the free gingival margin follows a more or less accentuated, scalloped course through the dentition.

The interdental region in premolar and molar teeth has two papillae, a vestibular (VP) and a lingual/palatal (LP) papilla, separated by the col region. The col region is lined by a thin non-keratinized epithelium (Fig. 1-10). This epithelium has many features in common with the junctional epithelium.

The attached gingiva is demarcated in the coronal direction by the free gingival groove (Fig. 1-11) or, when such a groove is not present, by a horizontal plane placed at the level of the CEJ. In clinical examinations, it was observed that a free gingival groove is only present in about 30–40% of adults. The free gingival groove is often most pronounced on the vestibular aspect of the teeth, occurring most frequently in the incisor and premolar regions of the mandible, and least frequently in the mandibular molar and maxillary premolar regions.

The attached gingiva extends in the apical direction to the mucogingival junction, where it becomes continuous with the alveolar (lining) mucosa. It is of firm texture, coral pink in color, and often shows small depressions on the surface. The depressions, called "stippling", give the appearance of orange peel. The gingiva is firmly attached to the underlying alveolar bone and cementum by connective

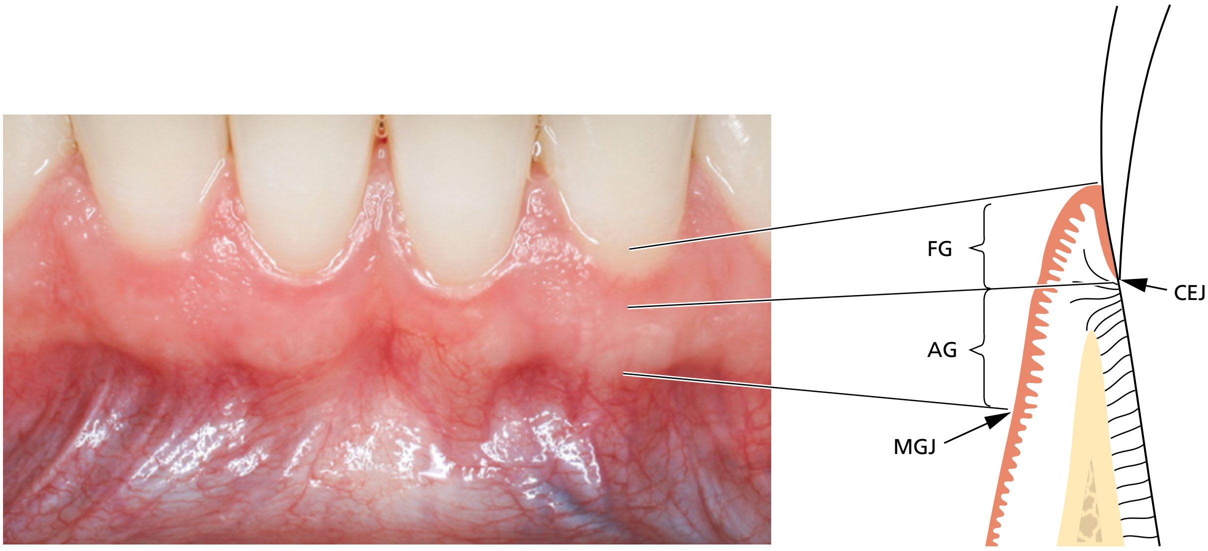

Fig. 1-7 Three parts of the gingiva can be identified: the free gingiva (FG), the interdental gingiva, and the attached gingiva (AG). The mucogingival junction (MGJ) demarcates the gingiva from the alveolar mucosa. CEJ, cementoenamel junction.

Fig. 1-8 A periodontal probe has been inserted into a clinically healthy tooth–gingiva interface and a "gingival crevice" was artificially opened approximately to the level of the cementoenamel junction.

tissue fibers, and is, therefore, comparatively immobile in relation to the underlying tissue. The darker red alveolar mucosa located apical to the mucogingival junction, on the other hand, is loosely bound to the underlying bone. Therefore, in contrast to the attached gingiva, the alveolar mucosa is mobile in relation to the underlying tissue and hence belongs to the lining mucosa.

The width of the gingiva varies in size in different parts of the dentition. In the maxilla (Fig. 1-12a), the vestibular gingiva is generally widest in the area of the incisors and narrowest adjacent to the premolars. In the mandible (Fig. 1-12b), the gingiva on the lingual aspect is particularly narrow in the area of the incisors and wide in the molar region. The range of variation is 1–9 mm. In the mandibular premolar region, the gingiva is extremely narrow (Fig. 1-13).

The result of a study in which the width of the attached gingiva was assessed and related to the

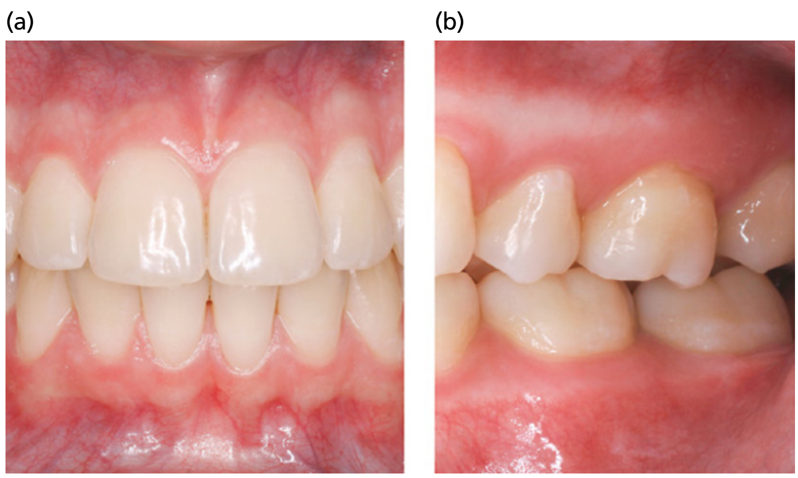

Fig. 1-9 Frontal view showing the shape of the interdental papillae in the anterior (a) and premolar/molar (b) regions.

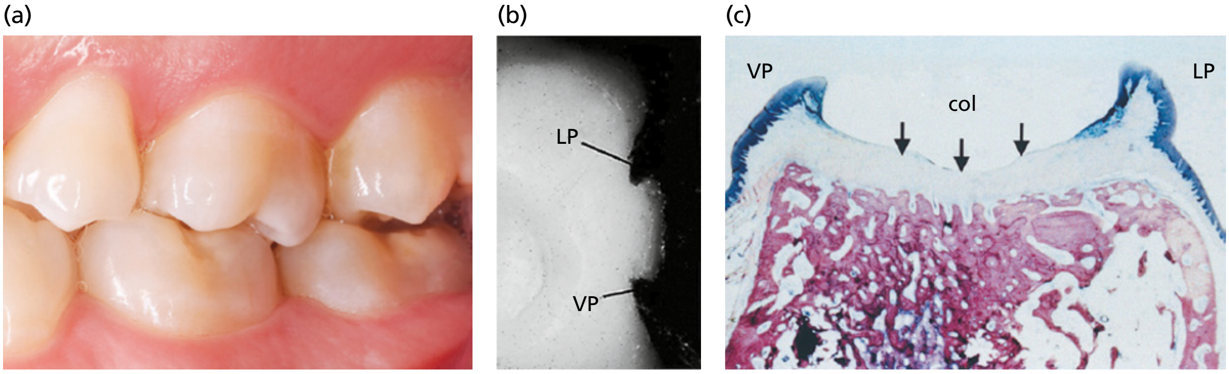

Fig. 1-10 (a) Premolar/molar regions of the dentition exhibit an approximal contact surface. (b) After removal of the distal tooth, a col can be seen between the vestibular (VP) and lingual papillae (LP). (c) Histologically, the bucco-oral section of the col region (arrows) demonstrates a thin non-keratinizing lining between the two papillae.

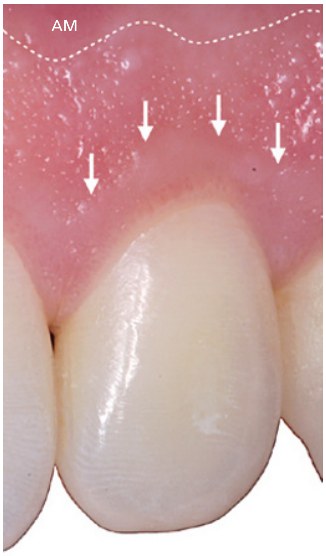

Fig. 1-11 Clinical view on the mucosal tissues. The mucogingival junction (arrows) demarcates the gingiva (masticatory mucosa) from the alveolar (lining) mucosa (AM).

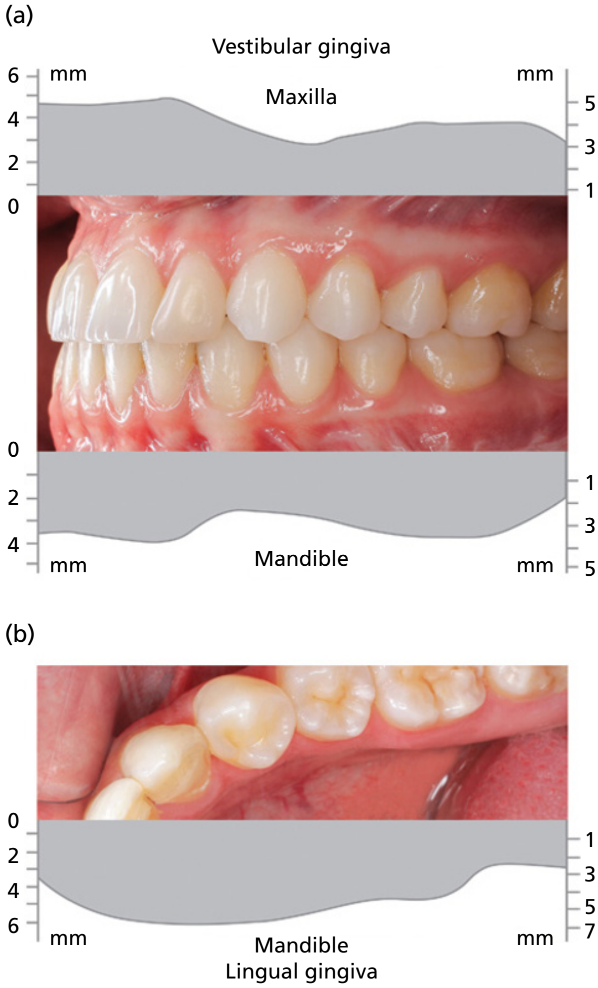

Fig. 1-12 Widths of the vestibular maxillary and mandibular gingivae (a) as well as the lingual extent of the gingiva in the mandible (b). The widths are depicted in millimeters.

age of the patients examined is depicted in Fig. 1-14 (Ainamo *et al*. 1981). The gingiva in the 63-year-olds was significantly wider than in the 40–50-year-olds. Moreover, the width of the gingiva in the 40–50-year-olds was significantly wider than that in 20–30-year-olds. This observation indicates that the width of the gingiva tends to increase with age. As the mucogingival junction remains stable throughout life in relation to the lower border of the mandible, the increasing width of the gingiva may suggest that the teeth erupt slowly throughout life as a result of occlusal wear.

Histology

Oral gingival epithelium

The dentogingival unit is schematically depicted in Fig. 1-15a. The free gingiva comprises all epithelial and connective tissue structures located coronal to a horizontal line placed at the level of the CEJ (Fig. 1-15b). The epithelium covering the free gingiva may be differentiated as follows:

- *Oral gingival epithelium*, which faces the oral cavity
- *Oral sulcular epithelium*, which faces the tooth without being in contact with the tooth surface
- *Junctional epithelium*, which provides the contact between the gingiva and the tooth.

Fig. 1-13 Minimal width of the vestibular gingiva in the premolar region of the mandible. The arrows demonstrate the outline of the mucogingival junction.

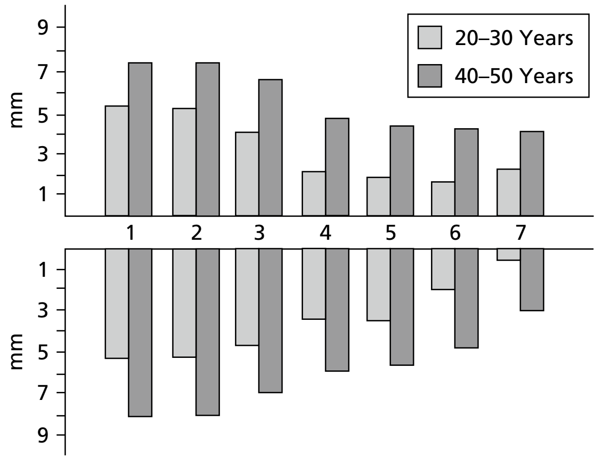

Fig. 1-14 Width of attached gingiva in two age cohorts of 20–30 years and 40–50 years. An increasing width of attached gingiva is recognizable throughout life. (Source: Ainamo & Talari 1976; Ainamo *et al*. 1981. Reproduced with permission from John Wiley & Sons.)

The boundary between the oral gingival epithelium and underlying connective tissue has a wavy course (Fig. 1-15c). The connective tissue portions, which project into the epithelium, are called *connective tissue papillae* and are separated from each other by *epithelial ridges* – so-called *rete pegs*. In non-inflamed gingiva, rete pegs and connective tissue papillae are lacking at the boundary between the junctional epithelium and its underlying connective tissue (Fig. 1-15b). Thus, a characteristic morphologic feature of the oral gingival epithelium and the oral sulcular epithelium is the presence of rete pegs: these structures are lacking in the junctional epithelium.

A wax model, constructed on the basis of magnified serial histologic sections at a magnification of 1:50, shows the subsurface of the oral epithelium of the gingiva after removing the connective tissue (Fig. 1-16). The subsurface of the oral epithelium (i.e. the surface of the epithelium facing the connective tissue) exhibits several depressions corresponding to the connective tissue papillae (see Fig. 1-17), which project into the epithelium. It can be seen that the epithelial projections, which in histologic sections separate the connective tissue papillae, constitute a continuous system of epithelial ridges.

A model of the connective tissue, corresponding to the model of the epithelium shown in Fig. 1-16 yields the connective tissue papillae which project into the space that was occupied by the oral gingival epithelium and by the oral sulcular epithelium at the back of the model (Fig. 1-17). The epithelium has been removed, thereby making the vestibular aspect of the gingival connective tissue visible.

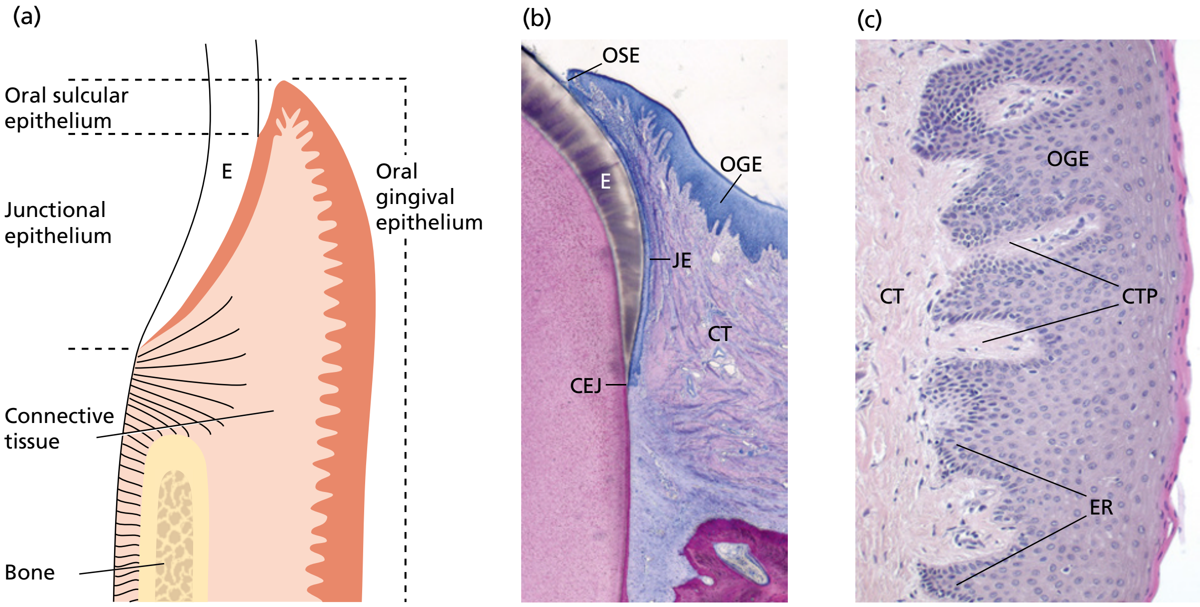

Fig. 1-15 (a) The dentogingival unit. The gingiva consists of three epithelia namely, oral gingival epithelium, oral sulcular epithelium, and junctional epithelium. (b) Histologic section with all the epithelia and soft connective tissue structures (CT). (c) Rete peg configuration (epithelial ridges, ER) interdigitating with the connective tissue papillae (CTP) in masticatory mucosa facing the oral cavity. CEJ, cementoenamel junction; E, enamel; JE, junctional epithelium; OGE, oral gingival epithelium; OSE, oral sulcular epithelium.

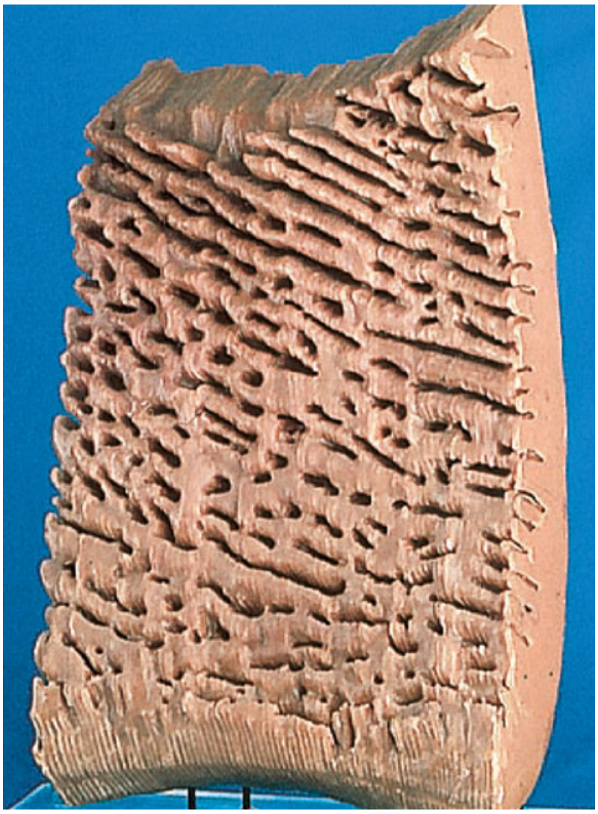

Fig. 1-16 Wax model illustrating the surface of the oral gingival epithelium facing the connective tissue following removal from the latter.

Fig. 1-17 Wax model of the connective tissue subjacent to the oral gingival epithelium that had been removed. OE, oral epithelium; OSE, oral sulcular epithelium.

In most adults, the attached gingiva shows a stippling on the surface (Fig. 1-18). The stippling corresponds to depressions on the surface in the areas of fusion between various epithelial ridges. Sometimes, the stippling is conspicuous (see also Fig. 1-11). However, it is not known to which degree the stippling manifests itself in different individuals.

The oral epithelium covering the free gingiva is a *keratinized*, *stratified*, *squamous epithelium* which, on the basis of the degree to which the keratin-producing cells are differentiated, can be divided into the following cell layers (Fig. 1-19a):

1. *Basal layer* (stratum basale or stratum germinativum)
2. *Prickle cell layer* (stratum spinosum)
3. *Granular cell layer* (stratum granulosum)
4. *Keratinized cell layer* (stratum corneum).

It should be observed that in the tissue section shown in Fig. 1-19a, cell nuclei are lacking in the outer cell layers. Such an epithelium is denoted *orthokeratinized*. Often, however, the cells of the stratum corneum of the epithelium of human gingiva contain remnants of the nuclei, as seen in Fig. 1-19b. In such a case, the epithelium is denoted *parakeratinized*.

In addition to the keratin-producing cells, which comprise about 90% of the total cell population, the oral gingival epithelium contains the following types of cells:

- *Melanocytes*
- *Langerhans cells*
- *Merkel's cells*
- *Inflammatory cells*.

These cell types are often stellate and have cytoplasmic extensions of various size and appearance. They are also called "clear cells", because in histologic sections, the zone around their nuclei appears lighter than that in the surrounding keratin-producing cells (Fig. 1-20). With the exception of the Merkel's cells, these "clear cells", which do not produce keratin, lack desmosomal attachment to adjacent cells. The melanocytes are pigment-synthesizing cells and are responsible for the melanin pigmentation occasionally seen on the gingiva. However, both lightly and darkly pigmented individuals have melanocytes in the epithelium.

The Langerhans cells are believed to play a role in the defense mechanism of the oral mucosa. It has been suggested that the Langerhans cells react with antigens that are in the process of penetrating the epithelium. An early immunologic response is thereby initiated, inhibiting or preventing further antigen penetration of the tissue. The Merkel's cells have been suggested to have a sensory function.

The cells in the *basal layer* are either cylindric or cuboidal, and are in contact with the *basement membrane* that separates the epithelium from the soft connective tissue (Fig. 1-21). The basal cells possess the ability to divide, that is undergo mitotic cell division. The cells marked with arrows in Fig. 1-21 are in the process of dividing. It is in the basal layer that the epithelium is renewed. Therefore, this layer is also termed *stratum germinativum*, and can be considered the *progenitor cell compartment* of the epithelium.

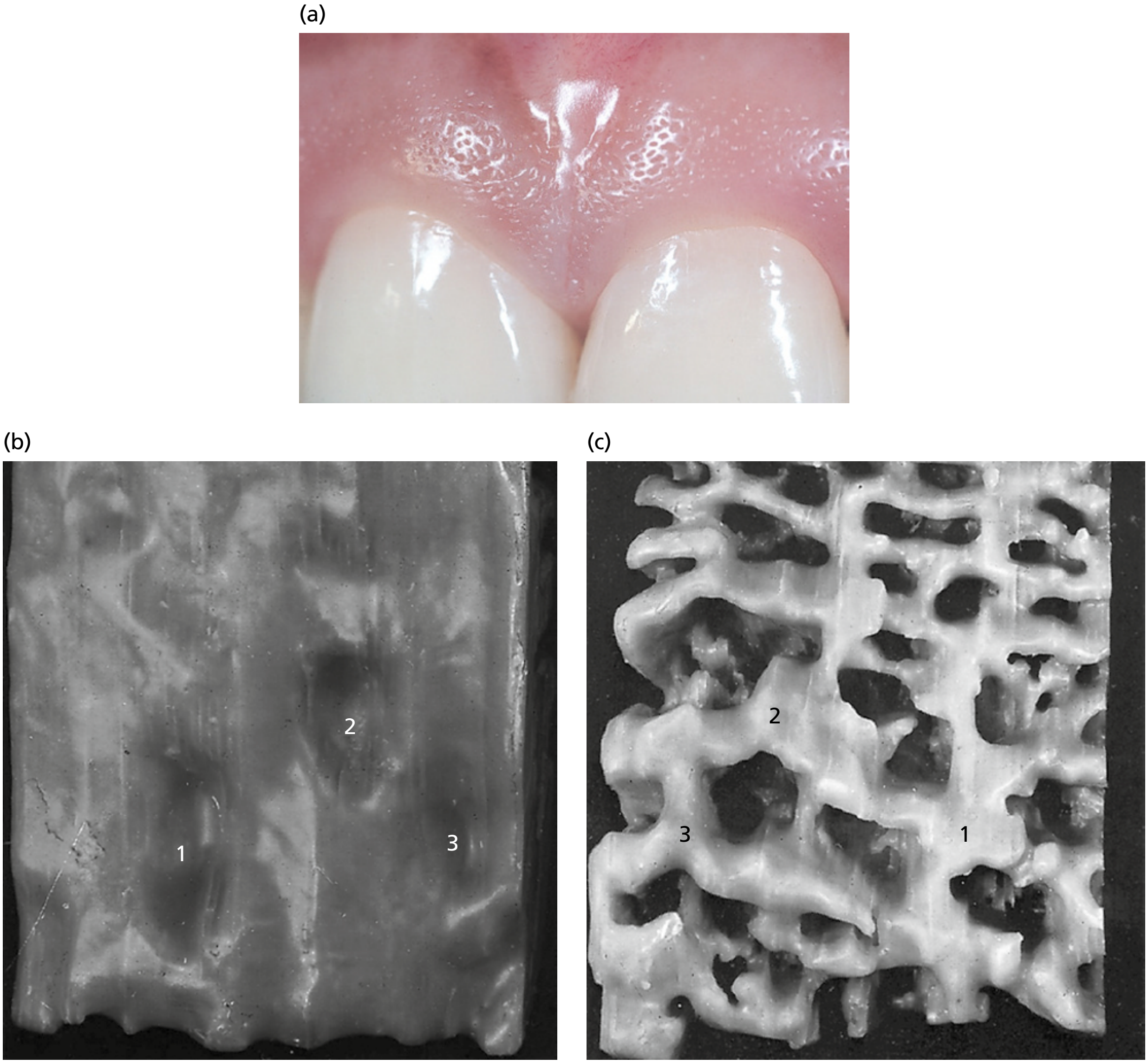

Fig. 1-18 (a) Conspicuous stippling of the masticatory mucosa of the gingiva, as seen macroscopically or clinically. (b) In a magnified model of the oral gingival epithelium of the attached gingiva, the surface exhibits the minute depressions, which give the gingiva its characteristic stippled appearance. (c) In the corresponding surface of the epithelium facing the soft connective tissue, the subsurface of the epithelium is characterized by the presence of epithelial ridges that merge at various locations. The numbers indicate the locations where the epithelial ridges merge and create the depressions seen in (b).

When two daughter cells have been formed by cell division, an adjacent "older" basal cell is pushed into the spinous cell layer and starts, as a *keratinocyte*, to traverse the epithelium (Fig. 1-22). It takes approximately 1 month for a keratinocyte to reach the outer epithelial surface, where it is shed from the stratum corneum. Within a given time, the number of cells which divide in the *basal layer* equals the number of cells which are shed from the surface. Thus, under homeostatic conditions, there is equilibrium between cell renewal and cell loss so that the epithelium maintains a constant thickness. As the basal cell migrates through the epithelium, it becomes flattened with its long axis parallel to the epithelial surface.

The basal cells are found immediately adjacent to the soft connective tissue and are separated from it by the basement membrane, probably produced by the basal cells themselves. Under the light microscope, this membrane appears as a structureless zone approximately 1–2 μm wide and reacts positively to a periodic acid-Schiff (PAS) stain (Fig. 1-23). This positive reaction demonstrates that the basement membrane contains carbohydrates (glycoproteins). The epithelial cells are surrounded by an extracellular substance which also contains protein–polysaccharide complexes.

At the ultrastructural level, the basement membrane has a complex composition (Fig. 1-24). Immediately beneath the basal cells, an approximately 400-Å wide electron-lucent zone can be seen, which is called the *lamina lucida*. Beneath the lamina lucida, an electron-dense zone of approximately the same thickness can be observed. This zone is called *lamina densa*. From the lamina densa, so-called *anchoring fibrils* project in a fan-shaped fashion into the soft connective tissue. The anchoring fibrils are approximately 1 μm

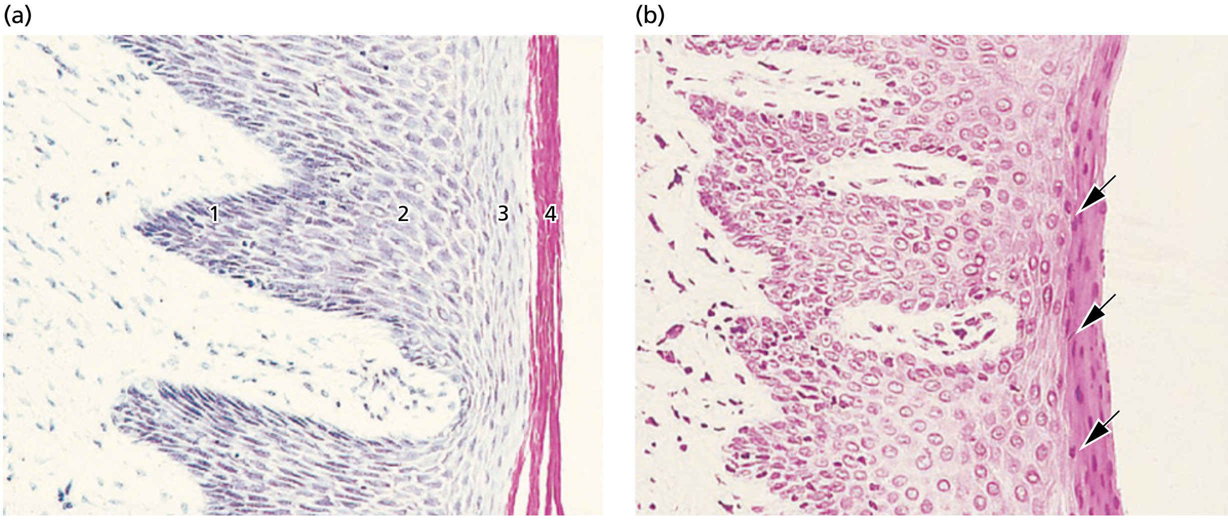

Fig. 1-19 The four layers of the oral gingival epithelium: (1) stratum basale, (2) stratum spinosum, (3) stratum granulosum, and (4) stratum corneum, as seen in the orthokeratinized (a) and parakeratinized (b) epithelium. The arrows indicate the presence of cell nuclei in the case of parakeratinization.

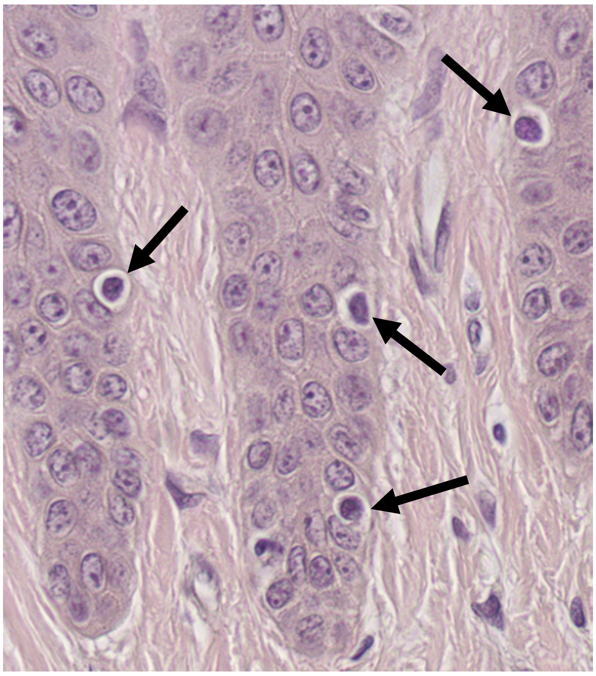

Fig. 1-20 "Clear cells" (arrows) located in or near the stratum basale of the oral gingival epithelium.

Fig. 1-21 The cells in the basal layer of the oral gingival epithelium are able to divide. The arrows indicate dividing cells.

in length and terminate freely in the soft connective tissue. The basement membrane, which under the light microscope appears as an entity, thus, in the electron micrograph, appears to comprise one lamina lucida and one lamina densa with adjacent anchoring fibrils that interdigitate with the soft connective tissue fibers. The cell membrane of the epithelial cells facing the lamina lucida harbors a number of electron-dense, thicker zones appearing at various intervals along the cell membrane. These structures are called *hemidesmosomes*. The cytoplasmic *tonofilaments* (cytokeratin filaments) in the cell converge towards the hemidesmosomes. The hemidesmosomes are involved in the attachment of the epithelium to the underlying basement membrane.

The stratum spinosum consists of 10–20 layers of relatively large, polyhedral cells, equipped with short cytoplasmic processes resembling spines (Fig. 1-25). These cytoplasmic processes occur at regular intervals and give the cells a prickly appearance. Together with intercellular protein–carbohydrate complexes, cohesion between the cells is provided by numerous "desmosomes" (pairs of hemidesmosomes), which are located between the cytoplasmic processes of adjacent cells. In the transmission electron microscope, the dark-stained structures between the individual epithelial cells represent the *desmosomes* (arrows) (Fig. 1-26). A desmosome may be considered to be two hemidesmosomes facing one another. The

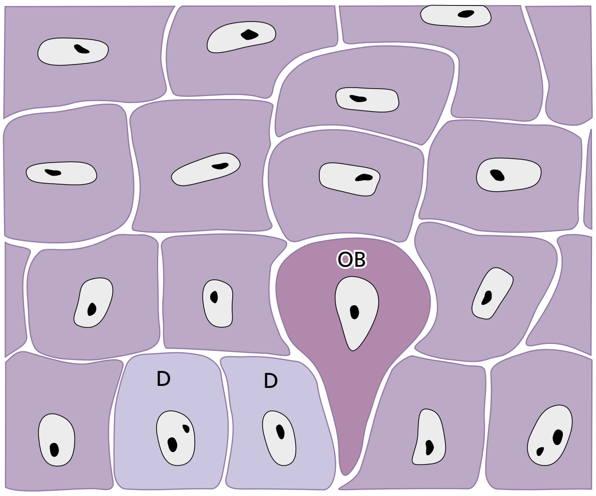

Fig. 1-22 Cell proliferation in the basal layer of the oral gingival epithelium. D, daughter cells; OB, "older" basal cell.

Fig. 1-23 A basement membrane (arrows), positive for periodic acid-Schiff (PAS) stain, separates the basal cells of the oral gingival epithelium from the adjacent soft connective tissue.

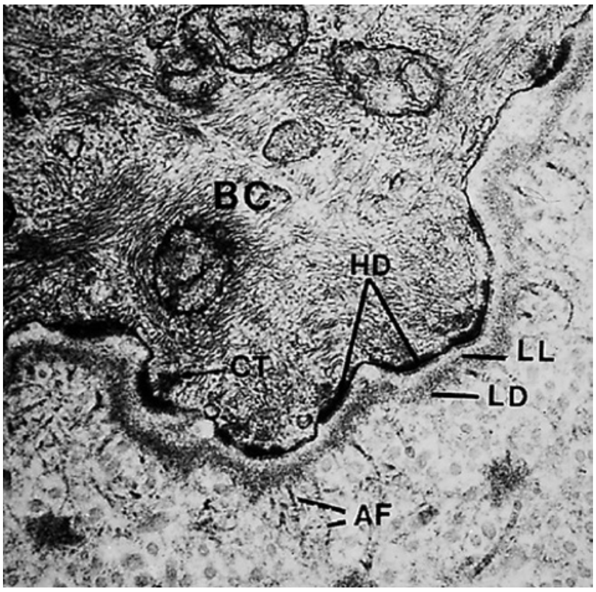

Fig. 1-24 Transmission electron micrograph (magnification ×70 000) illustrating the interfacial region of the basement membrane between a basal cell (BC) and the adjacent soft connective tissue. AF, anchoring fibrils; CT, cytoplasmic tonofilaments (cytokeratin filaments); HD, hemidesmosomes; LD, lamina densa; LL, lamina lucida.

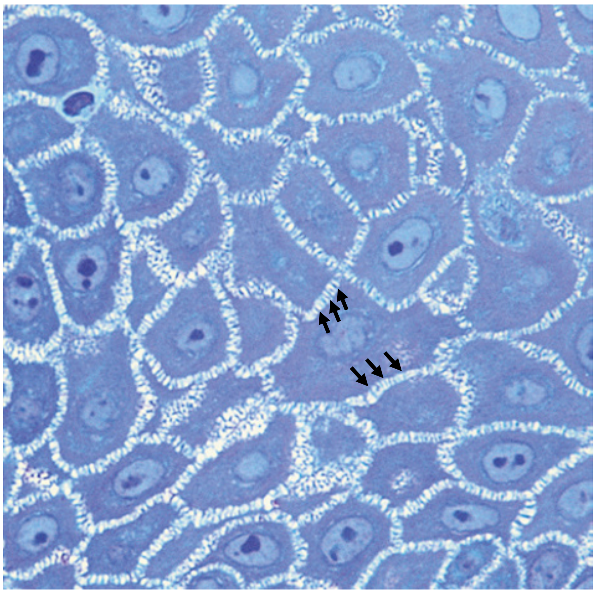

Fig. 1-25 Light micrograph depicting an area of the stratum spinosum in the oral gingival epithelium. Arrows point to short cytoplasmic processes between neighboring cells.

presence of a large number of desmosomes indicates that the cohesion between the epithelial cells is solid.

A schematic drawing of a desmosome is shown in Fig. 1-27. A desmosome can be considered to consist of two adjoining hemidesmosomes separated by a zone containing electron-dense granulated material. Thus, a desmosome comprises the following structural components: (1) the *outer leaflet* of the cell membranes of two adjoining cells; (2) the thick *inner leaflets* of the cell membranes; and (3) the *attachment plaques*, which represent granular and fibrillar material in the cytoplasm.

As mentioned previously, the oral epithelium also contains melanocytes, which are responsible for the production of the pigment melanin (Fig. 1-28). Melanocytes are present in individuals with marked pigmentation of the oral mucosa as well as in individuals in whom no clinical signs of pigmentation can be seen. In this transmission electron micrograph, a melanocyte is present in the lower portion of the stratum spinosum. In contrast to the keratinocytes, this cell contains melanin granules and has no tonofilaments or hemidesmosomes. Note the large number of tonofilaments in the cytoplasm of the adjacent keratinocytes. The inclusion of melanin granules may result in a distinct pigmentation of the oral gingival epithelium and is normally encountered in people with a dark complexion (Fig. 1-29).

As indicated previously, the keratinocytes undergo continuous differentiation and specialization when traversing the epithelium from the basal layer to the

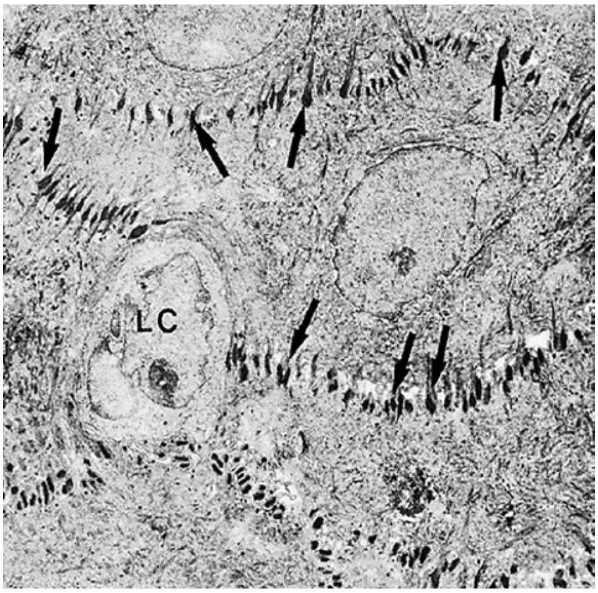

Fig. 1-26 Transmission electron micrograph of stratum spinosum highlighting (arrows) desmosomes between neighboring cells. The light cell (LC) harbors no hemidesmosomes and is, therefore, not a keratinocyte but rather a “clear cell”.

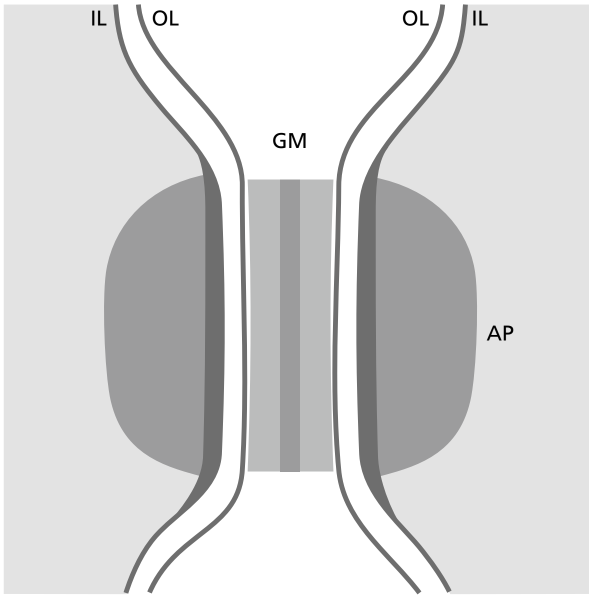

Fig. 1-27 The composition of a desmosome. AP, attachment plaque; GM, granulated material; IL, inner leaflets; OL, outer leaflets.

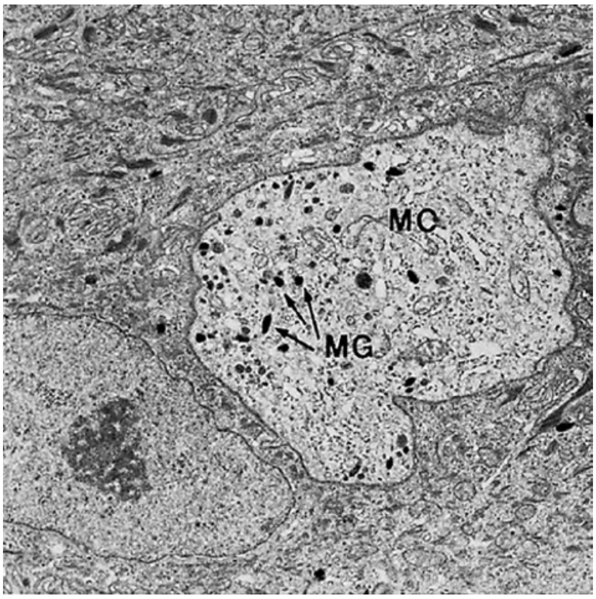

Fig. 1-28 Transmission electron micrograph illustrating a melanocyte (MC) surrounded by keratinocytes in the oral gingival epithelium. MG (arrows) points to melanin granules.

epithelial surface (Fig. 1-30). From the basal layer (stratum basale) to the granular layer (stratum granulosum) both the number of tonofilaments in the cytoplasm and the number of desmosomes increase. In contrast, the number of organelles, such as mitochondria, lamellae of rough endoplasmic reticulum, and Golgi complexes decrease in the keratinocytes on their way from the basal layer towards the surface. In the stratum granulosum, electron-dense *keratohyalin bodies* and clusters of glycogen-containing granules start to appear. Such granules are believed to be related to the synthesis of keratin.

There is an abrupt transition of the cells from the stratum granulosum to the stratum corneum (Fig. 1-31). This is indicative of a very sudden keratinization of the cytoplasm of the keratinocyte and its conversion into a horny squame. The cytoplasm of the cells in the stratum corneum is filled with keratin and the entire apparatus for protein synthesis and energy production, that is the nucleus, the mitochondria, the endoplasmic reticulum, and the Golgi complex, is lost. In a parakeratinized epithelium, however, the cells of the stratum corneum contain remnants of nuclei. Keratinization is considered a process of differentiation rather than degeneration. It is a process of protein synthesis which requires energy and is dependent on functional cells (i.e. cells containing a nucleus and a normal set of organelles).

In contrast to the oral gingival epithelium, the epithelium of the alveolar (lining) mucosa has no stratum corneum. Cells containing nuclei can be identified in all layers, from the basal layer to the surface of the epithelium (Fig. 1-32).

Dentogingival epithelium

The tissue components of the dentogingival region achieve their final structural characteristics in conjunction with the eruption of the teeth. This is illustrated in Fig. 1-33a–d.

When the enamel of the tooth is fully developed, the enamel-producing cells (ameloblasts) become reduced in height, produce a basal lamina, and form, together with cells from the outer enamel epithelium, the so-called reduced enamel epithelium. The basal lamina lies in direct contact with the enamel. The contact between this lamina and the epithelial cells is maintained by hemidesmosomes. The reduced enamel epithelium surrounds the crown of the tooth