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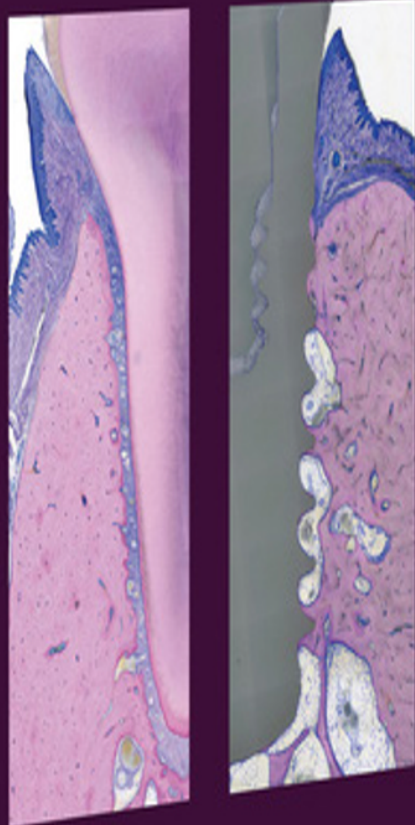
Clinical Periodontology and Implant Dentistry

EDITED BY

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

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Lindhe's Clinical Periodontology and Implant Dentistry

Seventh Edition

Edited by

Tord Berglundh

Department of Periodontology, Institute of Odontology,
The Sahlgrenska Academy at University of Gothenburg,
Gothenburg, Sweden

William V. Giannobile

Harvard School of Dental Medicine, Boston, MA, USA

Niklaus P. Lang

Department of Periodontology, School of Dental Medicine,
University of Bern, Bern, Switzerland

Mariano Sanz

Faculty of Odontology, ETEP (Etiology and Therapy of Periodontal
and Peri-Implant Diseases) Research Group, Complutense
University of Madrid, Madrid, Spain and Department of Periodontology,
Faculty of Dentistry, Institute of Clinical Dentistry,
University of Oslo, Oslo, Norway

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Contributors

Maurício Araújo

Department of Dentistry
State University of Maringá
Maringá
Paraná
Brazil

Gustavo Avila-Ortiz

Department of Periodontics
College of Dentistry
University of Iowa
Iowa City
IA
USA

Hans-Rudolf Baur

Department of Cardiology
Medical School
University of Bern
Bern
Switzerland

James Beck

Division of Comprehensive Oral Health/
Periodontology
Adams School of Dentistry
University of North Carolina
Chapel Hill
NC
USA

Tord Berglundh

Department of Periodontology
Institute of Odontology
The Sahlgrenska Academy at University of
Gothenburg
Gothenburg
Sweden

Michael M. Bornstein

Oral and Maxillofacial Radiology
Applied Oral Sciences & Community Dental Care
Faculty of Dentistry
The University of Hong Kong
Hong Kong SAR
China, and
Department of Oral Health & Medicine
University Center for Dental Medicine Basel UZB
University of Basel
Basel
Switzerland

Dieter D. Bosshardt

Department of Periodontology
School of Dental Medicine
University of Bern
Bern
Switzerland

Rino Burkhardt

Faculty of Dentistry
The University of Hong Kong
Hong Kong SAR
China, and
Clinic of Reconstructive Dentistry
University of Zurich
Zurich
Switzerland

Iain Chapple

Periodontal Research Group
School of Dentistry
University of Birmingham
Birmingham
UK

Lyndon F. Cooper

University of Illinois at Chicago
College of Dentistry
Chicago
IL
USA

Pierpaolo Cortellini

European Research Group on Periodontology
(ERGOPerio)
Genoa
Italy
and
Private Practice
Florence
Italy

Mike Curtis

Faculty of Dentistry
Oral and Craniofacial Sciences
King's College London
London
UK

Dorothea Dagassan-Berndt

Center for Dental Imaging
University Center for Dental Medicine Basel UZB
University of Basel
Basel
Switzerland

Francesco D'Aiuto

Periodontology Unit
UCL Eastman Dental Institute
London
UK

Ryan T. Demmer

Division of Epidemiology and Community Health
School of Public Health
University of Minnesota
Minneapolis
MN
USA

Jan Derks

Department of Periodontology
Institute of Odontology
The Sahlgrenska Academy at University of Gothenburg
Gothenburg
Sweden

Massimo de Sanctis

Department of Periodontology
Università Vita e Salute San Raffaele
Milan
Italy

Peter Eickholz

Department of Periodontology
Center of Dentistry and Oral Medicine (Carolinum)
Johann Wolfgang Goethe-University Frankfurt
am Main
Frankfurt am Main
Germany

Roberto Farina

Research Centre for the Study of Periodontal and
Peri-implant Diseases
University of Ferrara
Ferrara
Italy, and
Operative Unit of Dentistry
Azienda Unità Sanitaria Locale (AUSL)
Ferrara
Italy

Magda Feres

Department of Periodontology
Dental Research Division
Guarulhos University
Guarulhos
São Paulo
Brazil, and
The Forsyth Institute
Cambridge
MA
USA

William V. Giannobile

Harvard School of Dental Medicine
Boston
MA
USA

Filippo Graziani

Department of Surgical, Medical and Molecular
Pathology and Critical Care Medicine
University of Pisa
Pisa
Italy

Christoph H.F. Hämmeler

Clinic of Reconstructive Dentistry
Center of Dental Medicine
University of Zurich
Zurich
Switzerland

Hatice Hasturk

Forsyth Institute
Cambridge
MA
USA

Lisa Heitz-Mayfield

International Research Collaborative – Oral Health and
Equity
School of Anatomy, Physiology and Human Biology
The University of Western Australia
Crawley
WA
Australia

David Herrera

ETEP (Etiology and Therapy of Periodontal and
Peri-Implant Diseases) Research Group
Complutense University of Madrid
Madrid
Spain

Palle Holmstrup

Department of Periodontology
School of Dentistry
University of Copenhagen
Copenhagen
Denmark

Kuofeng Hung

Oral and Maxillofacial Radiology
Applied Oral Sciences & Community Dental Care
Faculty of Dentistry
The University of Hong Kong
Hong Kong SAR
China

Saso Ivanovski

School of Dentistry
The University of Queensland
Australia

Søren Jepsen

Department of Periodontology, Operative, and
Preventive Dentistry
Center of Oral, Dental, Maxillofacial Medicine
University of Bonn
Bonn
Germany

Mats Jontell

Oral Medicine and Pathology
Institute of Odontology
The Sahlgrenska Academy at University of Gothenburg
Gothenburg
Sweden

Ronald. E. Jung

Clinic of Reconstructive Dentistry
University of Zurich
Zurich
Switzerland

Darnell Kaigler

Department of Periodontics and Oral Medicine
University of Michigan School of Dentistry
and
Department of Biomedical Engineering
College of Engineering
Ann Arbor
MI
USA

Alpdogan Kantarci

Forsyth Institute
Cambridge
MA
USA

Janet Kinney

Department of Periodontics and Oral Medicine
University of Michigan School of Dentistry
Ann Arbor
MI
USA

Kenneth Kornman

Department of Periodontics and Oral Medicine
University of Michigan School of Dentistry
Ann Arbor
MI
USA

Marja L. Laine

Department of Periodontology
Academic Center for Dentistry Amsterdam (ACTA)
University of Amsterdam and Vrije Universiteit Amsterdam
Amsterdam
The Netherlands

Evanthia Lalla

Division of Periodontics
Section of Oral, Diagnostic, and Rehabilitation Sciences
Columbia University College of Dental Medicine
New York
NY
USA

Niklaus P. Lang

Department of Periodontology
School of Dental Medicine
University of Bern
Bern
Switzerland

Jan Lindhe

Department of Periodontology
Institute of Odontology
The Sahlgrenska Academy at University of Gothenburg
Gothenburg
Sweden

Bruno G. Loos

Department of Periodontology
Academic Center for Dentistry Amsterdam (ACTA)
University of Amsterdam and Vrije Universiteit
Amsterdam
Amsterdam
The Netherlands

Philip D. Marsh

Department of Oral Biology
School of Dentistry
University of Leeds
UK

Conchita Martin

Faculty of Odontology
Complutense University of Madrid
Madrid
Spain

Giedrė Matulienė

Private Practice
Zurich
Switzerland

Luigi Nibali

Department of Periodontology
Centre for Host–Microbiome Interactions
King's College London
Guy's Hospital
London
UK

Sture Nyman (deceased)

Department of Periodontology
Institute of Odontology
The Sahlgrenska Academy at University of Gothenburg
Gothenburg
Sweden

Panos N. Papapanou

Division of Periodontics
Section of Oral, Diagnostic, and Rehabilitation Sciences
Columbia University College of Dental Medicine
New York
NY
USA

Bjarni E. Pjetursson

Department of Reconstructive Dentistry
University of Iceland
Reykjavik
Iceland

Christoph A. Ramseier

Department of Periodontology
School of Dental Medicine
University of Bern
Bern
Switzerland

Giulio Rasperini

Department of Biomedical, Surgical, and Dental Sciences
Foundation IRCCS Ca' Granda Polyclinic
University of Milan
Milan
Italy

Giovanni E. Salvi

Department of Periodontology
School of Dental Medicine
University of Bern
Bern
Switzerland

Mariano Sanz

Faculty of Odontology
ETEP (Etiology and Therapy of Periodontal and
Peri-Implant Diseases) Research Group
Complutense University of Madrid
Madrid
Spain, and
Department of Periodontology
Faculty of Dentistry
Institute of Clinical Dentistry
University of Oslo
Oslo
Norway

Arne S. Schaefer

Department of Periodontology, Oral Medicine and Oral Surgery
Institute for Dental and Craniofacial Sciences
Charité–Universitätsmedizin
Berlin
Germany

Frank Schwarz

Department of Oral Surgery and Implantology
Centre for Dentistry and Oral Medicine
Frankfurt
Germany

Anton Sculean

Department of Periodontology
School of Dental Medicine
University of Bern
Bern
Switzerland

Jorge Serrano

ETEP (Etiology and Therapy of Periodontal and Peri-Implant Diseases) Research Group
Complutense University of Madrid
Madrid
Spain

Gregory J. Seymour

School of Dentistry
The University of Queensland
Brisbane
Australia

Dagmar Else Slot

Department of Periodontology
Academic Centre for Dentistry Amsterdam (ACTA)
University of Amsterdam and Vrije Universiteit
Amsterdam
Amsterdam
The Netherlands

Clark M. Stanford

University of Illinois at Chicago
College of Dentistry
Chicago
IL, USA

Franz J. Strauss

Clinic of Reconstructive Dentistry
University of Zurich
Zurich
Switzerland, and
Department of Conservative Dentistry
Faculty of Dentistry
University of Chile
Santiago
Chile

Jeanie E. Suvan

Unit of Periodontology
UCL Eastman Dental Institute
London
UK

Dimitris N. Tatakis

Division of Periodontology
Ohio State University
College of Dentistry
Columbus
OH
USA

Daniel S. Thoma

Clinic of Reconstructive Dentistry
University of Zurich
Zurich
Switzerland

Cristiano Tomasi

Department of Periodontology
Institute of Odontology
The Sahlgrenska Academy at University of Gothenburg
Gothenburg
Sweden

Maurizio S. Tonetti

Shanghai Jiao Tong University School of Medicine
and
Clinical Research Center of Periodontology and Oral and Maxillo-facial Implants, National Clinical Research Center of Oral Diseases and Medical Clinical Research Center
Shanghai 9th People Hospital
China, and
ERGOPerio (European Research Group on Periodontology)
Genova
Italy

Leonardo Trombelli

Research Centre for the Study of Periodontal and Peri-implant Diseases
University of Ferrara
Ferrara
Italy, and
Operative Unit of Dentistry
Azienda Unità Sanitaria Locale (AUSL)
Ferrara
Italy

Ubele van der Velden

Department of Periodontology
Academic Center for Dentistry Amsterdam (ACTA)
University of Amsterdam and Vrije Universiteit Amsterdam
Amsterdam
The Netherlands

Fridus van der Weijden

Department of Periodontology
Academic Centre for Dentistry Amsterdam (ACTA)
University of Amsterdam and Vrije Universiteit
Amsterdam
Amsterdam
The Netherlands

Fabio Vignoletti

Department of Periodontology
Faculty of Odontology
Complutense University of Madrid
Madrid
Spain

Jan L. Wennström

Department of Periodontology
Institute of Odontology
The Sahlgrenska Academy at University of Gothenburg
Gothenburg
Sweden

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 pre-clinical 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
William V. Giannobile
Niklaus P. Lang
Mariano Sanz

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Chapter 1

Anatomy and Histology of Periodontal Tissues

Dieter D. Bosshardt¹, Jan Lindhe², Niklaus P. Lang¹, and Maurício Araújo³

¹ Department of Periodontology, School of Dental Medicine, University of Bern, Bern, Switzerland

² Department of Periodontology, Institute of Odontology, The Sahlgrenska Academy at University of Gothenburg, Gothenburg, Sweden

³ Department of Dentistry, State University of Maringá, Maringá, Paraná, Brazil

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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

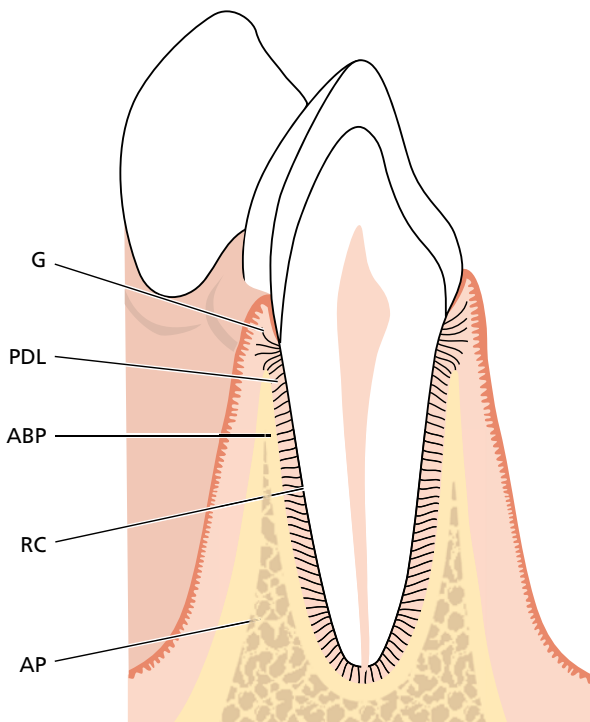


Fig. 1-1 A tooth and its periodontal tissues consisting of gingiva (G), periodontal ligament (PDL), alveolar bone proper (ABP), and root cementum (RC). AP, alveolar process.

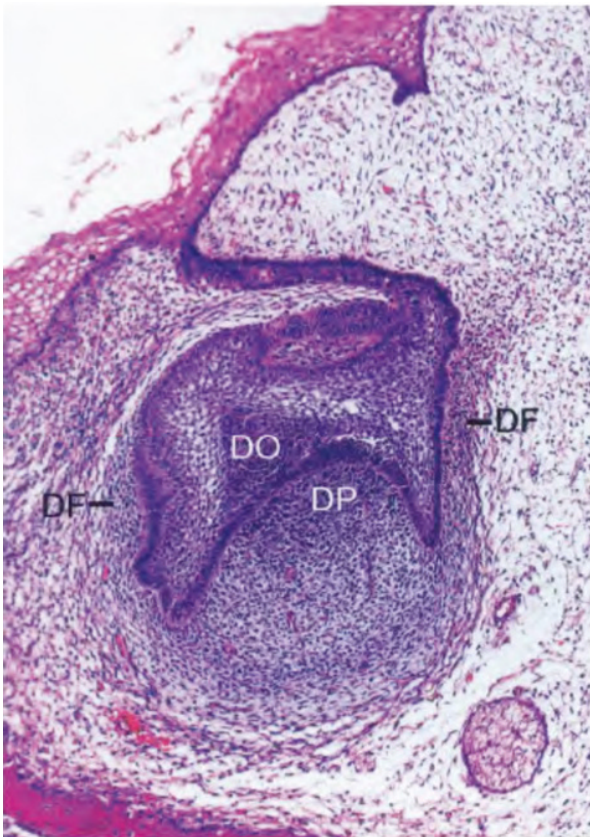


Fig. 1-2 Light micrograph of a tooth germ at the cap stage with the dental organ (DO), the dental papilla (DP), and the dental follicle (DF).

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

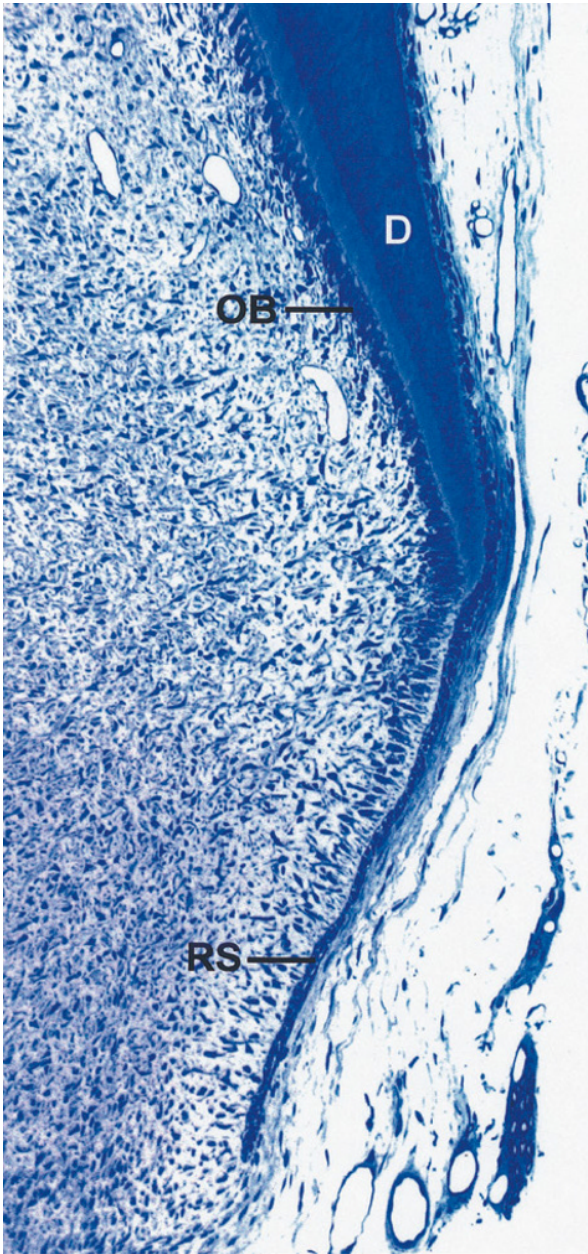


Fig. 1-3 Light micrograph illustrating the edge of a developing tooth root with the Hertwig's epithelial root sheath (RS), odontoblasts (OB), and dentin (D).

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 termed "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 cemento-enamel 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

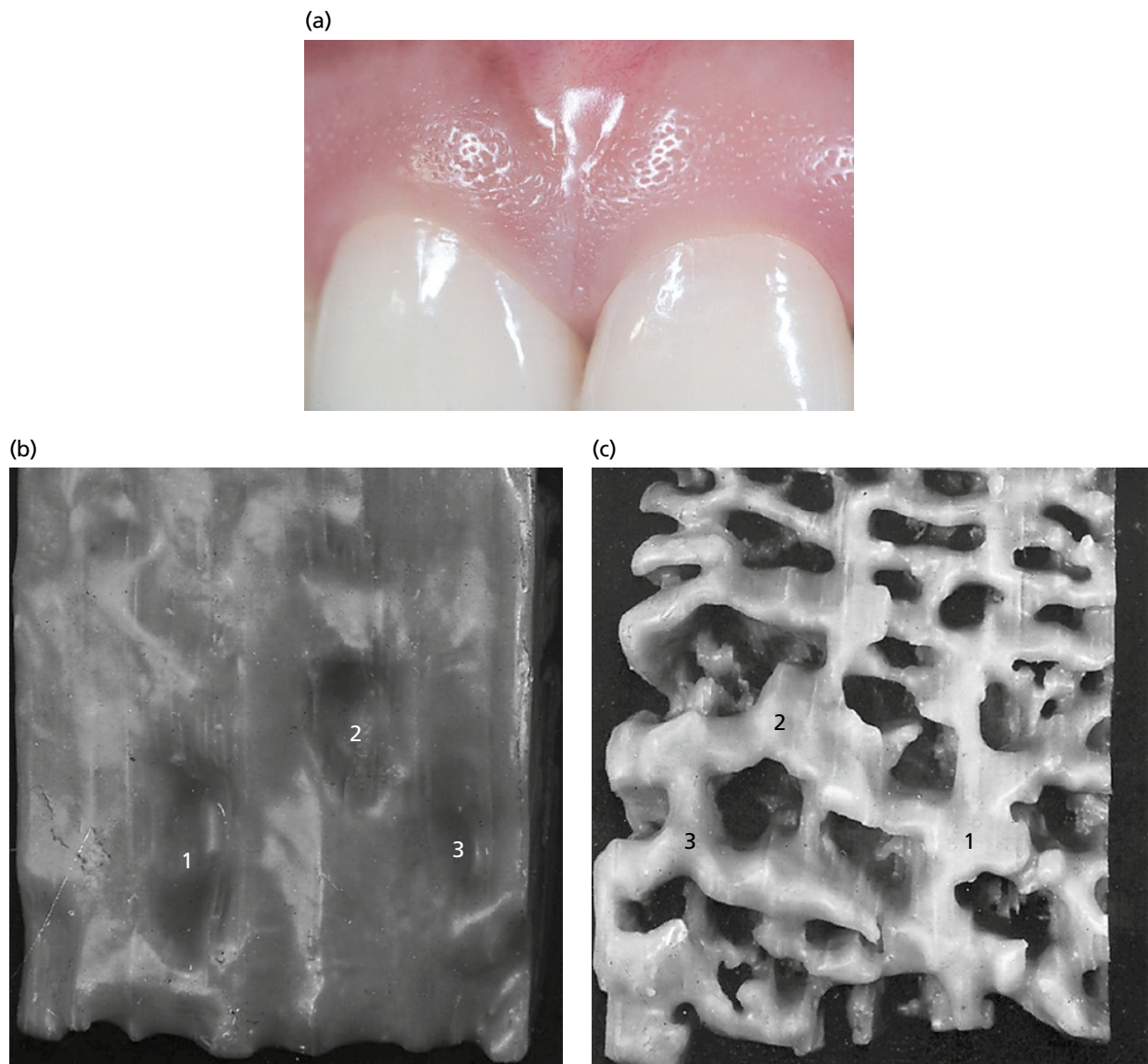


Fig. 1-18 (a) Conspicuous stippling of the masticatory mucosa of the gingiva, as seen macroscopically or clinically. (b) In a magnified model of the oral gingival epithelium of the attached gingiva, the surface exhibits the minute depressions, which give the gingiva its characteristic stippled appearance. (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- \AA 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

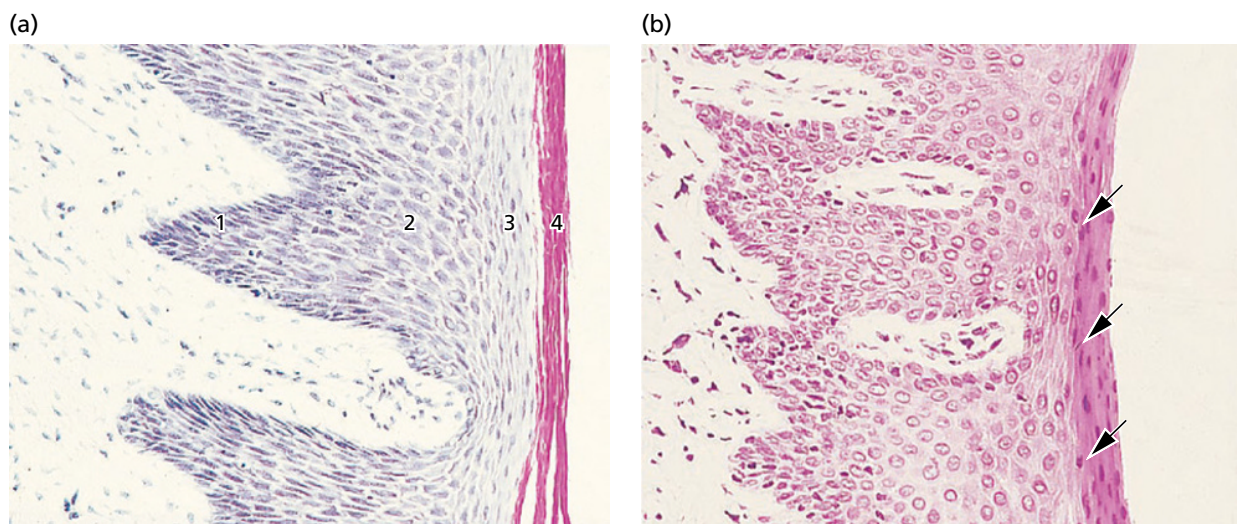


Fig. 1-19 The four layers of the oral gingival epithelium: (1) stratum basale, (2) stratum spinosum, (3) stratum granulosum, and (4) stratum corneum, as seen in the orthokeratinized (a) and parakeratinized (b) epithelium. The arrows indicate the presence of cell nuclei in the case of parakeratinization.

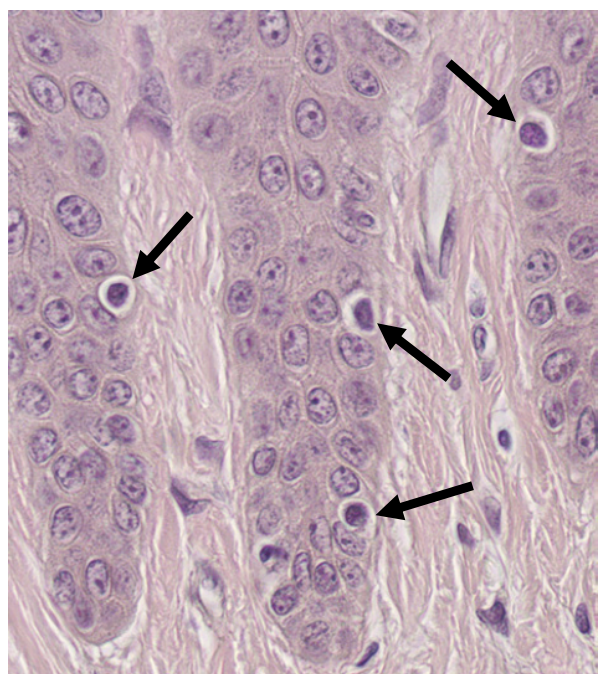


Fig. 1-20 "Clear cells" (arrows) located in or near the stratum basale of the oral gingival epithelium.

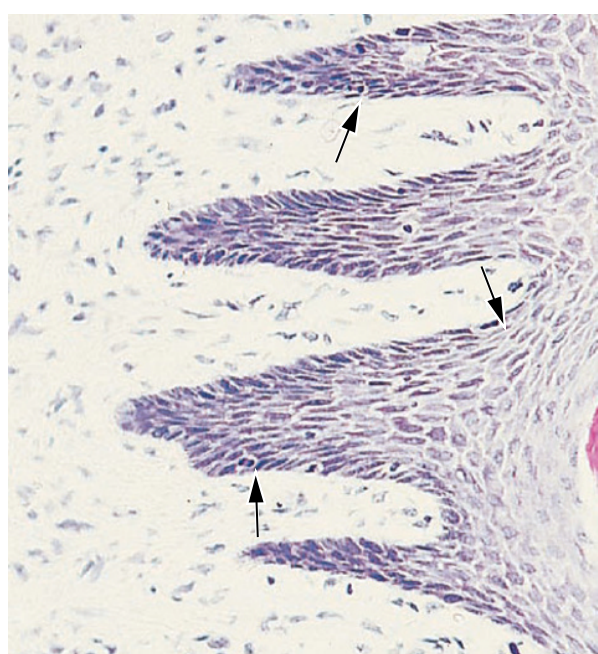


Fig. 1-21 The cells in the basal layer of the oral gingival epithelium are able to divide. The arrows indicate dividing cells.

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

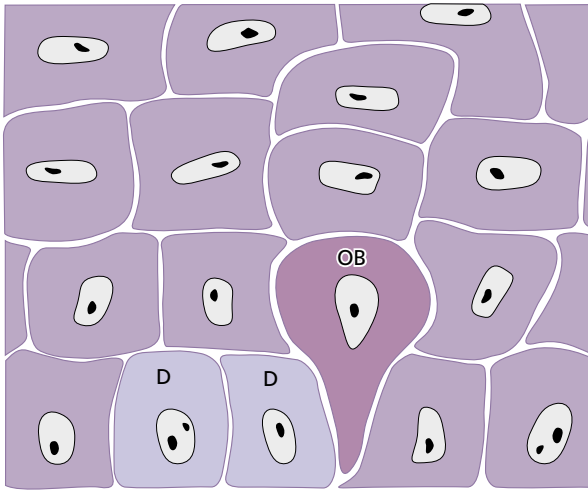


Fig. 1-22 Cell proliferation in the basal layer of the oral gingival epithelium. D, daughter cells; OB, "older" basal cell.

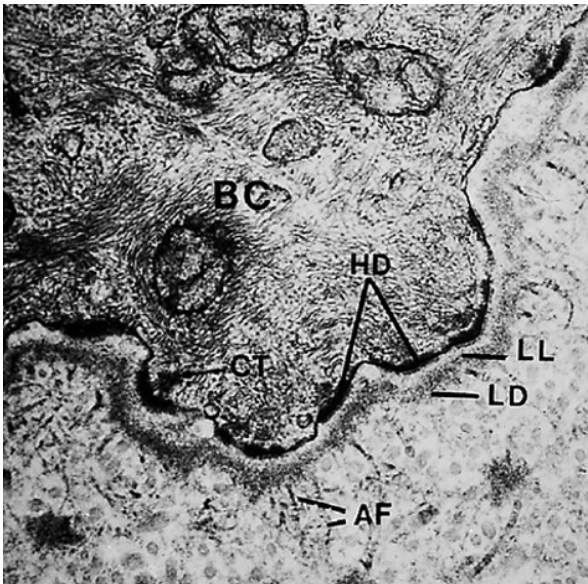


Fig. 1-24 Transmission electron micrograph (magnification $\times 70,000$) illustrating the interfacial region of the basement membrane between a basal cell (BC) and the adjacent soft connective tissue. AF, anchoring fibrils; CT, cytoplasmic tonofilaments (cytokeratin filaments); HD, hemidesmosomes;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

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).



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.

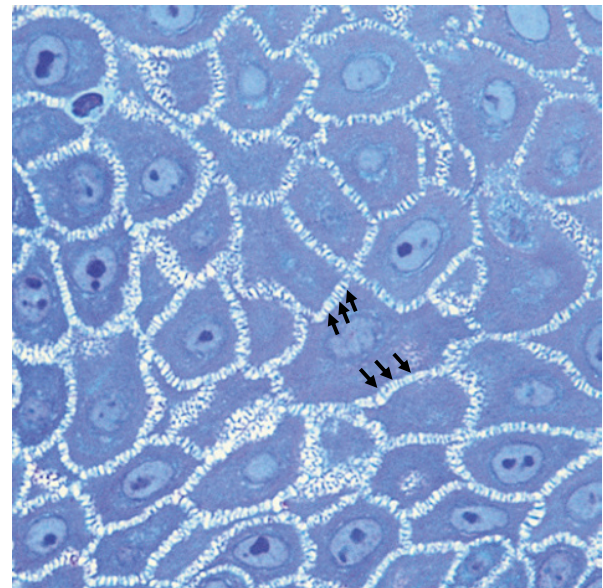


Fig. 1-25 Light micrograph depicting an area of the stratum spinosum in the oral gingival epithelium. Arrows point to short cytoplasmic processes between neighboring cells.

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

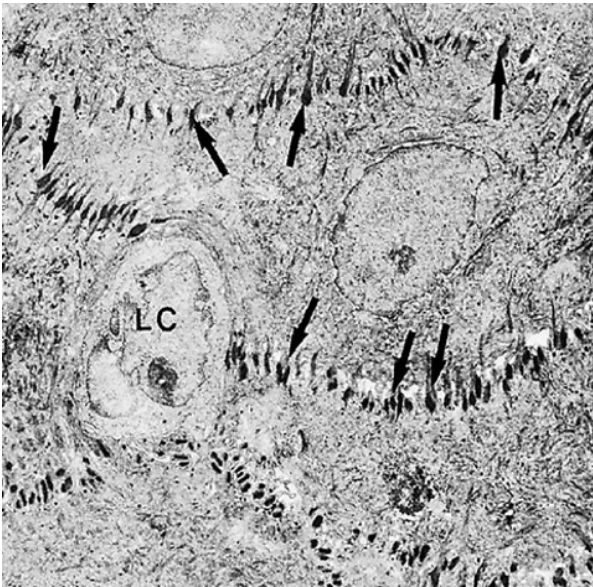


Fig. 1-26 Transmission electron micrograph of stratum spinosum highlighting (arrows) desmosomes between neighboring cells. The light cell (LC) harbors no hemidesmosomes and is, therefore, not a keratinocyte but rather a "clear cell".

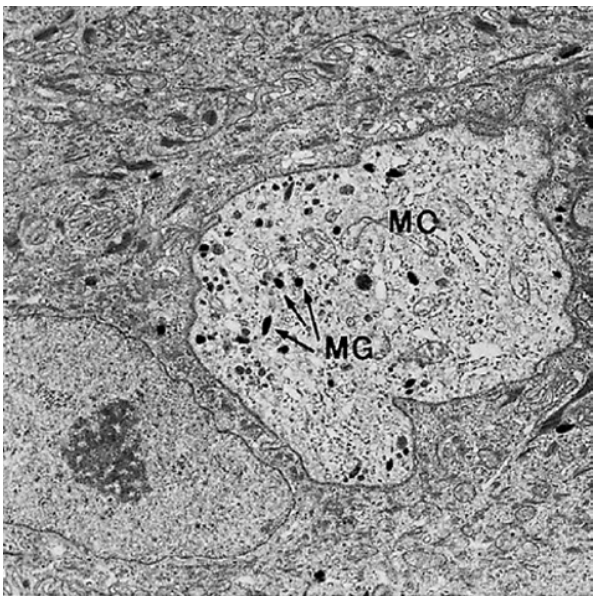


Fig. 1-28 Transmission electron micrograph illustrating a melanocyte (MC) surrounded by keratinocytes in the oral gingival epithelium. MG (arrows) points to melanin granules.

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.

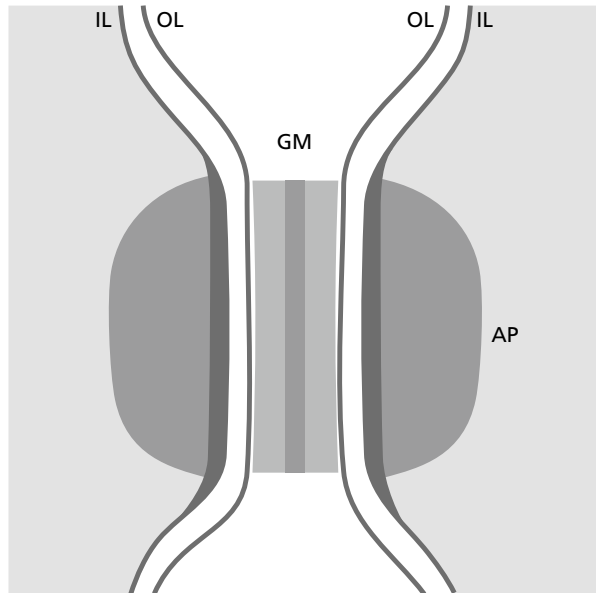


Fig. 1-27 The composition of a desmosome. AP, attachment plaque; GM, granulated material; IL, inner leaflets; OL, outer leaflets.

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