OTTO ZUHR MARC HÜRZELER

PLASTIC-ESTHETIC PERIODONTAL AND IMPLANT SURGERY

A Microsurgical Approach

QUINTESSENCE PUBLISHING

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A Microsurgical Approach

With the support of Bärbel Hürzeler and Stephan Rebele

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for Kira,
Emma, Paula, and Oskar

Preface

One of the really significant stories relating to the creation of this book happened at the beginning of 2005, in our old apartment in Munich, Germany. Like so often, my little daughter Emma was sitting beside me at my desk chatting while I was working at the computer, desperately trying to make some progress on the book manuscript. I can still remember the exact moment when she suddenly changed the subject and more or less asked me pointblank what color the book would be. Taken by surprise, I tried to explain to her that I had just started working on the book and that the last thing on my mind at that moment was the color of the book. However, she did not let up. To make a long story short, I finally had no other choice but to actually swear on my "great princess's honor" that the cover of the book, should it one day ever get finished, would be printed up in her favorite color. So it happened that I had to insist on having the book bound in pink despite the serious concerns raised by the publisher. In the end, the responsible parties at Quintessence accepted under protest. My reason for choosing that color, therefore, was not to attract more attention or to make allusions to "pink esthetics" but solely to honor my reckless promise to my daughter Emma, whose favorite color is pink...

At this point, I would like to extend my sincere gratitude and appreciation to the senior management of Quintessence Publishing—Horst-Wolfgang Haase, Alexander Ammann, Christian Haase, and Johannes Wolters—not only for bearing with my color choice but also for the great confidence and trust they have placed in me, for their enduring patience throughout this book project, which was indubitably trying at times, and, not least, for their tremendous support, cooperation, and partnership over the last few years. Many thanks also to Janina Kuhn, Ina Steinbrück, Valeri Ivankov, and Peter Rudolf for turning the manuscript into an actual book. In particular, I am deeply indebted to Peter Rudolf, who gave me the reassurance and peace of mind straight from the beginning that he was doing everything possible to make this book the best it could be. Thanks also to Christine Rose, Florian Curtius, Andreas Dollinger, and Jens Hoepfner for processing the clinical photographs for print and to the Quintessence TV team of Gerd Basting, Martin Jakovljevic, Fabian Pietsch, and Ireneusz Watola for producing the videos for the accompanying video compendium. Credit also goes to Angelika Kramer for her dedication and commitment in preparing the drawings and to Stefan Bogner, Annette Bauer, and Stephen Wittmann for their assistance in developing the layout for this book. My thanks also go to Suzyon O'Neal Wandrey for the English translation and to Chee Wan Ang for the enormous effort he undertook in proofreading the English version of this manuscript.

Furthermore, I would like to take this opportunity to thank all of my teachers, even if it is not possible to mention every single one of them by name here and now. In my years as a dentist and periodontist, I have had the extraordinary luck to work with a lot of great personalities in our field. I was not only able to see them in action and learn from these great teachers but also had the chance to engage in intense discussion, discourse, and debate with some of them on a large number of topics. In particular, I would like to thank Wolfgang Bolz and Hannes Wachtel for their long-standing support of my professional development and for many inspiring years of common ground...

Looking back, I can hardly put into words how much time and energy have actually gone into work on this book. This inevitably led to gaps in coverage of the daily needs and requirements for quality-oriented practice management and treatment, which had to be compensated for and closed by others. In this context, my most profound thanks to my dental practice team, Bärbel Hürzeler, Marc Hürzeler, Wolf Richter, and all our hard-working dental assistants, dental hygienists, and administrative staff: Thank you for your open-minded and sincere teamwork and for your ceaseless and unswerving pursuit of our ultimate goal of making patient care at our dental practice a little bit better each day, year after year. To Stefan Fickl, who stepped in to help us when we had just started and were short-handed, many thanks indeed. In addition, I owe my respect to the ar-

tist and sculptor Gerd Bischur, who was instrumental in the creation of object images and provided support in all aspects relating to digital photography. I am also deeply indebted to the dental laboratory technicians who performed all the prosthetic work in the scope of this book project and who have basically been a part of my team ever since I started my professional life: Rainer Janousch, Uli Schoberer, and Uli Werder. My special thanks go to Uli Schoberer for his exceptional analytical, creative, and technical skills, for his fundamental belief that a treatment outcome that is inferior to that which is technically feasible is never acceptable, and for his spirit of brotherhood.

The idea of having the book manuscript critically reviewed from the student perspective prior to its final completion proved to be a correct and rewarding decision: I would like to thank Stephan Rebele not only for drafting the rough sketches of the illustrations in this book but also for critically reading and creatively evaluating the manuscript. His input ultimately led to didactically valuable changes and additions in different parts of the book. I am also deeply indebted to Bärbel Hürzeler for the enormous amount of time she spent proofreading our manuscripts without complaint at various stages of development of this book, for the razor-sharp intellect with which she consistently enriched and constructively supported the book's development, and for her big heart.

Last but not least, I would like to thank Marc Hürzeler for his unparalleled way of practicing dentistry with a passion that is irresistibly motivating and contagious, for always being a model of partnership and team spirit for me, for standing by me all these years, and for helping whenever I needed him, without exception, without question, and without having to be asked: I feel extremely grateful and fortunate that our paths crossed. Without you, this book would never have become reality—my colleague, partner, very best friend...

With the deepest respect, I would like to thank my parents, Marianne and Otto, and my sisters, Marianne and Barbara, for showing and setting the example for me of what a home and family should be, for always allowing me to be who I really am, and for giving me their unconditional love.

From the bottom of my heart, I would most like to thank my children, Emma, Paula, and Oscar, for opening my eyes and, especially, my wife, Kira, for her enduring strength, serenity, and wisdom and for the continuous flow of energy, warmth, and love with which she has supported and motivated me over the years—I could not imagine living without you for one second. I love you, to the moon and back...

Uffing (Germany), September 2011 Otto Zuhr

1 Uli S. 2 Stefan 3 Stephan 4 Wolf 5 Rainer 6 Gerd 7 Otto 8 Bärbel 9 Marc 10 Uli W.

It is our deepest conviction that the surgical potentials of the present can only be achieved by consistently following a surgical approach in which minimal soft tissue trauma and maximally perfect wound closure are key elements.

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SECTION A

PRINCIPLES

CHAPTER 1

BASIC PRINCIPLES OF PERIODONTAL ANATOMY AND STRUCTURAL BIOLOGY

A sound knowledge of the macroanatomical and microanatomical structures of periodontal and peri-implant tissues is key to understanding the principles of plastic-esthetic periodontal and implant surgery. Therefore, anatomical structures relevant to the diagnostic and therapeutic procedures presented in later chapters of this book will be defined and described here (Fig 1-1). Because the scope of this chapter is limited to the information relevant to performance of these procedures, the reader should refer to more specific publications in the literature for a more detailed description of the anatomical and structural biology of periodontal and peri-implant tissues.[1]

1.1 Anatomy of Periodontal Structures

1.1.1 Gingiva

The oral mucosa, or mucous membrane epithelium of the mouth, can be divided into three types: *masticatory mucosa* (gingiva and hard palate), *lining mucosa* (lips, cheeks, vestibule, floor of the mouth, base of the tongue, and soft palate), and *specialized sensory mucosa* (taste buds on dorsum of the tongue).[2] The gingiva consists of gingival connective tissue and an epithelial covering. The surface of the gingiva is keratinized except in the interdental col region. The gingiva extends from the gingival margin to the mucogingival junction.

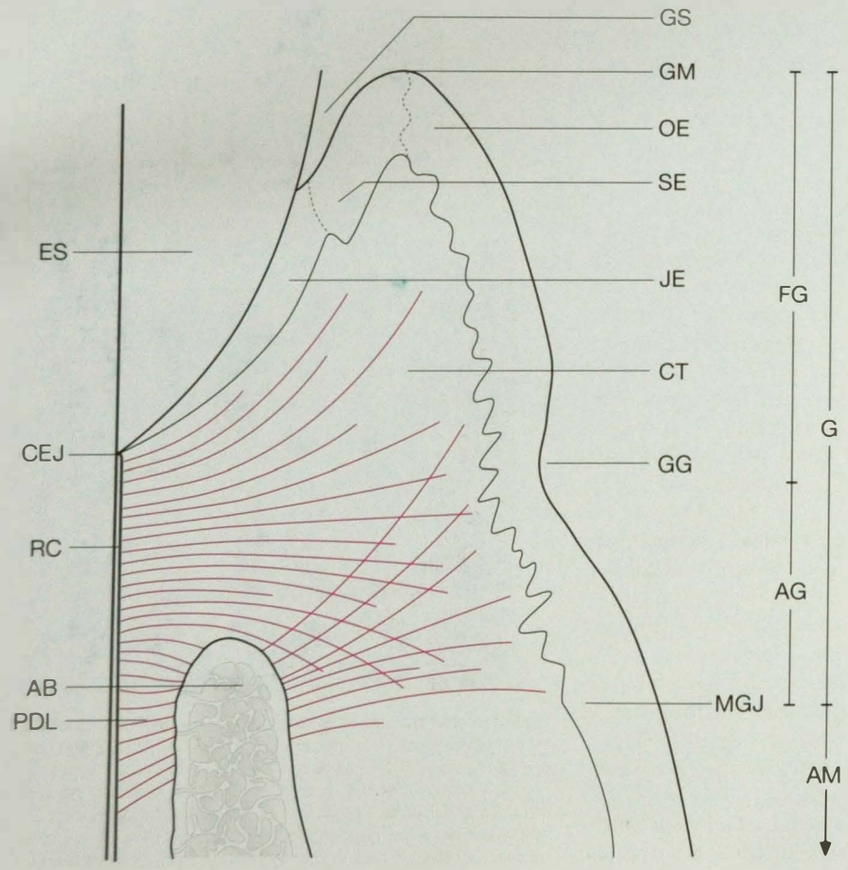

Fig 1-1 Anatomical structure of the marginal periodontium. ES: enamel space; CEJ: cementoenamel junction; RC: root cementum; AB: alveolar bone; PDL: periodontal ligament; GS: gingival sulcus; GM: gingival margin; OE: oral epithelium; SE: sulcular epithelium; JE: junctional epithelium; CT: gingival connective tissue; GG: gingival groove; MGJ: mucogingival junction; FG: free gingiva; AG: attached gingiva; G: gingiva; AM: alveolar mucosa.

The average thickness of the gingival tissue is around 1 mm.[3] Its vertical dimension is subject to great variation and can range from 1 to 9 mm but is generally greatest buccal to the maxillary anterior teeth and smallest lingual to the mandibular anterior teeth.[4,5] The width of the gingiva is basically determined by the position in which a tooth emerges through the alveolar ridge. The more buccal the tooth position, the narrower the gingiva on the buccal aspect of the tooth. Conversely, the more lingual the tooth position, the broader the gingiva on the buccal aspect of the tooth.[6]

The width of the gingiva increases during jaw growth in childhood.[7,8] Spontaneous buccolingual changes in tooth position during growth affect the dimensions of the gingiva, as does orthodontic movement in the buccolingual direction.[9,10] Buccal movement of a tooth results in narrowing of the gingiva on the buccal aspect of the tooth, whereas lingual movement results in widening of the gingiva.[10] The width of the gingiva also increases after orthodontic extrusion of teeth or coronal distraction of alveolar bone segments, including the respective tooth roots (see chapter 12).

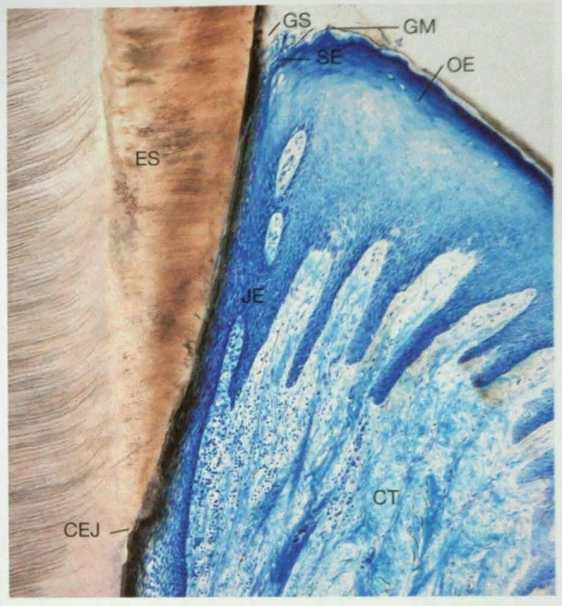

Fig 1-2 Histologic view of the free gingiva. ES: enamel space; CEJ: cementoenamel junction; GS: gingival sulcus; GM: gingival margin; OE: oral gingival epithelium; SE: oral sulcular epithelium; JE: junctional epithelium; CT: gingival connective tissue. (Courtesy of *Peter Schüpbach*, Zurich, Switzerland.)

Free gingiva

The free gingiva has a smooth appearance and extends along the buccal and lingual surfaces of the teeth from the *gingival margin* to the apical border of the epithelial attachment (Fig 1-2). This border, located at the level of the cementoenamel junction, can be identified clinically as the *gingival groove* in 30% to 40% of all patients.[5] Toward the oral cavity, the free gingiva is covered by stratified squamous keratinized epithelium.

Toward the tooth surface, it retracts slightly to form a shallow *sulcus* that, under healthy conditions, has a depth of approximately 0.5 mm. The sulcus is lined by oral sulcular epithelium, which extends coronally to merge with the oral gingival epithelium. Histologically, the overall structure of the oral sulcular epithelium resembles that of the oral gingival epithelium except for the outermost layers of cells. In the oral sulcular epithelium, they are thinner and, in part, incompletely keratinized. This pattern of incomplete keratinization is referred to as *parakeratinization* (Fig 1-3).

At the bottom of the gingival sulcus, the oral sulcular epithelium merges with the *junctional epithelium*, which forms a 1- to 2-mm-wide *epithelial attachment* on the enamel surface. The junctional epithelium is a stratified

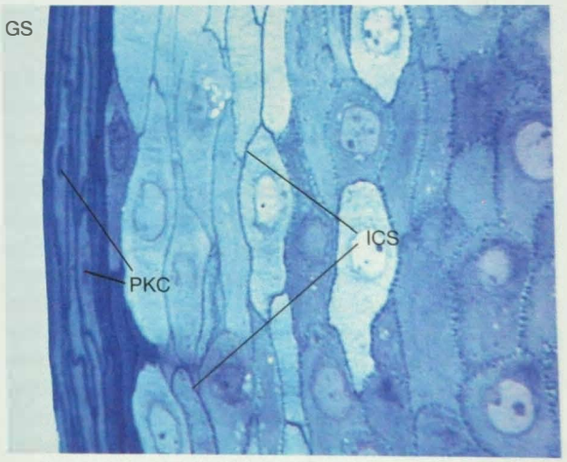

Fig 1-3 Histologic view of the oral sulcular epithelium. Parakeratinization is characterized by the presence of incompletely keratinized epithelial cells with cell nuclei in the outermost layer (stratum corneum). These are referred to as *parakeratinized epithelial cells* (PKC). Because of its narrow intercellular spaces (ICS), the oral sulcular epithelium has a low permeability to microorganisms. GS: gingival sulcus. (Courtesy of *Max Listgarten*, Philadelphia, Pennsylvania.)

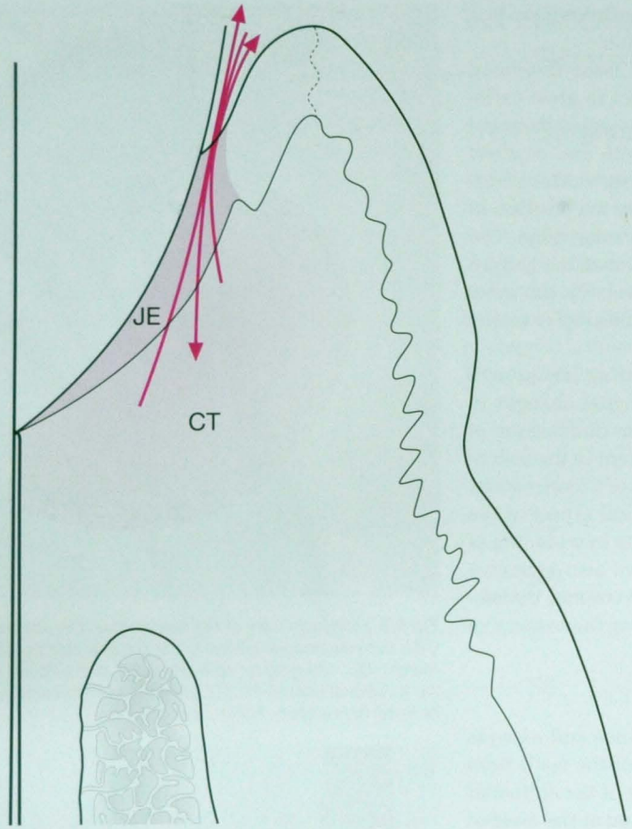

Fig 1-4 The junctional epithelium (JE) can be regarded as a reaction zone that enables the body to stage immunologic conflicts with oral microorganisms distant from the bone. The nonkeratinized structure of the junctional epithelium facilitates the immigration of immune cells from the subepithelial connective tissue (CT).

nonkeratinized epithelium that surrounds the tooth like a collar and resembles a thin wedge in cross section. Interdentally, the junctional epithelia of adjacent teeth touch, forming the nonkeratinized interdental col.

The junctional epithelium is demarcated by two basal laminae, one facing the tooth and the other facing the gingival connective tissue on the opposite side. Contrary to the widespread belief that the junctional epithelium attaches directly to the tooth surface by means of hemidesmosomes and integrins, hemidesmosomal attachment actually occurs at the internal basal lamina on the enamel surface. Compared to the conventional structure of the external basal lamina facing the gingival connective tissue, that of the internal basal lamina is very specialized.[11] The question of the exact mechanism of attachment of the internal basal lamina to the tooth surface cannot be answered adequately from a scientific perspective at this time.

The basic task of the junctional epithelium is to maintain the continuity of the epithelial lining of the oral cavity toward the tooth surface and thus to protect the underlying bone from microbial invasion. It allows bacteria and their toxic by-products to pass through the epithelium in the apical direction and allows components of cellular and humoral immunity that are chemotactically drawn from the connective tissue during a peripheral immune response to pass coronally in the direction of the sulcus. Therefore, the junctional epithelium can be regarded as a contact and reaction zone that enables the body to stage this immunologic conflict distant from the bone (Fig 1-4).

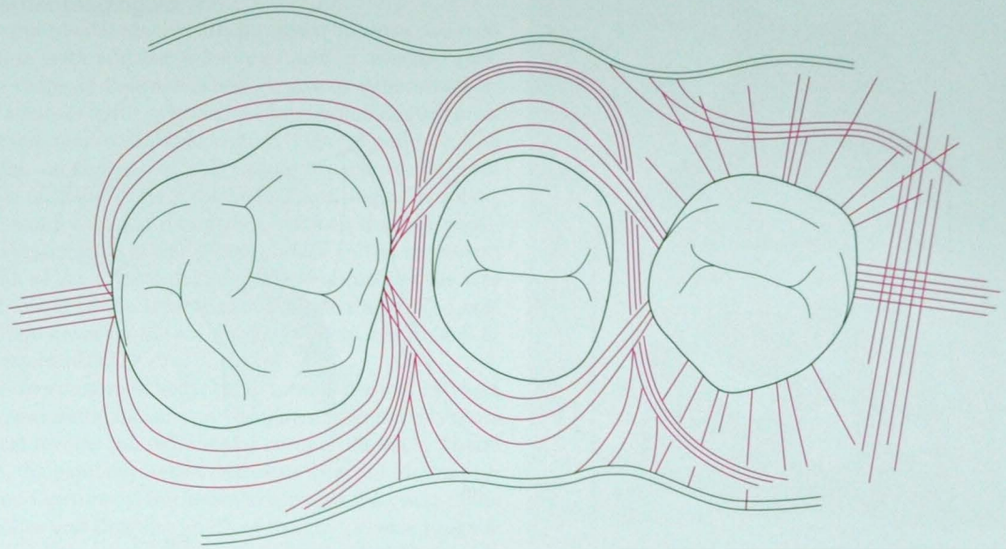

Fig 1-5 Arrangement of collagen fibers in gingival connective tissue.

The junctional epithelium undergoes continuous renewal, which is reflected by a very high rate of cell division. The turnover rate is only 4 to 6 days. During this time, epithelial cells from the basal layers of proliferative cells overlying the external basal lamina migrate coronally and are ultimately shed at the bottom of the sulcus. If the junctional epithelium is injured or removed, complete regeneration occurs within a few days by this mechanism.[12]

Attached gingiva

Buccal and lingual to the rows of teeth, the free gingiva becomes continuous with the attached gingiva, which is firmly connected to the cementum and alveolar bone. At the *mucogingival junction*, it merges with the mobile mucosa lining the alveolar bone. Palatally, the attached gingiva makes a smooth transition into the masticatory mucosa covering the hard palate.

When healthy, the surface of the attached gingiva has a pink color and a stippled appearance. Strong keratinization of the gingival epithelium is not an adaptive response to functional requirements but rather a result of genetic factors affecting the underlying connective tissue.[13,14]

The matrix of the gingival connective tissue contains fibers, cells, blood vessels, and nerves. Roughly 60% of its volume is occupied by collagen fibers, which are functionally arranged in bundles that form the supraalveolar fiber apparatus of the periodontium between the cementoenamel junction and the alveolar bone crest. The height of epithelial attachment is subject to strong individual variation, whereas the height of *connective tissue attachment* remains very constant at around 1 mm.[15,16] By virtue of the fact that they insert into the cementum and alveolar bone, the collagen fibers are able to attach the gingival tissues to the supraalveolar cementum and the alveolar bone crest. Due to their three-dimensional architecture, they stabilize the positions of the teeth and unite them into one closed row of dentition (Fig 1-5).

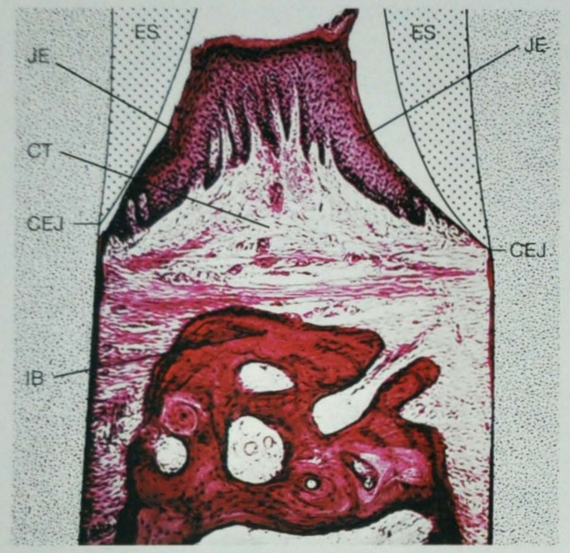

Fig 1-6 Histologic view of the interdental gingiva.[17] ES: enamel space; CEJ: cementoenamel junction; JE: junctional epithelium; CT: gingival connective tissue; IB: interdental bone septum. (Courtesy of *Niklaus P. Lang,* Bern, Switzerland.)

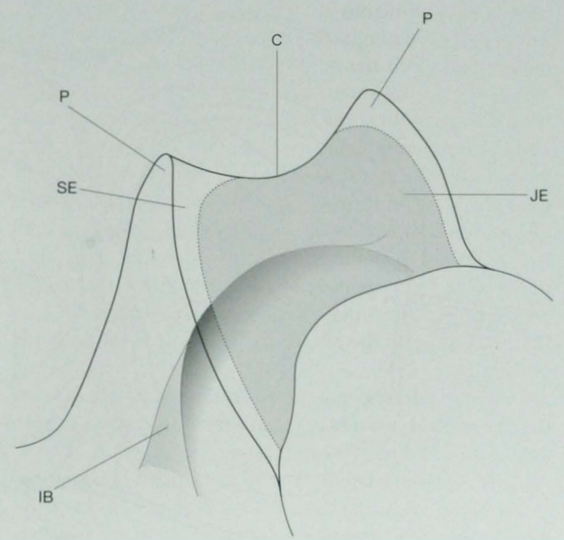

Fig 1-7 Interdental soft tissues. In this region, the junctional epithelia (JE) of adjacent teeth touch, resulting in the formation of a saddle-shaped, nonkeratinized interdental col (C) under the area of interproximal contact of the teeth. The soft tissues on the buccal and lingual aspects of the teeth bulge to form buccal and lingual papillae (P). IB: interdental bone septum; SE: oral sulcular epithelium.

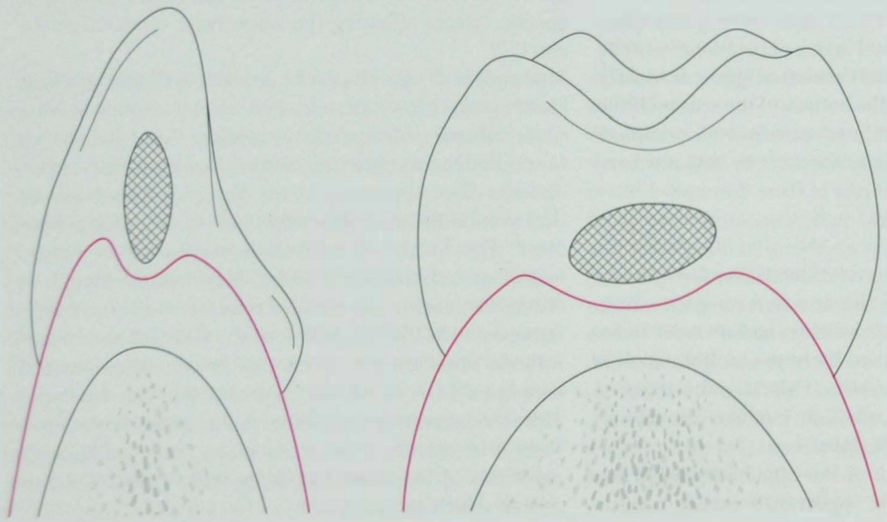

Fig 1-8 The geometry of the interdental col changes from anterior to posterior.

Interdental gingiva

The interdental gingiva fills the space between two contacting teeth and has a free part and an attached part. The shape of the interdental gingiva is determined by the adjacent tooth surfaces, the interdental contact area, and the interdental bone septum (Figs 1-6 and 1-7). The tissues on the buccal and lingual aspects of the teeth bulge outward to form the buccal and lingual *papillae*. The saddle-shaped depression between the two papillae is referred to as the *interdental col*.[18] The shape and depth of the interdental col are determined by the size and shape of the interproximal contact area. The epithelium covering the col normally is not keratinized or parakeratinized.[19]

The interproximal contact area is most coronal between the two central incisors and becomes progressively more apical toward the more distal parts of the arch. Therefore, the papillary height decreases from anterior to posterior. Conversely, the distance between the peaks of the papillae and thus the width of the col increase progressively from anterior to posterior[20] (Fig 1-8).The papillae are responsible for the typical scalloped shape of the gingival margin along the teeth.

1.1.2 Periodontal Fiber Apparatus and Cementum

The periodontal fiber apparatus develops during tooth eruption and root growth. Functionally arranged collagen fiber bundles insert on the root surface, forming two distinctive components, one supra-alveolar and the other alveolar. The supra-alveolar component (connective tissue attachment) provides attachment between the teeth and the marginal gingiva (Fig 1-9), whereas the alveolar component provides attachment between the teeth and the bony sockets in which they are suspended. The fiber bundles inserting into the cementum and cribriform plate of the alveolar bone lining the alveoli are called *Sharpey's fibers*. Most Sharpey's fibers extend diagonally in the apicoronal direction from the surface of the cementum to the bone (Fig 1-10).

Principal fibers of the periodontal ligament extending horizontally and radially can be found in the region of the crestal alveolar bone, the root apex, and furcations. In the unloaded state, the fibers are slightly wavy. When subjected to functional loading, they stretch to permit physiologic tooth mobility, which helps to absorb and counteract the forces acting on the teeth.

Fig 1-9 Histologic view of the supra-alveolar fiber apparatus (SAF) as seen by polarization microscopy. ES: enamel space; CEJ: cementoenamel junction; RC: root cementum; D: dentin. (Courtesy of *Peter Schüpbach,* Zurich, Switzerland.)

The periodontal ligament contains blood vessels, lymph vessels, and a dense network of sensory nerve endings that serves to monitor and control functional forces acting on the teeth. A rich cell population comprising fibroblasts, cementoblasts, osteoblasts, osteoclasts, and their respective progenitor cells completes this picture of highly vital tissue. Its vitality is also reflected in the collagen turnover, which is significantly higher than that of other connective tissues.[21]

Although mineralized, the cementum is vital connective tissue. The mineral content of the cementum ranges be-

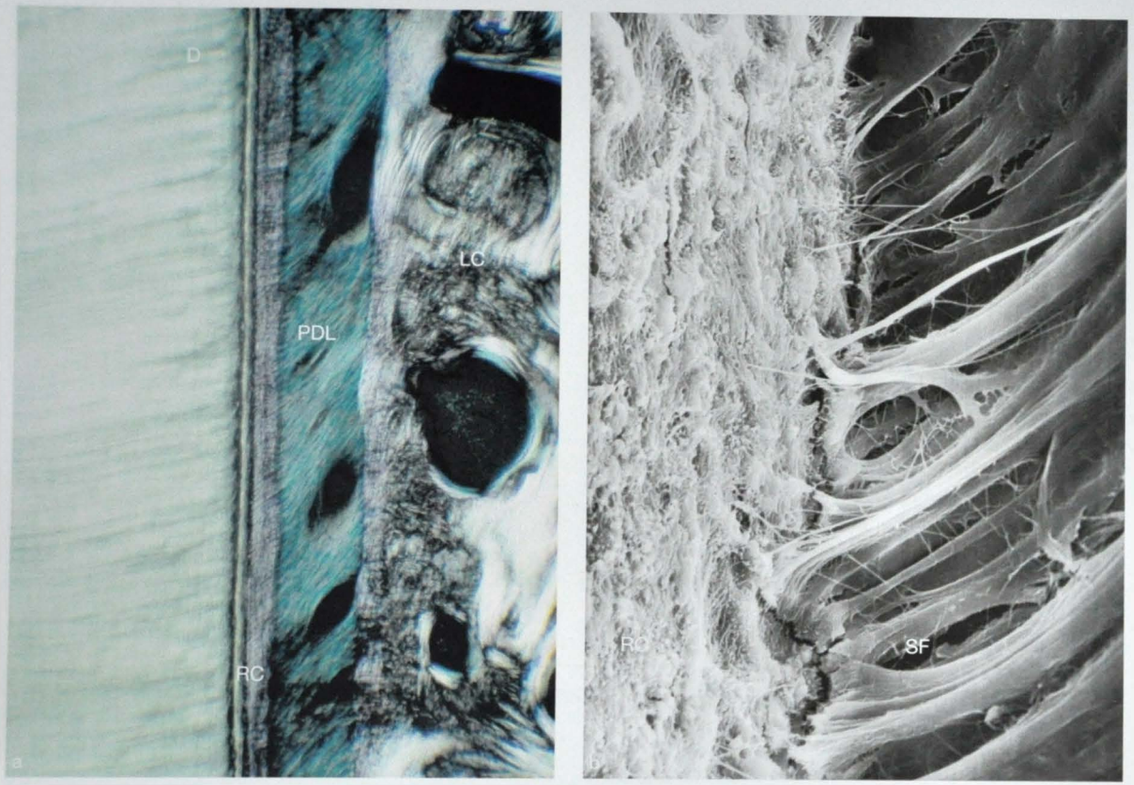

Fig 1-10 (a and b) Histologic and scanning electron microscopic views of the apicocoronal course of Sharpey's fibers (SF) in the periodontal ligament (PDL). D: dentin; RC: root cementum; LC: cribriform plate. (Courtesy of *Peter Schüpbach*, Zurich, Switzerland.)

tween that of other dental hard tissues and bone. Different types of cementum have been identified in histologic studies investigating the distribution of cementocytes and the composition and course of fiber components.[22] Based on these criteria, *cellular versus acellular cementum* and *fibrillar versus afibrillar cementum* can be distinguished (Fig 1-11).

Acellular afibrillar cementum (AAC) appears as small islands or "tongues" of cementum located at the cervical enamel margin. It is probably secreted by cementoblasts. AAC is thought to develop after completion of preeruptive enamel maturation, during the time of tooth eruption when the enamel comes in contact with the connective tissue because of discontinuities in the reduced enamel epithelium.

Acellular extrinsic fiber cementum (AEFC) is located directly on the dentin in the cervical and middle thirds of the root. As the site of insertion of extrinsic *Sharpey's* fibers, the AEFC is primarily responsible for anchorage of the tooth in the alveolus. This type of cementum forms both preeruptively and posteruptively.

Cellular intrinsic fiber cementum (CIFC) does not contain Sharpey's fibers. Consequently, it does not contribute to tooth anchorage. All fiber bundles in the CIFC are located exclusively within the cementum and thus are referred to as *intrinsic fibers* as opposed to *extrinsic fibers*. More precise information about the formation and function of this type of cementum is lacking, but it is thought to function primarily as repair cementum protecting against ankylosis and resorption of the root surface. Because CIFC is continuously produced and secreted by cementoblasts on the root surface throughout an individual's lifetime, its thickness increases throughout life. Cementocytes are enclosed in lacunae within the cellular intrinsic fiber cementum and can communicate with each other and their surroundings by means of cytoplasmic processes.

Cellular mixed stratified cementum (CMSC) is the relatively thick layer of cementum covering the middle and apical thirds of the root surface. It is called *mixed stratified cementum* because it contains extrinsic fibers crossing through a network of intrinsic fibers. Therefore, this type of cementum plays an important part in anchorage of the tooth in the alveolus. CMSC is produced by both cementoblasts and fibroblasts, and it also contains cementocytes enclosed in lacunae.[22]

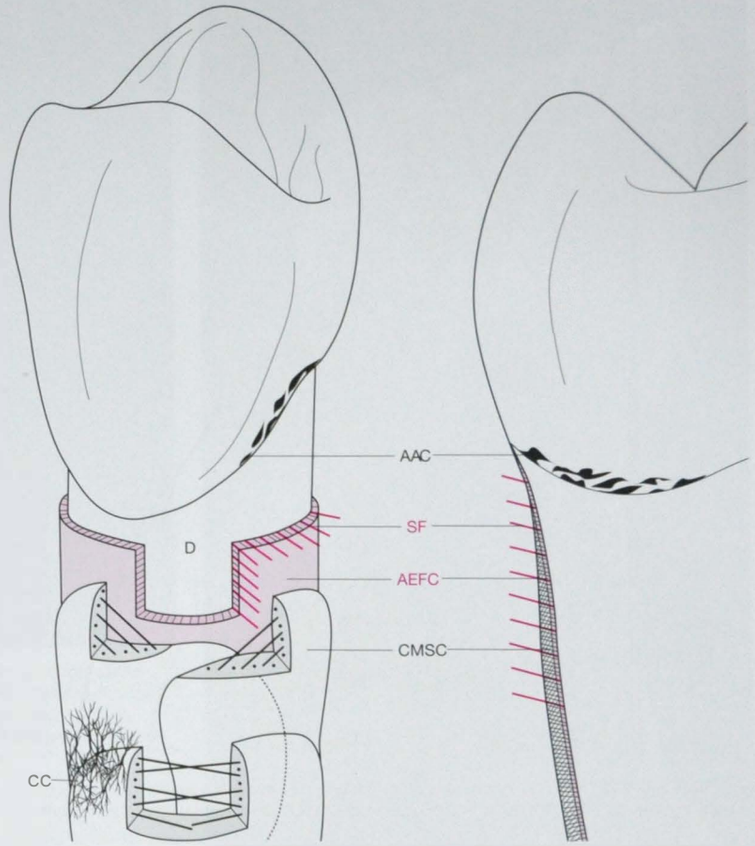

Fig 1-11 Location of the different types of cementum on the root surface. D: dentin; CC: cementocytes; AAC: acellular afibrillar cementum; SF: Sharpey's fibers; AEFC: acellular extrinsic fiber cementum; CMSC: cellular mixed stratified cementum.

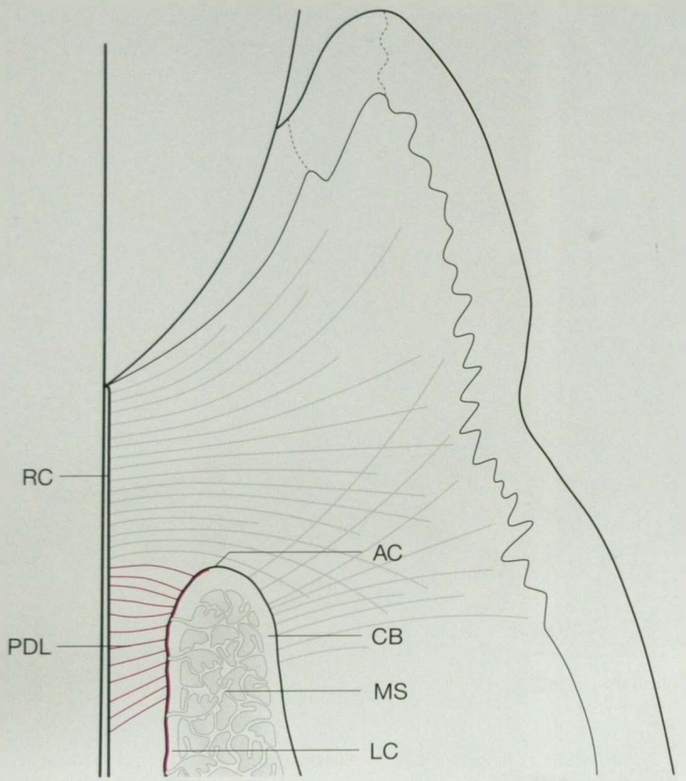

Fig 1-12 Alveolar process in the cervical region. At the alveolar crest (AC), the external cortical bone (CB) merges with the portion of alveolar bone that lines the alveolus, which is referred to anatomically as the *cribriform plate* (lamina cribriformis, LC) and radiologically as the *lamina dura*. The cribriform plate (bundle bone) is the part of the alveolar bone where fibers from the periodontal ligament (PDL) insert. MS: marrow space with cancellous bone.

1.1.3 Alveolar Process

The alveolar processes of the maxilla and mandible develop in conjunction with tooth eruption and root growth. In the congenital absence of teeth, rudimentary development of the corresponding sections of the alveolar process occurs. Similarly, extensive resorptive changes can be expected when teeth are lost.

The alveolar processes consist of buccal and lingual *cortical plates* of compact bone, a cribriform plate (*lamina cribriformis*) lining the alveoli, and cancellous or trabecular bone between them. Radiographically, the cribriform plate appears as a radiodense line referred to as the *lamina dura*. The cribriform plate (*bundle bone*) is the portion of the alveolar bone where fibers from the periodontal ligament insert (Fig 1-12). In the maxilla, the cortical plate is thicker on the palatal aspect than on the buccal aspect of the roots. The mandibular cortical plate is denser than the maxillary cortical plate, especially in the anterior region and on the lingual and buccal aspects of the molars, where it is reinforced by the *internal and external oblique ridges*.

From a histologic perspective, the bone lamellae are considered the mineralized building blocks of the cortical bone (Fig 1-13). The osteon is the basic functional unit of the cortical bone. Each osteon consists of multiple, densely packed concentric layers of bone lamellae surrounding a central cavity referred to as the *haversian canal*. Each haversian canal contains a neurovascular bundle responsible for supplying blood and nerves to osteocytes in the mineralized bone matrix of the osteon. *Volkmann's canals* connect each haversian canal with those of adjacent osteons, the marrow spaces of cancellous bone, and periosteal blood vessels. However, the overall ratio of blood vessels to bone mass in the cortical bone is low.

The cancellous bone located between the buccal and lingual cortical plate and the cribriform plate consists of a loose network of bone trabeculae between which well-perfused and cell-rich marrow spaces are interposed (Fig 1-14).

The *endosteum lines* the medullary cavities and all other internal bone surfaces in the canals of the cortex, whereas the external surfaces of the bone are lined with *periosteum*. These are thin layers of nonelastic, collagen-rich connective tissue containing osteoblasts, osteoclasts, the corresponding precursor cells, and many blood vessels and nerves responsible for supplying blood and nerves to the bone as well as for bone regeneration.

Alveolar bone undergoes constant remodeling. Through the continuous breakdown and synthesis of lamellae and osteons, osteoblasts and osteoclasts interact to ensure the continuous adaptation to changing functional loads and tissue repair after microtrauma. The endosteum and periosteum play key roles in this complex metabolic activity. Because it is controlled by hormones and growth factors, the bone is a highly reactive and vital tissue.[1,23,24]

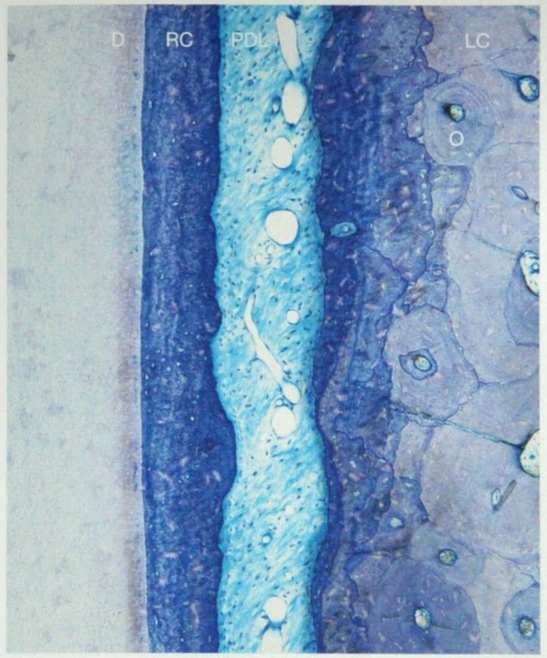

Fig 1-13 Histologic view of the mineralized components of the alveolar bone in the cribriform plate region (LC). Osteons (O), the basic functional units of the compact bone, are clearly visible. D: dentin; RC: root cementum; PDL: periodontal ligament. (Courtesy of *Peter Schüpbach*, Zurich, Switzerland.)

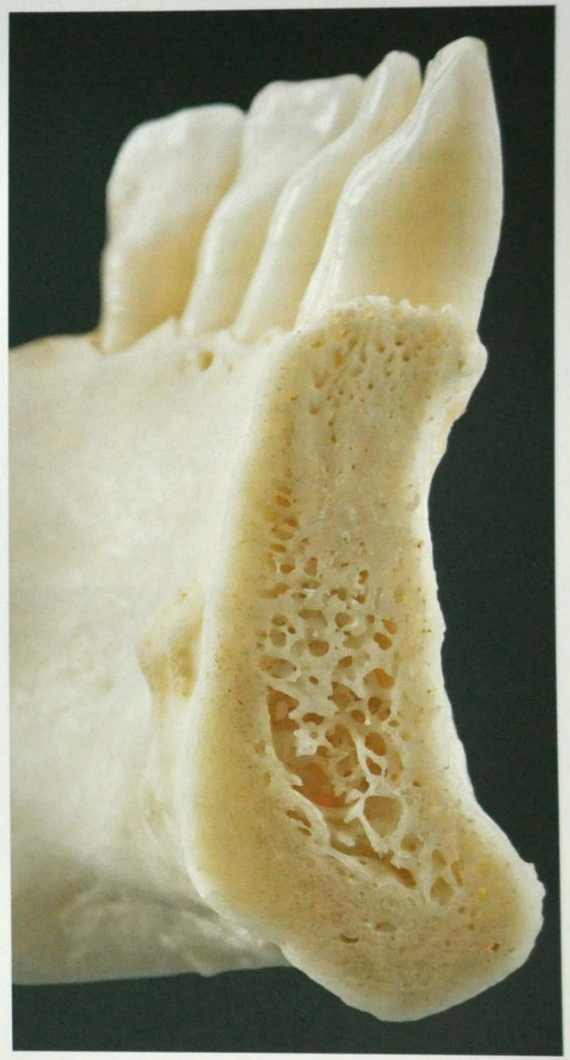

Fig 1-14 Section through the mandible in the region of the anterior teeth.

1.1.4 Blood Supply and Innervation

Healthy periodontal structures are well perfused. The primary blood supply to the maxilla is through the posterior superior alveolar arteries and the anterior superior alveolar arteries coming from the infraorbital arteries. The mandible receives its main blood supply from the inferior alveolar arteries.

The alveolar arteries divide into the dental arteries, which enter at the apices of the roots to supply the teeth. Before doing so, they supply blood to the gingival tissues by giving off branches that pass vertically through the *interdental septa* and the *periodontal ligament* (Fig 1-15). The buccal and lingual gingiva are supplied by numerous *supraperiosteal branches* of the facial arteries, the infraorbital arteries, the incisive artery, and the greater and lesser palatine arteries in the maxilla and by the sublingual arteries, the buccal arteries, and the mental arteries in the mandible. Thus, arterial blood to the periodontal tissues is supplied by vascular sources from three different territories—the interdental septa, the periodontal ligament, and the oral mucosa—and these vessels exhibit frequent anastomoses (Fig 1-16).

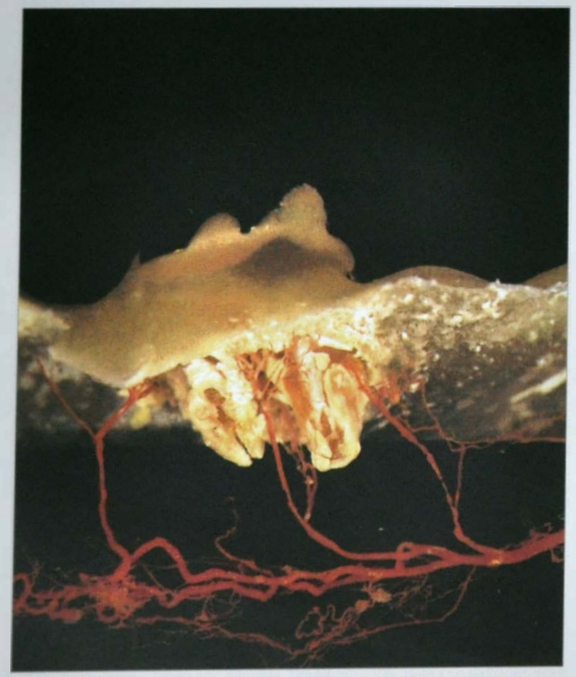

Fig 1-15 Corrosion specimen from the inferior alveolar artery in the mandibular second molar region. The blood vessels supplying the periodontal ligament space and the interdental and interradicular septa are clearly visible. (From *Tillmann.*[25] Reprinted with permission.)

The periodontal ligament contains a very dense vascular network that plays an important role in the absorption and distribution of occlusal forces.[21]

Gingival connective tissue appears to have *two terminal capillary beds*—an *external network* of subepithelial capillary loops below the marginal gingiva and oral epithelium (external network) and an *internal network* of postcapillary venules located below the junctional epithelium, which seems to be of great importance in host defense against infection.[26] Venous drainage of the periodontal ligament occurs via arterioles and arteries.[21]

The periodontium contains autonomic nerve endings as well as sensory receptors, that is, mechanoreceptors and nociceptive nerve fibers capable of sensing and transmitting pain, pressure, and tactile signals. The sensory nerves originate in trigeminal brainstem nuclei and are conducted to the periodontal structures of the maxilla via the second branch of the trigeminal nerve and to the periodontal structures of the mandible via the third branch of the trigeminal nerve. In the maxilla, sensory innervation of the labial gingiva is supplied by infraorbital nerve endings in the anterior and premolar region and by posterior superior alveolar branches in the molar region. The anterior palatal mucosa is supplied by the incisive nerve, whereas the rest of the palatal mucosa is supplied by the greater and lesser palatine nerves. In the mandible, sensory innervation of the labial gingiva is supplied by the mental nerve in the anterior and premolar region and by the buccal nerve in the premolar and molar region. The lingual gingiva is innervated by the sublingual nerve.

The teeth are innervated by the superior alveolar nerves in the maxilla and by the inferior alveolar nerve in the mandible. The pulpodentin complex and the corresponding periodontal space share sensory innervation. Therefore, they form a highly sensitive functional unit that can sense even the slightest forces exerted on the teeth during swallowing and chewing in order to control the mandibular opening and closing reflexes appropriately. Together with the receptors in the periodontium, the proprioceptors in the tendons of the masticatory muscles play a key role in the control of masticatory forces, masticatory movements, jaw position, and speech.[21]

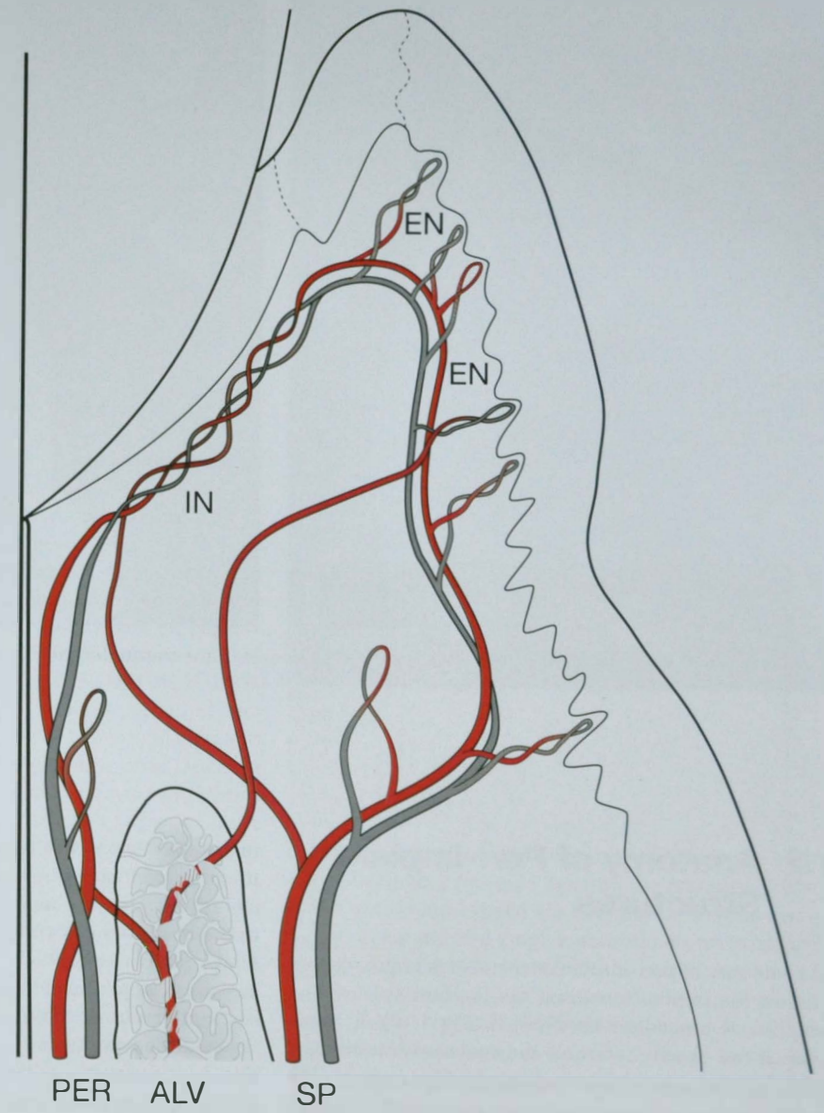

Fig 1-16 Periodontal blood supply. The periodontal tissue receives its blood supply from periodontal (PER), alveolar (ALV), and supraperiosteal (SP) blood vessels. IN: internal network (postcapillary venule plexus); EN: external network (subepithelial capillary loops).

Lymph from the periodontal tissues drains into lymph capillaries, which form a dense network in gingival connective tissue. Larger lymph vessels usually run along blood vessels and empty into lymph nodes. Lymph from periodontal tissues collects in the submental, submandibular, and deep cervical lymph nodes.[21]

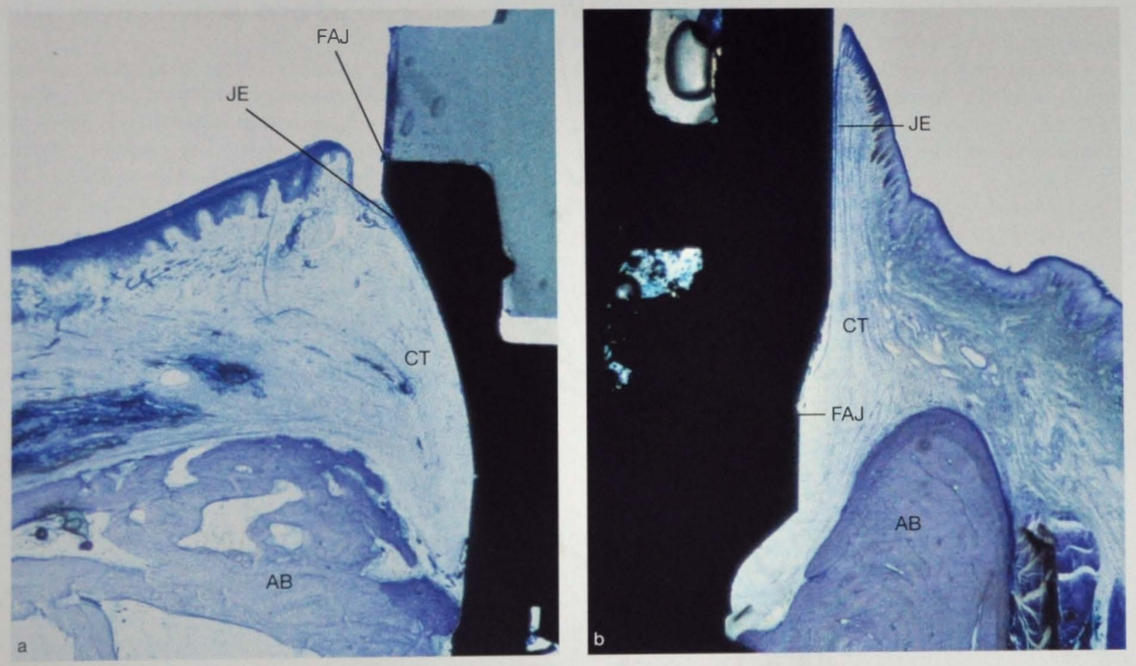

Fig 1-17 (a and b) Histologic views of peri-implant hard and soft tissues. JE: junctional epithelium; CT: connective tissue; AB: alveolar bone; FAJ: fixture-abutment junction. (Courtesy of *Peter Schüpbach*, Zurich, Switzerland.)

1.2 Anatomy of Peri-implant Structures

The anatomy of peri-implant structures is highly dependent on the implant position, the implant system, and the clinical procedure used[23,27,28] (Fig 1-17). In some cases, it can closely resemble the anatomy of structures around the natural teeth at first glance. Although it is impossible to find a general rule that accurately describes the complex architecture of the peri-implant tissue, one thing is certain: The establishment of adequate biologic width around an implant is crucial to the health of the peri-implant structures. The *biologic width* is defined as the sum of the heights of the junctional epithelium and the underlying connective tissue. As in natural teeth, the connective tissue height around implants should consistently fall within the range of approximately 1.0 to 1.5 mm.[23,29–31] Similar to conditions in natural teeth, the junctional epithelium around implants should have a height of 1.5 to 2.0 mm[23,29–31] and should be attached to the implant surface via hemidesmosomes and an internal basal lamina.[32]

The periodontal fibers insert into cementum on the root surfaces of natural teeth, whereas the connective tissue fibers around implants extend parallel to the surface of the implant and/or abutment[23,33,34] (Fig 1-18). Because the connective tissue around implants has a higher percentage of collagen fibers and a lower percentage of fibroblasts than that around natural teeth, it is very similar to scar tissue from a histomorphologic perspective.[35] Moreover, peri-implant connective tissue contains fewer blood vessels than the connective tissue around natural teeth. The gingiva around natural teeth is supplied by vascular sources from three different territories (the supraperiosteal region, the periodontal space, and interdental bone), whereas the *peri-implant mucosa* is only supplied by supraperiosteal vessels and a few vessels from the bone; moreover, no anatomical structure comparable to the periodontal space is present around implants.[36]

Because of these differences, a differential approach to diagnosis and treatment of peri-implant mucosa and the gingiva around natural teeth is necessary. Because of its scar tissue–like structure, absence of inserting fibers, and relatively poor blood supply, peri-implant tissue may be less resistant to mechanical and microbiologic impacts than the tissue around natural teeth.[24] Furthermore, the lower level of perfusion of peri-implant tissue might have a negative effect on healing after surgical interventions. It is important for the clinician to consider these factors when performing plastic-esthetic periodontal surgical procedures involving implants.

A few more important differences should be mentioned. The presence of keratinized gingiva seems to be related to the presence of nonelastic collagen fibers in the underlying connective tissue.[14] Because the majority of fibers in the periodontal space are nonelastic, there is always a band of keratinized gingiva around natural teeth, even if only minimal.[14] Implants, on the other hand, may be seated in either keratinized mucosa or lining mucosa.

Apart from keratinization, the attachment of peri-implant tissue is another important factor to consider. The gingiva around natural teeth forms as part of the biologic development process, whereas peri-implant mucosa forms as the result of the wound healing process following surgical implant placement or second-stage surgery. In cases where the junction between the keratinized mucosa and the lining mucosa comes to lie coronal to the bone in individuals with a high peri-implant soft tissue cuff, peri-implant mucosa may be mobile in spite of keratinization (Fig 1-19).

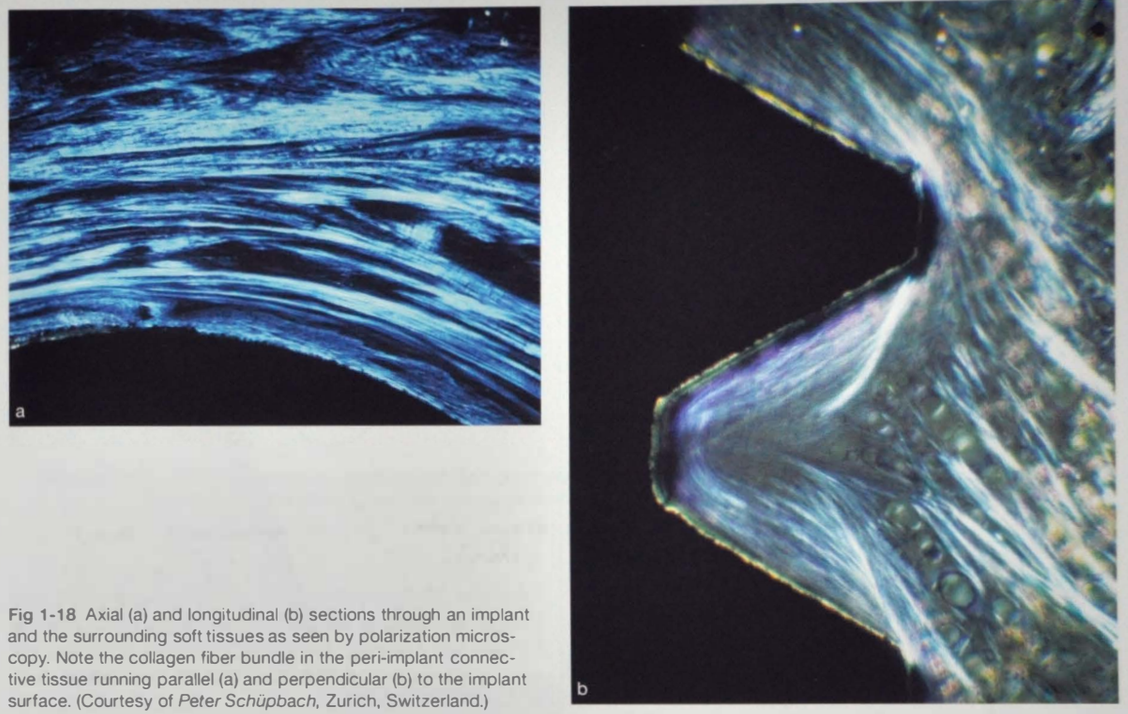

Fig 1-18 Axial (a) and longitudinal (b) sections through an implant and the surrounding soft tissues as seen by polarization microscopy. Note the collagen fiber bundle in the peri-implant connective tissue running parallel (a) and perpendicular (b) to the implant surface. (Courtesy of *Peter Schüpbach*, Zurich, Switzerland.)

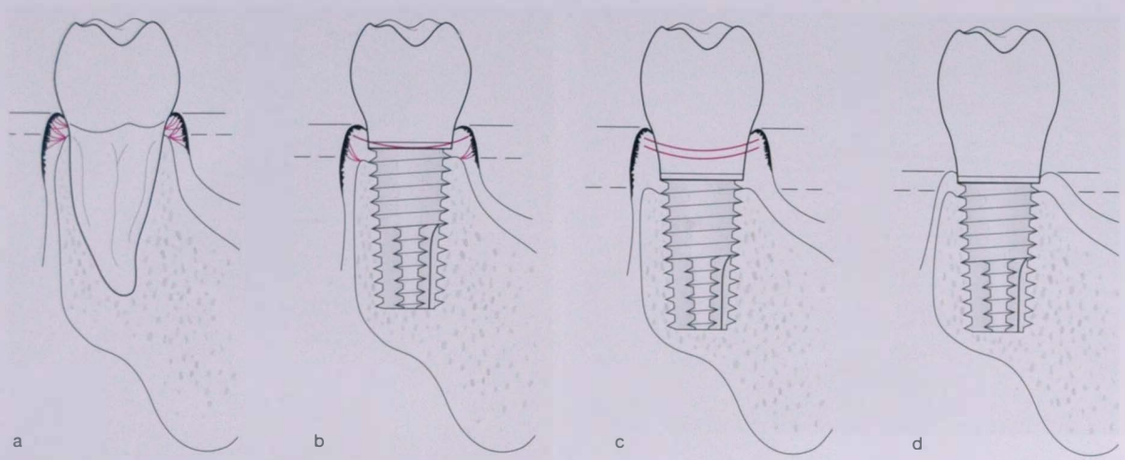

Fig 1-19 In contrast to the mucosa around natural teeth (a), peri-implant mucosa may be either keratinized (b and c) or nonkeratinized (d). Peri-implant mucosa may be mobile and not attached to the underlying peri-implant bone in spite of keratinization (c).

1.3 Biologic Relationships and Their Clinical Relevance

1.3.1 Biologic Width

The fact that teeth or implants emerge through the oral mucosa means that they interrupt the integrity of the epithelial lining. This places special configurational demands on the affected structures. The fundamental task of the gingiva or peri-implant mucosa at these weak spots is to protect the underlying anatomical structures from mechanical and biologic stress (Fig 1-20).

The gingiva fulfills this task by forming a combination of *epithelial* and *connective tissue attachments* on the tooth surface.[15] Epithelial attachment has a biologic protective function, while connective tissue attachment appears to confer mechanical stability.[37] The *biologic width* is the sum of these two structures.[38] Therefore, the biologic width can be understood as the body's response to the special challenges at the site where a tooth emerges through the oral mucosa.

The biologic width around natural teeth was found to be a mean of 2.04 mm, calculated as the sum of the levels of connective tissue attachment (1.07 mm) and epithelial attachment (0.97 mm).[15] The level of connective tissue attachment remains very constant, whereas the level of epithelial attachment is subject to strong individual variation.[15,16]

Likewise, the protective function of peri-implant mucosa is to establish the required biologic width around an implant. Although its connective tissue fibers run not perpendicular but rather parallel to the implant or abutment surface, the dimensions of epithelial and connective tissue attachment are comparable to those of natural teeth.[23]

Many contemporary periodontal, dental implant, and prosthodontic concepts are shaped by recent knowledge concerning the establishment and violation of the biologic width, although many questions and correlations have yet to be definitively explained (Fig 1-21).

Biologic width and dental prosthetics

The biologic width is of relevance to the prosthetic restoration of teeth only when intrasulcular restoration margins will be used for esthetic or functional reasons.[39] If the preparation margin extends to the epithelial or connective tissue attachment zone apical to the bottom of the sulcus, the microbiologic contact zone will be displaced apically. As the body reacts to this *violation of the biologic width*, adaptive and adjustment processes in the epithelial and connective tissue attachment zone can be expected.[40]

The affected tissues can launch two different types of response. The first is a self-regulatory response that attempts to restore adequate biologic width. This response is associated with the loss of alveolar bone and the clini-

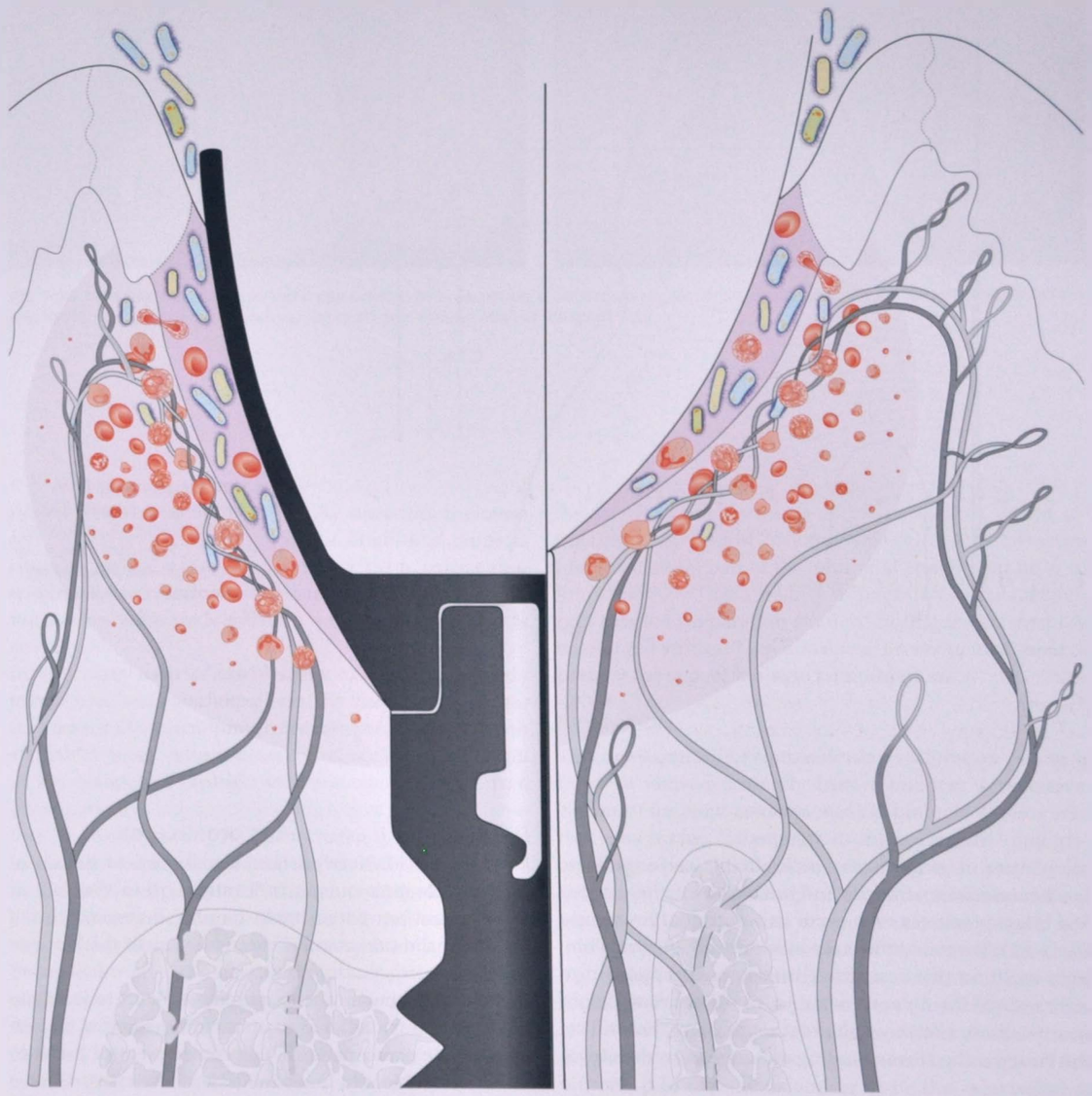

Fig 1-20 The establishment of the biologic width can be understood as the body's response to special microbiologic challenges at the site of emergence of implants and teeth in the oral cavity. The junctional epithelium functions as a semipermeable membrane that allows active interaction between microorganisms from the oral cavity on the one side and the host immune system on the other to keep the bone from becoming infected. Apical to this microbiologic contact zone, there is always a completely intact layer of connective tissue of more or less constant dimension that appears to serve as a barrier protecting the underlying alveolar bone.

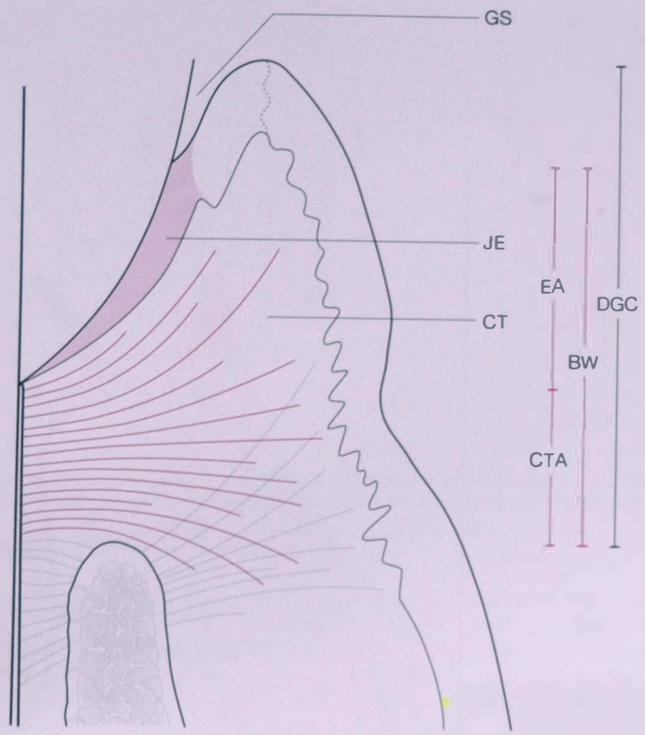

Fig 1-21 Biologic width (BW) and dentogingival complex (DGC). GS: gingival sulcus; JE: junctional epithelium; CT: gingival connective tissue; EA: epithelial attachment; CTA: connective tissue attachment.

cal picture of *gingival recession*. If this self-regulatory mechanism fails, *chronic inflammation* of the gingiva and other processes may occur as a secondary response (Fig 1-22). To enable the body to restore an adequate biologic width in this case, the clinician must either surgically reduce the alveolar bone to an appropriate height or orthodontically move the tooth, and thus the restoration margin, the corresponding distance from the alveolar bone.

At the present time, there is no evidence of a method that reliably predicts how the body will react to such a violation of the biologic width in a given case, but the possibility that the thickness of the affected alveolar bone might have a significant impact on this process has been discussed. Notwithstanding, the rule of thumb is: If the restoration margin is located within the sulcus, the preparation margin must be placed coronal to the bottom of the sulcus to prevent violation of the biologic width.[41]

In clinical practice, it is extremely difficult to estimate how far intrasulcularly a preparation margin can be placed in a given patient. The dimensions of biologic width are subject to great individual variation. Consequently, all published reference values are mean values with limited applicability.[16] Furthermore, the probing depth or clinical sulcular depth measured at chairside is not always consistent with the histologic sulcular depth.[42] According to *Kois*,[43] it is better to measure

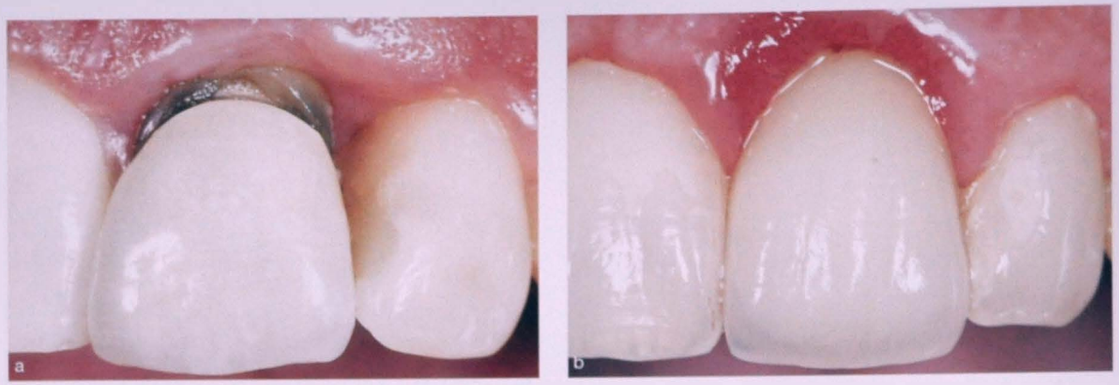

Fig 1-22 Violation of the biologic width can result in two responses, a self-regulatory response associated with the loss of alveolar bone and the formation of gingival recession (a) or chronic inflammation of the gingiva (b).

the total dentogingival complex by sounding the osseous crest with a periodontal probe. High total gingival complex values suggest a relatively deep sulcus that would allow preparation to extend relatively far into the sulcus, whereas low values suggest that caution is advised.[43]

In any case, each of these methods—depth measurements and bone sounding—can be considered an improvement of clinical procedure compared to relying on statistical mean values. Even so, reliable determination of the amount of biologic width actually present in a given patient is not possible using either method. Therefore, it would seem prudent to make it a general rule to place an intrasulcular preparation margin as coronal in the sulcus as possible. Placing the restoration margin at an intrasulcular depth of 0.2 to 0.5 mm can be considered safe for all conceivable anatomical variations.[44] Because the sulcus is usually slightly deeper interproximally, the intrasulcular margin can be placed slightly deeper in that region.[45]

Contrary to scientific theory, clinical practice has shown that most patients tolerate restoration margins that seem to lie slightly apical to the bottom of the sulcus.[44] It is therefore conceivable that there is a certain range of tolerance to inflammatory response, the extent of which may vary from one patient to another.

Should a restoration margin be placed any deeper than the safe intrasulcular range of 0.2 to 0.5 mm, a thin retraction cord should be inserted with gentle pressure into the coronal part of the epithelial attachment prior to preparation.[46] This is vitally important; cord placement prevents the preparation from extending too far past the base of the sulcus. This procedure seems to minimize or prevent the risk of biologic complications.

Key points:

The preparation of intrasulcular restoration margins must be viewed critically from a biologic perspective. The most frequent consequences of biologic width violation are chronic inflammation of the gingiva[47] and gingival recession.[48] Therefore, restoration margins should be placed supragingivally or crestally whenever possible. Should a restoration margin end in the gingival sulcus, the clinician should estimate the dimensions of the available biologic width. This can be accomplished by measuring the clinical sulcular depth (probing depth) or total dentogingival complex using a periodontal probe. Preparation margins that do not extend more than 0.2 to 0.5 mm into the sulcus appear to be the safest. Should the preparation margin be placed any deeper, the insertion of a thin retraction cord with gentle pressure into the coronal part of the epithelial attachment prior to preparation can reduce the risk of later biologic complications (Fig 1-23).

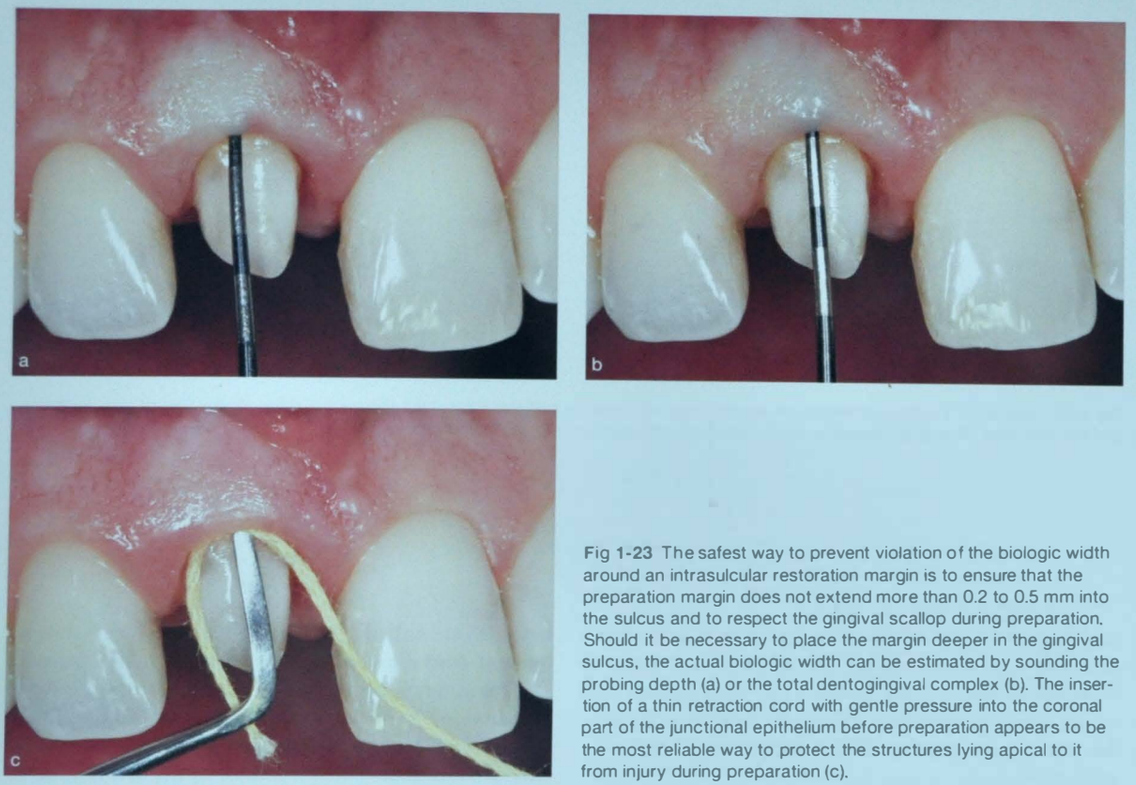

Fig 1-23 The safest way to prevent violation of the biologic width around an intrasulcular restoration margin is to ensure that the preparation margin does not extend more than 0.2 to 0.5 mm into the sulcus and to respect the gingival scallop during preparation. Should it be necessary to place the margin deeper in the gingival sulcus, the actual biologic width can be estimated by sounding the probing depth (a) or the total dentogingival complex (b). The insertion of a thin retraction cord with gentle pressure into the coronal part of the junctional epithelium before preparation appears to be the most reliable way to protect the structures lying apical to it from injury during preparation (c).

Biologic width and resective periodontal surgery

If periodontal surgery is to result in predictable apical displacement of the gingival margin, then the biologic width must be regarded as a constant dimension.

Whenever connective tissue or epithelial attachment is completely or partially removed during external gingivectomy or apically displaced during apical flap repositioning, the biologic width is always reestablished during the course of the healing process. Once healing is complete, a soft tissue height of approximately 3 mm and 4 mm above the bone level can be expected at buccal/lingual and interproximal sites, respectively.[45,49,50]

Because the reestablishment of biologic width can result from the coronal growth of the gingiva, the apical development of soft tissue in association with the related resorption of marginal alveolar bone, or a combination of these two processes, it is difficult to predict the final gingival margin position (Fig 1-24). This causes problems for the clinician during esthetic crown lengthening, for example, because the predicted gingival margin position is a defined goal of treatment that should be met as precisely as possible. To obtain successful and predictable results when performing such procedures, the clinician must precisely adapt the technique to the specific anatomical conditions present at baseline (see chapter 10).

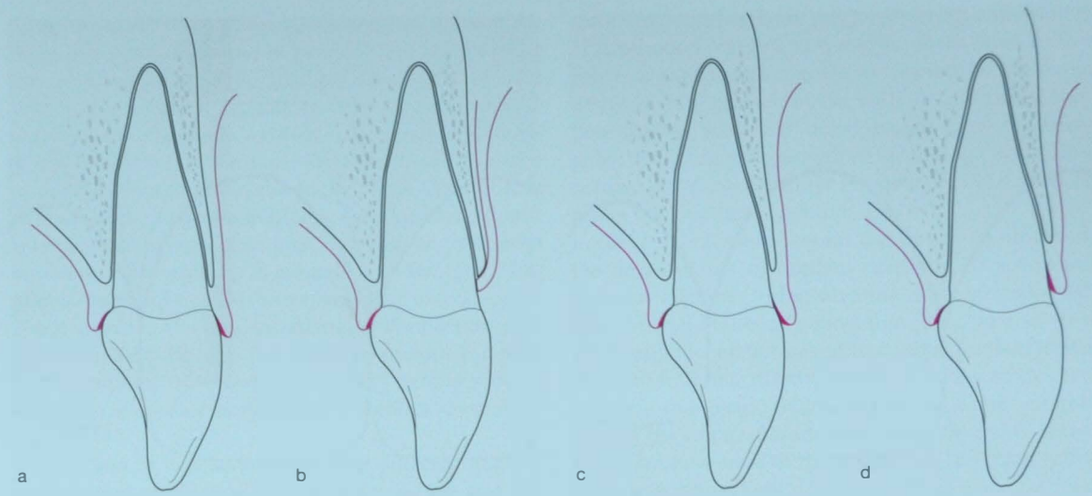

Fig 1-24 Whenever marginal connective tissue (a) is removed during the course of external gingivectomy or apically positioned flap surgery (b), biologic width growth can occur in an apical (c) and/or coronal (d) direction during the subsequent course of healing.

Biologic width and implant dentistry

Achieving naturally beautiful results in the esthetic zone has become one of the greatest challenges in modern implant dentistry. Ensuring the best possible preservation or reconstruction of peri-implant hard and soft tissues is crucial to achieving this goal.

From the contemporary perspective, the results of animal studies suggest that the development of hard tissue defects after tooth extraction cannot be prevented entirely.[51–53] Furthermore, the surgical trauma associated with implant bed preparation,[54] occlusal overloading following prosthetic implant loading,[55,56] peri-implant inflammation,[24,57] and the establishment of biologic width around implants during the course of healing[58] can lead to an additional loss of peri-implant bone secondary to the loss of soft tissue. From biologic and esthetic perspectives, the goal must therefore be to prevent, as far as possible, additional loss of peri-implant bone during the establishment of biologic width around an implant.

A number of studies have been conducted to elucidate the processes surrounding the development of biologic width around implants. Although the only available prospective, controlled histomorphologic study data are based on animal models, these findings can be extrapolated to understand the situation in humans, as documented using individual biopsy specimens. These studies fundamentally explain the radiographic changes in the peri-implant bone as detected in numerous human experimental studies. The results of exemplary animal studies investigating the establishment of biologic width around dental implants will be summarized below.

Ericsson et al[59,60] performed various studies on the establishment of biologic width around crestally positioned two-piece implants after one-stage and two-stage healing. They concluded that vertical bone loss must be expected around implants placed in a one-stage or two-stage approach and determined that the most coronal bone-to-implant contact lies at a mean of 1.1 to 1.3 mm apical to the implant-abutment connection.

They also identified two spatially distinct types of inflammatory infiltrate present in the peri-implant connective tissues. The first type (plaque-related inflammatory infiltrate) is located lateral to the junctional epithelium, and the second type is present in the region of the implant-abutment connection. The latter type of inflammatory infiltrate extends approximately 0.5 mm in the coronal,

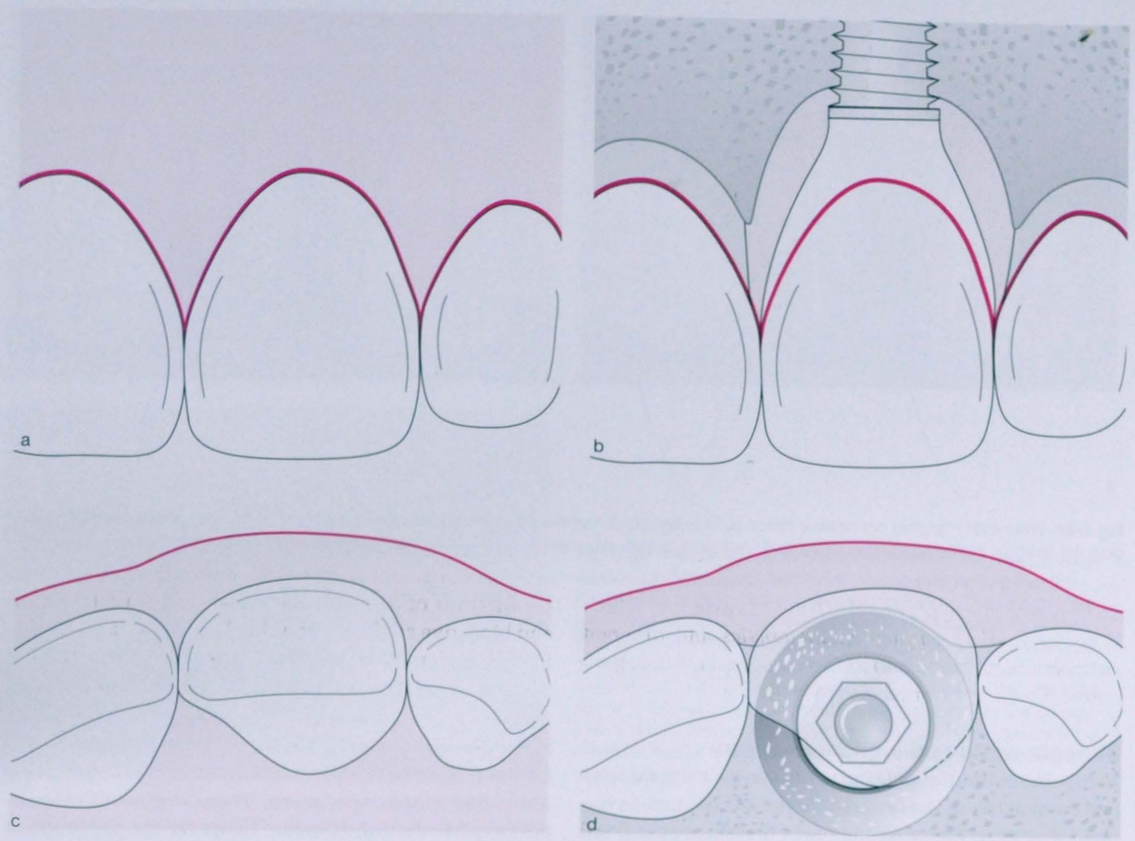

Fig 1-25 (a to d) The establishment of biologic width around an implant is a three-dimensional process similar to that around natural teeth.

apical, and lateral directions, and there is always an approximately 0.8-mm-wide layer of healthy connective tissue between the bone and the infiltrate. *Ericsson's* team interpreted this to mean that the microspace between the abutment and the implant shoulder is at the center of the inflammatory response associated with the formation of the inflammatory infiltrate.

The bone is apparently protected from this inflammatory infiltrate and kept sterile in all spatial directions by a constant layer of healthy connective tissue, similar to the situation in natural teeth. Consequently, the establishment of biologic width around a dental implant is a three-dimensional process, and the peri-implant bone loss occurring in association with this process has a horizontal component as well as the aforementioned vertical component[61] (Fig 1-25).

Other animal studies confirmed the findings of *Ericsson's* group,[59,60] which, although obtained using *Brånemark* implants, are fundamentally valid for other implant systems as well.[29,62]

Hermann et al[63,64] compared the resorption and remodeling processes occurring in peri-implant bone during the course of establishment of biologic width around one- and two-piece implant systems based on radiographic and histologic evidence collected in animal studies; they found that bone loss was directly related to the insertion depth of the implants. In the group of animals with one-piece implants, they observed that it was possible to stop bone loss at the rough-to-smooth junction of the implant. In animals with two-piece implants, bone loss could be expected to extend up to 2 mm apical to the implant-abutment connection and, in some cases, beyond the rough-to-smooth junction of the implant. However, subsequent animal studies and clinical studies have failed to confirm these findings.[29,65,66]

Nonetheless, it can be assumed that different implant systems and differences in their macrodesign and microdesign characteristics result in remodeling and adaptive processes of variable extent.[29,67] In the case of two-piece implants systems, the type of *abutment material* used also seems to play a role,[68] but the extent to which different *implant surface characteristics* and different *biomechanical characteristics* of the implant-abutment connection may be of relevance is unclear.

In an animal study prompted by questions relating to implant design, *Berglundh* and *Lindhe*[31] demonstrated that the *thickness of the peri-implant soft tissue* affects the extent of bone resorption occurring after second-stage surgery in association with the establishment of biologic width. They observed that animals with iatrogenic thinning of peri-implant soft tissues at the time of second-stage surgery developed greater peri-implant bone loss than did a nonmanipulated control group. They hypothesized that a minimum thickness of peri-implant soft tissue is needed for the establishment of biologic width and that, if necessary, the body's self-protective mechanism will ensure that these conditions are met at the expense of peri-implant bone.

Animal studies also showed that repeated *insertion and removal of threaded implant components* results in apical migration of the junctional epithelium with a consequent loss of peri-implant bone. This can be interpreted as repeated trauma to the connective tissue attached to the abutment and impairment of the related wound healing processes, which can be particularly relevant in the case of deeply inserted implants.[30]

The establishment of biologic width around an implant is part of an important endogenous fallback system. From the biologic and esthetic perspectives, an important goal of continuing research and development must be to improve methods to encourage the growth of the biologic width in a coronal direction without additional loss of peri-implant bone. The development of an implant capable of allowing the growth of the biologic width in the coronal direction based on the existing bone level falls under the heading of *periointegration*.

In this context, ssome recent trends can be observed in the development of implant dentistry. The first trend involves attempts to improve the microbiologic seal at the implant-abutment connection. The goal is to use the prosthetic advantages of two-piece implant systems without suffering disadvantages in terms of the establishment of biologic width. Achieving a *tight microbial seal at the implant-abutment connection* and *preventing micromovement* in this region are the main goals of these scientific efforts.

The second research trend involves efforts to optimize the *distribution of forces* in peri-implant bone in the coronal portion of implants based on the biomechanical findings of finite-element analysis. Microretention and bioactive surfaces should help to stabilize the bone in this region. Adequate wall strength in the coronal portion of an implant also appears to be an important factor.

One-piece scalloped implants were developed in an attempt to meet these demands while allowing for a scalloped shape of peri-implant bone according to the model of the natural teeth.[69] Theoretically, scalloped implants should enhance the preservation of hard and soft tissues between two implants. However, due to the lack of clinical success, the initial euphoria surrounding the scalloped implant design has sharply declined.

Platform switching pursues the same goal with a new design concept based on the theory that horizontally shifting the microbiologic contact zone away from the peri-implant bone and more toward the center of the implant will prevent bone loss.[70] Great hopes are pinned on the further development of platform switching. Although the first clinical and animal study findings support the platform switching concept and the hypothesis that it leads to horizontal shifting of the biologic width and thus allows for preservation of peri-implant bone in a more coronal position, they also showed that the bone preserving effect does not occur in every case and that the extent of this effect is variable[71,72] (Fig 1-26).

Fig 1-26 Innovative implant designs are being developed with the goal of enhancing the growth of the biologic width in the coronal direction.

Unlike the gingiva around natural teeth, the biologic width around implants lacks the insertion of connective tissue fibers horizontally into the abutment or implant surface and strong perfusion of the marginal soft tissue. Consequently, implants may have a lower resistance to external mechanical and microbiologic stresses.[24] In the future, it might be possible to enhance the resistance of the biologic width around implants by modifying the implant and/or abutment surface to allow connective tissue fibers to attach to implants similar to the way they attach to the cementum of natural teeth.[73]

Key points:

The fact that implants, like natural teeth, are exposed to the microbial environment of the oral cavity triggers adaptive processes intended to protect deep structures from infection. These processes result in the formation of biologic width, which leads to a three-dimensional loss of peri-implant bone due to remodeling processes.[61] Other undesirable consequences include soft tissue changes, consisting of gingival recession and loss of papillary height on the buccal and interproximal surfaces, respectively. From biologic and esthetic perspectives, it is not desirable to have the establishment of biologic width around an implant result in a loss of bone or soft tissue. Therefore, researchers are currently discussing a number of different factors that could have a positive effect on bone remodeling, including the stability of the implant-abutment connection, the microbial seal of the implant-abutment connection, and the microstructural and macrostructural characteristics in the coronal portion of implants. It is unclear whether other as yet unidentified factors may also play a role. The challenge in the future will be to identify all of the relevant factors and to understand how they interact. The goal would be to apply this knowledge to create new implant designs and clinical treatment protocols capable of predictably achieving more complete and stable preservation of peri-implant hard and soft tissues in the long-term.

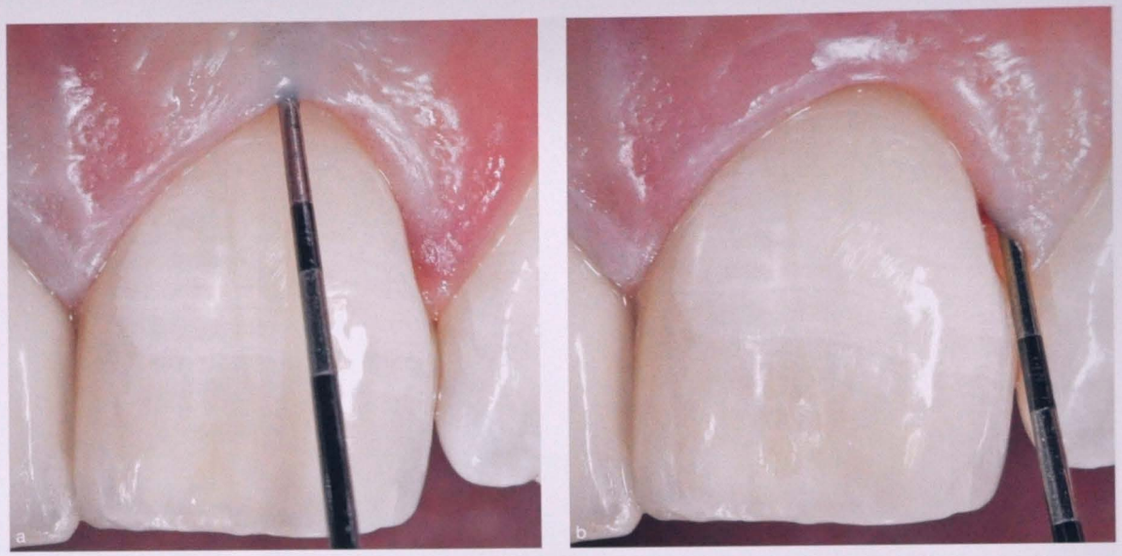

Fig 1-27 (a and b) The dentogingival complex can be measured by sounding to bone with a periodontal probe. The dimensions of the normal dentogingival complex are approximately 3.0 mm buccally and lingually and a mean of 4.5 to 5.0 mm interproximally.

1.3.2 Dentogingival Complex

The dentogingival complex is the sum of all supracrestal soft tissue components. Histomorphologically, the *dentogingival complex* is the sum of the biologic width and the gingival sulcus. In natural teeth, the vertical dimension of the dentogingival complex is approximately 3.0 mm at buccal and lingual sites. At interdental sites, the values are slightly higher (about 4.5 to 5.0 mm), presumably due to the support provided to the interdental soft tissues by adjacent teeth.[43]

Like the biologic width, the dentogingival complex is subject to individual variation.[15,16] Unlike the biologic width, however, the dentogingival complex can be measured by sounding to the alveolar bone with a periodontal probe under local anesthesia and increased pressure (Fig 1-27). Therefore, the clinical relevance of the dentogingival complex is much greater than that of the biologic width, which cannot be measured at chairside.

The dimension of the dentogingival complex is of greatest relevance to the clinician when the gingival contour is to be changed in the context of esthetic crown lengthening (see chapter 10). Measurement of the dentogingival complex is also useful where intrasulcular restoration margins are used.

1.3.3 Position of the Osseous Crest

The osseous crest is positioned 1 to 2 mm apical and parallel to the cementoenamel junction. The interdental bone septa rise slightly in the coronal direction, whereas the facial and lingual aspects of the alveolar bone crest arch apically (Fig 1-28). The degree of scallop of the osseous crest flattens progressively from anterior to posterior (Fig 1-29).

Dehiscence and fenestration of the alveolar bone are not uncommon, particularly in the maxillary anterior region (Fig 1-30).

The presence of supporting bone is important because it provides a supportive base for and positional stability to the soft tissue of the dentogingival complex.[74] Gingival recession can develop only in the presence of alveolar

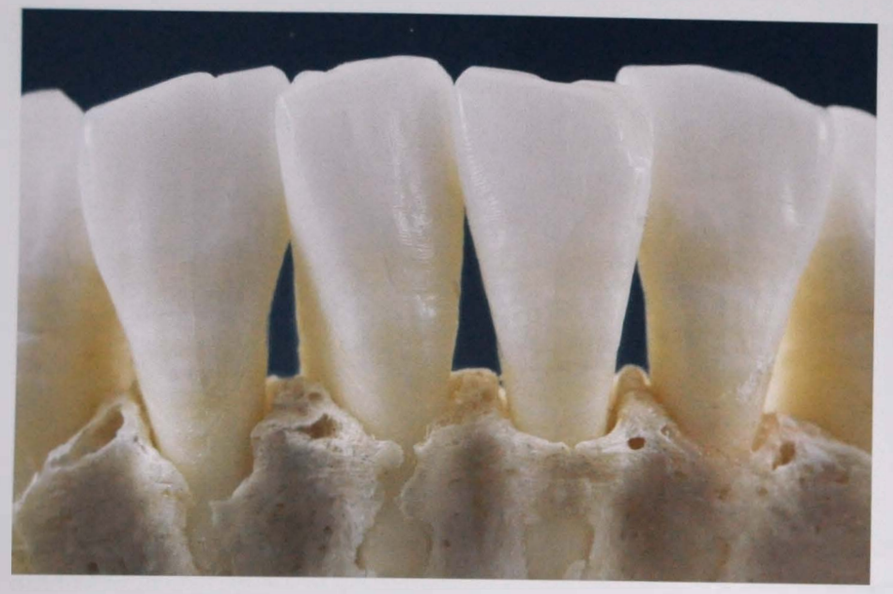

Fig 1-28 The alveolar bone follows the cementoenamel junction at a distance of 1 to 2 mm.

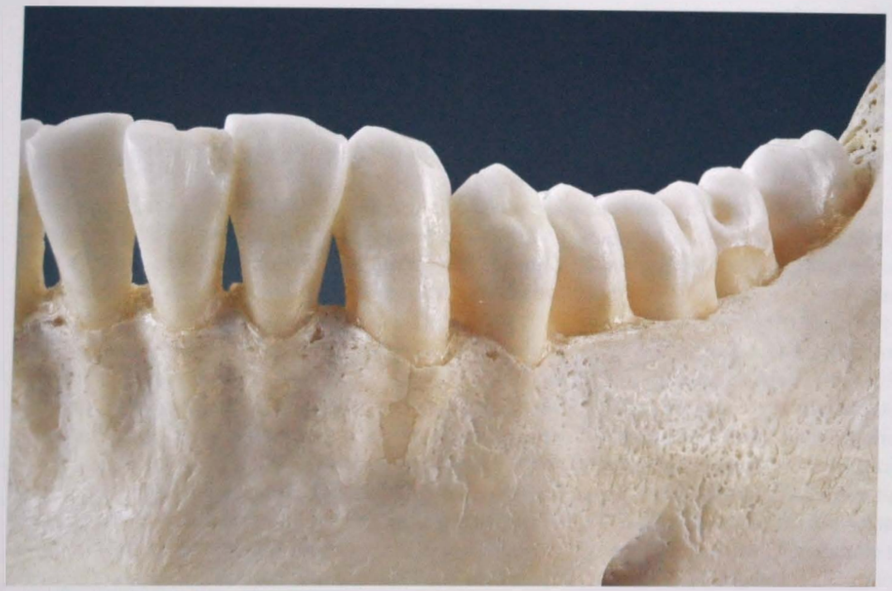

Fig 1-29 Like the cementoenamel junction, the degree of scallop of the alveolar bone decreases progressively from anterior to posterior.

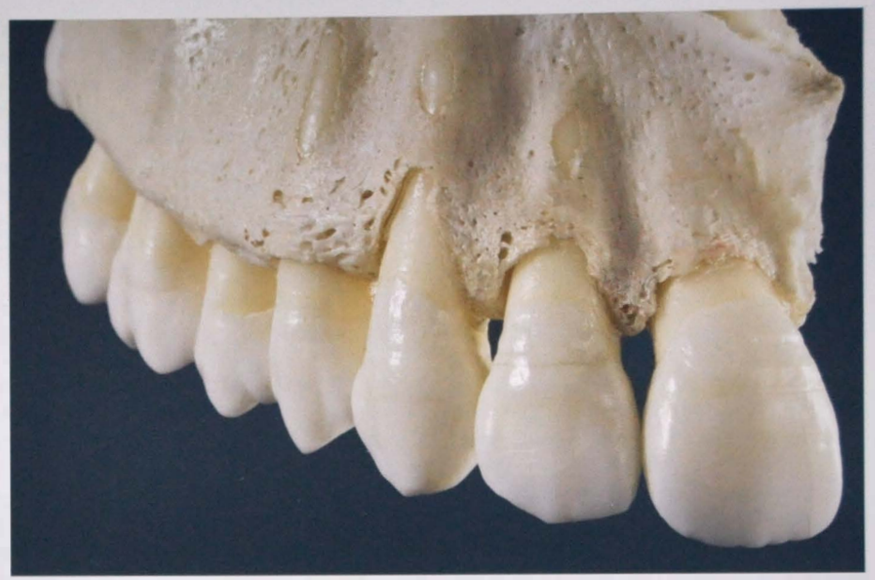

Fig 1-30 Dehiscence and fenestration of the alveolar bone are common, particularly in the maxillary anterior region.

Table 1-1

Classification of osseous crest type according to *Kois*[43]

Crest type	Incidence	TDC, buccal	TDC, interdental
Normal	85%	3.0 mm	3.0–4.5 mm
Low	13%	> 3.0 mm	> 4.5 mm
High	2%	< 3.0 mm	< 3.0 mm

TDC: total dentogingival complex.

bone dehiscences, which would allow the supracrestal soft tissue to recede without violation of the biologic width (see chapter 9).

Three types of relationships can be distinguished between the osseous crest and soft tissue: normal crest, low crest, and high crest[43] (Table 1-1).When the dimension of the dentogingival complex is measured, the vertical distance from the osseous crest to the free gingival margin can vary. Under healthy periodontal conditions, the osseous crest type of the dentogingival complex can be determined by clinical measurement. However, the dentogingival complex and the osseous crest type do not differ in terms of their clinical relevance.

1.3.4 Gingival Biotypes

Clinical differences in the shape, position, and thickness of the marginal periodontium can be distinguished. *Normal, thick flat, and thin scalloped gingival biotypes* or phenotypes can be distinguished based on these differences.[75]

The thin scalloped biotype is characterized by a highly scalloped gingival architecture, relatively thin and fragile gingival tissue, a narrow band of keratinized gingiva, the frequent occurrence of osseous dehiscence and fenestration, triangular anatomical crowns with short interproximal contacts in the incisal third, and a flat emergence profile.

The thick flat biotype is characterized by a relatively flat soft tissue and bony architecture, thick, dense, and fibrotic soft tissue, a wide band of keratinized gingiva, and rectangular or square anatomical crowns with a pronounced emergence profile and long interproximal contacts that often extend into the cervical third. The interdental papillae are long in the thin scalloped biotype, whereas those in the thick flat biotype are short.[76,77]

Individuals with the thin gingival biotype have a high risk of developing gingival recession on buccal tooth surfaces and in the papillary region after prosthetic, orthodontic, and surgical interventions. Conversely, individuals with the thick gingival biotype are less susceptible to gingival recession but have an increased risk of inflammation and pocket formation following treatment.[76,78–80]

The classification of thick and thin gingival biotypes is subjective and operator dependent because the borderline between what constitutes the different biotypes can be unclear (Fig 1-31). Based on clinical experience, there seems to be a direct correlation between tooth morphology and gingival biotype. Therefore, it would seem that tooth morphology could be useful as an objective parameter of gingival biotype, as was proposed by *Olsson* et al.[76,77] However, there is no scientific evidence confirming this hypothesis.

From the current perspective, the gingival biotype is one of the most important prognostic factors of the predictability of a plastic-esthetic periodontal surgery or implant surgery.

1.3.5 Keratinized Gingiva Around Teeth and Implants

As mentioned previously, there is always at least a minimal band of keratinized gingiva around natural teeth. For many years, a band of keratinized gingiva several millimeters wide was considered the prerequisite for keeping the periodontal tissue inflammation free and stable.[4,81,82] *Lang* and *Löe*[82] conducted a clinical study showing that sites with less than 2 mm of keratinized gingiva and less than 1 mm of attached gingiva exhibited significantly more signs of inflammation. Subsequent studies did not confirm these findings.[83–85] Furthermore, long-term clinical studies showed that the incidence of gingival recession on buccal tooth surfaces with narrow gingiva was not higher than that at surfaces with a wide zone of keratinized gingiva.[86–89] The fact that gingival recession is frequently associated with the narrow band of keratinized gingiva would seem to imply that the narrow band of keratinized gingiva is a consequence rather than the cause of gingival recession.[90]

The thickness of the gingival tissue at the affected tooth surfaces is probably more important for the development of recession. Thin gingival tissue seems to be the least resistant to the development of recession in individuals with toothbrush trauma or plaque-related inflammation.[91–93]

Ericsson and *Lindhe*[94] studied the relationship between the presence of keratinized gingiva and the development of gingival recession at sites with subgingival restoration margins and inflammatory changes. Eight months after placing cotton floss ligatures around the necks of the mandibular third and fourth premolars to induce experimental periodontitis in dogs, they performed surgical periodontitis treatment, consisting of an apically positioned flap in the control group and a gingivectomy in the test group. The keratinized gingiva was largely preserved in the apically positioned flap group and completely removed in the gingivectomy group.

After 4 months of intensive oral hygiene, the height of the gingival margin was marked by notching the affected teeth, and steel bands were cemented to the teeth at an intrasulcular depth of 1 mm. After another 6 months without oral hygiene, the animals were killed and histologically examined. Recession occurred more frequently in the test group than in the control group. However, the histologic examination showed that the healed gingiva was thinner after a gingivectomy that after an apically positioned flap. The authors therefore discussed a potential effect of gingival thickness on the development of recession in the group lacking keratinized gingiva.

Wennström and *Lindhe*[95] compared plaque-induced gingival inflammation in dogs with a wide zone of keratinized gingiva to that in dogs with a surgically narrowed zone of keratinized gingiva. No clinical signs of inflammation were detected in either the test group or the control group during the period in which adequate oral hygiene was provided. After 40 days without oral hygiene, clinical signs of inflammation developed. Inflammation was more severe around teeth with a narrow zone of keratinized gingiva than around those with a wide zone of keratinized gingiva.

Contrary to the clinical assessment, the subsequent histologic evaluation showed that the inflammatory infiltrates in the test group and control group were nearly identical in extent. The only difference was a *smaller*

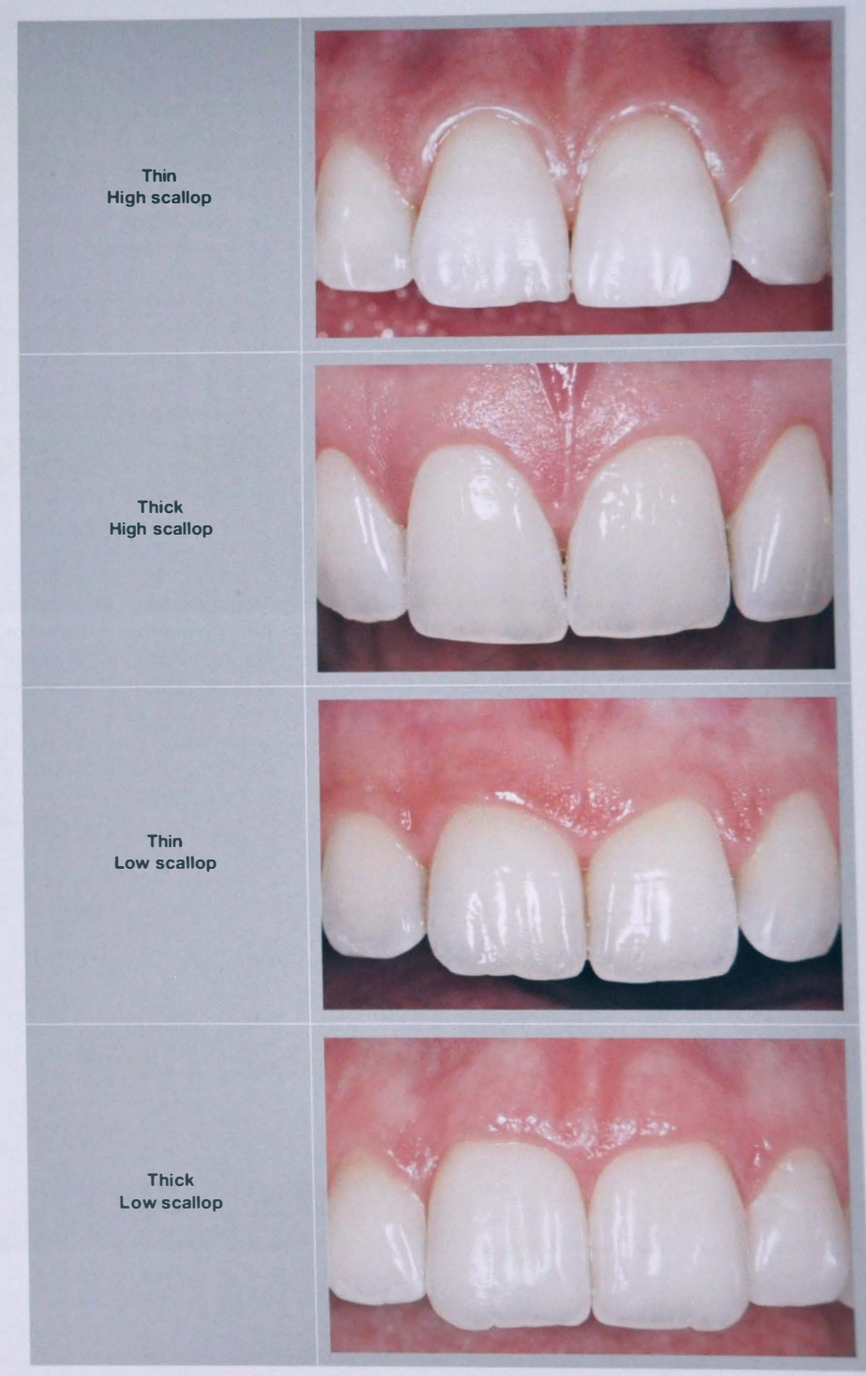

Fig 1-31 The classification of thick and thin gingival biotypes can be indistinct. Furthermore, it would appear that a scalloped margin and a flat gingival margin can be present independent of the given biotype.

dimension of marginal soft tissue *in the buccolingual direction* and a *lower degree of keratinization* of the covering epithelium in the group with the narrow zone of keratinized gingiva. The authors concluded that the inflammatory responses of teeth with a wide zone of keratinized gingiva were not significantly different from the responses of teeth with a narrow zone after 40 days without oral hygiene. The reduced thickness of the marginal soft tissue and the lower degree of keratinization of the covering epithelium in teeth with a narrow zone of keratinized gingiva only led to greater visibility of the blood vessels, which was clinically misinterpreted as a sign of more severe inflammation.

These results could explain why thin gingival tissue is more prone to recession in the presence of inflammation than thick gingival tissue. Although the size of the inflammatory infiltrate is the same in both cases, it occupies a larger proportion of the available soft tissue space at sites with a thin gingiva than at those with a thick gingiva. This could lower the resistance of the tissues, which could lead to the development of gingival recession in response to external stimuli.

In contrast to natural teeth, implants may be seated entirely in lining mucosa. The question of whether the presence of an adequate zone of masticatory mucosa around implants improves implant survival rates remains controversial,[96–98] although there is increasing evidence that the absence of keratinized tissue around implants can promote the development of peri-implant inflammation and recession.[99–102] After reviewing the literature, *Bühler-Frey* and *Burkhardt*[103] came to the conclusion that there is scientific evidence demonstrating that the absence of keratinized and attached mucosa around implants is associated with the development of gingival recession but is not correlated to the implant survival rate. In this context, the question of whether the thickness of the peri-implant mucosa affects the development of gingival recession has yet to be answered from a scientific perspective.

Although the impact of keratinized gingiva on the health and stability of gingival and peri-implant tissue is the subject of some controversy, it is certainly important from a clinical perspective. The presence of keratinized tissue makes it easier for the clinician to perform prosthetic procedures and makes it easier for the patient to perform home oral hygiene. Consequently, surgical procedures to widen the keratinized tissue components would appear to be useful, particularly where subgingival restoration margins and implants are involved.

From an esthetic perspective, detached from the medical debate, the presence of keratinized tissue is absolutely essential. A harmonious and even gingival margin as well as inflammation-free, pale pink, stippled, and keratinized tissue surfaces are symbols of perfect "pink esthetics." Therefore, it is inconceivable that good results of plastic-esthetic periodontal or implant surgery could ever be achieved without keratinized tissue (Fig 1-32).

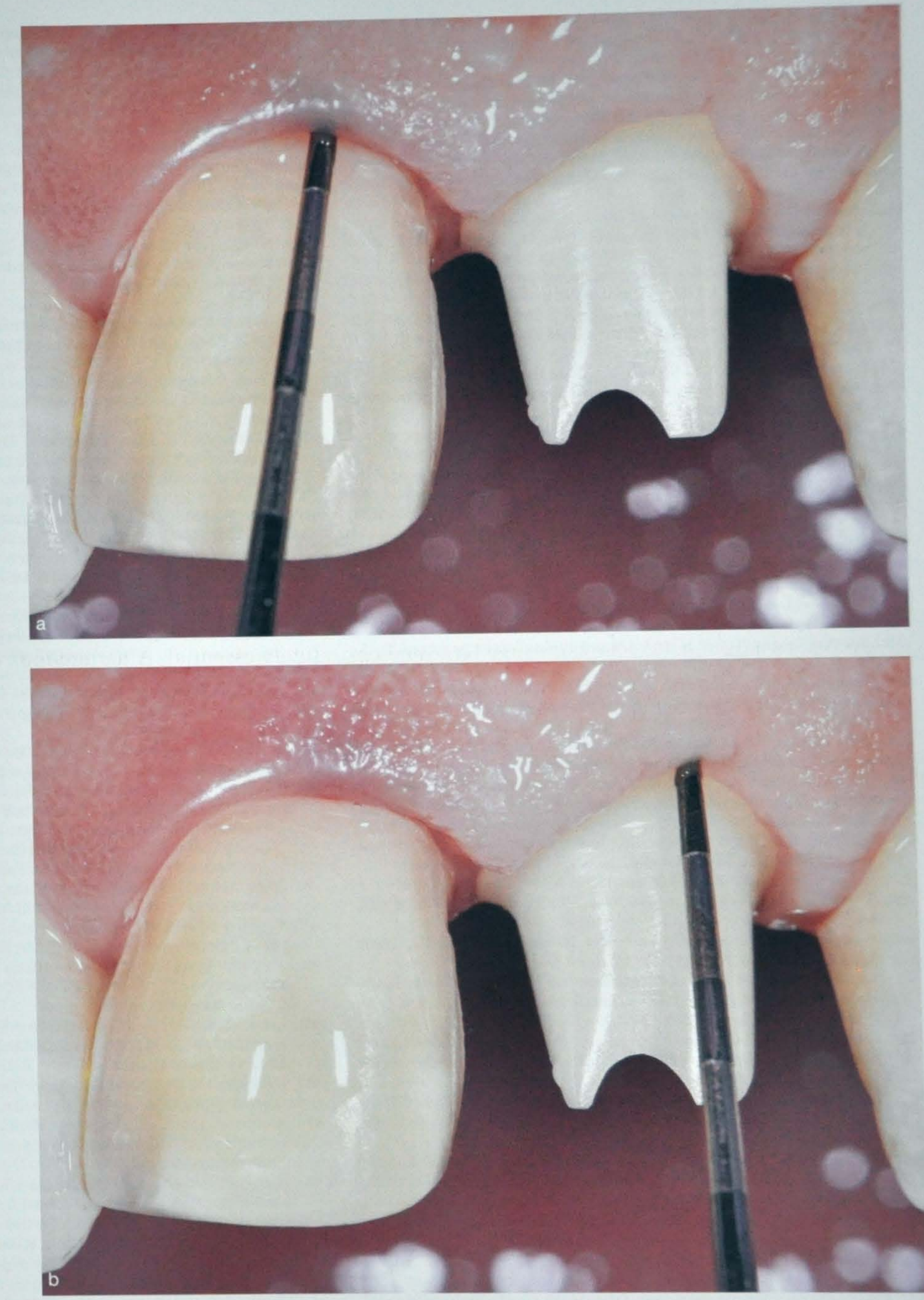

Fig 1-32 Although the biologic significance of keratinized gingiva around teeth (a) and implants (b) is the subject of controversy, the presence of keratinized gingiva is absolutely essential from an esthetic perspective.

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CHAPTER 2

MICROSURGERY: A NEW DIMENSION

2.1 Principles of Microsurgery

Microsurgery is the collective term for surgical procedures performed with the aid of optical magnification, which allows the clinician to perform very precise surgery with smaller instruments and finer suture materials than was possible before. The use of a microsurgical technique makes it possible to consistently minimize tissue trauma and maximize the precision of wound closure, two factors that play a decisive role in postoperative outcome (Figs 2-1 and 2-2).

Microsurgical and minimally invasive surgical procedures are already widely used in many medical specialties such as eye surgery, neurosurgery, and plastic surgery, where they have achieved significantly enhanced outcomes not possible with conventional macrosurgical procedures.[1–3] The idea that the deep healing of a wound can never be better than the quality of its surface closure was first expressed by a plastic surgeon.[4] Wound margin necrosis can be very detrimental to the postoperative outcome (see chapter 3). Necrosis generally is caused by an insufficient blood supply to the affected tissue regions, which can result from iatrogenic crushing of delicate microvascular structures in the capillary bed during surgery and the subsequent blockage of these vessels by microthrombi. Consequently, the use of a microsurgical technique can lead to a significant reduction of surgical trauma. As it minimizes tissue trauma while allowing more precise wound closure, microsurgery performed under an operating microscope or loupe results in a quality of healing that can rarely be achieved by conventional macrosurgery.

The concept of microsurgery has also gained increasing significance in periodontal surgery in recent years. However, because microsurgery is generally associated with greater time and costs, the use of microsurgical techniques is justified only if they are clearly superior to the conventional surgical alternatives.[5] In periodontology, this is most commonly the case in regenerative surgery and plastic-esthetic periodontal surgery.

In *guided tissue regeneration*, for example, closed healing of the membrane is absolutely essential to the success of the regenerative procedure. Studies have shown that membrane exposure and subsequent bacterial contamination of the regeneration site occur in up to 80% of cases, depending on the specific technique and type of materials used.[6–8] These complications compromise treatment outcomes and are associated with extensive tissue loss. A controlled clinical study by *Cortellini* and coworkers[9] demonstrated that the introduction of a new flap design could reduce the exposure rate by approximately one-third. The additional use of a microsurgical concept by the same authors decreased the exposure rate even further, to only 7.7%.[10,11] *Wachtel* and coworkers[12] made similar observations. In their controlled clinical study, the use of a microsurgical concept in combination with enamel matrix protein derivatives to repair infra-alveolar periodontal defects resulted in primary healing in nearly 90% of all microsurgically treated defects.

In the field of *plastic-esthetic periodontal surgery*, *Burkhardt* and *Lang*[13] conducted a controlled clinical comparison study of 10 patients with bilateral Miller Class I and Class II gingival recessions at maxillary sites that were repaired with pedicle flaps used in combination with subepithelial connective tissue grafts. In a split-mouth design, root coverage was accomplished by conventional macrosurgery on one side and by microsurgery on the other. Fluorescence angiography was performed to evaluate the course of healing immediately after surgery and 3 and 7 days later. Clinical outcome variables were assessed before surgery and 1, 3, 6, and 12 months postoperatively.

Fluorescence angiography showed that the incidence of postoperative anemia was lower at microsurgically treated sites than at macrosurgically treated sites at the time of the immediate postoperative assessment. This difference persisted over the course of wound healing, as was clearly reflected by faster vascularization at microsurgically treated sites. The authors also demonstrated the statistically significant superiority of the microsurgical technique, as determined based on the percentage of coverage of previously exposed root surfaces 1 year after surgery (Tables 2-1 and 2-2 and Fig 2-3).

Francetti and coworkers[14] reported similar results after a 12-month clinical study.

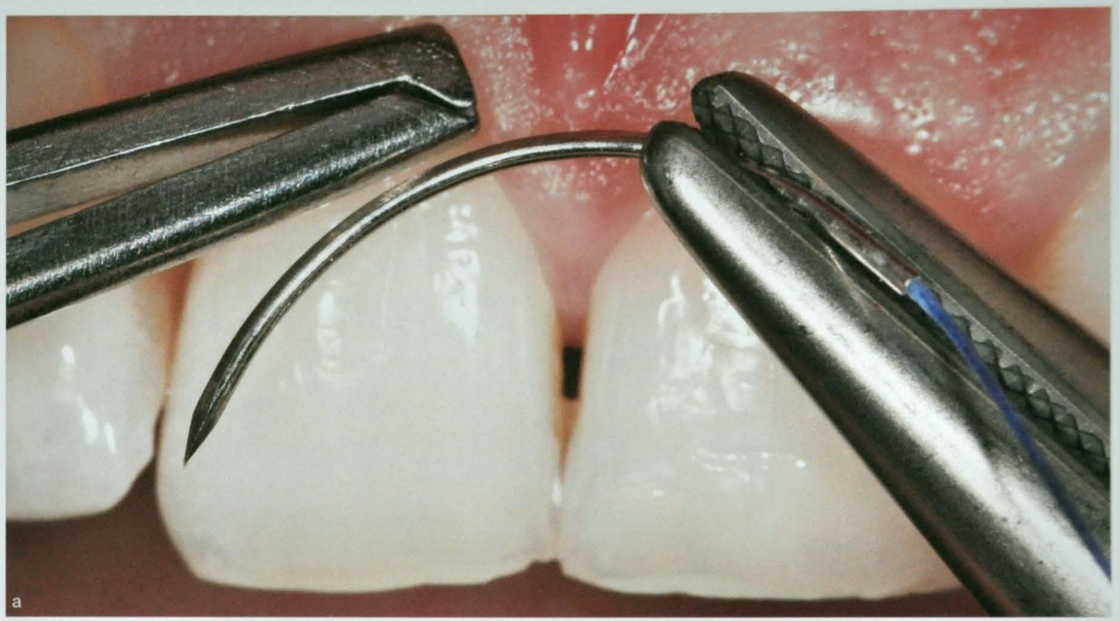
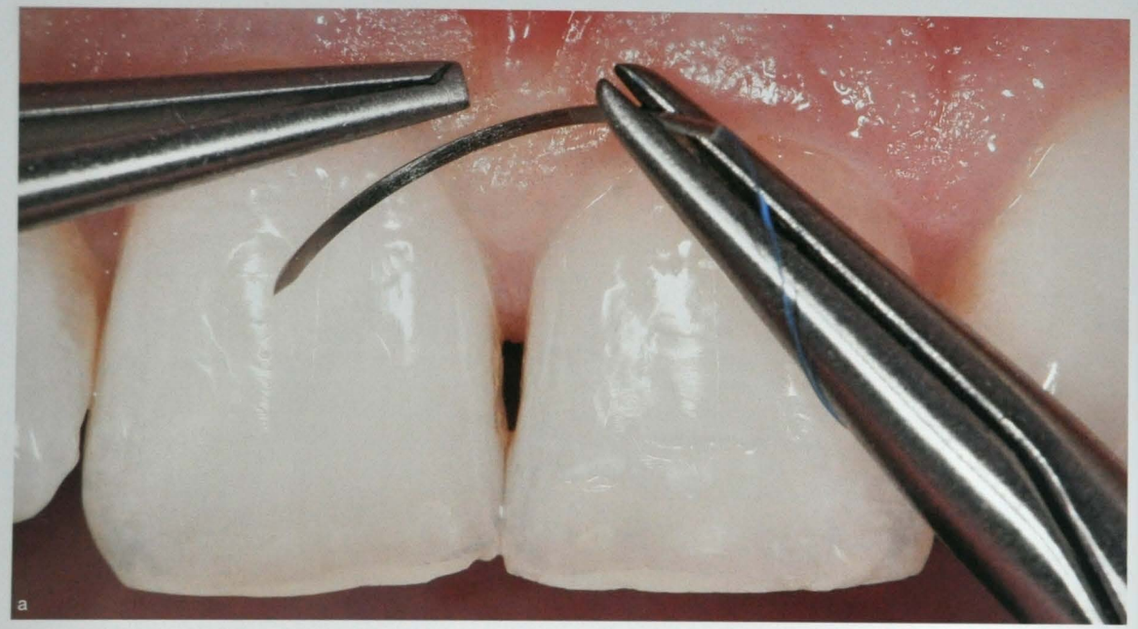
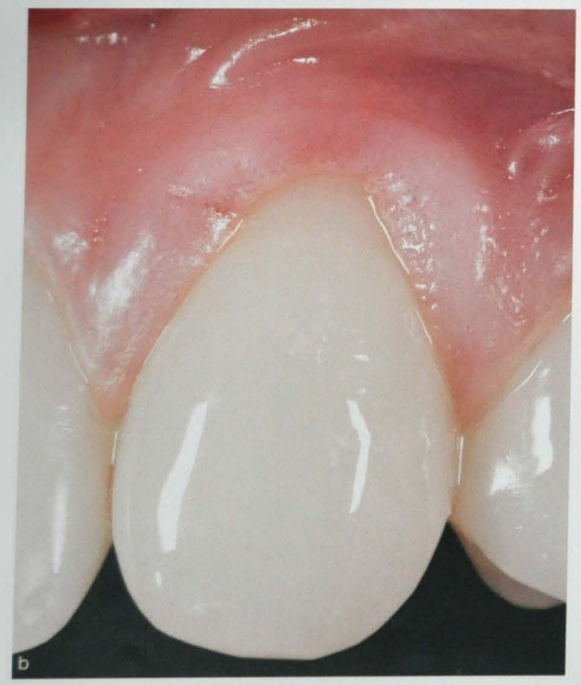


Fig 2-1 (a to c) The use of conventional macrosurgical instruments and suture materials results in a relatively high level of surgical trauma to the periodontal soft tissues. Precise approximation of the wound margins is often difficult to achieve under these conditions.





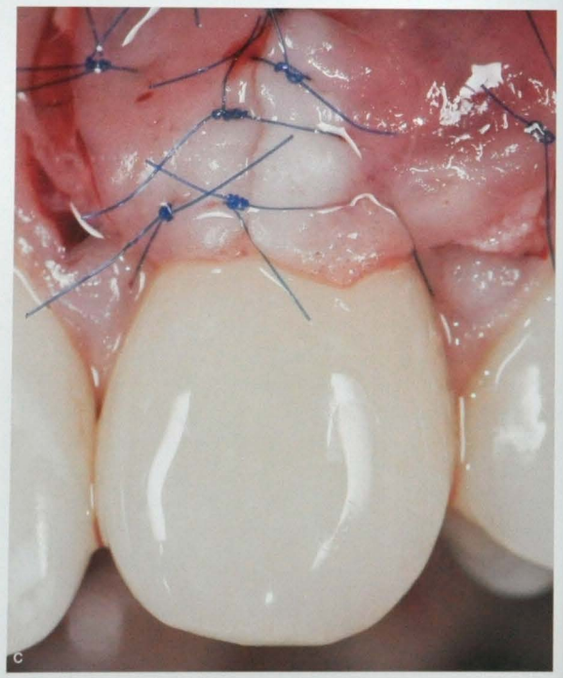


Fig 2-2 (a to c) The use of microsurgical instruments and suture materials minimizes trauma to the soft tissues. Precise approximation of the wound margins is easier to achieve.

Table 2-1

Results of the angiographic assessments performed immediately after surgery and 3 and 7 days postoperatively, expressed as the percentage of vascularization at the surgical site*

Treatment	Day 0 (%)	Day 3 (%)	Day 7 (%)
Microsurgery	8.9 (± 1.8)	53.3 (± 10.5)	84.8 (± 13.5)
Macrosurgery	8.0 (± 1.8)	44.5 (± 5.7)	63.9 (± 12.3)

*The microsurgical results were clearly superior to the macrosurgical results at all three sampling times. (From *Burkhardt* and *Lang*.[13] Reprinted with permission.)

Table 2-2

Coverage of exposed root surfaces 1 and 12 months after surgery, expressed as the percentage of coverage*

Treatment	Day 0 (%)	Day 12 (%)
Microsurgery	99.4 (± 1.7)	98.0 (± 3.4)
Macrosurgery	90.8 (± 12.1)	89.9 (± 8.5)

*Microsurgery resulted in statistically significant improvement of clinical treatment outcomes. (From *Burkhardt* and *Lang*.[13] Reprinted with permission.)

Key points:

Microsurgery is a collective term for surgical procedures performed under optical magnification, that is, an operating microscope or loupe. *Magnification* makes it possible to perform surgical procedures *more precisely* and to use *finer and smaller instruments and suture materials* than are possible in conventional macrosurgery. This reduces surgical trauma and allows more precise approximation of the wound margins, both of which are prerequisites for *enhanced and predictable healing*. The use of microsurgical principles and procedures provides clinically relevant advantages over conventional macrosurgical concepts for regenerative and plastic-esthetic periodontal surgery. *Natural appearance, harmonious transitions* between tissue structures, and the *absence of scarring* in the esthetic zone have become essential parameters of a successful treatment outcome. Microsurgery is also superior to conventional macrosurgery in this regard. Further evidence suggests that the consistent use of microsurgical procedures can reduce postoperative *morbidity* following periodontal surgery.[15]

The advent of microsurgery in periodontics and implant dentistry has only just begun. Considering its potential, the popularity of microsurgery in dentistry seems likely to grow in spite of the fact that microsurgical techniques are more time-consuming and cost intensive and require additional training.

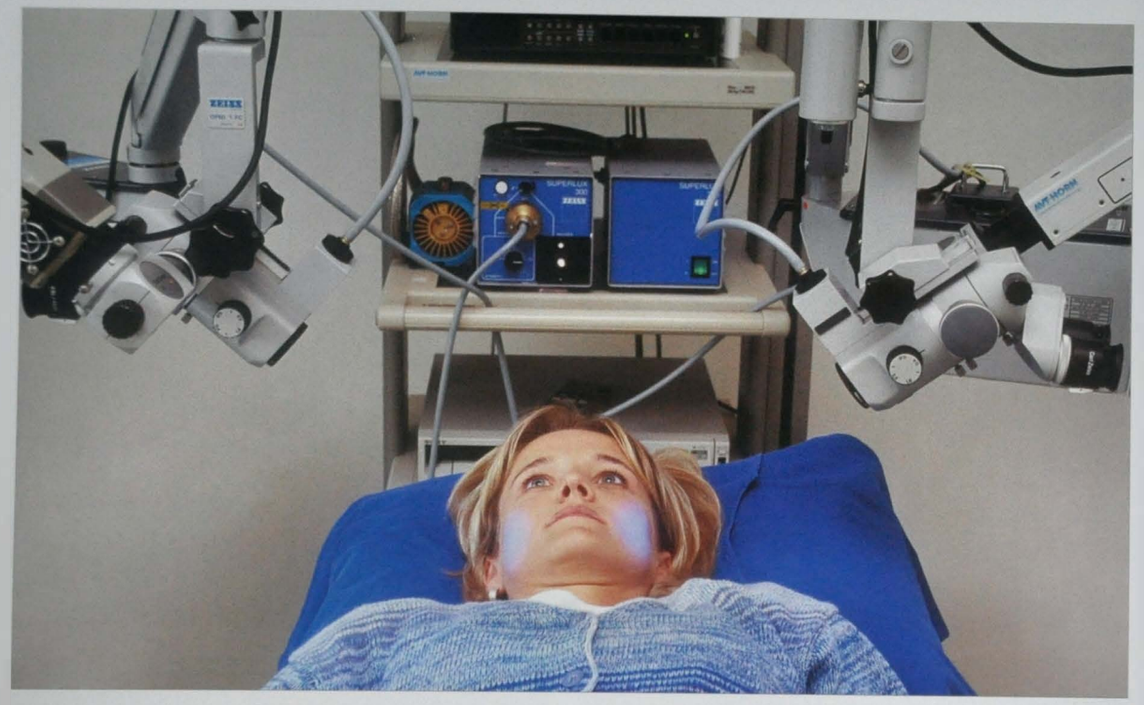


Fig 2-3a The outcomes of coverage of gingival recession defects were assessed in a study by *Burkhardt* and *Lang*.[13] Sites treated by conventional macrosurgery or microsurgery were evaluated by fluorescence angiography immediately after surgery and 3 and 7 days after the interventions. (From *Burkhardt* and *Lang*.[13] Reprinted with permission.)

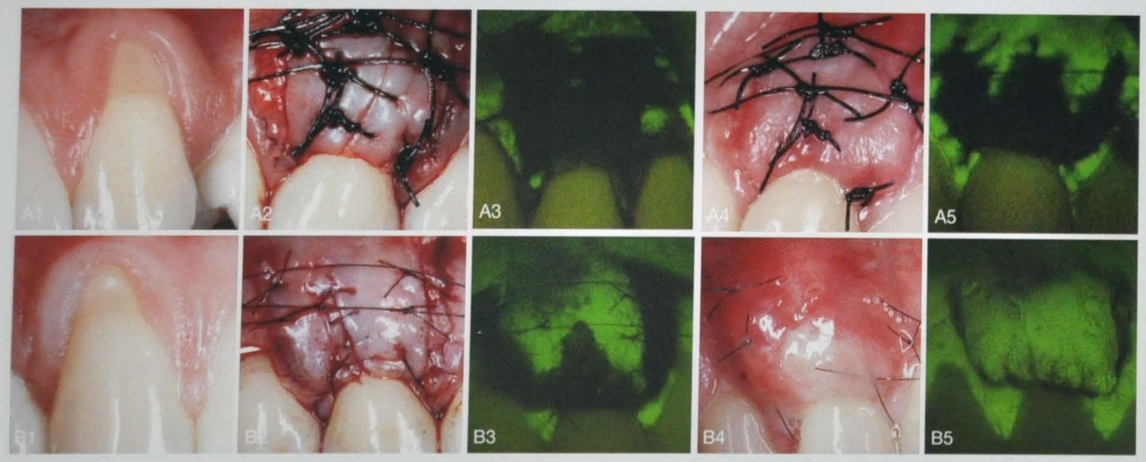


Fig 2-3b Clinical photographs and fluorescence angiograms were used to document the course of healing at sites treated by conventional macrosurgery (A1 to A5) or microsurgery (B1 to B5). The sites are shown at baseline (A1 and B1), immediately after surgery (A2 and A3, B2 and B3), and 7 days after the interventions (A4 and A5, B4 and B5). The corresponding clinical photographs and fluorescence angiograms are shown in each case. Anemic regions appear black in the angiograms. The vascularization of the microsurgically treated sites was clearly superior to that of the macrosurgically treated sites immediately after surgery and 7 days postoperatively. (From *Burkhardt* and *Lang*.[13] Reprinted with permission.)

2.2 Technical Requirements

2.2.1 Optical Magnification Systems

Magnification is absolutely essential for improved visualization of the surgical field and more precise manipulation of fine tissues during microsurgery. Any optical magnification system used in microsurgery must meet the following requirements:

- It must produce an enlarged, upright, and nonreversed image of the surgical field.
- It must generate stereoscopic (three-dimensional) images that allow for exact depth localization.
- Optical distortion must remain below the perception threshold to prevent eye strain.
- The working distance between the system and the surgical field must be large enough to allow the surgeon to work comfortably and ergonomically.
- The system must be equipped with a light source that optimally illuminates the surgical field.

In principle, both binocular loupes and operating microscopes meet these requirements.

Binocular loupes

Binocular loupes are magnifying eyeglasses in which loupes are mounted on the lenses. They have a lower range of magnification than operating microscopes but are less expensive and easier to use. Binocular loupes permit the surgeon to change the viewing angle at any time without having to adjust or even look at the lens system and without having to change his or her own working position. Different types of loupe can be distinguished based on their designs. The two types of loupe most commonly used in dentistry are Galilean loupes and Kepler loupes.

Galilean loupes

Galilean loupes have a convex and a concave lens and provide ×2 to ×3 magnification. Their main advantages are their small size, light weight, and relatively large field of view. Their main disadvantages are a relatively low level of magnification as well as a small working distance in some cases (Fig 2-4).

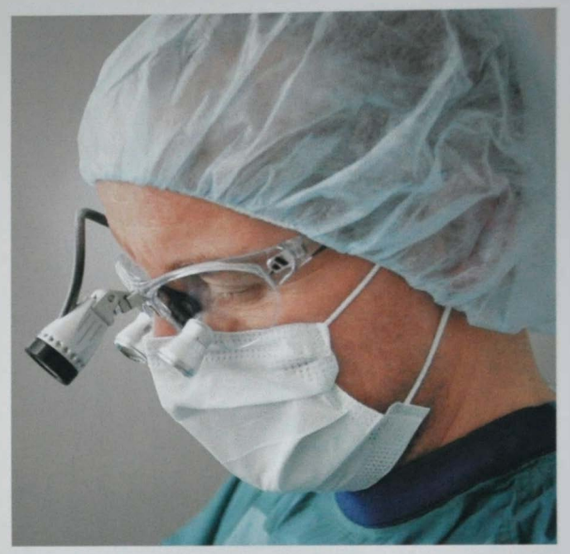


Fig 2-4 The main advantages of Galilean loupes are their small size, light weight, and relatively large field of view. They provide ×2 to ×3 magnification.

Kepler loupes (prism loupes)

Kepler loupes (prism loupes) contain a series of convex lenses and provide ×3 to ×8 magnification. They are ideal for periodontal microsurgery, where a magnification factor of ×3.5 to ×6.0 is recommended. Prism loupes of the Kepler design have very well-corrected optics that permit high magnification at an ideal working distance of 30 to 40 cm. The main drawback is that they are much larger and heavier than Galilean loupes and therefore require a special frame. The loupe system can be either bracket mounted to the frame of the eyeglasses or bonded directly to the lenses. Custom fitting by an optician is required in the latter case. Headband-mounted loupes are also available as an alternative but must be readjusted after each use.

Loupe systems are mounted at a certain forward and downward tilt angle (relative to the horizontal plane), which permits the surgeon to work with the head in a comfortable position without straining the neck muscles (Fig 2-5).

Operating microscope

The main components of the optical system of an operating microscope are the magnification changer, objective lens, binocular tube, eyepieces (ocular lenses), and a light source.

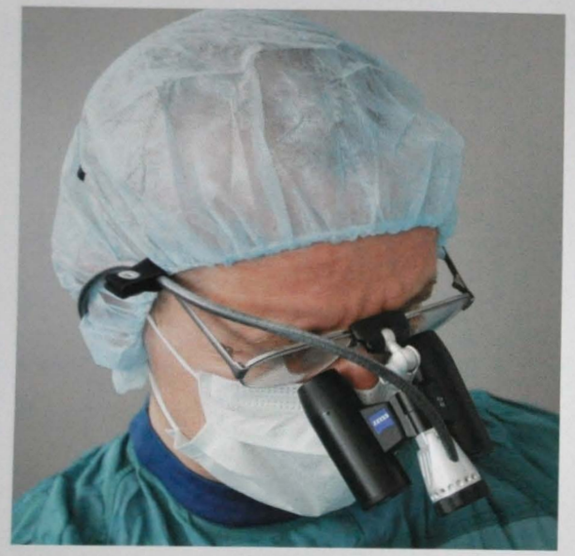


Fig 2-5 Prism loupes of the Kepler design are relatively large and heavy. They provide ×3 to ×8 magnification and are thus ideal for applications in plastic-esthetic periodontal and implant surgery.

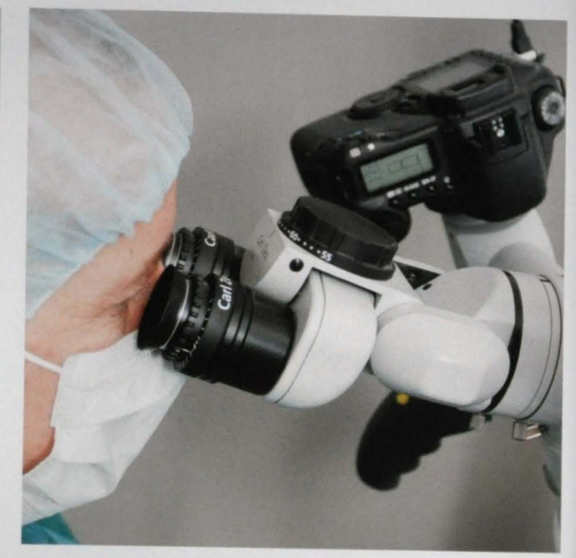


Fig 2-6 Operating microscopes can achieve ×3 to ×40 magnification.

Magnification changer

The magnification changer consists of two Galilean telescopes with different magnification factors inserted in a cylinder. To change the magnification factor, the relative position of the two telescopes is changed in either direction by rotating the cylinder. This system provides four different magnification factors plus a free passage position without optics, corresponding to a magnification factor of ×1. With rotation of the cylinder, the combined action of the magnification changer, objective lens, and eyepieces makes it possible to increase the magnification through a range of magnification steps. Magnification ranges of ×6 to ×40 can be achieved with these systems. Operating microscopes of the latest generation allow a continuous change of magnification without blackout.

Objective lens

The objective lens forms an image of the object processed by the magnification changer while projecting illumination from the light source onto the field of view. Objective lenses with a focal length of 200 to 300 mm are available for use in periodontal surgery. Ideally, an objective lens with a focal length of 200 to 250 mm should be used. Lenses with a continuously adjustable focal length are also available. The focal width generally corresponds to the working distance, that is, the distance from the lens to the surgical field.

Binocular tube

The conventional binocular tube contains two inverting prisms that rectify the inverted image produced by the objective lens and collected by the lenses in the end region of the tube. Both straight and inclined binocular tubes are available for operating microscopes. The type used depends on the application. Straight tubes are positioned parallel to the axis of the microscope, and inclined tubes are set at a 45-degree angle to the axis of the microscope. Binocular tubes with continuously adjustable viewing angles (tilting tubes) were recently introduced.

For ergonomic reasons, only tilting tubes that permit continuously adjustable viewing are used in dental surgery. They can be seamlessly adjusted to any viewing angle between 0 and 60 degrees, giving the surgeon a greater degree of freedom to manipulate the microscope without changing seating positions.

All binocular tube systems come with an individually adjustable range of pupil distance. Precise adjustment of the pupil distance is essential for stereoscopic (three-dimensional) viewing of the surgical field.

Eyepieces

The role of the eyepieces, or ocular lenses, is to magnify the intermediate image generated in the binocular tube. Eyepieces with magnification factors of ×10 to ×20 are available for operating microscopes. The type of eyepiece used determines not only the magnification factor but also the size of the field of view. The higher the magnification factor, the smaller the field of view. In periodontal surgery, a ×10 eyepiece generally provides a good compromise between magnification factor and size of the field of view.

Modern eyepieces allow for the correction of emmetropic and ametropic eyes, which enable surgeons with refractive errors to work without glasses. They can compensate for refractive errors in the range of –8 to +8 diopters but not for astigmatism. Therefore, surgeons with astigmatism must wear glasses when using an operating microscope. If glasses are worn, the surgeon must first push back the eye cups and adjust both eyepiece diopter settings to 0.

Operating microscopes can achieve ×3 to ×40 total magnification, but magnification ranging from ×4 to ×24 is usually sufficient and most commonly used in dental surgery (Fig 2-6).

Light source

Optimal lighting is needed to achieve maximum visual acuity. High-intensity halogen bulbs and more recently introduced xenon bulbs, which are used with cold light mirrors designed to protect the surgical field from heat generated by infrared light, are most commonly used in operating microscopes. The objective lens projects the light in a coaxial path via two inverting prisms to the surgical field, that is, in the direction of view. An increasing number of cold light systems (xenon, halogen, and light-emitting diode [LED]) have been introduced by the industry in recent years. Two types can be distinguished: semistationary systems connected to an AC power source and battery-operated mobile systems. Mobile systems are preferred because of the mobility and comfort they provide for the surgeon (Fig 2-7).

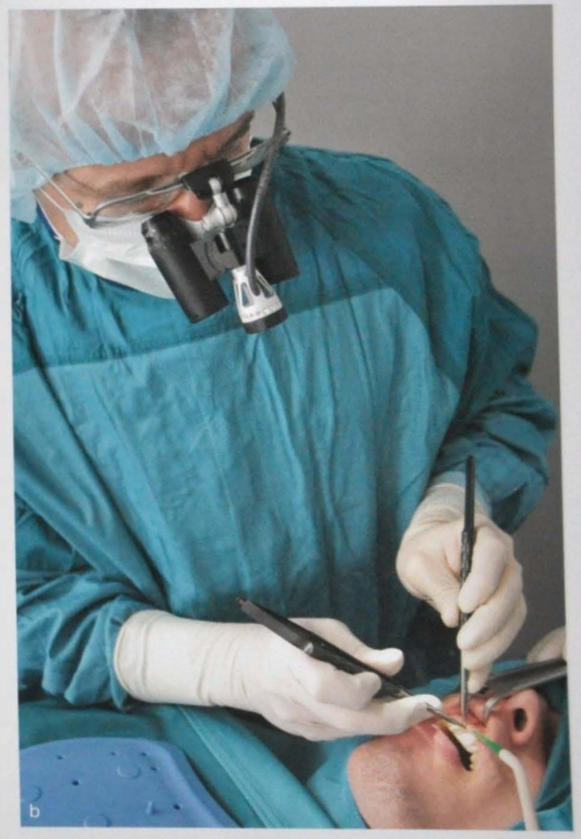


Fig 2-7 (a and b) The light source of an operating microscope is incorporated in the optical system, whereas the light source of a loupe is attached to the frame of the magnifying eyeglasses.

Table 2-3

Comparison of the advantages (+) and disadvantages (–) of loupes and operating microscopes

Feature	Loupes	Operating microscopes
Maximum magnification factor	×6 (–)	×24 (+)
Field of view	Larger (+)	Smaller (–)
Direct view of surgical field	Always possible (+)	Only indirect view possible in some cases (–)
Nonmagnified view (free passage position)	Possible (+)	Not possible (–)
Assistant scope	Not available (–)	Available depending on equipment model (+)
Optical zoom	Not available (–)	×4 to ×24 (+)
Shadow-free illumination	Possible with some light systems (+/–)	+
Flexibility/mobility of the system	+	–
Ergonomics/working comfort	–	+
Ease of handling	+	–
Protection against eye strain	–	+
Training time for surgeon	Shorter (+)	Longer (–)
Training time for assistant	Shorter (+)	Longer (–)
Camera/video documentation	Not possible (–)	Available depending on equipment model (+)
Acquisition cost	$1,000 to $3,300 (+)	$13,000 to $100,000 (–)

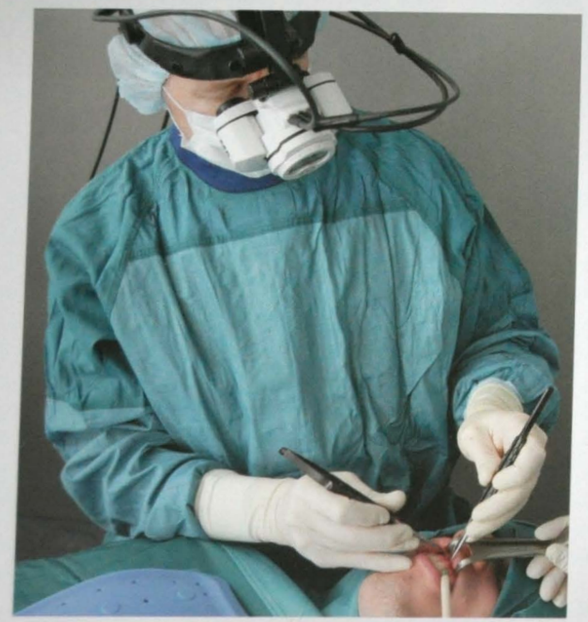


Fig 2-8 The Varioskop is a head-mounted microscope.

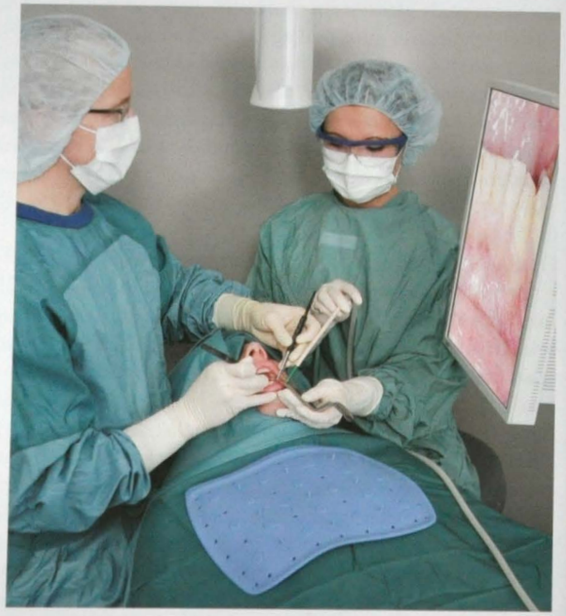


Fig 2-9 The Dentaloscope uses a flat-screen monitor to display three-dimensional camera images of the surgical site.

Comparison of loupes and operating microscopes

In contrast to loupes, operating microscopes are ergonomic by nature and encourage a comfortable working position. In operating microscopes, the rays of light strike the retina in a parallel configuration, so no ocular convergence is necessary. This reduces eye strain. However, operating microscopes have a small field of view that must be frequently adjusted when different structures are viewed. This can be tiresome when the clinician is performing periodontal and dental implant surgery. Table 2-3 summarizes the advantages and disadvantages of loupes and operating microscopes. Researchers developing new generations of optical systems are attempting to combine the optical and ergonomic advantages of operating microscopes with the greater flexibility, ease of use, and lower cost of loupes (Figs 2-8 and 2-9).

Ultimately, the decision to use a loupe or operating microscope should be determined by the treatment outcome. In endodontic surgery, operating microscopes achieve results that are clearly superior to those achieved using loupes. In fact, some procedures can only be performed using microscopes. In periodontal and implant surgery, on the other hand, none of the available operating microscopes has been shown to be clearly superior to loupes. Therefore, they are not routinely used for these indications. The extent to which technical innovations such as the integration of autofocus can result in wider application of operating microscopes in periodontal microsurgery remains to be seen.

All of the microsurgical procedures presented in this book can be performed using a Kepler-type prism loupe with ×3.5 to ×5.0 magnification.

2.2.2 Periodontal Surgical Instruments

Very precise and controlled guidance of the surgical instruments is essential in periodontal surgery, particularly when microsurgical procedures are performed. Therefore, surgical instruments should have rounded nonslip handles to allow secure rotation among the digits with the best fine motor control: the thumb, index finger, and middle finger. This is essential to produce small and precise coordinated movements. In addition, the instruments must be long enough (at least 18 cm) to be held securely in the thumb, index finger, and middle finger in a pen grip. The handles should also be well balanced: Slight top-heaviness facilitates precision work.

Macro instrument set for periodontal surgery

As macrosurgical instruments must sometimes be used for microsurgical procedures in plastic-esthetic periodontal and implant surgery, a special macro instrument set for general periodontal surgery is presented in Fig 2-10. These instruments are designed with two goals in mind: to meet the specific requirements of periodontal surgery and to keep the number of instruments as small as possible. The interchangeable tips of the instruments are made of surgical steel to provide optimal hardness, and their handles are made of titanium to make them lightweight.

Micro instrument set for periodontal microsurgery

The instruments used in periodontal microsurgery are basically the same as those used in conventional periodontal surgery. Although they are finer and smaller, they must be sturdy enough to effectively handle the gingival tissues, which can be relatively tough. Stainless steel is the material of choice for microsurgical instruments because it provides a greater degree of hardness and flexibility.

When purchasing instruments for periodontal microsurgery, the clinician should choose only needle holders and forceps with smooth jaws. Blood easily adheres to diamond-coated inserts or ridges, which can make it more difficult to grasp very fine sutures securely and can increase the risk of damaging or breaking the delicate suture threads used in microsurgery. Smooth carbide inserts have proved to be an excellent choice.

The individual components of an established microsurgical instrument are described in detail below (Fig 2-11).

Microsurgical scalpel handle

A microsurgical scalpel handle must have rounded handles to allow the surgeon to work safely and with adequate precision. The micro scalpel blade is inserted in the fitting at the top of the handle and locked in place by a rotating mechanism located at the end of the instrument (Fig 2-12). Particularly in the case of intrasulcular incisions, it is very difficult to make a precise incision with scalpel blades sized for conventional surgery (Fig 2-13a). Microsurgical scalpel blades with rounded ends and blades that cut in all directions therefore have been developed. They are also suitable for incisions in hard-to-reach places such as interdental spaces

Fig 2-10 (a to c) The mamadent Macro instrument set.

Fig 2-10a
(left to right)
- Minnesota cheek retractor
- *Castroviejo* needle holder
- Dissecting forceps
- Surgical scissors
- Surgical forceps

Fig 2-10b
(left to right)
- *Hilger* cheek retractor
- Mouth mirror with lip retractor
- Furcation probe
- Periodontal probe
- Two scalpel handles
- *Rhodes* chisel
- Modified *Ochsenbein/ Kramer-Nevins* chisel
- Kirkland gingivectomy knife
- *Orban* gingivectomy knife
- Furcation curette
- *Langer* universal curette, angled
- *Langer* universal curette, straight
- Periosteal elevator
- Prichard periosteal elevator

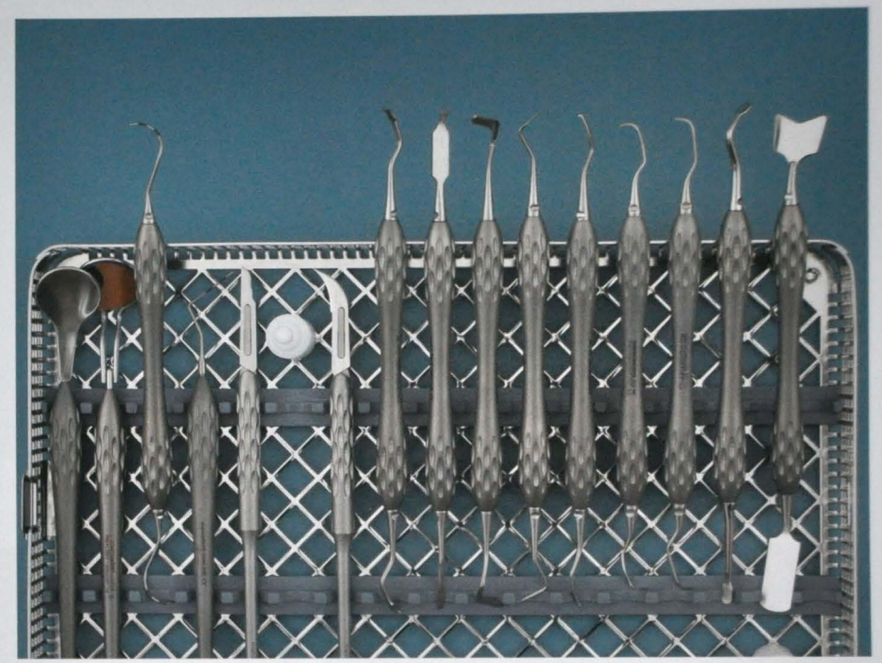


Fig 2-10c
(left to right)
- *Hilger* cheek retractor
- Mouth mirror with lip retractor
- Furcation probe
- Periodontal probe
- Two scalpel handles
- *Rhodes* chisel
- Modified *Ochsenbein/ Kramer-Nevins* chisel
- *Kirkland* gingivectomy knife
- *Orban* gingivectomy knife
- Furcation curette
- *Langer* universal curette, angled
- *Langer* universal curette, straight
- Periosteal elevator
- Prichard periosteal elevator

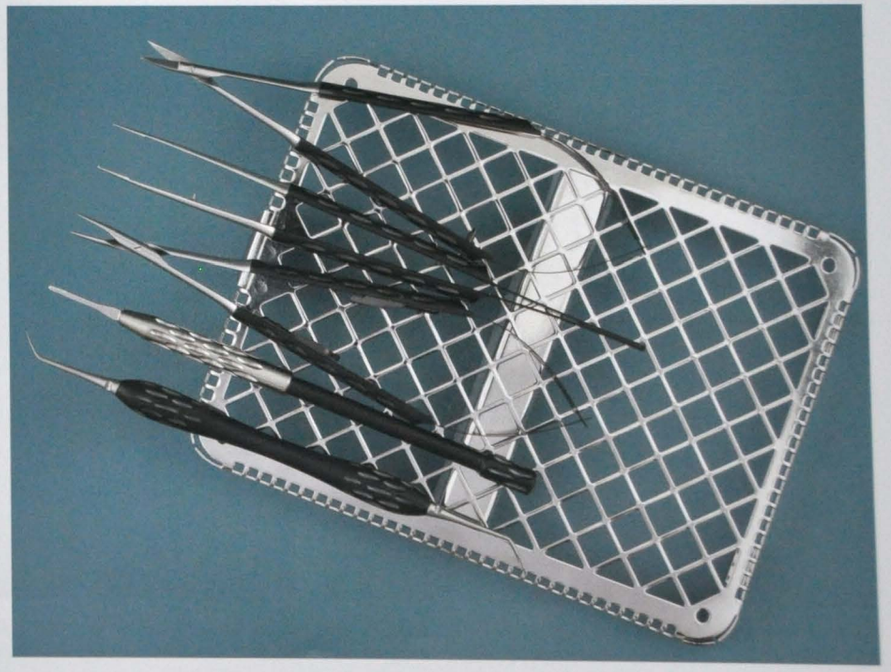


Fig 2-11 The mamadent Micro instrument set.
(top to bottom)
- Microsurgical spring scissors
- Microsurgical combination forceps
- Microsurgical needle holder
- Microsurgical scalpel handle
- Papilla elevator

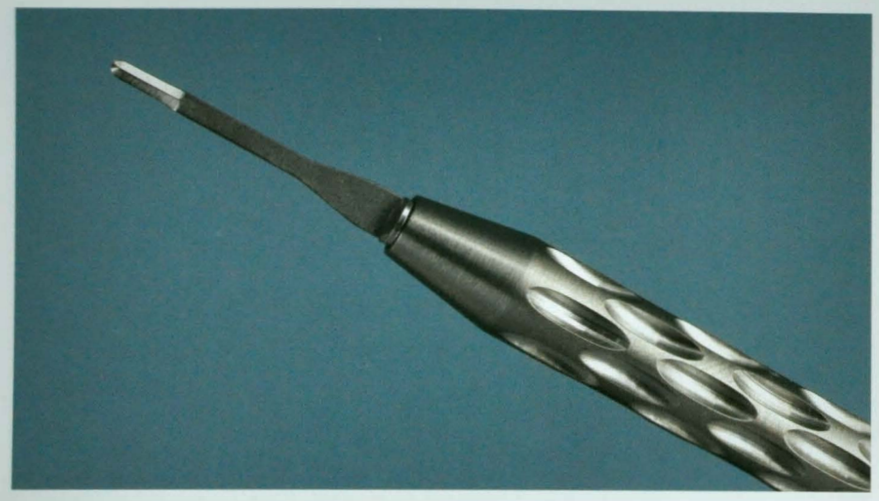
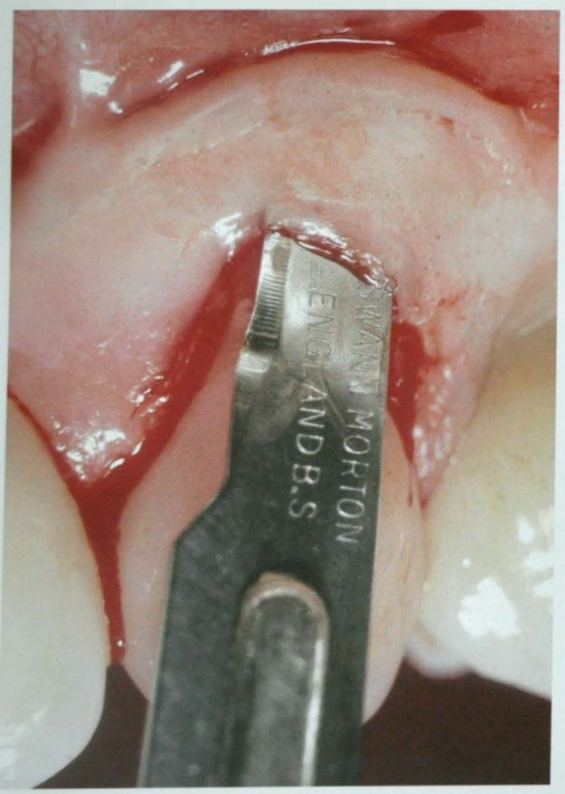


Fig 2-12 Microsurgical scalpel handle with a microscalpel blade attached.



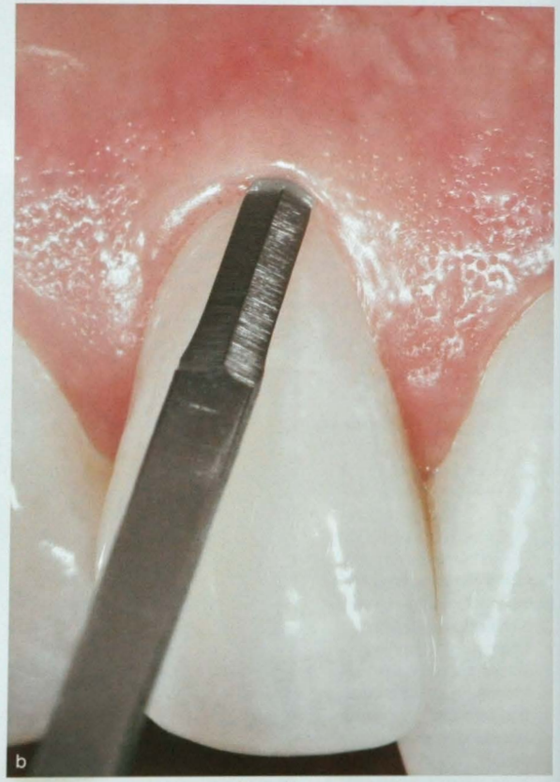
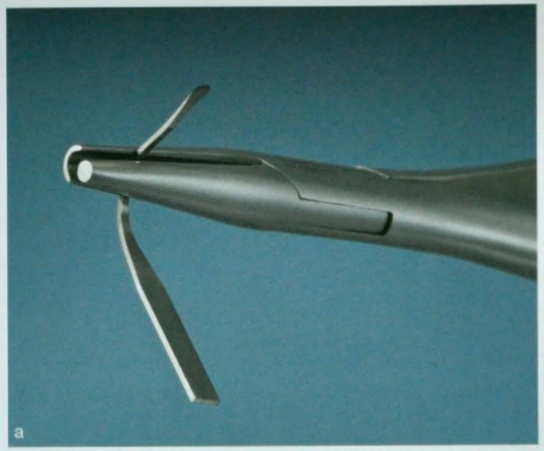


Fig 2-13 (a) It is very difficult to make a precise intrasulcular incision without tissue loss when a macrosurgical scalpel blade is used. (b) In contrast, microsurgical scalpel blades offer greater precision.



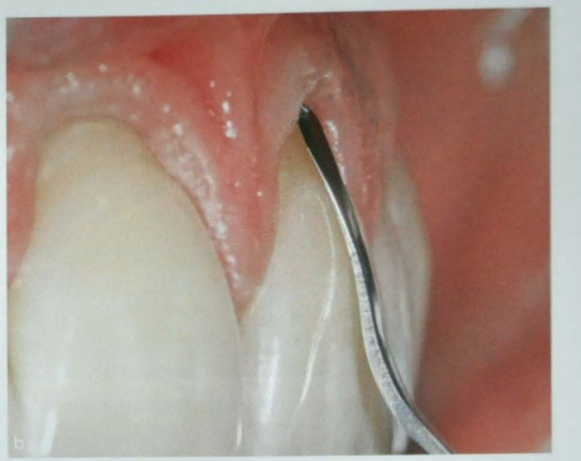


Fig 2-14 (a and b) The use of bendable microsurgical scalpel blades can be useful in hard-to-reach areas.

(Fig 2-13b). The use of bendable microsurgical scalpel blades can also be useful in special situations (Fig 2-14).

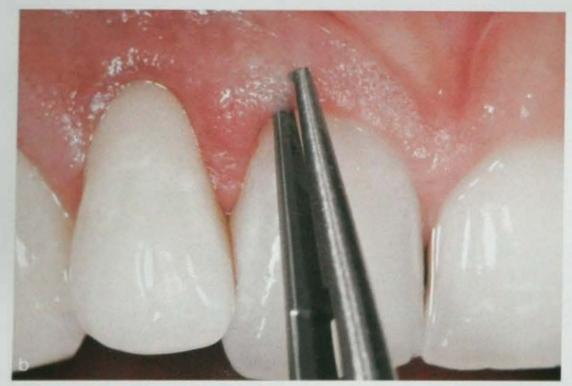
Microsurgical combination forceps

Dissecting forceps are the most commonly used instruments in microsurgery. They come in different shapes and sizes. Straight dissecting forceps with fine working tips fulfill the requirements of plastic-esthetic periodontal and implant surgery. As mentioned above, the jaws of the forceps should have smooth tips to allow the surgeon to tie knots with very thin sutures without damaging the thread when grasping it with the forceps. Dissecting forceps are held in the nondominant hand when the clinician is tying knots.

The working tips of the forceps must be 1 to 2 mm apart when held loosely in the hand. It should not be necessary to apply great force to close the forceps. The jaws of the forceps must be perfectly aligned when closed. A small guide pin is positioned in the lower third of the forceps to guide the closure of the working tips. The jaws of the forceps should close over a distance of 1 to 3 mm on moderate pressure from the index finger and thumb. When greater pressure is applied, the tips of the jaws should not drift apart.

When sutures are placed, it is often necessary to grasp the tissue with surgical forceps for easier passage of the needle through the flap. As the subsequent knot-tying step is usually performed with the aid of dissecting forceps, combination surgical and dissecting forceps have been developed to permit the surgeon to perform both work steps without changing instruments. Combination forceps are basically dissecting forceps, the jaws of which resemble those of surgical forceps. When slight pressure is applied to the arms of the forceps, the jaws of the surgical forceps–like part close while the arms of the straight dissecting forceps–like part remain open. To close the dissecting forceps–like part in order to tie knots, the surgeon must apply greater pressure (Fig 2-15).

Fig 2-15a Microsurgical combination forceps are dissecting forceps and surgical forceps in one. They are designed to prevent frequent instrument changes.



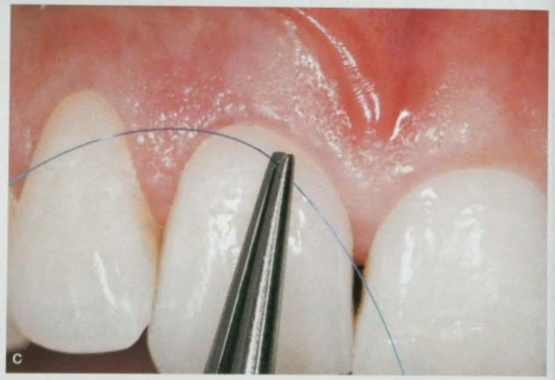


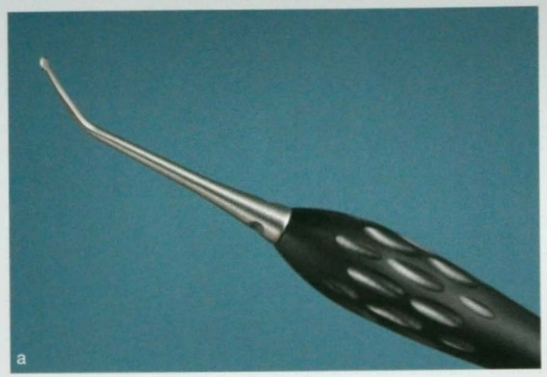
Fig 2-15 (b and c) Tissue can be securely grasped by applying light pressure to the combination forceps. Greater pressure must be applied while knots are tied.

Papilla elevator

The papilla elevator is a micro periosteal elevator used to raise flaps. It has semisharp, disk-shaped working ends of different sizes designed for atraumatic dissection of fine tissue structures, especially in the interdental area (Fig 2-16).

Microsurgical needle holder

As needles of various sizes are used in periodontal microsurgery, the microsurgical needle holder should be designed to grasp very fine to fine needles. It must also be slender enough to access interdental areas. Just as with the combination forceps, the microsurgical needle holder should have smooth jaws to allow simple and controlled knot tying without damaging the suture thread. In conventional microsurgery, nonlocking needle holders are normally used because opening and closing the clasp of a locking needle holder could cause uncontrolled and unwanted movement of the working tip. In periodontal microsurgery, on the other hand, locking needle holders are very useful. The needle can be securely grasped and advanced in controlled rotating movements through the tough gingival tissue without the surgeon's having to exert too much pressure on the handles of the needle holder (Fig 2-17).



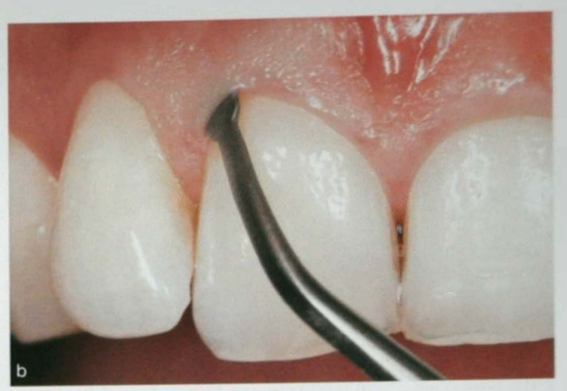
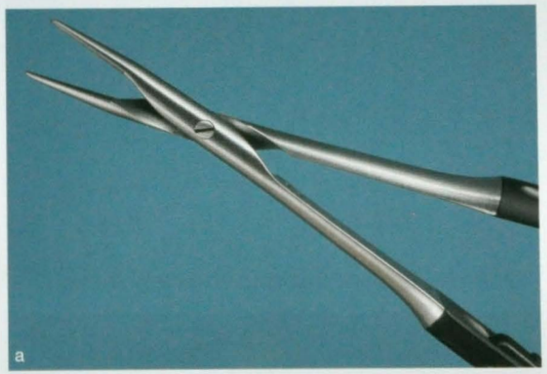


Fig 2-16 (a and b) The papilla elevator is a micro periosteal elevator used to raise full-thickness flaps. It can be used in hard-to-reach areas due to its small size.



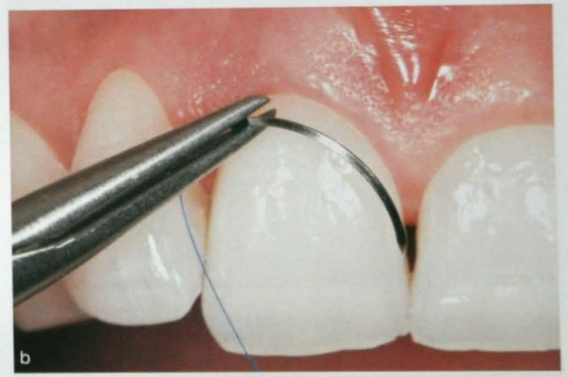
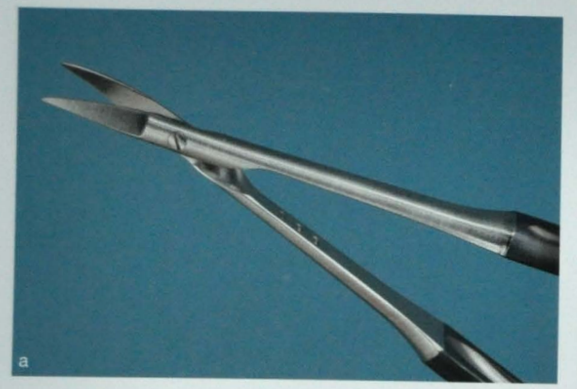


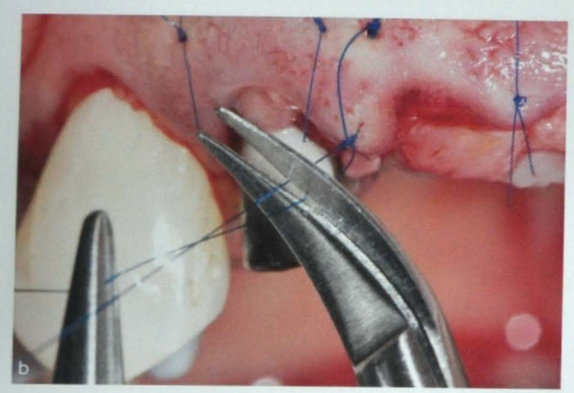
Fig 2-17 (a and b) The jaws of the microsurgical needle holder are smooth. The slender shape of the instrument tip makes it easier to work in hard-to-reach areas.

Microsurgical scissors

Curved microsurgical scissors with sharp working tips have proved ideal for periodontal microsurgical applications. They are mainly used to cut sutures and are sometimes used for controlled cutting of soft tissue. Microsurgical scissors also have rounded handles designed to facilitate rotational movement (Fig 2-18).

Technologic developments in the aforementioned microsurgical instruments include the incorporation of an additional joint in the handles of forceps and needle holders. Modifications in the geometry and transmission of forces at the working tips of the instruments have been made to further facilitate the secure and precise grasping of needles and sutures (Fig 2-19).





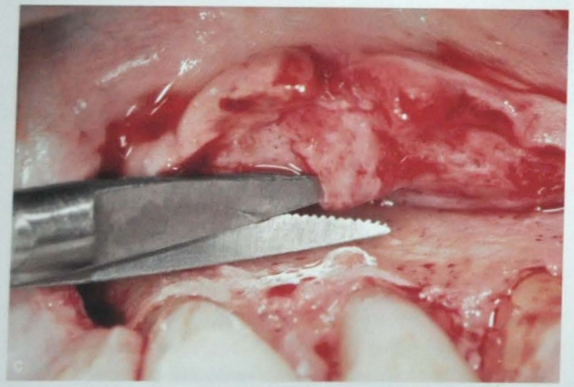
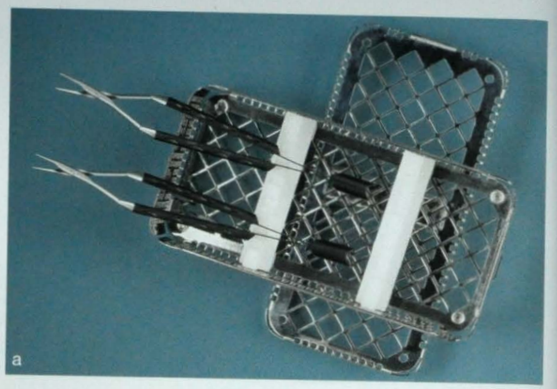
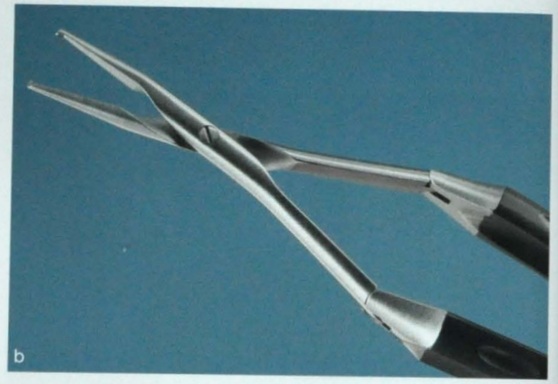


Fig 2-18 (a to c) Microsurgical scissors are generally used to cut sutures but are sometimes used for controlled cutting of soft tissue (eg, periosteal slitting).





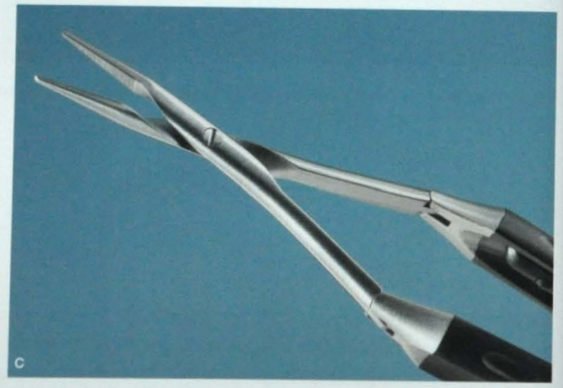
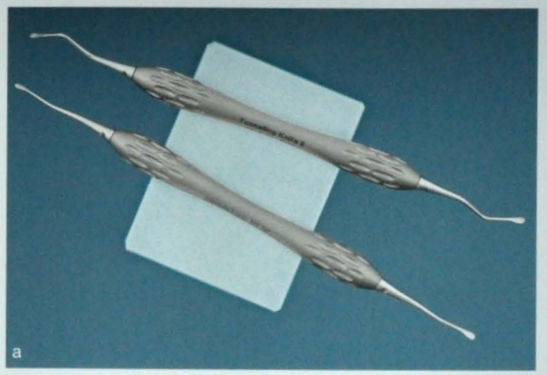
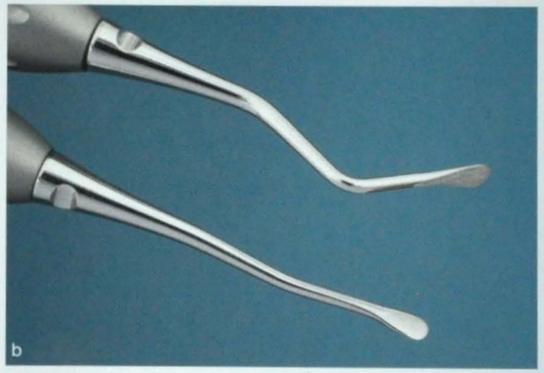


Fig 2-19 (a to c) The mamadent Master Microsurgical instrument set contains a needle holder and combination forceps. The additional joint in the instrument handle makes it possible to grasp needles and sutures more precisely and securely during suturing.





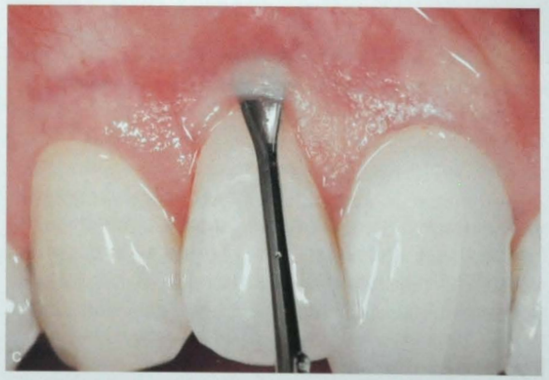


Fig 2-20 (a to c) Tunneling knives are specially designed for preparation of partial-thickness flaps according to the tunnel technique. To prevent perforation, only the side of the blade facing the periosteum or bone is sharp.

Tunneling knife

Special instruments are needed to perform advanced surgical techniques such as the tunnel technique of flap elevation without vertical releasing incisions. The buccal alveolar bone and overlying mucosa are curved, whereas most surgical instruments and scalpel blades are straight. Consequently, the use of conventional instruments to create partial-thickness flaps by the tunnel technique in this region carries a considerable risk of flap perforation.

The use of slightly curved dissection instruments could help to reduce the risk of perforation in these cases. Patented tunneling knives with such a curvature are specially designed for these situations. Two large platelike blades of different sizes are located at the working ends of the knife. The instrument is used with the sharp edge against periosteum or bone and the blunt edge against soft tissue. Tunnelling knife I has an angled blade and is designed for use in most sites. Tunneling knife II is straight and designed for use at sites with a very wide band of keratinized gingiva. To ensure safe and atraumatic elevation of partial-thickness flaps, the tunneling knife should always be sharpened prior to surgery (Figs 2-20 and 2-21).

Fig 2-21 Tunneling knives must be sharpened regularly with a flat Arkansas knife-sharpening stone.

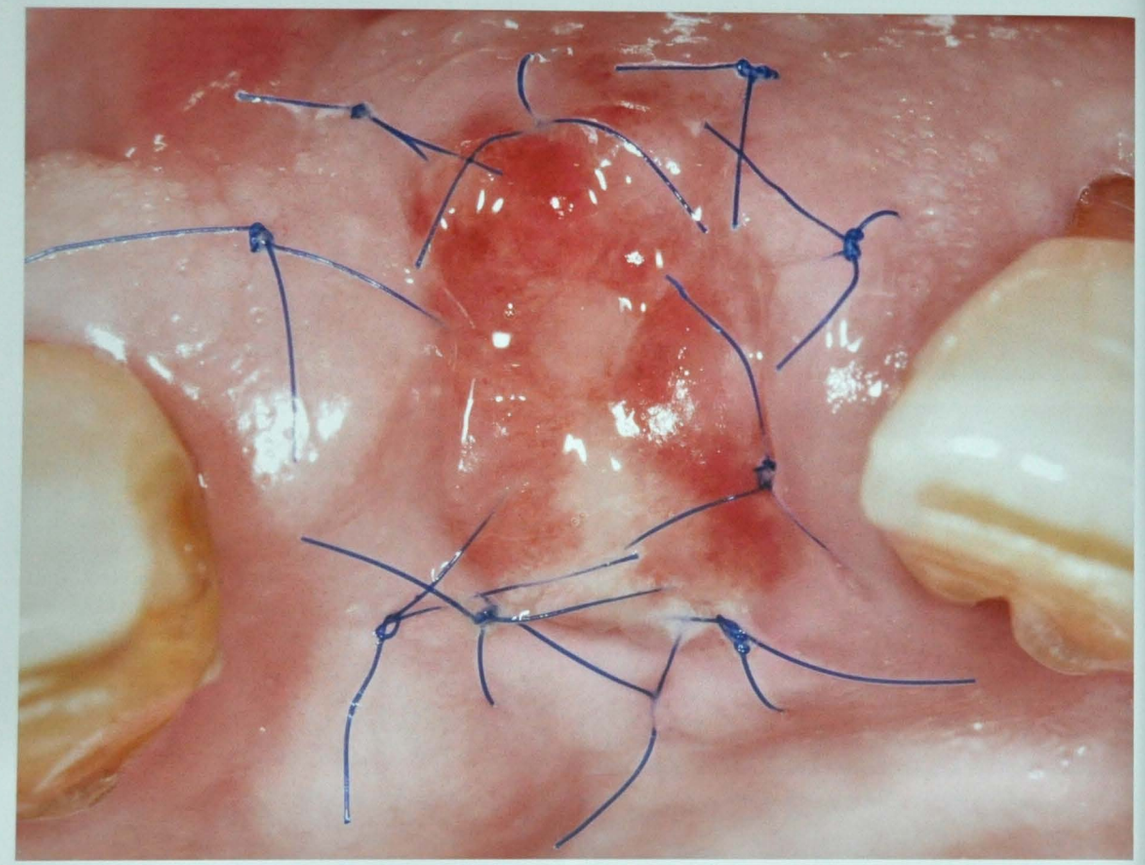


Fig 2-22 Synthetic microsurgical suture materials are characterized by high tissue compatibility and minimal plaque accumulation during the healing process.

2.2.3 Suture Materials

Different surgical procedures require the use of different suture materials. The physical and chemical properties of the suture material must be appropriate for the expected mechanical and biologic stresses on the wound. Suture materials used in periodontal microsurgery must meet a number of physical requirements including high tensile strength, high tearing strength, good knotting characteristics, and high knot security. Moreover, the suture materials should have a surface that facilitates atraumatic passage through the tissues without causing capillarity in order to minimize immune response in the affected tissues. *Capillarity* is the process by which suture materials, particularly those with multifilament fibers, draw fluids and microorganisms into the wound like the wick of a candle.[16] Consequently, it is also referred to as the *wick effect*. Last but not least, absorbable suture materials must have a defined absorption time.

Types of suture material

Suture materials may be classified according to the origin of their raw materials (*natural* versus *synthetic*), their ability to disintegrate in tissue (*absorbable* versus *nonabsorbable*), and their structure (monofilament versus multifilament). Monofilament sutures consist of a single strand of material, whereas multifilament sutures have several strands of material that are braided together.

Nonabsorbable sutures are generally preferred to absorbable sutures because the latter always induce inflammatory reactions in tissue when they disintegrate. If absorbable sutures must be used, they should preferably be made of synthetic materials. This is because compared to sutures made of natural materials, sutures made of synthetic materials cause milder inflammation as they disintegrate. Serafit, a suture made of polyglycolic acid, has proved to be a suitable synthetic product. Size 6-0 Serafit sutures have an absorption time of 60 to 90 days. Nonabsorbable sutures are characterized by high tissue compatibility.[17–19] Compared to multifilament sutures, monofilament nonabsorbable threads cause much less capillarity but are stiffer and therefore have poorer knotting characteristics and knot security. Seralene suture materials provide a good compromise between capillarity and knotting characteristics. These are synthetic monofilament sutures made of polyvinyl fluoride, which makes them very tissue compatible. Seralene 6-0 and 7-0 sutures have good knotting characteristics and relatively low stiffness. Still, precise knot-tying technique is necessary for secure suture closure when monofilament sutures are used.

Expanded polytetrafluoroethylene (e-PTFE) sutures are a special type of nonabsorbable suture (Fig 2-22). Sutures made of e-PTFE are monofilament threads with air pockets incorporated in the material. Their tissue compatibility is excellent, but their porosity (air content of 50% to 60%) results in a high swelling capacity, making e-PTFE sutures prone to bacterial biofilm colonization of the thread surface. These are major drawbacks, but e-PTFE also has some important advantages, such as excellent glide characteristics. Consequently, Gore-Tex CV-5 suture materials can be recommended as standard materials for macrosurgical suture applications in modern periodontal surgery.

The *European Pharmacopoeia (EP)* provides a standardized system for suture size classification in which size denotes the diameter of the suture thread. The EP classification is based on the metric system, and diameter is indicated in units of 0.1 mm on the metric scale. Under the EP system, the diameter of a size 1 suture ranges between 0.100 and 0.149 mm. Although the suture size printed on the label denotes the minimum diameter of the thread, the actual thread diameter usually lies at the upper end of the tolerance range.

The commonly used suture sizes such as 5-0, 6-0, and 7-0 are based on the *United States Pharmacopeia (USP)* system. To maintain uniformity, the USP has also adopted the metric classification system, and today both metric and USP size gauges are printed on the labels of most suture packaging. Table 2-4 provides a side-by-side comparison of the metric and USP suture size classification systems.

Table 2-4

Comparison of the European Pharmacopoeia (EP) and United States Pharmacopeia (USP) suture size classification systems

Metric (EP)	USP	Diameter (mm)
0.01	12-0	0.001–0.009
0.1	11-0	0.010–0.019
0.2	10-0	0.020–0.029
0.3	9-0	0.030–0.039
0.4	8-0	0.040–0.049
0.5	7-0	0.050–0.069
0.7	6-0	0.070–0.099
1.0	5-0	0.100–0.149
1.5	4-0	0.150–0.199
2.0	3-0	0.200–0.249
2.5	2-0	0.250–0.299
3.0	2-0	0.300–0.349
3.5	1	0.350–0.399
4	2	0.400–0.499
5	3	0.500–0.599
6	3	0.600–0.699
7	5	0.700–0.799
8	6	0.800–0.899
9	7	0.900–0.999

Surgical needles

Microsurgical needles must have high flexural strength to ensure that they do not bend when passed through tough tissues. Furthermore, they must be ductile enough to prevent breakage when overloaded. The material that best meets these requirements is high-quality stainless steel, which is usually plated with nickel or chrome to facilitate polishing.

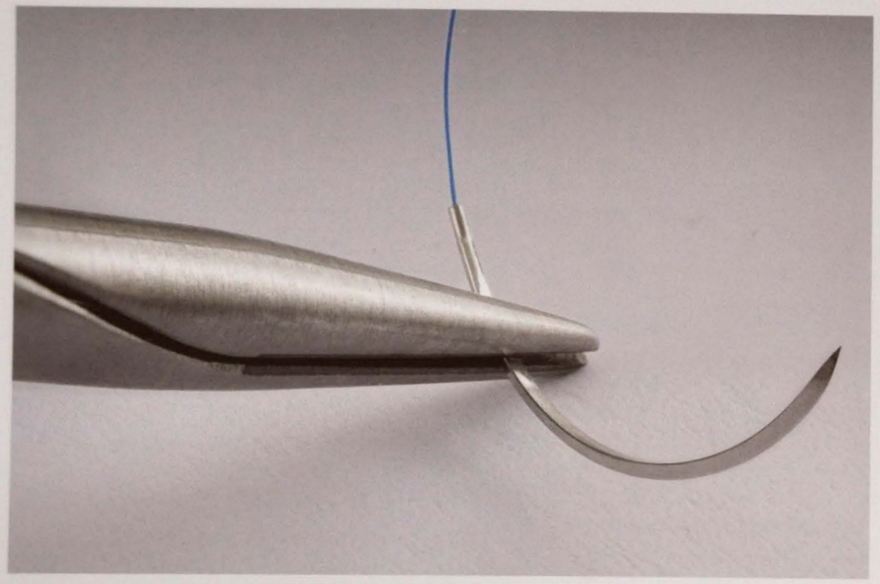


Fig 2-23 Atraumatic suture needles with a curved body and a triangular cutting tip have proven effective in plastic-esthetic periodontal and implant surgery.

Curved needles are easier to handle in tight spaces, and they guide the path of the suture in such a way that when the ends of the thread are pulled, it is possible to achieve apposition of the wound margins with a tendency for *eversion*. Straight needles, on the other hand, result in *inversion* of the wound margins, which should be avoided in periodontal surgery. When interdental sutures are placed, it should be possible to insert the needle through an interdental space in a single pass. This requires the use of longer needles, especially in the molar region. Therefore, needles with a 3/8 or 1/2 curve and an arc length of 8 to 15 mm are preferred for use in periodontal surgery.

Cutting needles with a triangular cross section have proved effective in periodontal microsurgery. Only the front third (tip) of the needle should be sharp, and the middle third (shaft) should be flattened for better retention in the needle holder. Round-bodied needles are not recommended because they bend more easily and are more difficult to pass through periodontal tissues. A polished surface enhances the ability of the needle to glide smoothly through tissues.

The junction between the needle and the thread is another important factor. Conventional needles are reusable and have an eye through which thread is inserted. The eye of the needle and the doubled strand of thread running through it produce a relatively broad suture footprint, which results in considerable tissue trauma.

Atraumatic suture needles were developed to solve this problem. Unlike conventional needles, the suture thread is glued or welded to the blunt end of the atraumatic suture needle, creating a smooth junction (swage) between the needle and the thread. Because these are disposable needles designed for single use only, they are always new and sharp. Consequently, the use of atraumatic suture needles results in a substantial reduction of tissue trauma. All of the evidence points to the benefits of using atraumatic suture needles in periodontal surgery, particularly when microsurgical procedures are performed (Fig 2-23).

A suture set commonly used in plastic-esthetic periodontal and implant surgery is shown in Fig 2-24 and Table 2-5.

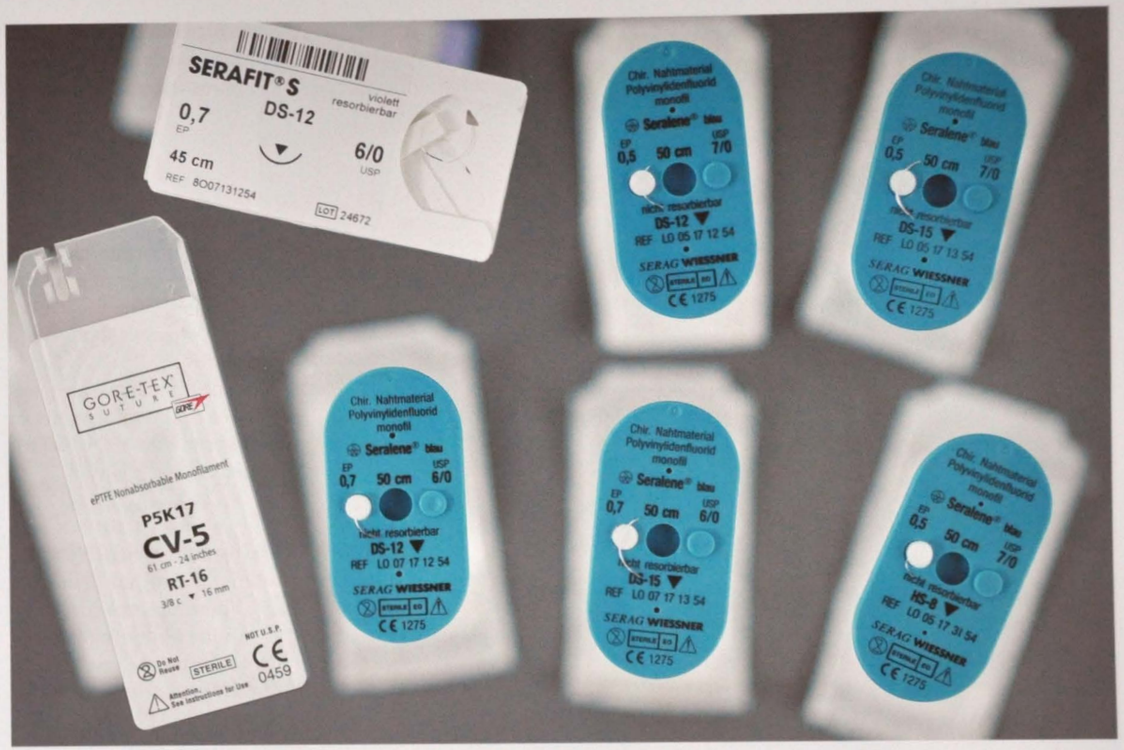


Fig 2-24 The mamadent suture set contains an assortment of different suture materials used in plastic-esthetic periodontal and implant surgery. It contains absorbable and nonabsorbable suture materials for both macrosurgery and microsurgery.

Table 2-5

Characteristics of materials included in the mamadent suture set

Name	Material	Construction	Size	Needle length	Needle shape	Indications	Absorbability
Seralene DS12 6.0	Polyvinylidene fluoride	Monofilament	6-0	12 mm	3/8 circle needle	Periosteal sutures, anchoring sutures in the anterior region	Nonabsorbable
Seralene DS15 6.0	Polyvinylidene fluoride	Monofilament	6-0	15 mm	3/8 circle needle	Periosteal sutures, anchoring sutures in the posterior region	Nonabsorbable
Seralene DS12 7.0	Polyvinylidene fluoride	Monofilament	7-0	12 mm	3/8 circle needle	Standard microsurgical suturing	Nonabsorbable
Seralene DS15 7.0	Polyvinylidene fluoride	Monofilament	7-0	15 mm	3/8 circle needle	Microsurgical suturing in the molar and premolar interproximal region	Nonabsorbable
Seralene HS8 7.0	Polyvinylidene fluoride	Monofilament	7-0	8 mm	1/2 circle needle	Detailed closure in hard-to-reach areas	Nonabsorbable
Gore-Tex CV-5	Polytetrafluorethylene	Monofilament	5-0	16 mm	3/8 circle needle	Standard macrosurgical suturing	Nonabsorbable
Serafit DS12 6.0	Polyglycolic acid	Mulitfilament	6-0	12 mm	3/8 circle needle	Subepithelial connective tissue graft fixation	Absorbable (60–90 days)

2.3 Microsurgical Training for Clinical Practice

2.3.1 Adapting to the Use of Magnification

The use of optical magnification is becoming more and more commonplace in contemporary dentistry. Many clinicians already routinely use a *Galilean* loupe with ×2 to ×3 magnification. Magnification significantly reduces the visibility of the surgical field, making it much harder to control hand movements and work sequences. Clinicians must therefore adapt their old hand motor skills and master new ones (eg, picking up and putting down the needle when tying knots). There are specific courses that can facilitate the transition to working with optical magnification. As the power of magnification increases, a person's awareness of the physiologic tremor of the hands also increases. To ensure that this awareness does not impair performance during surgery, the clinician should learn appropriate behavioral and mental preparatory techniques before performing microsurgical interventions.

Lack of sleep or excessive stress in the period prior to surgery can impair fine motor control, affect hand muscle coordination, and cause increased tremor. Nicotine, caffeine, and certain medications are known to persistently aggravate physiologic tremors. Emotional factors such as stress and nervousness also have a negative effect on physiologic tremor. Therefore, the surgeon must make sure that he or she is well rested and in a relaxed state of mind when performing microsurgery. Proper training prior to the first microsurgical intervention can also help reduce tension and nervousness and is therefore highly recommended.

2.3.2 Training Exercises Using Rubber Dam

The most important skills to practice are the handling of suture materials and the tying of knots under optical magnification. Any surgeon wishing to perform microsurgery must be able to confidently pick up and guide a needle with microsurgical instruments, put down the needle in the field of view when tying knots, easily retrieve a needle placed outside the visual field, and tie instrument knots. These skills can be practiced by stretching a piece of rubber dam over a wooden board that has a hole cut out in the middle (Fig 2-25).

A simple exercise for practicing microsurgical skills and procedures for tying microsurgical knots under optical magnification with the aid of microsurgical instruments is described below.

Incision technique

Using a scalpel, the clinician makes a practice incision in a piece of rubber dam stretched over a wooden board. The incision should extend diagonally, either from left to right and up to down (right-handed surgeon) or in the reverse direction (left-handed surgeon). The placement of two additional parallel incisions prevents the need to apply excessive tension on the sutures.

In later training, the surgeon should change the position of the rubber dam to practice making incisions in different directions with the instruments at a different angle and the hands in an unaccustomed position.

Postural support

When the practitioner is working under magnification, movement of the instruments is controlled primarily by finger and wrist movement. Therefore, the surgeon's arms should rest comfortably on the operating table or on the armrests of the chair. Instruments are held in a pen grip while the little finger and ring finger rest against a stable surface for support (Fig 2-26). The support prevents premature fatigue and minimizes physiologic tremor.

Picking up the needle

The surgeon should use the needle holder to grasp the back third of the needle perpendicular to the axis of the needle. The following procedure is recommended.

With forceps in the nondominant hand, the surgeon should grasp the thread 3 to 4 cm away from the needle and lift it until only the tip of the needle is still on the undersurface. Now the needle holder can be used to grasp and secure the correct section of the needle. This procedure excludes the possibility of holding the needle with two instruments at the same time, which could result in bending. The tip of the needle should never be grasped because this contact could bend and blunt the tip.

Inserting the needle

Bite size is the distance from the incision line to the sites where the needle enters and exits the tissue on either side of the incision line. It is determined by the thickness of the flap or the desired depth of the suture path in the tissue. The more superficially the needle is to be passed through the tissue, the smaller the distance from the incision line to the needle insertion and exit sites. However, a minimum tissue thickness is needed to prevent the sutures from tearing the tissue and causing additional tissue trauma. Uniform bite size is crucial for precise suture closure without overlapping wound margins. Therefore, the distances between the incision line and the needle insertion and exit sites must always be equal (Fig 2-27).

The creation of uniformly sized sutures should be practiced on rubber dam. The correct distance between the incision line and the needle insertion or exit site is approximately twice the thickness of rubber dam. The

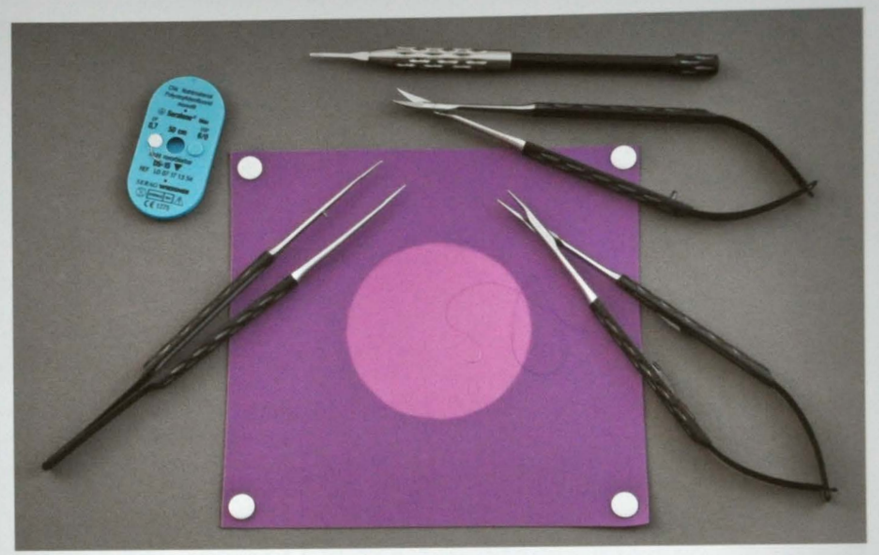


Fig 2-25 Microsurgical suture skills can be practiced by stretching a piece of rubber dam over a wooden board that has a hole cut out in the middle.

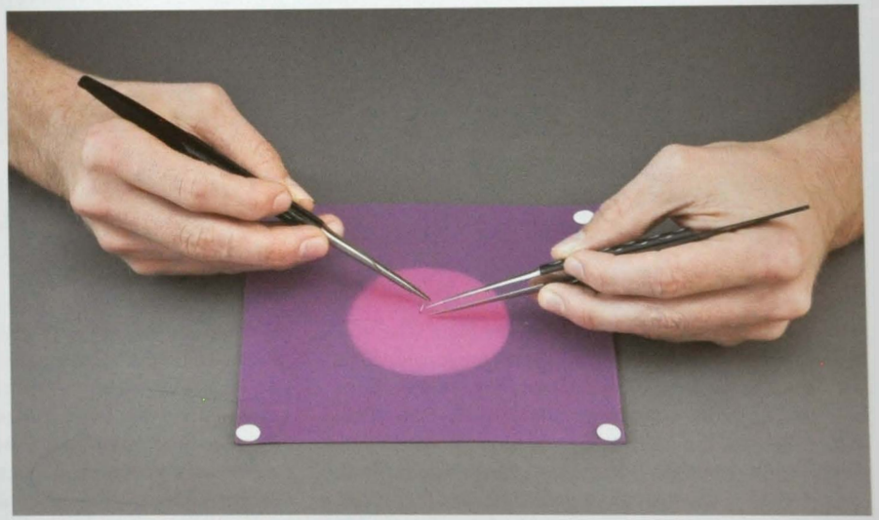


Fig 2-26 Microsurgical instruments are held in a pen grip. The working hand is supported via the little finger and ring finger.

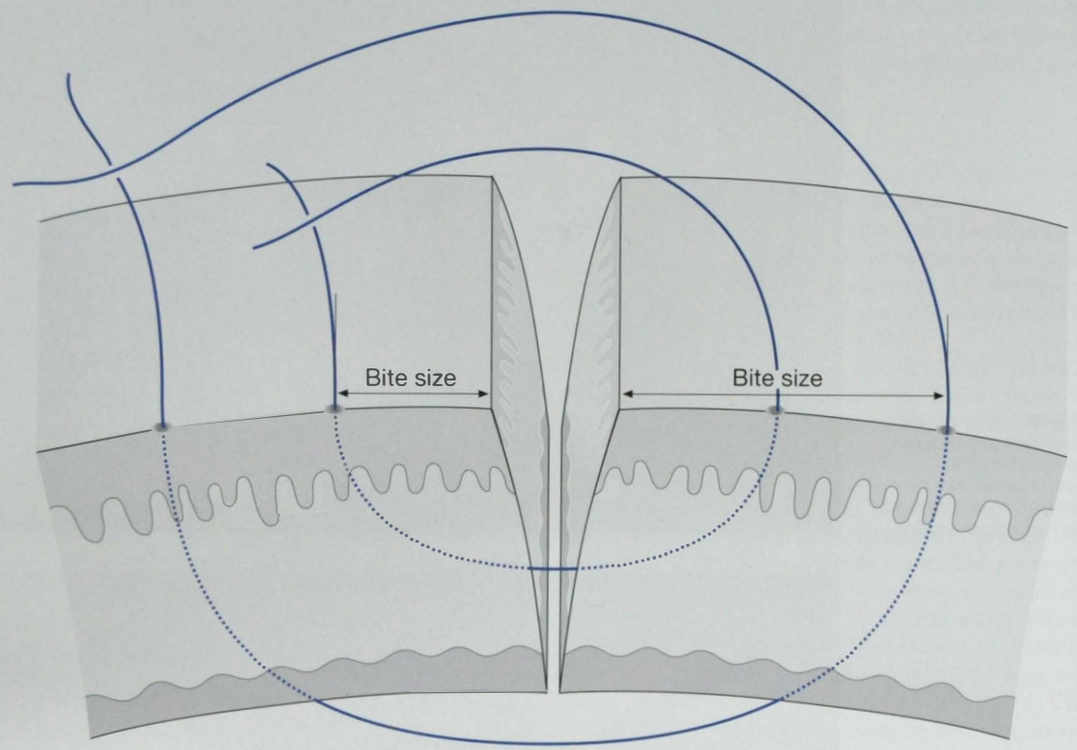


Fig 2-27 To achieve a uniform bite size, the distances between the incision line and the points where the needle enters and exits the tissue on either side of the incision line must be equal.

needle should be inserted at a 90-degree angle to the incision line and perpendicular to the surface of the rubber dam. The clinician can facilitate this positioning by holding the forceps against the underside of the rubber dam. Likewise, the surgeon can facilitate removal of the needle on the opposite side by gently pressing against the opposite side of the rubber dam with forceps (Fig 2-28). During insertion, the needle is pushed through the rubber dam as far as possible before the needle holder is opened and the needle is released. Next, the needle holder is used to grasp the shaft of the needle (middle third) and pull it all the way through the rubber dam. The needle should never be grasped by the tip if this can be avoided. Furthermore, use of another instrument in the nondominant hand to remove the needle from of the needle holder can easily bend the needle. If only the tip of the needle emerges from the exit site, the clinician should grasp it very gently without fully closing the jaws of the needle holder and then pull the needle out only as far needed to grasp its middle portion. Passage of the needle into and out of the material can be accomplished in one or two steps. After the needle has completed its passage through the rubber dam, the needle is either set down, preferably somewhere within the field of view, or inserted in the rubber dam to facilitate retrieval of the needle with the needle holder after the suture knot is tied (Fig 2-29).

Tying a surgeon's knot

Microsurgical sutures are tied with microsurgical instruments. A simple surgeon's knot, consisting of an initial double throw followed by a second single throw in the opposite direction, is commonly used. The clinician should practice tying a surgeon's knot on rubber

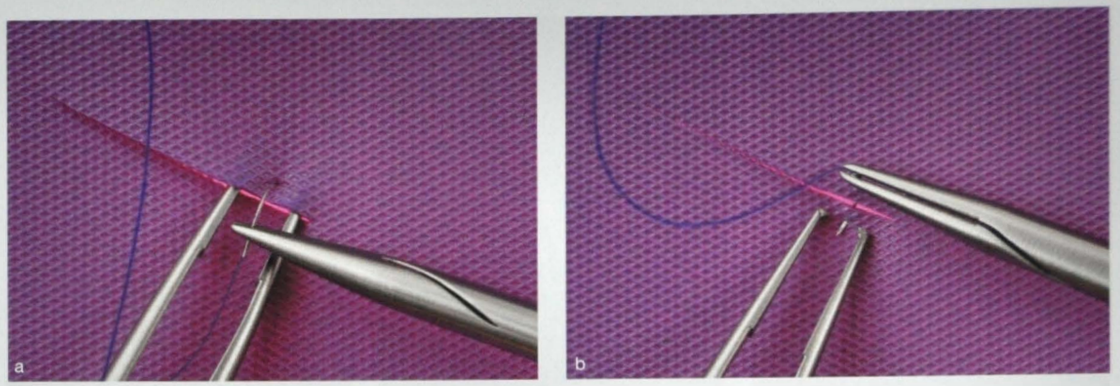


Fig 2-28 (a and b) The needle is inserted perpendicular to the surface of the rubber dam. Passage of the needle into and out of the rubber dam can be facilitated by gently pressing with forceps on the opposite side.

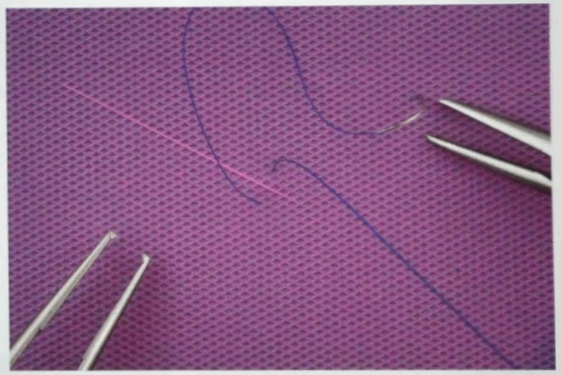


Fig 2-29 The needle should be set down within the field of view before a suture knot is tied so that it can be located immediately after this task is completed.

dam until the movements become routine and refined. The terms *long end* and *short end* of the suture are used in the following explanations of the procedure. The long end is the one attached to the needle, whereas the short end is the one protruding from the insertion site.

1. The surgeon should grasp the long end of the suture approximately 3 cm away from the needle exit site using microsurgical forceps held in the nondominant hand.
2. The surgeon should center the needle holder directly above the incision line and between the two ends (long and short) of the suture using the dominant hand.
3. The clinician should form a double throw by wrapping the long end of the suture around the needle holder twice using the forceps held in the nondominant hand.
4. The short end of the suture should be grabbed with the needle holder and pulled through the double throw. This draws the short end in the needle holder toward the needle exit site while the long end is pulled toward the needle insertion site.
5. After releasing the short end of the suture, the surgeon should center the needle holder in the dominant hand above the knot and between the two ends of the suture.
6. The surgeon should make a single throw by wrapping the long end of the suture around the needle holder in the opposite direction once using the forceps in the nondominant hand.
7. The short end of the suture is grasped with the needle holder again and pulled through the single throw. This time, the short end of the suture is drawn in the opposite direction, back toward the insertion site.
8. The knot is gently tightened and placed lateral to the incision line (Figs 2-30 and 2-31).

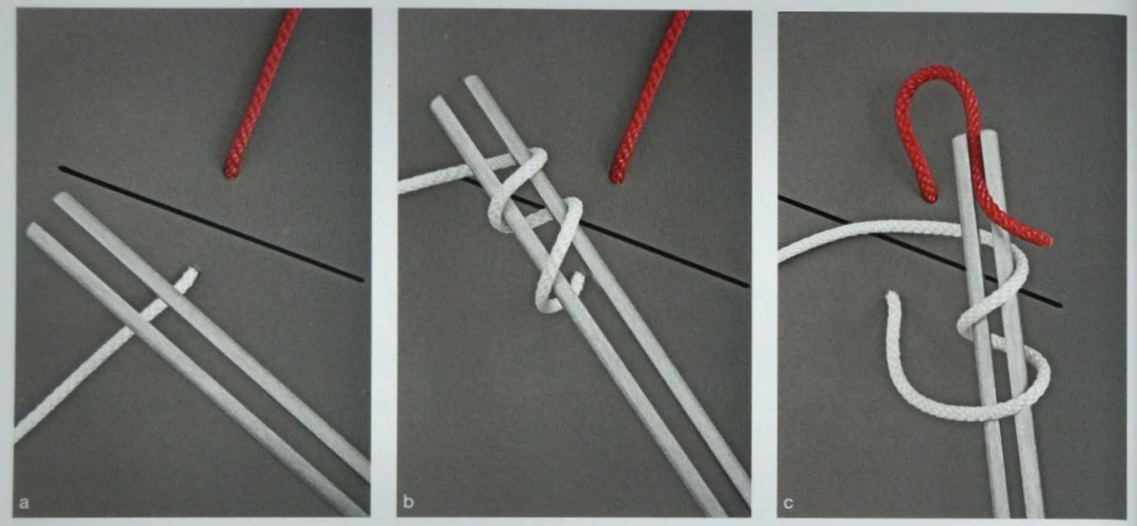


Fig 2-30 (a to c) First, the suture is pulled through the wound margins until just a small amount (about 1 cm) remains at the short end. Next, the long end of the suture is grasped approximately 3 cm away from the needle exit site using forceps, and the tip of the needle holder is centered between the two ends of the suture. A double throw is made by wrapping the long end of the suture around the needle holder twice using the forceps, and the short end of the suture is grasped with the needle holder.

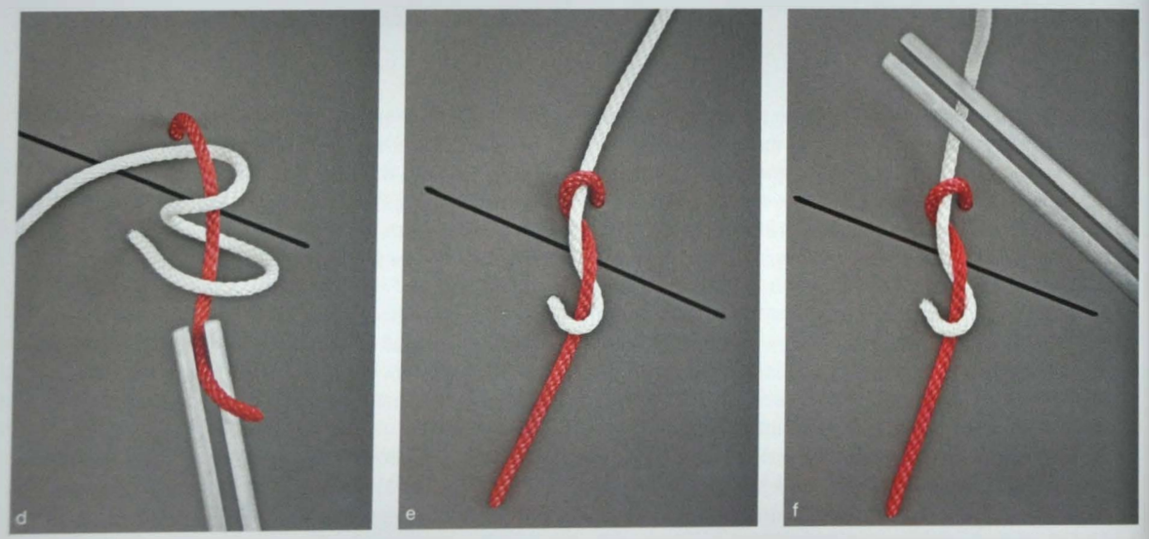


Fig 2-30 (d to f) The first throw is loosely tightened by pulling the short end of the suture through the double throw, in the direction of the needle exit site. The tip of the needle holder is then centered between the two suture ends again.

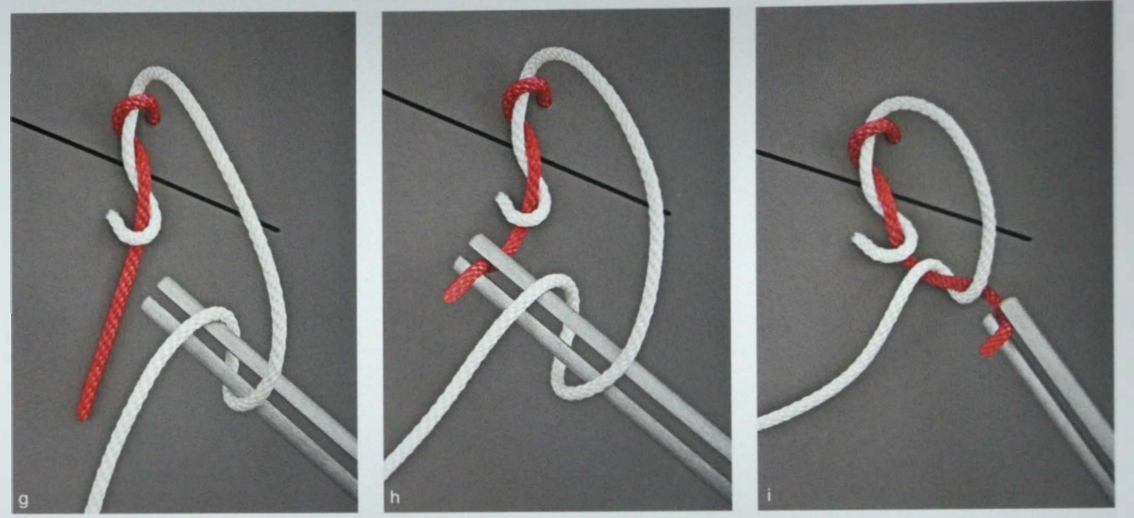


Fig 2-30 (g to i) A single throw is made by wrapping the long end of the suture once around the needle holder in the opposite direction using the forceps, and the short end of the suture is grasped again.

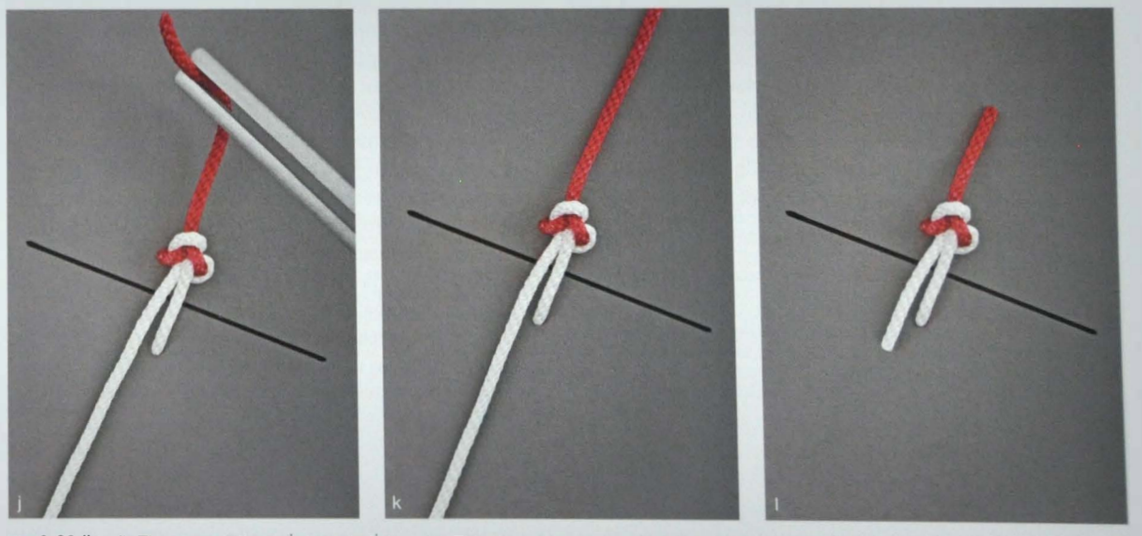


Fig 2-30 (j to l) The second throw is loosely tightened. This time, the short end of the suture is drawn in the opposite direction, back toward the insertion site. The knot is then placed lateral to the incision line.

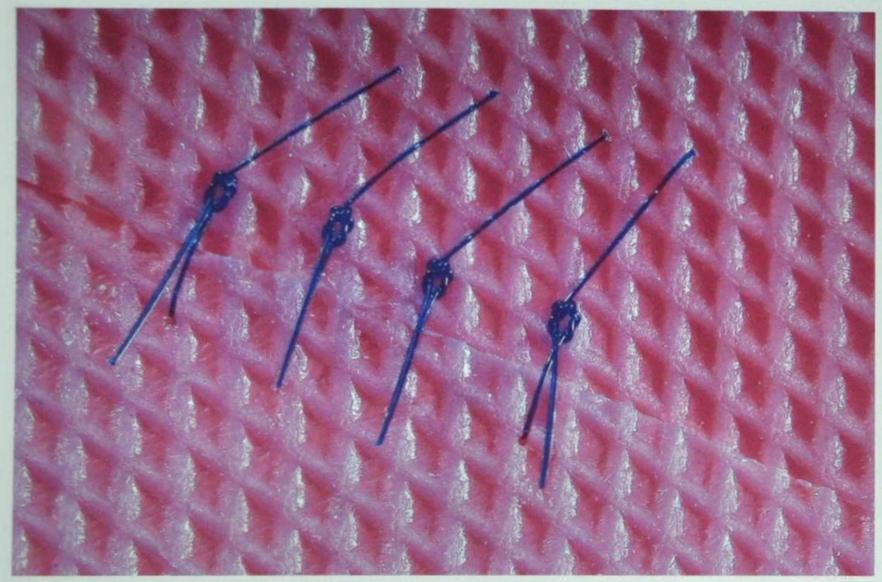


Fig 2-31 A simple surgeon's knot, consisting of an initial double throw followed by a second single throw in the opposite direction, can be tied with microsurgical instruments.

Cutting the sutures

The suture materials used in microsurgery are cut with microsurgical scissors. It is important to ensure that the cut ends are no shorter than 3 mm but also not much longer than that. If the needle is not in the field of view at first, then only the short end of the suture is cut with the microscissors after knot tying is completed and the end is removed from the field of view. The long end of the suture is then grasped with the forceps and cut. Finally, the thread grasped with the forceps is slowly drawn through the open jaws of the needle holder until the needle reappears in the field of view and can be grasped with the needle holder.

2.3.3 Advanced Training

Incision and flap design are further important elements of microsurgical training. In addition to learning the movement sequences, it is important to become accustomed to the unusual visual dimensions of microsurgery. When working under optical magnification, it is easy to overestimate the actual thickness of an elevated flap. Consequently, the flap could be too thin and prone to necrosis. The use of microsurgical procedures and instruments makes it possible to perform flap procedures that are completely different from those used in conventional surgery. The clinician should first practice these techniques on an appropriate model before performing them on a patient. Pig jaws are very well suited for hands-on training in microsurgical procedures (Fig 2-32). When performing surgical exercises under a microscope for the first time, the surgeon should take a microsurgical training seminar with an experienced instructor.

Fig 2-32 Pig jaws are very well suited for hands-on training in microsurgical procedures.

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CHAPTER 3

PRIMARY HEALING: THE KEY TO SUCCESS

Primary wound healing is an essential part of successful reconstructive surgery. Rapid and unimpaired healing is crucial, particularly in plastic-esthetic periodontal and implant surgery, where soft and hard tissue grafts and artificial substitutes are frequently used. The survival and integration of grafts and graft substitutes depend on a number of factors, including the quality of the blood supply to the affected tissues and the prevention of bacterial infection. Both are crucial for achieving proper incorporation of graft materials into the surrounding tissues. The oral microflora contains a number of different bacteria. Primary wound closure over natural or artificial graft material ensures that healing will occur in an environment that is impossible or very difficult for microorganisms to enter.

Healing following plastic-esthetic periodontal and implant surgery is often complicated by the fact that the surgical wound is located on a rigid and avascular tooth or implant surface, resulting in an impairment of local immune defenses and a reduction of the supply of nutrients to vital tissues at the site.[1] Impaired healing can lead to wound dehiscence, tissue defects, and the formation of fibrotic tissue and hypertrophic scars, all of which adversely affect the cosmetic outcome. Optimal wound healing is crucial to the success of plastic-esthetic periodontal and implant surgery (Fig 3-1).

The term *wound healing* encompasses all of the physiologic regenerative processes involved in restoring the integrity of damaged body tissues. Because surgical wounds are created in a more or less controlled environment, the surgeon has a great degree of control over a range of factors involved in the wound healing process, from incision placement to wound closure.

The physiologic processes involved in wound healing will be described in the following section. Those factors crucial to achieving optimal wound healing following periodontal and implant surgery will be discussed in detail.

3.1 Principles of Wound Healing

3.1.1 General Principles

Wound healing occurs by one of two mechanisms: regeneration or repair. *Wound regeneration* refers to the replacement of lost or damaged tissue with identical tissue, resulting in restoration of the tissue to its original condition (restitutio ad integrum). *Wound repair*, on the other hand, involves the replacement of lost or damaged tissue by nonspecific scar tissue; therefore, the tissue is not restored to its original condition.[2] If a wound is caused by trauma, regenerative healing generally is not possible because these wounds tend to be extensive—in some cases, with complete tissue loss. In surgical wounds, on the other hand, regenerative healing is possible, and the surgeon should always strive to achieve complete regeneration of the damaged tissues to prevent formation of extensive scar tissue.

Reparative healing is basically determined by the wound closure status during the healing process. If a wound such as an abrasion is left to open, reparative tissue must form to cover the tissue defect and restore the integrity of the body surface. The reparative tissue formed by this route transforms into scar tissue during the later phases of healing. Generally speaking, *healing by secondary intention* (per secundam intentionem) occurs when the wound is left open to heal, whereas primary wound closure results in *healing by primary intention* (per primam intentionem).

From a biologic perspective, the end result of wound healing by primary or secondary intention is basically the same: wound closure. However, the two processes differ significantly in terms of the chronology of the different phases of wound healing and the quality of tissues formed during the healing process.

3.1.2 Primary and Secondary Wound Healing

Wound healing by primary intention is characterized by the relatively uncomplicated healing of a wound with formation of either very little or no scar tissue. In other words, the tissue is made intact and restored to its original condition. From a surgical perspective, the smooth, well-vascularized, tension-free, and precisely approximated wound margins are the most important conditions for healing by primary intention. After *primary wound closure*, a *thin but stable blood clot* forms between the wound margins, and *little to no local tissue ischemia* occurs. Consequently, *bacteria cannot infiltrate the wound*, particularly the deep tissue layers. *Blood circulation* to the wound is rapidly restored, and a provisional matrix quickly forms to cover the wound. Under favorable conditions, primary wound healing can occur within a few days in the absence of clinically detectable inflammation, wound secretion, and granulation tissue formation.[2,3]

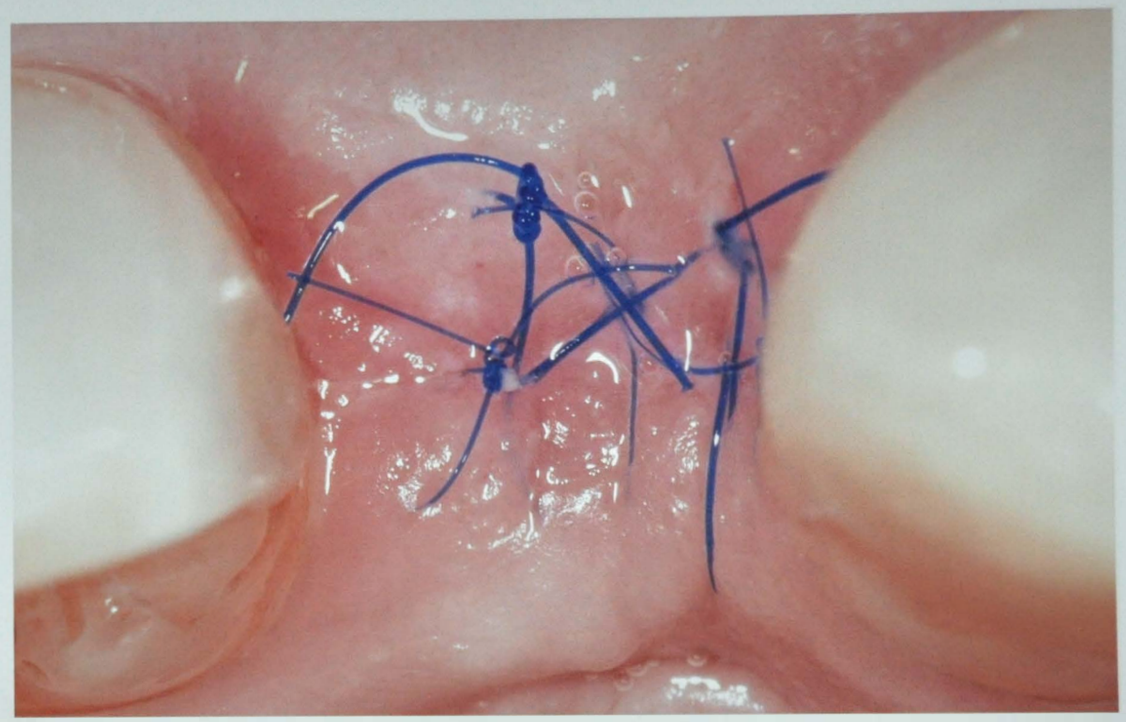


Fig 3-1 Immediately prior to suture removal 1 week after implantation and hard tissue augmentation, the site shows optimal wound healing, characterized by complete wound closure, minimal fibrin, and absence of signs of inflammation.

The surgeon should always attempt to create optimal conditions for primary wound healing, which normally ensures that the course of postoperative healing will be quick and uncomplicated. If these conditions are met, the acute inflammatory response that invariably occurs during the healing process will be short and hardly noticeable clinically, patient discomfort and impairment will be minimal, necrosis-related tissue defects will not occur, the regeneration processes below the surface can proceed unimpaired, and healing will culminate in nearly scar-free restoration of the original condition (Fig 3-2).

Secondary wound healing occurs if the wound is intentionally left open to heal or if primary wound closure is not possible due to the presence of tissue defects. Secondary healing is associated with the formation of reparative tissue. To quickly close the wound and rapidly restore the integrity of the epithelial lining of the oral cavity, the body produces low-grade scar tissue to bridge the gap caused by the damaged or missing tissue. Flap edge necrosis often occurs if the sutures exert too much tension on the flap, if the sutures are poorly knotted and loose, or if there is local tissue hypoperfusion, resulting in secondary healing after primary wound closure. Bacterial infection and the resulting immunologic reaction can delay healing.

The time required for wound healing is mainly determined by the size of the wound and the presence or absence of bacterial infection. Scarring usually remains after the process is completed. The texture and color of the scar tissue can vary greatly from that of the surrounding tissues. The surface of the scar tissue often

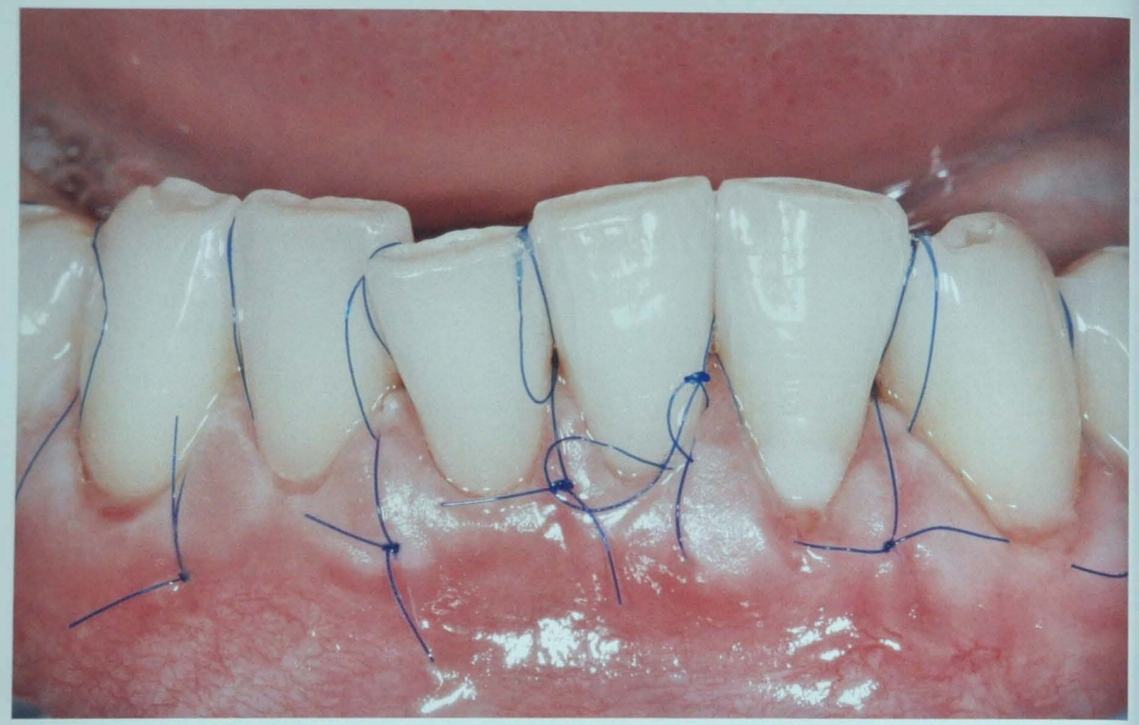


Fig 3-2 Healing by primary intention 1 week after placement of a coronally positioned flap for root coverage in a patient with gingival recession.

exhibits projections and irregularities because of the contraction of the collagen fiber–rich tissue during the course of healing.

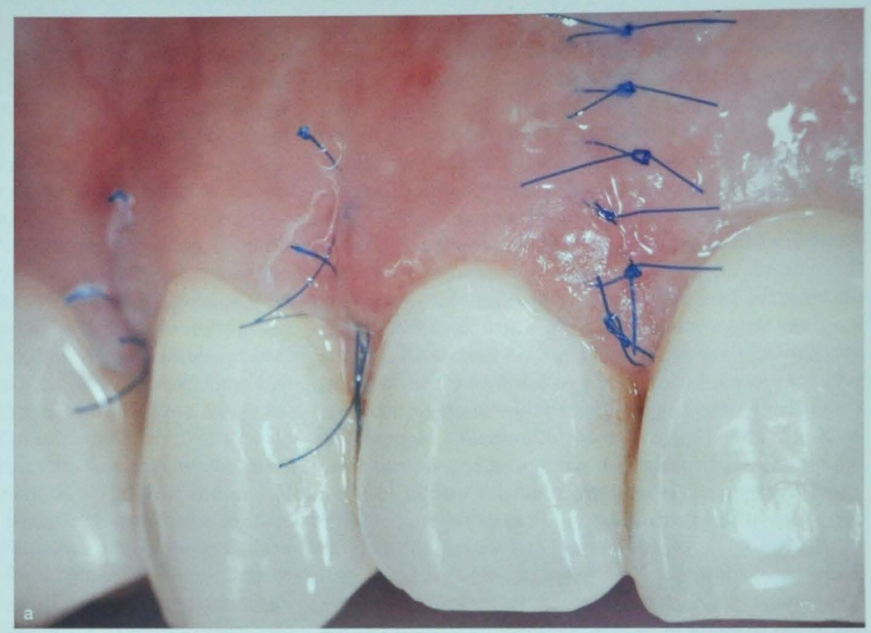
Secondary healing is associated with a higher risk of bacterial infection, postoperative discomfort, and scar tissue formation. Hence, secondary healing of surgical wounds should be avoided whenever possible, especially if the surgery was performed for cosmetic reasons. There are exceptions, however: In cases such as gingival recession coverage and esthetic crown lengthening, specific areas of the wound are intentionally left open and allowed to heal by secondary intention (Fig 3-3).

3.1.3 Phases of Wound Healing

The process of wound healing encompasses all of the physiologic regenerative processes initiated by the body to restore the continuity of its tissues. Interactions between mesenchymal and epithelial cells, which are mediated and coordinated by a large number of chemical mediators with local and systemic effects (eg, growth factors and cytokines), play an important part. The overall wound healing process can be broken down into a series of distinct phases, which are described below.

Inflammatory phase

The inflammatory phase mainly functions to establish temporary wound closure in order to restore the integrity of the body surface. Dead cells are eliminated from the wound, and invading microorganisms are killed. The inflammatory phase is a two-part process consisting of an exudative phase and a resorptive phase.



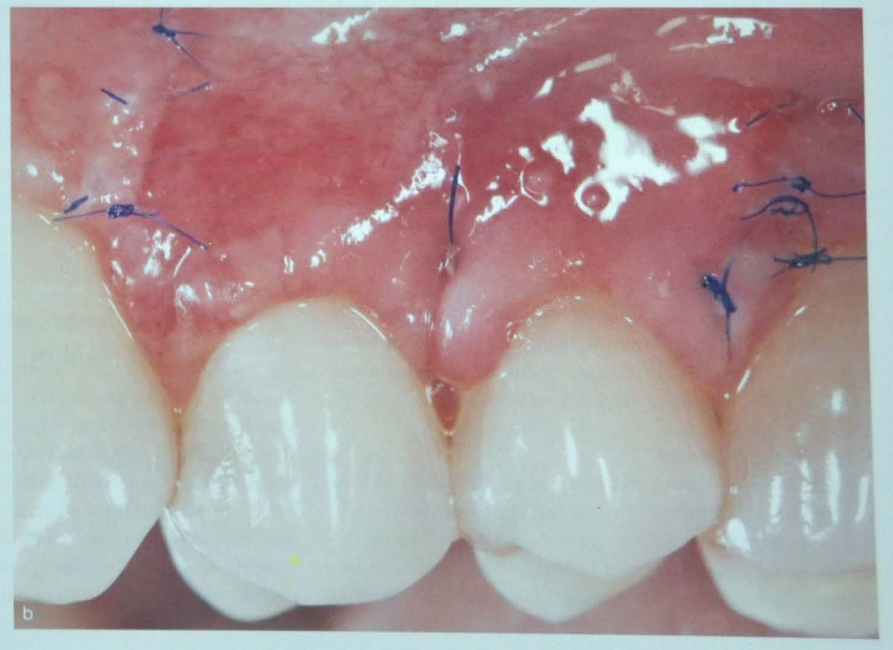


Fig 3-3 Differences in the healing outcomes of two vertical releasing incisions 1 week after surgery. (a) Primary wound healing. (b) Secondary wound healing.

Exudative phase

The exudative phase is the first stage of wound healing. It occurs within the first 48 hours of an injury and is characterized by an influx of blood, lymph, and tissue fluid into the wound. The first local response, vasoconstriction, occurs within seconds. The affected blood vessels constrict to minimize blood loss. A blood clot consisting of platelets and red blood cells enmeshed in a network of plasma proteins forms on the wound. This cell complex is organized to form a fibrin-stabilized provisional matrix, which temporarily glues the wound together. In addition to stabilizing the wound, the provisional matrix serves as a reservoir for growth factors and as a scaffold to guide blood vessels and migrating cells into the wound. A narrower wound opening will lead to a smaller clot, which enables faster healing and closure of the wound. The overall effect is a rapid closure of the wound to limit exposure to the germ-laden oral cavity.[2,4]

Resorptive phase

The chemotactic stimulation within the wound attracts neutrophils to migrate down the provisional matrix into the wound after a period of roughly 6 hours. The neutrophils phagocytose the pathogens and ensure their intracellular elimination in the scope of a cell-mediated immune response. High levels of bacterial contamination are associated with excessive neutrophil stimulation, which can quickly result in the extracellular release of proteolytic enzymes. These enzymes can produce defects in endogenous tissues and cause local acidosis, resulting in cell damage. In a second wave of cell-mediated immune response, macrophages differentiating from histiocytes systematically degrade and eliminate the cellular and pathogenic debris. In this context, the exudation of plasma from the wound serves a number of purposes: It not only facilitates the distribution of locally released mediators and ensures sufficient mobility of the aforementioned immune cells in tissue but also serves as a nutrient medium for the later waves of fibroblasts migrating into the wound.

Restoration phase

After the initial differentiation and proliferation of mesenchymal cells, there is a continuous transition from the inflammatory phase to the restoration phase. Central elements of this process include the ingrowth of capillary tissue and formation of granulation tissue (proliferative phase) and redifferentiation of scar tissue (repair phase).[2]

Proliferative phase

The end of the inflammatory phase of wound healing is marked by the formation of new capillaries and their ingrowth into the wound. Anastomoses are formed to successively reestablish the blood supply to the wound. How smoothly this stage progresses is determined by the quality of blood supply to the wound margins, which is determined by how many adjacent vascular structures were injured by tissue trauma (eg, strain, contusion, or incision).

Subsequently, the proliferative phase occurs 24 to 74 hours after injury. This is an anabolic process, characterized by epithelization starting from the wound margins and transformation of the clot into well-vascularized, cell- and collagen-rich granulation tissue. The initial blood and fibrin clot serves as a guide that leads the migrating fibroblasts and endothelial cells to the wound.[2,4] In wounds healing by primary intention, only a small amount of granulation tissue has to form, so wound healing proceeds quickly, and the tensile strength of the wound increases rapidly. If a wound heals by secondary intention, massive quantities of granulation tissue must be formed to cover a larger defect, and it takes much longer to achieve stable wound conditions.

Repair phase

Repair is the final stage of wound healing. Epithelial closure of a wound is achieved by the lateral migration of epithelial cells along the margins of the wound to the granulation tissue. Scar formation after primary wound healing is minimal. In most cases, the scar line remaining after wound healing is inconspicuous or, ideally, invisible. Wound healing by secondary intention often results in wider, unesthetic scars, some of which result in functional impairment due to excessive tissue contraction.[3]

3.1.4 Clinical Assessment of Wound Healing

It can be hard to distinguish between primary and secondary wound healing a few days after surgery. To address this problem, *Wachtel* and coworkers[5] developed the Early Wound Healing Index (EHI) to facilitate differentiation between primary and secondary healing and to provide a more objective assessment of postoperative wound healing quality. The EHI distinguishes five classes of wound healing 5 days after surgery (Fig 3-4).

EHI 1

Grade 1 wound healing is characterized by complete flap closure with no fibrin line 5 days after primary wound closure (primary wound healing). Because of the excellent quality of wound healing, the sutures can be removed and the recommended postoperative wound management measures started at this time (see chapter 6).

EHI 2

Grade 2 wound healing is characterized by complete flap closure and a fine fibrin line 5 days after primary wound closure. In EHI 2, the sutures should be left in place another 2 days for further stabilization of the wound area. The sutures are removed and the recommended postoperative management measures started 7 days after surgery.

EHI 3

Grade 3 wound healing is characterized by complete flap closure with fibrin coverage of the incision line and adjacent parts of the flap 5 days after surgery (still classified as primary wound healing). The sutures are removed and the recommended postoperative management measures started 7 days after surgery.

EHI 4

Grade 4 wound healing is characterized by incomplete flap closure and partial necrosis of the wound margins. Due to the postoperative wound infection and the increased tissue pressure in the inflamed region, the wound margins drift apart, and secretions drain out of the wound. Healing occurs by secondary intention, and increased wound pain and marked swelling can be observed around the surgical site. The sutures can be removed 7 days after surgery. Complications such as scar formation cannot be excluded. Postoperative management of these cases is described in chapter 17.

EHI 5

Grade 5 wound healing is characterized by incomplete flap closure and necrosis of the wound margins. Because of the wound infection, pus drainage through the incision line or through the sulcus of adjacent teeth may be observed, depending on the situation. The most common surgical causes of impaired wound healing in these cases are flap edges that are too thin and thus poorly perfused and/or the lack of precise and tension-free primary wound closure. Pus sometimes drains from apparently well-approximated wound margins, for example, if graft necrosis has occurred deep within the wound. In these cases, healing occurs by secondary intention and is often accompanied by inflammation, which is frequently associated with significant problems such as increased wound pain and swelling. Complications must be expected in patients with EHI 5 wound healing, and a second surgery may be needed to correct these problems. The sutures can be removed 7 days after surgery. Postoperative management of these cases is described in chapter 17.

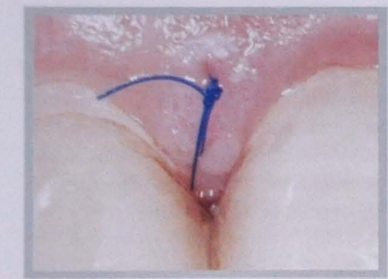
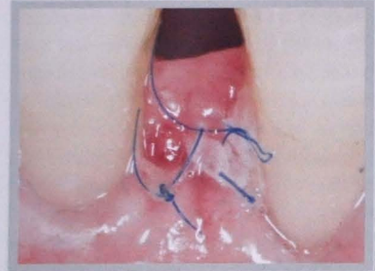
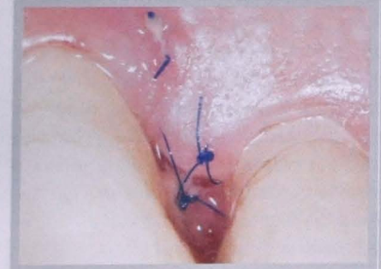
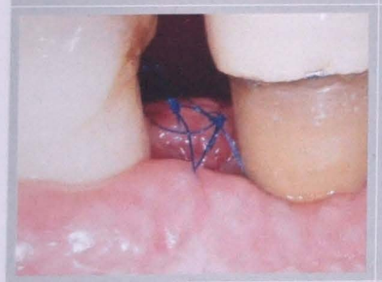
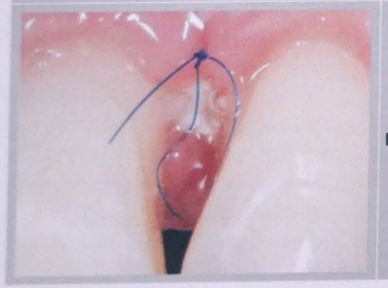
	**EHI 1**	No fibrin at the incision line
	**EHI 2**	Slight fibrin at the incision line
	**EHI 3**	Fibrin at the incision line and adjacent parts of the flap
	**EHI 4**	Open wound with suppuration
	**EHI 5**	Open or closed wound with localized pus collection

Fig 3-4 The Early Wound Healing Index (EHI) distinguishes five classes of wound healing, as determined 5 days after surgery.[5] It provides an objective assessment of wound healing. The clinical photographs show the characteristics of healing in different cases 5 days after regenerative periodontal surgery.

3.2 Factors That Influence Wound Healing

A number of local (Table 3-1) and systemic (Table 3-2) factors influence the healing of surgical wounds. All should be taken into consideration to achieve primary wound healing (EHI 1, 2, or 3), which is the quality of healing required for successful plastic-esthetic periodontal and implant surgery.

3.2.1 Local Factors that Influence Wound Healing

Absence of inflammation

Gingival inflammation and periodontal disease negatively affect the quality of the marginal soft tissue. The inflammatory process results in a marked decrease in collagen content and a significant increase in blood flow, interstitial fluid, and inflammatory cells in the soft tissues. Apart from impairing wound healing after surgery, this also causes technical problems during surgery. In the presence of inflammation, the marginal soft tissue has a spongy consistency and an increased bleeding tendency that makes it difficult to achieve precise microsurgical incisions, flap elevation, and approximation of the wound margins. Because plastic-esthetic periodontal and implant surgery are elective procedures, they should only be performed in the absence of inflammation.

All inflammatory periodontal conditions must be eliminated prior to plastic-esthetic periodontal and implant surgery to ensure the predictability of the planned procedure. Before surgery, patients with inflammatory periodontal diseases must receive adequate periodontal pretreatment by a dental hygienist or dental assistant with comparable training. The periodontal pretreatment program should include multiple professional supragingival and subgingival tooth cleaning sessions as well as personal oral hygiene instruction and motivation. One of the established plaque and bleeding indices should be used to evaluate the efficacy of personal oral hygiene. Plastic-esthetic periodontal or implant surgery should not be performed unless the Plaque Index (PI) score is less than 20% and the Papillary Bleeding Index (PBI) score is less than 5% (see chapter 6).

Root surface biocompatibility

When periodontal plastic surgery is performed to cover exposed roots, the biocompatibility of the root surface is important for the healing process and treatment success. Even in individuals with optimal personal and professional oral hygiene, exposed root surfaces are always covered with a thin layer of biofilm. The biocompatibility of the root surface is crucial to achieving attachment of the soft tissue to the tooth surface after root coverage surgery. Therefore, the root surface should be mechanically cleaned immediately prior to surgery to thoroughly remove the biofilm and the microorganisms in it. If this is not accomplished, there is a high risk that the soft tissue will not attach to the root surface after surgery. This could result in the formation of periodontal pockets instead of new attachment to the root surface of the affected teeth (see chapter 9).

Use of a microsurgical approach

One of the most important keys to achieving optimal wound healing is the use of a microsurgical approach. The five basic elements of a microsurgical approach are *optical magnification*, *microsurgical instruments*, *microsurgical suture materials*, *microsurgical flap designs*, and *microsurgical suturing techniques*. The central goal of treatment based on these five elements is to achieve primary wound healing by handling the tissues atraumatically and with maximum precision (see chapter 2).

Flap design

Mucoperiosteal flaps, *mucosal flaps*, or a *combination of the two* can be used in plastic-esthetic periodontal and implant surgery. In mucoperiosteal flap procedures, a full layer of soft tissue (ie, periosteum, connective tissue, and epithelium) is elevated from the bone surface by blunt dissection. Mucosal flaps, on the other hand, are elevated by sharp dissection of subepithelial connective tissue while the periosteum and parts of the connective tissue are left on the bone. Consequently, mucosal flaps are usually thinner than mucoperiosteal flaps and do not contain any of the well-perfused periosteal soft tissue.

Mucoperiosteal flaps are technically simpler, whereas mucosal flaps are more demanding. In addition to enhanced healing, mucosal flaps have a number of other advantages, such as better flap mobility, which facilitates primary wound closure. Consequently, mucosal flaps are preferentially used in plastic-esthetic periodontal and implant surgery (see chapter 4).

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Blood supply to the flap margins

The flap margins are the most critical zones during the entire wound healing process. Ischemia-related necrosis or impaired wound healing in the region of the flap margins immediately results in wound dehiscence. This leads to secondary healing in association with deep bacterial infection. Maintenance of a good blood supply to the flap margins must be a central goal of all intraoperative and postoperative treatment measures.

The risk of flap edge necrosis is inversely proportional to the thickness of the flap. The thinner the edges of the flap, the smaller the number of vessels supplying the flap edges and, hence, the higher the risk of postoperative necrosis. When a mucosal flap is elevated, it is crucial that the *flap does not thin out toward the edges.* When the initial incision is made, the scalpel blade should always be held perpendicular to the surface of the soft tissues. If these fundamental rules are observed, the elevated flap will have square-cut margins of uniform thickness instead of acute-angled margins. This design has particular advantages in terms of flap perfusion. Intersecting incision lines should be slightly overcut to achieve a flap of uniform thickness, even along the edges (see chapter 4).

Atraumatic soft tissue handling is essential for good postoperative flap perfusion and the prevention of flap edge necrosis. Basic prerequisites for optimal wound healing include the use of a sharp scalpel blade and atraumatic tissue dissection (see chapter 2).

Flap thickness

In many cases, flap thickness is crucial not only for perfusion along the flap edges during the initial phase of wound healing but also for the final outcome of periodontal surgery.[6,7] *Baldi* et al[6] compared coronally advanced flap procedures for root coverage to determine whether flap thickness was a relevant predictor of root coverage in patients with gingival recession. They determined that complete root coverage was possible in 100% of all sites with a flap thickness greater than 0.8 mm. The complete-coverage rate for thinner flaps was lower, and the difference was statistically significant.[6] These findings suggest that the mean thickness of mucosal flaps should be uniform and no less than 1.0 mm. Flap thickness has important clinical implications (see chapter 4).

Flap tension

Precise approximation of the wound margins without tension is another critical factor for achieving primary wound healing following surgery.[8–10] Flap repositioning is often necessary in plastic-esthetic periodontal and implant surgery. It is crucial that the sutures do not exert tension on the wound margins because tension could result in constriction and collapse of blood vessels, impairing flap perfusion and consequently increasing the risk of impaired healing and flap necrosis. Flap tension is also associated with a risk of postoperative flap retraction, which could result in secondary wound healing and its related problems.

Tension-free approximation of the wound margins is therefore crucial to the success of plastic-esthetic periodontal and implant surgery. Adequate flap mobility can be ensured through the use of an appropriate flap design and releasing incisions (see chapter 4). Size 6-0 and 7-0 microsurgical suture materials will tear if too much force is used when the sutures are tied.[11] In clinical practice, this has actually proved to be a useful limitation because it prevents the surgeon from exerting excessive tension on the edges of the flap during suture closure.

3.2.2 Systemic Factors

Diabetes

Individuals with diabetes (type 1 and type 2) often have impaired wound healing.[12] The tissue perfusion disorders associated with diabetic micro- and macroangiopathies impair local immune defenses and wound healing. Consequently, diabetic patients have a high risk of suboptimal wound healing and necrosis, particularly when diabetes is poorly managed.[12,13]

When treating diabetic patients, the surgeon should consult the attending primary care physician or specialist to determine how well the disease is controlled. The glycohemoglobin fraction (HbA1c), as a percentage of total hemoglobin, has been shown to have high diagnostic value for long-term monitoring of blood glucose management. An HbA1c of less than 6.5% indicates that diabetes is well managed, and predictable and satisfactory results of plastic-esthetic surgery can be expected in these patients.[14] Elective surgery should never be performed on individuals with poorly managed or uncontrolled diabetes. Even if performed in patients with well-managed diabetes, surgery should preferably be performed under prophylactic antibiotic coverage (see chapter 6).

Table 3-1

Local factors that influence wound healing

Absence of inflammation	• Periodontal pretreatment and good personal oral hygiene help to eliminate inflammation of the marginal gingiva. • Treatment prerequisites: Plaque Index (PI) < 20%. Papillary Bleeding Index (PBI) < 5%.
Root surface biocompatibility	• Biocompatibility is particularly relevant for root coverage in gingival recession treatment. • Mechanical cleaning of exposed root surfaces is required immediately prior to surgery.
Use of a microsurgical approach	• Optical magnification. • Microsurgical instruments and suture materials. • Atraumatic tissue handling.
Flap design	• Mucosal flaps are technically more difficult to raise but easier to reposition and suture.
Blood supply to the flap margins	• Acute-angled flap margins should be avoided. • The initial incision should always be made with the scalpel blade held perpendicular to the tissue surface. • Intersecting incision lines should be overcut. • Trauma to the wound margins should be minimized.
Flap thickness	• Minimum flap thickness is 1 mm.
Flap tension	• Tension-free approximation of the wound margins is crucial.

Smoking

Nicotine and the toxic aerosols in tobacco smoke have systemic effects on wound healing in the oral cavity that occur in combination with local factors directly influencing the healing of oral tissues. In this context, the most relevant effects of smoking are a dose-dependent reduction of blood flow to tissues supplied by terminal vessels and reduced immune defense.[15,16] The surgeon can assume that wound healing complications will occur in smokers, even if the surgery is carefully planned and precisely executed. Therefore, elective plastic periodontal and implant surgery should never be performed on smokers.[17–20] Short-term abstinence from smoking prior to surgery is not sufficient. Long-term complete nicotine abstinence could be acceptable, but there is no scientifically validated evidence indicating how long this period of abstinence should be. However, it can be assumed that a minimum of 6 months of nicotine abstinence is required before surgery.[21]

Immunosuppression

Immunosuppressive medications such as cytostatics and corticoids diminish the immunologic competence of the patient and therefore may impair or delay wound healing.[22] Patients who have received organ transplants require long-term immunosuppressive therapy to prevent transplant rejection. Immunosuppressive therapy is not an absolute contraindication to plastic-esthetic periodontal and implant surgery. However, surgical procedures should never be scheduled for a patient undergoing immunosuppressive therapy before the patient's physician is consulted, and procedures should always be performed under prophylactic antibiotic coverage. Precise approximation of the wound margins and primary wound closure are necessary to minimize complications during healing in patients who are taking immunosuppressive medications.[22] Compliance with all relevant hygiene requirements is mandatory (see chapter 6).

HIV and AIDS

Modern antiviral drugs and treatment protocols have significantly improved the feasibility and prognosis of surgery in HIV-infected patients in recent years. Immunocompetence, ie, the presence of adequate quantities of $CD4^+$ T cells in the blood, determines whether treat-

Table 3-2

Systemic factors that influence wound healing

Diabetes	• Consult with the patient's physician. • Plastic surgical interventions may be performed if the diabetes is well managed (HbA1c < 6.5 %). • Extensive surgery should be conducted under prophylactic antibiotic coverage, even if the diabetes is well managed.
Smoking	• Periodontal and implant surgery should never be performed in active smokers. • Plastic surgical procedures may be performed if the patient has abstained from nicotine for at least 6 months.
Immunosuppression	• Consult with the patient's physician. • Antibiotic prophylaxis is required for surgery.
HIV and AIDS	• Consult with the patient's physician. • Surgical procedures may be performed during the latency phase. • Antibiotic prophylaxis is required for surgery. • Strict compliance with hygiene requirements is mandatory.
Patient-specific factors	• Each patient has an individual healing capacity. • Accurate preoperative prediction of the individual healing capacity of a given patient is not possible.

ment is feasible. The physician managing the patient with HIV should always be consulted to determine the optimal timing of surgery. Periodontal and implant surgical procedures are contraindicated during the acute phases of HIV infection and after the outbreak of AIDS[22] but may be performed under prophylactic antibiotic coverage during the latency phase of HIV infection.[23] Strict compliance with all relevant infection-control procedures is essential to ensure the protection of these patients and the dental personnel treating them (see chapter 6).

Patient-specific factors

Even if all known factors relevant to healing are taken into account, patient-specific factors result in individual differences in wound healing. The reasons for these differences have been scarcely investigated and, in most cases, only speculatively discussed in the literature. Age plays an important role. General medical studies have clearly shown that patients older than 70 years have significantly lower rates of successful wound healing than younger patients.[24]

Genetic predisposition, especially the expression of growth factors, appears to be another major patient-specific factor in wound healing. Growth factors are involved in various stages of wound healing: They are chemotactic for fibroblasts, and they stimulate immune cells and angiogenesis.[25] High levels of central cytokines such as platelet-derived growth factor, transforming growth factor β, platelet-derived angiogenesis factor, platelet factor 4, and platelet-derived epidermal growth factor have been shown to improve an individual's wound healing capacity.[25]

Platelet-rich plasma is a concentrated source of preoperatively harvested and processed autologous platelets, which contain large quantities of growth factors involved in wound healing. An adjuvant treatment approach involves the intraoperative application of platelet-rich plasma to surgical wounds in an attempt to improve wound healing. The results reported in the literature are inconsistent,[26] and the effects demonstrated so far have been limited, particularly in the field of plastic-esthetic periodontal surgery.[27] It is generally assumed that topically administered growth factors have a short duration of action and thus are unable to achieve any profound effects in the wound.[26]

Enamel matrix proteins, which are commonly used in regenerative periodontal therapy, are also reported to improve and accelerate wound healing. In vitro studies have shown that enamel matrix proteins are able to stimulate both periodontal and gingival fibroblasts.[28] Because these cells increase secretion of transforming growth factor β1, the application of enamel matrix proteins could have a positive effect on soft tissue healing.[29–31] They also seem to have a certain positive effect on angiogenesis during the early healing phase, which could also be beneficial.[32] Furthermore, enamel matrix proteins produce an antimicrobial environment, which could additionally boost wound healing processes.[33–35] Reports in the literature regarding the effects of enamel matrix proteins on wound healing are contradictory. Some clinical studies have shown that they have positive effects,[36,37] whereas others could not demonstrate any effect.[38]

To date, there is no definitive checklist of parameters that a clinician can use to predict a patient's wound healing capacity or the effects of a given treatment on the wound healing capacity. Basic research in molecular biology could make an important contribution by uncovering more of the mechanisms underlying wound healing and elucidating the correlations between them, which could be translated into clinically useful applications in the future.

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CHAPTER 4

INCISIONS, FLAP DESIGNS, AND SUTURING TECHNIQUES