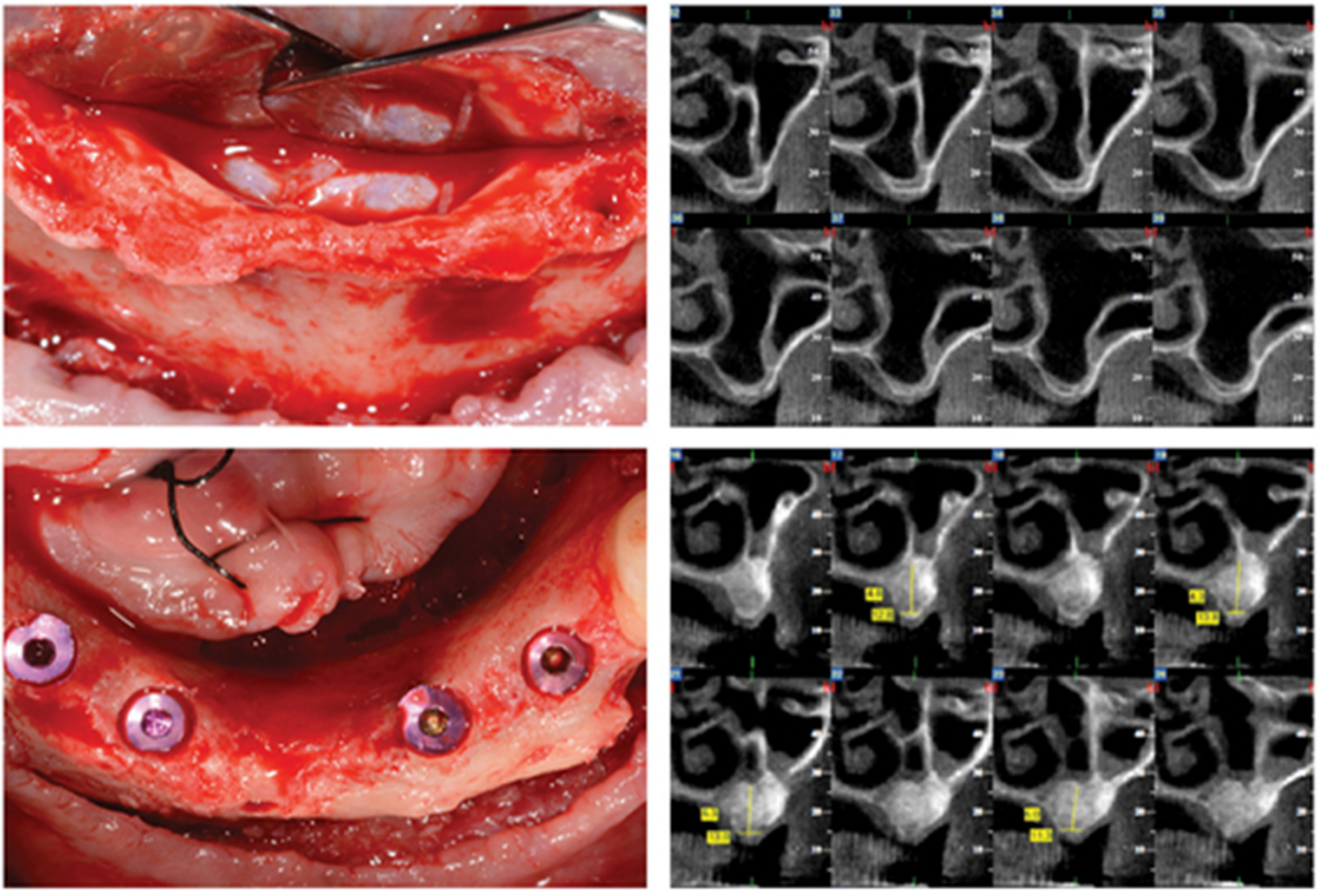
Bone Augmentation by Anatomical Region

Techniques and Decision-Making

Edited by Zvi Artzi



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This edition first published 2020
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Library of Congress Cataloging-in-Publication Data

Names: Artzi, Zvi (Professor of periodontology), editor.
Title: Bone augmentation by anatomical region : techniques and decision-making / edited by Zvi Artzi.
Description: Hoboken, NJ : John Wiley & Sons, [2020] | Includes bibliographical references and index.
Identifiers: LCCN 2019054476 (print) | LCCN 2019054477 (ebook) | ISBN 9781119427841 (cloth) | ISBN 9781119427889 (adobe pdf) | ISBN 9781119427902 (epub)
Subjects: MESH: Orthognathic Surgical Procedures–methods | Bone Regeneration | Bone Transplantation–methods
Classification: LCC RD123 (print) | LCC RD123 (ebook) | NLM WU 600 | DDC 617.4/710592–dc23
LC record available at https://lccn.loc.gov/2019054476
LC ebook record available at https://lccn.loc.gov/2019054477

Cover Design: Wiley
Cover Image: Courtesy of Zvi Artzi

Set in 9.5/12.5pt STIXTwoText by SPi Global, Pondicherry, India

10 9 8 7 6 5 4 3 2 1

To my beloved wife, Malca, and my dearest kids, Yoav, Eran and Ronnie

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Preface

Bone Augmentation by Anatomical Region: Techniques and Decision-Making

It is always a great satisfaction when you are asked to write a preface of a book. Moreover, when the book enlarges our scientific culture and promotes the training of our students and professionals.

Frequently these books introduce new knowledge or new technologies. It is, however, less frequent that a book is purposely focused on training surgical procedures to students and professionals. This book focuses on the surgical treatment of bone defects in the jaws by bone augmentation interventions. These surgical procedures must be based on a thorough knowledge of the anatomy of the jaws and adjacent tissues, in the physiology of wound healing, in deep understanding of the properties of the currently used biomaterials in bone regeneration and in the surgical management of both soft and hard tissues. The information provided is in this book is fully relevant to provide this important information. The content is well organized in a very practical manner, but at the same time it is rigorous and up to date with current knowledge, covering comprehensively the fundamentals of bone regeneration as well as the decision making and technical aspects of the different surgical interventions and biomaterials.

The author Prof Zvi Artzi has dedicated many years of his academic and professional life to research and innovate on bone regeneration and reconstructive surgery with the objective of improving the health and quality of life of affected patients. Moreover, the contribution to this work by a numerous group of highly respected academicians and professionals clearly enhance the quality and relevance of this work.

When reading this book, it is evident, not only the excellent scientific background of the author and contributors, but also their teaching abilities by combining scientific rigor and at the same time providing key practical relevance for those professionals looking for expanding their knowledge in this fascinating area of oral surgery and periodontology.

In summary, this book is clear, well written and provides very useful and relevant content to support well trained dentists as well as periodontists and oral surgeons in expanding their learning how to apply modern bone and reconstructive surgical interventions.

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Acknowledgement

I would like to thank all my post-graduate Periodontal and Prosthetic students, supervised by their mentors Dr. S. Levartovsky and myself, for their meticulous fulfilment of all case documentations.

About the Companion Website

Don't forget to visit the companion website for this book:

www.wiley.com/go/artzi/bone_augmentation_anatomical_region

The website contains videos and clinical slides.

Introduction

Why a book on Bone augmentation?

It is essential that the residual alveolus shape and the different physiological bone resorption wound healing events, following tooth extraction in the different sites in the maxilla and the mandible, are recognized (Lekholm & Zarb 1985).

A deficient alveolar ridge can be re-established via different bone augmentation procedures. Whether via guided tissue regeneration (GTR) principles, autogenous bone block transplantation, or any other innovative techniques, these surgical modalities show stable peri-implant osseous housing as the original native bone (Lutz et al 2015).

Bone augmentation procedures should be based on meticulous surgical protocol, establishing biomaterial stability, managing careful soft tissue coverage, and understanding the wound healing cascades.

Any applied surgical technique is determined upon its efficacy, predictability and eventually on the implant's long-term success rate. Once these are achieved, any treatment modality can be applied (Lindhe et al 2012).

In order to decide which surgical technique to choose from, the recognition of the jaw anatomy and its inserted organs should be clear and familiar. An in-depth review (Greenstein et al 2008) of the anatomical structures and their variations emphasized the importance of profound knowledge of the upper and lower jaw anatomy and its surrounding muscles, vessels and innervations. These should be a prerequisite before any surgical execution.

When examining the composition of the osseous tissue, there is a marked difference between the edentulous maxilla to the mandible. The proportion of bone marrow is greater in the maxilla than in the mandible. The anterior maxilla comprises a high proportion of bone marrow whereas the anterior mandible contains large amounts of mineralized bone. Nevertheless, both jaws comprise a high proportion of lamellar bone. In addition, the cortical crest is wider in the mandible than in the maxilla, particularly at the symphyseal area, where it is in its widest (Lindhe et al 2012, 2013; Aghaloo et al 2016).

Different anatomical locations would be more amenable to a given surgical modality. This book addresses and emphasizes the unique anatomical neighboring structures that are relevant in soft and hard tissue augmentation procedures. Muscle insertion, the blood network, certain anatomical sites such as the incisive and the mental foramina, the innervation; all are very important landmarks during any given applied surgery.

In any surgical technique, certain principles must be observed. Space maintaining, i.e. clot/biomaterial stability (Wikesjö et al 1990; Haney et al 1993) and non-tensional soft tissue closure, is essential and should be observed. Adequate blood supply and angiogenesis could be enhanced by cortical perforations that would enhance the revascularization at the augmented site (Majzoub et al. 1999; Greenstein et al 2009).

This book is focused on each anatomical location and its unique characteristics, on how to achieve wound site stabilization, on how to handle and predict soft tissue tension-free primary closure, and on which suitable interim prosthesis should be applied.

Different surgical techniques are recommended for different bony deficiencies at the different anatomical locations. These along with each clinical case are shown, step by step, along with the relevant literature.

Proficient knowledge, surgical skill and experience are mandatory prerequisites for a predictable, successful treatment execution. Therefore, a meticulous slow learning curve is unavoidable.

In this book, an attempt to ease this learning curve along with ample surgical tips with emphasis on how to avoid and /or confront complications, are elaborated in depth with step-by-step clinical slides

Last, but not less important, this book is not only covering the bone augmentation subjects, but also addressing related issues such as the soft peri-implant tissue, the implant biofilm, peri-implant infection and its prevention.

These are imperative topics to understand the etiologic factors which cause bone destruction followed by the necessity to rebuild the osseous alveolar ridges. Other interesting topics such as prosthognatic surgery in service of prosthetic implant rehabilitation are also highlighted.

I hope any qualified practitioner would find fundamental tools and guidelines in this book to improve his knowledge and skills for a better clinical practice.

Zvi Artzi, DMD

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Part I

Basic Mechanisms

1

The Anatomy of the Maxilla and the Mandible

Related Structures and Inserted Muscles

Dmitri Lev and Zvi Artzi

The success of oral rehabilitation and related surgical interventional procedures in oral implantology depends upon in-depth knowledge and understanding of the head and neck anatomy. Anatomical structures in the head and neck region are numerous and densely packed in a relatively small volume. These organs are designed to serve various systems, such as masticatory, olfactory, lacrimal, visual, and others. Overlapping of these systems, however, makes it almost impossible to draw clear demarcation lines between them.

This chapter will focus mainly on the oral anatomy, and additionally consider the structures which are topographically and functionally part of the oral apparatus.

Bones

The mandible, maxilla, and palatine bones form the boundaries of the oral cavity. Because the number of teeth changes during an individual's lifetime, the mandible and maxilla, more than the other bones of the viscerocranium, are permanently and extensively developed and modified during childhood and adolescence, only to undergo significant degeneration with aging.

Maxilla

Each maxilla is composed of two bones, the maxilla proper and the premaxilla, which fuse during the last trimester of fetal development (Figure 1.1). The incisive suture connecting the maxilla proper and premaxilla is located on the inferior surface of the hard palate, and it becomes obliterated in varying degrees during midlife. Two maxillae form the entire upper jaw and most of the middle face. Maxillary occupation of the central part of the facial skeleton involves the oral, nasal, and orbital cavities, and their articulation with the ethmoid, frontal, lacrimal, nasal, inferior nasal concha, vomer, palatine, and opposite maxilla bones. Its hollowed pyramidal-shaped body includes four processes (see Table 1.1) which radiate from the maxilla in directions corresponding to the buttress lines of the viscerocranium.

The long **frontal process** ascends between the lacrimal and nasal bones to articulate with the frontal bone via the frontomaxillary suture. The short **zygomatic process** protrudes laterally and connects with the maxillary process of the zygomatic bone via the zygomaticomaxillary suture. The ridge on the inferior aspect of the zygomatic process separates the anterior and posterior concavities: the former continues up to the anterolateral surface of the maxillary body, while the latter terminates opposite the infratemporal fossa. The **alveolar process** (Figure 1.1) descends from the anterolateral and posterior maxilla body surface. It supports the teeth and gradually becomes wider in a posterior direction. The alveolar process is composed of one external and one internal cortical plate, and a considerable amount of trabecular bone tissue is sandwiched between them. Posteriorly, the cortical plates are united. The inferior edge of the alveolar process is deeply grooved, and the cortical plates are interconnected by perpendicular interalveolar septa, which divide the groove into eight alveolar sockets in the adult maxilla. In the posterior/distal three sockets, the inter-radical septa separate between the individual roots in multirooted teeth. The inter-radical septum of the first premolar socket is parallel to the alveolar/cortical plates. The configuration and size of the roots determine the alveolar socket morphology. Tooth extraction causes gradual resorption of the alveolus. The **palatine process** originates from the border between the anterior two-thirds of the maxilla and its alveolar process. It projects medially to meet its fellow palatine process at the intermaxillary suture. The posterior edge of the palatine process connects with the horizontal process of the palatine bone at the transverse palatine suture. The horizontal plate of the palatine process forms a right angle with the posterior aspect of the

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Companion website: www.wiley.com/go/artzi/bone_augmentation_anatomical_region

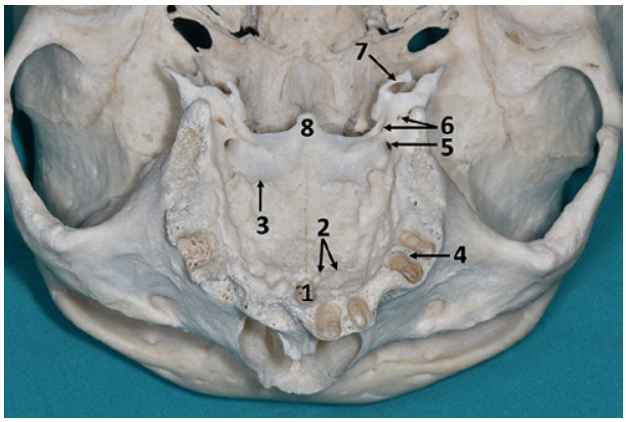

Figure 1.1 Hard palate (inferior view). 1 – Incisive foramen, 2 – incisive suture, 3 – transverse palatine suture, 4 – interalveolar septum, 5 – greater palatine foramen, 6 – lesser palatine foramina, 7 – hamulus pterygoidei, 8 – posterior nasal spine.

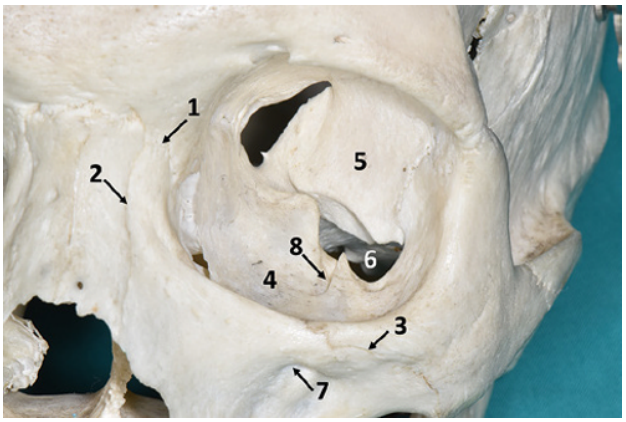

Figure 1.2 Orbit (anterior view). 1 – Frontomaxillary suture, 2 – nasomaxillary suture, 3 – zygomaticomaxillary suture, 4 – superior surface of the maxillary body, 5 – greater wing of the sphenoid bone, 6 – infraorbital fissure, 7 – infraorbital foramen, 8 – infraorbital groove.

Table 1.1

Process	Direction	Articulation
Frontal	Superior	Frontal, nasal, lacrimal bones
Zygomatic	Lateral	Zygomatic bone
Palatine	Medial/ horizontal	Palatine, contralateral maxilla, and vomer bones
Alveolar	Inferior	Upper teeth

alveolar process. The angle is poorly defined anteriorly, and the oral surface of the palatine process slopes down at this point. The concave, rough undersurface of the palatine process provides firm attachment of the masticatory mucosa. The superior nasal surface is also concave but smooth, and the mucosa is loosely attached to it. Two palatine processes have an elevation along the intermaxillary suture, which forms the nasal crest for attachment of the vomer bone. The prominent anterior part of the nasal crest (the "incisor spine") is the site of attachment of the cartilaginous nasal septum. The nasopalatine canal traverses the palate just posteriorly to the incisor spine.

The **nasopalatine canal** is usually described as a Y-shaped channel starting from two Stenson's foramina on the nasal surface of both palatine processes and ending inferiorly as a single opening on the oral roof on the bottom of the incisive fossa, just posterior to the central incisors. However dominant, this arrangement is present in only fewer than 50% of the population. The nasopalatine canal may contain from one to four channels between the superior and inferior openings (Song et al. 2009). Within the nasopalatine canal, the nasopalatine nerve communicates with the greater palatine nerve, and the greater (descending) palatine artery anastomoses with the posterior septal branch of the sphenopalatine artery.

The hollowed **maxillary body** has a pyramidal shape. The *pyramid apex* protrudes laterally and continues to the base of the zygomatic process. The *base (medial surface)* of the maxillary body contributes to the lateral wall of the nasal cavity. The posterosuperior portion of the medial surface of the disarticulated maxilla has a large opening (the maxillary hiatus), which connects the maxillary sinus with the nasal cavity. The greater palatine groove descends toward the posterior edge of the palatine process along the posterior edge of the medial maxillary wall. Another greater palatine groove is present on the perpendicular lamina of the adjacent palatine bone. When these two bones articulate with each other, their grooves form a canal for the greater palatine vessels and nerve. The lacrimal groove is located anteriorly to the maxillary hiatus. When the lacrimal bone and inferior nasal concha articulate with the maxilla, the groove is converted to a canal which contains a nasolacrimal duct. From the lacrimal groove, the conchal crest descends obliquely in an anteroinferior direction to eventually articulate with the inferior nasal concha.

The *superior side* of the maxillary pyramid faces the orbit and forms a considerable part of the orbital floor (Figure 1.2). Three bones articulate with the medial border of the orbital surface of the maxilla. They are (in an anteroposterior direction) the lacrimal and ethmoid bones and the orbital process of the palatine bone. The inferior orbital fissure separates the posterior border of the superior wall from the greater wing of the sphenoid bone. The infraorbital groove, which contains the infraorbital neurovascular bundle, begins from the midpoint of the posterior border.

In their anatomical study, Nguyen et al. (2016) demonstrated that the groove was present only in 10% of cadavers, and that it was roofed by osseous tissue in the remaining skulls. When the groove approaches the round and thick anterior border of the maxillary orbital surface, it curves in an inferomedial direction, about 20 degrees in the sagittal plane and about 30 degrees in the horizontal plane (Aggarwal et al. 2015), extending towards the infraorbital foramen on the anterior surface of the maxilla.

The anterolateral or malar surface is separated from the posterolateral surface by a curved ridge that descends from the zygomatic process toward the first molar tooth. The medial edge of the malar surface forms the lateral and inferior borders of the piriform aperture. A number of fossae and elevations are present on the anterolateral surface. They are produced by the roots of the teeth. The infraorbital foramen is located in the upper, deepest part of the canine fossa about 6 mm inferior to the infraorbital margin (Aggarwal et al. 2015).

The canine fossa is the depression situated just laterally to the canine eminence which is formed by the socket of the canine tooth. The canine eminence separates the canine fossa laterally and incisive fossa medially to it (Figure 1.3).

Several mimic muscles, including the depressor septi, nasalis, and levator anguli oris, that are associated with movements of the lips and external nose originate from the anterior maxillary surface.

The convex *posterolateral or infratemporal surface* of the maxillary body (Figure 1.4) forms an anterior wall of the infratemporal fossa. The posteroinferior part of the maxillary body, the maxillary tuberosity, articulates with the pyramidal process of the palatine bone and occasionally with the lower part of the lateral pterygoid plate of the sphenoid bone. The maxillary tuberosity is associated with the upper molar teeth and can be fractured during a molar tooth extraction.

Maxillary Sinus

The maxillary sinus was described, although not discovered, by Nathaniel Highmore in 1651 and named after him ("antrum of Highmore"). It is the largest paranasal sinus, with an average volume of 15 ml. Its inner surface is lined by the Schneiderian membrane, a 1-mm-thick layer of pseudostratified ciliated columnar epithelium attached to the periosteum and continuing to the epithelium of the nasal cavity. The maxillary sinus cavity resembles a four-sided pyramid, the base and the apex of which coincide with those of the pyramid of the maxillary body. The size and morphology of the sinus are also dependent upon the size of the adjacent cavities or fossae. The extent of pneumatization varies from person to person. For instance, the apical part of the sinus pyramid can invade the zygomatic

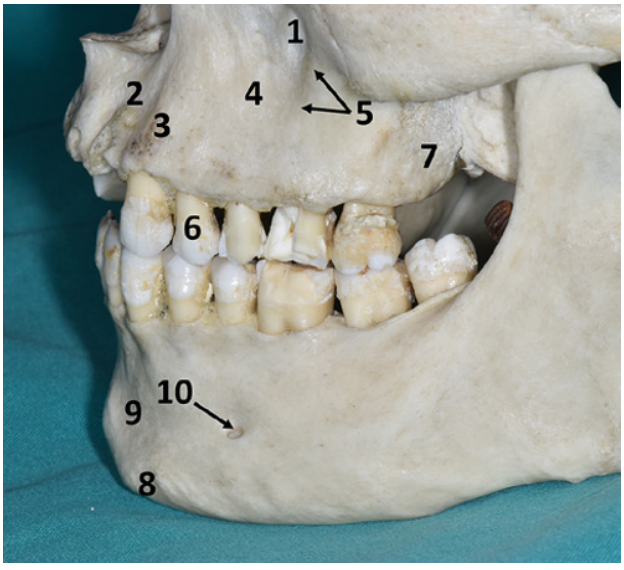

Figure 1.3 Maxilla and mandible (lateral view). 1 – Infraorbital foramen, 2 – incisor fossa, 3 – canine eminence, 4 – canine fossa, 5 – ridge between the anterolateral and posterolateral maxillary surface, 6 – 1st upper molar tooth, 7 – tuber of maxilla, 8 – mental tubercle, 9 – mental fossa, 10 – mental foramen.

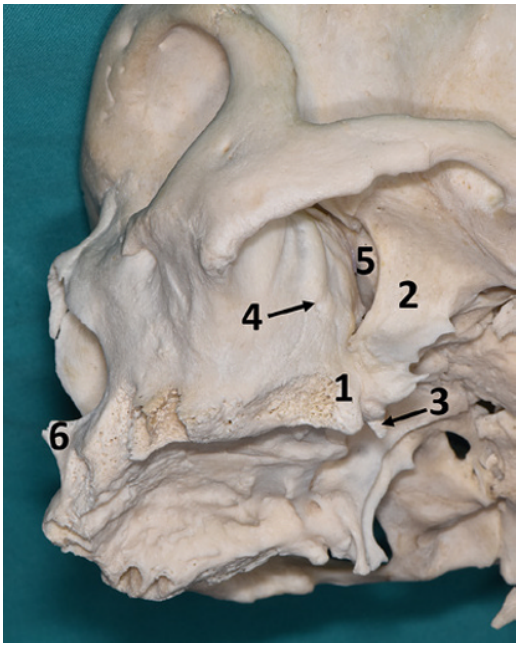

Figure 1.4 Posterolateral aspect of the maxilla. 1 – Maxillary tuberosity, 2 – lateral pterygoid plate, 3 – pyramidal process of the palatine bone, 4 – entrance into the posterior superior alveolar canal, 5 – pterygopalatine fossa, 6 – anterior nasal spine.

process of the maxilla or even the zygomatic bone. Asymmetry in size and shape is also common, and a larger size is usually associated with thinner walls. The walls of the maxillary sinus separate it from the adjacent spaces in the skull. The hollowed medial wall is located between the sinus and the nasal cavity, the roof is inferior to the orbit, the alveoli of the alveolar process are inferior to the floor of the sinus, and the infratemporal and canine fossae are defined by the posterior and anterior walls, respectively.

The most prominent feature of the *medial wall* is the antrum of Highmore through which the maxillary sinus communicates with the bony nasal cavity. The passage between those two cavities is considerably narrowed when the uncinate process of the ethmoid bone, inferior nasal concha, and perpendicular plate of palatine bone articulate with the maxilla. Inferiorly, the maxillary antrum is defined by the upper premolar and molar teeth. The *roof* of the maxillary sinus is defined by to the orbital floor. The variations in thickness of the sinus roof are related to the risk of the spread of odontogenic infection to the orbit (Mills and Kartush 1985). The infraorbital neurovascular bundle passing in the infraorbital canal is embedded into the roof of the maxillary sinus and, in some cases, protrudes into the maxillary cavity (Lantos et al. 2016). The *sinus floor* is lower than the hard palate and much lower than the maxillary antrum. The reason for this anatomical position, which is inadequate for mucous drainage, is that the sinus of the fetus starts to develop very superiorly, just below the orbital floor, and maintains its drainage point at the same level during growth in an inferior direction. One of the clinically important anatomical variations is the presence of the septae, which usually arise from the sinus floor and divide the sinus into compartments. The prevalence of the septae presence ranges from 13–35.3% (Maestre-Ferrin et al. 2010).

The anterior superior alveolar canal and its neurovascular bundle pass through the *anterior wall* of the maxillary sinus. The *posterior wall* is associated with transmission of the posterior superior alveolar nerve and vessels, also through the alveolar canal (Figure 1.4).

Palatine Bone

The palatine bone is sandwiched between the maxilla anteriorly and the pterygoid process of the sphenoid bone posteriorly. It consists of the horizontal and perpendicular plates. Together with its contralateral fellow, the former comprises the posterior 1/4 of the bony palate, and, together with the medial plate of the pterygoid process of the sphenoid bone, the latter contributes to the posterior part of the lateral nasal wall. Both plates have two surfaces and four borders.

The medial or nasal surface of *the perpendicular plate of the palatine bone* is smooth and contains a numbers of concavities and ridges, which include (from superior to inferior directions): the groove of the superior nasal meatus, ethmoid crest, depression of the middle nasal meatus, conchal crest, and depression of the inferior nasal meatus. Ethmoid and conchal crests serve for attachment of the middle and inferior nasal conchae, respectively. The lateral or maxillary surface is in contact with the posterior aspect of the maxillary body. The greater palatine groove descends to the lateral surface from the sphenopalatine notch toward the junction of the perpendicular and horizontal plates. Together with the greater palatine groove of the maxilla, it forms the greater palatine canal.

The superior border contains the orbital and sphenoid processes, which are separated by the sphenopalatine notch. When the body of the sphenoid bone articulates with this area, the notch is converted into the sphenopalatine foramen through which the pterygopalatine fossa communicates directly with the posterosuperior aspect of the nasal cavity. From the anterior border, on the level of the conchal crest, the maxillary process points anteriorly and considerably lessens the hiatus between the maxillary sinus and the nasal cavity. The posterior border extends between the sphenoid and pyramidal processes and articulates with the medial pterygoid plate via the serrated suture. The inferior border corresponds to the lateral border of the horizontal plate.

The superior surface of the *horizontal plate of the palatine bone* is smooth and concave, while the inferior surface is rough and slightly concave. The anterior and medial borders of the horizontal plate articulate with the palatine process of the maxilla and the contralateral palatine bone, respectively (Figure 1.1). The medial border has two elevations, the crest and the spine. They form the posterior part of the nasal crest and the posterior nasal spine, while two palatine bones articulate with each other by the interpalatine suture. Musculus uvulae fibers originate from the posterior nasal spine at the angle between the medial and posterior margins of the horizontal plate. The thin, concave posterior margin is the site of attachment to the palatine aponeurosis. The pyramidal process is at an angle between the posterior and lateral horizontal plate border, protruding in a posterolateral direction. Its posterior surface slopes down and has two furrows for articulation with the lateral and medial plates of the pterygoid process. In combination, the pyramidal process, tuber of maxilla, and inferior portion of the pterygoid process of the sphenoid bone form a complex which is important for implant placement in the posterior aspect of the maxilla (Lee et al. 2001).

The lateral border of the horizontal plate is notched by the descending pterygopalatine groove at the base of the

pyramidal process. When the maxilla is attached to the lateral aspect of the palatine bone, this notch becomes the greater palatine foramen which is seen on the inferior surface of the hard palate (Figure 1.1). In the vast majority of cases, the greater palatine foramen is located opposite or distally to the 3rd molar tooth (Chrcanovic and Custodio 2010, Dave et al. 2013). The lesser palatine foramina are present on the inferior surface of the pyramidal process and vary in number from 1 to 4 (Saralaya and Nayak 2007).

Mandible

The mandible develops from two halves which fuse at the midline during the first year of life. The adult mandible is a single, irregular bone composed of a horizontally oriented body which supports the teeth and two vertical rami that articulate with the temporal bones and serves for attachment of the masticatory muscles. The vertex of the angle between the lower border of the body and the posterior border of the ramus (the gonion) varies between 110 to 140 degrees.

The complete fusion of the mandibular halves forms the midline ridge descending from the lower margin of the alveolar process on the *external (labial) surface* of the adult mandible. The inferior end of the mental ridge points towards the apex of the mental protuberance or mental trigon. The base of the mental protuberance is found at the lower margin of the mandible. The inferior ends of the lateral extremities of the protuberance (the mental tubercles) are usually slightly elevated. A median depression, the mental fossa, lies inferiorly to the incisors and superolaterally to the mental protuberance. The complex of the protuberance, mental tubercles, and mental fossa is unique to the human chin. It is thought to be a result of the postnatal bone resorption in the upper part of the mandibular body and/or bone deposition at its lower margin (Schwartz and Tattersall 2000).

The mental foramen (Figure 1.3) is the opening of the mandibular canal and it is situated on the mandibular buccal surface halfway between the lower borders of the alveolar part and mandibular body. The position of the mental foramen in the anteroposterior direction varies considerably among sexes and races, with the highest prevalence on the level of the 2nd premolar for the Mongoloid and African populations, and on the level between the 1st and 2nd premolar for Caucasians. The mental foramen has sharp anteroinferior and round posterosuperior margins for accommodation of the mental nerve which emerges from the foramen at a sharp angle to the mandibular surface.

The oblique line descends on the lateral surface of the mandibular body from the anterior margin of the mandibular ramus and gradually becomes less prominent, almost disappearing when it approaches the mental tubercle. The buccinator and depressor anguli oris muscles originate from the posterior and anterior parts, respectively, of that oblique line.

The round and thick inferior border of the mandible has a sinusoid shape, and it is concave posteriorly and convex anteriorly. The digastric fossa for attachment of the digastric muscle anterior belly is located on its anterior end, below the mental tubercle.

The alveolar part of the mandible contains 16 sockets for tooth accommodation. Anteriorly, the curvature of the alveolar part matches that of the mandibular body, while the molar sockets are in a more medial plane than the mandibular body at this level. Similar to the maxillary alveolar process, the alveolar process of the mandible is composed of two outer laminae of the cortical bone and the inner region of the trabecular bone. The cortical bone of the alveolar process is thicker in the mandible than in the maxilla, with the maximal thickness located in the premolar and molar regions.

The *inner surface of the chin area* distributes one to four mental spines for the attachment of two pairs of muscles, the genioglossi superiorly and the geniohyoid inferiorly. The variations in the number of mental spines is a result of their fusion in vertical or horizontal planes or both. The lingual foramen is found just superior to the mental spine. It enters the bony canal and transports a branch of the lingual and/or submental arteries. The mylohyoid line starts from the inferior aspect of the mental spine, where it is barely visible, and run obliquely toward the 3rd molar where it becomes much more prominent. Apexes of the 2nd and 3rd molar teeth are located below the mylohyoid line, while the apexes of the incisors and the premolar and 1st molar teeth are above it. The mylohyoid muscle, which forms the mouth floor, originates from the mylohyoid line. Thus, the surface above the mylohyoid muscle attachment is part of the oral cavity, and it is covered with mucosa. The submandibular fossa is below the posterior portion of the mylohyoid line, and the sublingual fossa is above its anterior portion. The former contains the superficial part of the submandibular salivary gland, and the latter contains the sublingual salivary gland.

Vertically elongated, the *quadrilateral mandibular ramus* articulates with the temporal bone and serves as the site of attachment of the masticatory muscles. Both the lateral and medial surfaces of the inferior aspect of the ramus have ridges for insertion of the masseter and medial pterygoid muscles, respectively. The ridges on the lateral surface are more or less parallel to each other. They extend anterosuperiorly, sometimes to the level of one-half of the ramus, and their direction coincides with that of the masseter fibers. The medial surface ridges are less organized and restricted to the area of the gonion.

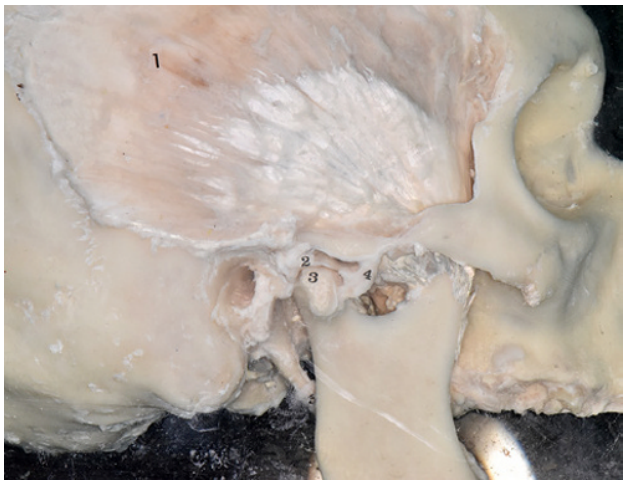

Figure 1.5 Temporomandibular joint (sagittal section, lateral view). 1 – Temporalis muscle, 2 – articular disk, 3 – mandibular condyle, 4 – fibrous capsule.

Two processes protrude from the superior aspect of the ramus, the anterior coronoid and the posterior condylar (Figure 1.5). The superior border of the ramus between them (the "mandibular notch") is deeply concave. The condylar process is composed of the head (condyle) and neck, and the size and shape of the mandibular condyle vary considerably. A superior view reveals an oval shape, while its side-to-side dimension is double that in the anteroposterior direction. The convex articular surface is in contact with the articular disk of the temporomandibular joint. The neck of the condylar process is flattened in an anteroposterior direction. The pterygoid fovea is found on the neck anterior surface, medially to the border of the mandibular notch where it approaches the lateral aspect of the condyle. More than 90% of the lateral pterygoid muscle fibers are inserted into the pterygoid fovea (Bittar et al. 1994). The coronoid process is flat and triangular in shape. Its tip is higher than the condylar process. The concave posterior edge of the coronoid process is an anterior continuation of the mandibular notch, and the convex anterior edge continues to the sharp anterior border of the ramus. However, both the temporalis and masseter muscles insert into the lateral surface of the coronoid process, which is smooth compared with its rough medial surface into which most of the temporalis muscle fibers are inserted. Here, the vertical temporal crest extends from the apex of the coronoid process to the level of the 3rd molar tooth, turning anteriorly and approaching its distal surface. The retromolar trigon is the wider horizontal part of the temporal crest immediately posterior to the last molar. The retromolar trigon is included in the larger, triangular area, the retromolar fossa, which is bounded by the temporal crest laterally, by the anterior border of the ramus medially and by the 3rd molar tooth at the base. One of the important variations of the retromolar fossa is the presence of the retromolar foramen, which found in 8–16% of people in various human populations (e.g., Ossenberg 1987). It is situated 10.5 mm posterior to the 3rd molar (Gamieldien and Van Schoor 2016). The foramen leads into the retromolar canal and transmits a neurovascular bundle that supplies the area of the 2nd and 3rd molar teeth.

The lingula is located close to the center of the medial surface of the ramus, and the sphenomandibular ligament is attached to its irregular sharp spine. It is in close proximity to the upper end of the mylohyoid line and the mandibular foramen. The mandibular foramen is the entrance for the inferior alveolar nerve and vessels into the mandibular canal, and it is inferior to the occlusal plane or at its level in most cases (Nicholson 1985).

The mandibular canal follows the direction of the mandibular ramus and body and ultimately approaches the region of the incisors. It communicates with the apexes of the lower tooth alveoli via small bony canals. On the level of the premolar teeth, the mental canal branches out from the mandibular canal, traversing in a postero-superior direction and opening into the mental foramen. The "incisor" part of the mandibular canal lies anterior to the mental canal. Several types of bifid mandibular canals that must be taken in account in dental surgery have been described in the literature (e.g., Kang et al. 2014).

Two fossae are associated with the maxilla and mandible, the infratemporal and the pterygopalatine. The *infratemporal fossa* is formed when the mandible articulates with the temporal bone. It can be easily identified between the mandibular ramus laterally and the lateral plate of the pterygoid process medially. This fossa is limited anteriorly by the posterior surface of the maxillary body which separates it from the maxillary sinus (Figure 1.4). The upper border of the fossa is on the level of the zygomatic arch. Medially to the zygomatic arch, there is free passage from the infratemporal fossa superiorly to the temporal fossa, which is found on the lateral aspect of the cranium. The inferior aspect of the greater wing of the sphenoid bone forms part of the roof of the fossa where the oval foramen and foramen spinosum are located. The infratemporal fossa communicates with the middle cranial fossa through these foramina. The infratemporal fossa is patent in both the posterior and inferior directions. The pterygomaxillary fissure leading into the pterygopalatine fossa is located between the medial and anterior walls of the fossa.

The pterygopalatine fossa is a well-delineated space resembling an inverted pyramid. It is located between the root of the pterygoid process of the sphenoid bone posteriorly and the posterior surface of the maxilla anteriorly

(Figure 1.4). The posterior wall of the pterygopalatine fossa is perforated by the pterygoid canal and the foramen rotundum, connecting it with the middle cranial fossa. The distal part of the greater palatine canal is in relation to the inferior aspect of the pterygopalatine fossa. Both the infratemporal and the pterygopalatine fossa communicate anteriorly with the orbit via the inferior orbital fissure.

Muscles

The muscles that are anatomically and functionally part of the oral cavity belong to several groups comprised of the suprahyoid, mimic, masticatory, extrinsic, and intrinsic muscles of the tongue and the palatal muscles.

Suprahyoid Muscles

The origin of the *stylohyoid muscle* is on the posterior and lateral surfaces of the base of the styloid process. It inserts into the junction of the body and greater horn of the hyoid bone. The stylohyoid muscle descends obliquely, anteriorly to the digastric muscle posterior belly, and is pierced by an intermediate tendon of the digastric muscle at the insertion point. The stylohyoid muscle is positioned medially to the parotid and submandibular glands and laterally to the hypoglossal nerve and hyoglossus muscle. The *digastric muscle* is composed of anterior and posterior bellies. The posterior belly originates from the mastoid notch of the temporal bone, and the anterior belly originates from the digastric fossa of the inferior border of the mandible. A tendinous loop extends from the deep cervical fascia and connects the curved intermediate tendon of the digastric muscle to the junction of the greater horn and the body of the hyoid bone. The posterior belly of the digastric muscle is covered by the inferior portion of the parotid gland near the mandibular angle. The posterior aspect of the intermediate tendon is crossed medially by the hypoglossal nerve. The anterior belly is defined by the floor of the mouth and found superficially to the mylohyoid muscle (Figure 1.6).

The *mylohyoid muscle* originates on the inner mandibular surface and extends from the symphysis to the 3rd molar tooth. It inserts into the anterior surface of the hyoid bone and the median raphe, extending from the symphysis menti to the anterior aspect of the hyoid bone. It is the principal muscle of the floor of the mouth floor, separating the oral cavity from the neck area. The posterior, free border of the mylohyoid muscle is in contact with the submandibular gland, whose superficial part is below the mylohyoid muscle and deep part above it. The deep surface of the mylohyoid muscle is influenced by the extrinsic muscles of the tongue, the styloglossus and the hyoglossus.

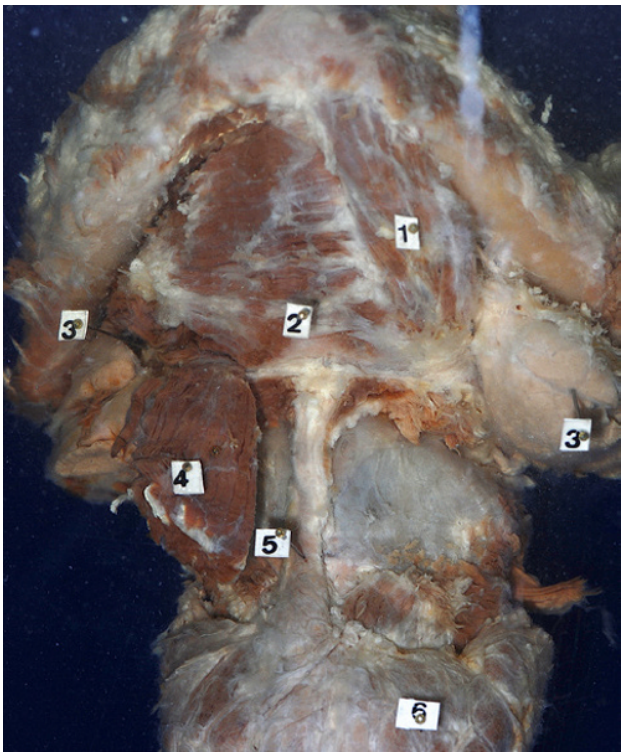

Figure 1.6 Mouth floor (anteroinferior view). 1 – Anterior belly of the left digastric muscle, 2 – mylohyoid muscle, 3 – submandibular gland, 4 – anterior belly of the right digastric muscle (reflected), 5 – pyramidal lobe of the thyroid gland, 6 – left lobe of the thyroid gland.

The mylohyoid muscle separates the sublingual and submandibular spaces which communicate with each other posteriorly to the free border of the muscle. The floor of the mouth is reinforced by the anterior belly of the digastric muscle inferiorly and the geniohyoid muscle superiorly.

The *geniohyoid muscle* originates in the inferior mental spine of the mental tubercle and inserts into the anterior aspect of the hyoid bone body. The anterior belly of the digastric and mylohyoid muscles are innervated by the trigeminal nerve (the nerve of the first branchial arch), while the posterior belly of the digastric and stylohyoid muscles is innervated by the facial nerve (the nerve of the second branchial arch). The geniohyoid muscle derives from the somites, and it receives motor fibers from the C1 spinal cord segment via the hypoglossal nerve.

The suprahyoid muscles can be divided into posterior and anterior groups in accordance with their relation to the hyoid bone. The anterior group includes the geniohyoid, mylohyoid, and anterior belly of the digastric muscles. The posterior group is composed of the posterior belly of the digastric and stylohyoid muscles. The anterior group of suprahyoid muscles is attached to the mandible superiorly and to the hyoid bone inferiorly, and has a dual action: it

elevates the hyoid bone when the mandible is fixed by contraction of the masticatory muscles, and it depresses the mandible when the hyoid bone is stabilized by contraction of the infrahyoid group of muscles. Contraction of the anterior group of muscles causes protrusion of the hyoid bone, while contraction of the posterior group retracts it. The suprahyoid muscles in combination elevate the hyoid bone.

Mimic Muscles

The common characteristics of this group of muscles is that they are all embedded into the hypodermis or, in anatomical terms, into the superficial fascia. The superficial musculoaponeurotic system is a complex of the fascia and mimic muscles. The origin of mimics is usually bone or dermis, and their insertion is mostly into the skin, but also into the fascia, cartilaginous structures, and the modiolus (a fibromuscular mass situated immediately laterally to the mouth commissure). Muscles which are inserted into the modiolus decussate and blend with each other. This arrangement very effectively controls the position of the angle of the mouth. Despite the term "mimic" or muscles of facial expression, their primary function is to regulate the size of the primary openings of the face, i.e., the orbits, nostrils, and mouth. Contraction of the mimic muscles is under the control of the facial nerve. The origin and insertion of the mimic muscles, which are functionally and anatomically part of the oral cavity, are summarized in Table 1.2.

Muscles of Mastication

The four muscles of mastication are designed to move the mandible during mastication and speech, and they include the temporalis, masseter, and medial and lateral pterygoid.

The origin of the *temporalis muscle* (Figure 1.5) is the temporalis fossa and the deep temporal fascia. It inserts into the coronoid process, and continues along the anterior surface of the mandibular ramus down to the alveolar process. At their origin, the temporalis muscle fibers gradually change their direction from vertical-anterior to horizontal-posterior. All the fibers converge towards the zygomatic arch, where they partly blend with it and with the masseter muscle. They are then replaced by a thick tendon. The anterior tendinous fibers which insert into the anterior border of the mandibular ramus and temporal crest bypass the retromolar fossa.

The *masseter muscle* is composed of both superficial and deep parts. The origins of the superficial part are the zygomatic process of the maxilla, the maxillary process of the zygomatic bone, the inferior border of the body of the zygomatic bone, and the inferior border of the anterior two thirds of the zygomatic arch. The origin of the deep part is the medial aspect of the zygomatic arch, with the exception of the area posterior to the articular eminence of the zygomatic process of the temporal bone. The masseter muscle inserts into the external surface of the mandibular angle, but it can extend to the entire mandibular ramus lateral surface. There is a space between the superficial and deep portions at their origin which is filled with loose connective tissue. The fibers of the deep part descend vertically, and their attachment area occupies mostly the superior half of the ramus. The fibers of the superficial part run in a posteroinferior direction and blend with the deep portion of the muscle.

The origins of the *medial pterygoid muscle* (Figure 1.7) are the medial surface of the lateral pterygoid plate, the inferolateral surface of the pyramidal process of the

Table 1.2

Muscle	Origin	Insertion
Levator labii superioris	Body of the maxilla, parallel to the inferior orbital rim	Lateral aspect of the upper lip
Levator anguli oris	Canine fossa of the maxilla	Modiolus
Zygomaticus major	Zygomaticotemporal suture	Modiolus
Risorius	Zygomatic arch, parotideomasseteric fascia	Modiolus
Depressor anguli oris	Anterior part of the oblique line of the mandible	Modiolus
Depressor labii inferioris	Oblique line of the mandible, above the depressor anguli oris origin	Skin of the lower lip
Mentalis	Incisive fossa of the mandible	Skin of the chin
Platysma	Fascia of the pectoralis major and deltoid muscles	Lower border of the mandible, modiolus
Buccinator	Base of the mandibular and maxillary alveolar processes at the level of the molar teeth, pterygomandibular raphe	Modiolus
Orbicularis oris	Modiolus	Skin of the lips

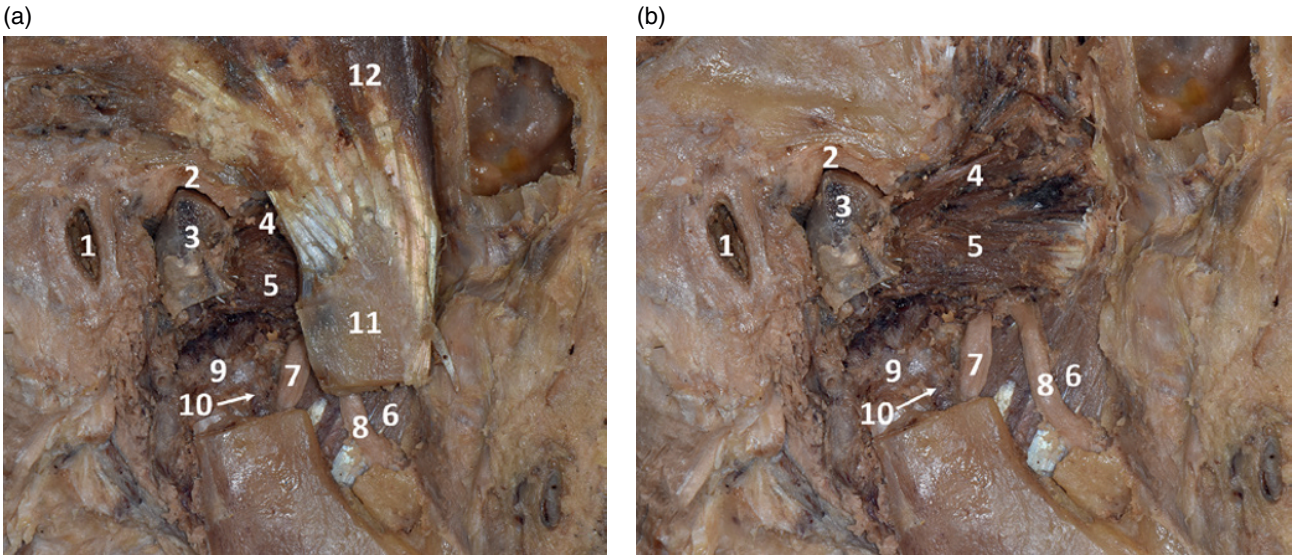

Figure 1.7 Temporomandibular joint (sagittal section, lateral view) and associated structures. The segment of the mandibular ramus is removed to expose the contents of the infratemporal fossa (a,b); the coronoid process and the temporalis muscle are reflected superiorly (b). 1 – External acoustic meatus, 2 – articular disk, 3 -mandibular condyle, 4 – superior head of the lateral pterygoid muscle, 5 – inferior head of the lateral pterygoid muscle, 6 – medial pterygoid muscle, 7 – inferior alveolar nerve, 8 – lingual nerve, 9 – maxillary artery, 10 – inferior alveolar artery, 11 – coronoid process, 12 – temporalis muscle.

palatine bone, and the maxillary tuberosity. It inserts into the medial surface of the mandibular angle. It is a thick, rectangular-shaped muscle whose fibers descend in a posterolateral direction. The space between the muscle and the medial surface of the mandibular ramus contains a number of extremely important structures: the sphenomandibular ligament, maxillary artery, lingual nerve, inferior alveolar nerve and vessels, lateral pterygoid muscle, and a deep extension of the parotid gland.

The *lateral pterygoid muscle* (Figure 1.7) is composed of superior and inferior heads. The origin of the superior head is the infratemporal crest and the inferior surface of the greater wing of the sphenoid bone. The origin of the inferior head is the lateral surface of the lateral pterygoid plate. It inserts into the anterior aspect of the fibrous capsule of the temporomandibular articulation, the pterygoid fovea of the mandibular condyle. The superior head curves posteriorly, inferiorly, and laterally towards the mandibular neck where it fuses with the inferior head fibers. The attachment of the lateral pterygoid muscle to the disk-capsule complex of the temporomandibular joint varies. However, the most common site of the superior head insertion is the fibrous capsule and articular disk, with the superior head fibers having been reported as being exclusively attached to the condyle in approximately one third of the cases (Naidoo 1996). The tendon of the temporalis muscle pass laterally to the lateral pterygoid muscle, sphenomandibular ligament, mandibular nerve, and the upper portion of the medial pterygoid muscle which are located medially to it (Figure 1.7a).

The temporalis, masseter, and medial pterygoid muscles are powerful elevators of the mandible, and the lateral pterygoid is the main protrusion muscle. The posterior fibers of the temporalis and the deep portion of the masseter muscle act as retractors. Lateral deviation of the mandible can be performed by contraction of the contralateral lateral pterygoid muscle alone. However, the contralateral medial pterygoid muscle and the ipsilateral temporalis and masseter muscles are also physiologically active in the lateral movement of the mandible. All the muscles of mastication are derivatives of the 1st branchial arc, and they all are innervated by the mandibular division of the trigeminal nerve.

Extrinsic and Intrinsic Muscles of the Tongue

The extrinsic muscle of the tongue are named according to the structures from which they originate. The s*tyloglossus muscle* originates mainly from the styloid process, while some fibers can originate from the stylomandibular ligament and/or the angle of the mandible. Fibers of the styloglossus muscle run in an anteroinferior direction and reach the inferior aspect of the tongue where they blend with the posterior fibers of the hyoglossus muscle and continue anteriorly to the tip of the tongue. The *hyoglossus muscle* originates from the greater horn and the

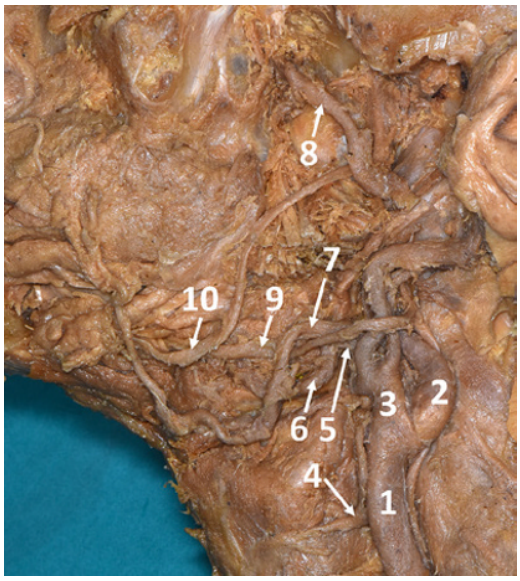

Figure 1.8 Blood supply of the oral apparatus. 1 – Common carotid artery, 2 – internal carotid artery, 3 – external carotid artery, 4 – superior thyroid artery, 5 – linguofacial trunk, 6 – lingual artery, 7 – facial artery, 8 – maxillary artery (cut), 9 – hypoglossal nerve, 10 – lingual nerve.

adjoining part of the body of the hyoid bone. Thin fibers of this delicate muscle rise almost vertically and insert into the lateral aspect of the tongue. The styloglossus and hyoglossus muscles are retractors and depressors of the tongue, respectively. The fan-like fibers of two *genioglossi muscles* begin from the superior mental spines and spread from tip of the tongue to its root as well as to the body of the hyoid bone. The genioglossus muscle protrudes the tongue and depresses its central part. The intrinsic muscles are entirely incorporated into the tongue, and act together with the extrinsic muscles to alter its shape. All the muscles of the tongue are innervated by the hypoglossal nerve (Figure 1.8).

Muscles of the Palate

This group of muscles is composed of:

1) the tensor and levator veli palatini muscles, which are situated above the palate
2) the palatoglossal and palatopharyngeus muscles, which extend from the palate downwards
3) the musculus uvulae, which is embedded in the soft palate.

The origin of the *levator veli palatini* is the cartilaginous part of the eustachian tube and the inferior surface of the petrous portion of the temporal bone. It extends obliquely in the antero-inferomedial direction and inserts into the soft palate aponeurosis.

The *tensor veli palatini* originates from the scaphoid fossa, the spine of the sphenoid bone, and the cartilaginous part of the eustachian tube. It inserts into the posterior aspect of the horizontal plate of the palatine bone and into the palatine aponeurosis. The tensor veli palatini descends laterally to the levator veli palatini muscle. The muscular fibers are replaced by the tendon, which hooks around the hamulus pterygoidei prior to being inserted into the palatine aponeurosis.

The origin of the *palatoglossus muscle* is the palatine aponeurosis. It inserts into the lateral aspect of the tongue, anteriorly to the palatine tonsil. When covered by mucosa, it forms the palatoglossal arch.

The *palatopharyngeus muscle* originates on the posterior border of the horizontal plate of the palatine bone, which is the upper surface of the palatine aponeurosis on both sides of the palatoglossal muscle. It inserts into the posterolateral pharyngeal wall at the posterior aspect of the thyroid cartilage. This descending muscle forms the palatopharyngeal arch, after which its muscle fibers blend with the fibers of the stylopharyngeus muscle forming the longitudinal muscular layer of the pharynx.

The origin of the *musculus uvulae* is the posterior nasal spine of the palatine bone and palatine aponeurosis. It inserts under the uvular mucosa. The palatal muscle acts in concert with it in order to isolate a bolus when it is in the oropharynx.

The levator and tensor veli palatini muscles elevate and tightly stretch the soft palate, respectively, and, together with the musculus uvulae, prevent the entrance of the bolus into the nasopharynx. This action is assisted by contraction of the palatopharyngeus muscles, which elevate and adduct the palatopharyngeal folds. Simultaneously, the palatoglossal muscles approach each other and elevate the tongue, thus closing the oropharyngeal isthmus.

The tensor veli palatini muscle is supplied by the mandibular nerve, and the other palatal muscles are innervated by the cranial accessory nerve fibers via the nerves of pharyngeal plexus, the vagus and the glossopharyngeal.

Nerves

Most of the structures of the middle and lower face are innervated by branches of the trigeminal and facial cranial nerves. Only a small area of the angle of the mandible is innervated by the spinal nerves C2–3. Innervation of the tongue is provided by the facial, trigeminal, glossopharyngeal, and hypoglossal cranial nerves. The fibers of the facial and hypoglossal cranial nerves are involved in the secretomotor innervation of the salivary glands. The branches of the nerves which are closely related to the maxilla and mandible will be discussed in the present chapter.

Trigeminal Nerve

The trigeminal nerve divides into the ophthalmic, maxillary, and mandibular nerves in the cranial cavity. The latter two supply the area related to the masticatory apparatus. The *maxillary nerve* is a pure sensory nerve. It originates from the Gasserian ganglion, between the ophthalmic and mandibular nerves. The meningeal branch starts from the cranial portion of the maxillary nerve before it passes through the foramen rotundum to the pterygopalatine fossa. In this fossa, the parasympathetic pterygopalatine ganglion is connected by the sphenopalatine nerve, or sensory root, to the inferior aspect of the maxillary nerve. The maxillary nerve sensory fibers continue uninterruptedly through the pterygopalatine ganglion and enter the nerves which are referred to as the pterygopalatine ganglion branches, namely, orbital, nasal, palatine, and pharyngeal. These branches convey both the sensory fibers of the trigeminal nerve and the taste fibers from the soft palate and postganglionic parasympathetic fibers innervating the mucosa. Both the taste and parasympathetic fibers belong to the facial nerve.

The *orbital branches* of the pterygopalatine ganglion supply the internal surface of the orbit, as well as the intraorbital structures and mucosa of both the sphenoidal and ethmoid sinuses. The longest and largest of the *nasal branches,* the *nasopalatine nerve,* enters the nasal cavity through the sphenopalatine foramen, descends obliquely under the mucosa of the ipsilateral surface of the nasal septum where it gives off a few branches, and reaches the nasopalatine or incisive canal of the maxilla. In the upper part of the canal, the left and right nasopalatine nerves pass either separately through the anterior and posterior foramen, respectively, or together through the common foramen. In the incisive canal, the nasopalatine nerve communicates with its contralateral fellow and with the terminal part of the greater palatine nerve. Two nasopalatine nerves innervate the palatal tissue of six upper anterior teeth, namely, four incisors and two canine teeth.

The *palatine nerve* branches into the *greater and lesser palatine nerves*. The greater palatine nerve descends through the palatine canal, traverses the greater palatine foramen, and branches into the hard palate in a plane between the bony tissue and mucosa. The communication of the greater palatine and nasopalatine nerve has been described earlier. The lesser palatine nerve occupies the palatine canal and emerges from the lesser palatine foramen. It provides full scale sensation including taste, as well as the parasympathetic fibers for the soft palate and for the palatine tonsil (with the exception of the taste fibers).

The *pharyngeal nerve* leaves the pterygopalatine fossa via the palatovaginal canal and supplies the mucosa of the posterior aspect of the nasopharynx.

In addition to the sphenopalatine branch, the short pterygopalatine segment of the maxillary nerve sends the zygomatic and posterior superior alveolar branches. The zygomatic nerve splits into the zygomaticotemporal and zygomaticofacial branches which supply the skin of the temporal area and the cheek prominence, respectively.

The posterior superior alveolar nerve arises from 1 or 2 trunks of the pterygopalatine portion of the maxillary nerve. These trunks branch out and enter into a number of irregularly scattered foramina found on the infratemporal surface of the maxillary body. The branches which provide a sensory supply for the maxillary sinus are located between the mucosa and the bony tissue. Other branches descending into the posterior alveolar canals form the posterior part of the alveolar plexus and innervate the upper molar teeth.

After giving off branches in the pterygopalatine fossa, the maxillary nerve passes through the infraorbital fissure into the orbit. It is lodged in the infraorbital groove and canal, after which it becomes the infraorbital nerve. The branches given off by the infraorbital nerve are the middle and anterior superior alveolar nerves, which descend into the bony canals of the lateral and anterior maxillary walls, respectively. The middle superior alveolar nerve supplies the premolar teeth and partially supplies the middle part of the alveolar plexus. In its absence, the posterior superior alveolar nerve takes over its function. The anterior superior alveolar nerve originates from the infraorbital nerve in the posterior part of the infraorbital canal, enters its own canal, and descends towards the incisors and canine teeth. It forms the anterior part of the alveolar plexus, which supplies these teeth, and split as nasal branches to the mucosa of the anterior aspect of the lateral wall and floor of the nasal cavity. The terminal portion of the infraorbital nerve exits the infraorbital foramen on the anterior surface of the maxilla and divides into terminal branches named after the areas they supply, namely, inferior palpebral, external and internal nasal, and superior labial.

Mandibular Nerve

This is a mixed sensory and motor nerve. Its sensory fibers innervate the lower teeth and gums, as well as the mucosa of the anterior two-thirds of the tongue and floor of the mouth. Externally, it innervates the skin over the temporal area, anterior wall of the external acoustic meatus, tragus of the auricle, and lower jaw. The motor component of the mandibular nerve innervates the masticatory, tensor veli palatini, and tensor tympani muscles. *The sensory and motor roots* pass separately in the posterior and middle cranial fossa and join each other only at the oval foramen, which transports the mandibular nerve into the infratemporal fossa. The mandibular nerve branches located in the infratemporal fossa are intimately related to the fossa

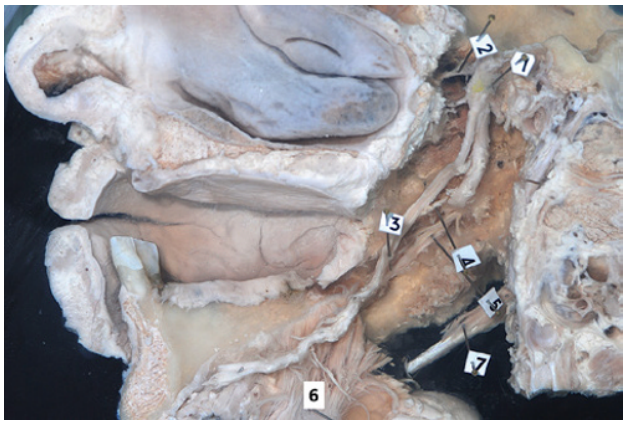

Figure 1.9 Mandibular nerve branches. 1 – Mandibular nerve, 2 – anterior division, 3 – lingual nerve, 4 – chorda tympani, 5 – inferior alveolar nerve, 6 mylohyoid muscle, 7 – digastric muscle (posterior belly).

contents comprised of the muscles of mastication, pterygoid venous plexus, maxillary artery branches, etc. The first branches given off by the nerve beneath the skull are the sensory meningeal branch and the nerve to the medial pterygoid muscle. The latter also supplies the tensor veli palatini and the tensor tympani muscles. The mandibular nerve then divides into smaller anterior and larger posterior trunks (Figure 1.9), both of which are mixed nerves.

The *anterior trunk* gives off only one sensory branch, the *buccal nerve*. It is closely related to the lateral pterygoid muscle, passing between its two heads to reach the anterior border of the masseter and join the buccal branch of the facial nerve. The buccal nerve fibers innervate the skin and mucosa related to the buccinator muscles and the gingivae on the buccal surface of the first two molars. Other motor branches of the anterior trunk, namely, the masseteric, deep temporal and lateral pterygoid nerves, supply the corresponding muscles.

The *masseteric nerve* passes above the lateral pterygoid muscle and mandibular notch and enters the medial surface of the masseter muscle. *The deep temporal nerves* (usually two and sometimes three in number) are also found superiorly to the lateral pterygoid muscle, between it and the skull base. The anterior and posterior deep temporal nerves may communicate with the buccal and masseteric nerves, respectively. The *lateral pterygoid nerve* arises either directly from the anterior trunk or from the buccal nerve. It approaches the medial surface of the lateral pterygoid muscle. The *posterior trunk* is a direct continuation of the mandibular nerve. It gives rise to the auriculotemporal nerve, after which it splits into the lingual and inferior alveolar nerves. All of them are sensory nerves, and only the latter conveys the motor fibers for the mylohyoid and anterior belly of the digastric muscles.

The *auriculotemporal nerve* usually arises from two roots encircling the middle meningeal artery, however, the number of roots can vary from one to five (Komarnitki et al. 2015). The roots of the auriculotemporal nerve are located near the lateral pterygoid muscle and sometimes run through its fibers. After surrounding the middle meningeal artery, the roots of the auriculotemporal nerve form a single trunk, which crosses the mandibular condyle and turns superficially behind it. Here, the nerve enters the parotid gland and divides into the branches that innervate the temporal region, part of the auricle and external acoustic meatus, auriculotemporal joint, and skin of the posterior cheek. The auriculotemporal nerve receives the postganglionic parasympathetic fibers from the otic ganglion of the glossopharyngeal nerve. It also communicates with the upper terminal branches of the facial nerve, thus conveying stimuli from the mimic muscle proprioceptors.

The *lingual nerve* (Figures 1.7–1.9) starts approximately 1 cm below the skull base. At the beginning, it is located anteromedially to the inferior alveolar nerve, after which it descends between the lateral and medial pterygoid muscles. The chorda tympani, which is a branch of the facial nerve, crosses the inferior alveolar nerve medially to it and joins the posterior aspect of the lingual nerve at the lower border of the lateral pterygoid muscle. The chorda tympani carries the taste fibers for the anterior two-thirds of the tongue and for the parasympathetic preganglionic fibers that innervate the submandibular ganglion. Distally to the junction of the chorda tympani, the lingual nerve descends towards the superior end of the mylohyoid line where it is sandwiched between the medial pterygoid muscle and mandibular ramus. At this point, the nerve acquires a more horizontal position and runs anteriorly in the space between the mylohyoid and hyoglossus muscles. When the lingual nerve approaches the superior aspect of the deep portion of the submandibular gland, it sends off communicating branches to the submandibular ganglion. The postganglionic parasympathetic fibers of this ganglion innervate both the submandibular and sublingual glands. The terminal portion of the lingual nerve crosses the submandibular duct (of Wharton) and branches out laterally to the genioglossus muscle.

The *inferior alveolar nerve* (Figure 1.7, 1.9) is the largest branch of the mandibular nerve. It lies on the lateral surface of the medial pterygoid muscle, between it and the lateral pterygoid muscle. It then turns under the lateral pterygoid muscle toward the inner surface of the mandibular ramus, passes very close to the medial aspect of the temporomandibular joint capsule and articular disk, and finally squeezes through the interval between the ramus and the sphenomandibular ligament. It now enters the mandibular canal where it is accompanied by the inferior

alveolar vessels which are found just posteriorly to it. The mylohyoid nerve arises from the inferior alveolar nerve at the entrance into the canal. This branch contains the motor fibers that innervate the mylohyoid and anterior belly of the digastric muscle and a few sensory fibers that are delivered to the skin over the mental protuberance. The mylohyoid nerve proceeds anteriorly along the mylohyoid line. It approaches the inferolateral surface of the mylohyoid muscle where it divides into muscular and sensory branches.

The inferior alveolar nerve follows the mandibular canal and, from the depth of the mandible, it sends off three sensory branches: the dental branches, the mental nerve, and the incisive branch. The dental branches are inserted one to each other, and form the inferior dental plexus, which supplies the premolar and molar teeth. The mental nerve is a single nerve in more than 90% of the population. It appears from the mental foramen and divides into between two and four branches. Each of these branches divides further into variable numbers of secondary branches (Loyal 2013) that supply the skin of the chin and the mucosa of the lower lip.

Blood Vessels

Arteries

The vast majority of the arteries of the oral cavity are branches that originate from the external carotid system, namely, the superior thyroid, lingual, facial, posterior auricular, occipital, ascending pharyngeal, maxillary, and superficial temporal arteries. The lingual, facial, and maxillary arteries are directly related to the blood supply of the oral cavity (Figure 1.8).

The *lingual artery* originates in the carotid triangle, either directly from the external carotid or, in almost 20% of the population, from the common linguofacial trunk (Figure 1.8). It rarely forms a common thyrolingual trunk together with the superior thyroid artery. The proximal part of the lingual artery forms an ascending loop, which is crossed laterally by the hypoglossal nerve. The artery then proceeds anteriorly and runs along the medial surface of the mylohyoid muscle, between it and the genioglossus muscle. The terminal part of the lingual artery (the deep lingual artery) runs along the ventral surface of the tongue towards its tip where it is covered solely by the oral mucosa. The suprahyoid branch arises from the proximal part of the lingual artery. It supplies the suprahyoid muscles at their attachment to the hyoid bone. The sublingual artery branches out from the lingual artery at the anterior margin of the hyoglossus muscle. This branch is located on the medial surface of the sublingual gland, and it supplies that gland as well as the mucosa of the oral floor.

When the lingual artery crosses the hyoglossus muscle, it sends from one to three dorsal lingual arteries to supply the posterior aspect of the tongue and the adjacent part of the oropharynx. The sublingual and submental arteries anastomose with each other in reciprocal relationships.

The origin of the *facial artery* is hidden from the lateral view by the posterior belly of digastric muscle. This artery passes just medially to the angle of the mandible and then cut through the submandibular gland. The facial artery enters the submandibular triangle, passes under the inferior border of the mandibular body at the anterior aspect of the masseter attachment, and turns in an anterosuperior direction towards the nasolabial groove. Here, the facial artery has a very characteristic tortuous course until it reaches the lateral border of the nose. The distal part of the facial artery that approaches the medial angle of the eye is labeled the "angular" artery. The facial artery gives off two main branches in the neck. One is the ascending palatine artery, which anastomoses with the descending or greater palatine artery from the maxillary artery system, and the other is the submental artery, which anastomoses with the sublingual artery.

The external carotid artery divides into its terminal branches, the maxillary and superficial temporal arteries, within the parotid gland. Embryologically, the maxillary artery is a continuation of the external carotid artery. The course of the maxillary artery can be generally described as anterior, superior, and medial. The most proximal portion of the maxillary artery is found between the sphenomandibular ligament and the mandibular neck. The relation of the maxillary artery to other structures in the infratemporal fossa varies. It can be found either laterally or medially to the lateral pterygoid muscle. It crosses the inferior alveolar nerve either medially (most of the time) or laterally to it, and the same holds true for the lingual nerve. Finally, the maxillary artery passes between the two heads of the lateral pterygoid muscle and enters the pterygopalatine fossa via the pterygomaxillary fissure. Among the numerous branches of the maxillary artery, those which are directly related to the oral cavity are the inferior alveolar, buccal, posterior superior alveolar, infraorbital, and greater (descending) palatine arteries. They follow the course of the branches of the trigeminal nerve of the same names.

The sphenopalatine artery is the direct continuation of the maxillary artery when it passes through the sphenopalatine foramen. It appears in the nasal cavity on the level of the superior nasal meatus and gives off the lateral branches to the posterior aspect of the nasal conchae. The lateral arteries also contribute to the blood supply of the maxillary, frontal, ethmoid, and sphenoidal sinuses. The posterior septal branch of the sphenopalatine artery

runs diagonally from the posterosuperior to anteroinferior corner of the nasal septum, and enters the incisive canal where it anastomoses with the terminal branch of the greater palatine artery.

Veins

The veins of the upper and lower jaws essentially follow the course of the corresponding arteries and nerves, forming neurovascular bundles.

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2

Biologic Conditions for Bone Growth and Maintenance

Managing the Oxidative Stress

Joseph Choukroun, Elisa Choukroun, and Maximilien Parnot

The multidisciplinary field of tissue engineering has tackled a wide variety of medical challenges over the years with the aim of predictably repairing, regenerating or restoring damaged and diseased tissues (Coury 2016, Dai 2016, Rouwkema and Khademhosseini 2016, Zhu 2016). Many strategies have since been adapted to regenerate these tissues. One of (if not the) key component during the regenerative phases during wound healing is the absolute necessary for ingrowth of a vascular blood source capable of supporting and contributing to cellular function and the future development and maintenance of nutrients across this newly created blood supply. Although biomaterials and tissue engineered scaffolds are typically avascular by nature. Over 15 years ago, a series of proposed motifs introduced blood concentrates as a regenerative modality, in order to improve the vascular network and to obtain successfully regenerated soft or hard tissues, where lack of a blood supply was often at the forefront of the defect (Upputuri 2015).

However, angiogenesis and blood supply can be affected by several mechanisms or physio-pathological situations (such as diabetes and smoking), whose common denominator is oxidative stress (Yoshikawa and Naito 2002).

In clinical practice, oxidative stress can have a negative impact in the maintenance of bone. We should consider bone, native or grafted, to be subject to resorbtion when facing chronic oxidation. Many and various therapies aimed at reducing this stress have been tried with variable results. We conclude that, in surgical patients, the assessment of oxidative stress, improving understanding of its role, both positive and negative, and devising appropriate therapies are of great clinical importance and represent fruitful fields for further research.

The aim of this chapter is to highlight the relationship between biologic conditions, oxidative stress and long-term stability in bone management.

Background

The long-term success of implants and bone grafts is every oral surgeon's goal. The respect of numerous factors (surgical, prosthetic, occlusal) is not enough to achieve this goal.

Some failures remain unexplained and biology is often left apart. The presence of biological phenomenon like oxidative stress will decide the tissues behavior and its stability.

Oxidative Stress: Definition, Origin and Consequences

The term "oxidative stress" first appeared in the medical literature in 1985. Aerobe species, in contact with oxygen, physiologically produce numerous oxidants (also named free radicals). The cell reaction is to produce antioxidants in order to neutralize these oxidants.

When the level of oxidants exceeds the one of antioxidants, the tissue is considered under oxidative stress. This situation occurs when the production of oxidants is excessive or when antioxidant release is insufficient. This physio-pathological event causes damages, first molecular (alteration of DNA), and further cellular with genetic mutations or apoptosis.

Furthermore, oxidative stress favors the occurrence of certain illness and an accelerated cells aging.

The main events originally causing oxidative stress are: ischemia, inflammation, anxiety and some diseases, such as diabetes, smoking, hypercholesterolemia and vitamin D deficiency.

There is a considerable evidence that those patients are under oxidative stress. Therefore, they meet more complications or infections.

Numerous clinical studies have confirmed the association of oxidative stress markers and periodontitis. One of

Bone Augmentation by Anatomical Region: Techniques and Decision-Making, First Edition. Edited by Zvi Artzi.
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the largest observational studies has shown that the anti-oxidant status in blood and calculated total antioxidant capacity were inversely associated with mild or severe periodontitis (Chapple et al. 2007). The more severe is periodontitis, the clearer is the association with oxidative stress. Additionally, in a subgroup of never-smokers, antioxidants seemed to protect against development of periodontitis. Lowering oxidative stress markers might be a secondary effect of anti-inflammatory or antibacterial agents.

To understand the relationship between success and a low level of oxidative stress, we can cite two of the most difficult patients in oral surgery such as diabetics and smokers (Karam et al. 2017, Golbidi et al. 2018).

These patients are under a chronic oxidative stress: hyperglycemia induces a high production of oxidants and the smoke destroys anti-oxidants produced during the defense reaction.

In order to improve the soft and hard tissues healing and their maintenance, we are proposing here a review of biological and clinical status which could lead to an oxidative stress and their solution or prevention.

Why Should Oral Surgery be Considered as a Source of Oxidative Stress?

Numerous surgical gestures induce ischemia and facilitate the over-production of oxidants:

- Local anesthetics with vaso-constrictors are used to lengthen anesthesia. They also reduce blood supply, and thus, a relative ischemia.
- Contamination, as surgeries are done into the septic oral cavity, is mandatory and induces inflammation.
- Flap elevation and bone exposition: the larger the surgery is, the more ischemic it becomes. As soon as a flap is raised, ischemia begins.
- Periosteal incision is an unavoidable gesture in bone augmentations. This incision will increase the laxity of the flap but also decrease its blood supply.
- The raised flap becomes mobile and will be submitted to muscle tension.
- Implant placement can be compressive and then followed by ischemia of the cortical bone (marginal bone loss).
- Late revascularization of grafts: bone graft is by definition avascular at the beginning. Ischemia is an inducing factor of angiogenesis but still induces a transitory oxidation.
- Anxiety of patients undergoing oral surgery induces oxidation.
- Finally, other sources of oxidative stress exist: some biological conditions, such as diabetes, smoking, vitamin D deficiency and hypercholesterolemia.

The review of these factors must encourage us to consider operative and post-operative periods as potential oxidative situations.

Before surgery, each cause has to be systematically investigated and treated.

During the procedure, the surgeon has to prevent ischemia, both acute and chronic. The negligence of these elements will slow wound healing and could cause a long-term tissue loss.

Biological Status Associated with Oxidative Stress

Cholesterol and vitamin D have a major influence on bone and tissue metabolism (Choukroun et al. 2014).

Hypercholesterolemia

Cholesterol is a lipid from cell membranes, transported by 2 types of lipoproteins: HDL (High Density Lipoprotein) and LDL (Low Density Cholesterol). HDL-binding cholesterol is considered as the "good" cholesterol, through its antioxidant properties. On the contrary, LDL cholesterol is one of the most oxidant component of the human body, therefore called the "bad" cholesterol. Its effects on arteriosclerosis and its oxidant action on bony cells have been proved: a high level of LDL cholesterol induces osteoblast apoptosis (Brodeur et al. 2008).

LDL above 1,40 mg/L will have a negative impact of bone metabolism (Mandal 2015). In the same time, bone becomes fatter and can take a yellow color, losing a part of its osteogenic repair potential.

In conclusion, the pre-operative testing and correction of LDL cholesterol serum level should be systematic before each bony surgery (bone graft or implants).

Vitamin D Deficiency

Vitamin D is mainly synthetized in the skin after sun exposure (80–90%). The remaining part comes from diet. Vitamin D is first hydroxylated in the liver and then transformed in the kidney in an active form after a second hydroxylation: 1,25 OH_2 vit. D, which is released in the blood, thus having an endocrine activity. The major hormone activity is the calcium absorption regulation and bone health.

In addition, vitamin D, after production or oral absorption, also diffuses in the whole body where cells have a specific receptor: the VDR (*V*it. *D R*eceptor): in contact with the cells, its activity is both paracrine and autocrine.

Vitamin D acts as a local neuro-mediator and regulates the cells growth with a wide range. Evidence of extraskeletal effects of $1,25(OH)_2D3$ includes xenobiotic detoxification, oxidative stress reduction, neuroprotective functions, antimicrobial defense, immunoregulation, anti-inflammatory/anticancer actions, and cardiovascular benefits.

The latest findings showed a novel hormonal activity of vitamin D due to the presence of the VDR in other cells such as keratinocytes, promyelocytes, monocytes, lymphocytes, ovarian cells, islet cells of the pancreas, and so on (DeLuca 2003).

Commonly, an optimal serum level is described to be between 30ng/mL (or 75nmol/L) and 100ng/mL (250nmol/L) (Figure 2.1).

- Between 10 and 30ng/mL: the level is insufficient.
- Below 10ng/mL (25nmol/L): the term "severe deficiency" is used.

Numerous studies have shown that vitamin D deficiency affects 70 to 80% of the population (Chapuy et al. 1997, Choukroun 2016, Holick 2006, 2007).

The most frequent deficient population is the elderly. Over 60 years old, the body is not able to produce enough vit. D, even after sun exposure: the production capacity drops by 75%. Pregnant/breast feeding women, obese, dark skin people and depressive patients are also generally deficient.

Among risky patients, there are two types to highlight:

- *Smokers*: are already in oxidative stress as explained above. The majority are also deficient on account of an inhibition of the vitamin D production. These cumulative factors could explain their healing difficulties. As antioxidants are destroyed by the smoke, the medical examination must identify passive smokers and consider them with the same risk level.
- *Diabetics*: in addition to a chronic oxidative stress, they are often deficient in vitamin D. Vitamin D allows a better glucose metabolism regulation by its action on insulin secretion, improves the lipid profile, reduces the glycemia, and improves wound healing by its paracrine properties.

High cholesterol level is more frequently found in people with lower vitamin D levels. This relation cannot be accidental, as cholesterol and vitamin D have the same precursor and metabolic pathway: from hydroxymethylglutaryl-coenzyme A (HMG-CoA) to 7DHC.

Bogh et al. (2010) came to the conclusion that vitamin D synthesis after UVB exposure positively correlates with baseline total cholesterol level.

In recent years, numerous publications proved the capacity of vitamin D to increase antioxidant production (Asemi et al. 2013, Gil et al. 2018, Sharifi et al. 2014). Thus, vitamin D gains a new property: fighting oxidative stress.

Indeed, if oral surgery creates oxidative stress, the so-called "normal vitamin D level" should be considered as insufficient. This physiologic level is only acceptable for people not undergoing surgery. So, 100% of patients planned for surgery should receive supplementation in order to prevent oxidative stress and to improve wound healing.

The right therapeutic attitude should be the following:

- Systematic serum testing of both vitamin D and cholesterol.
- LDL hypercholesterolemia, if found, will be managed by the physician. However, hypovitaminosis D can be handled directly by oral surgeons:
- Vitamin D supplementation starts the day of the consultation: 2.000 UI/day.

After receiving the lab test results, the prescription has to be adapted (Figure 2.2):

- > 30 ng/mL: 2000 UI/day
- 20–30 ng/mL: 4000 UI/day
- 10–20 ng/mL: 6000 UI/day
- < 10ng/mL: 10.000 UI/d

This supplementation will be maintained 3 to 6 months (duration of mineralization/ osseointegration). After this period, the patient will be managed by his physician. For diabetics and smokers, long-time supplementation has to be done with higher doses (min. 4–6.000 UI/day), in order to improve the patient biologic profile.

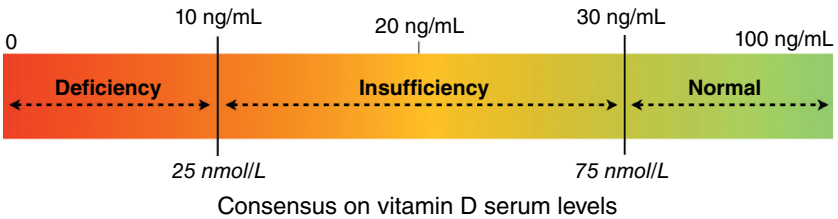

Figure 2.1 Consensus on Vitamin D levels. Lab test results are expressed in ng/mL or nmol/L. Credits: E. CHOUKROUN/J. CHOUKROUN/M. PARNOT

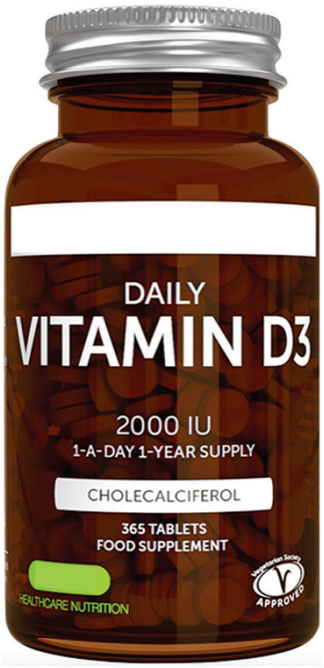

Figure 2.2 Example of vitamin D daily tablets: dietary supplement.Credits: E. CHOUKROUN/J. CHOUKROUN/M. PARNOT

Anxiety and Oxidative Stress

Anxiety is a major oxidative stress factor. Studies conducted over the past years suggest that anxious behavior may increase oxidative stress by lowering antioxidant defenses and increasing the oxidative damages on tissues. Evidently, the number of post-operative complications dramatically increase in anxious and depressive patients (Black et al. 2017, Britteon 2017, Wang et al. 2017).

The easiest way to decrease this stress and its effects on surgical outcomes is to perform pre and per-operative sedation, oral, or IV. The objective is to help patients to face the surgery more serenely. The most used oral sedatives are benzodiazepines or anti-histaminics.

Sedation can be continued few days after the operation if needed, at bedtime.

Local Anesthesia and Ischemia

Local anesthetics are acid solutions: articain, the most-used molecule in oral surgery, has a pH of approximately 3.4. This explains the pain generated by the injection.

Because of this acidity, 97% of the cartridge is ionized. This fraction is non-active. Only the remaining non-ionized fraction (3%) is active for anesthesia.

After administration, the solution pH is buffered by the tissues, which are neutral.

Figure 2.3 Isotonic sodium bicarbonate 1.4%. pH= 10. Credits: E. CHOUKROUN/J. CHOUKROUN/M. PARNOT

When the pH increases, the ionization decreases and the non-ionized fraction becomes predominant and consequently the anesthesia deepens. This is the mandatory condition of the success of the anesthesia.

When the local environment is acid (e.g. infection, multiple extractions), the buffering by the tissues is lowered and hence the non-ionized fraction increases slightly. In these conditions, a deep anesthesia is difficult to achieve.

Repeated injections of anesthetics will cause more acidity and more vaso-constriction followed by ischemia, resulting an obvious oxidative stress. This could partially explain tissue necrosis after multiple injections.

The solution is to increase the local pH, by injecting an alkaline solution like isotonic sodium bicarbonate isotonic (1.4%) (Figure 2.3). This is a physiologic saline solution with bicarbonate, which pH is around 10. The volume of sodium bicarbonate injected should be the same as the anesthetics.

This is the simplest way to reach enough active fraction and a fast and deep anesthesia.

Surgery and Oxidative Stress

Origin of Inflammation

After the same type of surgery, patients swell differently. This variable inflammatory response has not yet been explained, but often allocated to the invasivity.

Inflammation is part of a very basic form of immune response: acute inflammation is a short-term inflammatory response to an insult to the body. The following edema is caused by an increased capillary permeability.

In reality, tissue inflammatory response is mainly coming from the contamination: patients breathe during the

surgery and instruments are in contact with saliva. Consequently, the surgery is mandatory contaminated.

This contamination was demonstrated by an early CT scan analysis one week after sinus augmentation. The presence of bubbles of gas is the testimony of an anaerobe bacteria contamination (Choukroun 2008).

The purpose is to use a small dose of pure metronidazole powder, mixed with the bone graft, in order to reduce its contamination when entering the oral cavity. This is a simple and efficient way to reduce inflammation and post-operative swelling.

This protocol is now largely used in all grafting procedures, not only the sinus augmentation.

Origin of ischemia

Preventing all situations of ischemia and favoring angiogenesis have to be constant aims. Several solutions can allow the surgeon to achieve those objectives.

Causes of Chronic Ischemia: Pressure and Tension

Every pressure on the extra cellular matrix slows the angiogenesis and leads to the loss of vascularization (Mammoto 2009). In other words, pressure kills blood supply and facilitates oxidative stress and tissue resorbtion.

Pressure can be translated into a positive force, or a so-called "mechanical pression", or a negative force: its tension.

From a clinical point of view, it is highly preferable to prevent those complications instead of treating them afterward.

Tension

Tension is known to be a major factor of post-operative failures.

Each buccal flap raised becomes mobile and potentially movable by the muscles (talking, yawning, smiling, coughing...). It will suffer from a permanent tension, generating ischemia and periosteum re-attachment will be upset.

In order to reduce the flap mobility at its maximum, a deep horizontal mattress called the "apical mattress" can be performed, at least 1–1.5cm from the edge (Figure 2.4).

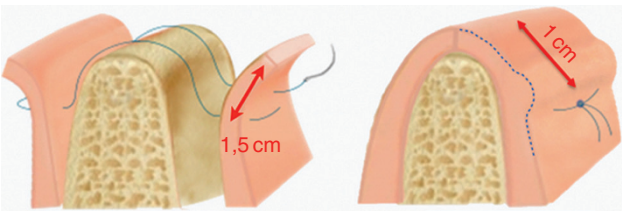

Figure 2.4 Apical mattress suture technique (horizontal). Credits: E. CHOUKROUN/J. CHOUKROUN/M. PARNOT

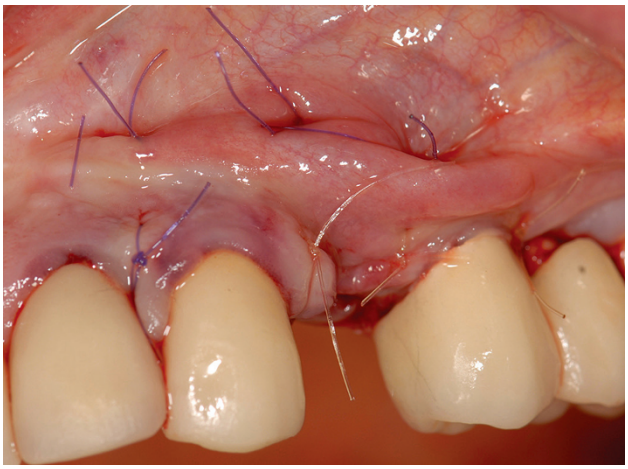

Figure 2.5 Apical mattress suture: after the suture, the gum bead is the proof of zero tension. Credits: E. CHOUKROUN/J. CHOUKROUN/M. PARNOT

Then a continuous or discontinuous sutures will be used for the edges.

After suturing, the apparition of a gum bead will be the evidence of a proper tension free flap closure (Figure 2.5).

Pressure

After a bone augmentation, the flap applies a continuous pressure on the bone underneath, which may lead to a delayed vascularization.

To prevent it, every technique protecting the particular graft from the flap pressure must be used: screw-tenting, titanium mesh, titanium membrane, cortical bone plate.

The position of mesh or screws will decide the final volume of the graft: pressure of the flap stops at their level.

Flap Release and Periosteum Integrity: Proposition of the Soft Brushing Technique

Periosteal incisions are essential for the lengthening of the flap in bone augmentations.

They are made on the periosteum fibrous layer. Its stiffness comes from aggregation of collagen fibers by elastin and proteoglycans.

Instead of incising the periosteum, often an hemorrhagic and ischemic gesture, a new technique has been suggested: the *soft brushing*, where the periosteum is gently brushed with specific tools (Choukroun 2017) (Figure 2.6). This technique permits a separation of collagen fibers, and so, the release of the flap, up to 1–2 cm (Figure 2.7).

Obviously, like every technique, there are exceptions and limits to the *soft brushing*, like multi operated/scar type tissues. In those cases, periosteum needs a micro incision to have a fully efficient soft brushing.

Figure 2.6 Soft brushing instruments kit. Credits: E. CHOUKROUN/J. CHOUKROUN/M. PARNOT

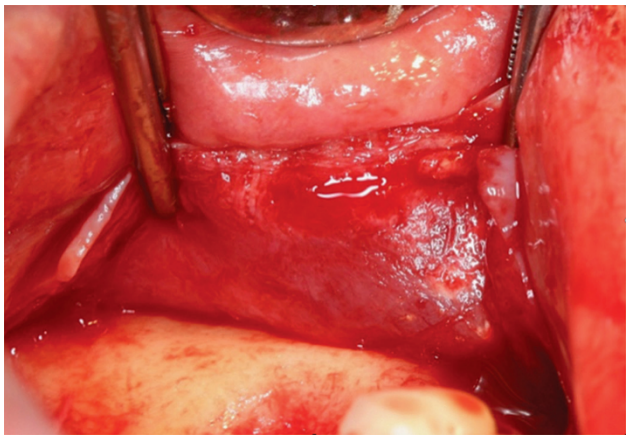

Figure 2.7 Buccal flap with intact periosteum after soft brushing. Credits: E. CHOUKROUN/J. CHOUKROUN/M. PARNOT

Bone Healing After Implant Placement

Implants are placed in native or grafted bone. In case of tissue damage, inflammation and/or infection may secondarily develop and results in peri-implantitis. Approximately 30% of patients with implants develop peri-implantitis, a major reason for implant failure (Berglundh 2002).

No evidence was found that primary infection caused marginal bone resorbtion (Albrektsson 2012).

These complications have given rise to numerous theories, such as biomaterials resorbtion, inadequacy of protocols or the influence of a concomitant periodontal disease.

In fact, mechanisms are simple: the fundamentals of physiology and bone anatomy could explain the reasons of this acute or long-term failure...

Anatomy

The bones of the face are flat plates, from membraneous differentiation. They are made of trabecular bone, surrounded by cortical bone (Figure 2.8).

Vascularization comes from the periosteum, through Volkmann canals, which participate in the organization of the vascular network between osteons (Figure 2.9). Vessels pass through the entire cortex to connect to the spongy tissue vascular network (Figure 2.10).

- The cancellous bone is composed of trabeculae (size about 50 microns). They are made of lamellar bone: very resistant (as much as cortical bone) and composed of collagen fibers, which are oriented following the affected forces. Between the trabeculae, bone marrow and vessels are found.
- Cortical bone is made up of joined osteons: a rigid structure, with vessels in the center. Osteocytes are enclosed in their cavity and communicate with each other through the canaliculi. Inside these canaliculi, transmission of stress is operated by the fluid (Figure 2.11).

Physiology

Bone physiology is well known: bone is in constant remodeling. This is essentially a cellular phenomenon (involving osteoblasts, osteoclasts and osteocytes), influenced by physical activity. Bone tissue needs a minimum of activity to maintain itself (Rieger 2011). If not, it will resorb. Likewise, if the stress is excessive, the balance between apposition and resorption becomes deficient, also resulting in bone loss.

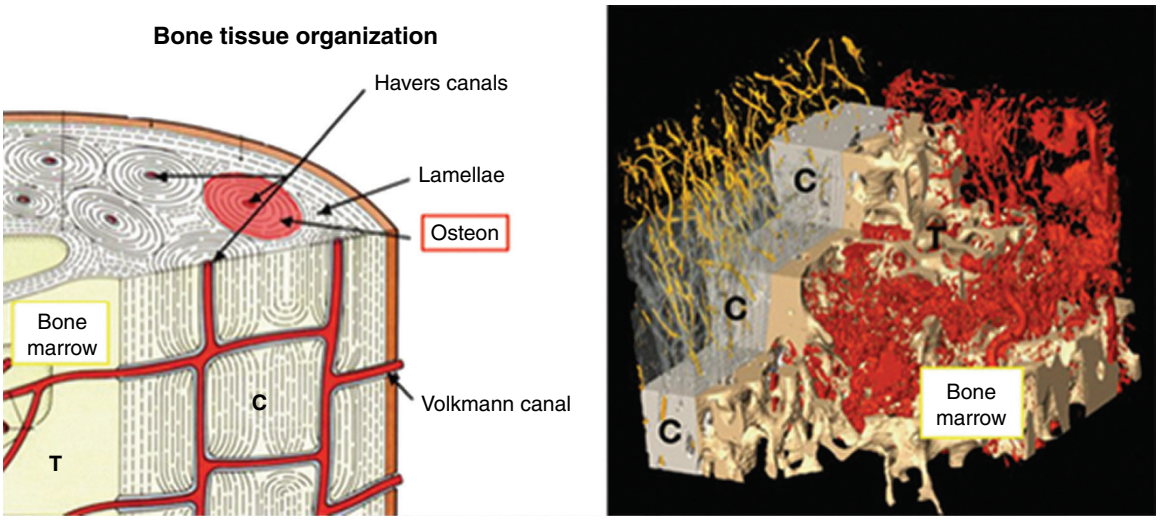

Figure 2.8 Bone organization: trabecular (T) and cortical bone (C) & Micro-CT vascular network. Credits: E. CHOUKROUN/J. CHOUKROUN/M. PARNOT

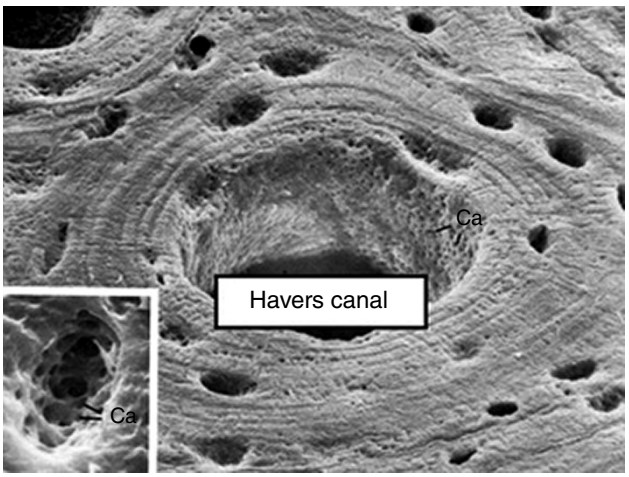

Figure 2.9 Osteon and Havers canal in electronic microscopy. Credits: E. CHOUKROUN/J. CHOUKROUN/M. PARNOT

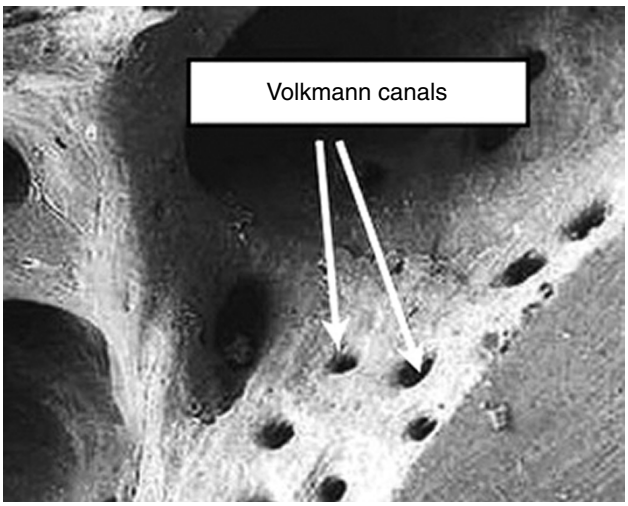

Figure 2.10 Volkman Canals: emergence of vessels coming from the periosteum to the spongiosa. Credits: E. CHOUKROUN/J. CHOUKROUN/M. PARNOT

The stress applied on the bone tissue will be transmitted to the osteocytes through the fluids contained in the bone canaliculi and bone marrow

However, the remodeling of the grafted bone is not so well clarified.

About bone resistance: Cortical bone, although strong as trabecular bone, has little space to absorb pressure. It will therefore be very sensitive to excessive stress.

Vascularization is a crucial element for the formation or survival of bone tissue. During rehabilitation, the number of new vessels will determine the volume of new formed bone (Udagawa et al. 2013). Any excessive pressure on this tissue in formation, or already formed, will lead to ischemia and oxidative stress followed by a more or less rapid resorbtion.

What is the Nature of the Grafted Bone?

A careful histological study provides a better understanding of the nature of the new formed bone. It shows a trabecular type, but its structure and organization are totally different: the trabeculae are wider than normal (reminder: 50 microns) and are stuck to the biomaterial granules: forming a compact magma. In the following histological sections, arrows show the intimate contact between biomaterial granules and the de novo bone (Figures 2.12–20).

This architecture results in a significant stiffness with a reduced flexibility.

Moreover, vessels don't follow the classic pattern of cortical delivery: the network is disorganized (Figure 2.21).

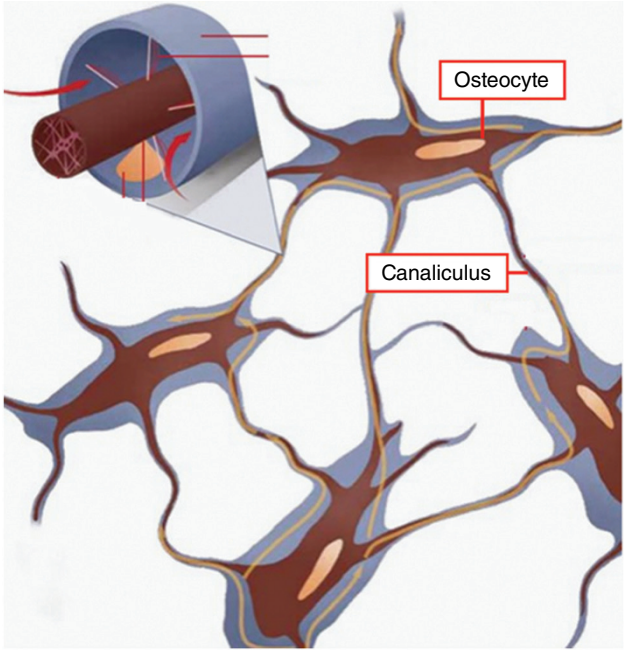

Figure 2.11 Osteocytes linked together through canalicules containing interstitial fluids. Credits: E. CHOUKROUN/J. CHOUKROUN/M. PARNOT

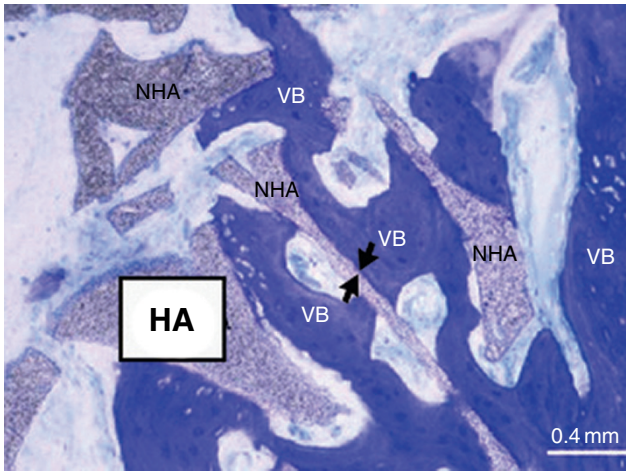

Figure 2.12 Histology after bone graft with hydroxyapatite synthetic biomaterial. Credits: E. CHOUKROUN/J. CHOUKROUN/M. PARNOT

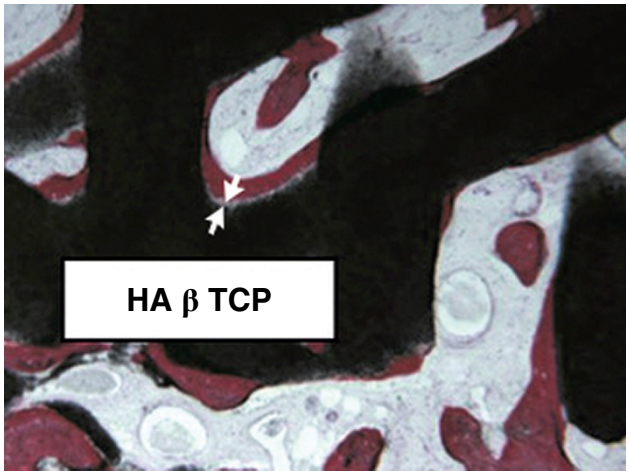

Figure 2.13 Histology after graft with hydroxyapatite and β-TCP. Credits: E. CHOUKROUN/J. CHOUKROUN/M. PARNOT

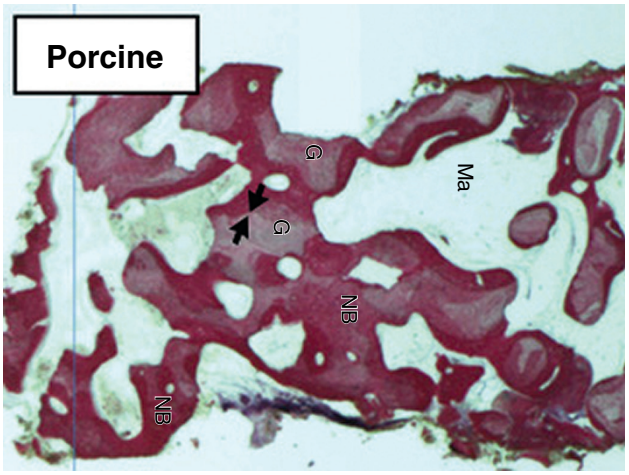

Figure 2.14 Histology after graft with porcine xenograft. Credits: E. CHOUKROUN/J. CHOUKROUN/M. PARNOT

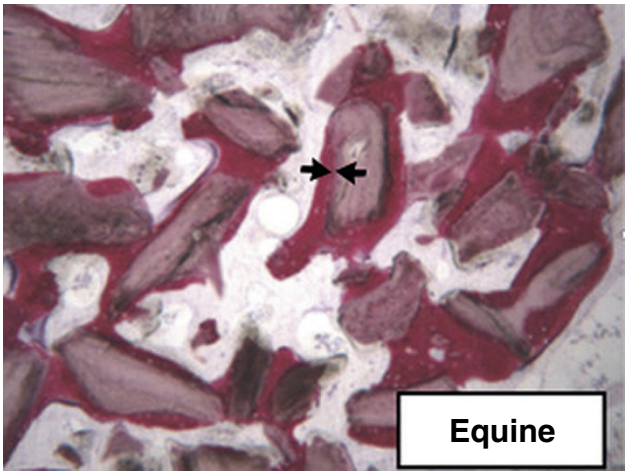

Figure 2.15 Histology after graft with equine xenograft. Credits: E. CHOUKROUN/J. CHOUKROUN/M. PARNOT

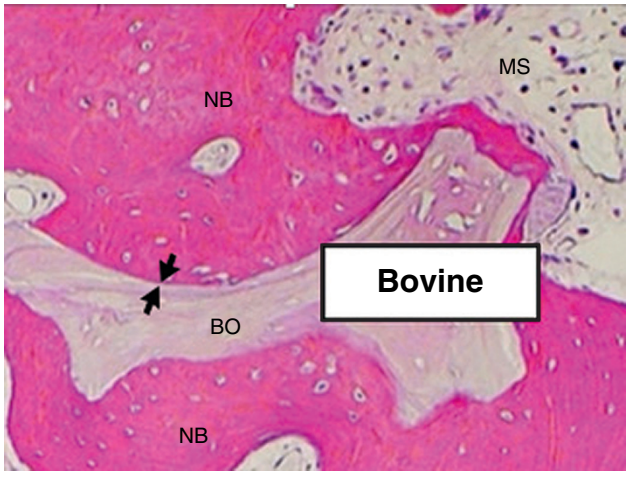

Figure 2.16 Histology after graft with bovine xenograft. Credits: E. CHOUKROUN/J. CHOUKROUN/M. PARNOT

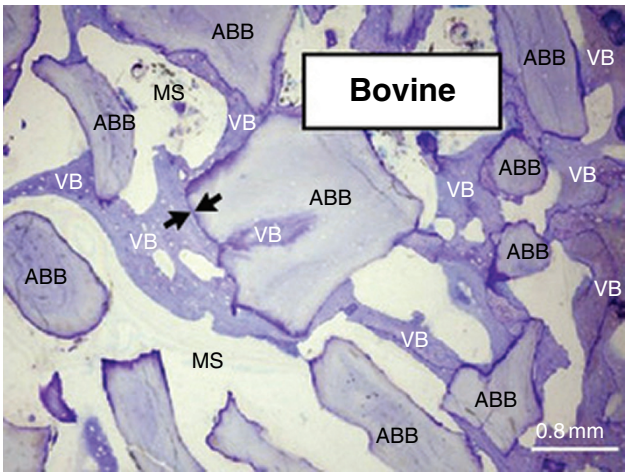

Figure 2.17 Histology after graft with bovine xenograft. Credits: E. CHOUKROUN/J. CHOUKROUN/M. PARNOT

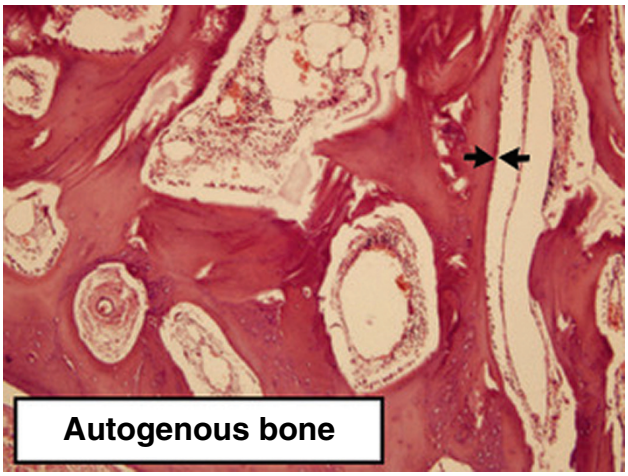

Figure 2.20 Histology after autogenous bone graft. Credits: E. CHOUKROUN/J. CHOUKROUN/M. PARNOT

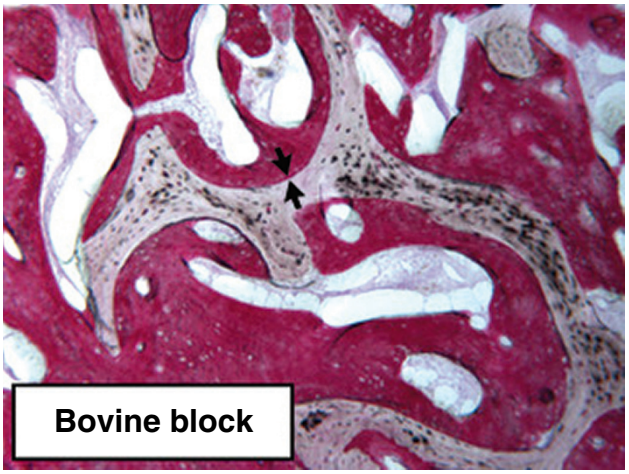

Figure 2.18 Histology after graft with bovine bloc xenograft. Credits: E. CHOUKROUN/J. CHOUKROUN/M. PARNOT

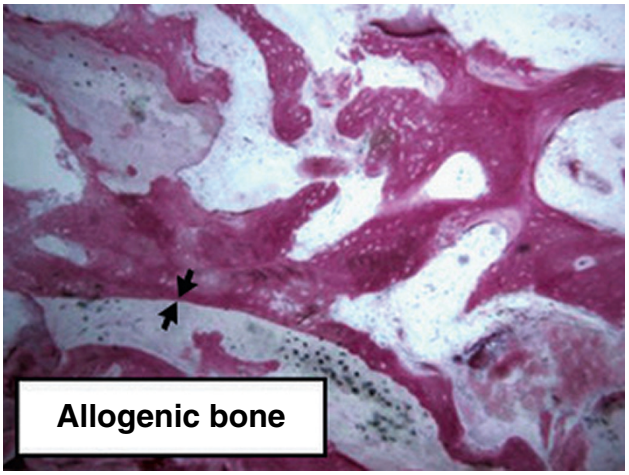

Figure 2.19 Histology after graft with allogenic biomaterial. Credits: E. CHOUKROUN/J. CHOUKROUN/M. PARNOT

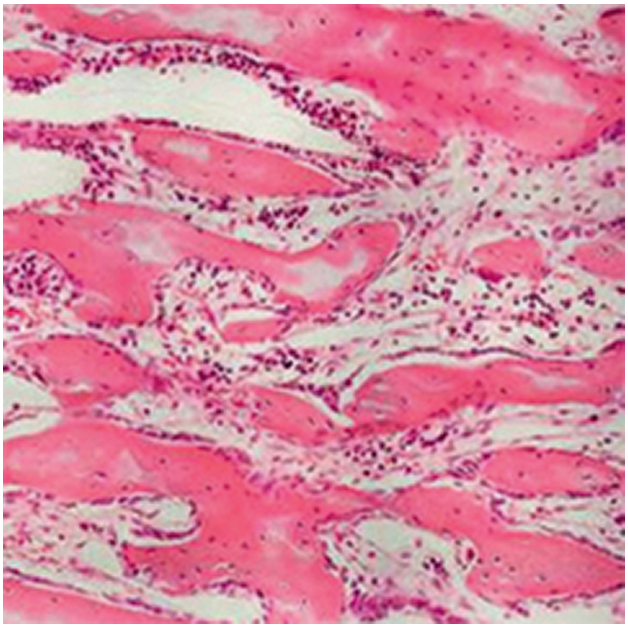

Figure 2.21 Histology of a native trabecular bone. Credits: E. CHOUKROUN/J. CHOUKROUN/M. PARNOT

Without using biomaterials, with only the blood clot, the regenerated bone is different: in a study of sinus lifts, with a bone plate in apical position, Scarano et al. (2018) showed a normal trabecular structure (Figure 2.22).

Likewise, when the socket is filled with only PRF, the new formed bone is a physiological trabecular bone (Figure 2.23).

We may conclude that the non-use of biomaterial particles, autogenous or exogenous, is the only situation that allows the ad-integrum regeneration of trabecular bone.

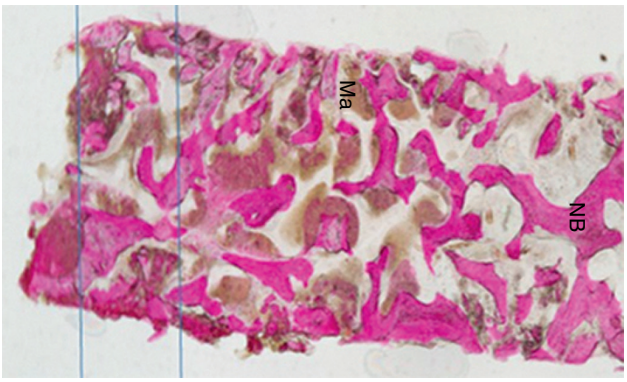

Figure 2.22 Histology after sinus lift (cortical plate apically positioned): no biomaterials, blood clot only. The trabecular bone has a normal aspect. Credits: E. CHOUKROUN/J. CHOUKROUN/M. PARNOT

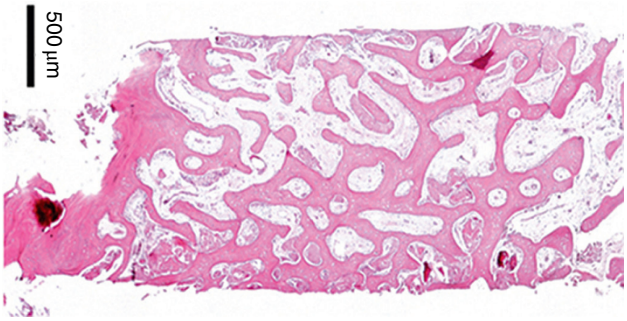

Figure 2.23 Histology after socket management with PRF alone: normal trabeculations and physiological aspect of the new bone. Credits: E. CHOUKROUN/J. CHOUKROUN/M. PARNOT

Bone Behavior After Implant Placement

All studies on bone behavior under mechanical stress are performed with cyclic stimulations (such as walking). On the opposite, a screwed implant will exert a non-physiologic and permanent stress on the bone (Figure 2.24). This situation will have a negative influence on bone remodeling.

- In native bone, the implant should be placed within the trabecular bone, maxillary or mandibular.
- Primary stability is achieved by using a torque of a certain value, absorbed by the spaces in the trabecular bone or fractures of trabeculae. This bone trauma is beneficial and will lead to an appropriate healing reaction.

  If the implant is in contact with the crestal or buccal cortical bone then it'll induce first bone ischemia by closing the Volkmann canals and also a constant pressure on the cortical bone with a disturbed remodeling and oxidative stress (Figure 2.25).

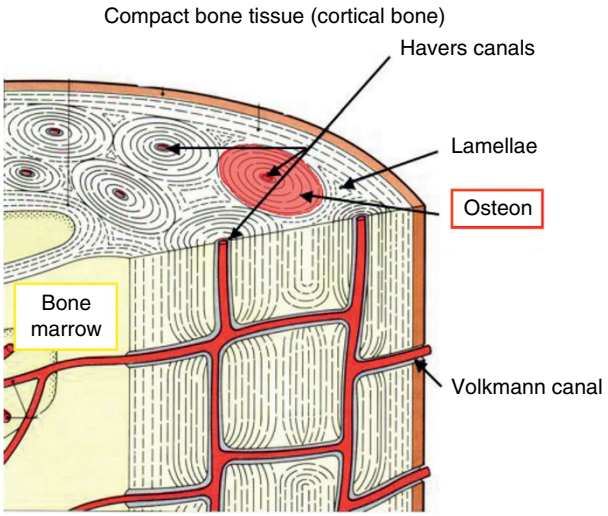

Figure 2.24 Behavior of materials under stress. When rigidity increases, the stress is higher. Above a certain value, the material reaches its breaking point. Credits: E. CHOUKROUN/J. CHOUKROUN/M. PARNOT

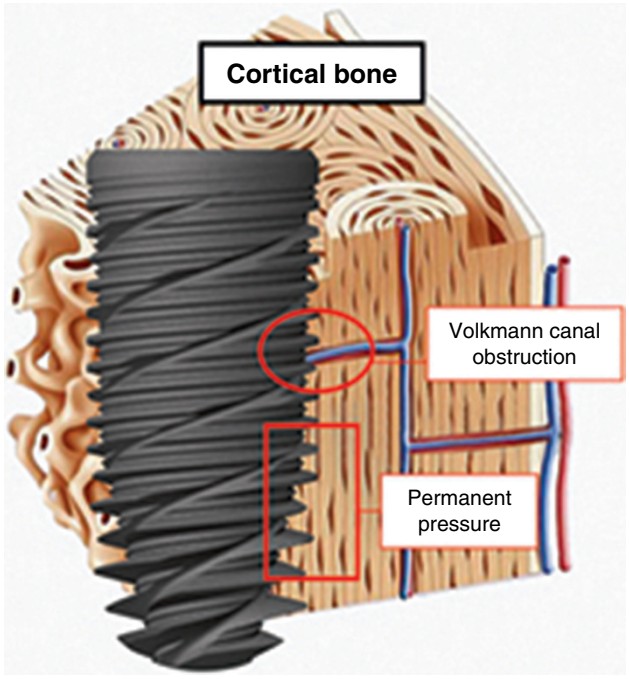

Figure 2.25 Bone remodeling decreases when implants are placed in contact with cortical bone: excessive stress and blood supply loss by Volkmann canals obstruction. Credits: E. CHOUKROUN/J. CHOUKROUN/M. PARNOT

- In bone grafted area, as mentioned earlier, the histological structure of the grafted bone is a compact type... This gives it a higher stiffness, close to cortical bone one. The vascular structure, even if important, is different from the physiologic periosteum supply.

So, when drilling a dense bone, the following implant placement should be careful: the torque must be reduced in order to do not stress too much the grafted bone.

Placing the implant with an usual torque (35 N/cm^2) will be an unwise protocol, causing excessive trauma. Therefore, immediate loading of implants in a grafted bone is not recommended.

Significant bleeding is interpreted as a sign of good vitality. This simply reflects a large number of vessels cut by the drill. These vessels will be blocked by the implant followed by an oxidative stress. The more the bone bleeds, the more delicate the implant placement should be.

In conclusion, in order to reduce ischemia and oxidative stress, implants must be placed without contact with the bone cortex:

- In the crestal cortical bone, overdrilling and/or subcrestal placement will be preferred. The space created will quickly be filled with a de-novo bone of excellent quality.
- In a grafted bone, contact is inevitable. Therefore, it will be as non-aggressive as possible, with a reduced torque. As much as possible.

Several cases of peri-implantitis could be explained by this mechanism: the bone resorbs because the remodeling has deteriorated..!

Biomaterial Choice and its Effect on Oxidative Stress

Collagen is a favorable factor to new-vessels growth. It is the main component of the extra cellular matrix, and offers a mechanical and proteinic support to the vessel' development (Markowicz 2005, Senger and Davis 2011, Shamloo et al. 2012). The biomaterial has to be chosen depending on its collagen content.

Only non-fritted human bone keeps its native collagen. Human bone can be autogenous (60% of collagen) or allogenic (90%). This difference can be explained by the preparation technique of allogenic bone: lipids are cleared, proteins and collagen remain intact and their final concentration increases.

Human bone should be the first choice. Moreover, it has the best antigenic compatibility and promotes angiogenesis, a way to reduce oxidative stress during the first hours and days of the graft (as it is not yet well vascularized).

However, human bone (autogenous or allogenic) faces a volume loss because of its fast resorption. Consequently, it is advised to add a slowly resorbable biomaterial (cortical allogenic bone or xenograft).

If human bone is not used, following the compatibility ranking, the best xenogeneic material is porcine (in medicine, cardiac valves are only from porcine origin.)

Wound Healing, Growth Factors and Oxidative Stress

Wound healing is a complex biological process that includes the active participation of numerous cell types, an extracellular matrix and soluble factors. By nature, these normal healing events take place in response to normal tissue injury involving a cascade of complex, orderly and elaborate events (Guo and Dipietro 2010). Numerous studies have already demonstrated that the delivery of multiple growth factors in a well-controlled manner can enhance bone formation (Gosain and DiPietro 2004, Eming et al. 2007a, 2007b). Generally, wound healing is divided into four overlapping phases, which are hemostasis, inflammation, proliferation and remodeling. One of the key players during these phases are platelets, which are important regulators of hemostasis through vascular and fibrin clot formation. Ongoing studies over the past decades have revealed platelets as the responsible cells for the activation and release of important biomolecules including platelet-specific proteins, growth factors, coagulation factors, adhesion molecules, cytokines/chemokines and angiogenic factors, which are capable of stimulating the proliferation and activation of cells involved in wound healing (fibroblasts, neutrophils, macrophages and mesenchymal stem cells (MSCs)) (Nurden 2011). For these reasons, it was proposed in the 1990s that platelet concentrates could be utilized and centrifuged to reach supraphysiological doses, to achieve wound healing and tissue regeneration by facilitating angiogenesis. While numerous studies have previously demonstrated that the delivery of multiple growth factors can enhance new tissue formation, it has since been shown that more importantly blood vessel formation is tightly coupled with tissue regeneration. The ideal scenario for tissue regrowth is to deliver a multitude of growth factors to induce angiogenesis and tissue regeneration simultaneously. As an interesting property, growth factors by the induction of vasculogenesis facilitate the production of antioxidants.

Brief History of Platelet Concentrates

Only quite recently, platelets concentrates have become popular and widely used in dentistry and surgery, especially with the invention of platelet-rich fibrin (PRF). Their main use is to promote local healing and wound closure (de Vries et al. 1993, Anfossi et al. 1989, Fijnheer et al. 1990).

PRP and PRF

Platelet-rich plasma (PRP) was the first platelet concentrate to be introduced in oral surgery.

However, the use of anticoagulants limited the action and power of growth factors and thus a new generation of platelet concentrate was later developed by Dr Joseph Choukroun in the early 2000s: Platelet-rich fibrin (PRF), without any anticoagulation factors or additives (Choukroun et al. 2001).

Drawn blood tubes were centrifugated at 2700 rpm (700g) for 12 minutes and the supernatant fibrin gel (fibrin clot) could be used in surgery (Choukroun et al. 2006, Dohan et al. 2006a, 2006b, 2006c). PRF (also named L-PRF for leukocyte-PRF) contains white blood cells, necessary for wound healing, immunity and the secretion of growth factors (Martin and Leibovich 2005, Tsirogianni et al. 2006, Adamson 2009, Davis et al. 2014a, 2014b).

Platelets, neutrophils and white blood cells are the main cells found in PRF, and they give them the healing properties and enhance angiogenesis and so bone formation (Choukroun et al. 2006, Dohan et al. 2006a, 2006b, 2006c, Adamson 2009).

Indeed, three components are needed to improve tissue repair and healing, which are a 3D matrix, cells and active growth factors.

All three are found in PRF and contribute to its powerful action on tissue healing:

- Fibrin acts as a bioactive scaffold.
- Platelets, neutrophils, macrophages and white blood cells attract others cells on site.

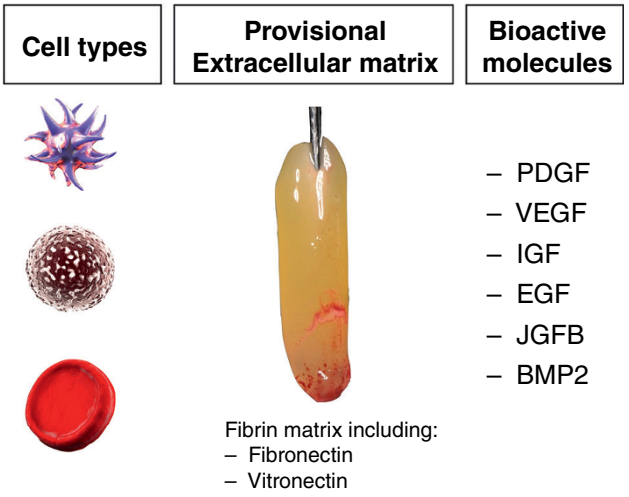

Figure 2.26 Components of PRF: cells types and bioactive molecules Credits: E. CHOUKROUN/J. CHOUKROUN/M.PARNOT

- Fibrin is a reservoir of growth factors, which is slowly released on site (until 14 days).

Major Types of Cells in PRF

Platelets

Platelets are the common denominator of most platelet concentrate including PRF and PRF. They are parts of the main cells found in PRF and are found in the fibrin clot, which is slowly released on site with growth factors (Ghasemzadeh and Hosseini 2015). Recent researches demonstrate that blood alone can radically improve angiogenesis and tissue repair alone (Barbeck et al. 2015).

Platelets are continually produced in the bone marrow and last between 8 and 10 days. Once activated, they release their cytoplasm granules to initiate the coagulation process (Weibrich et al. 2001, 2003).

Leucocytes

Leucocytes are at the center of tissue regeneration cascade and immunity (Davis et al. 2014a, Ghasemzadeh and Hosseini 2015). They also release growth factors on site (Kawazoe and Kim 2012, Perut et al. 2013, Pirraco et al. 2013).

Platelet-Rich Fibrin (PRF): A Fibrin Matrix

Due to the absence of anticoagulants in PRF, a majority of platelets are activated in a few minutes and initiate the coagulation process.

Fibrinogen is a plasmatic, soluble molecule found in high quantity in both plasma and platelets.

After activation by thrombin, fibrinogen is transformed into fibrin, which is an insoluble gel.

Fibrin is the first matrix to be obtain in an injured site, and it will act as a provisional matrix for further cells migration (Miron and Bosshardt 2016, Mosesson et al. 2001, Chase and Newby 2003, Mazzucco et al. 2010, Nguyen et al. 2012).

In drawing tubes, the fibrin clot is located in the middle, under the acellular plasma (PPP) and above the red corpuscles (Figure 2.27).

Cytokines

Cytokines, of which the growth factors are a part, are released after clotting through specific cell receptors. Among the most important growth factors, we can find:

TGFb-1: Transforming growth factor b1 (TGFb1) is a part of a large group of more 30 fibrosis agents (Border and Noble 1994, Bowen et al. 2013). The most important molecule of this family is TGFb-1 (Bowen et al. 2013), which is the major inductor of type 1 collagen and fibronectin synthesis, adhesive proteins of the matrix. TGFb-1 is also an inflammation regulator.

- **PDGF:** Platelet-derived growth factors (PDGFs) are in charge of stimulation, migration, proliferation and survival of the families of mesenchymal cells. They are recovered in high amount in PRF fibrin clots.
- **VEGF:** Vascular endothelial growth factor (VEGF) is a key factor in angiogenesis mechanisms. It is known to increase bone formation through neovascularization (Shamloo et al. 2012).
- **IGF family:** Insulin-like growth factors (IGFs) I and II are involved in the proliferation and differentiation of numerous cells (Giannobile et al. 1996). IGFs also influence cell regulation and apoptosis.

The Low-Speed Concept

A-PRF: Advanced Platelet-Rich Fibrin

The number of growth factors was for a long time the top criterion of platelet concentrates.

Their survival and their release on site were later identified as the real important factor.

The impact and benefits of PRF have been investigated in various fields of medicine and clinical situations. Studies demonstrated that most useful cells in tissue healing were founded at the bottom of PRF fibrin clots (Weibrich et al. 2001). Centrifugation settings (speed and duration) were found to influence the amount of cells in PRF.

Indeed, high-speed spinning actually pushes cells at the bottom of drawing tubes, outside the fibrin clot.

Dr Joseph Choukroun and Dr Shahram Ghanaati confirmed by their study that a high G force was deleterious for cells and was driving them downward the tubes, in the red corpuscles.

The spinning speed has been decreased from 2700 rpm (700g) to 1300 rpm (200g).

A higher number of leucocytes, monocytes and growth factors were found inside the fibrin with this new RPM (rotation per minute) (Weibrich et al. 2001). This kind of PRF was named advanced PRF or A-PRF, compared with the first generation of PRF or L-PRF (Ghanaati et al. 2014, Choukroun and Ghanaati 2018, El Bagdadi et al. 2017, Lekovic et al. 2012, Panda et al. 2014, Pradeep et al. 2012, Sharma and Pradeep 2011, Kumar and Shubhashini 2013) and the concept took the name of low-speed centrifugation concept (LSCC).

Other tests have been performed with a decreased RPM and a lower duration of centrifugation. This protocol is named A-PRF (advanced PRF) (Ghanaati et al. 2014).

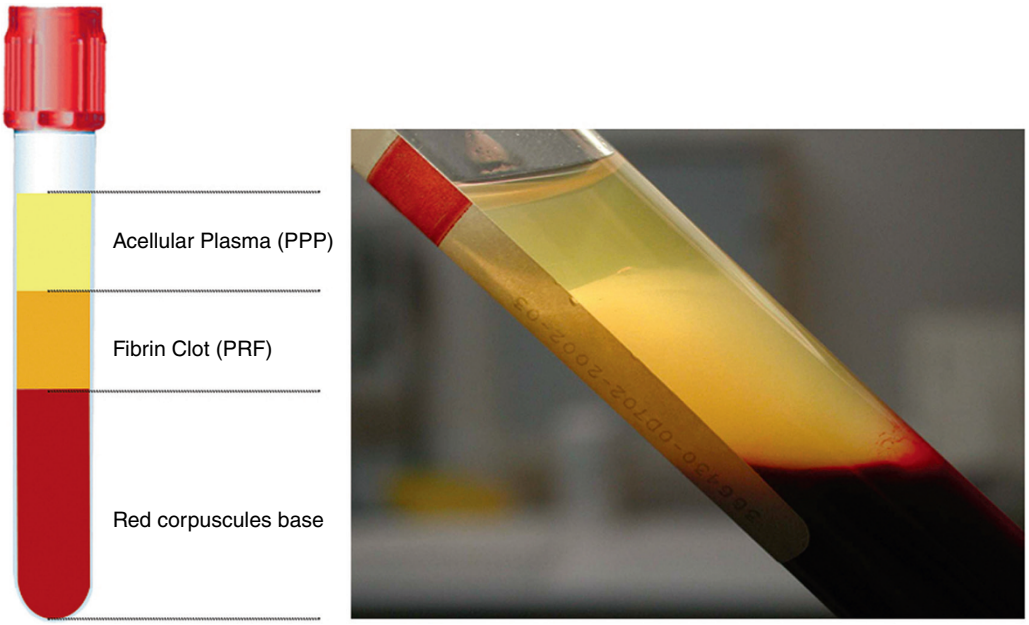

Figure 2.27 Fibrin clot in the tube after centrifugation. Credits: E. CHOUKROUN/J. CHOUKROUN/M.PARNOT

Results have shown increased number of leucocytes and growth factors, which are the crucial elements for bone regeneration (Soltan et al. 2012), and they have also shown a higher collagen production of gingival fibroblasts, in comparison with PRP or L-PRF.

i-PRF: Injectable Platelet-Rich Fibrin

By pushing the low-speed centrifugation concept further, the authors found that lowering even more the speed and time of centrifugation could provide a liquid form of PRF.

The protocol is following 700 RPM (60g) and 3 minutes of spinning.

It was named i-PRF (injectable PRF). A number of cells are available with this type of PRF.

The injectable version can be used to decrease local inflammation but it can also be used in TMJ injection (Albilia et al. 2018), regenerative medicine, orthopedics and facial aesthetics.

Its regenerative and angiogenic properties make it one of the most promising product of modern medicine.

Clinical Use of PRF and Indications

For the past 20 years, clinical uses of PRF have been extended in both dentistry and medicine.

Its fast and easy handling have made it an ally also in oral surgery, from bone grafts to the management of soft tissues. Most popular procedures using PRF are socket filling (Sammartino et al. 2011, Suttapreyasri and Leepong 2013, Yelamali and Saikrishna 2015), gingival recessions (Anilkumar et al. 2009, Jankovic et al. 2012, Eren et al. 2015), palatal wound closure (Jain et al. 2012, Kulkarni et al. 2014, Femminella et al. 2016), repair of potentially malignant lesions (Pathak et al. 2015), regeneration of periodontal defects (Ajwani et al. 2015), hyperplastic gingival tissues (di Lauro et al. 2015) and periodontally accelerated osteogenic orthodontics (Munoz et al. 2016).

PRF is mainly mentioned in the literature under its membrane or plug shape.

PRF clots can be flattened in membranes or compressed into plugs using the PRF metallic box.

Systematic reviews showed that 86% of articles came to the conclusion that PRF enhanced tissue healing and regeneration (Miron et al. 2017a, 2017b).

Other fields of medicine have utilized PRF to enhance tissue repair and patient healing.

PRF can be used in various procedures such as ulcers treatments (on diabetic foot, hand ulcers, venous leg ulcers and chronic leg ulcers) (Danielsen et al. 2008, O'Connell et al. 2008, Steenvoorde et al. 2008, Jorgensen et al. 2011, Londahl et al. 2015, Chignon-Sicard et al. 2012). PRF is also used in facial soft tissue defects (Desai et al. 2013), laparoscopic cholecystectomy (Danielsen et al. 2010), dermatology (Sclafani 2011), induction of dermal collagenesis (Sclafani and McCormick 2012), vaginal prolapse repair (Gorlero et al. 2012), urethracutaneous fistula repair (Guinot et al. 2014), lipostructure surgical procedures (Braccini et al. 2013), chronic rotator cuff tears (Zumstein et al. 2014) and acute traumatic ear drum perforations (Habesoglu et al. 2014).

Socket Preservation

The use of PRF in extraction sockets is one of the most popular and published applications of PRF in dentistry

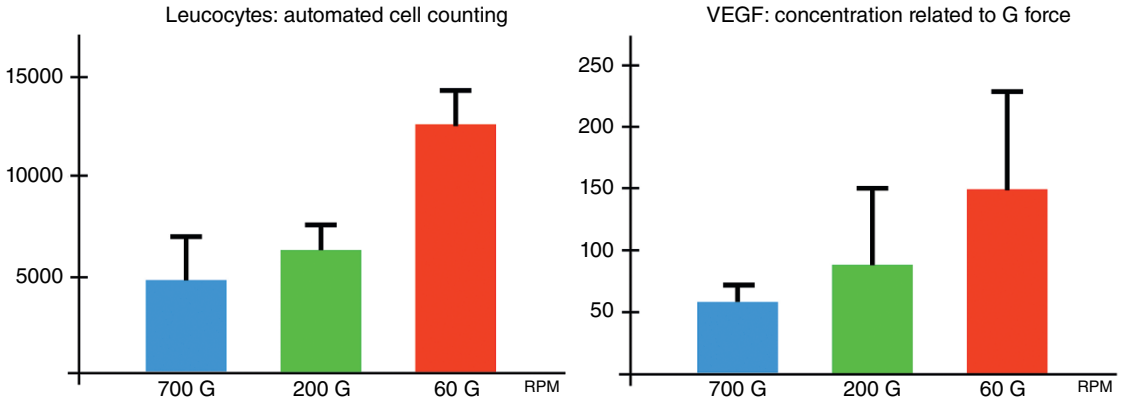

Figure 2.28 Higher number of leucocytes and VEGF found in PRF centrifuged at lower g-forces. Credits: E. CHOUKROUN/J. CHOUKROUN/M.PARNOT

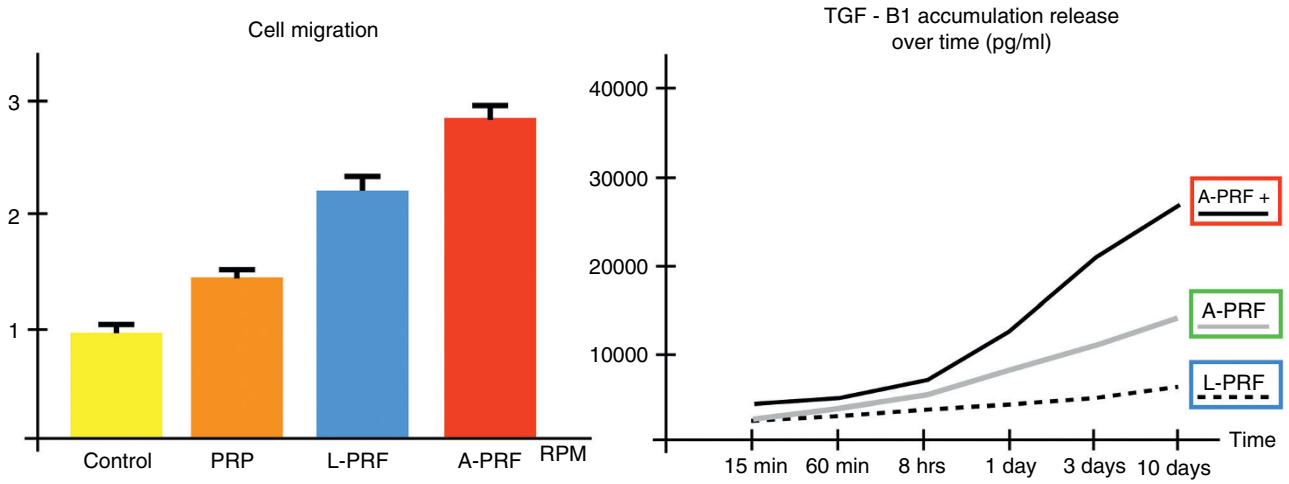

Figure 2.29 Higher number of gingival fibroblast cell migration from A-PRF when compared to PRF and PRP as well as higher growth factor released from the slow speed concept. Credits. Kobayashi et al. «Optimized platelet-rich fibrin with the low speed concept: growth factor release, biocompatibility and cellular response » J Periodontol 2017; 88: 112–121

(Sammartino et al. 2011, Zumstein et al. 2014, Hauser et al. 2013). As PRF is a natural and physiologic matrix, clinicians can easily and quickly regenerate bone in extraction sites. This way, biomaterials and collagen membranes can be replaced by PRF plugs only, to perform a physiological and enhanced healing. Protocols are cost effective and simplified as PRF just need to be sutured to be held in place but can remain exposed in the oral cavity.

In about 10 days, fibrin is transformed in both bone matrix in the socket and soft tissue at the surface.

This type of procedure also decreases the risks of infection, dry socket and post-operative pain (Sammartino et al. 2011, Girish Rao et al. 2013, Hauser et al. 2013).

After 3 months, a de-novo bone is regenerated and can be used for implant placement.

Sinus Lift

With the same concept of socket filling, PRF can be used in sinus lift surgeries.

Used alone or combined with bone grafts, PRF speeds up vascularization and thus bone formation.

Numerous studies have shown that PRF alone, with the osseoinductive properties of the Schneiderian membrane and an immediate implant placement, can be sufficient to perform sinus bone formation (Tajima et al. 2013, Mazor et al. 2009, Simonpieri et al. 2011).

PRF membranes can also be utilized to repair Schneiderian membrane perforations or to close the maxillary window during lateral sinus lifting procedures.

Figure 2.30 The newer formulation of i-PRF is a liquid formulation of PRF found in the top 1-ml layer of centrifugation tubes following a 700-rpm spin for 3 minutes. This liquid can be collected in a syringe and re-injected into defect sites or mixed with biomaterials to improve their bioactive properties. Credits: E. CHOUKROUN/J. CHOUKROUN/M.PARNOT

Soft Tissue Management

Periodontological issues and more specifically gingival recessions can be treated with PRF.

Numerous clinical studies report Miller Class I and II recessions treatment with only PRF membranes, replacing connective tissue grafts (Anilkumar et al. 2009, Agarwal et al. 2016, Aleksic et al. 2010, Aroca et al. 2009, Dogan et al. 2015, Eren and Atilla 2014, Gupta et al. 2015, Jankovic et al. 2010, Keceli et al. 2015, Padma et al. 2013, Rajaram et al. 2015, Thamaraiselvan et al. 2015, Tunaliota et al. 2015). Advantages of this technique are first to avoid palatal harvest and the following morbidity, especially in multiple sites treatment. Root coverage results are similar compared to connective tissue grafts but they do not significantly increase soft tissue thickness.

On the other hand, PRF cannot rebuild an absent tissue. Therefore, it cannot be used to replace keratinized tissue graft in case of lack of keratinized gingiva. In those situations, PRF can be combined to improve vascularization and accelerate the healing.

Intrabony Defects

Other fields of periodontology such as intrabony and furcation defects treatment can also benefit from PRF properties (Pathak et al. 2015, Agarwal et al. 2016, Elgendy and Abo Shady 2015, Joseph et al. 2014, Panda et al. 2016, Pradeep et al. 2015, Shah et al. 2015, Thorat et al. 2011, Pradeep et al. 2012, Chadwick et al. 2016). PRF can be used alone or associated with bone substitute to fill such defects (Sharma and Pradeep 2011). It has also been showed significant improvement in class II furcation defects (Bajaj et al. 2013, Pradeep et al. 2016).

Autologous Stem Cell-Bases Therapies

Mesenchymal stem cells may be isolated from various locations in the human body. Recently, it has been shown that low levels of mesenchymal stem cells also exist within peripheral blood. The LSCC concept, using a very low speed (60g) permits to retrieve a certain amount of MSCs. This technique, comparing to the lab culture and growth, is simpler and with a reduced cost (Di Liddo et al. 2018).

New Indications of i-PRF Injection

In order to reduce the oxidative stress after the flap raising, a new protocol is proposed: i-PRF injection in the whole flap area, after local anesthesia and before mucosa incision.

The aim of this procedure is to initiate the healing process as soon as possible, instead of waiting for the end of the surgery and thus avoiding ischemia and oxidative stress. First results are promising, and immediate healing seems to be even quicker.

Sticky Bone Concept

When performing a GBR bone graft, several factors can slow down the osseointegration of biomaterials. Particles mobility, for example, is a major factor of oxidative stress and slows down the vascularization of the graft and therefore its integration.

The space between the granules is also often too wide. Indeed, the space must allow the growth of neo-vessels, which are only 5–7 μm wide. The space between the biomaterials granules must be reduced and also maintained.

To overcome these issues, our team developed a new kind of PRF, which is called S-PRF, for the preparation of StickyBone.

StickyBone is obtained by adding S-PRF to the biomaterial.

At the end of the centrifugation, the supernatant, still liquid (S-PRF), can be punctured and poured over the bone substitute. Its rapid coagulation will form a fibrin gel containing the bony particles. The compaction of both the fibrin gel and the biomaterial will provide a compact and dense graft. The whole bonded biomaterial becomes completely immobile by the action of the fibrin. The space between the granules is thus reduced. Fibrin, whose rapid vascular invasion properties have been demonstrated, will occupy all the empty spaces between the particles and promote angiogenesis.

This protocol has revolutionized all bone grafting procedures with biomaterials. The time taken for osseointegration has been reduced and the clinical handling of the particular grafts has been greatly facilitated, avoiding scattered particles in the surgical site.

PRF Conclusion

Since 2001, PRF efficiency is no longer to prove. Its use in regenerative medicine has now seen a huge increase in its use across many fields of medicine.

After more than 15 years of research and 850 publications in Medline, there continues to be growing evidence and support for its use. Future strategies are continuously