SECOND EDITION

Biological Mechanisms of Tooth Movement

Edited by

Vinod Krishnan

Ze'ev Davidovitch

WILEY Blackwell

Biological mechanisms of tooth movement

Edited by

Vinod Krishnan

and

Ze'ev Davidovitch

Second edition

WILEY Blackwell

Registered Office
John Wiley & Sons, Ltd, The Atrium, Southern Gate, Chichester, West Sussex, PO19 8SQ, UK

Editorial Offices
9600 Garsington Road, Oxford, OX4 2DQ, UK
The Atrium, Southern Gate, Chichester, West Sussex, PO19 8SQ, UK
1606 Golden Aspen Drive, Suites 103 and 104, Ames, Iowa 50010, USA

For details of our global editorial offices, for customer services and for information about how to apply for permission to reuse the copyright material in this book please see our website at www.wiley.com/wiley-blackwell

Library of Congress Cataloging-in-Publication Data

Biological mechanisms of tooth movement / editors, Vinod Krishnan and Ze'ev Davidovitch. – Second edition.
p. ; cm.
Includes bibliographical references and index.
ISBN 978-1-118-68887-8 (cloth)
I. Krishnan, Vinod, editor. II. Davidovitch, Ze'ev, editor.
[DNLM: 1. Tooth Movement. WU 400]
QP88.6
612.3′11–dc23

2014026268

A catalogue record for this book is available from the British Library.

Wiley also publishes its books in a variety of electronic formats. Some content that appears in print may not be available in electronic books.

Cover image: Left hand image: photograph by J. Haack. Right hand image: courtesy of Dr Young Guk Park, Kyung Hee University, South Korea.

Set in 9/11pt Minion by SPi Publisher Services, Pondicherry, India
Printed and bound in Singapore by Markono Print Media Pte Ltd

1 2015

My ever inspiring family, especially Ambili (my wife), who supported (and tolerated) me throughout this project.

All my teachers, colleagues and students, who made me think about the science behind orthodontic tooth movement.

Vinod Krishnan

My wife, Galia, for her enduring support, and my grandsons, Yaniv, Nitzan, and Nadav Levi, for enabling my computer to remain alive throughout the preparation of this volume.

Ze'ev Davidovitch

Dedication to Vincent DeAngelis

For relentless attention to cells, tissues and patients in orthodontic tooth movement

> *Although extensive investigations have been conducted to describe cellular changes associated with various biomechanical manipulations of teeth and exhaustive research efforts have been directed toward ascertaining the mode of cellular action, relatively little time has been devoted to determining the transducing mechanism by which the biomechanical stimulus is converted to a cellular response. It is in this particular direction that future investigations in tissue changes associated with orthodontic tooth movement should be directed . . .*
>
> Vincent DeAngelis, 1970

Many reasons justify our dedication of this book to Vincent De Angelis. He has devoted his life to promoting "physiologic" tooth movement. As a resident with the legendary educator Coenraad CFA Moorrees at the Forsyth Dental Center/Harvard orthodontic program, he researched the biology of tooth movement in rats. Having previously conducted an autoradiographic investigation of calvarial growth in normal and rachitic rats, he suspected that the alterations within alveolar bone induced by orthodontic forces were analogous to changes within membranous bones of the calvarium induced by intracranial forces (DeAngelis, 1970). He used a model of separation of maxillary incisors that also indicated, through autoradiography, cell changes within the adaptive midpalatal suture. This leading biologic knowledge imprinted DeAngelis's clinical thought and strategy.

Later, as clinical instructor and admired professor in the same program, he developed the "Amalgamated" technique, (DeAngelis, 1976; 1980) combining the "best" of the edgewise and the Begg techniques, to provide light forces, and avoid the unnecessary side effects of "round tripping" teeth and root resorption. In this creative and scientific scheme, De Angelis demonstrated the essence of orthodontic tooth movement, which is to emulate physiologic tooth movement as much as possible in an individualized and controlled plan, rather than via a generic recipe of treatment.

Through this approach, those of us who were his residents rightly (and at times mistakenly) saw orthodontics as a simple undertaking, provided by a master clinician who had treated many thousands of patients. His teaching colleagues sought his "second opinion." In reality, what his "seemless" orthodontics reflected was an amalgamation of sound scientific principles and practical mechanics (DeAngelis, 2010a). This dual approach is reflected in the dilemma he has been presenting to his students: "Do you want root apices and intact paradental tissues at the end of treatment, or ideal occlusion? The discerning clinician should demand both." (DeAngelis, 2010b). This outlook threads across his published articles, chapters, worldwide presentations, and frequent letters to the editor.

Vincent DeAngelis is a principled straight shooter in his orthodontic method. He came from Massachusetts, studied dentistry at Tufts, and orthodontics at Harvard/Forsyth, and practiced in Medford, MA, shunning complicated or complicating matters. Honest, outspoken, respectful, considerate, generous, courageous, are all attributes that fit his "common-sense" personality. Joining this all-American life (proudly tinted by Italian origins) with a wife who defines the word "lady," and four loving children, completed the dream and framed the legacy.

On the professional front, he has been an active player in local and national orthodontic and dental associations, serving in various capacities including president of many (e.g. the Northeastern Society of Orthodontists, Angle East), and earning various awards and accolades. The Harvard Society for the Advancement of Orthodontics honored him in 2002 by naming the Vincent DeAngelis Education Award to deserving educators. True to the proverb, he teaches a student how to fish to feed him for a lifetime, rather than giving the fish that satisfies him for a day.

A specific side of Vincent DeAngelis is described in the words he wrote about CFA Moorrees, the mentor he called "the Boss," and which apply to himself as well: "[Moorrees] refused recognition for his selfless efforts. This reluctance was owing to his humble, gentle nature. He was truly a 'rare bird.'" To another "rare bird," also described as a statesman, a gentleman "who looks you in the eyes," a giant practitioner and educator of high-standard clinical orthodontics who moves teeth with calculated respect to their biological environment, we dedicate this book. To a consummate clinician and an accomplished educator with an indelible legacy of countless patients and grateful students, this dedication also reflects untold thanks on their behalves.

Joseph G. Ghafari
and
Ze'ev Davidovitch

References

DeAngelis, V. (1970) Observations on the response of alveolar bone to orthodontic force. *American Journal of Orthodontics* **58**(3), 284–294.

DeAngelis, V. (1976) Begg-edgewise, an amalgamated technique. *American Journal of Orthodontics* **69**(3), 301–317.

DeAngelis, V. (1980) The amalgamated technique, a mechanically and biologically efficient method for controlled tooth movement. *The Angle Orthodontist* **50**(1), 1–15.

DeAngelis, V. (2010a) A 50-year journey from Begg to Straight Wire and beyond: Is orthodontics on the right course today? *Journal of the Massachusetts Dental Society* **59**(2), 38–42.

DeAngelis, V. (2010b) Letters to the editor. *Journal of Massachusetts Dental Society* **59**(3), 6.

Contributors

Hila Bahar, DMD, PhD
Department of Oral Biology,
The Maurice and Gabriela Goldschleger School of Dental Medicine,
Tel Aviv University, Tel Aviv,
Israel.

Itzhak Binderman, DMD
Professor, Department of Oral Biology,
The Maurice and Gabriela Goldschleger School of Dental Medicine,
Tel Aviv University, Tel Aviv,
Israel.

Nabil F. Bissada, DDS, MSD
Professor and Chairman,
Department Periodontics,
Case Western Reserve University,
School of Dental Medicine,
Cleveland, Ohio,
United States.

Carine Carels, DDS, PhD
Professor of Orthodontics,
Department of Oral Health Sciences—Orthodontics,
KU Leuven and Dentistry,
University Hospitals Leuven,
Belgium.

Song Chen, DDS, PhD
Associate Professor, Department of Orthodontics,
West China College of Stomatology,
Sichuan University,
Chengdu, Sichuan,
China.

Ze'ev Davidovitch, DMD, Cert. Ortho
Clinical Professor,
Department of Orthodontics,
Case Western Reserve University,
Cleveland, Ohio,
United States.

Vincent Everts, PhD
Department of Oral Cell Biology,
Academic Centre for Dentistry Amsterdam (ACTA),
University of Amsterdam and VU University,
MOVE Research Institute,
Gustav Mahlerlaan 3004, 1081 LA Amsterdam,
Netherlands.

Nasser Gadban, DMD, PhD
Department of Oral Biology,
The Maurice and Gabriela Goldschleger School of Dental Medicine,
Tel Aviv University, Tel Aviv,
Israel.

Gustavo Pompermaier Garlet, DDS, PhD
Associate Professor,
Head of Department of Biological Sciences,
School of Dentistry of Bauru—FOB/USP,
Al. Octávio Pinheiro Brisola, 9–75,
17012-901—Bauru, Sao Paulo, Brazil.

Jan Van Gastel, DDS, PhD
Assistant Professor,
Department of Oral Health Sciences—Orthodontics,
KU Leuven and Dentistry,
University Hospitals Leuven,
Belgium.

Ellen Ghijselings, DDS
Department of Oral Health Sciences—Orthodontics,
KU Leuven and Dentistry,
University Hospitals Leuven,
Belgium.

Jing Guo, DDS, PhD
Department of Oral Cell Biology,
Academic Centre for Dentistry Amsterdam (ACTA),
University of Amsterdam and VU University,
MOVE Research Institute,
Gustav Mahlerlaan 3004, 1081 LA Amsterdam,
Netherlands.

James K. Hartsfield, Jr., DMD, PhD, FACMG
Diplomate of the American Board of Orthodontics,
Diplomate of the American Board of Medical Genetics,
Founding Fellow in the American College of Medical Genetics and Genomics,
Professor and E. Preston Hicks Endowed Chair in Orthodontics and Oral Health Research,
Co-Director of the University of Kentucky Center for the Biologic Basis of Oral/Systemic Diseases,
Hereditary Genetics/Genomics Core,
Adjunct Professor, Department of Orthodontics and Oral Facial Genetics,
Indiana University School of Dentistry,
Adjunct Professor, Department of Medical and Molecular Genetics,
Indiana University School of Medicine, Indianapolis,
Adjunct Clinical Professor, Department of Orthodontics,
University of Illinois at Chicago College of Dentistry,
University of Kentucky Center for the Biologic Basis of Oral/Systemic Diseases,
Hereditary Genetics/Genomics Core,
800 Rose Street, D416,
Lexington, KY 40536-0297,
United States.

Haikun Hu, DDS, PhD
Department of Orthodontics,
West China Dental Implantology Hospital, Sichuan University, No.75,
Xiaotianzhu Road, Chengdu,
Sichuan 610041,
China.

Laura R. Iwasaki, DDS, MSc, PhD, CDABO
Associate Professor,
Departments of Orthodontics and Dentofacial Orthopedics and Oral and Craniofacial Sciences,
L.A. Rogers Chair, Department of Orthodontics and Dentofacial Orthopedics,
UMKC School of Dentistry,
650 E. 25th Street,
Kansas City, MO 64108-2784,
United States.

Vinod Krishnan, BDS, MDS, MOrth RCS, FDS RCS, PhD
Professor of Orthodontics,
Sri Sankara Dental College,
Varkala, Trivandrum, Kerala,
India.

Anne Marie Kuijpers-Jagtman, DDS, PhD, FDSRCS Eng
Professor of Orthodontics,
Chair, Section of Orthodontics and Craniofacial Biology,
Department of Dentistry,
Radboudumc, PO Box 9101, 6500 HB Nijmegen,
Netherlands
and
Adjunct Professor, Faculty of Dentistry,
Universitas Indonesia, Jakarta,
Indonesia.

Ulf H. Lerner, DDS, PhD
Department of Molecular Periodontology,
Faculty of Medicine, Umeå University,
Umeå,
Sweden
and
Centre for Bone and Arthritis Research at Institute of Medicine,
Sahlgrenska Academy at University of Gothenburg,
Gothenburg,
Sweden.

Jaap C. Maltha, PhD
Em. Associate Professor of Orthodontics,
Section of Orthodontics and Craniofacial Biology,
Department of Dentistry,

Radboudumc, PO Box 9101, 6500 HB,
Nijmegen,
Netherlands.

Neal C. Murphy, DDS, MS
Clinical Professor,
Departments of Orthodontics and Periodontics,
Case Western Reserve University ,
School of Dental Medicine,
Cleveland, Ohio,
United States.

Rajesh Ramachandran, MSc
Director, Biogenix Research Center,
Sabeer Lane, Valiyavila,
Thiruvananthapuram, Kerala,
India.

W. Eugene Roberts, DDS, PhD
Professor Emeritus, Orthodontics,
Adjunct Professor, Mechanical Engineering,
Indiana University and Purdue University,
Indianapolis, IN,
United States
and
Adjunct Professor, Orthodontics,
Loma Linda University,
Loma Linda, CA,
United States.

Vaska Vandevska-Radunovic, MSc, Dr. odont.
Professor of Orthodontics,
Department of Orthodontics,
Institute of Clinical Dentistry,
University of Oslo,
Norway.

Rodrigo F. Viecilli, DDS, PhD
Diplomate of the American Board of Orthodontics,
Associate Professor, Center for Dental Research,
Department of Orthodontics,
Loma Linda University School of Dentistry
11092 Anderson St, Loma Linda,
CA 92350,
United States.

William M. Wilcko, DDS, MSD
Assistant Professor,
Department of Orthodontics,
University of Pennsylvania,
School of Dental Medicine,
Philadelphia, Pennsylvania,
United States.

Sara H. Windahl, PhD
Centre for Bone and Arthritis Research at Institute of Medicine,
Sahlgrenska Academy at University of Gothenburg,
Gothenburg,
Sweden.

Gang Wu, DDS, MD, PhD
Assistant Professor,
Department of Oral Implantology
and Prosthetic Dentistry,
Academic Centre for Dentistry Amsterdam (ACTA),
University of Amsterdam and VU University,
MOVE Research Institute,
Gustav Mahlerlaan 3004, 1081 LA Amsterdam,
Netherlands.

Avinoam Yaffe, DMD
Professor,
Department of Prosthodontics,
Hebrew University Hadassah School
of Dental Medicine,
Jerusalem,
Israel.

Masaru Yamaguchi, DDS, PhD
Associate Professor,
Department of Orthodontics,
Nihon University School of Dentistry at Matsudo,
2-870-1 Sakaecho-Nishi, Matsudo,
Chiba 271-8587,
Japan.

Lital Young, DMD, PhD
Department of Oral Biology,
The Maurice and Gabriela Goldschleger School
of Dental Medicine,
Tel Aviv University, Tel Aviv,
Israel.

James J. Zahrowski, DMD, MS, PharmD
Diplomate of American Board of Orthodontics,
13372 Newport Avenue,
Suite E,
Tustin, CA 92780,
United States.

Maggie Zeichner-David, PhD
Clinical Professor,
Ostrow School of Dentistry of the University
of Southern California,
Division of Biomedical Sciences,
925 West 34th Street, R4220,
Los Angeles, CA 90089,
United States.

Preface to the first edition

The first international conference on the biology of tooth movement was held in November 1986 at the University of Connecticut, under the leadership of Louis A. Norton and Charles J. Burstone. In the Foreword to the book that emanated from that conference, Coenraad F.A. Moorrees, to whom the first edition of this book is dedicated, wrote:

> Notwithstanding continued progress from numerous histologic and biochemical studies describing tissue behavior after force application, the key question on the biology of tooth movement remains unresolved: namely, how force application evokes molecular response in the cells of the periodontal membrane. Only when this fundamental question in bone physiology is better understood can appliances for optimal tooth movement in orthodontics be achieved.

In the two decades that have passed since that conclusion, scientists worldwide seem to have followed the direction pointed out by Professor Moorrees. Basic research pertaining to the response of tissues and cells to mechanical loading has grown broader and deeper. The emphasis at the end of the first decade of the twenty-first century is on molecular biology and molecular genetics. Genes are being identified which seem to play important roles in the response of paradental cells and tissues to orthodontic forces, and a growing number of signal molecules that modulate this process have been elucidated. These findings now enable clinicians to utilize some of these molecules as markers of processes associated with tooth movement, such as inflammation and root resorption.

This unrelenting increase of knowledge in basic science has not yet resulted in the development of orthodontic appliances that can be tailored to fit the biological peculiarities of individual patients. But with the growing understanding of the nature of various common diseases, such as diabetes, asthma, arthritis, obesity, and various cardiovascular diseases, it is now possible to assess their potential effects on orthodontic tooth movement, clinically and molecularly. The time seems to be approaching when the nature of optimal orthodontics will be fully exposed as a consequence of the increasing widening of the highway connecting clinical and basic sciences.

The goal of this book is to inform orthodontic students as well as practitioners on the known details of the biological aspects of tooth movement. We hope that this information will enhance their ability to render excellent treatment to all of their patients, young and old. Moreover, we hope that this compendium will convince readers that the dentofacial complex is an integral part of the complete human body, and as such, and like any other region of the body, is prone to be influenced by many factors, genetic or environmental.

Vinod Krishnan
Ze'ev Davidovitch
Editors

Preface to the second edition

Basic biologic research in orthodontics has witnessed rapid growth since the publication of the first edition of *Biological Mechanisms of Tooth Movement*. This research not only identified biologic factors associated with tooth movement and its iatrogenic reactions but has expanded even deeper into exploration at the molecular and genomic levels, to generate new knowledge that can be used in clinical settings.

The concept of personalized or individualized medicine is rapidly gaining a hold in medicine as may be seen from the global annual conferences on this subject. In medicine, at this time, the focus is on the personal determinants of cancer and diabetes. Efforts to adapt this concept to all of medicine are gaining momentum. Dentistry is no exception, and orthodontics is potentially the pioneer in this regard. Orthodontists have long been customizing their diagnoses and treatment plans according to the physical characteristics of their patients but now we are entering a period when it would be possible to evaluate the biological features of each patient, by measuring specific tissue markers in fluids, such as saliva and gingival crevicular fluid. The task of establishing reliable tests for the identification of the sought-for markers may not be imminent because of the complexity and variability of the individual genomics but investigations of this pathway have already begun.

The role of basic biologic research has frequently been portrayed as the identification of factors and processes that participate in clinical functions, and test the validity of any hypothesis regarding the efficacy and safety of new and old clinical methods. The specialty of orthodontics has benefitted from this relentless flow of new information, derived from a plethora of publications in numerous scientific periodicals, which focused on mechanism of mechanotransduction, the birth, life and death of the osteoclast, the molecular genetics of bone modeling and remodeling, and the effects of hormones and drugs on soft and mineralized connective tissues. This ongoing growth in information is already affecting clinical orthodontics. One major concept gaining support is the proven ability of bone and periodontal fibroblastic cells to respond simultaneously to more than one signaling factor. Evidence in support of this principle has already led to the application, in addition to orthodontic force, of surgical procedures, vibrations, laser radiation, electricity, and vitamin D_3. All of these factors have displayed an ability to enhance the velocity and reduce the duration of tooth movement. The orthodontist now has at his disposal a choice of methods, invasive and noninvasive, local and systemic, that can augment the pace of tissue changes that facilitate tooth movement. These mechanisms act on the tissue and cellular levels, and can be manipulated based on increasing knowledge derived from worldwide laboratory experiments and clinical trials, all of which elevate the clinical potential of orthodontics to attain positive results, with a long-range stability, and with a low risk for undesirable side effects.

We are pleased to present this second edition of *Biological Mechanisms of Tooth Movement,* in which we have assembled chapters about topics closely related to the *basic biologic aspects of orthodontics,* which affect the movement of teeth during orthodontic treatment. It updates most of the subjects addressed in the first edition, and includes new topics, such as the search for efficient methods to accelerate tooth movement.

We would like to thank all our contributors who have demonstrated dedication to this project. We would also like to express our sincere appreciation to the book reviewers, who critically analyzed the first edition of the book and let us know its shortcomings so that the second edition is made much stronger. We express our gratitude to our publisher, Wiley-Blackwell, especially Sophia Joyce, Hayley Wood, Jessica Evans, Sara Crowley-Vigneau, and Katrina Hulme-Cross, who helped us complete the project successfully. We would also like to thank the support staff, Jayavel Radhakrishnan, David Michael and all others, who worked tirelessly to facilitate this publication.

As we have stated in the preface to the first edition of this book, "we *really* hope that this compendium will convince the readers that the dentofacial complex is an integral part of the complete human body, and as such, is prone to be influenced by any factor, genetic or environmental, like any other region of the body." Orthodontic academicians and clinicians increasingly recognize this principle and try to treat patients as humans, not merely as typodonts. We hope that this book will assist all orthodontists in this effort.

Vinod Krishnan
and
Ze'ev Davidovitch
Editors

Contents

PART 1

Evolution of biological concepts

CHAPTER 1

Biological basis of orthodontic tooth movement: An historical perspective

Ze'ev Davidovitch[1] and Vinod Krishnan[2]
[1]Case Western Reserve University, United States
[2]Sri Sankara Dental College, India

Summary

For millennia, we were unable to understand why teeth can be moved by finger pressure, as advocated by Celsus around the dawn of the Common Era, but it was working. Indeed, our ancestors were keenly aware of malocclusions, and the ability to push teeth around by mechanical force. The modern era in dentistry began in earnest in 1728 with the publication of the first comprehensive book on dentistry by Fauchard. In this, Fauchard described a procedure of "instant orthodontics," whereby he aligned ectopically erupted incisors by bending the alveolar bone. A century-and-a-half later, in 1888, Farrar tried to explain why teeth might be moved when subjected to mechanical loads. His explanation was that teeth move either because the orthodontic forces bend the alveolar bone, or they resorb it. The bone resorption idea of Farrar was proven by Sandstedt in 1901 and 1904, with the publication of the first report on the histology of orthodontic tooth movement. Histology remained the main orthodontic research tool until and beyond the middle of the twentieth century. At that time medical basic research began evolving at an increasing pace, and newly developed research methods were being adapted by investigators in the various fields of dentistry, including orthodontics; Farrar's assumption that orthodontic forces bend the alveolar bone was proven to be correct, and the race was on to unravel the mystery of the biology of tooth movement. During the second half of the twentieth century, tissues and cells were challenged and studied *in vitro* and *in vivo* following exposure to mechanical loads. Among the investigative tools were high-quality light and electron microscopes, and a large array of instruments used in physiological and biochemical research. The main fields of research that have been plowed by these investigations include histochemistry, immunohistochemistry, immunology, cellular biology, molecular biology, and molecular genetics. A logical conclusion from this broad research effort is that teeth can be moved because cells around their roots are enticed by the mechanical force to remodel the tissues around them. This conclusion has opened the door for quests aimed at discovering means to recruit the involved paradental cells to function in a manner that would result in increased dental velocity. The means tried in these investigations have been pharmaceutical, physical, and surgical. In all these categories, experimental outcomes proved that the common denominator, the cell, is indeed very sensitive to most stimuli, physical and chemical. Hence, the way ahead for orthodontic biological researchers is clear. It is a two-lane highway, consisting of a continuous stream of basic experiments aimed at uncovering additional secrets of tissue and cellular biology, alongside a lane of trials exploring means to improve the quality of orthodontic care. Gazing toward the horizon, these two lanes seem to merge.

Biological research has exposed differences between individuals based on molecular outlines and entities. In people who possess similar facial features and malocclusions, this variability, which should be reflected in the diagnosis, may require the crafting of treatment plans that address the individual molecular peculiarities. These differences may be due to genetic and/or environmental factors, and should be addressed by a personalized orthodontic treatment plan, which benefits from the rapidly accumulating knowledge about the molecular composition and functions of the body, and the interactions of its tissue systems.

Introduction

Orthodontics, the first specialty of dentistry, has evolved and progressed from its inception to the present time, and the credits for this evolution belong to pioneers, who aimed at improving their clinical capabilities. The evolution of clinical orthodontics is rooted in strong foundations, based on scientific studies and mechanical principles. However, as the specialty began prospering, interest in its association with biological facts began to decline. For a while, orthodontics was taught predominantly as a mechanical endeavor. It can be taught in a short course lasting a few days, usually without any associated clinical exposure. However, recent advancements in medicine have provided orthodontic researchers with investigative tools that enable them to pave new roads toward the target of personalized orthodontics, adapted to the biological profile and needs of each individual patient.

The unfolding of science behind the biology of orthodontic tooth movement (OTM) has been slow and tedious. Our ancestors, as far back as the dawn of history, in all civilizations, cultures, and nations, were interested in images of bodies and faces, covered or exposed. Their artists painted these images on cave walls, cathedral ceilings, and on canvas pieces that were hung in private homes. They also created a huge array of sculptures as monuments, religious fixtures, or outdoor

Biological Mechanisms of Tooth Movement, Second Edition. Edited by Vinod Krishnan and Ze'ev Davidovitch.

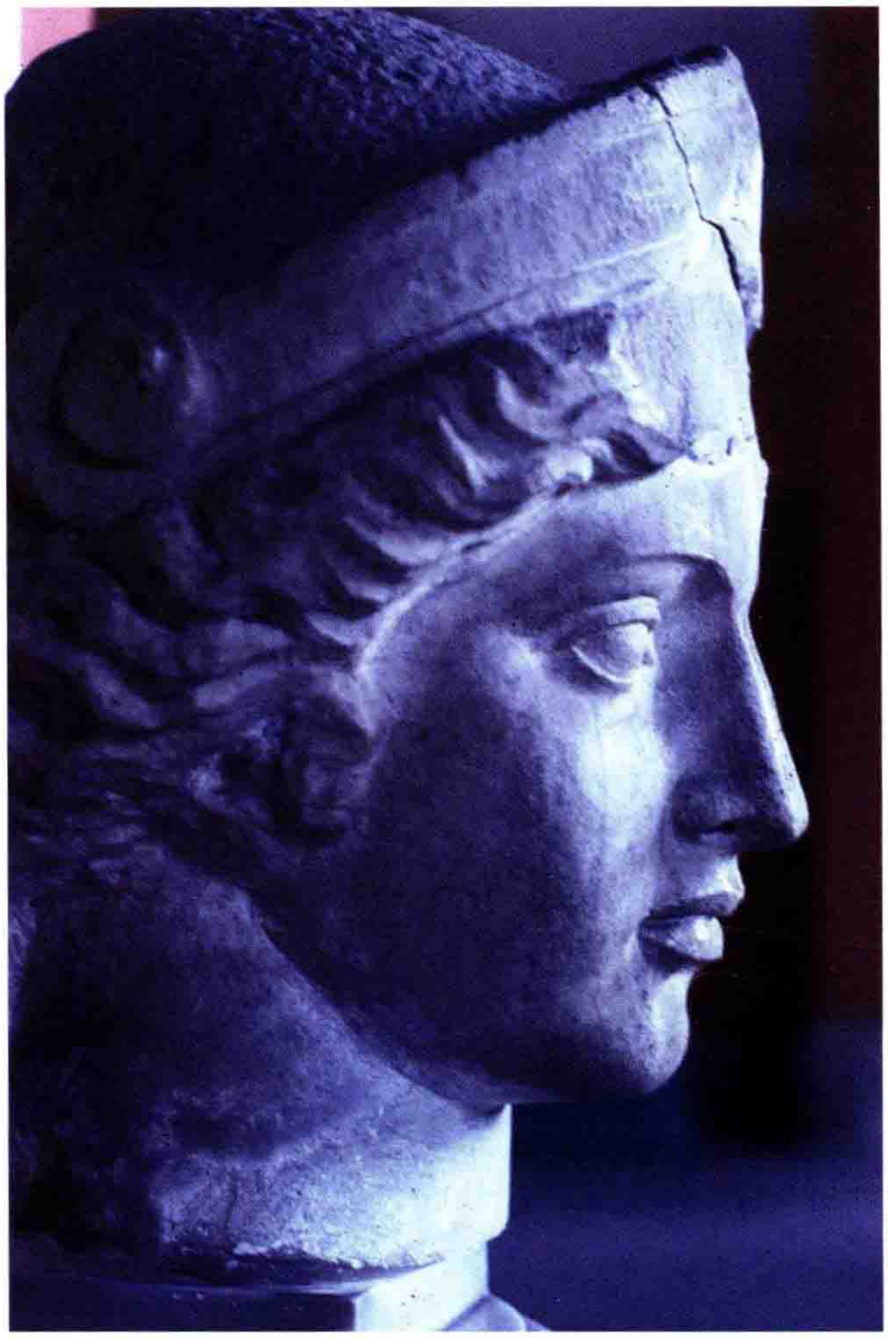


Figure 1.1 Ancient Greek marble statue of a man's head. National Museum of Greece, Athens.

Figure 1.2 Contemporary bust sculpture of a shrine guardian, Seoul, Korea.

decorations. These works of art reflected images of faces that were curved and crafted along guidelines unique for each tribal, ethnic, and cultural group. Figure 1.1 presents a profile view of a marble statue of a man's head, found in an archeological dig in Greece. Typically, the facial profile is divided into three equal parts (upper, middle, and lower), and the outline of the nose is continuous with the forehead. Figure 1.2 shows a contemporary sculpture of a shrine guardian in Korea. The features are exaggerated, but the facial proportions are similar to those of the ancient Greek statue. Some artists, like Picasso, attracted attention by intentionally distorting well established facial features. Frequently, facial features in old and contemporary paintings and sculptures express a variety of emotions, ranging from love to fear, and a wide array of shapes, from the ideal to the grotesque.

The importance of possessing a full complement of teeth was very evident in ancient times as evidenced by the complimentary words of Solomon to queen of Sheba "Thy teeth are like a flock of sheep that are even shorn, which came up from the washing" (Song of Solomon 4:2). Even the first code of Roman law, written in 450 BCE, specifies the importance of teeth by incorporating penalties for the master or his agent if they dare to pull out the teeth of slaves or freemen. If this happens, the law stated that the slave is eligible for immediate freedom. The prose and poetry of the Greek and Roman era portrays numerous references to teeth, smiling faces, and the importance of having a regular arrangement of teeth, indicating a desire to correct dental irregularities. There was an emphasis on a correct relationship between the dental arches, and its importance in defining female beauty, and a correct enunciation in oratory. With attention focusing on correction of dental irregularities, orthodontia at that era was already divided into biological and mechanical fields, and it was assumed that a successful practitioner should have clear idea of both. The first orthodontic investigators adopted the biological knowledge of the day, and concluded that success or failure in the treatment of malocclusions depends on these fields. The superstructure of orthodontics is built upon this fundamental relationship.

Naturally, therefore, orthodontic research has followed closely the scientific footsteps imprinted by biologists and physicians. Present day orthodontists are aware of frequent scientific advances in material and biological sciences, that gradually move us all closer to an era of personalized medicine and dentistry, in which a high degree of diagnostic accuracy and therapeutic excellence is required.

Orthodontic treatment in the ancient world, the Middle Ages, and through the Renaissance period: Mechanics, but few biological considerations

Archeological evidence from all continents and many countries, including written documents, reveal that our forefathers were aware of the presence of teeth in the mouth, and of various associated health problems. These early Earth dwellers confronted diseases like caries and periodontitis with a variety of medications, ranging from prayers to extractions, and fabrication of dentifrice pastes. Gold inlays and incisor decorations were discovered in South America, and gold crowns and bridges, still attached to the teeth, were discovered in pre-Roman era Etruscan graves (Weinberger, 1926). All these findings bear witness to the awareness of our ancestors to oral health issues.

Recognition of malocclusions and individual variability in facial morphology and function were first noted in Ancient Greece. Hippocrates of Cos (460–377 BCE), who is the founder of Greek medicine, instituted for the first time a careful, systematic, and thorough examination of the patient. His writings are the first known literature pertaining to the teeth. He discussed the timing of shedding of primary teeth and stated that "teeth that come forth after these grow old with the person, unless disease destroys them." He also commented that the teeth are important in processing nutrition, and the production of sound. Hippocrates, like other well educated people of his time, was keenly aware of the variability in the shapes of the human craniofacial complex. He stated that "among those individuals whose heads are long-shaped, some have thick necks, strong limbs and bones; others have highly arched palates, their teeth are disposed irregularly, crowding one on the other, and they are afflicted by headaches and otorrhea" (Weinberger, 1926). This statement is apparently the first written description of a human malocclusion. Interestingly, Hippocrates saw here a direct connection between the malocclusion and other craniofacial pathologies.

A prominent Roman physician, Celsus (25 BCE–50 CE; Figure 1.3), was apparently the first to recommend the use of mechanical force to evoke tooth movement. In his Book VII, Chapter XII entitled "Operations requisite in the mouth," he wrote: "If a permanent tooth happens to grow in children before the deciduous one has fallen out, that which should have dropped must be scrapped round and pulled out; that which is growing in place of former must be pushed into its proper place with the finger every day, till it comes to its own size." Celsus was also the first to recommend the use of a file in the mouth, mainly for the treatment of carious teeth (Weinberger, 1926). Another Roman dentist, Plinius Secundus (23–79), expressed opposition to the extraction of teeth for the correction of malocclusions, and advocated filing elongated teeth "to bring them into proper alignment." Plinius was evidently the first to recommend using files to address the vertical dimension of malocclusion, and this method had been widely used until the nineteenth century (Weinberger, 1926).

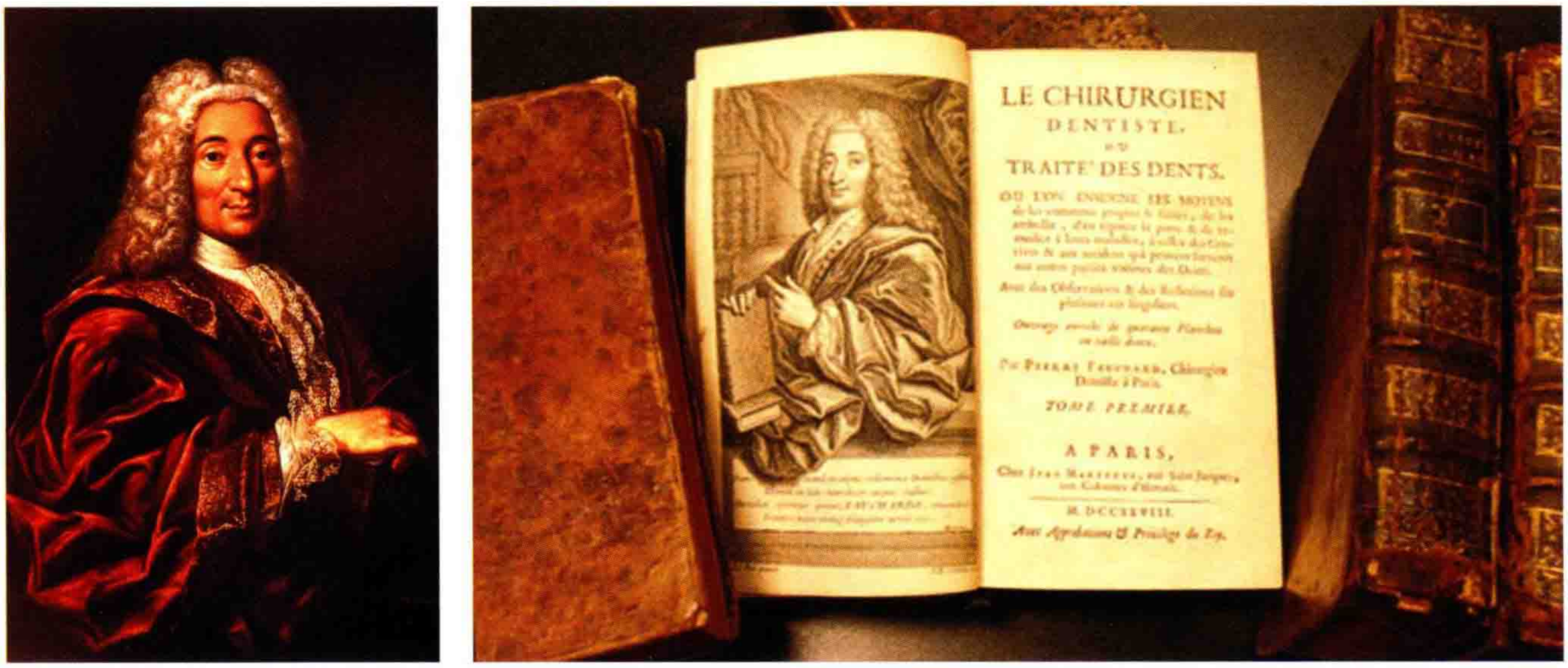
There were few, if any known advances in the fields of medicine, dentistry, and orthodontics from the first to the eighteenth centuries, with the exception of Galen (131–201), who established experimental medicine, and defined anatomy as the basis of medicine. He devoted chapters to teeth, and, like Celsus, a century earlier, advocated the use of finger pressure to align malposed teeth. Galen advocated the same method that of Celsus through his writings in 180 CE, which stated that a tooth that projects beyond its neighbors should be filed off to reduce the irregularity (Caster, 1934). Another exception was Vesalius (1514–1564), whose dissections produced the first illustrated and precise book on human anatomy.

For reasons connected with the church, Galen and his writings monopolized medicine for more than a thousand years, and there were minor advancements in European medicine during that protracted era. However advancements continued during that period, as evidenced by writings of Muslim physicians' from Arabia, Spain, Egypt and Persia.

Figure 1.3 Aulus Cornelius Celsus (25 BC–AD 50). (Picture courtesy: http://www.general-anaesthesia.com/.)

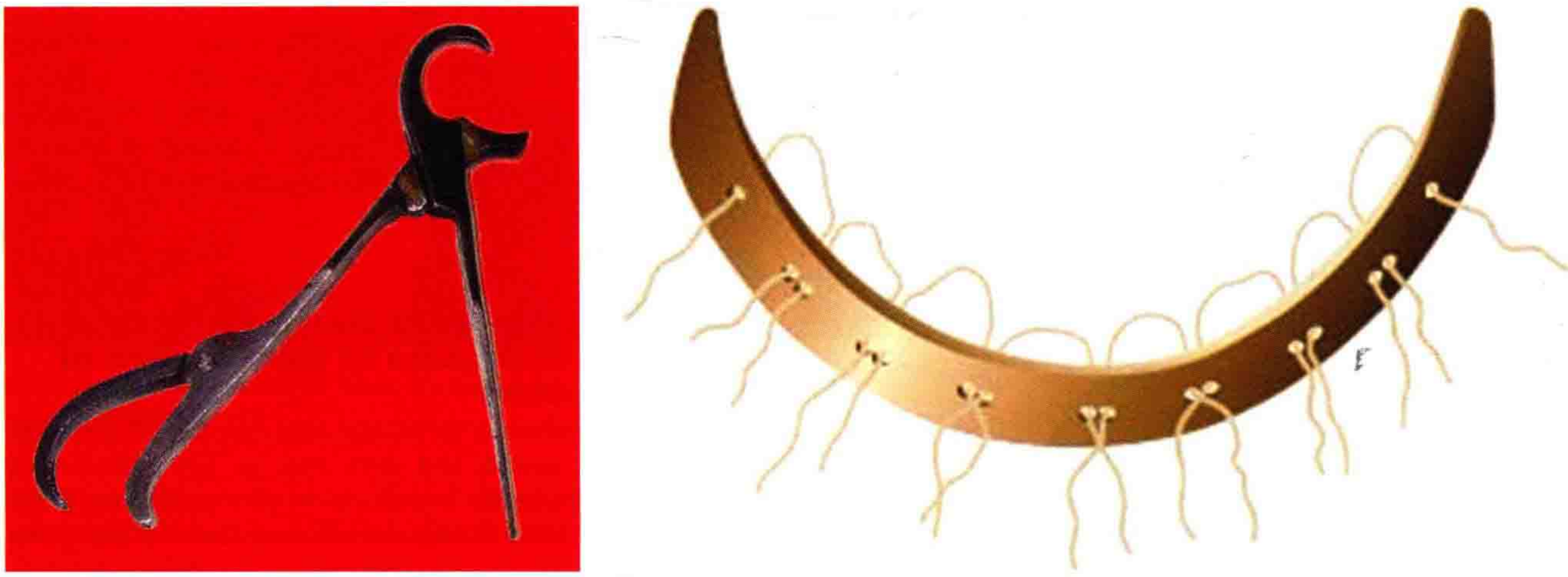
Orthodontic treatment during the Industrial Revolution: Emergence of identification of biological factors

The writings of authors in the Middle Ages were mainly repetitions of what already existed, and there were no new references to mechanical principles for correcting dental irregularities. It was Pierre Fauchard (1678–1761), the father of dentistry and orthodontics (Figure 1.4), who organized previous knowledge and opinions, and provided an extensive discussion on the rationale for numerous clinical procedures (Wahl, 2005a). His book titled *Le chirurgien dentiste* (*The Surgeon-Dentist*) was published in two editions, the first in 1728 and the second in 1746. The second edition of the book described a few orthodontic cases (Vol. II, Chapter VIII) along with an extensive description of appliances and mechanical principles. This book is considered to be dentistry's first scientific publication. Fauchard also advocated keeping young patients under observation and removing long-retained deciduous teeth as a means to prevent irregularity in the permanent dentition. He also stated that blows and violent efforts may increase the chances of developing an irregular tooth arrangement, and reported that the greatest incidence of these mishaps occur in the incisor and canine regions. Most of the appliances he fabricated were made of gold or silver, and were designed for each patient according to their needs, marking the beginning of "customized orthodontic appliances" (Figure 1.5). The orthodontic appliance described by Fauchard used silk or silver ligatures to move malposed teeth to new positions, and "pelican" pliers for instant alignment of incisors, facilitated by bending of the alveolar bone. After placing teeth in position with pelican forceps, he retained them



(a) (b)

Figure 1.4 (a) Pierre Fauchard (1678–1761), the father of dentistry and orthodontics. (Source: Vilella, 2007.) (b) His book titled *Le chirurgien dentiste* (*The Surgeon-Dentist*). (Picture courtesy: Andrew I. Spielman.)



(a) (b)

Figure 1.5 (a) Dental pelican forceps (resembling a pelican's beak). (Courtesy of Alex Peck Medical Antiques.) (b) Bandeau–the appliance devised by Pierre Fauchard (Source: Vilella, 2007.)

with silver ligatures or lead plates adjusted on either side, over which linen was placed and sewed into position with needle and thread, between interproximal spaces and over the occlusal surfaces of the teeth. This device, named bandeau, marked the beginning of the era of modern orthodontic appliances and their utilization in treating malocclusions (Asbell, 1990).

Hunter (1728–1793), in 1778, in his book titled *A Practical Treatise on the Diseases of the Teeth,* stated that teeth might be moved by applied force, because "bone moves out of the way of pressure." This book, along with his previously published book, titled *The Natural History of Human Teeth,* marked the beginning of a new era in the practice of dentistry in England (Wahl, 2005a). Hunter recognized the best time to carry out orthodontic treatment to be the youthful period, in which the jaws have an adaptive disposition. In 1815, Delabarre reported that orthodontic forces cause pain and swelling of paradental tissues, two cardinal signs of inflammation.

Up to 1841, about a century after Fauchard had written a chapter about orthodontics, there was no single book devoted entirely to orthodontics alone, but in 1841, Schange published a book solely confined to orthodontics (Wahl, 2005a), which, served as a stimulus for conducting investigations in this defined clinical field. Moreover, this book initiated the notion that orthodontics is a unique dental specialty. Schange described the tooth-eruption process, causes of irregularities, their prevention, and classified defects of conformation. In treating irregularities, Schange took a different view from Fauchard, who had advocated the use of radical procedures. He warned practitioners of the attendant danger to the tooth when these procedures were performed, and favored application of delicate forces in a continuous manner, hence being the first to favor light orthodontic forces. He recommended silk ligatures to apply light forces, and gold for constructing bands and plates, and recognized the importance of retaining teeth after OTM.

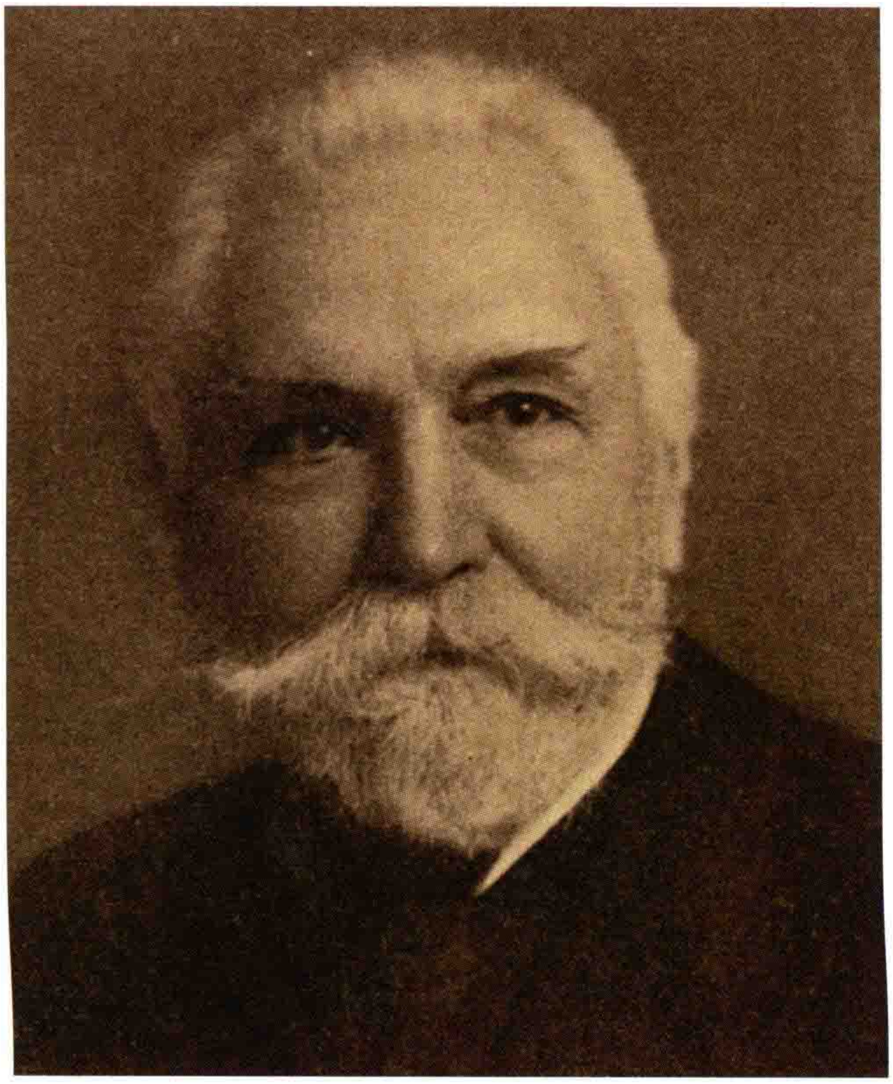
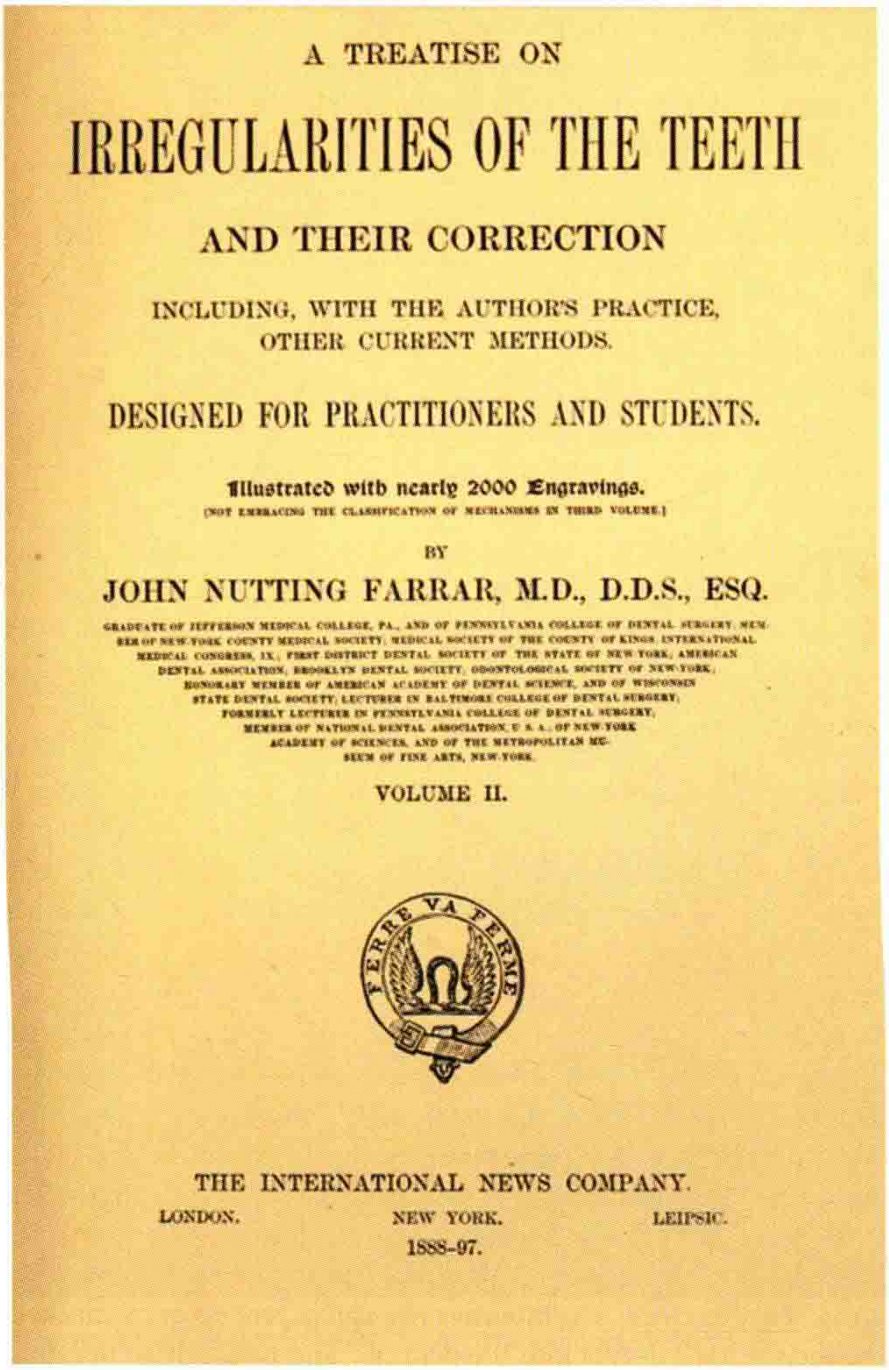


Figure 1.6 Norman William Kingsley. (Source: Dr Sheldon Peck, University of North Carolina at Chapel Hill. Reproduced with permission of Dr Sheldon Peck.)



A TREATISE ON

IRREGULARITIES OF THE TEETH

AND THEIR CORRECTION

INCLUDING, WITH THE AUTHOR'S PRACTICE, OTHER CURRENT METHODS.

DESIGNED FOR PRACTITIONERS AND STUDENTS.

Illustrated with nearly 2000 Engravings.

[NOT EMBRACING THE CLASSIFICATION OF MECHANISMS IN THIRD VOLUME.]

BY

JOHN NUTTING FARRAR, M.D., D.D.S., ESQ.

GRADUATE OF JEFFERSON MEDICAL COLLEGE, PA., AND OF PENNSYLVANIA COLLEGE OF DENTAL SURGERY; MEMBER OF NEW-YORK COUNTY MEDICAL SOCIETY; MEDICAL SOCIETY OF THE COUNTY OF KINGS; INTERNATIONAL MEDICAL CONGRESS, IX.; FIRST DISTRICT DENTAL SOCIETY OF THE STATE OF NEW-YORK; AMERICAN DENTAL ASSOCIATION; BROOKLYN DENTAL SOCIETY; ODONTOLOGICAL SOCIETY OF NEW-YORK; HONORARY MEMBER OF AMERICAN ACADEMY OF DENTAL SCIENCE, AND OF WISCONSIN STATE DENTAL SOCIETY; LECTURER IN BALTIMORE COLLEGE OF DENTAL SURGERY; FORMERLY LECTURER IN PENNSYLVANIA COLLEGE OF DENTAL SURGERY; MEMBER OF NATIONAL DENTAL ASSOCIATION, U. S. A., OF NEW-YORK ACADEMY OF SCIENCES, AND OF THE METROPOLITAN MUSEUM OF FINE ARTS, NEW-YORK.

VOLUME II.

FERME VA FERME

THE INTERNATIONAL NEWS COMPANY.

LONDON. NEW YORK. LEIPSIC.

1888-97.

Figure 1.7 The front page of the book *A Treatise on the Irregularities of the Teeth and their Correction* by John Nutting Farrar. (Picture courtesy: https://openlibrary.org.)

Samuel Fitch's book titled *A System of Dental Surgery,* published in 1835, marked the beginning of a new era in the practice of dentistry in America. He drew attention to the mobility of teeth within the alveolar process during OTM, and characterized the growth period as the time for attaining best results of treatment. Norman Kingsley's treatise on "oral deformities" (1880) had an immediate impact, by placing orthodontics as a specialty, which requires more than general information to solve many of the problems its practitioners face. The book emphasized the importance of basic biology and mechanical principles while studying orthodontia as a science. While describing structural changes due to tooth-moving forces, Kingsley (Figure 1.6) stated that "the physiological fact being that bone will yield or become absorbed under some influences, and also be reproduced . . . and in moving teeth, the power used creates a pressure which produces absorption." He also stated that "the function of absorption and reproduction may or may not go coincidentally, simultaneously and with equal rapidity."

The article published in *Dental Cosmos* by John Nutting Farrar in 1887 titled "An enquiry into physiological and pathological changes in animal tissues in regulating teeth" stated that "in regulating teeth, the traction must be intermittent and must not exceed certain limits." He also stated that the system of moving teeth with rubber elastic is unscientific, leads to pain and inflammation, and is dangerous to future usefulness of the teeth. He tried to describe optimal rate of tooth movement as 1/240 inch twice daily, in the morning and the evening, and stated that at this rate, tooth movement will not produce any pain or nervous exhaustion. He stated further that the tissue changes with this procedure are physiological, but if the rate exceeds this range, the tissue reactions will become pathological. His work, which appeared as a series of articles in *Dental Cosmos* from 1876 to 1887, was summed up in his book titled *Irregularities of Teeth,* published in 1888 (Figure 1.7). In this book he devoted a large section to fundamental principles behind orthodontic mechanics and to the use of various mechanical devices (Asbell, 1998). Farrar, the "Father of American Orthodontics," was credited with developing the hypothesis that rated intermittent forces as best for carrying out orthodontic tooth movement which led to the introduction of a screw device for controlled delivery of such forces. A remarkable statement by Farrar was that OTM is facilitated by bending or resorption of the alveolar bone, or both. His publications endowed him as the founder of "scientific orthodontics" (Wahl, 2005b).

Eugene Talbot, in his book titled *Irregularities of Teeth and their Treatment* (1888) rightly mentioned that "without the knowledge of etiology, no one can successfully correct the deformities as is evident in the many failures by men who profess to make this a specialty." He argued that every case of malocclusion is different, making it difficult to classify, and proposed customizing appliances suited for each patient. He was the first to use X rays as a diagnostic aid in orthodontics, to identify abnormal and broken roots, locate third molars, and expose absorption of roots and alveolar process due to OTM.