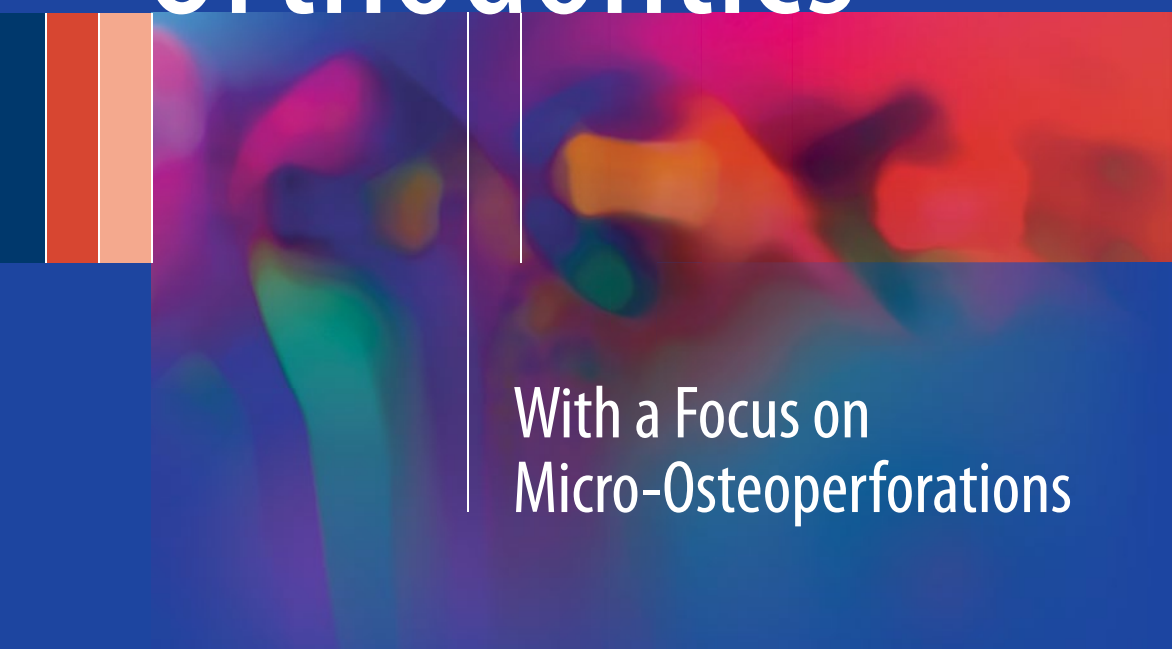
Clinical Guide to Accelerated Orthodontics



With a Focus on Micro-Osteoperforations

Mani Alikhani
Editor

Springer

Clinical Guide to Accelerated Orthodontics

Mani Alikhani
Editor

Clinical Guide to Accelerated Orthodontics

With a Focus on Micro-Osteoperforations

Springer

Editor
Mani Alikhani
Department of Developmental Biology
Harvard School of Dental Medicine
Boston, MA
USA

Department of Applied Oral Sciences
The Forsyth Institute
Cambridge, MA
USA

Consortium for Translational
Orthodontic Research
Hoboken, NJ
USA

ISBN 978-3-319-43399-8 ISBN 978-3-319-43401-8 (eBook)
DOI 10.1007/978-3-319-43401-8

Library of Congress Control Number: 2017933479

Printed on acid-free paper

This Springer imprint is published by Springer Nature
The registered company is Springer International Publishing AG
The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland

Preface

As scientists and orthodontists investigating tooth movement, I would be telling an incomplete story in this book if I did not introduce our readers to another movement – the CTOR Movement.

Several years ago, alongside a team of like-minded individuals, I started the Consortium for Translational Orthodontic Research (CTOR, www.orthodonticscientist.org), a center dedicated to translating bench and animal research into improved and innovative orthodontic therapies. This approach of performing basic science research that addresses specific clinical problems is the keystone of the CTOR Movement. Micro-osteoperforation (MOP) treatment, and the catabolic and anabolic effects described in this book, is the first successful result of this targeted research effort.

Since MOP treatment was patented, the CTOR Movement gained momentum, as CTOR researchers are busy developing new orthodontic treatment approaches. In fact, CTOR now has 7 patents for innovations that will revolutionize orthodontic and craniofacial orthopedic treatment. These include products and methods to enhance alveolar bone healing and maintenance, expand the boundaries of craniofacial and orthopedic corrections, and automated fully adjustable braces.

The CTOR Movement cannot survive without continued involvement of passionate clinician-scientists, each of whom is equal parts highly skilled orthodontist and highly skilled researcher. Motivated clinicians who strive to improve the profession of orthodontics but feel that their research skills are not up to the task are welcome to enroll in the CTOR Fellowship Program. Here, fellows find a welcoming environment where they learn to integrate their passion for clinical orthodontics with their imaginations and newly acquired research skills to become a unique clinician-scientist ready to tackle challenging problems in our profession. CTOR Fellowship graduates fit well in a number of roles, as evidenced by their careers as clinicians, educators, and leaders in their countries.

Another aspect of the CTOR Movement is CTOR's numerous collaborators at universities around the world. These richly rewarding collaborations bring clinicians and scientists together with CTOR scientists to develop, perform, and test methods and device prototypes in orthodontics and craniofacial orthopedics clinical trials. This aspect of the CTOR Movement is further enhanced through the numerous industrial partnerships that CTOR nurtures. These partnerships not only expand the range of CTOR-driven research and development, but they also allow CTOR to

establish partnerships and consulting relations with a variety of orthodontics and biomedical manufacturing companies. This greatly improves the efficiency of getting our research ideas from concept to market.

The CTOR Movement represents a novel approach to translational research, which emphasizes research aimed specifically at real-life clinical problems that orthodontists face in their practices. In its short existence, CTOR has been a driving force for innovation in orthodontics, rooted on solid biological principles, advancing new theories for tooth movement and craniofacial growth, changing the way orthodontists will practice in this century. We believe the future of orthodontics is here and CTOR will be shaping it one invention at a time.

Boston, MA, USA
Cambridge, MA, USA
NJ, USA

Mani Alikhani

Conflict of Interest

The original work on the effect of micro-osteoperforations on tooth movement resulted in a patent filled by New York University in which two of the editors/authors are named as inventors: Mani Alikhani and Cristina Teixeira.

The authors declare no further potential conflicts of interest with respect to the authorship and/or publication of this book.

Contents

Contributors

Sarah Jassem Alansari Department of Applied Oral Sciences, The Forsyth Institute, Cambridge, MA, USA

Consortium for Translational Orthodontic Research, Hoboken, NJ, USA

Mani Alikhani Department of Developmental Biology, Harvard School of Dental Medicine, Boston, MA, USA

Department of Applied Oral Sciences, The Forsyth Institute, Cambridge, MA, USA

Consortium for Translational Orthodontic Research, Hoboken, NJ, USA

Pornpan Hiranpradit Consortium for Translational Orthodontic Research, Hoboken, NJ, USA

Mohammed Al Jearah Consortium for Translational Orthodontic Research, Hoboken, NJ, USA

Edmund Khoo Department of Orthodontics, New York University College of Dentistry, New York, NY, USA

Jeanne Nervina Department of Orthodontics, New York University College of Dentistry, New York, NY, USA

Chinapa Sangsuwon Consortium for Translational Orthodontic Research, Hoboken, NJ, USA

Cristina C. Teixeira Consortium for Translational Orthodontic Research, Hoboken, NJ, USA

Department of Orthodontics, New York University College of Dentistry, New York, NY, USA

Miang Chneh Teo Consortium for Translational Orthodontic Research, Hoboken, NJ, USA

Biphasic Theory and the Biology of Tooth Movement

1

Cristina C. Teixeira, Sarah Alansari, Chinapa Sangsuwon, Jeanne Nervina, and Mani Alikhani

Contents

C.C. Teixeira (✉)
Department of Orthodontics, New York University College of Dentistry, New York, NY, USA

Consortium for Translational Orthodontic Research, Hoboken, NJ, USA
e-mail: ct40@nyu.edu; cristina.teixeira@nyu.edu

S. Alansari
Consortium for Translational Orthodontic Research, Hoboken, NJ, USA

Department of Applied Oral Sciences, The Forsyth Institute, Cambridge, MA, USA

C. Sangsuwon
Consortium for Translational Orthodontic Research, Hoboken, NJ, USA

J. Nervina
Department of Orthodontics, New York University College of Dentistry, New York, NY, USA

M. Alikhani
Consortium for Translational Orthodontic Research, Hoboken, NJ, USA

Department of Applied Oral Sciences, The Forsyth Institute, Cambridge, MA, USA

Department of Biology, Harvard School of Dental Medicine, Boston, MA, USA

M. Alikhani (ed.), *Clinical Guide to Accelerated Orthodontics*,
DOI 10.1007/978-3-319-43401-8_1

1.1 Introduction

Teeth move through alveolar bone through naturally occurring drift or in response to orthodontic forces. Orthodontists want to optimize this movement while reducing potential risk factors. Orthodontic researchers have taken on this clinical challenge by uncovering the biological phenomena associated with tooth movement.

There is a general consensus that the major biological events that permit orthodontic tooth movement are bone resorption to remove alveolar bone in the path of movement followed by bone formation to maintain the integrity of alveolar bone. The rates of bone resorption and tooth movement are directly proportional, while the rate of bone formation determines treatment success. In broader terms, orthodontic tooth movement can be divided into two phases: bone resorption occurs during the catabolic phase, and bone formation occurs during the anabolic phase.

While we generally agree on the overall cellular and histological events necessary for orthodontic movement, the detailed mechanisms mediating these events are not completely understood. How do orthodontic forces activate bone resorption and formation? Do orthodontic forces directly or indirectly induce tooth movement? Does the periodontal ligament (PDL) influence the rate of tooth movement? To address these questions, we will begin by examining how bone cells function.

1.2 Bone Cells and Their Role in the Biology of Tooth Movement

Three types of bone cells play a significant role in the biology of tooth movement: osteoblasts, osteocytes, and osteoclasts. Osteoblasts are mononuclear cells found along bone surfaces. They are derived from mesenchymal stem cells in the bone marrow and synthesize collagenous and non-collagenous proteins that comprise the organic bone matrix, known as osteoid. Inactive osteoblasts, particularly in the adult skeleton, are called bone-lining cells. These cells are quiescent until growth factors or other anabolic stimuli induce their proliferation and differentiation into cuboidal osteoblasts. Osteoblasts are the main cells participating in the anabolic phase of orthodontic tooth movement with a limited role during the catabolic phase.

Osteocytes are mature osteoblasts immobilized in lacunae within the bone matrix. Notable for exquisitely fine processes that traverse the mineralized matrix in tunnels called canaliculi, osteocytes make contact with each other and with osteoblasts residing on the bone surface. As the most numerous cell type in the bone, the osteocyte's intricate three-dimensional intercellular network serves as the key mechanosensor for recognizing mechanical load and signaling osteoclasts and osteoblasts to reshape bone to fit the mechanical demand.

The mechanism by which mechanical stimulation activates osteocytes is not clear. Bone loading under physiologic condition results in strain, or deformation, in the bone matrix and the osteocyte lacunae and canaliculi. Some investigators suggest that it is the strain magnitude in the matrix, rather than in the lacunae or canaliculi, that triggers bone remodeling [1]. Conversely, others argue that load is not the

major osteogenic trigger. They posit instead that load by-products, including strain rate [2], strain distribution [3], or fluid flow [4], are the primary remodeling initiators. While this controversy remains under active investigation, there is consensus that osteocytes detect mechanical stimulation via fluid shear stress resulting from increased fluid flow in the lacuno-canalicular system and electrical strain potentials. These responses to mechanical load activate osteocytes to secrete key factors, such as prostaglandins, nitric oxide, or insulin-like growth factors (IGFs), which then activate osteoclasts and osteoblasts in a tightly synchronized biological phenomenon called bone remodeling.

While it is clear that osteocytes are critical for normal bone remodeling, the precise role they play in the biology of tooth movement is unclear. They may play a role in the catabolic phase of movement by activating osteoclasts. However, it is more probable that they play a role in the anabolic phase by coordinating osteoblast activation.

Osteoclasts are the bone cells carrying out the critical job of resorbing bone during orthodontic tooth movement. Unlike osteoblasts and osteocytes, osteoclasts are specialized monocyte/macrophage family members, notable for forming through fusion of numerous monocytic precursors to create giant multinucleated cells. Terminal differentiation in this lineage is characterized by the acquisition of mature phenotypic markers, such as the calcitonin receptor and tartrate-resistant acid phosphatase (TRAP), and the appearance of a ruffled border rich in proton pumps that acidify the bone surface to which the cells are attached, resulting in resorption pits.

Osteoclasts control the rate of bone resorption during orthodontic treatment and, therefore, the rate of tooth movement. However, osteoclasts do not function independently. In fact, they require signals from several other cell types for their maturation, activation, and ability to perform targeted, site-specific bone resorption. The consequences of unregulated osteoclast activation would be catastrophic as bone resorption would proceed unchecked producing weakened bone and fractures. Consequently, osteoclasts cannot be direct targets of orthodontic forces. Instead, the upstream events that control osteoclast formation and activation must be the main targets. What these upstream events are remains controversial; but they can be foundations for developing new theories in the biology of tooth movement. We have compiled the scientific evidence to support a new *Biphasic Theory of Tooth Movement*.

1.3 Catabolic Phase of Orthodontic Tooth Movement

1.3.1 Theories on Initiation of Tooth Movement

Orthodontic forces produce different types of movement depending on the magnitudes of forces and couples applied to the teeth. Each type of tooth movement causes a specific stress distribution across the PDL and alveolar bone. It is widely accepted that areas experiencing the highest compression stresses undergo the highest levels of osteoclastic bone resorption. Many theories have been proposed to explain the

initial events leading to osteoclast activation in these compression sites. In general, these theories split into two camps: one proposes that bone cells (especially osteocytes) are the direct target of orthodontic forces (*Direct View*), while the other proposes that the PDL is the key target of orthodontic treatment (*Indirect View*) (Fig. 1.1). Importantly, there is agreement in both theories that osteoclasts are the cells that resorb bone and, therefore, are the cells that control the rate of tooth movement.

Based on research involving stress responses in weight-bearing bone, the Direct View proponents claim that there are two mechanisms by which direct loading may activate osteocytes. First, when mechanical stimulation is at physiologic levels, osteocytes "measure" the different components of mechanical stimulation (such as matrix deformation) and direct the bone remodeling machinery by triggering osteoclasts to remove weakened old bone and rebuild new load-tolerant bone by activating osteoblasts. By this mechanism, orthodontic tooth movement is considered a physiologic adaptation to mechanical stimulation induced by orthodontic forces. Second, higher (pathologic) mechanical loads produce microfractures in the matrix, which are detected by osteocytes, resulting in increased bone remodeling at the

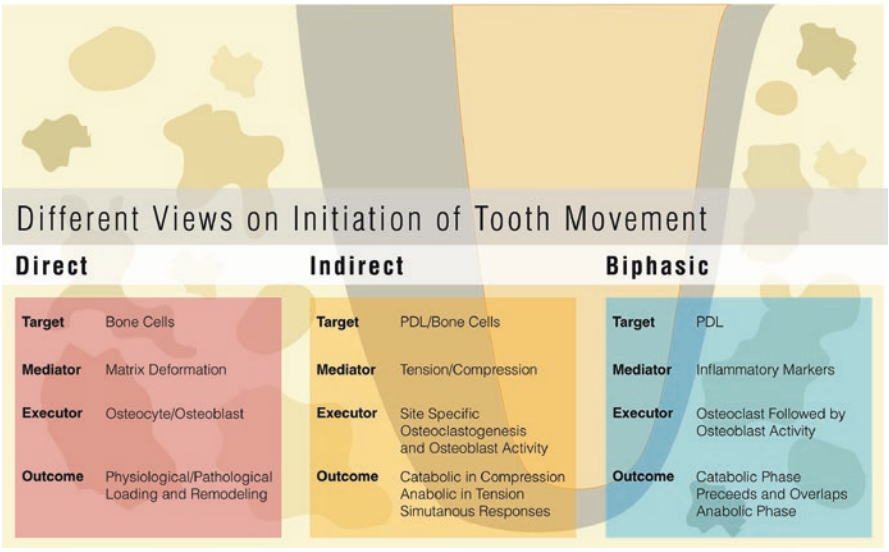


Fig. 1.1 Theories on initiation of tooth movement. Histological studies have supported classical theories on the biological mechanism responsible for tooth movement. This schematic summarizes the main differences among currently accepted theories that can be described in terms of targets, mediators, executers, and outcomes. The Direct and Indirect views have different targets for the initial orthodontic force. However, they assume that catabolic and anabolic responses in bone are independent, simultaneous, and geographically limited to areas exposed to compression and tension stresses, respectively. The Biphasic Theory incorporates the latest evidence on the biology of tooth movement and proposes an initial phase of catabolism in response to trauma and inflammation, which in turn activates an anabolic phase. Geographically, these catabolic and anabolic responses can overlap due to extensive coupling of osteoclast and osteoblast activation

damaged site. By this mechanism, orthodontic tooth movement is considered a response to trauma caused by orthodontic forces.

While the osteocyte-driven bone remodeling response to physiologic or pathologic levels of forces is supported by data derived from studies of weight-bearing bones, applying this theory of bone remodeling in response to orthodontic forces is questionable. Experiments in long bones and alveolar bone demonstrate that at physiologic levels, osteocytes do not recognize static forces [5, 6]. This argues against considering orthodontic tooth movement as a physiologic adaptation to mechanical stimulation, since orthodontic forces are mostly static rather than intermittent, as long bones would experience. Further rejecting that idea, forces applied to dental implants used as anchorage during orthodontic treatment do not induce movement of the implant.

Can orthodontic forces stimulate tooth movement by inducing microfractures in the bone? While microfractures occur in response to orthodontic forces [7], the possibility that this is the main mechanism triggering tooth movement is low because orthodontic force cannot move an ankylosed tooth. Moreover, the relationship between force magnitude and tooth movement is not linear, and soon after applying orthodontic force, the bone remodeling rate reaches a saturation point. If microfractures are the trigger for tooth movement, higher forces should continually increase the rate of movement, without ever reaching a saturation point [8]. It should be emphasized that while application of high-magnitude forces (at the pathologic level) may damage the bone around an implant significantly to the point of implant failure, high-magnitude forces do not move the implant in bone. Taken together with the fact that low-magnitude forces (at the physiologic level) are applied during clinical orthodontics, these data strongly suggest that microfractures are not the trigger for orthodontic tooth movement.

Supporters of the Indirect View of tooth movement propose that the PDL is the primary target of orthodontic forces. Consider the impossibility of moving an ankylosed tooth, which lacks a PDL. Based on this proposal, different orthodontic forces produce characteristic compression and tension patterns within the PDL, and these patterns are time dependent. For example, if a compressive force is applied for only a few seconds (i.e., it is intermittent), fluids filling PDL spaces prevent quick displacement of the tooth because the fluids are incompressible. However, if a compressive force is sustained (i.e., it is static, as in orthodontic treatment), fluids are squeezed out of the PDL, providing space for tooth displacement in the socket and further PDL compression. The immediate result of this displacement is blood vessel constriction in the compression site, resulting in decreased blood flow and nutrient and oxygen levels (hypoxia) in the compression site. Depending on the magnitude of pressure and blood flow impairment, some of the cells undergo apoptosis, while other cells die nonspecifically, resulting in necrosis that is identified histologically as the cell-free zone. Apoptotic or necrotic changes are not limited to PDL cells, and osteoblasts and osteocytes in adjacent alveolar bone may also die in response to orthodontic forces.

The physiologic and pathological responses to orthodontic force may have different outcomes, but initially both responses produce an aseptic, acute inflammatory