Burstone's Biomechanical Foundations of Clinical Orthodontics, Second Edition

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Burstone's Biomechanical Foundation of Clinical Orthodontics

SECOND EDITION

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Contents

Preface to the Second Edition

Welcome aboard! This book will lead you on an adventurous journey never before experienced in dental school. It is my hope that this book provides an exciting and refreshing foray into the world of biomechanics.

When a force is applied to the tooth, there is a law that governs its resulting orthodontic tooth movement. Though you may question the need to discuss Dr Burstone's work, it is imperative for me to state that the law of orthodontic force was founded by him. It remains a great privilege and point of pride to have studied biomechanics from him through years of personal discourse.

Looking back, my academic journey was much like listening to Sherlock Holmes profiling a person before he explains the reasons for his deductions or like revisiting a movie I had not quite grasped the first time around. Only after tackling many more journals was I able to put scattered pieces of jigsaw puzzles together to answer some of my many questions. This process is precisely why I suggested to Dr Burstone that we publish an organized set of materials that could follow the journey I went through to provide a more straightforward conceptual understanding of biomechanics.

Many years later, all of our lectures of 35mm slide films and blackboards filled with white chalk at the University of Connecticut and Yonsei University were bound together into the first edition of this book—his legacy. While working on the first edition of the book, we wanted to focus on the following objective: that learning and thinking about biomechanics is fun at its core. For both students and teachers, we wanted this book to be an entertaining thinking journey. We also added clinical cases so the reader can see the theoretical principles applied in clinical practice. The chapters of the book are organized by stage. In other words, the book follows a somewhat cumulative method of learning and teaching; as such, the reader should follow along in page order. The first few chapters may be easy for anyone with an engineering background, but they will still help familiarize the reader with new terminologies that are scientific but unique to orthodontics as well as less scientific orthodontic terminologies as well. (We tried to eliminate jargon as much as possible.) So it is my personal suggestion that the introductory chapters NOT be skipped. Many orthodontists regard biomechanics as a tricky subject, but if by following the sequence of this book readers are able to break that stereotype, I would consider it a great personal success of mine.

In this new edition, I've tried to restructure the book but remain true to our original mission. After all, this is a book of WHY (the concepts of orthodontics) rather than a book of HOW (the techniques of orthodontics). Therefore, the larger infrastructure of the textbook remains intact from its previous edition. As you might have noticed by the new title, I believe this is the best Watson can do without Sherlock around. In addition, many suggestions from readers are reflected in the new edition. Specifically, all the images of the book were recreated so as to provide higher resolution and more detailed depictions. Also, video files have been added to supplement the concepts where still images can't quite cut it. You can readily access them by scanning the accompanying QR codes using your smartphone or tablet.

We've also formed a discussion group to encourage questions or comments: https://www.facebook.com/groups/BiomechanicalFoundation. In fact, readers of the first edition actually spotted a couple errors that have since been corrected, so please engage with me!

Acknowledgments

It is simply impossible for me to list everyone who has been of help in publishing this book. To the staff at Quintessence—Bryn Grisham, who directed the publishing of this book; Leah Huffman, who spent time combing through my rough writing; Sue Zubek, who offered a new and fresh design; and to Sue Robinson, who put all the pieces together in layout—thank you. To my students, who ask intriguing questions at every step of our biomechanical journey. Your passion fills me with happiness and excitement every moment in the classroom. Without your curiosity and passion, this book would not have been completed. I would also like to recognize Drs Nazario Rinaldi and Wislei de Oliveira for their significant contribution in the conceptual developments. Lastly, to my better half, Annie, and my daughter, Christa, who have always been there for me and encouraged me.

"Now, let's start a journey of deduction, the game is on!"
–Sherlock Holmes

Preface to the First Edition

Historically, the mainstay of orthodontic treatment has been the appliance. Orthodontists have been trained to fabricate and use appliances and sequences of appliance shapes called *techniques*. However, appliances are only the instrument to produce force systems, which are the basis of tooth position and bone modification. And yet a thorough understanding of scientific biomechanics has not been a central part of orthodontic training and practice. Both undergraduate and graduate courses in most dental schools lack sound courses in mechanics and physics. What makes this problem worse is that there are few textbooks that describe biomechanics in a way that is suitable for the clinician. The authors hope this text will fill this void.

This book was motivated by the request of orthodontists at all levels—from graduate students to experienced clinicians—to learn, understand, and apply scientific orthodontics and, in particular, efficiently manipulate forces in their everyday practices. This is particularly relevant at this time, when orthodontics is undergoing a wide expansion in scope. Twenty-first-century orthodontics has introduced substantial changes in the goals and procedures: bone modification by orthognathic surgery and distraction osteogenesis, airway considerations, temporary anchorage devices, plates and implants, brackets with controlled ligation forces, new wire materials, and nonbracket systems such as aligners. No longer can clinicians depend entirely on their technical skills in the fabrication and selection of appliance hardware to adequately treat their patients. The establishment of treatment goals and the force systems to achieve them has become the paramount characteristic of contemporary orthodontics.

Different orthodontic audiences can benefit in special ways from a force-driven approach to treatment. The clinician is aided in the selection of appliances, creative appliance design, and treatment simulation. Simulation is the most valuable because it allows the clinician to plan different strategies using force systems and then select the best. It enables more predictive appliance shapes that approach optimal forces. Unlike an older approach of trying out new procedures directly in the mouth, it is also cost-effective. Particularly in orthodontics, clinical evaluation requires long-term observation. With sound theory, many appliances can be evaluated so that long-term studies or trials can be avoided.

While commercial orthodontic companies may not initially welcome clinical orthodontists who are knowledgeable in biomechanics, it is to their advantage when new important products are introduced to be able to discuss the innovations with scientifically trained clinicians. Researchers in orthodontic physics and material science also need this background. Biologic research at all levels also needs to control force variables. Studies on experimental animals where forces or stresses are delivered must control the force system to have valid results. Many times biologists do not understand the forces in their research and, hence, erroneous or insignificant results are obtained.

Because most orthodontists do not have a strong background in physics and mathematics, the goal of this book is simplicity and accuracy in developing a scientific foundation for orthodontic treatment. In an orderly, step-by-step approach, important concepts are developed from chapter to chapter, with most chapters building on the previous one. From the most elementary to the most advanced concepts, examples from orthodontic appliances are used to demonstrate the biomechanical principles; thus, the book reads like an orthodontic text and not a physics treatise. Yet the principles, solutions, and terminology are scientifically rigorous and accurate.

The biomechanics described in the book are ideal for teachers and students. The simplest way to teach clinical orthodontics is to describe the force systems that are used. Clear force diagrams are far better than vague descriptions. The teaching of the past, such as “I make a tip-back bend here” or “I put a reverse curve of Spee in the arch,” is obviously lacking.

What is the best way to learn biomechanics? The simplest approach is to carefully read each chapter and to understand the fundamental principles. Then solve each of the problems at the end of the chapter. It will be quickly apparent if one genuinely understands the material. Over time, introduce biomechanics into your practice. When undesirable side effects are observed, use what has been learned to explain the problem. How could the side effect be avoided with an altered force system and appliance? Critically listening to lectures and reading articles can also be good training for developing a high level of biomechanical competence. One learns to bond a bracket quickly, but development of creative-thinking skills using biomechanics will take time.

It was the intent of the authors to write a basic book on orthodontic biomechanics that would be simple and readable. Clear diagrams and clinical cases throughout ensure that it is neither dull nor pedantic. Our philosophy is that the creative thinking involved in manipulating forces and appliance design should be fun.

Note on the metric system

The authors have adopted the metric system as their unit system of choice. However, the long shadow of American orthodontics has influenced the terminology in this book. Because the United States is the only major country not to fully adopt the metric system and is a major contributor to the literature, some units used throughout the book are not metric. Tradition and familiarity require some inconsistencies: inches are used for wire and bracket slot and a nonstandard unit—the "gram force"—is the force unit. It is our hope that the specialty of orthodontics will adhere fully to the International System of Units in the future; therefore, future editions of this book will most likely use only metric units.

Acknowledgments

This book would not have been possible without the input of many graduate students and colleagues. One of the authors (CJB) has been teaching graduate students for over 62 years. Long-term teaching has guided us both in how to most effectively present material and where most difficulties lie in acquiring biomechanical skills in a group of biologically trained orthodontists. This book could not have been developed in this manner without their intriguing questions and interaction.

Special thanks are given to the staff at Quintessence Publishing for their valuable contribution in the development of this book: Lisa Bywaters, Director of Publications; Sue Robinson, Production Manager, Book Division; and particularly Leah Huffman, our editor, who worked so hard on a difficult book combining biology, physics, and clinical practice complicated by specialized dental and physics terminologies and equations.

Dr Choy wishes to acknowledge the help he received from his wife Annie and his daughter Christa in the preparation of the manuscript. He is also grateful to his student Dr Sung Jin Kim for taking the time out of his busy schedule to review the questions and answers.

Sadly for us, after finishing this book, a giant fell.

Most of the contents of this book are based on Dr Burstone's energetic and rigorous research for more than 200 research articles. The format of this book was adapted from the lectures on biomechanics that we gave at the University of Connecticut and Yonsei University for many years. Over the last 3 years, my work with Dr Burstone to convert those lectures and ideas into this book was one of the most challenging, most exciting, and the happiest moments in my life. As one of his students, an old friend, and a colleague, I have to confess that all of the concepts in this book are his.

In the beginning, Force was created with the Big Bang. Fifteen billion years later, Newton discovered the Law of Force in the universe. However, the knowledge of how to control orthodontic force remained an occult practice that was only revealed through years of orthodontic apprenticeship. It was Dr Burstone who uncovered the magic and found the principles governing this treatment method that was once thought to be mysterious. There is no doubt that the Law of Orthodontic Force was his discovery.

I would like to share Dr Burstone's words from his last lecture with me on February 11, 2015, in Seoul: "Don't believe blindly in experience, but believe in theory, and think creatively."

My father shaped my body; you shaped my thoughts. Charles, our dearest friend, may you rest in peace.

Kwangchul Choy

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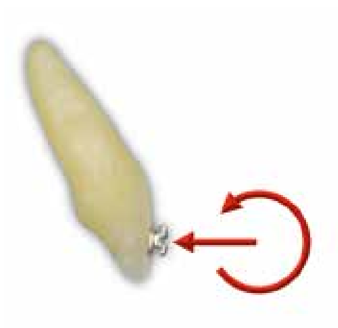
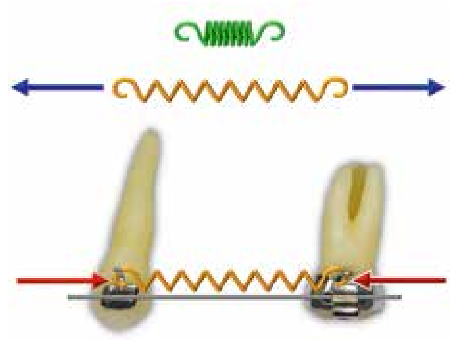
A Color Code Convention for Forces

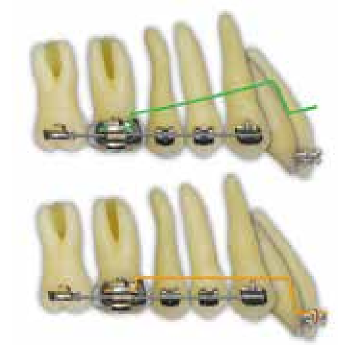
This book has several force illustrations that are used for different applications; there are activation and deactivation forces, equivalent forces, and resultant and component forces. To make it easier for the reader to understand the logical development of important concepts, a color code convention is utilized in this book. In situations where multiple forces must be shown, other colors may be utilized.



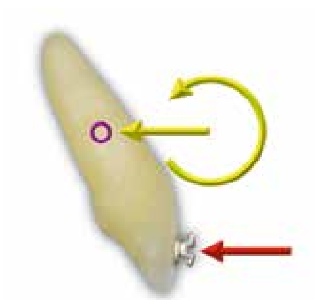
Solid straight arrows and *solid curved arrows* represent forces and moments, respectively. *Red arrows* are forces that act on the teeth. Newton's Third Law tells us that there are equal and opposite forces acting on the wire or an appliance.



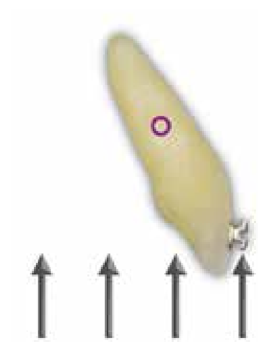
Forces acting on a wire are drawn in *blue*. In special situations, forces can act both on a wire and on the teeth; in this book, therefore, depending on the point of view, the function being considered determines the color of the arrow.



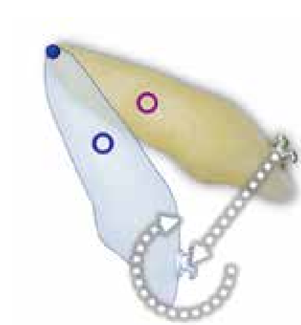
The *green* wire represents the wire in a deactivated state. The *orange* wire represents the wire in its activated state when it is elastically bent. The *gray* wire represents a rigid stabilizing archwire. This wire is regarded as a rigid body that has infinite stiffness.



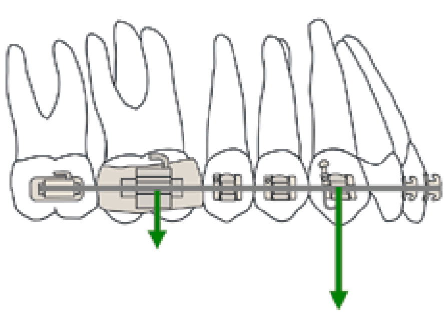
Equivalent forces such as a force and a couple or components are identified with *yellow arrows*.



Gray arrows denote unknown or incorrect forces.



Body motion including tooth motion is shown by a *dotted straight or curved arrow*. Motion arrows that describe linear and angular displacement are purposely different so that they are not confused with forces or moments. The *blue dot* represents the center of rotation.



The diagrams for the "Problems" in each chapter and their solutions at the end of the book are kept simple, so the standard code above is not used. Problem figures for emphasis show known and unknown forces as *green arrows*. Solutions are shown in *red arrows*. Equilibrium diagrams (forces acting on a wire, for example) can show force arrows in *blue* in the solution section.

PART I

The Basics and Single-Force Appliances

1

Why We Need Biomechanics

"Don't believe blindly in experience, but believe in theory, and think creatively."
—Charles J. Burstone

Dentofacial changes are primarily achieved by the orthodontist applying forces to teeth, the periodontium, and bone. Hence, the scientific basis of orthodontics is physics and Newtonian mechanics applied to a biologic system. The modern clinician can no longer practice or learn orthodontics as a trade or a technique. The orthodontist must understand forces and how to manipulate them to optimize active tooth movement and anchorage. Communication with fellow clinicians and other colleagues in other fields requires a common scientific terminology and not a narrow "jargon." There is no such thing as a unique "orthodontics physics" divorced from the rest of the scientific community. New appliances and treatment modalities will need a sound biomechanical foundation for their development and most efficient use.

Every profession has its trade tools. The carpenter uses a hammer and a saw. The medical doctor may prescribe medication and is therefore a student of proper drug selection and dosage. Traditionally, the orthodontist is identified with brackets, wires, and other appliances. Such hardware is only a means to an end point: tooth alignment, bone remodeling, and growth modification. The orthodontist achieves these goals by manipulating forces. This force control within dentofacial orthopedics is analogous to the doctor's dosages. An "orthodontic dosage" includes such quantities as *force magnitude*, *force direction*, *point of force application* (moment-to-force ratios), and *force continuity*.

Historically, because the end point for treatment is the proper force system, one might expect the development and usage of orthodontic appliances to be based on concepts and principles from physics and engineering. On the contrary, however, most appliances have been developed empirically and by trial and error. For that reason, treatment may not be efficient. Many times undesirable side effects are produced. If appliances "work," at a basic minimum the forces must be correct, which is independent of the appliance, wires, or brackets. Conversely, when bad things happen, there is a good possibility that the force system is incorrect.

These empirically developed appliances rarely discuss or consider forces. Forces are not measured or included in the treatment plan. How is it possible to use such mechanisms for individualized treatment? The answer is that they are *shape driven* rather than *force driven*. Different shapes and configurations are taught and used to produce the desired tooth movement. This approach is not unreasonable because controlled shapes can lead to defined wire deflections that relate to the produced forces. Unfortunately, there is so much anatomical variation among different patients that using a standard shape for a bracket or a wire or even modifying that shape will not always produce the desired results predictably.

An example of a shape-driven orthodontic appliance is what E. H. Angle called the *ideal arch*. In a typical application of this ideal arch, an archwire is formed with a shape so that if crooked teeth (brackets) are tied into the arch, the deflected wire will return to its original shape and will correctly align the teeth. Today, wires have been improved to deflect greater distances without permanent deformation, and brackets may have compensations to correct anatomical variation in crown morphology. The principle is the same as Angle's ideal arch, but this approach is now called *straight wire*. Straight-wire appliances can efficiently align teeth but can also lead to adverse effects in other situations. The final tooth alignment may be correct, but the occlusal plane may be canted or the arch widths disturbed. Intermediate secondary malocclusions can also occur. An understanding of biomechanical principles can improve orthodontic treatment even with shape-driven appliances by identifying possible undesirable side effects before any hardware is placed. Aligners also use the shape-driven principle of an ideal shape.

All orthodontic treatment modalities, including different brackets, wires, and techniques, can be improved by applying sound biomechanics, yet much of clinical orthodontics today is delivered without consideration of forces or force systems. This suggests that many clinicians believe that a fundamental knowledge and application of biomechanics has little relevance for daily patient care.

Scientific Biomechanics

There are many principles and definitions used in physics that are universally accepted by the scientific community. At one extreme, there is classical physics—concepts developed by giants like Newton, Galileo, and Hooke. There are also other scientific disciplines, such as quantum mechanics. What the author finds disturbing is the hubris of what is called *pseudo-biomechanics*—new physical principles developed by orthodontists that are separate and at odds with classical mechanics. Orthodontists' journal articles and lecture presentations are filled with figures and calculations that do not follow the principles of classical mechanics. Orthodontists may be intelligent, but we should not think we can compete with the likes of Newton.

There is another major advantage in adopting scientific or classical mechanics. The methodology, terminology, and guiding principles allow us to communicate with our scientific colleagues and set the stage for collaborative research. Imprecise words can confuse. We speak of "power arms," but *power* has a different meaning to an engineer than it does to a politician or a clinician. Force diagrams in orthodontic journals are difficult to decipher and may not be in equilibrium. The concepts, symbols, and terminology presented in this book are not trade jargon but will be widely recognized in all scientific disciplines.

Note that the theme of this book is orthodontic biomechanics. The "bio" implies the union of biologic concepts with scientific mechanics principles. Let us now consider some specific reasons why the modern orthodontist needs a solid background in biomechanics and the practical ways in which this background will enhance treatment efficacy.

Optimization of Tooth Movement and Anchorage

The application of correct forces and moments is necessary for full control during tooth movement, influencing the rates of movement, potential tissue damage, and pain response. Furthermore, different axes of rotation are required that are determined by moment-to-force ratios applied at the bracket. For example, if an incisor is to be tipped lingually around an axis of rotation near the center of the root, a lingual force is applied at the bracket. If the axis of rotation is at the incisor apex, the force system must change. A lingual force and lingual root torque with a proper ratio must then be applied. These biomechanical principles are relevant to all orthodontic therapy and appliances—headgears, functional appliances, sliding mechanics, loops, continuous arches, segments, and maxillomandibular elastics (also sometimes referred to as *intermaxillary elastics*). The hardware is only the means to produce the desired force system.

Equally important as active tooth movement is the control over other teeth so that they do not exhibit undesirable movements. This is usually referred to as *anchorage* and depends in part on optimally combining and selecting forces. Some orthodontists might think that anchorage is determined by factors independent of forces. For instance, the idea that more teeth means greater anchorage is very limiting. Working with forces can be more effective in enhancing anchorage, such as in pitting tipping movement against translation. All archwires produce multiple effects. Many of these effects are undesirable, which should also be considered anchorage loss. In a sense, a new malocclusion is created, resulting in an increased treatment time. Let us assume that translation of teeth could be accomplished at the rate of 1 mm per month. In a typical orthodontic patient, rarely does tooth movement exceed 5 mm. Not considering any waiting for growth, total treatment time should be no longer than 5 months. So why is treatment longer? Usually, more time is required to correct side effects. The use of temporary anchorage devices (TADs) may eliminate side effects. A good biomechanical understanding is required to successfully use TADs; otherwise, adverse effects can still occur.

Selecting or Designing a New Appliance

New appliances and variations of older existing appliances are continually presented in journal articles or at meetings. What is the best way to evaluate these appliances? One approach is to try them in your clinical practice. This evaluation will be quite limited because there is a lot of variation in a small sample of malocclusions. Moreover, it is time-consuming and unfair to the patient. Because treatment is so long term, it may take many years to arrive at a conclusion on the efficacy of a new appliance. A better approach would be an evaluation based on sound and fundamental biomechanical principles. Drawing some force diagrams is much easier than protracted treatment. This is particularly valid when considering that most new appliances and techniques do not stand the test of time.

Orthodontists have always been very creative. Not all great research has come from university research laboratories. Whether in their own offices or on typodonts in the lab, clinicians have made significant achievements in bracket design, various wire configurations, and treatment sequences (techniques). It is much more efficient to work with a pencil and a sheet of paper (or a computer) than it is to go through the demanding trial and error approach. The best appliances of the future will require rigorous engineering and sound biomechanical methodology.

Let us assume for now that we have selected the best appliance for our individual patient. There are still many variables that require a sound biomechanical decision. For example, what size wire should we use? A 0.014-inch nickel-titanium (Ni-Ti) superelastic wire is not the same as a 0.014-inch Nitinol wire. The choice between a 0.016- and a 0.018-inch stainless steel (SS) archwire is significant. The larger wire gives almost twice the force.

Research and Evaluation of Treatment Results

The clinician can be surprised at the progress of a patient. When the patient arrives for an appointment, mysterious changes are sometimes observed. Why is there now an open bite or a new reverse articulation (also referred to as *crossbite*), or why is the malocclusion not improving? These unexpected events may be attributed to biologic variation. Or it may be the wrong appliance (or manufacturer). In reality, most of the clinical problems that develop can be explained by deviation from sound biomechanical principles. Thus, an understanding of applied biomechanics allows the orthodontist to determine both why a puzzling and problematic treatment change occurred and also what to do to correct it. Sometimes the force system is almost totally incorrect; other times, a small alteration of the force system can produce a dramatic improvement.

The prediction of treatment outcomes requires precise control and understanding of the applied force system as well as the usual cephalometric and statistical techniques. Good clinical research must control all of the known variables if the efficacy of one appliance is to be compared to another. Let us consider a study that is designed to compare the different outcomes between a functional appliance and an occipital headgear. It is insufficient to simply specify headgear or even occipital headgear. Headgears can significantly vary not only in force magnitude but also in direction and point of force application. It is little wonder that some research studies lead to ambiguous and confusing conclusions.

A biomechanical approach to clinical studies opens up new avenues for research to help predict patient outcomes. The relationship between forces and tooth movement and orthopedics requires more thorough investigation. Relationships to be studied include force magnitudes, force constancy, moment-to-force ratios at the bracket, and stress-strain in bone and the periodontal ligament.

Force systems and "dosage" determine not only tooth or bone displacement with its accompanying remodeling; unwanted pathologic changes involving tissue destruction can also occur. Root resorption, alveolar bone loss, and pain are common undesirable events during treatment. Some histologic and molecular studies suggest a relationship between force or stress and tissue destruction. Although other variables may be involved, a promising direction for research is between stress-strain and the mechanisms of unwanted tissue changes. To control pain a[illegible]ous tissue destruction, it is likely that future research will validate that "dosage" does count.

How Scientific Terminology Helps

As previously discussed, orthodontic appliances work by the delivery of force systems. In this book, the methods and terminology of the field of physics are adopted. Tooth movement is only part of a subset of a broader field of physics. This allows orthodontic scientists and clinicians to communicate with the full scientific community outside of dentistry, setting the stage for collaborative research. Many of the specialized orthodontic terms produce a jargon that is imprecise and certainly unintelligible to individuals in other disciplines. The orthodontist speaks of "torque." Sometimes it means a moment (eg, the force system). At other times, however, it means tooth inclination (eg, "the maxillary incisor needs more torque"). Imprecision leads to faulty appliance use, which will be discussed later.

A universal biomechanical and scientific language is the simplest way to describe an appliance and how it works. It not only allows for efficient communication with other disciplines for joint research but also offers the best way to teach clinical orthodontics to residents or other students. The old approach was primarily to teach appliance fabrication. Treating patients was just following a technique. An adjustment was how you shaped an arch: "Watch how I make a tip-back bend, and duplicate it." Emphasis was on shape, and therefore we can call it *shape-driven orthodontics*. The biomechanical approach emphasizes principles and force systems. This approach, *force-driven orthodontics*, is the theme of this book.

With clear terminology and sound scientific principles, the learner can better understand how to fabricate and use any appliance or configuration. It shortens the time and confusion in teaching students. It is said that a number of years of experience is required to complete the education of an orthodontist. Some say as many as 10 years. Why? It is the time needed to make and learn from your mistakes. If the student understands the biomechanical basis of an appliance, many common mistakes will never be made.

It is not only the beginning student who benefits from sound biomechanical teaching. As new appliances are developed, the experienced orthodontist can better learn the "hows" and "whys" so that the learning interval is shortened. More importantly, fewer errors will be made. Lectures at meetings will be shorter and easier to understand.

FIG 1-1 Jacques Carelman painting of a pitcher. Although the pitcher looks reasonable, it will not actually pour coffee, much like some orthodontic appliances seem reasonable but do not actually work.

FIG 1-2 A wine bottle in a curved wine rack. Although it would seem that the bottle would fall over, it is in a state of static equilibrium so that it does not move. Similarly, some orthodontic principles that seem illogical are actually quite effective because they are based on sound biomechanics.

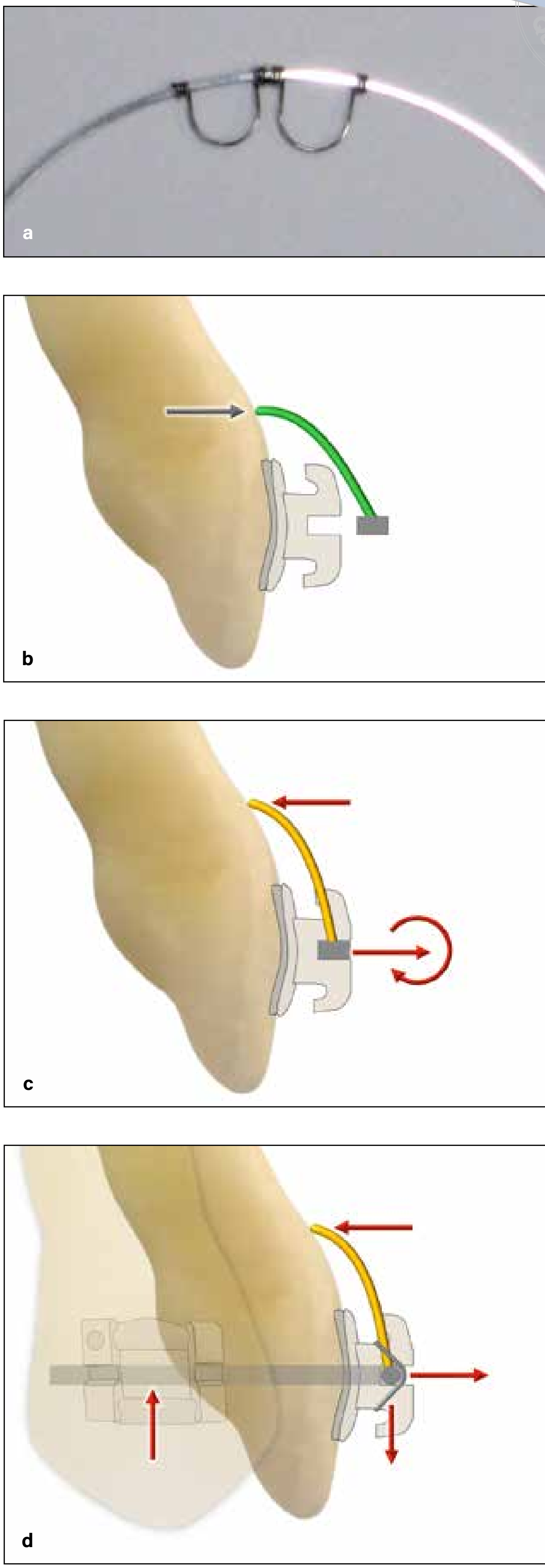
Knowledge Transfer Among Appliances

The orthodontist may feel comfortable treating with a given appliance because routine treatment has become satisfactory and predictable. However, if he or she wants to change appliances (eg, moving from facial to lingual orthodontics), the mechanics may not be the same. When lingual orthodontic appliances were introduced a few years ago, some orthodontists were troubled that their mechanics (wire configurations and elastics) did not do the same on the lingual that they did on the buccal. Biomechanical principles that determine the equivalent force system on the lingual are simple to apply. Clinicians could have saved much "learning time" spent doing trial and error experimentation. A few simple calculations covered in chapter 3 could have helped the clinician avoid any aggravation.

Advantages of Biomechanical Knowledge

Historically, there have been many exaggerated claims made by clinicians and orthodontic companies about the superiority of appliances or techniques. Hyperbole is used with such terms as *controlled*, *hyper*, *biologic*, and *frictionless*. Journals and orthodontic associations are now doing a better job of monitoring possible conflicts of interest. The best defense against unwanted salesmanship is to stay vigilant and always apply scientific biomechanics. What may look possible becomes clearly impossible when the underlying principles are understood. The pitcher in Jacques Carelman's painting looks reasonable, but it will not pour coffee (Fig 1-1). On the other hand, a sound biomechanical background can make possible what appears impossible. A filled wine bottle is placed in a curved wine rack. The rack is not glued to the table, so one might think that the bottle will tip over, but it does not (Fig 1-2). As will be discussed later, the bottle is in static equilibrium, and hence the impossible becomes possible. Figure 1-3a shows an auxiliary root spring on an edgewise arch designed to move the maxillary incisor roots to the lingual. Is this possible or impossible? A labial force is required to insert the spring (Fig 1-3b). After insertion, the spring is bent to push lingually on the cervix of the crown to produce lingual root torque. What is easily overlooked in this situation is that the rectangular wire in the slot will produce an equal and opposite force with labial root torque, making this appliance impossible (Fig 1-3c). Placing the auxiliary root spring on a round or undersized wire makes the mechanism possible (Fig 1-3d).

The many advantages of biomechanical knowledge for the clinician, including better and more efficient treatment, have been mentioned here. But what about for the patient? Obviously, one benefit is better and shorter treatment. Another significant advantage is the elimination of undesirable side effects. Side effects might require more patient cooperation. To correct problems, new elastics, headgear, surgery, or TADs may be prescribed. With better mechanics, such anchorage loss would not have happened. It is not fair to ask our patients to cover



[illegible]n auxiliary root spring on an edgewise arch designed to move the maxillary incisor roots to the lingual (before insertion). *(b)* A labial force is required to insert the spring. *(c)* After insertion, the spring is bent to push lingually on the cervix of the crown to produce lingual root torque. However, the rectangular wire in the slot will produce an equal and opposite force with labial root torque, making this appliance impossible. *(d)* Placing the auxiliary root spring on a round or undersized wire makes the mechanism possible.

up our mistakes with added treatment time or added therapy requiring considerable appliance wear, such as headgear.

The future of the profession will be determined by how well we train our residents. Currently, not all graduate students are being trained in scientific biomechanics in any depth. Ideally, when a student graduates from a program, an understanding of biomechanics should be second nature. Otherwise, he or she will not be able to apply it clinically. Lectures and problem-solving sessions are very useful; however, biomechanical principles must be applied during chairside treatment. Carefully supervised patients and knowledgeable faculty are the key ingredients to teaching biomechanics.

Conventional wisdom in orthodontics has emphasized the appliance. Graduate students and orthodontists were taught to fabricate appliances or make bends or adjustments in these appliances. Perhaps some lip service was given to biomechanics or biology, but basically the clinician was a fabricator and user of appliances. Treatment procedures were organized into a technique sequence. This empirical approach to clinical practice led to the development of different schools of thought, sometimes identified with the name of a leading clinician. Shape-driven orthodontics (where forces are not considered) is usually a standard sequence or cookbook approach that does not adequately consider the individual variation among patients.

The new wisdom is not appliance oriented. It involves a thinking process in which the clinician identifies treatment goals, establishes a sequence of treatment, and then develops the force systems needed for reaching those goals. Only after the force systems have been carefully established are the appliances selected to obtain those force systems. This is quite a contrast to the older process in which the orthodontist considered only wire shape, bracket formulas, tying mechanisms, friction, play, etc, without any consideration whatsoever of the forces produced.

It is easy for the clinician to harbor negative feelings about orthodontic biomechanics. Some may believe that treatment mechanics are only common sense and that intuition and everyday knowledge are sufficient. Others may regard biomechanics as too sophisticated, demanding, and complicated for daily practice. Indeed, many of us became dentists and orthodontists because, as students, we disliked mathematics and physics and preferred the biologic disciplines. Fortunately, the physics used in orthodontics is not complicated, and many simple principles and concepts can be broadly and practically applied. Orthodontics is not nuclear physics. Scientific biomechanical thinking is actually easier than vague and disorderly thought processes, and it simplifies our overall treatment.

The genius of pioneers such as Newton is that their principles are anything but common sense. Aristotle reasoned that if a heavy weight and a light weight were dropped from the same height, the heavy weight would hit the ground first. This seems like common sense. Galileo, on the other hand, thought that both weights would hit the ground at the same time. He supposedly dropped two different weights from the Leaning Tower of Pisa to prove his point. Many common-sense ideas are false. Common sense would tell you that the earth is flat and that the sun revolves around the earth, and yet the earth is round, and it revolves around the sun. As will be shown in this text, many of our conventional and accepted orthodontic ideas from the past are invalid.

There are many textbooks and articles that describe techniques involving different types of brackets, sequences of wire change, and slot formulas, much like a recipe in a cookbook. Many malocclusions might be successfully treated following such cookbook procedures. However, surprises can occur as unpredicted problems develop during treatment. One or more recipes will not always work because malocclusions vary so much. Therefore, the clinician must seek sound biomechanical principles rather than a technique to correct the problem. Thus, bioengineering is needed not only for the challenging situation but also for the routine patient who may show an unexpected response to an appliance. Even if we typically treat by a certain technique, we must have biomechanical knowledge and skill in reserve, which will be required when unfortunate surprises strike. If that knowledge is not readily available because we do not continually apply it, we limit our ability to get out of trouble. By way of analogy: The author recently tried to do some simple plumbing. When the house became flooded, an experienced plumber was called, and his backup knowledge and expertise solved the problem. Unfortunately, when the orthodontist gets into trouble, he or she traditionally does not seek the advice of others, leading to either a poorer result or a lengthier treatment time.

What about the “easy” case we may routinely treat successfully? It could be argued that applying creative biomechanics could also improve our treatment result or allow us to treat more efficiently. We might treat a Class II patient without extraction with some leveling arches and Class II elastics. A certain technique might work, negating any biomechanical thinking. However, the end point might be different than our treatment goals. Perhaps the mandibular incisors are undesirably flared or the occlusal plane angle steepened too much. The goals and quality of treatment can vary so much that it is difficult to define what a routine or “easy” case entails. It takes a very knowledgeable orthodontist to identify what an “easy” case really is.

Technical competence is developed by fabricating and inserting appliances, but understanding principles involves thinking. Admittedly, technical skill is important in daily practice. But performing techniques without understanding the fundamental principles behind them is risky. At the same time, principles without technique lack depth. This book therefore explains the “hows” and “whys” of orthodontic treatment, which are inseparable.

Orthodontic biomechanics is not just a theoretical subject for academics and graduate students. It is the core of clinical practice; orthodontists are biophysicists in that daily bread-and-butter orthodontics is the creative application of forces. The 21st century will be characterized by a major shift from shape-driven orthodontic techniques to a biomechanical approach to treatment, and with this shift will come rapid advancements in treatment and concepts.

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