Second Edition

TEMPORARY ANCHORAGE DEVICES in ORTHODONTICS

NANDA | URIBE | YADAV

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Temporary Anchorage Devices in Orthodontics

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SECOND EDITION

Ravindra Nanda, BDS, MDS, PhD

Professor Emeritus
Division of Orthodontics
Department of Craniofacial Sciences
School of Dental Medicine
University of Connecticut
Farmington, Connecticut, USA

Flavio Uribe, DDS, MDentSc

Burstone Professor of Orthodontics
Graduate Program Director
Division of Orthodontics
Department of Craniofacial Sciences
School of Dental Medicine
University of Connecticut
Farmington, Connecticut, USA

Sumit Yadav, DDS, MDS, PhD

Associate Professor
Division of Orthodontics
Department of Craniofacial Sciences
School of Dental Medicine
University of Connecticut
Farmington, Connecticut, USA

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Preface

The new millennium brought about a new era in orthodontics with the advent of temporary anchorage devices (TADs). The realm of possibilities to correct malocclusions that in the past were only treatable by means of orthognathic surgery was made available in a cost-effective manner through the insertion of small screws and miniplates during orthodontic treatment. Clinicians quickly became interested in adopting this new approach in their patients, and precise indications for the use of skeletal anchorage started to shape up. The first edition of *Temporary Anchorage Devices in Orthodontics*, which was compiled in the early days of skeletal anchorage, was a very timely book that introduced many aspects of this new approach. The chapters of this first book described the use of miniplates and screws with emphasis on the multiple locations of placement in the maxilla and mandible and a myriad of screw systems and appliances. The biomechanics involved with new skeletal anchorage orthodontic adjuncts was described in detail, with many case reports illustrating the expanded possibilities to correct complex malocclusions and enhance smile esthetics.

Approximately a decade has transpired since the first edition, and significant refinements to the techniques and appliances have been developed. In this second edition, we wanted to highlight these advances described by multiple authors that had been at the forefront of skeletal anchorage era since the early days. The first chapters in this edition review the biology and interaction of the titanium hardware and bone and the basic biomechanic principles that apply when using skeletal anchorage. The application of space closure, distalization, and overall molar control form palatal appliances is described in depth with different approaches. Later in the book, the versatility of miniplates and infrazygomatic mini-implants is presented by multiple authors managing cases of significant complexity. Finally, the management with skeletal anchorage of anteroposterior and vertical problems, such as the management of the Class III malocclusion, second molar protraction, anterior openbite correction, and the mechanical advantages of TADs in multidisciplinary patients, are described.

A very interesting development in skeletal anchorage presented in this new edition is the integration of three-dimensional (3D) technologies for the placement of mini-implants and the fabrication of TAD-supported appliances. With the advent of 3D-printing, precise palatal appliances are now available as described in this book with the MAPA appliance. Overall, this new approach sets a trend where the application of 3D-printing facilitates the insertion of mini-implants and the delivery of appliances in a single visit in a very precise and predictable manner. Another novel and interesting approach is the combination of clear aligner therapy with skeletal anchorage. Clear aligners are increasingly becoming the elected orthodontic appliance by adults, and a tightly coupled synergy with TADs for the treatment of more complex malocclusions in patients demanding non-visible appliances is described in this book.

We want to thank all the contributors who have invested time and effort to advance our knowledge regarding skeletal anchorage. We also appreciate the contributions of numerous individuals who are not part of this book but who have influenced all of us with their scientific publications. We hope you will enjoy reading it, and various methods of skeletal anchorage usage shown will help in efficient treatment of patients.

Ravindra Nanda
Flavio Uribe
Sumit Yadav
Farmington, Connecticut, USA

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Contributors

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Brent Allan, BDS, MDSc, FRACDS, FFD RCS (Ireland), FDS RCS (England)
Oral and Maxillofacial Surgeon
Department of Orthodontics
The University of Western Australia
Nedlands, Western Australia, Australia;
Private Practice
Leederville, Western Australia, Australia

Marcio Rodrigues de Almeida, DDS, MSc, PhD
Unopar
Orthodontics
UNOPAR
Londrina, Parana, Brazil

Un-bong Baik, DDS, MS, PhD
Second Molar Protraction and Third Molar Uprighting Head
Smile-with Orthodontic Clinic
Seoul, Republic Of Korea

John Robert Bednar, BA, DMD
Assistant Clinical Professor in Orthodontics (Ret)
Department of Orthodontic
Boston University Henry M. Goldman School of Dental Medicine
Boston, Massachusetts, USA

Kyu-Rhim Chung, DMD, MSD, PhD
Clinical Professor
Department of Orthodontics
Graduate School, Kyung Hee University
Seoul, Republic of Korea

Toru Deguchi, DDS, MSD, PhD
Associate Professor
Orthodontics
The Ohio State University
Columbus, Ohio, USA

Nejat Erverdi, DDS, PhD
Professor
Faculty of Dentistry
Department of Orthodontics
Okan University
Istanbul, Turkey

Bettina Glasl, MD
Orthodotics
Praxis Dr. Ludwig Dr. Glasl
Traben-Trarbach, Germany

Mithran Goonewardene, BDSc, MMedSc
Orthodontics
The University of Western Australia
Nedlands, Western Australia, Australia

Yasuhiro Itsuki, PhD, DDS
Private Practice
Jingumae Orthodontics
Tokyo, Japan

Seong-Hun Kim, DMD, MSD, PhD
Professor and Head
Department of Orthodontics
Graduate School, Kyung Hee University
Seoul, Republic Of Korea

Eric J.W. Liou, DDS, MS
Associate Professor
Department of Craniofacial Orthodontics
Chang Gung Memorial Hospital
Taipei, Taiwan

Luca Lombardo, DDS
Associate Professor
Postgraduate School of Orthodontics
Ferrara University
Ferrara, Italy

Björn Ludwig, PhD
Orthodontics
Praxis Dr. Ludwig Dr. Glasl
Traben-Trarbach, Germany

Giovanna Maino, DMD
Dentistry
Adjunct Professor
Postgraduate School of Orthodontics
Ferrara University;
Private practice
Vicenza, Italy

B. Giuliano Maino, MD, DDS
Postgraduate School of Orthodontics
Ferrara University and Insubria University;
Private Practice
Vicenza, Italy

Hiroshi Nagasaka, DDS, PhD
Chief
Department of Oral and Maxillo-facial Surgery
Sendai Aoba Clinic
Sendai, Japan

Ravindra Nanda, BDS, MDS, PhD
Professor Emeritus
Division of Orthodontics
Department of Craniofacial Sciences
School of Dental Medicine
University of Connecticut
Farmington, Connecticut, USA

Gerald Nelson, DDS
Clinical Professor
Orofacial Sciences
UCSF School of Dentistry
San Francisco, California, USA

Kenji Ojima, DDS, MDSc
Smile Innovation Orthodontics
Hongo Bunkyo-ku
Tokyo, Japan

Emanuele Paoletto, SDT
Certified Orthodontic Technician (COT)
Teacher
Postgraduate School of Orthodontics
Ferrara University
Ferrara, Italy;
Private practice
Thiene, Italy

Çağla Şar, DDS, PhD
Associate Professor
Private Practice
Istanbul, Turkey

Nor Shahab, MSc Orthodontics
Faculty of Dentistry
Department of Orthodontics
Istanbul Aydın University
Istanbul, Turkey

Bradley Shepherd, BDSc, MDSc, FRACDS
Prosthodontist
Department of Prosthodontics
The University of Western Australia
Nedlands, Western Australia, Australia;
Private Practice
Leederville, Western Australia, Australia

Giuseppe Siciliani, DDS
Chairman
Postgraduate School of Orthodontics
Ferrara University
Ferrara, Italy

Junji Sugawara, DDS, DDSc
Sendai Aoba Clinic
Orthodontics
Dentistry
Sendai, Japan

Aditya Tadinada, DDS, MS, MDS
Director of Student Research, Program Director of the Residency Program
Oral and Maxillofacial Radiology
UCONN School of Dental Medicine
Farmington, Connecticut, USA

Madhur Upadhyay, BDS, MDS, MDentSc
Associate Professor
Orthodontics
UCONN Health
Farmington, Connecticut, USA

Flavio Uribe, DDS, MDentSc
Burstone Professor of Orthodontics
Graduate Program Director
Division of Orthodontics
Department of Craniofacial Sciences
School of Dental Medicine
University of Connecticut
Farmington, Connecticut, USA

Sivabalan Vasudavan, BDSc, MDSc, MPH, M Orth, RCS, FDSRCS, MRACDS (Orth)
Certified Craniofacial and Cleft Lip/Palate Orthodontics
Specialist Orthodontist
Orthodontics on Berrigan
Orthodontics on St Quentin
Perth, Western Australia, Australia

Keiichiro Watanabe, DDS, PhD
Postdoctoral Researcher
Orthodontics
The Ohio State University
Columbus, Ohio, USA;
Assistant Professor
Orthodontics and Dentofacial Orthopedics
Tokushima University Graduate School
Tokushima, Japan

Benedict Wilmes, DDS, DMD, PhD
Professor
Department of Orthodontics
University of Duesseldorf
Duesseldorf, Germany

Sumit Yadav, DDS, DMD, PhD
Associate Professor
Division of Orthodontics
Department of Craniofacial Sciences
School of Dental Medicine
University of Connecticut
Farmington, Connecticut, USA

Satoshi Yamada, DDS, PhD
Chief
Department of Orthodontics
Sendai Aoba Clinic
Sendai, Japan

So Yokota, DDS, PhD
Sendai Aoba Clinic
Department of Oral and Maxillo-facial Surgery
Sendai Aoba Clinic
Sendai, Japan

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We dedicate this book to our parents for all that we have and all that we do.

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PART I

Biology and Biomechanics of Skeletal Anchorage

1. **Biomechanics Principles in Mini-Implant Driven Orthodontics**
   Madhur Upadhyay and Ravindra Nanda

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1

Biomechanics Principles in Mini-Implant Driven Orthodontics

MADHUR UPADHYAY, RAVINDRA NANDA

Introduction

The physical concepts that form the foundation of orthodontic mechanics are the key in understanding how orthodontic appliances work and are critical in designing the treatment methodologies and appliances that carry out these plans.

Mechanics can be defined as a branch of physics concerned with the mechanical aspects of any system. This can be divided into two categories:

Statics, the study of factors associated with nonmoving (rigid) systems, and

Dynamics, the study of factors associated with systems in motion: a moving car, plane etc. When the knowledge and methods of mechanics are applied to the structure and function of living systems (biology) like, for example, a tooth together with its surrounding oral architecture, it is called ***biomechanics***. It is our belief that the study of biomechanics of tooth movement can help researchers and clinicians optimize their force systems applied on teeth to get better responses at the clinical, tissue, cellular, or molecular level of tooth movement.

Approaches for Studying Tooth Movement

Two approaches are used for studying the biological and mechanical aspects of tooth movement—a quantitative approach and a qualitative approach. The ***quantitative approach*** involves describing movement of teeth or the associated skeletal structures in numerical terms. We all are familiar with terms like 3 millimeters of canine retraction, or 15 degrees of incisor flaring. However merely describing tooth movement quantitatively does not describe the complete nature of the movement. It is also important to understand the type or nature of tooth movement that has occurred. A ***qualitative*** *approach* describes movement in nonnumerical terms (i.e., without measuring or counting any parts of the performance). This approach is often followed at the clinical level or inferred from x-rays and/or stone models like tipping, translation, etc.

Both qualitative and quantitative analyses provide valuable information about a performance; however, a qualitative assessment is the predominant method used by orthodontists in analyzing tooth movement. The impressions gained from a qualitative analysis may be substantiated with quantitative data, and many hypotheses for research projects are formulated in such a manner.

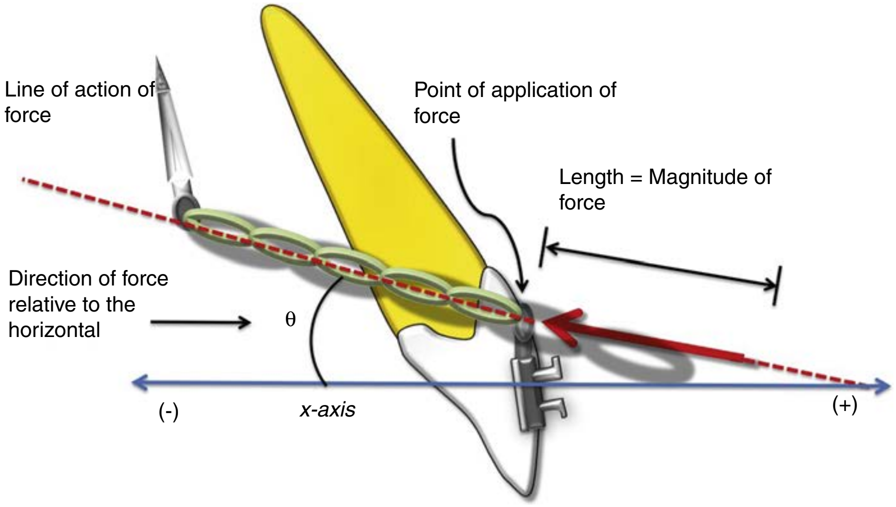
Basic Mechanical Concepts

Force

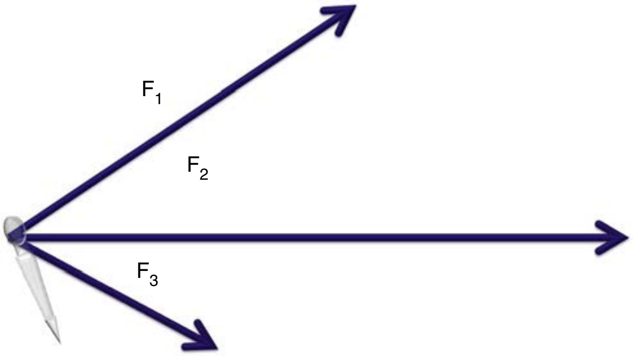
The role of force in everyday life is a familiar one. Indeed, it seems almost superfluous to try to define such a self-evident concept as force. To put it in a simple way, force can be thought of as a measure of the push or pull on an object. However, the study of mechanics of tooth movement demands a precise definition of force. A force is something that causes or tends to cause a change in motion or shape of an object or body. In other words, force causes an object to accelerate or decelerate. It is measured in Newton (N), but in orthodontics nearly always force is measured in grams (g). 1 N = 101.9 g (≈ 102 g) (see appendix).

Force has four unique properties as shown by graphic representation of a force acting at an angle to a central incisor in Fig. 1.1:

- Magnitude: how much force is being applied (e.g., 1 N, 2 N, 5 N).
- Direction: the way the force is being applied or its orientation to the object (e.g., forward, upward, backward).
- Point of application: where the force is applied on the body or system receiving it (e.g., in the center, at the bottom, at the top).
- Line of action/force: the straight line in the direction of force extending through the point of application.



• **Fig. 1.1** The four properties of an external force applied to a tooth illustrated by an elastic chain applying a retraction (distalizing) force on a maxillary incisor to a mini-implant.



• **Fig. 1.2** The length of the force vector describes the magnitude of the force vector. Example: F1 = 2 N, F2 = 3 N, F3 = 1 N.

Force Diagrams and Vectors

Physical properties (such as distance, weight, temperature, and force) are treated mathematically as either scalars or vectors. Scalars, including temperature and weight, do not have a direction and are completely described by their magnitude. Vectors, on the other hand, have both magnitude and direction. Forces may be represented by vectors.

To a move a tooth predictably, a force needs to be applied with an optimal magnitude, in the desired direction, and at the correct point on the tooth. Changing any property of the force will affect the quality of tooth displacement. A force may be represented on paper by an arrow. Each of its four properties may be represented by the arrow whose length is drawn to a scale selected to represent the magnitude of the force—for example, 1 cm = 1 N or 2 cm = 2 N, etc. (Fig. 1.2). The arrow is drawn to point in the direction in which the force is applied, and the tail of the arrow is placed at the force's point of application. The line of action of the force may be imagined as continuing indefinitely in both directions (head and tail end), although the actual arrow, if drawn to scale, must remain of a given length. A graphic representation of a force of 1 N acting at an angle of 30 degrees to a central incisor is shown in Fig. 1.1.

Principle of Transmissibility

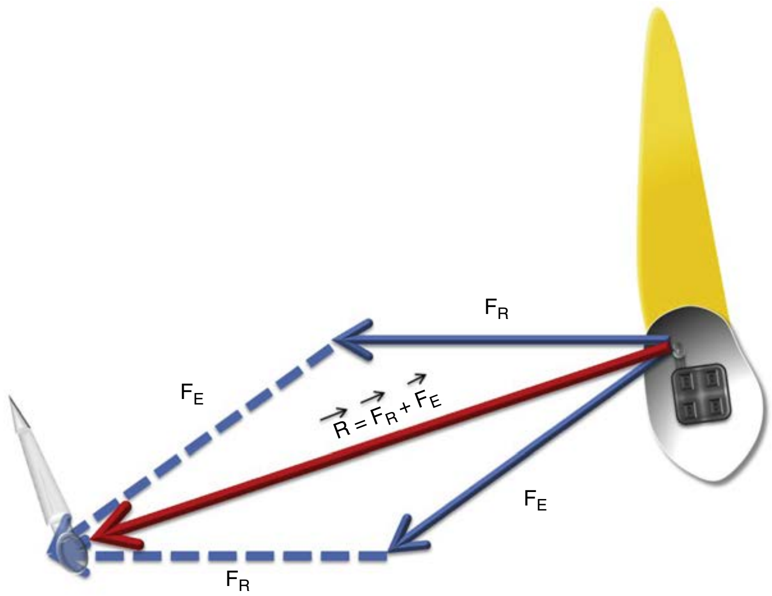
This concept is very important for vector mechanics, especially in understanding equilibrium and equivalent force systems as we will see later. It implies that a force acting on a rigid body results in the same behavior regardless of the point of application of the force vector as long as the force is applied along the same line of action.

The Effect of Two or More Forces on a System: Vector Addition

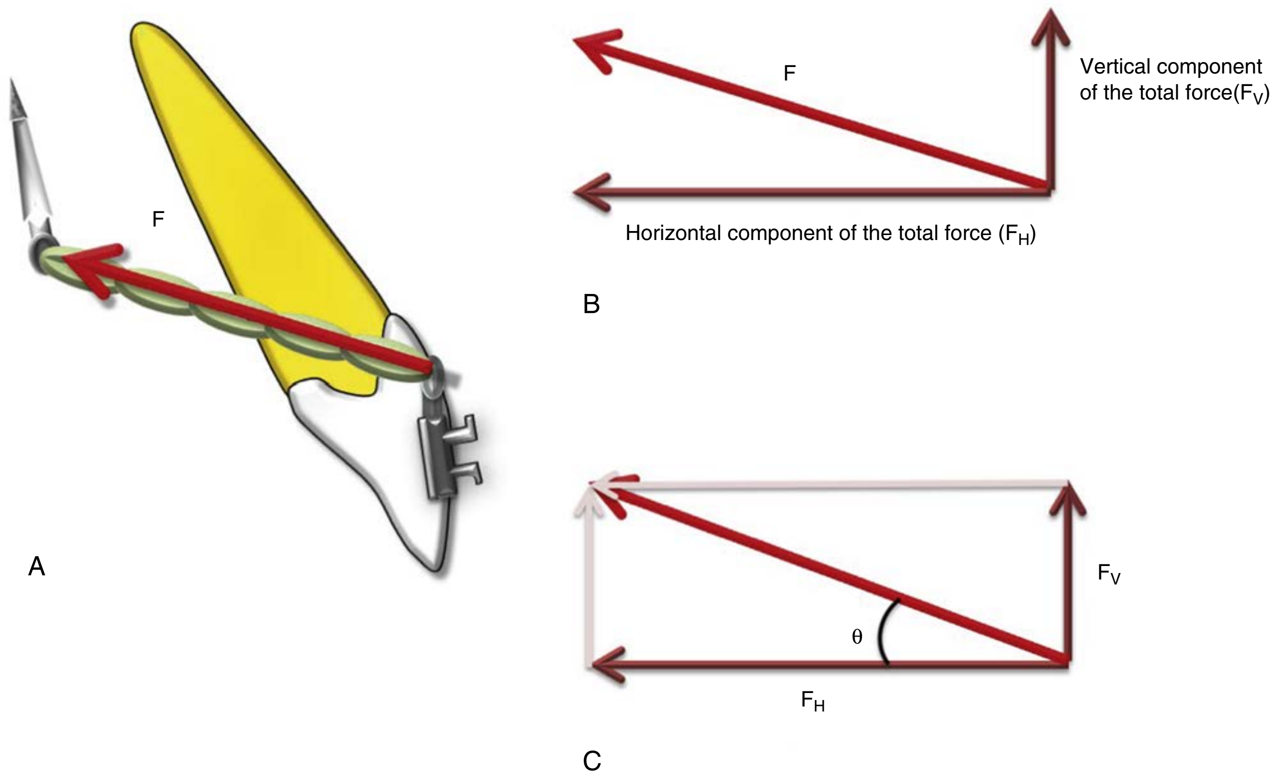
Teeth are often acted on by more than one force. The net effect or the **resultant** of multiple forces acting on a system, in this case teeth, can then be determined by combining all the force vectors. This process of combining all the forces may be found by a geometric rule called ***vector addition***, or ***vector composition***. We place the vectors head to tail, maintaining their magnitudes and directions, and the resultant is the vector drawn from the tail of the first vector to the head of the final vector. Vector addition can be accomplished graphically by drawing diagrams to scale and measuring or by using trigonometry. Fig. 1.3 shows how the two forces are visualized as two sides of a parallelogram and how the opposite sides are then drawn to form the whole parallelogram. The resultant force, R, is represented by the diagonal that is drawn from the corner of the parallelogram formed by the tails of the two force vectors.

The Directional Effects of Force: Vector Resolution

Often an occasion arises in which the observed movement of a system or single force acting on a system is to be analyzed in terms of identifying its component directions. In such cases, the single vector quantity given is divided into two components: a horizontal component and a vertical component. The directions of these components are relative to some reference frame, such as the occlusal plane or the Frankfort horizontal plane (FHP), or to some axis in the system itself. The horizontal and vertical components are usually perpendicular to each other. Such a process maybe thought of as the reverse of the process of vector



• **Fig. 1.3** Illustration showing the law of vector addition by the parallelogram method. Here, FR can be thought of as a retractive force on the incisor and FE as a force from a Class II elastics. The net effect of the two forces is represented by the resultant R.



• **Fig. 1.4** The process of vector resolution.

composition. The operation is called ***vector resolution*** and is the method for determining two component vectors that form the one vector given initially.

For example, a mini-implant as shown in Fig. 1.4A is being used for retraction of anterior teeth. It may be useful to resolve this force into the components that are parallel and perpendicular to the occlusal plane, to determine the magnitude of force in each of these directions. Resolution consists of these steps (Fig. 1.4B–C): (1) draw the vector given initially to a selected scale; (2) from the tail of the vector, draw lines representing the desired directions of the two perpendicular components; (3) from the head of the vector, draw lines parallel to each of the two direction lines so that a rectangle is formed. Note that the new parallel lines constructed have the same magnitude and direction as the corresponding lines on the opposite side of the rectangle.

It is important to note that if it is desirable to estimate the magnitude of the components, then simple trigonometric rules can be invoked to do so. The sine and cosine are in particular very useful in finding the horizontal and vertical components of the force vector. In this case if, for example, the horizontal component of magnitude F_H makes an angle θ with the force (F), we can derive the components using the definitions of sine and cosine:

Horizontal component (F_H): $F_H/F = \cos\theta$; $F_H = F \cos\theta$
Vertical component (F_V): $F_V/F = \sin\theta$; $F_V = F \sin\theta$

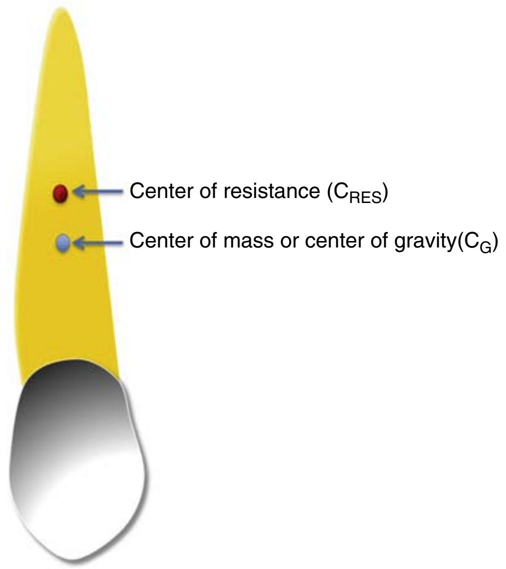
With a little practice, it is easy to get the component directly as a product, skipping the step involving the proportion. Think of sin θ and cos θ as fractions that are used to calculate the sides of a right triangle when the hypotenuse is known. The side is always less than the hypotenuse and the sine and cosine are always less than one. To get the side opposite the angle, simply multiply the hypotenuse by the sine of the angle. To get the side adjacent to the angle, multiply the hypotenuse by the cosine of the angle.

Center of Resistance, Center of Gravity, and Center of Mass

The **center of mass** of a system may be thought of as that point at which all the body's mass seems to be concentrated (i.e., if a force is applied through this point, the system or body will move in a straight line). On similar lines recall that the earth exerts a force on each segment of a system in direct proportion to each segment's mass. The total effect of the force of gravity on a whole body, or system, is as if the force of gravity were concentrated at a single point called the ***center of gravity.*** Again, if a force is applied through this point, it will cause the body to move in a straight line without any rotation. The difference between the center of mass and center of gravity is that the system in question in the latter is a 'restrained system' (restrained by the force of gravity).

Teeth are also a part of a restrained system. Besides gravity, they are more dominantly restrained by periodontal structures that are not uniform (involving the root but not the crown) around the tooth. Therefore the center of mass or the center of gravity will not yield a straight line motion if a force is applied through it because the surrounding structures and their composition alter this point. A new point analogous to the center of gravity is required to yield a straight-line motion; this is called the ***center of resistance* (C_{RES})** of the tooth (Fig. 1.5).

The C_{RES} can also be defined by its relationship to the force: a force for which the line of action passes through the C_{RES} producing a movement of pure translation. It must be noted that, for a given tooth, this movement may be mesiodistal or vestibulolingual, intrusive or extrusive. The position of the C_{RES} is directly dependent on what may be called the "clinical root" of the tooth. This concept considers the root volume, including the periodontal bone (i.e., the distance between the alveolar crest and the apex), incrementing this value with the thickness (i.e., the surface) of the root.[1]



• **Fig. 1.5** The center of resistance (C_{RES}) of a tooth is usually located slightly apical to the center of gravity (CG). The periodontal structures surrounding the tooth root cause this apical migration of the CRES.

Thus the position of the C_{RES} is also a function of the nature of the periodontal structures, and the density of the alveolar bone and the elasticity of the desmodontal structures that are strongly related to the patient's age.[2–4] These considerations implore us to speak of the "C_{RES} associated with the tooth," rather than of "the C_{RES} of the tooth."

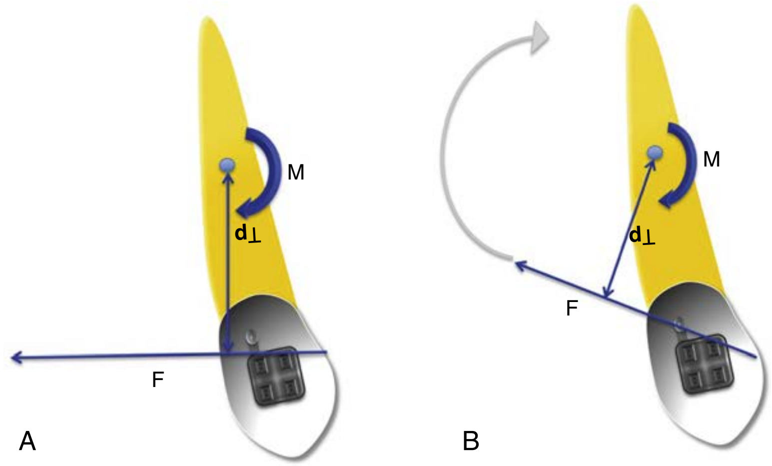
Moment (Torque)

When an external force acts on a body at its center of gravity (CG), it causes that body to move in a linear path. Such a type of force with its **line of action** through the CG or C_{RES} of a body is called a ***centric force***. On similar lines, eccentric **forces** (off-center) act away from the C_{RES} of a body.

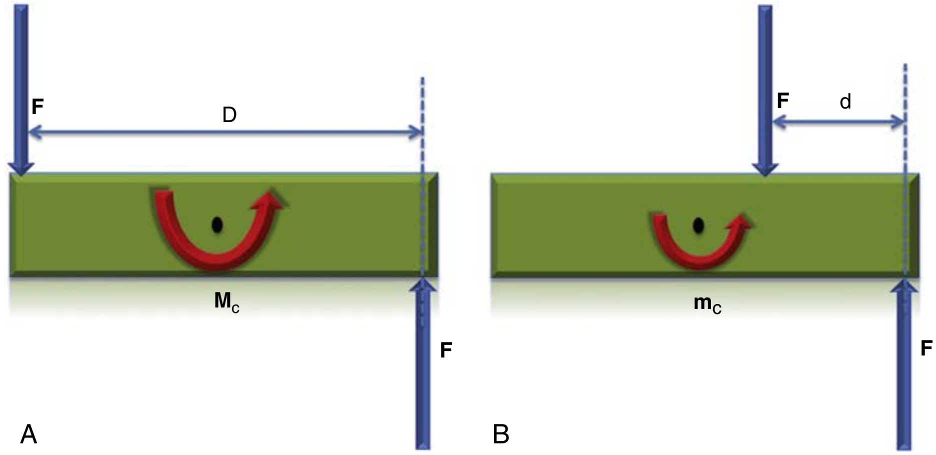
What kind of effect will these forces have? Besides causing the body to move in a linear path, it will have a turning effect on the body called *torque*, or in other words the force will also impart a **"moment"** on the body. The off-axis distance of the force's line of action is called the ***force arm*** (or sometimes the *moment arm, lever arm,* or *torque arm*). The greater this distance, the greater the torque produced by the force. The specifications of the force arm are critical. The force arm is the shortest distance from the axis of rotation to the line of action of force. Invariably the shortest distance is always the length of the line that is perpendicular (90 degrees) to the force's line of action ($d\perp$). The symbol "⊥" designates perpendicular. Force arm is critical in determining the amount of moment acting on the system.

The amount of moment (M) acting to rotate a system is found by multiplying the magnitude of the applied force (F) by the force arm distance ($d\perp$):

$M = F(d\perp)$, where F is measured in Newton and $d\perp$ in millimeter (Fig. 1.6A). Therefore the unit for moment as used in orthodontics is Newton millimeter (Nmm). As mentioned previously, often for force Newton is replaced



• **Fig. 1.6** (A) The moment of a force is equal to the magnitude of the force multiplied by the perpendicular distance from its line of action to the center of resistance. (B) The direction of the moment of a force can be determined by continuing the line of action around the center of resistance.



• **Fig. 1.7** (A) The moment created by a couple is always around the center of resistance (C_{RES}) or center of gravity (CG) (M_C = F × D). (B) No matter where the pair of force are applied, the couple created will always act around the C_{RES} or CG. As the distance between the two forces decreases (d<D), the overall magnitude of the couple decreases (m_c<M_C).

with gram (g), therefore the unit for moment becomes: Grammillimeter (gm-mm). The larger the force and/or longer the force arm, larger the moment. Because of this intrinsic relationship of the moment and the associated force, it is also known as *moment of the force* (M_F).

If forces are indicated by straight arrows, moments can be symbolized by curved arrows. With two-dimensional diagrams, clockwise moments will be arbitrarily defined as positive and counterclockwise moments negative or vice versa. Values can then be added together to determine the net moment on a tooth relative to a particular point, such as the C_{RES}.

Point of application and line of action are not needed; nor are graphic methods of addition. The direction of a moment can be determined by continuing the line of action of the force around the C_{RES}, as shown in Fig. 1.6B.

Couple (A Type of Moment)

A couple is a form of moment. It is created by a pair of forces having equal magnitudes but opposite sense (direction) to one another with noncoincidental line of action (parallel forces). Because the forces have the same magnitude but are oppositely directed, the net potential of this special force system to translate the body on which it acts is nil and there is only rotation.

A typical couple is shown in Fig. 1.7A. Although the couple's vector representation is shown midway between the two forces, the vector has no particular line-of-action location and maybe drawn through any point of the plane of the couple. Therefore a couple is also known as a *free vector*. This freedom associated with the couple vector has far reaching implications in clinical orthodontics and to certain force analysis procedures (Fig. 1.7B). As an example, no matter where a bracket is placed on a tooth, a couple applied at that bracket can only cause the tooth to feel a tendency to rotate around its C_{RES}. This is also referred to as the ***moment of the couple*** (M_C).

The magnitude of the moment of the couple (M_C) is dependent on both force magnitude and distance between the two forces. The moment created by a couple is actually the sum of the moments created by each of the two forces. Now if the two forces of the couple act on opposite sides of the C_{RES}, their effect to create a moment is additive. If they are on the same side of the C_{RES}, they are subtractive