Principles and Biomechanics of Aligner Treatment

Ravindra Nanda BDS, MDS, PhD
Professor Emeritus, Department of Orthodontics, University of Connecticut Health Center, Farmington, Connecticut, USA

Tommaso Castroflorio DDS, PhD, Ortho. Spec.
Department of Surgical Sciences, Postgraduate School of Orthodontics, Dental School, University of Torino, Torino, Italy

Francesco Garino MD, Ortho. Spec.
Private Practice, Torino, Italy

Kenji Ojima DDS, MDSc
Private Practice, Tokyo, Japan
Table of Contents

Cover image
Title page
Copyright
Dedication
Contributors
Foreword

1. Diagnosis and treatment planning in the three-dimensional era
   Introduction
   Intraoral scans and digital models
   3D imaging
   References

2. Current biomechanical rationale concerning composite attachments in aligner orthodontics
   Introduction
   Geometry (active surface orientation)
   Location
   Size
Functions

Basic attachment configurations in current aligner orthodontics

References

3. Clear aligners: Material structures and properties

   Introduction

   Polymer molecular structure and thermal properties

   Physical and chemical aging of aligner polymers

   Conclusions and outlook

   References

4. Influence of intraoral factors on optical and mechanical aligner material properties

   Introduction

   Water absorption

   Optical changes

   Short-term mechanical loading of aligner materials

   Long-term loading

   Clinical loading patterns of aligner materials

   References

5. Theoretical and practical considerations in planning an orthodontic treatment with clear aligners

   Introduction

   Theoretical and practical considerations in CAT

   Biologic considerations in aligner orthodontics

   Patient compliance

   CAT fundamentals recap
6. Class I malocclusion
   Introduction
   Diagnostic reference
   Treatment plan
   Class I conditions
   References

7. Aligner treatment in class II malocclusion patients
   Introduction
   The clinical protocol
   Maxillary distalization case reports
   References

8. Aligners in extraction cases
   Introduction
   Diagnosis and treatment plan
   Treatment progress
   Treatment results
   Discussion
   Conclusion
   References

9. Open-bite treatment with aligners
   Diagnosis of anterior open bite
   Biomechanics for anterior open-bite correction
10. Deep bite
   Introduction
   Leveling of the curve of spee
   Leveling the upper incisors
   Case report 1
   Case report 2
   References

11. Interceptive orthodontics with aligners
   Introduction
   Maxillary expansion
   Expansion case reports
   Class II malocclusion
   Mandibular advancement case reports
   Conclusions
   References

12. The hybrid approach in class II malocclusions treatment
   Introduction
   Tooth-borne hybrid approach with distalizing device
   Case report 1
13. Aligners and impacted canines

Introduction

Early diagnosis and treatment

Late diagnosis

Treatment planning and orthodontic management

Labial impactions

Palatal impactions

Clinical case

References

14. Aligner orthodontics in prerestorative patients

Introduction

Space management in the anterior region

Case study

Space management in the posterior region

Management of posterior overerupted molars

Management of patients with a history of temporomandibular disorders

Case study

References

15. Noncompliance upper molar distalization and aligner treatment for correction of class II malocclusions

Upper molar distalization in aligner treatment

Clinical procedure and rational of the Beneslider
Clinical case
Clinical considerations
Conclusions
References

16. Clear aligner orthodontic treatment of patients with periodontitis
   Malocclusions related to periodontal disease
   Orthodontic treatment in patients with periodontal disease
   Diagnosis and treatment planning
   Orthodontic movements
   Retention
   Conclusions
   Clinical case
   References

17. Surgery first with aligner therapy
   Historic background
   Splint-aided maxillary and mandibular fixation without labial fixed appliances
   Transitioning into and out of surgery with clear aligners
   Surgery first and cat
   Case study
   Conclusions
   References

18. Pain during orthodontic treatment: Biologic mechanisms and clinical management
   The importance of orthodontic pain
Biologic mechanisms of orthodontic pain and clinical correlates
Orthodontic tooth pain in clear aligner therapy
Modulators of pain: Psychological factors
Clinical considerations for the management of orthodontic pain
References

19. Retention and stability following aligner therapy
Retention and stability in orthodontic treatment
Retention protocols and the choice of retention appliance
References

20. Overcoming the limitations of aligner orthodontics: A hybrid approach
Introduction
Transverse expansion of the posterior teeth
Canine and premolar rotation
Extrusion, intrusion, and overbite control
Molar distalization
Conclusions
References

Index
Dedication

To Catherine, for her love, support, inspiration, and encouragement.

RN

To Katia, for showing me what love is and for keeping my feet on the ground. To Alessandro, Matilda, and Sveva, because you made the world a brighter place. To my friends, Francesco and Kenji, for your passion, enthusiasm, commitment, and support: you are always an example to follow. To Ravi, for your trust and friendship, for your guidance and leadership: you have translated a vision into reality. It was a wonderful journey with you; thanks for your time and for sharing your experience.

TC

I would like to dedicate this book to all my family with a special thought to my dad, mentor and a visionary, who shared with me a passion in aligner orthodontics for 20 years.

FG

My thanks to Francesco and Tommaso for sharing their friendship with me over so many years. The time I spent writing this book with Ravi was amazing, like a dream for me. I am truly grateful to my family for all of their support.

KO
Contributors

Masoud Amirkhani, PhD, Institute for Experimental Physics, Ulm University, Ulm, Germany

Sean K. Carlson, DMD, MS, Associate Professor, Department of Orthodontics, School of Dentistry, University of the Pacific, San Francisco, California, USA

Tommaso Castroflorio, DDS, PhD, Ortho. Spec. Researcher and Aggregate Professor, Department of Surgical Sciences, Postgraduate School of Orthodontics, Dental School, University of Torino, Torino, Italy Orthodontics Unit, San Giovanni Battista Hospital, Torino, Italy

Chisato Dan, DDS, Private Practice, Smile Innovation Orthodontics, Tokyo, Japan

Iacopo Cioffi, DDS, PhD, Associate Professor, Division of Graduate Orthodontics and Centre for Multimodal Sensorimotor and Pain Research, Faculty of Dentistry, University of Toronto, Toronto, Ontario, Canada

David Couchat, DDS, Ortho. Spec., Private Practice, Cabinet d’Orthodontie du dr. Couchat, Marseille, France

Fayez Elkholy, DDS, Senior Physician, Department of Orthodontics, Ulm University, Ulm, Germany

Francesco Garino, MD Ortho. Spec., Private Practice, Studio Associato dott.ri Garino, Torino, Italy

Aldo Giancotti, DDS MS, Researcher and Aggregate Professor, Department of Clinical Sciences and Translational Medicine, University of Rome “Tor Vergata”, Rome, Italy

Juan Pablo Gomez Arango, DDS, MSc, Associate Professor, Orthodontics Program, Universidad Autonoma de Manziales, Manziales, Colombia

Mario Greco, DDS, PhD
Visiting Professor, University of L’Aquila, L’Aquila, Italy
Visiting Professor, University of Ferrara, Ferrara, Italy

Luis Huanca, DDS, MS, PhD, Research Associate, Department of Orthodontics, University of Geneva, Geneva, Switzerland

Josef Kučera, MUDr., PhD
Assistant Professor, Department of Orthodontics, Clinic of Dental Medicine, First Medical Faculty, Charles University, Prague, Czech Republic
Lecturer, Department of Orthodontics, Clinic of Dental Medicine, Palacký University,
Olomouc, Czech Republic

Bernd G. Lapatki, DDS, PhD, Department Head and Chair, Department of Orthodontics, Ulm University, Ulm, Germany

Luca Lombardo, DDS, Ortho. Spec., Chairman and Professor, Postgraduate School of Orthodontics, University of Ferrara, Ferrara, Italy

Tiantong Lou, DMD, MSc, Division of Gradual Orthodontics and Centre for Multimodal Sensorimotor and Pain Research, Faculty of Dentistry, University of Toronto, Toronto, Ontario, Canada

Kamy Malekian, DDS, MSc, Private Practice, Clinica Bio, Madrid, Spain

Gianluca Mampieri, DDS, MS, PhD, Researcher and Aggregate Professor, Department of Clinical Sciences and Translational Medicine, University of Rome “Tor Vergata”, Rome, Italy

Edoardo Mantovani, DDS, Ortho. Spec., Research Associate, Department of Surgical Sciences, Postgraduate School in Orthodontics, Dental School, University of Torino, Torino, Italy

Ivo Marek, MUDr., PhD, Assistant Professor, Department of Orthodontics, Clinic of Dental Medicine, Palacký University, Olomouc, Czech Republic

Consultant, Department of Orthodontics, Clinic of Dental Medicine, First Medical Faculty, Charles University, Prague, Czech Republic

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

Kenji Ojima, DDS, MDSc, Private Practice, Smile Innovation Orthodontics, Tokyo, Japan

Simone Parrini, DDS, Ortho. Spec., Research Associate, Department of Surgical Sciences, Postgraduate School in Orthodontics, Dental School, University of Torino, Torino, Italy

Serena Ravera, DDS, PhD, Ortho. Spec., Research Associate, Department of Surgical Sciences, Postgraduate School in Orthodontics, Dental School, University of Torino, Torino, Italy

Gabriele Rossini, DDS, PhD, Ortho. Spec., Research Associate, Department of Surgical Sciences, Postgraduate School in Orthodontics, Dental School, University of Torino, Torino, Italy

Waddah Sabouni, DDS, Ortho. Spec., Private Practice, Cabinet d’Orthodontie du dr. Sabouni, Bandol Rivage, Sanary-sur-Mer, France

Silva Schmidt, DDS, Department of Orthodontics, Ulm University, Ulm, Germany

Jörg Schwarze, DDS, PhD, Ortho. Spec., Private Practice, Kieferorthopädische
Praxis Dr. Jörg Schwarze, Cologne, Germany

**Giuseppe Siciliani, MD, DDS**, **Chairman and Professor**, School of Dentistry, University of Ferrara, Ferrara, Italy

**Ali Tassi, BSc, DDS, MCID (Ortho)**, **Assistant Dean and Chair**, Division of Graduate Orthodontics, Schulich School of Medicine and Dentistry, The University of Western Ontario, London, Ontario, Canada

**Johnny Tran, DMD, MCID**, Division of Graduate Orthodontics, Schulich School of Medicine and Dentistry, The University of Western Ontario, London, Ontario, Canada

**Flavio Uribe, DDS, MDentSc**, **UConn Orthodontics Alumni/Nanda Orthodontics Endowed Chair**, Program Director and Chair, Division of Orthodontics, Department of Craniofacial Sciences, University of Connecticut, School of Dental Medicine, Farmington, Connecticut, USA

**Benedict Wilmes, DDS, MSc, PhD**, **Professor**, Department of Orthodontics, University of Düsseldorf, Düsseldorf, Germany
Aligners represent the new frontier in the art and science of orthodontics. This new frontier offers new opportunities and challenges, but also requires the need for additional knowledge. A rethinking of biomechanics and force delivery concepts is needed along with the role of materials used for aligners. There is a need for combining established concepts with new tools and technologies which aligner treatment requires.

When considering new methodologies, orthodontists should always remember that technology is a tool and not the goal. Diagnosis, treatment plan, and biomechanics are always the key elements of successful treatment, regardless of the treatment methodology. Aligner orthodontics is quite different than traditional methods with brackets and wires. Force delivery with aligners is through plastic materials. Thus, the knowledge of the aligner materials, physical properties, attachment design, and the sequentialization protocol is crucial for treatment of malocclusions. It is also imperative to understand limitations of aligner treatment and how to overcome them with the use of miniscrews and auxiliaries.

Aligner treatment requires new knowledge; the number of clinical and scientific reports about all the different aspects of aligner orthodontics is increasing year by year. This book represents an up-to-date summary of the available research in the field as well as a clinical atlas of treated patients based on the current evidence. We have made an attempt to provide benchmark for clinicians, researchers, and residents who want to improve their skills in aligner orthodontics.

We would like to express our great appreciation to all the friends and colleagues who have contributed to this book. It was a pleasure to work with all these talented orthodontists.

We would like to say thank you to the Elsevier team for their support, patience, and guidance during the challenging Covid pandemic.
List of Tables

Table 5.1  Suggested Amount of Movement per Aligner
Table 9.1  Case Study 1: Problem List
Table 9.2  Case Study 1: Treatment Objectives
Table 9.3  Case Study 1: Summary of Cephalometric Changes
Table 9.4  Case Study 2: Problem List
Table 9.5  Case Study 2: Treatment Objectives
Table 9.6  Case Study 2: Summary of Cephalometric Changes
Table 11.1 Pre- and post-treatment volumetric and linear measurements obtained in the reported cases.
Table 13.1  Factors Affecting Prognosis
Table 15.1  Cephalometric Summary
Table 16.1  Framework for Staging and Grading of Periodontitis
Table 16.2  Periodontitis Stage
Table 16.3  Orthodontic Movements And Malocclusion Features
Table 16.4  Stages of Periodontitis
Table 16.5  Grades of Periodontitis
Table 18.1  Strategies to Reduce Pain During Orthodontic Treatment
List of Illustrations

**Fig. 1.1** Steps in diagnosis and treatment planning in the digital orthodontics era.
**Fig. 1.2** Integration of cone-beam computed tomography data, facial three-dimensional scan, digital models from intraoral scans, and virtual orthodontic setup.
**Fig. 1.3** (A) Digital models and measurements obtained from cone-beam computed tomography data. (B) Digital models and measurements obtained from intraoral scans.
**Fig. 1.4** New generation of intraoral scanners with integrated near infrared (NIR) technology. (A) Itero Element 5D (Align Technology, San José, CA, USA) decays detection scheme. (B) 3Shape Trios 4 (3Shape A/S, Copenhagen, Denmark) fluorescent technology for surface decay detection (*left*) and NIR technology for interproximal decay detection (*right*).
**Fig. 1.5** Cone-beam computed tomography data elaboration for enhancing diagnosis and treatment planning.
**Fig. 1.6** Case of impacted lower canine in which the cone-beam computed tomography data are helpful in defining the right mechanics.
**Fig. 1.7** Occasional report of misunderstood right condyle neck fracture results in a 9-year-old child being prescribed cone-beam computed tomography for orthodontic reasons.
**Fig. 1.8** Airway measurements from cone-beam computed tomography data.
**Fig. 1.9** Example of cone-beam computed tomography data integration in a surgery three-dimensional planning software.
**Fig. 1.10** Cone-beam computed tomography data used to plan an orthodontic expansion in a subject with poor periodontal support (*upper*). Orthodontic expansion, corticotomies, and bone grafts were planned to obtain an excellent final result without bone dehiscence (*lower*).
**Fig. 1.11** Stereophotogrammetry (A) and laser scan (B) three-dimensional reconstructions of the face of the same patient.
**Fig. 1.12** Superimposition of the virtual setup on the smile picture of a patient with unilateral agenesis, visualizing from left to right the initial situation, the postorthodontic situation, and the final smile with restorative simulation.
**Fig. 1.13** The virtual patient in which cone-beam computed tomography data, facial three-dimensional reconstruction, and virtual setup obtained after teeth segmentation are superimposed.
**Fig. 2.1** (A) Mesial tipping moments (*red curved arrows*) produced by aligner forces (*red arrows*) occurring during space closure. Antitipping moments (*blue curved arrows*) produced by forces (*blue arrows*) acting at rectangular vertical attachments (B). Opposing moments are canceled out, promoting bodily movement.
**Fig. 2.2** The typical force couple generated during bracket-based alignment of rotated
tooth with a fully engaged 0.014 NiTi archwire consists of two force vectors: one that pushes against the posterior wall of the slot (red arrow) and a second that pulls away from the same wall (blue arrow).

**Fig. 2.3** (A) Aligner-tooth mismatch. (B) Elastic aligner deformation and activation of forces upon aligner insertion. (C) Tooth alignment after aligner sequence.

**Fig. 2.4** (A) Active surfaces of attachments. (B) Direction of forces acting at active surfaces. (C) Resultant force affecting the first premolar will produce extrusion and clockwise, second-order rotation.

**Fig. 2.5** (A) Due to the distance between the center of resistance (blue dot) and the line of action (red dotted line), large mesial tipping and negligible mesiolingual rotational moments should be expected. (B) A more mesial and apical attachment location will result in reduced mesial tipping and increased mesiolingual rotational moments, increasing clinical efficacy.

**Fig. 2.6** During expansion, labial attachment location (A) produced smaller net buccal molar tipping moments than lingually bonded attachments (B).

**Fig. 2.7** (A) Attachments located on teeth adjacent to force application increase aligner retention when using intermaxillary elastics. (B) Attachment position close to the gingival margin and occlusally beveled geometry is ideal for aligner retention.

**Fig. 2.8** (A) Multiple tangential forces (red arrows) acting during aligner-based, bicuspid rotation. (B) Due to slipping effect, incomplete expression of expected rotation with space between tooth and aligner (in yellow) will be observed.

**Fig. 2.9** (A) Properly designed attachments produce complementary force vectors required for predictable tooth movement. (B) Polymer stress relaxation and creep, along with incomplete rotation and unintended force (blue arrow), may occur during sequence of aligner-based, tooth rotation stages.

**Fig. 2.10** (A) Image from ClinCheck treatment plan. (B) Loss of tracking with incomplete expression of rotation and extrusion of left upper bicuspid. Lack of coincidence between attachment (green shaded area) and its corresponding recess in the aligner (green outline) is observed.

**Fig. 2.11** (A) Converging buccal and lingual crown surfaces. (B) Undesired aligner dislodgment during extrusive movement.

**Fig. 2.12** (A) Optimized Extrusion Attachments (Align Technology, Santa Clara, CA) on central incisors. (B) Gingivally oriented inclined plane with optimal active surface angulation.

**Fig. 2.13** (A) Forces transmitted by the aligner (red arrows) and resultant forces (purple arrows) acting on the tooth. (B) A reduction of the angle between active attachment surface and buccal tooth surface produces stronger resultant extrusive forces.

**Fig. 2.14** Intrusion in the posterior segment (red arrows) produces reactive forces that will tend to dislodge the aligner anteriorly (blue arrows). Adequate attachment selection on anterior teeth will counteract this undesired occurrence.

**Fig. 2.15** (A) Rotational forces produced by the aligner (purple arrows) are transmitted to the tooth as normal force components (red arrows), which are perpendicular to tooth surface tangents (purple dotted lines). (B) Incorporation of bonded attachment increases the magnitude and efficacy of rotational moment by increasing the perpendicular
distance (green dotted line) between the line of action (red dotted line) and the center of resistance (CRes).

**Fig. 2.16** (A) Without attachment, the tooth lagged behind the aligner almost by 30%. With attachment incorporation, this lag dropped to 5%. (B) Intrusive forces observed at the periodontal ligament without attachments was 0.078 N for every degree of rotation, while with attachments the load was reduced to 0.021 N for every degree. ATT, Attachment.

**Fig. 2.17** (A) Digital image of occlusal view of right upper canine. Occlusal view of finite element method simulation of upper right canine during mesiolingual rotation. (B) Distinctly intrusive pressure areas (red) on mesiolabial and distolingual aspects of the tooth crown appear upon aligner insertion. The dotted line represents the aligner’s profile.

**Fig. 2.18** Optimized Rotation Attachment (Align Technology, Santa Clara, CA) with active surface oriented to provide a compensatory extrusive force.

**Fig. 2.19** (A) Force couple produced during bracket-based correction of excessive mesial tip. (B) Equivalent force couple produced at Optimized Root Control Attachments (Align Technology, Santa Clara, CA) during aligner-based tipping.

**Fig. 2.20** Tooth displacement patterns during aligner-based distalization of upper right canine. (A) Without attachments, distinct uncontrolled distal tipping was observed, with center of rotation between apical and middle thirds of the root (red arrow). (B) With attachments, the canine expressed distal bodily movement.

**Fig. 2.21** Periodontal ligament strain patterns during aligner-based distalization of upper right canine. (A) Without attachments, distocervical pressure (in blue) and distoapical tension (in red) areas were observed, typical of uncontrolled distal tipping. (B) With attachments, uniform pressure along the distal root surface (in blue) and uniform tension (in red) along the medial surface, typical of distal bodily movement, were observed.

**Fig. 2.22** (A) Uprighting moment produced at single rectangular horizontal attachment. (B) Alternative twin attachment configuration.

**Fig. 2.23** Producing equivalent moments (curved arrows), an increase in intervector distance proportionately reduces force magnitude (blue arrows) acting at attachment surface. Two degrees of distal tipping with a 4-mm rectangular attachment (A) will produce higher forces on the aligner than with a two-attachment configuration that significantly separates the force vectors (B) of the acting couple.

**Fig. 2.24** Class II case in which reciprocal moments between anterior and posterior segments during extraction space closure (A) will result in 50% anchorage loss and class II occlusion (B).

**Fig. 2.25** Clockwise moments (blue curved arrows) produced by attachments bonded to posterior teeth (A) will counteract posterior anchorage loss, reducing it to 25%, resulting in class I occlusion (B).

**Fig. 2.26** (A) By preactivating (red shaded) and subsequently inserting (red) the archwire, a force couple (blue arrows) and its corresponding counterclockwise moment (blue curved arrow) will be produced. (B) The same positive torque can be achieved with aligners by producing an equivalent couple, with lower forces and increased intervector
distance.

**Fig. 2.27** (A) Aligner-based expansive force (*red arrow*) applied at a distance from the center of resistance (*CRes*) will produce counterclockwise moment (*red curved arrow*). (B) Without preventive measures, buccal tipping with center of rotation (*CRot*) above the furcation will occur, followed by aligner deformation and loss of control.

**Fig. 2.28** (A) Opposing forces (*blue arrows*) acting at the occlusal surface and gingival aspect of a rectangular horizontal buccal attachment will provide a clockwise moment (*blue curved arrow*) that reduces buccal tipping, with apical migration of the center of rotation (*CRot*) (B).

**Fig. 2.29** (A) Programmed expansive mismatch between aligner and dental arch. (B) Once inserted, the resultant expansive forces will have a distally decreasing magnitude gradient.

**Fig. 2.30** Low angle patient (A), with bilateral posterior crossbite (B, D) and midline discrepancy (C).

**Fig. 2.31** (A) Initial ClinCheck stage. (B) Aligners inserted, prior to bonding of upper palatal and lower buccal buttons. (C) Crossbite elastic.

**Fig. 2.32** A 100-gmf intermaxillary elastic force will produce a 90-gmf effective transverse force, expanding the upper arch and compressing the lower arch. Additionally, 42 gmf of extrusive force will equally influence upper and lower arches.

**Fig. 2.33** In the upper arch, the moments provided by upper buccal attachments (*blue curved arrows*) will counteract moments (*red curved arrows*) produced by elastic expansive forces (*red arrows*), reducing undesired upper tipping. In the lower arch, unopposed lingual elastic forces (*dotted red arrows*) will result in expected lingual tipping (*dotted red curved arrows*).

**Fig. 2.34** (A, B) Initial bilateral crossbite and midline discrepancy. (C, D) Aligner-based correction with complementary use of intermaxillary elastics.

**Fig. 3.1** Chemical structure of polyethylene terephthalate glycol material (PET-G).

**Fig. 3.2** Chemical structure of polyurethane material (PU).

**Fig. 3.3** Specific volume versus temperature. *Tm* represents the melting temperature and *Tg* the glass transition temperature.

**Fig. 3.4** Differential scanning calorimetry of polyethylene terephthalate glycol (PET-G).

**Fig. 4.1** Bending forces depending on the (dry or wet) storage conditions and the unloaded or loaded condition. Note 0.75-mm polyethylene terephthalate glycol (PET-G) specimens were investigated in a three-point bending setting with a span length of 8 mm at a deflection of 0.1 mm. The specimens were either only thermoformed and then underwent only one short deflection with simultaneous force, stored for 24 hours in water without loading, loaded continuously for 24 hours without water immersion, or loaded continuously for 24 hours with water immersion. The error bars represent the standard deviation for the different measurements.

**Fig. 4.2** Invisalign aligners. (A) Prior to first intraoral application. (B) After a 1-week wearing period.

**Fig. 4.3** Forces measured for 0.75-mm polyethylene terephthalate glycol (PET-G) specimens in a three-point bending setup with a span length of 8 mm. The central support was deflected by 0.1 mm. Two short loading-measuring cycles with 0.1-second
duration, separated by a 2-minute recovery break, were performed. **Fig. 4.4** (A) Forces measured during multiple 5-minute loading and 5-minute loading cycles for a 0.5-mm polyethylene terephthalate glycol (PET-G) specimen in a three-point bending setup with a span length of 8 mm and a deflection of 0.2 mm. (B) Enlargement of a data segment (see top of A) showing the gradual force decrease during the 5-minute loading time. (C) Enlargement of a data segment (see bottom of A) showing the slight force increase during the 10-minute minimal load time at the corresponding deflections. **Fig. 4.5** Average force reduction reported for polyethylene terephthalate glycol (PET-G) aligners in the course of 50 aligner seating-removal procedures based on the data published by Skaik et al. The error bars indicate the standard deviation. **Fig. 4.6** Schematic modeling of viscoelastic material behavior using a standard linear solid model. (A) Maxwell representation of a standard linear solid model. (B) Kelvin representation of a standard linear solid model. Such models combine springs and dashpots in a certain arrangement to describe the overall behavior of a system under different loading conditions. Springs represent the elastic component of a viscoelastic material, whereas dashpots represent the viscous component. Due to combination of such elements, an applied stress varies with the time-dependent change of the strain. **Fig. 4.7** Two fundamentally different experiments and parameters, respectively, describing the time-dependent behavior of a viscoelastic aligner material. (A) The creep phenomenon is observed if the load (and stress level, respectively) is kept constant over time. (B) The stress relaxation behavior is characterized by loading the material under constant strain and deflection, respectively. **Fig. 4.8** Normalized stress relaxation for polyethylene terephthalate glycol (PET-G) materials loaded for 1 week in a three-point bending setup with a constant deflection of the specimen leading to a constant strain. **Fig. 4.9** Decay of the forces measured after the loading and unloading periods during the 1-week observation time. **Fig. 5.1** Thresholds of acceptance of smile esthetics from laypeople point of view. **Fig. 5.2** Rectangular attachments on posterior teeth in CA Digital software. **Fig. 5.3** Rectangular attachments on anterior teeth in CA Digital software. **Fig. 5.4** Rectangular attachments on posterior teeth in Align Technology ClinCheck software. **Fig. 5.5** Optimized and conventional attachments in Align Technology ClinCheck software. **Fig. 5.6** Initial tooth displacement of second molar distalization with class II elastics applied directly on upper canine (sagittal view). **Fig. 5.7** Initial tooth displacement of second molar distalization with class II elastics applied directly on upper canine (occlusal view). **Fig. 5.8** Initial tooth displacement of second molar distalization with class II elastics applied on aligner at upper canine level (sagittal view). **Fig. 5.9** Initial tooth displacement of second molar distalization with class II elastics applied on aligner at upper canine level (occlusal view). **Fig. 5.10** Initial aligner displacement of second molar distalization with class II elastics applied directly on upper canine.
Fig. 5.11 Initial aligner displacement of second molar distalization with class II elastics applied on aligner at upper canine level.
Fig. 5.12 Initial tooth displacement of second molar distalization with class II elastics applied on aligner at first premolar level. Initial displacement amount is shown in the attached legend.
Fig. 5.13 Initial tooth displacement of first molar and second premolar distalization without class II elastics. The mesial shift of posterior teeth is clinically relevant.
Fig. 6.1 Biomechanical design of conventional attachments for extrusion (A) and distal rotation (B)
Fig. 6.2 ClinCheck tools to check incisor inclination.
Fig. 6.3 Pretreatment records young adult patient with severe crowding and negative premolar torque. (A-E intraoral pictures)
Fig. 6.4 Posttreatment records young adult patient with severe crowding and negative premolar torque treated with torque correction and interproximal reduction. (A-E intraoral pictures)
Fig. 6.5 (A) Pretreatment records young adult patient with narrow upper arch and smile black corridors. (B) Posttreatment records young adult patient with narrow upper arch and smile black corridors treated with upper expansion and lower torque correction.
Fig. 6.6 Double conventional attachment in case of severe rotation.
Fig. 6.7 Pretreatment records tooth size discrepancy A-D intraoral pictures.
Fig. 6.8 Posttreatment records tooth size discrepancy treated by space opening and interproximal reduction A Digital project B-E intraoral pictures.
Fig. 6.9 Cross (A-B intraoral pictures) elastics to support posterior expansion.
Fig. 6.10 Anterior contact during buccal movement for crossbite resolution.
Fig. 6.11 Pretreatment records of lateral incisor in anterior crossbite. A-D intraoral pictures
Fig. 6.12 Posttreatment records with complete correction of crossbite in reduced number of aligners. A-B intraoral pictures
Fig. 6.13 Pretreatment records of severe posterior crossbite with maxillary contraction. A-E intraoral pictures
Fig. 6.14 Posttreatment records after expansion + torque correction + interproximal reduction + bite ramps. A-E intraoral pictures F Digital setup showing bite ramps for posterior disocclusion.
Fig. 6.15 Class III elastics. A intraoral pictures B Digital Setup
Fig. 6.16 Space opening for Peg shaped restoration. A pre-treatment B digital plan C post treatment
Fig. 6.17 Pretreatment records of lateral incisor agenesis with apical distance less than 5 mm. A-D intraoral pictures E panoramic x-ray
Fig. 6.18 Posttreatment records of monolateral, lateral incisor agenesis with Invisalign and fixed sectional for root control. A-E intraoral pictures
Fig. 6.19 Pretreatment records of bilateral, lateral incisors agenesis. A-D intraoral pictures
Fig. 6.20 Posttreatment records of bilateral, lateral incisors agenesis treated by space closure and teeth reshaping. A-D intraoral pictures
Fig. 6.21 Space opening by distal tipping of molars. A pre-treatment intraoral picture B post-treatment intraoral picture with implant inserted
Fig. 6.22 Pretreatment records of overerupted upper second molar. A-B intraoral pictures C panoramic x-ray
Fig. 6.23 Posttreatment records of overerupted upper second molar treated by aligners only. A-B intraoral picture C panoramic x-ray
Fig. 7.1 Case 1 initial clinical and radiographic records.
Fig. 7.2 Case 1 frontal and sagittal views of initial ClinCheck.
Fig. 7.3 Case 1 final clinical and radiographic records.
Fig. 7.4 Case 1 frontal and sagittal views of final ClinCheck.
Fig. 7.5 Case 1 lateral x-ray comparison and cephalometric maxillary superimposition before and after therapy.
Fig. 7.6 Case 2 initial clinical and radiographic records.
Fig. 7.7 Case 2 frontal and sagittal views of initial ClinCheck.
Fig. 7.8 Case 2 upper occlusal views at the beginning, after molar distalization, and at the end of therapy.
Fig. 7.9 Case 2 end of distalization; intraoral frontal, occlusal, and sagittal views.
Fig. 7.10 Case 2 final clinical and radiographic records.
Fig. 7.11 Case 2 frontal and sagittal views of final ClinCheck.
Fig. 7.12 Case 2 lateral x-ray comparison and cephalometric maxillary superimposition before and after therapy.
Fig. 7.13 Case 3 initial clinical and radiographic records.
Fig. 7.14 Case 3 sagittal views of initial, intermediate, final pre- and postjump ClinCheck.
Fig. 7.15 Case 3 final clinical and radiographic records.
Fig. 8.1 (A) Smile appearance of the patient. (B) Frontal picture at rest. (C) Three-quarter picture at rest. (D) Three-quarter smile appearance. (E) Profile smiling. (F) Profile at rest.
Fig. 8.2 Initial intraoral pictures.
Fig. 8.3 (A) Initial orthopantomography. (B) Initial lateral x-ray.
Fig. 8.4 ClinCheck initial stage. (A) Frontal view. (B) Right view. (C) Left view. (D) Upper arch view. (E) Lower arch view.
Fig. 8.5 Schematic representation of vertical orthodontic tooth movement design in the frontal plane (A). Amount of vertical movements for upper canines and central incisors (B).
Fig. 8.6 Schematic representation of attachments and auxiliaries required in extraction cases.
Fig. 8.7 (A) Initial smile esthetic analysis. (B) ClinCheck simulation into the smile frame of the Digital Smile Design software.
Fig. 8.8 Treatment progresses in the frontal view.
Fig. 8.9 Treatment progresses in the right view.
Fig. 8.10 Treatment progresses in the occlusal views.
Fig. 8.11 Posttreatment pictures.
Fig. 8.12 Final smile esthetic analysis.
Fig. 8.13 (A) Final orthopantomography. (B) Final lateral x-ray.
Fig. 8.14 Posttreatment extraoral pictures.
Fig. 8.15 Final stage of the ClinCheck refinement.
Fig. 9.1 Optimized extrusive attachments of the Invisalign system.
Fig. 9.2 The anterior extrusive forces and reciprocal posterior intrusive forces work in synergy to correct the anterior open bite.
Fig. 9.3 Rectangular shape attachments with beveled edge toward gingiva.
Fig. 9.4 Palatal attachments and occlusal attachments on upper molars.
Fig. 9.5 Case Study 1: Initial clinical records.
Fig. 9.6 Case Study 1: Pretreatment x-ray records.
Fig. 9.7 Case Study 1: Pre- and post-ClinCheck superimposition.
Fig. 9.8 Case Study 1: Final clinical records.
Fig. 9.9 Case Study 1: Posttreatment x-ray records.
Fig. 9.10 Case Study 2: Initial clinical records.
Fig. 9.11 Case Study 2: Pretreatment x-ray records.
Fig. 9.12 Case Study 2: Pre- and post-ClinCheck superimposition.
Fig. 9.13 Case Study 2: Invisalign with temporary anchorage devices for posterior intrusion.
Fig. 9.14 Case Study 2: End of posterior intrusion.
Fig. 9.15 Case Study 2: Final clinical records.
Fig. 9.16 Case Study 2: Radiographic control and cephalometric superimposition.
Fig. 10.1 Schematic representation of the optimized bite ramps designed by Align Technology (San José, CA, USA) and embedded into aligners. They change shape and positioning along the treatment to provide optimal support to lower incisors at every stage of treatment.
Fig. 10.2 Schematic representation of pressure areas designed by Align Technology (San José, CA, USA) and incorporated into the aligner to redirect the intrusive force along the long axis of the incisor.
Fig. 10.3 Initial extraoral photos.
Fig. 10.4 Initial intraoral photos.
Fig. 10.5 (A) Initial orthopantomography. (B) Initial lateral x-ray. (C) Initial tracing.
Fig. 10.6 Treatment stages scheme illustrating the frog protocol in which alternate intrusion movements of canines and incisors are planned. On the Y axis teeth are displayed, while on the X axis treatment stages are displayed: every stage corresponds to five aligners. The blue lines indicate active movements, brown lines indicate overcorrection stages. Red arrows down indicate when attachments should be placed, while red arrows up indicate when attachments should be removed.
Fig. 10.7 (A) Initial curve of Spee. (B) Final curve of Spee.
Fig. 10.8 Final extraoral photos.
Fig. 10.9 Final intraoral photos.
Fig. 10.10 (A) Final orthopantomography. (B) Final lateral x-ray. (C) Final tracing.
Fig. 10.11 Tracing superimposition.
Fig. 10.12 Initial extraoral photos.
Fig. 10.13 Initial intraoral photos.
Fig. 10.14 (A) Initial orthopantomography. (B) Initial lateral x-ray.
In progress intraoral photos. Molar tubes were used on lower first molars for class II elastic anchorage.

Fig. 10.16 Final extraoral photos.

Fig. 10.17 Final intraoral photos.

Fig. 10.18 (A) Final orthopantomography. (B) Final lateral x-ray.

Fig. 11.1 Invisalign First optimized attachments for maxillary expansion.

Fig. 11.2 Invisalign First maxillary expansion protocol staging.

Fig. 11.3 CG intercanine widths assessed at gingival level, CC intercanine widths assessed at cusp level, cG inter-E widths assessed at gingival level, cC inter-E widths assessed at cusp level, MG intermolar widths assessed at gingival level, MC intermolar widths assessed at cusp level.

Fig. 11.4 The anterior and posterior depth of the palatal vault is defined as the vertical distance from the contact line between the cusp of the right and left canine and mesiopalatal cusp tips of the right and left first molars to the palatal vault, respectively. The palatal volume was defined by the median sagittal, distal, and gingival planes as boundaries of the palate. The distal plane (DP) passed through two points at the distal of the first upper permanent molars. The gingival plane (GP) was created by intersecting the distal and median sagittal planes (MSP) through the center of incisive papilla, which is considered a stable point structure. All planes were perpendicular to each other.

Fig. 11.5 The palatal surface area was defined by the median sagittal (MSP), distal (DP), and gingival (GP) planes as boundaries of the palate. The distal plane (DP) passed through two points at the distal of the first upper permanent molars.

Fig. 11.6 Case 1 pre- (A) and post (B) therapy scans of the maxillary arch.

Fig. 11.7 Case 2 pre- (A) and post (B) therapy scans of the maxillary arch.

Fig. 11.8 Runner appliance. Upper arch aligner (A) and lower arch aligner (B).

Fig. 11.9 Intraoral Invisalign First with mandibular advancement feature.

Fig. 11.10 Invisalign First with mandibular advancement feature. Upper arch aligner (A) and lower arch aligner (B)

Fig. 11.11 Case 3 Initial extraoral pictures.

Fig. 11.12 Case 3 initial intraoral pictures.

Fig. 11.13 Case 3 initial radiographic records.

Fig. 11.14 Case 3 sagittal view of ClinCheck.

Fig. 11.15 Case 3 final clinical records.

Fig. 11.16

Fig. 11.17 Case 3 changes of mandibular profile and cephalometric values before and after therapy.

Fig. 11.18 Case 4 initial clinical and radiographic records.

Fig. 11.19

Fig. 11.20

Fig. 11.21 Case 4 sagittal view of ClinCheck and superimposition of initial ClinCheck with final ClinCheck (occlusal view).

Fig. 11.22 Case 4 final clinical records and changes of mandibular profile.

Fig. 11.23
Fig. 11.24 Case 4 cephalometric values before and after therapy.
Fig. 12.1 Case 1. Extraoral pictures before treatment.
Fig. 12.2 Case 1. Intraoral pictures before treatment.
Fig. 12.3 Case 1. (A) Panoramic x-ray before treatment. (B) Lateral x-ray before treatment.
Fig. 12.4 Case 1. Intraoral pictures at end of sagittal first phase.
Fig. 12.5 Case 1. Intraoral pictures before additional aligner stage.
Fig. 12.6 Case 1. Extraoral pictures at end of treatment.
Fig. 12.7 Case 1. Intraoral pictures at end of treatment.
Fig. 12.8 Case 1, (A) Panoramic x-ray at end of treatment. (B) Lateral x-ray at end of treatment.
Fig. 12.9 Case 2. Extraoral pictures before treatment.
Fig. 12.10 Case 2. Intraoral pictures before treatment.
Fig. 12.11 Case 2. (A) Panoramic x-ray before treatment. (B) Lateral x-ray before treatment.
Fig. 12.12 Case 2. Intraoral pictures before sagittal first phase.
Fig. 12.13 Case 2. Intraoral pictures before additional aligner stage.
Fig. 12.14 Case 2. Extraoral pictures at end of treatment.
Fig. 12.15 Case 2. Intraoral pictures at end of treatment.
Fig. 12.16 Case 2. (A) Panoramic x-ray at end of treatment. (B) Lateral x-ray at end of treatment.
Fig. 13.1 (A–E) Early deciduous teeth extraction leads to loss of space and canine impaction.
Fig. 13.2 (A–C) Small size lateral incisors and impacted cuspids.
Fig. 13.3 (A) Missing lateral incisors and (B) bilateral cuspid impaction.
Fig. 13.4 (A–C) Back of right canine prominence in late mixed-dentition patient.
Fig. 13.5 (A, B) The orthopantomography refers to the patient in Fig. 13.4, Ericson and Kurol canine impaction analysis.
Fig. 13.6 Success rate of early deciduous canine extraction (from Ericson and Kurol).
Fig. 13.7 (A–C) Inclination of the canine on lateral cephalometric analysis; parents of this patient refused phase 1 treatment, and upper left canine impaction occurred 3 years later.
Fig. 13.8 (A, B) Canine eruption in alveolar mucosa.
Fig. 13.9 (A, B) Canine erupted labially with lack of keratinized gingiva and higher risk of recession.
Fig. 13.10 (A–E) Deep horizontal impaction may undermine the eruption with a good periodontal support.
Fig. 13.11 (A, B) Lateral incisor on the eruption path of the impacted canine.
Fig. 13.12 (A–C) Clinical case study baseline extraoral.
Fig. 13.13 (A–E) Clinical case study baseline intraoral.
Fig. 13.14 (A–G) Clinical case study baseline x-rays.
Fig. 13.15 (A–E) Clinical case study progression.
Fig. 13.16 (A–F) Clinical case study progression.
Fig. 13.17 (A–C) Clinical case study extraoral final.
Fig. 13.18 (A–E) Clinical case study intraoral final.
Fig. 13.19 (A, B) Clinical case study final x-rays.
Fig. 14.1 Initial intraoral pictures showing multiple restorations.
Fig. 14.2 Initial orthopantomograms.
Fig. 14.3 Clear aligner treatment with attachments and buttons was started. The upper front fixed restoration was sectioned prior the orthodontic treatment start. Class II elastics anchored on upper canines and lower first molars were used to reinforce canine class I relationship.
Fig. 14.4 An implant was placed in 1.2 area.
Fig. 14.5 Frontal view of 1.2 implant with (A) and without (B) aligner.
Fig. 14.6 Frontal view of the final upper anterior restoration.
Fig. 14.7 Final intraoral pictures.
Fig. 14.8 Final extraoral pictures and x-rays.
Fig. 14.9 Initial orthopantomogram of a patient for which a prerestorative orthodontic treatment was required. 12.2 and 2.2 were congenitally missing. The interdisciplinary treatment plan was designed to recover a proper interarch relationship and preparing the case for future restorations on upper front teeth and in the lower arch after the uprighting of 3.7 and intrusion of overerupted 1.7.
Fig. 14.10 Initial intraoral and ClinCheck lateral views in relation to the mesial tipping of 3.7, caused by the premature loss of 3.6.
Fig. 14.11 Initial intraoral and ClinCheck occlusal views in relation to the mesial tipping of 3.7.
Fig. 14.12 Attachment configuration used to recover a proper alignment and leveling of the arches and the uprighting of 3.7. Pontic was not prescribed in 3.6 area to increase the stiffness of the aligner.
Fig. 14.13 Final intraoral and ClinCheck lateral views with successful uprighting of 3.7.
Fig. 14.14 Final intraoral and ClinCheck occlusal views with successful uprighting of 3.7.
Fig. 14.15 Initial intraoral and ClinCheck lateral views in relation to the overeruption of 1.7, caused by the premature loss of 4.6.
Fig. 14.16 Initial intraoral and ClinCheck occlusal views of the upper arch.
Fig. 14.17 Attachment configuration used to recover a proper alignment and leveling of the arches.
Fig. 14.18 Final lateral intraoral and ClinCheck views of the right side showing intrusion and leveling of 1.7 obtained with the aid of a buccal miniscrew and a segmented auxiliary arch bonded on 1.8 and 1.6 after proper modification of the aligners. Intrusion of 1.4 was planned to level gingival edge to the 2.4 one. An implant was placed in 4.6 area during the final stages of the orthodontic treatment.
Fig. 14.19 Final intraoral and ClinCheck occlusal views of the upper arch.
Fig. 14.20 Final orthopantomogram.
Fig. 14.21 Initial intraoral pictures.
Fig. 14.22 Initial extraoral pictures and orthopantomogram.
Fig. 14.23 Initial cone-beam computed tomography scans highlighting the asymmetric condyles position.
**Fig. 14.24** Lower occlusal splint.

**Fig. 14.25** Cone-beam computed tomography scans showing condyle repositioning due to the splint effect.

**Fig. 14.26** Acrylic provisionals used to keep the new mandible position during the orthodontic treatment.

**Fig. 14.27** Initial stage of the ClinCheck.

**Fig. 14.28** Final stage of the first ClinCheck.

**Fig. 14.29** Intraoral pictures at the end of the first set of aligners.

**Fig. 14.30** (A) Lateral and (B) posteroanterior x-rays at the end of the first set of aligners.

**Fig. 14.31** Intraoral pictures at the end of the second set of aligners.

**Fig. 14.32** Final stage of the second ClinCheck.

**Fig. 14.33** (A) Final orthopantomogram and (B) lateral x-ray.

**Fig. 14.34** Intraoral pictures showing the lower implants and the final prosthodontic restorations.

**Fig. 14.35** Final extraoral pictures.

**Fig. 15.1** The Beneslider appliance is based on one or two mini-implants with exchangeable abutments.

**Fig. 15.2** The aligners can cover the bonded connection like a big attachment. After distalization, steel ligatures are to modify the active Beneslider into a passive anchorage device.

**Fig. 15.3** The aligners can be cut out in this connection area (“button cutout”). Springs are removed in this case to modify the active Beneslider into a passive anchorage device.

**Fig. 15.4** A 37-year-old female patient with an angle class II malocclusion characterized by anterior crowding and a deep bite.

**Fig. 15.5** After insertion of two Benefit mini-implants in the anterior palate (A) and installation of the Beneslider mechanics (B). Superimposition of an intraoral picture of the maxillary arch and the ClinCheck to demonstrate desired tooth movement directions (C).

**Fig. 15.6** Beneslider was activated by pushing open springs distally after delivery of the aligners. Connection areas of the Beneslider with the molars are covered by the aligner (“big attachment”).

**Fig. 15.7** Radiographs after 5 months of treatment. Ortopantomography and lateral x-ray after 5 months of treatment.

**Fig. 15.8** Intraoral pictures after 8 months.

**Fig. 15.9** Intraoral pictures after 10 months showing many small spaces due to the semisequential distalization.

**Fig. 15.10** Intraoral pictures after 12 months. Molars are distalized in a Class I occlusion. The Beneslider is modified into a molar anchorage device by two steel ligatures, which are deactivating the Beneslider. From this moment, bicuspid, canine, and incisor retractions are following.

**Fig. 15.11** Intraoral pictures after 14 months.

**Fig. 15.12** Upper arch after 15 months. All spaces were to be closed to the distal. Subsequently, the Beneslider was removed for refinement.
Fig. 15.13 Treatment result after 19 months.

Fig. 15.14 Superimposition of before and after cephalograms (S-N). Upper incisor retraction is significant.

Fig. 16.1 Pathologic tooth migration in an old man.

Fig. 16.2 Pathologic tooth migration in a young woman. (A) Intraoral picture highlighting the tissue breakdown. (B) Extraoral picture (please note the position of element 2.1). (C) Scheme representing tissue breakdown.

Fig. 16.3 Transseptal fibers balance loss and pathologic tooth migration.

Fig. 16.4 Preliminary evaluation of an ortho-perio patient.

Fig. 16.5 In this class II adult patient, incisors are crowded, extruded, and proclined. Soft and hard tissue grafting can be helpful before orthodontic treatment to prevent the development of recessions.

Fig. 16.6 In this adult patient, a previous excessive orthodontic expansion promoted a gingival recession on teeth 13 and 23. The occlusal instability has led to orthodontic relapse.

Fig. 16.7 Orthodontic relapse in a young patient; teeth 33, 32, and 43 are located outside the buccal bone. The twisted retainer, probably not passive, allowed a radicular torque movement on tooth 32 that promoted a gingival recession with lack of adherent gingiva.

Fig. 16.8 Different tooth shapes.

Fig. 16.9 Center of resistance variation in case of bone loss.

Fig. 16.10 In this patient, a stainless steel power-arm has been bonded to tooth 12, and retraction has been performed using maximum anchorage.

Fig. 16.11 Mesialization of lower third molars.

Fig. 16.12 Selective intrusion of worn teeth.

Fig. 16.13 Baseline intraoral view.

Fig. 16.14 Baseline smile.

Fig. 16.15 Working contacts.

Fig. 16.16 Baseline status.

Fig. 16.17 Baseline periodontal chart.

Fig. 16.18 Reevaluation chart.

Fig. 16.19 (A) Tooth-by-tooth diagnosis. (B) Tooth-by-tooth prognosis.

Fig. 16.20 Periodontal status and chart at reevaluation.

Fig. 16.21 Regenerative therapy on tooth 14. (A) Bone sounding, (B) incisional photos, (C) flap photos.

Fig. 16.22 Regenerative therapy on tooth 14: biomaterial photos. (A) Defect cleaning. (B) Emdogain (EMDs). (C) Pref Gel (EDTA). (D) BioOss.

Fig. 16.23 Regenerative therapy on tooth: suture photos.

Fig. 16.24 Regenerative therapy on incisors. (A) Incision photos and, (B) flap photos.

Fig. 16.25 Regenerative therapy on incisors: biomaterial photos. (A) Defect cleaning. (B) Emdogain (EMDs). (C) Pref Gel (EDTA). (D) BioOss.

Fig. 16.26 Osseous resective surgery 6-degree sextant. Alternative therapies: periodontal supportive therapy, conservative surgery, resective bone surgery.
Fig. 16.27 Resective surgery: bone remodeling.
Fig. 16.28 Orthodontic records.
Fig. 16.29 ClinCheck beginning (A) and end (B): frontal view.
Fig. 16.30 ClinCheck beginning (A) and end (B): upper arch.
Fig. 16.31 ClinCheck beginning (A) and end (B): lower arch.
Fig. 16.32 ClinCheck beginning (A) and end (B): right side.
Fig. 16.33 ClinCheck beginning (A) and end (B): left side.
Fig. 16.34 End of preprosthetic orthodontics.
Fig. 16.35 Implant 1.5, 1.7.
Fig. 16.36 Implant placement.
Fig. 16.37 Implant placement photos.
Fig. 16.38 Implant placement: biomaterials. (A) Bony window. (B) Sinus membrane elevation. (C) BioOss. (D) BioOss and membrane positioning.
Fig. 16.39 Final orthodontic x-rays.
Fig. 17.1 Surgical splint with holes to be used in a patient undergoing orthognathic surgery using Invisalign as the only appliance for orthodontic treatment. Note that no labial orthodontic appliances are present.
Fig. 17.2 Surgical final splint without occlusal coverage to be left for 4 to 5 weeks postsurgically due to a three-piece-maxilla osteotomy.
Fig. 17.3 Three-dimensional virtual surgical plan. (A) Presurgery. (B) Planned osteotomies consisting of three-piece-maxilla with impaction of the posterior segments and mandibular advancement with genioplasty.
Fig. 17.4 Postsurgical occlusion deviating slightly from the planned occlusion. A) Right buccal, B) Left buccal, C) frontal occlusal views.
Fig. 17.5 Occlusion seated with intermaxillary elastics and clear aligners to the planned outcome after 3 months. A) Right buccal, B) Left buccal, C) frontal occlusal views.
Fig. 17.6 Pretreatment extraoral photos. A) Frontal lips relaxed, B) smile, C) profile, D) Oblique, E) Oblique smiling views.
Fig. 17.7 Pretreatment intraoral photos. A) Right buccal, B) Frontal, C) Left buccal occlusion. D) Maxillary and E) Mandibular occlusal views.
Fig. 17.8 Pretreatment digitized lateral cephalogram.
Fig. 17.9 Pretreatment panoramic radiograph.
Fig. 17.10 (A) Three-dimensional (3D) virtual surgical plan presurgery. (B) Landmark changes with the planned surgery in 3D. (C) Counterclockwise rotation of the maxillomandibular complex.
Fig. 17.11 Planned postsurgical occlusion with overcorrection. A) Right buccal, B) Frontal, C) Left Buccal views of the planned occlusion.
Fig. 17.12 Extraoral photos 2 weeks postsurgery. A) Frontal, B) Profile, and C) Smiling views.
Fig. 17.13 Intraoral photos 2 weeks postsurgery. A) Right buccal, B) Frontal and C) Left buccal views of patient in occlusion.
Fig. 17.14 Reduction of facial swelling 2 months postsurgery. A) Frontal, B) Profile, and C) Smiling views.
Fig. 17.15 Intraoral photos 2 months postsurgery. A) Right buccal, B) Frontal, and C)
Left buccal views.

**Fig. 17.16** Lateral open bite on the right is still present 5 months after surgery. A) Right buccal, B) Frontal, and C) Left buccal views of patient in occlusion.

**Fig. 17.17** Cantilever arm extended from bonded lower right molar tube to upright this tooth using an elastic from the maxillary miniscrews; aligner cut distal to the lower right canine to allow eruption of the buccal segment.

**Fig. 17.18** Extraoral photos 12 months postsurgery.

**Fig. 17.19** Intraoral photos 12 months postsurgery. A) Right buccal, B) Frontal, and C) Left buccal views of patient in occlusion.

**Fig. 17.20** Posttreatment extraoral photos. A) Frontal, B) Smiling and C) Profile views.

**Fig. 17.21** Posttreatment intraoral photos. A) Right buccal, B) Frontal, and C) Left buccal views of patient in occlusion. D) Maxillary and E) Mandibular occlusal views.

**Fig. 17.22** Posttreatment lateral cephalogram.

**Fig. 17.23** Posttreatment panoramic radiograph.

**Fig. 17.24** Superimposition of the skeletal and soft tissue changes.

**Fig. 18.1** Trajectory of dental pain after orthodontic procedures.

**Fig. 19.1** Examples of relapse after orthodontic treatment, where either the patient failed to wear the retention appliances after rapid maxillary expansion (A-C) or the retention regime selected was insufficient for a noncompliant patient; the rotational relapse of lateral incisors (D-F) and palatal movement of upper left canine (G-I) shown could have been prevented by bonding a fixed retainer and including problematic teeth.

**Fig. 19.2** Calculus accumulation and gingival inflammation around the lower bonded retainer (A and B).

**Fig. 19.3** Examples of failures of bonded retainers. (A) The detachment of a composite resin layer is usually a consequence of bonding errors. (B) The loss of the adhesive layer due to mastication or premature contact on the bonded retainer. (C) Premature contact on the retainer wire, wire fatigue, or selection of a wire with insufficient mechanical properties (small diameter dead-soft wire) resulting in fracture of the wire. (D) Extending the upper retainer to the canines increases the risk of fracture, with consequent wire activation and unwanted tooth movement.

**Fig. 19.4** Two distinct types of unexpected complication of lower bonded retainers: opposite torque on two adjacent incisors (X effect; A, B) and opposite inclination of contralateral canines (Twist effect; C, D). Both X effect and Twist effect may be accompanied by severe gingival recession (A, C).

**Fig. 19.5** Unexpected complication of lower bonded retainer (Twist effect): lower left canine moving out of the bony envelope (A-C). Significant bony dehiscence can be identified on dental cone-beam computed tomography (B, C).

**Fig. 19.6** Treatment of a complication associated with a lower bonded retainer. (A-C) Lower left central and lateral incisors severely proclined by a fractured bonded retainer and lingual gingival recessions occurring on both incisors. (D-F) Retreatment with a full lower fixed appliance corrected the torque of the incisors and was followed by a periodontal reconstructive surgery. (G-I) Final reconstruction with full porcelain crowns and bonding of a new lower fixed retainer.

**Fig. 19.7** When long-term retention is indicated, regular recalls are necessary to check
retainers; however, attendance of patients decreases in the retention period, as seen on this graph.

**Fig. 19.8** Hawley retainer with frontal bite plane in occlusal (A), front (B), and lateral (C) views.

**Fig. 19.9** Vacuum-formed thermoplastic retainer in the upper jaw in frontal view (A) and smile (B).

**Fig. 19.10** Retention activator after class II treatment in lateral right (A), frontal (B), and lateral left (C) views.

**Fig. 19.11** Different types of commonly used fixed retainers. Upper retainers can include incisors only (A), or even both canines, either continuous (B) or segmented (C); the segmented version is more suitable because premature contact on the retainer can be avoided, thereby decreasing both the incidence of fracture and the adhesive layer. (D) Lower fixed retainer usually includes canines and incisors. Vestibular retainers can be used after difficult extraction space closure (E) or as a space maintainer prior to implant placement (F).

**Fig. 19.12** Examples of typical indication in which use of fixed retainers is recommended. (A, B) Difficult extraction space closure. (C, D) Large midline diastema closure in a periodontally compromised patient. (E, F) Space closure in a patient with generalized spacing. (G, H) Severe crowding and tooth rotations.

**Fig. 19.13** (A, B) Lateral open bite often occurs after aligner treatment. (C, D) The clinical picture at the end of treatment may thus differ when compared to the final situation depicted in the treatment planning software. (E, F) However, the clinical situation after 2 years in recall shows that the teeth will eventually settle into the desired position.

**Fig. 19.14** Natural settling of teeth after orthodontic treatment in recall after 6 months, as visualized on T scans of a patient wearing a Hawley retainer at nighttime (A, B) and a thermoplastic retainer (C, D).

**Fig. 19.15** Treatment of an open bite with aligners that was facilitated by intrusive force in the lateral segments.

**Fig. 19.16** Relapse of anterior open bite due to short retention thermoplastic retainers and consequent extrusion of second molars. Situation after treatment (A-C) and 1.5 years in recall (D-F).

**Fig. 19.17** Treatment planning software can be used to plan the position of lower incisors exactly, avoiding unwanted proclination of the lower incisors and thus preventing the risk of relapse.

**Fig. 20.1** Initial intraoral photographs of adult patient with class I malocclusion dentoalveolar contraction in both arches.

**Fig. 20.2** Intraoral photographs during aligner therapy with composite buttons.

**Fig. 20.3** Final intraoral photographs after 20-step aligner treatment.

**Fig. 20.4** Initial intraoral photographs of a young patient with skeletal and dental class III and narrow upper jaw.

**Fig. 20.5** Rapid palatal expansion with arms for Delaire mask on deciduous second molars.

**Fig. 20.6** Hybrid expander with dental and skeletal anchorage in upper jaw and arms for Delaire mask.
Fig. 20.7 Intraoral photograph during aligner therapy.
Fig. 20.8 Final intraoral photographs after 11-step aligner treatment.
Fig. 20.9 Initial intraoral photographs of adult patient with skeletal contraction of upper jaw, class III tendency and gingival recession in both arches.
Fig. 20.10 Rapid palatal expansion with skeletal anchorage (MAPA method).
Fig. 20.11 Intraoral photograph during aligner therapy.
Fig. 20.12 Final intraoral photographs after aligner therapy.
Fig. 20.13 Initial occlusal intraoral photographs of an adult patient with severe rotation of the upper incisors (A) and right lower canine (B).
Fig. 20.14 Occlusal intraoral photographs during treatment with composite buttons on the lingual surfaces of teeth 1.3, 2.1, 2.2, and 4.3.
Fig. 20.15 Intraoral photograph during aligner therapy.
Fig. 20.16 Final intraoral photographs after 20-step aligner treatment.
Fig. 20.17 Initial photographs of a young patient with rotation greater than 20 degrees of left upper canine and left second premolar.
Fig. 20.18 Application of microtubes on rotated, mesial, and distal teeth.
Fig. 20.19 Occlusal photographs. (A) Upper arch with thermal NiTi 0.013 sectional. (B) Upper arch with aligner covering thermal NiTi 0.013 sectional. (C) Lower arch with thermal NiTi 0.013 sectional. (D) Occlusal photograph of lower arch with aligner covering thermal NiTi 0.013 sectional.
Fig. 20.20 Final intraoral photographs after seven-step aligner treatment.
Fig. 20.21 Initial intraoral photographs of young patient with anterior open bite and maxillary contraction.
Fig. 20.22 Bite-block expander with anterior grille.
Fig. 20.23 Frontal intraoral photograph after the first stage of treatment with palatal expander and grille.
Fig. 20.24 Intraoral photograph during aligner therapy.
Fig. 20.25 Final intraoral photographs after 10-step aligner treatment.
Fig. 20.26 Initial intraoral photographs of a young patient with deep bite and class II.
Fig. 20.27 Lateral intraoral photograph during aligner therapy combined with class II elastics.
Fig. 20.28 Final intraoral photographs after 14-step aligner treatment.
Fig. 20.29 Right initial intraoral photograph of a patient with class II subdivision and contraction of the upper jaw.
Fig. 20.30 Lateral intraoral photograph during aligner therapy combined with class II elastics.
Fig. 20.31 Right lateral intraoral photograph lateral after aligner treatment.
Fig. 20.32 Left initial intraoral photograph of a patient with class II subdivision and contraction of the upper jaw.
Fig. 20.33 Rapid palatal expansion and pendulum with skeletal anchorage (MAPA method).
Fig. 20.34 Lateral intraoral photographs during aligner therapy (A) and combined with class II elastics (B).
Fig. 20.35 Left lateral intraoral photograph after aligner therapy.