



One book, one tree: In support of reforestation worldwide and to address the climate crisis, for every book sold Quintessence Publishing will plant a tree (<https://onetreepanted.org/>).

Library of Congress Cataloging-in-Publication Data

Names: Tai, Sandra Khong, author.

Title: Clear aligner technique / Sandra Khong Tai.

Description: Second edition. | Batavia, IL : Quintessence Publishing, [2025] | Includes bibliographical references and index. | Summary: "Explains how to use clear aligners to treat various malocclusions, including Class II growth modification and early interceptive treatment, and teaches clinicians how to program a suitable treatment plan using the available software, how to design the digital tooth movements to match the treatment goals, and finally how to execute the treatment clinically and finish the case well"-- Provided by publisher.

Identifiers: LCCN 2024057836 | ISBN 9780867159516 (hardcover)

Subjects: MESH: Tooth Movement Techniques--methods | Orthodontic Retainers | Orthodontic Appliances, Removable

Classification: LCC RK521 | NLM WU 400 | DDC 617.6/43--dc23/eng/20250129

LC record available at <https://lcn.loc.gov/2024057836>



© 2025 Quintessence Publishing Co, Inc

Quintessence Publishing Co, Inc
411 N Raddant Road
Batavia, IL 60510
www.quintessence-publishing.com

5 4 3 2 1

All rights reserved. This book or any part thereof may not be reproduced, stored in a retrieval system, or transmitted in any form or by any means, electronic, mechanical, photocopying, or otherwise, without prior written permission of the publisher.

Editor: Leah Huffman

Production: Angelina Schmelter

Design: Sue Zubeck

Printed in Croatia

CLEAR ALIGNER TECHNIQUE

SECOND
EDITION

Sandra Khong Tai, BDS, MS

Clinical Assistant Professor in Orthodontics
Faculty of Dentistry
University of British Columbia
Vancouver, British Columbia, Canada

Adjunct Clinical Assistant Professor in Orthodontics
Arthur A. Dugoni School of Dentistry
University of the Pacific
San Francisco, California

Certified Specialist in Orthodontics
Private Practice
Vancouver, British Columbia, Canada



QUINTESSENCE PUBLISHING

Berlin | Chicago | Tokyo
Barcelona | London | Milan | Paris | Prague | Seoul | Warsaw
Beijing | Istanbul | Sao Paulo | Sydney | Zagreb

Contents

Preface *vi*

Acknowledgments *vii*

Dedication *viii*

1	A BRIEF HISTORY OF THE ORTHODONTIC APPLIANCE	1
2	A COMPARISON BETWEEN FIXED APPLIANCES AND CLEAR ALIGNERS	7
3	CASE SELECTION FOR CLEAR ALIGNER TREATMENT	17
4	DIGITAL WORKFLOW AND MONITORING TREATMENT	27
5	DIGITAL TREATMENT PLANNING AND SOFTWARE DESIGN	37
6	STAGING TOOTH MOVEMENTS IN THE DIGITAL SOFTWARE PLAN	57

7	TROUBLESHOOTING, FINISHING, AND RETENTION	75
8	RESOLUTION OF SPACING AND CROWDING	99
9	DEEP BITE TREATMENT	123
10	ANTERIOR OPEN BITE TREATMENT	139
11	CLASS II TREATMENT	155
12	CLASS II GROWTH MODIFICATION WITH CLEAR ALIGNERS	183
13	CLASS III TREATMENT	207
14	EARLY INTERCEPTIVE TREATMENT	229

Preface

The first edition of *Clear Aligner Technique* has become the authoritative text on clear aligner treatment since it was published in English in 2018. The world of clear aligners has changed exponentially since then, with numerous clear aligner systems in the market today. And yet the principles of moving teeth—such as biomechanics, anchorage, and occlusion—based on a proper diagnosis and treatment plan remain timeless. This textbook should be a valuable resource to any clinician, regardless of the aligner system employed in their practice, as the principles of moving teeth and staging tooth movements with aligners described in this text may be applied universally to any aligner system.

This second edition of *Clear Aligner Technique* is a beautifully updated version of the original and definitive text on clear aligner treatment. Chapter 3 on case selection and chapter 4 on digital workflow have been completely rewritten to reflect the integration of digital imaging, 3D CBCT treatment planning, and treatment visualization. In the chapters on Class II and Class III treatment, the concept of combining anteroposterior (AP) protocols with vertical protocols for deep bite and open bite treatment is introduced to assist the clinician in formulating an effective treatment plan for different types of malocclusions. An entire chapter is also devoted to Class II growth modification with clear aligners. Finally,

the last section of the textbook is entirely new with a focus on early interceptive treatment including maxillary skeletal expansion. There are a total of 32 case reports to illustrate the principles taught in the text. Each case report has a QR code that leads to an accompanying video that demonstrates the digital treatment plan design, including staging patterns, attachment design, and final occlusal plan. In the years since the first edition, numerous research studies that contribute to our understanding of how clear aligners work have been published. As such, the bibliography has been updated to reflect these latest research publications.

In our rapidly evolving world with artificial intelligence, 3D simulations for both soft tissue and tooth movements with CBCT integration, and improved software algorithms, we are now able to treat almost every type of malocclusion with clear aligners. More complex cases may be treated with a hybrid approach in conjunction with auxiliaries like segmental brackets or temporary anchorage devices. There is limitless potential for the future of orthodontics. Integrating digital technology into our orthodontic practices helps us deliver superior clinical outcomes. I invite you to step into the future of digital orthodontics in clear aligners together with me.

The future is clear!

Acknowledgments

I would like to express my gratitude and appreciation to all who helped in realizing the second edition of *Clear Aligner Technique*. Firstly, Dr Charlene Tai Loh, who is also my partner in the practice, for incorporating the latest research studies on clear aligners in the bibliography. To my team at Astra Orthodontics, who helps us deliver the excellent clinical outcomes you see in this text. A special thank you to Dr Heesoo Oh for her assistance in the cephalometric superimpositions for chapter 12.

I am also deeply grateful to the team at Quintessence Publishing for their expertise in making sure this book meets the highest standards of quality. Their photographic reproduction truly sets the

standard for all dental publications. It is through their efforts that the first edition was translated into 13 languages, making this critical resource available to thousands of doctors globally.

Finally, I am truly inspired by all the doctors around the world who came up to me with copies of the first edition of *Clear Aligner Technique* that had been studied, highlighted, and underlined, with written notes in the margins, showing how this valuable resource and knowledge have been instrumental in transforming their lives, their practices, and their patients' smiles. Thank you for pushing the boundaries of innovation together with me.

Dedication

To my daughter, Charlene Tai Loh—you exemplify the next-generation orthodontist. I am inspired by your perseverance, compassion, and dedication in your life's journey. May your passion for creating beautiful smiles transform the lives of many.

To my husband, Merv Chia, my partner in love and life—your unwavering love and support have encouraged me to pursue my dreams. In every challenge, you have been my strength; in every joy, you have been my rock. Thank you for standing with me and believing in me.

01

A BRIEF HISTORY OF THE ORTHODONTIC APPLIANCE

In this chapter:

Fixed Appliances 1

Clear Aligners 3

Future Directions 4

Fixed Appliances

The history of orthodontics dates back more than 2,000 years, making it the oldest specialty in the field of dentistry. Around 300 to 500 BC, Hippocrates and Aristotle reflected on different ways to straighten teeth and address various other dental conditions. Excavations from the Etruscan period revealed human mandibles with wire ligatures and bands splinting teeth together (Fig 1-1). In 1728, Pierre Fauchard, known as the “father of modern dentistry,” published a book called *The Surgeon Dentist*. In the chapter on orthodontics, he proposed a horseshoe-shaped piece of precious metal that helped to expand the dental arch, known as *Fauchard's bandeau* (Fig 1-2). It was ligated to the teeth with wire ligatures and expanded the dental arches to move the teeth into alignment.

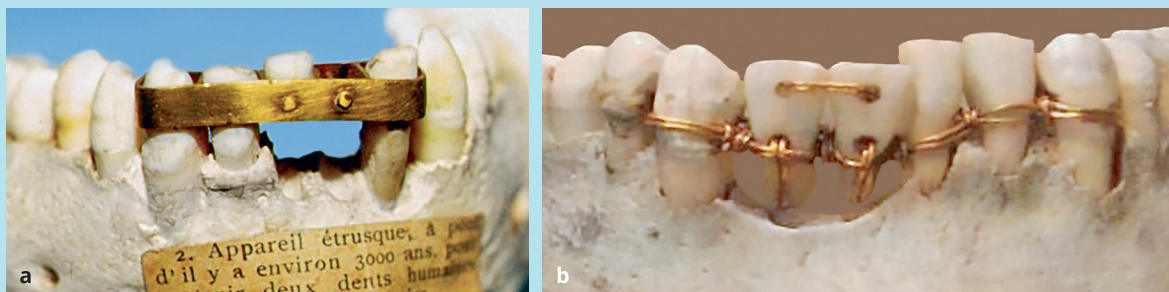


FIG 1-1 (a and b) Excavations from the Etruscan period showing metal bands and gold wire ligatures splinting teeth together.



FIG 1-2 Fauchard's bandeau.



FIG 1-3 Pin and tube design of the "ribbon arch" appliance.



FIG 1-4 Full-banded stainless steel appliances.

In 1901, Edward Angle founded the first school of orthodontics in St Louis, Missouri. Angle devised a simple classification for malocclusion that is commonly used today. In the early 1900s, fixed appliances were known as the "ribbon arch" appliance and consisted of gold bands formed around

individual teeth with brackets soldered onto the band (Fig 1-3). Wire ligatures and pins were used to secure the archwire to the bracket. Precious metals that were soft and malleable such as gold and silver-nickel alloy were used.

By the 1950s and 1960s, these once relatively expensive bands were being made out of stainless steel (Fig 1-4). Full-arch banded appliances remained the norm until the innovation of direct bonding allowed orthodontists to directly bond a bracket onto enamel. At that time, the fixed edgewise appliance was known as a "zero-degree" appliance. The orthodontist had to make first-order (in-and-out or labiolingual), second-order (tip), and third-order (torque) bends in the archwire to finish the occlusion.

In 1970, Dr Lawrence Andrews proposed building the in-and-out, tip, and torque into the appliance itself, either into the bracket base or the bracket slot. This eliminated the need to make bends in the archwire. This became known as the "straight-wire" appliance and remains the standard of fixed appliances used today (Fig 1-5). There are now many different bracket prescriptions with varying degrees of tip and torque available. Clinicians can choose the bracket prescription based on their preference, their orthodontic philosophy, and the treatment mechanics employed to move teeth.

In 1975, two orthodontists, one American and the other Japanese, independently developed a bracket and wire system that could be placed on the lingual surfaces of teeth. "Lingual braces," as they were known, became an esthetic alternative for patients who did not want the brackets to be visible. Lingual bracket systems have also evolved over time to include digital computer imaging to assist with custom-fabricated bracket bases and archwires (Fig 1-6).

As the quest for a more esthetic orthodontic appliance progressed, sapphire and ceramic brackets became available in the early 1990s. Around the same time, new archwires with elastic and thermal properties such as nitinol, titanium molybdenum alloy (TMA), and heat-activated nickel-titanium



FIG 1-5 Direct bonded straight-wire metal fixed appliance.



FIG 1-6 Lingual bracket system.



FIG 1-7 Custom 3D-printed brackets from LightForce Orthodontics.

eliminated the need to make complex loops and bends in the archwire. Today there are a plethora of variations of the standard twin bracket available; there are self-ligating and non-self-ligating brackets, brackets with different prescriptions, and brackets made of different materials (metal, plastic, ceramic). The latest evolution in bracket variation is 3D-printed custom brackets. Innovations in digital technology and the field of 3D printing now enable the final occlusion of the patient to be set up in a treatment planning software. Based on the final occlusion, brackets can be 3D printed with a customized prescription and custom bracket base, designed specifically for the patient's individual tooth morphology and final occlusion (Fig 1-7).

As we trace the evolution of the orthodontic appliance over the last 100 years, we can see a distinct shift toward an orthodontic appliance that is more esthetic, more hygienic, occupies less surface area on the teeth, is able to accurately move teeth into the final occlusion with compatible biologic forces, and is customized for each unique individual patient.

Clear Aligners

The history of clear aligners can be traced back to 1945, when Dr H. D. Kesling first proposed a clear, vacuum-formed tooth-positioning appliance for minor tooth movement. It was a labor-intensive process that required manually repositioning teeth reset in wax, and a clear vacuum-formed retainer was made for every tooth movement in a series of stages until the teeth were aligned. This technique was capable of minor tooth alignment. However, the amount of labor required for the task precluded its use on a wide scale, particularly for correction of more complex malocclusions.

Another half-century went by until two graduate students at Stanford University in 1997 applied 3D computer imaging graphics to the field of orthodontics and created the world's first mass-produced, customized clear aligner system. This new technology

revolutionized the world of dentistry and orthodontics, launching it into the 21st century and the digital age.

There is a distinct difference between evolutionary change and revolutionary change. Evolutionary change comprises incremental changes that take place gradually over time. The evolution of fixed appliances represents variations and incremental improvements to a bracket and wire system that has taken place over the last 100 years. Revolutionary change, in contrast, is transformational change. It is profound, dramatic, and disruptive. Revolutionary change challenges conventional thinking and requires a radical paradigm shift in our mindset. Clear aligner technology represents a revolutionary, transformational change in orthodontics that challenges the conventional thinking of how orthodontists move teeth. However, the advent of clear aligner technology does not mean that 150 years of orthodontic principles are no longer valid. The time-tested principles and concepts of bone biology, biomechanics, anchorage, and occlusion still apply. However, in this 21st century of digital technology, the clinician must now learn to apply those principles of orthodontics to the field of clear aligner technique.

Clear aligners have already evolved since they were released to the market in 1999. In the early days of clear aligners, most clinicians understood them to be an orthodontic appliance that was suitable for the treatment of Class I cases with minor crowding, resolved primarily with interproximal reduction. Today, clear aligners from Align Technology are made of a new tripolymer plastic and make use of optimized attachments with force activations built into the design of the aligner itself (Fig 1-8). The teeth are moved according to sophisticated computer algorithms developed in the software program. Currently most aligners on the market are thermoformed, but the future will be in 3D printing the actual aligner itself. There are many clear aligner systems being developed all over the world, and it is evident that this will be the future of orthodontics.



FIG 1-8 Clear aligners.

It is important to understand that **clear aligner treatment is a technique, not a product**. There is a common misconception that clear aligners are a “compromise” orthodontic appliance that is only capable of minor tooth movement. However, the clear aligner system of today is a *comprehensive* orthodontic appliance capable of treating a wide range of malocclusions. The remaining chapters of this text discuss the principles of clear aligner technique and lead the clinician through a process of learning how to apply the principles of orthodontics to clear aligner technique.

Future Directions

As we look toward the future evolution of orthodontics, the ideal orthodontic appliance could be conceived as a custom-made orthodontic appliance made to adapt to individual tooth morphology and anatomy. It would be customized to move each individual tooth with the exact amount of force required to move it based on the tooth morphology and root surface area. It would have customized biomechanics and would be able to adjust the rate of tooth movement according to the individual's bone physiology. The final occlusal outcome would be customized according to the individual's dental arch form, smile esthetics, and soft tissue lip support. The tip, torque, in-and-outs, and occlusal

contacts would be designed uniquely for each individual. This ideal appliance would be esthetic, hygienic, and comfortable and would accomplish correction of the malocclusion in the shortest time frame possible.

In reality, the future evolution of orthodontics has already arrived in the present, as clear aligners utilize digital technology together with CBCT integration for diagnosis, treatment planning, and designing the final occlusal outcome. To a certain degree, it is possible to customize the biomechanics and manage anchorage by staging tooth movements in a specific sequence in the software program. The rate of tooth movement may also be adjusted according to the individual's bone physiology by altering the scheduled number of days for aligner changes, depending on the individual's response to tooth movement. The final occlusion setup in the software may be customized according to the individual's dental arch form and preferences for smile esthetics. Soft tissue facial scanners allow for integration of the patient's soft tissue data with software programs that move teeth, allowing us to design an esthetic, harmonious smile that is customized for an individual's face.

If the future is already here, where do we go now? As orthodontists, it takes courage to step outside our comfort zone of the familiarity of brackets and wires to embrace a new orthodontic technique. It takes vision to challenge the status quo of conventional orthodontic thinking. It takes innovation to think of new ways of moving teeth. Finally, it takes diligence and time to produce well-designed scientific research in the field of clear aligners so that we can continue to practice clinically sound, evidence-based orthodontics. The future lies in continuing to innovate with passion to transform the future of our profession.

Bibliography

Align Technology, Inc. <http://www.aligntech.com/>. Accessed 5 February 2018.
Almogbel A. Clear aligner therapy: Up to date review article. *J Orthod Sci* 2023;12:37.

- Almogbel A, Alshawy ES, Alhusainy A. Efficacy of clear aligner therapy over conventional fixed appliances in controlling orthodontic movement: A systematic review. *J Orthod Sci* 2024;13:23.
- Andrews LF. The straight-wire appliance. *Br J Orthod* 1979;6:125–143.
- Asbell MB. A brief history of orthodontics. *Am J Orthod Dentofacial Orthop* 1990;98:206–213.
- Baan F, de Waard O, Bruggink R, Xi T, Ongkosuwito EM, Maal TJJ. Virtual setup in orthodontics: Planning and evaluation. *Clin Oral Investig* 2020;24:2385–2393.
- Bichu YM, Alwafi A, Liu X, et al. Advances in orthodontic clear aligner materials. *Bioact Mater* 2022;22:384–403.
- Brown MW, Koroluk L, Ko C, Zhang K, Chen M, Nguyen T. Effectiveness and efficiency of a CAD/CAM orthodontic bracket system. *Am J Orthod Dentofacial Orthop* 2015;148:1067–1074.
- Chattoo A. A view from behind: A history of lingual orthodontics. *J Orthod* 2013;40(suppl 1):S2–S7.
- Galan-Lopez L, Barcia-Gonzalez J, Plasencia E. A systematic review of the accuracy and efficiency of dental movements with Invisalign. *Korean J Orthod* 2019;49:140–149.
- Ghafari JG. Centennial inventory: The changing face of orthodontics. *Am J Orthod Dentofacial Orthop* 2015;148:732–739.
- Kesling HD. The philosophy of the tooth positioning appliance. *Am J Orthod Dentofacial Orthop* 1945;31:297–304.
- Leonardi R. Cone-beam computed tomography and three-dimensional orthodontics. Where we are and future perspectives. *J Orthod* 2019;46(1 suppl):45–48.
- LightForce Orthodontics. <https://lf.co/sp/technology>. Accessed 23 September 2024.
- Malik OH, McMullin A, Waring DT. Invisible orthodontics part I: Invisalign. *Dent Update* 2013;40:203–204,207–210,213–215.
- McLaughlin RP, Bennett JC. Evolution of treatment mechanics and contemporary appliance design in orthodontics: A 40-year perspective. *Am J Orthod Dentofacial Orthop* 2015;147:654–662.
- Robertson L, Kaur H, Fagundes NCF, Romanyk D, Major P, Flores Mir C. Effectiveness of clear aligner therapy for orthodontic treatment: A systematic review. *Orthod Craniofac Res* 2020;23:133–142.
- Shrivastava A, Mohanty P, Dash BP, Jena S, Sahoo N. Proficiency of clear aligner therapy: A systematic review and meta-analysis. *Cureus* 2023;15:e45072.
- Simon M, Keilig L, Schwarze J, Jung BA, Bourauel C. Forces and moments generated by removable thermoplastic aligners: Incisor torque, premolar derotation, and molar distalization. *Am J Orthod Dentofacial Orthop* 2014;145:728–736 [erratum 2014;146:411].
- Wahl N. Orthodontics in 3 millennia. Chapter 1: Antiquity to the mid-19th century. *Am J Orthod Dentofacial Orthop* 2005;127:255–259.
- Wahl N. Orthodontics in 3 millennia. Chapter 3: The professionalization of orthodontics. *Am J Orthod Dentofacial Orthop* 2005;127:749–753.
- Wahl N. Orthodontics in 3 millennia. Chapter 5: The American Board of Orthodontics, Albert Ketcham, and early 20th-century appliances. *Am J Orthod Dentofacial Orthop* 2005;128:535–540.
- Wahl N. Orthodontics in 3 millennia. Chapter 16: Late 20th-century fixed appliances. *Am J Orthod Dentofacial Orthop* 2008;134:827–830.
- Weber NDJ, Koroluk LD, Phillips C, Nguyen T, Proffit WR. Clinical effectiveness and efficiency of customized vs. conventional preadjusted bracket systems. *J Clin Orthod* 2013;47:261–266.
- Wiechmann D, Rummel V, Thalheim A, Simon JS, Wiechmann L. Customized brackets and archwires for lingual orthodontic treatment. *Am J Orthod Dentofacial Orthop* 2003;124:593–599.
- Zheng M, Liu R, Ni Z, Yu Z. Efficiency, effectiveness and treatment stability of clear aligners: A systematic review and meta-analysis. *Orthod Craniofac Res* 2017;20:127–133.

02

A COMPARISON BETWEEN FIXED APPLIANCES AND CLEAR ALIGNERS

In this chapter:

*Force, Engagement,
and Anchorage* 7

*Extrusion, Intrusion, Torque,
and Root Inclinations* 11

*Clear Aligner
Biomechanics* 14

Clear aligner treatment is an orthodontic technique. As such, the orthodontic principles of force application, engagement, anchorage, and biomechanics need to be applied to clear aligner technique. However, clear aligners move teeth differently than fixed appliances do. Therefore, a clear understanding of the similarities and differences between fixed appliances and clear aligners is essential for the clinician when making a decision whether to treat a case with fixed appliances or clear aligners. Clear aligners are uniquely suited to treat some malocclusions more efficiently than fixed appliances, offering better vertical control and superior management of anchorage considerations. Knowing the strengths and weaknesses of clear aligners as an orthodontic appliance will assist the clinician in selecting the best orthodontic appliance to address a specific malocclusion.

Force, Engagement, and Anchorage

Table 2-1 compares the force, engagement, and anchorage of fixed appliances and clear aligners.

TABLE 2-1 Patterns of force, engagement, and anchorage in fixed appliances versus clear aligners

	Fixed appliances	Clear aligners
Force	Exerts a “pull” on teeth	Exerts a “push” on teeth
Engagement	Archwire into bracket: The thicker the wire, the better the engagement	Plastic around teeth: The more plastic wrapped around teeth, the better the engagement
Anchorage	Reciprocal anchorage: Newton’s third law	Anchorage segments may be predetermined

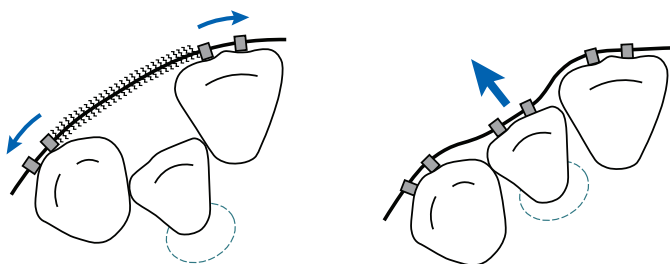


FIG 2-1 As the archwire reverts to its original form, it pulls the lingually erupted tooth into the dental arch.

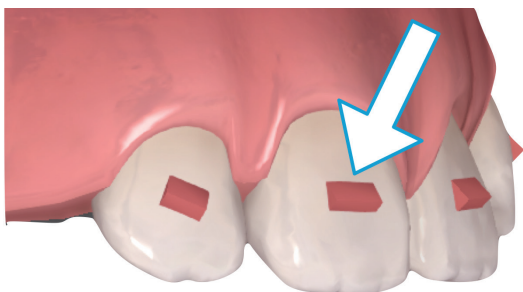


FIG 2-2 Clear aligners push against the flat surface of an attachment to move teeth.

Force

A fundamental difference between the way a bracket and wire system moves teeth and the way clear aligners move teeth is that fixed appliances *pull* on teeth while clear aligners *push* on teeth.

Figure 2-1 shows that when an archwire is engaged onto a lingually erupted tooth, the elasticity in the archwire causes the archwire to return to its original arch form. As the archwire returns to its original shape, it pulls on the lingually erupted tooth to move it into the arch. The force applied to the tooth is dependent on the flexibility of the archwire and the amount of deflection it undergoes to engage the tooth. Similarly, in space closure with fixed appliances, an elastomeric chain is stretched to engage the teeth across the space, and when the elastomeric chain contracts and rebounds to its original shape, it pulls the teeth together and the space closes.

In contrast, clear aligners move teeth by exerting a push force. When an aligner is inserted over teeth, there are minor differences between the positions of the teeth intraorally and the positions of the teeth in the aligner. The aligner deforms over the teeth, and the elasticity in the aligner material pushes the teeth into position. Optimized attachments

provide an active, flat surface that the aligner may push against to effect tooth movements such as extrusion or rotation (Fig 2-2).

There are two main mechanisms of moving teeth with clear aligners. Aligner systems are either force driven or displacement driven. In a force-driven aligner system, the aligner is designed and shaped differently to exert a precise force to move the tooth in the direction needed. This may include intrusion, extrusion, expansion, torque, and/or rotation. The force needed for specific teeth as well as the type of tooth movement required is calibrated for an optimal clinical outcome. In a displacement-driven aligner system, the aligner is passively thermoformed for the next stage in treatment, and the difference between the tooth position in the aligner and the actual tooth position intraorally causes the aligner to deform over the teeth and move it into the next programmed position, stage by stage.

Engagement

Fixed appliances engage teeth via an archwire ligated into the bracket slot. The thicker and more rigid the archwire, the better the engagement. The archwire sequence starts with round, flexible archwires with

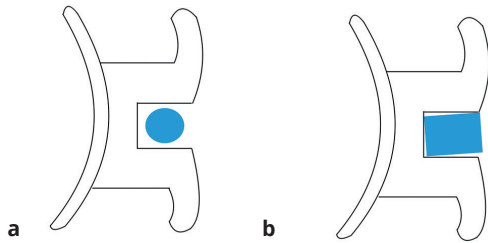


FIG 2-3 (a) The round, flexible initial archwire engages the tooth to move it into position. (b) A full-size rectangular archwire fully engages the bracket slot so that the torque and tip built into the bracket slot will express clinically.

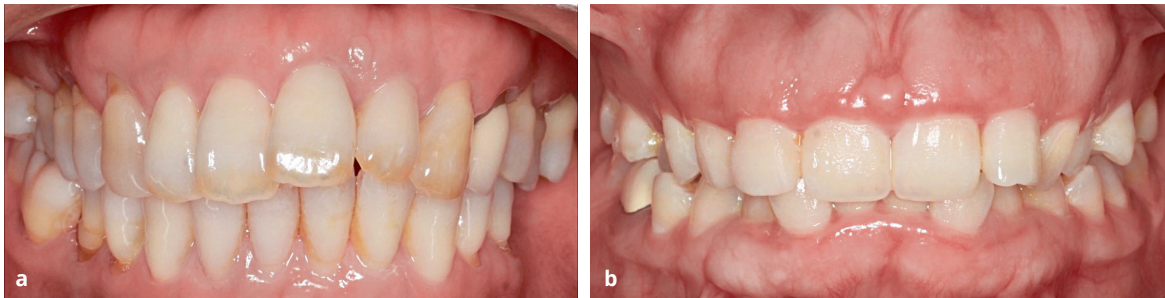


FIG 2-4 Long clinical crowns (a) provide better engagement for clear aligners, while short clinical crowns (b) offer less engagement.

a long working range and high elasticity and gradually moves toward rigid, rectangular stainless steel archwires. In an archwire that approximates the size of the bracket slot, the tip, torque, and in-and-outs that are built into the bracket slot or base will be more fully expressed (Fig 2-3). Clear aligners engage teeth by having aligner material wrapped around teeth. The more aligner material wrapped around a tooth, the better the engagement. In teeth with long clinical crowns and a larger surface area, there is better engagement and therefore better expression of tooth movement (Fig 2-4a). Conversely, in teeth with short clinical crowns and less surface area, there is less engagement and less expression of tooth movement (Fig 2-4b). One way to increase the engagement of the aligner onto teeth with small morphology—for example, peg-shaped lateral incisors—is to place an attachment on the tooth. This increases the surface area of the tooth and offers a point of engagement for the aligner material to grip the tooth, therefore helping the tooth movement to express clinically. Similarly, in cases where sequential distalization is planned, it is critical to register the distal surface of the distalmost tooth in the arch so that the aligner can fully engage that

tooth to distalize it. Where second molars are partially erupted, it is recommended to place an attachment where possible to engage the tooth into the aligner.

Anchorage

In fixed appliances, the most common anchorage model is that of reciprocal anchorage, based on Newton's third law: For every action, there is an equal and opposite reaction (Fig 2-5). One segment of teeth will act as an anchorage unit for another segment of teeth. For example, in first premolar extraction site closure, the posterior teeth act as an anchorage segment for the anterior teeth. At the same time, the anterior teeth act as an anchorage segment for the posterior teeth. Because the root surface area of the posterior segment is larger than that of the anterior segment, the anterior segment will retract more than the posterior segment will move forward. The forward movement of the posterior segment is called a *loss in anchorage* in orthodontics. This loss in anchorage is often taken into account by the clinician when treatment planning extraction cases to ensure that the buccal occlusion finishes in a cusp-to-fossa relationship in the final occlusion.

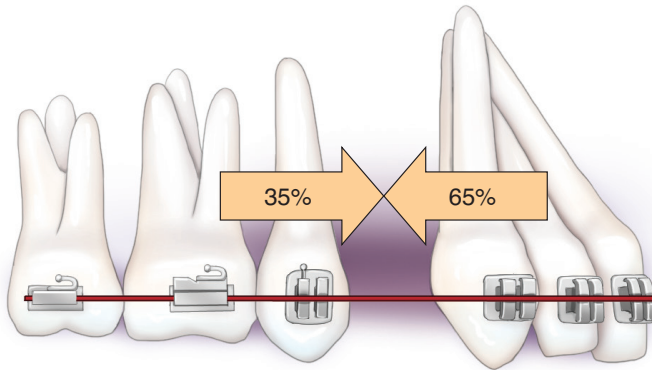


FIG 2-5 The concept of reciprocal anchorage in fixed appliance extraction space closure.

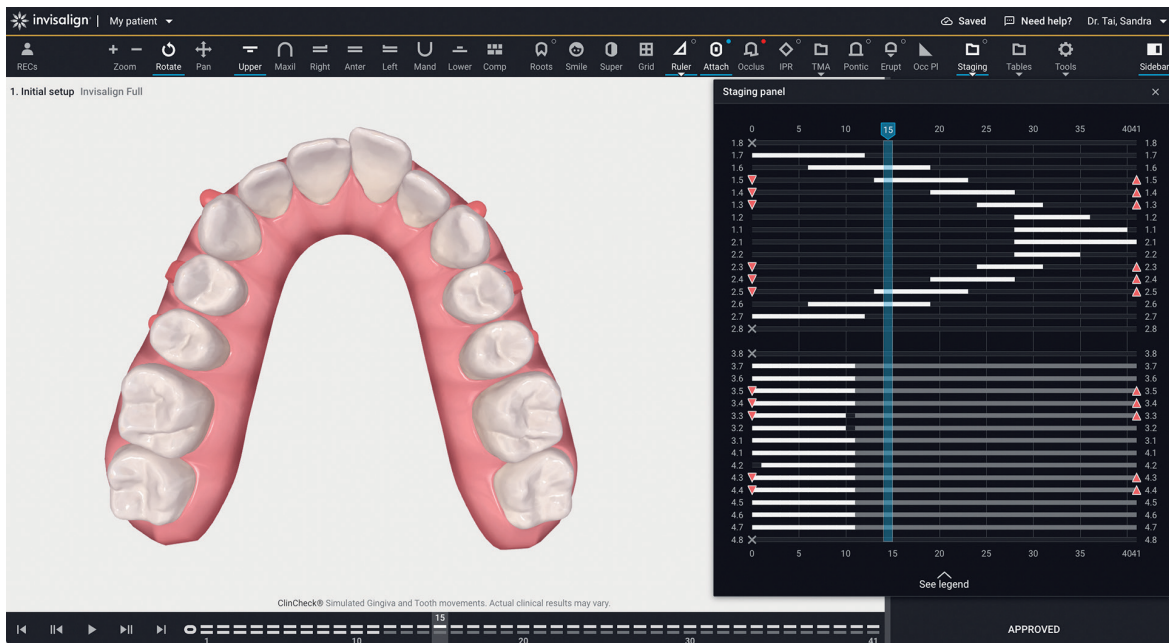


FIG 2-6 Staging pattern for sequential distalization of maxillary molars. From stage 1 to 6, only the maxillary second molars are moving. The rest of the maxillary teeth from first molar to first molar act as an anchorage segment.

In clear aligner treatment, the anchorage segments can be predetermined and may change at different stages in treatment. In this respect, clear aligners offer extremely good control of anchorage because the anchorage teeth may be made immovable at different stages of treatment. For example, in the staging of sequential distalization of the maxillary arch, only the second molars are

distalized in the initial stages of treatment. The remaining teeth in the arch from first molar to first molar do not move in the initial stages and act as an anchorage segment to push the second molars distally for anteroposterior correction (Fig 2-6).

In the G6 maximum anchorage protocol for first premolar extraction (Align Technology), only the canines and posterior teeth move in the initial

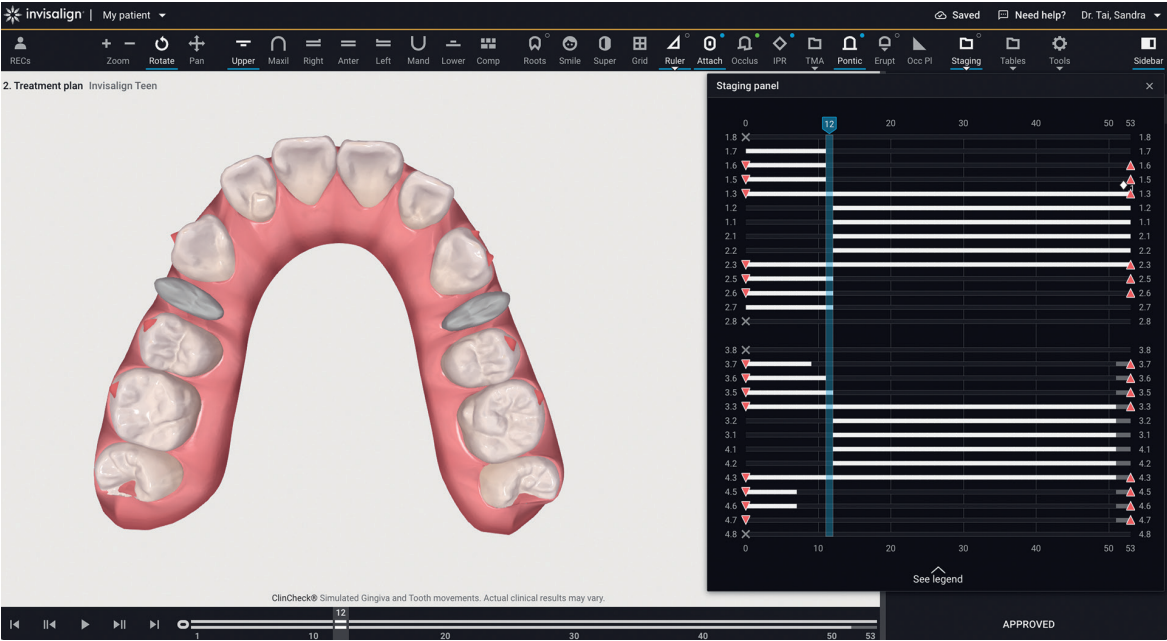


FIG 2-7 Staging pattern for G6 first premolar extraction space closure. In the initial stages of treatment, the incisors do not move and act as an anchorage segment to push the canine distally into the extraction site. After stage 12, the posterior teeth no longer move and act as an anchorage segment for continued retraction of the canine and incisors for extraction space closure.

TABLE 2-2 Capabilities of fixed appliances versus clear aligners in terms of extrusion, intrusion, torque, and root inclinations

	Fixed appliances	Clear aligners
Extrusion	Single tooth	Anterior segment
Intrusion	Relative intrusion only	Entire segments or selective intrusion
Torque	Labial and lingual root torque	Lingual root torque through power ridges
Root inclinations	Control of root inclinations through bracket positioning and archwire bends	Control of root inclinations through root control attachments and virtual gable bends

stages of treatment. The incisors do not move, and they act as an anterior anchorage segment to distalize the canine into the extraction site for space closure. At a certain stage in treatment, the second premolar and molars stop moving, and they become the posterior anchorage segment as the canines and incisors are retracted for the remainder of the extraction site closure (Fig 2-7).

Extrusion, Intrusion, Torque, and Root Inclinations

Table 2-2 compares fixed appliances and clear aligners in terms of extrusion, intrusion, torque, and root inclinations.

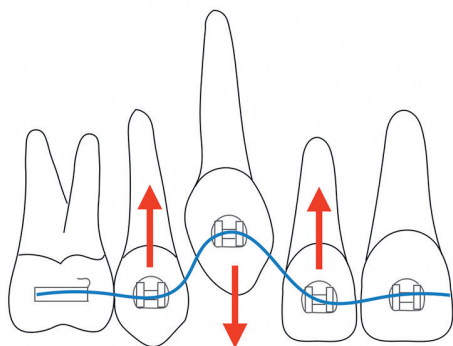


FIG 2-8 With fixed appliances, extrusive force on the canine produces intrusive forces on the adjacent teeth.

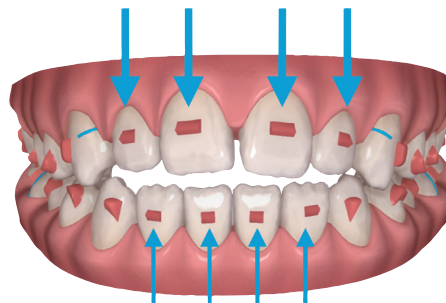


FIG 2-9 Extrusion of maxillary incisors with multitooth optimized extrusive attachments to close an anterior open bite.

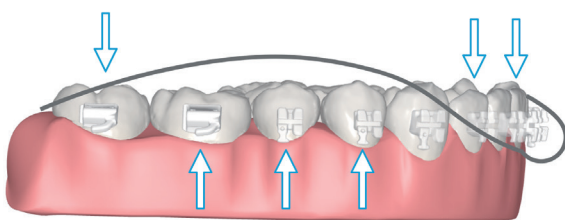


FIG 2-10 Relative intrusion with a reverse curve in the archwire.

Extrusion

In fixed appliances, extrusion of a single tooth may be accomplished relatively easily. However, because all the teeth in the arch are connected by an archwire, there are reciprocal movements of the adjacent teeth. For example, in a case where a buccally erupted canine requires extrusion, as the canine extrudes, the adjacent lateral and central incisors and first premolar will intrude (Fig 2-8). This may create a temporary cant to the occlusal plane. Eventually as the treatment progresses into more rigid archwires, the occlusal plane will level out. In the event reciprocal tooth movements are undesirable, a rigid archwire may be placed to stabilize the occlusal plane, and a flexible twin-wire overlay may be placed to extrude the buccally erupted canine.

Extrusion of a single tooth is a moderately difficult tooth movement for clear aligners, depending on the amount of extrusion required. At times, some

auxiliary treatment such as buttons and elastics may have to be incorporated to assist with single-tooth extrusion. However, extrusion of groups of teeth, for example when maxillary incisors are extruded to close an anterior open bite, may be performed successfully with clear aligners (Fig 2-9).

Intrusion

In fixed appliances, dental arches are leveled through relative intrusion with reverse curves in the archwire (Fig 2-10). As the anterior teeth intrude, there is concurrent extrusion of the posterior teeth. Alternatively, segmental intrusive base arches may be used with careful management of the posterior anchorage through transpalatal or lingual arches or high-pull headgear in the maxillary arch to manage any unwanted reciprocal extrusion of the posterior segments.



FIG 2-11 Superimposition in the software program showing anterior intrusion to level out the curve of Spee.



FIG 2-12 Superimposition in the software program showing posterior intrusion to create occlusal clearance.



FIG 2-13 Power ridge feature for incisor torque on maxillary and mandibular incisors. (Reprinted with permission from Align Technology.)

In clear aligner treatment, entire segments of teeth may be intruded successfully, or selective intrusion of individual teeth may be programmed to correct an occlusal cant or level out gingival margins. This may be performed without concurrent extrusion of the posterior segments if so desired. As a result, clear aligners offer extremely good vertical control. In Fig 2-11, anterior intrusion is programmed to level out the curve of Spee in the mandibular arch to correct a deep bite. In Fig 2-12, posterior intrusion is programmed to create occlusal clearance after the posterior teeth have hypererupted due to lack of opposing dentition.

Torque

In fixed appliances, torque is built into the bracket slot. The amount of torque expressed is related to the size of the archwire and the amount of torque built into the bracket slot. There are varying torque

prescriptions for different bracket systems. Some clinicians will use different torque prescriptions for individual patients depending on the initial malocclusion. Additional torque may be added by making torquing bends in the archwire. However, where there is a size difference between the archwire and the bracket slot, the wire has an angle of freedom to move within the bracket slot; this is commonly known as *play*. This element of play between the bracket slot and the archwire is responsible for the fact that the actual torque expressed will always be less than the torque prescription in a fixed appliance system.

Clear aligners offer the power ridge feature for lingual root torque (Fig 2-13). The incisor torque in the finished occlusion may be predetermined for individual patients depending on the initial malocclusion, desired final occlusion, and soft tissue lip support. Clear aligners are very efficient in managing incisor torque where excessive torque is not desired.

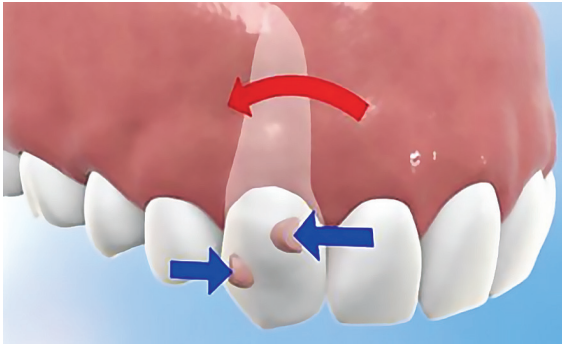


FIG 2-14 Optimized root control attachments for control of root inclination. (Reprinted with permission from Align Technology.)

TABLE 2-3 Capabilities of fixed appliances versus clear aligners in terms of incisor inclination, vertical control, midline correction, and tooth size discrepancy

	Fixed appliances	Clear aligners
Incisor inclination	Incisors tend to procline on alignment	Excellent control of incisor inclination
Vertical control	Overbite and overjet decreases with incisor proclination and alignment	Excellent vertical control in cases with minimal overbite and overjet
Midline correction	Dependent on elastic wear	Predictable
Tooth size discrepancy	Needs to be calculated or adjusted for midway through treatment	May be accurately calculated using digital software plan

Excessive torque may be undesirable in cases with mild incisor protrusion that are treated nonextraction, with maxillary incisor torque in mandibular incisor extraction cases, and where the incisor mandibular plane angle (IMPA) requires careful management. However, just like with fixed appliances, there is an element of play between the aligner and the teeth, making the actual torque expressed clinically less than that prescribed. Therefore, in extraction cases where some loss of incisor torque is anticipated, additional torque should be built into the final occlusion in the software. Management of the interincisal angle is discussed in chapter 7.

Root inclinations

In fixed appliances, tip is built into the bracket slot. If further adjustment to root inclinations is required, then root-tip bends may also be made

in the archwire. Once again, there may be some play between the bracket slot and the archwire that precludes the full expression of the tip built into the bracket slot.

In clear aligner treatment, optimized root control attachments offer control of root inclinations (Fig 2-14). Long, vertical rectangular attachments will offer control of root inclinations as well. In mandibular incisor or premolar extraction cases, virtual gable bends may be requested to ensure careful management of root inclinations as the extraction spaces are closed.

Clear Aligner Biomechanics

Table 2-3 compares fixed appliances and clear aligners in terms of incisor inclination, vertical control, midline correction, and tooth size discrepancy.

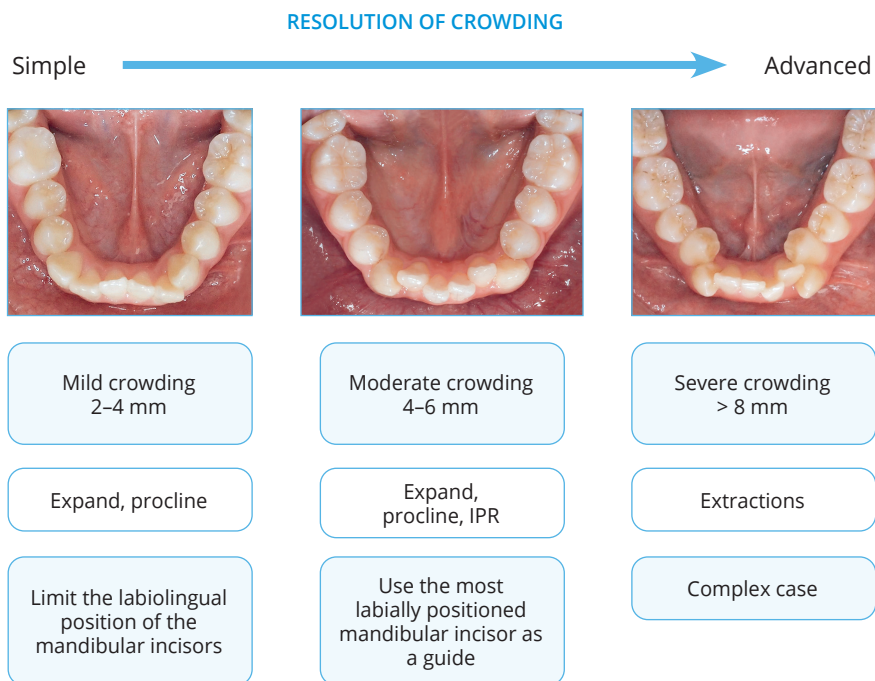
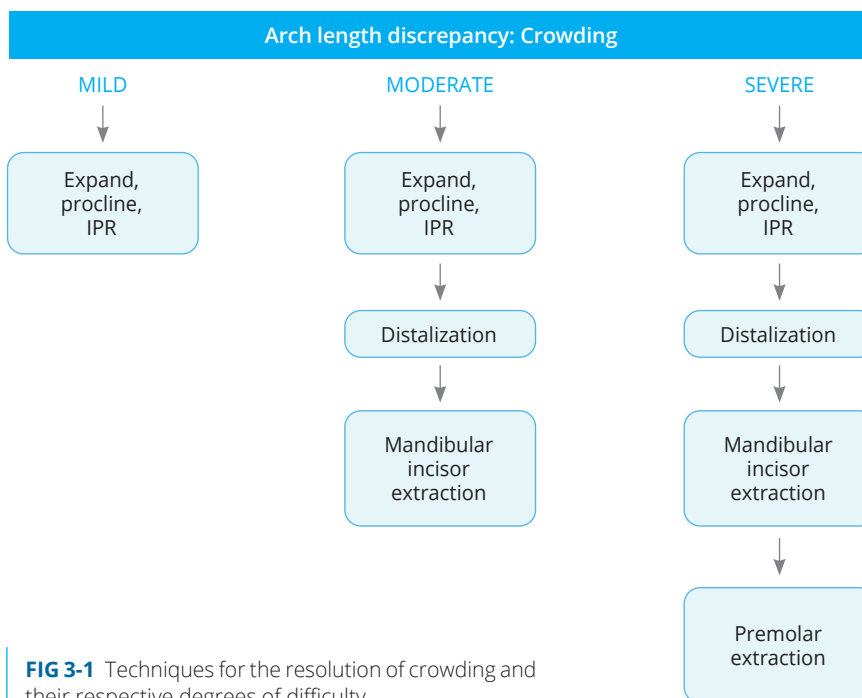


FIG 3-2 Degree of difficulty for arch length discrepancy.

treatment. See chapter 8 for more information on the resolution of crowding.

Vertical Discrepancies

In deep bite malocclusions, there are three options in the software that may be prescribed to correct the deep bite. “Show resulting overbite after alignment” may be selected on the prescription form when the maxillary and mandibular incisors are very upright or retroclined. As the teeth are proclined for alignment, there will be relative intrusion, and this results in a reduced overlap of the anterior teeth, leading to correction of the deep bite. Deep bites may also be corrected through maxillary and mandibular incisor intrusion. Finally, a combination of anterior intrusion and posterior extrusion may also be prescribed. The cases treated will range from simple to advanced as shown in Figs 3-3 and 3-4.

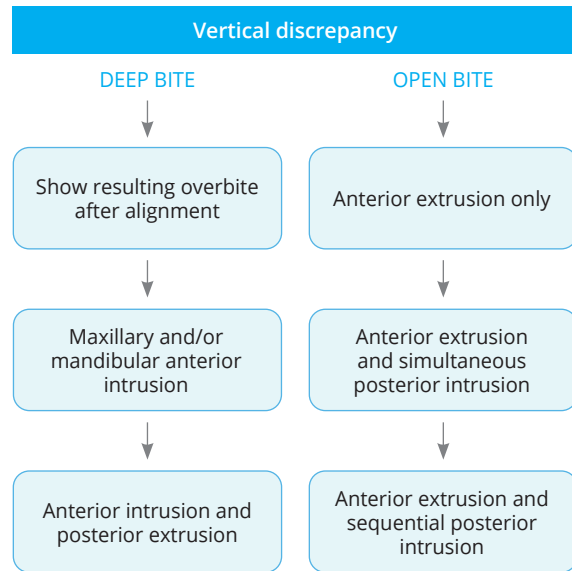


FIG 3-3 Techniques for the treatment of vertical discrepancies.

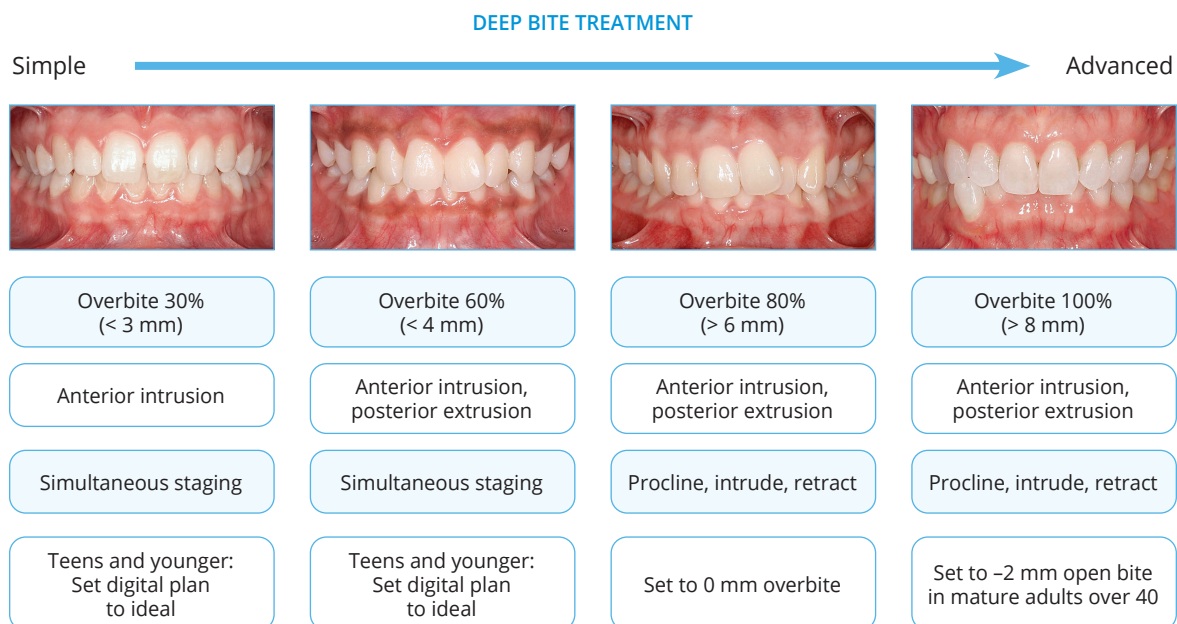


FIG 3-4 Degree of difficulty for deep bite treatment.

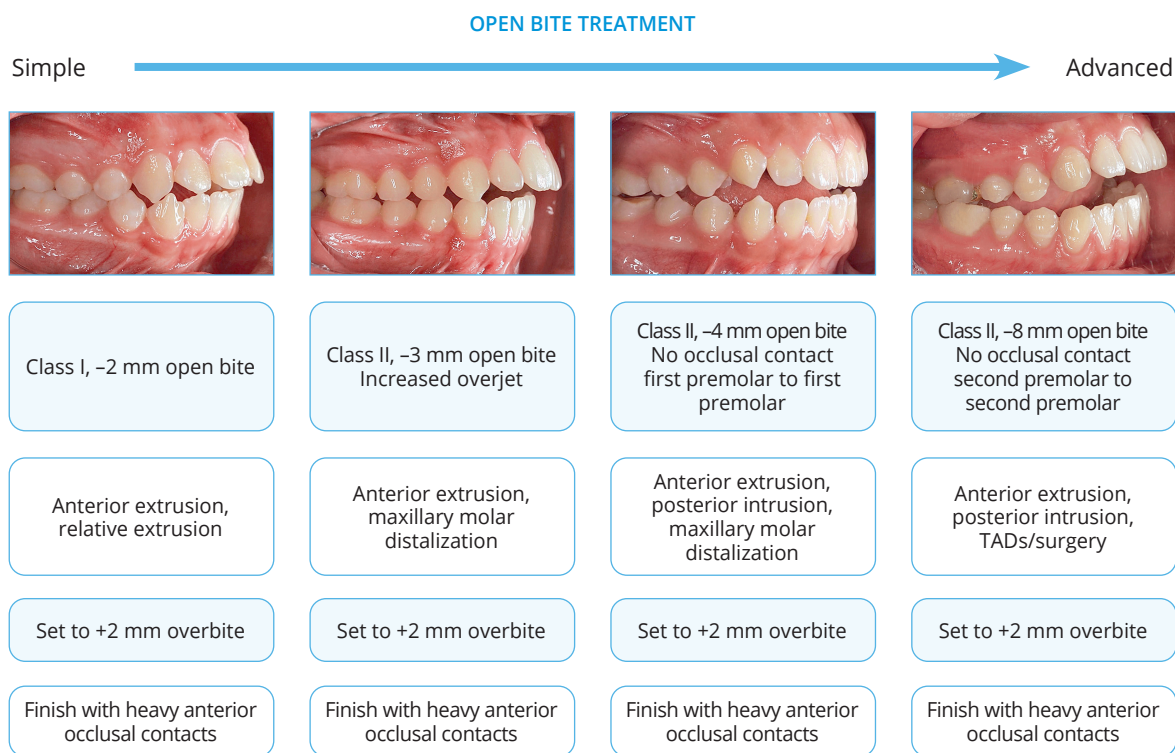


FIG 3-5 Degree of difficulty for open bite treatment.

In anterior open bite malocclusions, the anterior open bite may be closed by anterior extrusion with or without concurrent posterior intrusion. Minor posterior intrusion will be predictable, but posterior intrusion over 1 mm may require additional anchorage in the basal bone with temporary anchorage devices (TADs). The complexity of the case increases with the severity of the anterior open bite and the vertical skeletal discrepancy (Fig 3-5).

Chapters 9 and 10 discuss deep bite treatment and anterior open bite treatment, respectively.

Transverse Discrepancies

A transverse discrepancy could be dental or skeletal in origin. A single-tooth crossbite is a simple case for clear aligners that may be corrected through minor

expansion or proclination (Fig 3-6). The aligners will act as a bite plane to disocclude the teeth and eliminate occlusal interference, assisting with the crossbite correction.

Multiple-tooth crossbite may be more challenging. Posterior expansion with aligners is predictable up to a range of 2 mm or less per quadrant, thus allowing for 4 mm of predictable expansion across the dental arch. Additionally, anterior or posterior bite ramps may be prescribed to allow teeth to expand freely without the limitation of the initial malocclusion. Auxiliary treatment with cross elastics may be required to assist the posterior expansion to express clinically.

If the crossbite is skeletal in origin, then rapid maxillary expansion or maxillary skeletal expansion with temporary anchorage devices in a nongrowing patient