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Clear Aligner Therapy: Up to date review article

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Abstract

The advantages of Clear Aligners Therapy (CAT) include the braces being virtually invisible, comfortable to wear, and removable for eating and brushing; that way, CAT can be used to treat a wide range of orthodontic issues. In 1999, the company Align Technology introduced the first commercial clear aligner system called Invisalign. The Invisalign system was initially only available to orthodontists, but later became available to general dentists as well. The system quickly gained popularity among patients who were looking for a more discreet and comfortable alternative to traditional braces. In 2000, Align Technology received FDA clearance for the Invisalign system, which further increased its popularity. The biomechanics of clear aligners involve the use of custom-made tooth aligners that are specifically shaped to guide teeth into desired positions. These aligners are typically made from flexible materials such as polyurethane or ethylene vinyl acetate and are adjusted to apply the necessary forces for tooth movement. Attachment devices, such as power ridges or buttons, are often used to enhance or assist in specific tooth movements and for retention of the aligner. The use of attachments allows for the exertion of desired force on the teeth, which is crucial for the success of Clear Aligner Therapy. CAT should be used if patients are concerned about the esthetic appearances of their teeth—for example, actors and other individuals that rely on their appearances in public in a professional context—and if the misalignment is not severe, so that clear aligners can still work. One should not use CAT in cases of severe crowding or spacing issues that require extractions. If the patient has complex jaw discrepancies or skeletal issues or if teeth need to be moved extensively in multiple directions, CAT is likely not going to be strong enough. In conclusion, Clear Aligner Therapy is a safe, effective, and convenient orthodontic treatment option that offers patients a virtually invisible way to achieve a straighter, more beautiful smile. With continued advancements in technology and a growing body of research supporting its effectiveness, the future of Clear Aligner Therapy looks bright.

Keywords:

CAT, clear aligners therapy, invisalign, orthodontics, tooth movement, evidence-based dentistry, dentistry

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Introduction

Clear Aligner Therapy (CAT) is a method of straightening teeth using clear, custom-made plastic aligners. The aligners apply gentle pressure to the teeth to gradually move them into the desired position. The advantages of CAT include the braces being virtually invisible, comfortable to wear, and removable for eating and

brushing; that way, CAT can be used to treat a wide range of orthodontic issues.^[1]

One of the main challenges of CAT is compliance. Clear aligners need to be worn for at least 22 hours a day to be effective, and patients must be diligent in wearing them as directed. If aligners are not worn as prescribed, treatment can take longer or may not be successful.^[2] Another challenge is that clear aligners are not suitable for all types of orthodontic cases, particularly more significant cases such as severe bite issues, large gaps, or severe crowding. These

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cases may require traditional braces or other forms of treatment.^[3] Additionally, it can be difficult for patients to clean their teeth and aligners effectively, which may lead to an increased risk of tooth decay, gingivitis, and bad breath. Lastly, CAT is generally more expensive than traditional braces, and it may not be covered by insurance or provided in government hospitals, so it might not be an option for everyone.

While CAT has clear advantages and disadvantages, there are several aspects that are not yet well understood. For example, the effectiveness of CAT compared to traditional braces and other orthodontic treatments in terms of the amount of time needed to achieve the desired results and the overall success rate.^[3] The factors influence patient compliance with CAT, and how can orthodontists and other healthcare professionals increase compliance will be addressed.^[4] Also, the cost of clear aligner therapy compares to traditional braces and other orthodontic treatments, and is it a cost-effective option for patients?^[5] We will investigate the satisfaction rates for clear aligner therapy compared to traditional braces and other orthodontic treatments,^[6] the rate of retention and relapse after treatment with clear aligners, and how does this compare to traditional braces and other orthodontic treatments.^[7,8] In this paper, I will try to go through the history of clear aligner, indications, and its limitations. Moreover, the biomechanics of the aligners and its effectiveness of moving the teeth will be addressed as well.

History

The history of clear aligner therapy began in the twentieth century, when dental physicians began experimenting with using clear plastic aligners to straighten teeth. They realized that by using a series of clear plastic aligners, each one slightly different from the previous, one could gradually move teeth into their desired positions. This was a significant departure from traditional braces, which used metal brackets and wires to achieve the same goal.^[9] In 1999, the company Align Technology introduced the first commercial clear aligner system called Invisalign. The Invisalign system was initially only available to orthodontists, but later became available to general dentists as well. The system quickly gained popularity among patients who were looking for a more discreet and comfortable alternative to traditional braces. In 2000, Align Technology received FDA clearance for the Invisalign system, which further increased its popularity.^[10]

The early Invisalign system featured a series of clear, custom-made aligners that were worn over the teeth. These aligners were made from a thermoplastic material and were designed to gradually shift the teeth into the

desired position over time. The aligners were typically worn for about two weeks before being replaced with the next set in the series. One of the key features of the early Invisalign system was its use of computer technology to create the aligners.^[11] The process began with a digital scan or impression of the patient's teeth, which was then used to create a virtual model of the patient's bite. This virtual model was used to plan the sequence of aligners and to determine the exact movements that would be necessary to achieve the desired final result.^[12] Another important feature of the early Invisalign system was its use of "SmartTrack" material, which was specifically designed to provide optimal force and control during tooth movement.^[13] This material was said to be more comfortable and effective than the materials used in traditional metal braces, and it was also less visible, which made it more appealing to patients who were self-conscious about their appearance.^[14] The early Invisalign also made it possible for orthodontists to provide treatment for a wider range of cases, including mild to moderate crowding, spacing, crossbite, overbite, and underbite.^[15] Additionally, the aligners were removable, which meant that patients could eat, brush, and floss as normal, without having to navigate around brackets and wires.^[16] This made the treatment process more convenient and comfortable for patients, and it also helped to reduce the risk of dental decay and gum disease, which can be a problem with traditional braces.^[17] Overall, the early Invisalign system was designed to be a more comfortable, convenient, and esthetically pleasing alternative to traditional metal braces. It was very promising, and it is still widely used today.^[18]

The company behind Invisalign also began to expand its product line, introducing new features such as the ability to treat more complex cases and the use of computer-generated treatment plans. As the popularity of CAT grew, other companies began to enter the market with their own clear aligner systems. One of the most notable of these is ClearCorrect, a company founded in 2006 that offers clear aligners to both orthodontists and general dentists.^[19] In recent years, clear aligner therapy has continued to evolve and improve. Advances in digital technology have made it possible to create more accurate treatment plans and to monitor treatment progress more closely. Additionally, new materials and manufacturing techniques have led to the development of more comfortable and durable aligners.^[20]

Clear aligner therapy is now a widely accepted form of orthodontic treatment, and it is used to treat a wide range of dental issues, including crowding, spacing, overbite, underbite, and open bite. Clear aligners are also being used to treat sleep apnea and to improve the esthetics of the teeth by closing gaps and straightening teeth.^[21,22]

The future of clear aligner therapy looks promising, since advancements in 3D printing and digital scanning technology are making it possible to create even more precise and accurate treatment plans.^[23-25] Additionally, research is being conducted to develop new materials and manufacturing techniques that will make aligners even more comfortable and durable.^[26-28]

Biomechanics

To discuss the biomechanics of CAT, it might be instructive to first study the forces and pressures at play during tooth development.^[29-31] Teeth become misaligned by the misdirected application of those forces; therefore, any artificial realignment has to counteract those forces. In this context, the major forces that teeth exert on the gum include pressure from the growth of the tooth: As the tooth develops and grows, it exerts pressure on the surrounding gingival tissue, which helps to shape and mold the gingiva to fit the tooth.^[32] Force of eruption: As the tooth emerges through the gingiva tissue, it exerts a force that pushes the gingiva tissue up and away from the tooth.^[33] Force of attachment: As the tooth becomes fully erupted and begins to function, it exerts a force on the surrounding gingiva tissue that helps to keep the tooth securely in place.^[34] Force of occlusion: The force exerted by opposing teeth during biting and chewing, which helps to maintain the proper alignment of the teeth. It is important to note that these forces are also regulated by the surrounding bone and ligament structure, which are important for the teeth stability and proper functioning.^[35,36] Of course, in cases of orthodontic treatment, the teeth exert force on the surrounding gingival tissue as they are moved into their desired position.^[37-39]

The biomechanics of clear aligners involves the use of custom-made tooth aligners that are specifically shaped to guide teeth into desired positions. These aligners are typically made from flexible materials such as polyurethane or ethylene vinyl acetate and are adjusted to apply the necessary forces for tooth movement.^[40,41] The process of using clear aligners begins with molding the movement of target teeth to complement the shape of the aligner being used. This shape molding effect is achieved by making small incremental movements that cause the aligner to deflect and stretch over the teeth when inserted. Once the aligner is seated, the force features apply pressure to move the teeth into the desired position. It should be noted that digital images of the patient's teeth—as shown in Figure 1—can also be used to construct a proper shape for the aligners.^[31]

Attachment devices, such as power ridges or buttons, are often used to enhance or assist in specific tooth movements and for retention of the aligner. The use of attachments allows for the exertion of desired force on

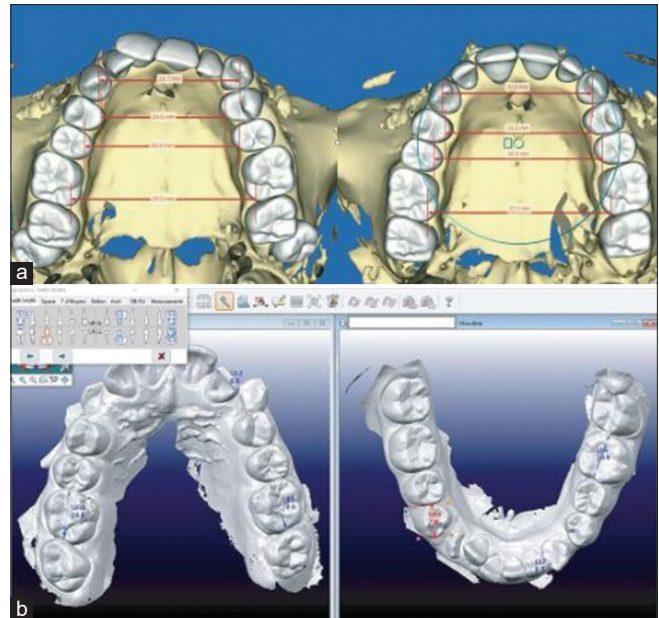


Figure 1: Digital reconstructions of dentures, based on (a) cone-beam computed tomography and (b) intraoral scans^[31]

the teeth, which is crucial for the success of Clear Aligner Therapy. The biomechanics of Clear Aligner Therapy is used in orthodontic tooth movement to achieve tooth alignment, particularly for anterior tooth movements. It can also be used for post-treatment retention. The accuracy of the application of forces is closely monitored using three-dimensional digital assessment tools and integrated into the treatment plan. Clear aligners also differ from traditional braces in their ability to exert pull force, which allows for more predictable movements of the teeth.^[42,43] The biologic force generated by the clear aligner is the key to its success, as it is designed to pre-activate its attachment interface with a specific tooth and then optimized attachment form morphology to exert a desirable orthodontic force for moving it in a specified direction. Overall, however, it is important to note that the nature of the underlying forces needed to correct and align—that is, “straighten out”—teeth is complex and multi-faceted.^[44,45] This raises questions of accuracy; in other words, how good are aligners in moving teeth, that is, how much does the prediction of their function correspond to the actual readout? Recent studies show that fixed appliances are still better in terms of both precision and treatment predictability, possibly due to the nature of the material used.^[46]

In some cases, attachments are used to give distal tipping force to the first molar extraction area [Figure 2]. These attachments are used to extrude the middle dental arch and obtain the lowest tooth displacement. The use of attachments allows for the exertion of desired force on the teeth, which is crucial for the success of clear aligner therapy.^[47-49]

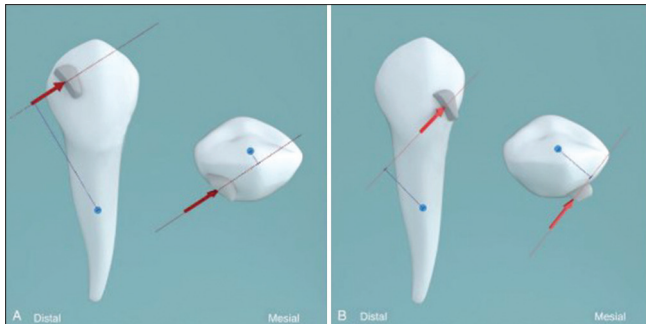


Figure 2: Tooth movements using attachments to transmit forces. The center of resistance is blue, while the line of action is red^[50]

In terms of tooth movements, CAT can provide a variety of movements to correct dental misalignments. Crowding corrections involve moving teeth that are too close together to create more space and improve their alignment. Spacing corrections aim to close any gaps between teeth, and bite corrections involve moving teeth to correct an overbite, underbite, or crossbite. All these types of movement aim at restoring a proper, consistent spacing between teeth and may be the most difficult to execute, as the forces that are required to move the teeth in place are complex and not uniform.^[51-53] Figure 3 shows the correction of a severe case of multiple tooth displacement in a 12-year-old girl, using Invisalign treatment.

Other movements involve rotational corrections, where teeth are turned around their long axis to eventually face into the correct direction. Vertical corrections are done to adjust the height of teeth and to improve their appearance and bite. Transversal corrections move teeth in a side-to-side direction to create a better bite and improve the overall cosmetic appearance. Using CAT, these movements can be accomplished by gradually adjusting the shape of the clear aligners to apply gentle pressure to the teeth over time [Figure 4].^[55,56]

In summary, the biomechanics of clear aligner therapy involves the use of custom-made tooth aligners that are specifically shaped to guide teeth into desired positions, the use of attachment devices to enhance or assist in specific tooth movements and for retention of the aligner, and the use of digital assessment tools to closely monitor the accuracy of the application of forces. Clear aligners differ from traditional braces in their ability to exert pull force, which allows for more predictable movements of the teeth.^[58,59]

Indications

In general, and based on the previous discussion, CAT should be used if patients are concerned about the esthetic appearances of their teeth—for example, for actors and other individuals that rely on their appearances in public

in a professional context—and if the misalignment is not severe, so that clear aligners can still work.^[60] There does not seem to be any type of misalignment that is unsuited for CAT per se; the main challenge for using CAT seems to emerge when the dental misalignment is too severe. If that is not the case, CAT can be used for all main categories of positional aberrations, such as crowding or spacing, bite issues such as over-, under-, or crossbite, and a rotational aberration, where the teeth are in the correct place with the proper distance to their neighbors, but are facing into the wrong direction.^[61-65]

Clear aligners are suitable for patients who have mild to moderate dental issues and who are committed to wearing the aligners as directed by their dentist or orthodontist. They are also a good option for patients who are concerned about the appearance of traditional metal braces or who have active lifestyles and need a more discreet orthodontic option.^[66-70] In general, CAT is indicated in cases of mild crowding or spacing issues between 1 mm and 5 mm; deep overbites; dental arches that are too narrow and require expansion; intrusion of one or two teeth; severe crowding, if the lower incisor gets extracted; and any molars that needed to be tilted in distal direction.^[71]

CAT has been successfully used for the treatment of anterior crossbite in two 8-year-old children; the procedure took five months and was able to completely correct the problem in either case, without any further problems or discomfort, suggesting that CAT may be especially useful in growing teeth which still have enough flexibility to become realigned.^[72] In addition, compliance routines are more likely to be turned into life-long habits if implemented in early years.^[66,73-75] Indeed, the use of clear aligners in mixed dentition (CAMD)—that is, during a period where children have both primary and secondary teeth—will provide a convenient use case for CAT. Even though CAs are currently used less often than fixed aligners (FAs), the situation appears to move toward a significant increase in the application of CAMD. This is likely due to its numerous advantages especially during childhood and adolescence, namely the opportunity to correct misalignments during physical growth and expansion of the skeleton, corrections in sagittal direction, and the easier implementation of compliance and dental hygiene habits (Lynch, 2023).^[76]

In general, however, distinguishing whether a specific dental misalignment should be corrected using CAT or fixed appliances requires a considerable amount of experience by the dentist, so much so that the patient should probably be seen by a specialist if the initial dentist is not able to make an unambiguous recommendation. Using any aligner is a considerable investment of time, money, and other resources. It



Figure 3: Before (top) and after (bottom) pictures of Invisalign treatment of a severely crowded and misaligned dental arrangement in a 12-year-old girl. The procedure took 16 months^[54]



Figure 4: Successive aligner application for dental space closure; (a-d) denote the different sets of aligners^[57]

is important that the correct decision is made.^[77] It is important to note that clear aligners may not be the best

option for all patients and that a thorough evaluation by a dentist or orthodontist is necessary to determine if

clear aligners are a good fit for an individual's specific needs and goals.^[78-80]

Limitations

As mentioned above, CAT is not indicated in all cases of dental realignment, and the technology has some limitations as well.^[81-84] One should not use CAT in cases of severe crowding or spacing issues that require extractions. Furthermore, despite the positive experiences in the case of anterior crossbites, some bite problems can be too complex for CAT to work well. Likewise, if the patient has complex jaw discrepancies or skeletal issues or if teeth need to be moved extensively in multiple directions, CAT is likely not going to be strong enough.^[84-88] If the patient is suffering from active periodontal disease, or has uncontrolled decay or gingival disease, CAT might be contraindicated.^[89-91]

As for the limitations of CAT, despite its esthetical appeal makes wearing aligners less uncomfortable, the treatment time may be longer compared to traditional braces. This is because clear aligners work more gradually, making small adjustments over time, whereas traditional braces can make quicker, more drastic changes. Furthermore, compliance is required for success; in other words, the aligners need to be worn for almost an entire day—22–23 hours; and patients need to switch to a new set of aligners every week or two, as directed by their orthodontist. If a patient is not diligent in wearing their aligners, treatment time can be prolonged, and the desired results may not be achieved. Another limitation—which is one of the major reasons for CAT being contraindicated in case of complex dental problems—is the difficulty in achieving significant tooth movements. In these cases, orthodontic treatments that focus specifically on bite problems, such as traditional braces or jaw surgery, may be needed to fully address these issues. Moreover, importantly, if the dental problems are due to a different source, for example, in the jaw joints, any realignment of the teeth will not solve the bite problem. Lastly, clear aligners can be more expensive than traditional fixed aligners. This is especially true for more complex cases, where multiple sets of aligners may be needed to achieve the desired results. In addition, CAT may not always be suitable for children or patients with developmental problems, as they may not provide the necessary stability and control for proper tooth and jaw development.^[92] In these cases, traditional braces or other orthodontic treatments may be more appropriate.^[93,94]

That being said, CAT is still a young technology, will still improve in terms of application protocols and materials. It might even be possible to start out with fixed aligners to correct the most severe issues and then switch to clear aligners later on. It is also probably good to start early in development once dental alignment problems start emerging.^[95]

Effectiveness

Clear aligner therapy can be an effective orthodontic treatment option for a variety of teeth movements.^[93,96-100] When it comes to mild or moderate crowding or spacing issues, clear aligners can effectively treat mild to moderate crowding or spacing issues by gradually shifting teeth into their desired position. This is achieved by applying gentle, controlled force to the teeth using the aligners. The success rate of clear aligner therapy for correcting crowding or spacing issues is high, but can be influenced by the complexity of the case and patient compliance. Second, clear aligners can effectively straighten rotated or tipped teeth, resulting in improved esthetics and bite function, by gradually repositioning the teeth into the correct alignment. This can improve the appearance of the smile and the overall function of the bite. Clear aligners can also effectively close gaps between teeth by gradually shifting them into a more closely spaced position. This can improve the appearance of the smile and reduce the risk of food impaction and tooth decay. Lastly, CAT can be used to align the front teeth, which are highly visible when smiling and talking. This can greatly improve the appearance of the smile and boost a patient's confidence.

The success of clear aligner therapy depends on several factors, including the complexity of the tooth movements required, patient compliance, and the experience of the orthodontist. On average, clear aligner therapy has a success rate of 80–90% for mild to moderate tooth movements, but this can vary based on the individual case.

As mentioned before, it is important to note that clear aligner therapy may not be the best option for more complex orthodontic cases, such as severe crowding or spacing issues, complex bite problems, or significant jaw discrepancies. In these cases, traditional braces or other orthodontic treatments may be more appropriate.^[101-103]

Conclusion

Clear aligner therapy is a modern orthodontic treatment option that has gained popularity in recent years due to its convenience, comfort, and virtually invisible appearance. The biomechanics of clear aligner therapy involves the application of gentle, controlled force to the teeth using a series of custom-made, clear plastic aligners. This force gradually moves the teeth into their desired position, correcting a range of issues including mild to moderate crowding or spacing, straightening rotated or tipped teeth, closing gaps between teeth, and aligning the anterior teeth.

Clear aligner therapy has a success rate of 80–90% for mild to moderate tooth movements and can be

an effective alternative to traditional braces or other orthodontic treatments. However, it may not be the best option for more complex orthodontic cases, such as severe crowding or spacing issues, complex bite problems, or significant jaw discrepancies.

When deciding between clear aligner therapy and fixed braces, patients should consider their specific orthodontic needs and preferences, as well as the experience and recommendations of their orthodontist. Clear aligners may be more appealing to patients who prioritize comfort, convenience, and discretion, while fixed braces may be a better choice for those with more complex orthodontic needs or who prefer a more predictable treatment outcome.

The future of clear aligner therapy looks promising, with continued advancements in technology and materials, allowing for more effective and efficient treatment outcomes. The history of clear aligner therapy dates back to the late 1990s when the first clear aligner systems were introduced. Since then, clear aligner therapy has evolved and become increasingly popular as a preferred orthodontic treatment option for a growing number of patients.

In conclusion, clear aligner therapy is a safe, effective, and convenient orthodontic treatment option that offers patients a virtually invisible way to achieve a straighter, more beautiful smile. With continued advancements in technology and a growing body of research supporting its effectiveness, the future of clear aligner therapy looks bright.

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Conflicts of interest

There are no conflicts of interest.

References

- Rossini G, Parrini S, Castroflorio T, Deregibus A, Debernardi CL. Efficacy of clear aligners in controlling orthodontic tooth movement: A systematic review. *Angle Orthod* 2015;85:881-9.
- Timm LH, Farrag G, Baxmann M, Schwendicke F. Factors influencing patient compliance during clear aligner therapy: A retrospective cohort study. *J Clin Med* 2021;10:3103. doi: 10.3390/jcm10143103.
- Ke Y, Zhu Y, Zhu M. A comparison of treatment effectiveness between clear aligner and fixed appliance therapies. *BMC Oral Health* 2019;19. doi: 10.1186/s12903-018-0695-z.
- Hansa I, Katyal V, Ferguson DJ, Vaid N. Outcomes of clear aligner treatment with and without Dental Monitoring: A retrospective cohort study. *Am J Orthod Dentofacial Orthop* 2021;159:453-9.
- Tamer I, Öztas E, Marsan G. Orthodontic treatment with clear aligners and the scientific reality behind their marketing: A literature review. *Turk J Orthod* 2019;32:241-6
- Alami S, Sahim S, Hilal F, Essamlali A, Quars F. Perception and satisfaction of patients treated with orthodontic clear aligners. *Open Access Library J* 2022;9:1-11. doi: 10.4236/oalib.1109300.
- Littlewood SJ, Dalci O, Dolce C, Holliday LS, Naraghi S. Orthodontic retention: What's on the horizon? *Br Dent J* 2021;230:760-4.
- Johal A, Bondemark L. Clear aligner orthodontic treatment: Angle Society of Europe consensus viewpoint. *J Orthod* 2021;48:300-4.
- Weir T. Clear aligners in orthodontic treatment. *Aust Dent J* 2017;62:58-62.
- Tiantong L, Mair A. An historical overview of clear aligner therapy the evolution of clear aligners. 2020. Available from: <https://www.oralhealthgroup.com/features/an-historical-overview-of-clear-aligner-therapy-the-evolution-of-clear-aligners/>. Accessed 10/3/2023
- Bichu YM, Alwafi A, Liu X, Andrews J, Ludwig B, Bichu AY, *et al.* Advances in orthodontic clear aligner materials. *Bioact Mater* 2023;22:384-403.
- Izhar A, Singh G, Goyal V, Singh R, Gupta N, Pahuja P. A prospective comparative study between the software models and clinical models of clear aligner treatment. *Orthod J Nepal* 2019;9:28-34.
- Morton J, Derakhshan M, Kaza S, Li C. Design of the Invisalign system performance. *Semin Orthod* 2017;23:3-11.
- Rakesh T, Gupta A. Invisalign: Invisible orthodontic treatment-A review. *J Adv Med Dent Sci Res* 2015;3:S42-4.
- Tuncay O. The invisalign system. *Digital Planning and Custom Orthodontic Treatment*. Hoboken, NJ, USA: John Wiley & Sons, Inc.; 2017. p. 69-79.
- Takara Y, Haga S, Kimura H, Maki K. Mechanical analysis of factors affecting clear aligner removability. *Dent Mater J* 2022;41:2021-176.
- Perkelvald, A. (2022). Are Clear Aligners Better than the Conventional Orthodontic Fixed Appliances?. *The Science Journal of the Lander College of Arts and Sciences*, 15 (2), 46-53. Retrieved from <https://touro scholar.touro.edu/sjlcas/vol15/iss2/9>
- Wong BH. Invisalign A to Z. *Am J Orthod Dentofac Orthop* 2002;121:540-1.
- Sawan NM. Clear aligners in patients with amelogenesis and dentinogenesis imperfecta. *Int J Dent* 2021;2021:1-8. doi: 10.1155/2021/7343094.
- Tartaglia GM, Mapelli A, Maspero C, Santaniello T, Serafin M, Farronato M, *et al.* Direct 3D printing of clear orthodontic aligners: Current state and future possibilities. *Materials* 2021;14:1799. doi: 10.3390/ma14071799.
- Fountoulaki G, Thurzo A. Change in the constricted airway in patients after clear aligner treatment: A retrospective study. *Diagnostics* 2022;12:2201. doi: 10.3390/diagnostics12092201.
- Atali P. Combining orthodontic and sleep apnea treatment using acceleration techniques. *EC Dent Sci* 2018;17:968-77.
- Maspero C, Tartaglia GM. 3D printing of clear orthodontic aligners: Where we are and where we are going. *Materials* 2020;13:5204. doi: 10.3390/ma13225204.
- Yu X, Li G, Zheng Y, Gao J, Fu Y, Wang Q, *et al.* 'Invisible' orthodontics by polymeric 'clear' aligners molded on 3D-printed personalized dental models. *Regen Biomater* 2022;9:rbac007. doi: 10.1093/rb/rbac007.
- Venezia P, Ronsivalle V, Rustico L, Barbato E, Leonardi R, lo Giudice A. Accuracy of orthodontic models prototyped for clear aligners therapy: A 3D imaging analysis comparing different market segments 3D printing protocols. *J Dent* 2022;124:104212. doi: 10.1016/j.jdent.2022.104212.

26. Nucera R, Dolci C, Bellocchio AM, Costa S, Barbera S, Rustico L, *et al.* Effects of composite attachments on orthodontic clear aligners therapy: A systematic review. *Materials* 2022;15:533.
27. Macrì M, Murmura G, Varvara G, Traini T, Festa F. Clinical performances and biological features of clear aligners materials in orthodontics. *Front Mater* 2022;9. doi: 10.3389/fmats. 2022.819121.
28. Gold BP, Siva S, Duraisamy S, Idaayath A, Kannan R. Properties of orthodontic clear aligner materials-A review. *J Evol Med Dent Sci* 2021;10:3288-94.
29. Wang Q, Dai D, Wang J, Chen Y, Zhang C. Biomechanical analysis of effective mandibular en-masse retraction using Class II elastics with a clear aligner: A finite element study. *Prog Orthod* 2022;23:23.
30. Khosravi R. Biomechanics in lingual orthodontics: What the future holds. *Semin Orthod* 2018;24:363-71.
31. Upadhyay M, Arqub SA. Biomechanics of clear aligners: Hidden truths & first principles. *J World Fed Orthod* 2022;11:12-21.
32. Zamani NSM, Ashari A, Ali SHM, Gan KB, How RAWM, Wahab RMA, *et al.* Distributed force measurement and mapping using pressure-sensitive film and image processing for active and passive aligners on orthodontic attachments. *IEEE Access* 2022;10:52853-65.
33. Roulias P, Kalantzis N, Doukaki D, Pachiou A, Karamesinis K, Damanakis G, *et al.* Teeth eruption disorders: A critical review. *Children* 2022;9:771. doi: 10.3390/children9060771.
34. Iliadi A, Koletsis D, Eliades T. Forces and moments generated by aligner-type appliances for orthodontic tooth movement: A systematic review and meta-analysis. *Orthod Craniofac Res* 2019;22:248-58.
35. Nawaz MS, Yazdanie N, Hussain S, Moazzam M, Haseeb M, Hassan M. Maximum voluntary bite force generated by individuals with healthy dentition and normal occlusion. *J Pak Dent Assoc* 2020;29:199-204.
36. Li L, Chen H, Wang Y, Sun Y. Construction of virtual intercuspal occlusion: Considering tooth displacement. *J Oral Rehabil* 2021;48:701-10.
37. Zeno KG, Mustapha S, Ayoub G, Ghafari JG. Effect of force direction and tooth angulation during traction of palatally impacted canines: A finite element analysis. *Am J Orthod Dentofac Orthop* 2020;157:377-84.
38. Gomez-Gomez S, Villarraga-Ossa J, Diosa-Pena J, Ortiz-Restrepo J, Castrillon-Marin R, Ardila C. Comparison of frictional resistance between passive self-ligating brackets and slide-type low-friction ligature brackets during the alignment and leveling stage. *J Clin Exp Dent* 2019;11:e593-600. doi: 10.4317/jced. 55913.
39. Alsabti N, Bourauel C, Talic N. Comparison of force loss during sliding of low friction and conventional TMA orthodontic archwires. *J Orofac Orthop* 2021;82:218-25.
40. Daniele V, Macera L, Taglieri G, Spera L, Marzo G, Quinzi V. Color stability, chemico-physical and optical features of the most common PETG and PU based orthodontic aligners for clear aligner therapy. *Polymers (Basel)* 2021;14:14. doi: 10.3390/polym14010014.
41. Kundal S, Shokeen T. Aligners: The science of clear orthodontics. *Int J Dent Med Spe* 2020;7:38-42.
42. Vaid NR, Sabouni W, Wilmes B, Bichu YM, Thakkar DP, Adel SM. Customized adjuncts with clear aligner therapy: "The Golden Circle Model" explained! *J World Fed Orthod* 2022;11:216-25.
43. Greco M, Machoy M. Impacted canine management using aligners supported by orthodontic temporary anchorage devices. *Int J Environ Res Public Health* 2022;20:131. doi: 10.3390/ijerph20010131.
44. Elshazly TM, Bourauel C, Aldesoki M, Ghoneima A, Abuzayda M, Talaat W, *et al.* Computer-aided finite element model for biomechanical analysis of orthodontic aligners. *Clin Oral Investig* 2022;27:115-24.
45. Zhu Y, Hu W, Li S. Force changes associated with differential activation of en-masse retraction and/or intrusion with clear aligners. *Korean J Orthod* 2021;51:32-42.
46. Papageorgiou SN, Koletsis D, Iliadi A, Peltomaki T, Eliades T. Treatment outcome with orthodontic aligners and fixed appliances: A systematic review with meta-analyses. *Eur J Orthod* 2020;42:331-43.
47. Fan D, Liu H, Yuan CY, Wang SY, Wang PL. Effectiveness of the attachment position in molar intrusion with clear aligners: A finite element study. *BMC Oral Health* 2022;22:474.
48. Liu JQ, Zhu GY, Wang YG, Zhang B, Wang SC, Yao K, *et al.* Different biomechanical effects of clear aligners in bimaxillary space closure under two strong anchorages: Finite element analysis. *Prog Orthod* 2022;23:41. doi: 10.1186/s40510-022-00435-2.
49. Smith JM, Weir T, Kaang A, Farella M. Predictability of lower incisor tip using clear aligner therapy. *Prog Orthod* 2022;23:37.
50. Arango JPG. Current biomechanical rationale concerning composite attachments in aligner orthodontics. In: **Nandra R, Castroflorio T, Garino F, Ojima K, editors.** Principles and Biomechanics of Aligner Treatment. 2021. p. 13-29.
51. Weinstein T, Marano G, Aulakh R. Five-to-five clear aligner therapy: Predictable orthodontic movement for general dentist to achieve minimally invasive dentistry. *BMC Oral Health* 2021;21:671.
52. Huang AT, Huang D. Problematic complex movements: Can clear aligners treat them alone? *Controversies in Clear Aligner Therapy*. Cham: Springer International Publishing; 2022. p. 67-87.
53. Happe A, Blender S, Luthardt RG. Orthodontic pretreatment with aligners for optimizing the result prior to fixed restorations in the esthetic zone. *J Esthet Restor Dent* 2023;35:279-90
54. Wheeler TT. Orthodontic clear aligner treatment. *Semin Orthod* 2017;23:83-9.
55. Palone M, Pignotti A, Morin E, Pancari C, Spedicato GA, Cremonini F, *et al.* Analysis of overcorrection to be included for planning clear aligner therapy: A retrospective study. *Angle Orthod* 2023;93:11-8.
56. Seo JH, Eghan-Acquah E, Kim MS, Lee JH, Jeong YH, Jung TG, *et al.* Comparative analysis of stress in the periodontal ligament and center of rotation in the tooth after orthodontic treatment depending on clear aligner thickness—Finite element analysis study. *Materials* 2021;14:324.
57. Machado RM. Space closure using aligners. *Dental Press J Orthod* 2020;25:85-100.
58. Kankam H, Madari S, Sawh-Martinez R, Bruckman KC, Steinbacher DM. Comparing outcomes in orthognathic surgery using clear aligners versus conventional fixed appliances. *J Craniofac Surg* 2019;30:1488-91.
59. Kassam SK, Stoops FR. Are clear aligners as effective as conventional fixed appliances? *Evid Based Dent* 2020;21:30-1.
60. Thai JK, Araujo E, McCray J, Schneider PP, Kim KB. Esthetic perception of clear aligner therapy attachments using eye-tracking technology. *Am J Orthod Dentofacial Orthop* 2020;158:400-9.
61. Sachdev S, Tantidhnazet S, Saengfai NN. Accuracy of tooth movement with in-house clear aligners. *J World Fed Orthod* 2021;10:177-82.
62. Hong K, Kim WH, Eghan-Acquah E, Lee JH, Lee BK, Kim B. Efficient design of a clear aligner attachment to induce bodily tooth movement in orthodontic treatment using finite element analysis. *Materials* 2021;14:4926. doi: 10.3390/ma14174926.
63. Cheng Y, Gao J, Fang S, Wang W, Ma Y, Jin Z. Torque movement of the upper anterior teeth using a clear aligner in cases of extraction: A finite element study. *Prog Orthod* 2022;23:26.
64. Lione R, Paoloni V, de Razza FC, Pavoni C, Cozza P. Analysis of maxillary first molar derotation with invisalign clear aligners in permanent dentition. *Life* 2022;12:1495. doi: 10.3390/life12101495.
65. Cortona A, Rossini G, Parrini S, Deregiibus A, Castroflorio T. Clear aligner orthodontic therapy of rotated mandibular round-shaped teeth: A finite element study. *Angle Orthod* 2020;90:247-54.

66. Cremonini F, Vianello M, Bianchi A, Lombardo L. A spectrophotometry evaluation of clear aligners transparency: Comparison of 3D-printers and thermoforming disks in different combinations. *Appl Sci* 2022;12:11964. doi: 10.3390/app122311964.
67. Zhang B, Huang X, Huo S, Zhang C, Zhao S, Cen X, *et al.* Effect of clear aligners on oral health-related quality of life: A systematic review. *Orthod Craniofac Res* 2020;23:363-70.
68. Shi C, Feng Y, Hsiao YC, Smith J, Jin C, Farella M, *et al.* Clear aligners brands and marketing claims: An overview of available information on the web. *Aust Orthod J* 2022;38:252-62.
69. Pithon MM, Baião FCS, Sant Anna LIDA, Paranhos LR, Cople Maia L. Assessment of the effectiveness of invisible aligners compared with conventional appliance in aesthetic and functional orthodontic treatment: A systematic review. *J Investig Clin Dent* 2019;10:e12455. doi: 10.1111/jicd. 12455.
70. Caruso S, Darvizeh A, Zema S, Gatto R, Nota A. Management of a facilitated aesthetic orthodontic treatment with clear aligners and minimally invasive corticotomy. *Dent J* 2020;8:19. doi: 10.3390/dj8010019.
71. Aljabaa A. Clear aligner therapy--Narrative review. *J Int Oral Health* 2020;12:1-4. doi: 10.4103/jioh.jioh_180_19.
72. Staderini E, Patini R, Meuli S, Camodeca A, Guglielmi F, Gallenzi P. Indication of clear aligners in the early treatment of anterior crossbite: A case series. *Dental Press J Orthod* 2020;25:33-43.
73. Zhao R, Mei L, Long H, Jian F, Lai W. Changing clear aligners every 10 days or 14 days? A randomised controlled trial. *Aust Orthod J* 2023;39:1-12. doi: 10.2478/aoj-2023-0002.
74. Timm LH, Farrag G, Wolf D, Baxmann M, Schwendicke F. Effect of electronic reminders on patients' compliance during clear aligner treatment: An interrupted time series study. *Sci Rep* 2022;12:16652. doi: 10.1038/s41598-022-20820-5.
75. Thirumoorthy SN, Gopal S. Is remote monitoring a reliable method to assess compliance in clear aligner orthodontic treatment? *Evid Based Dent* 2021;22:156-7.
76. Lynch NM. Clear aligner therapy in the mixed dentition: Indications and practitioner perspectives. *Am J Orthod Dentofacial Orthop* 2023. doi: 10.1016/j.ajodo. 2022.11.018
77. Varshini GN, Kannan MS. Clear aligner therapy-a review. *Eur J Mol Clin Med* 2020;7:1689-93.
78. Izhar A, Singh G, Goyal V, Singh R, Gupta N, Pahuja P. Comparative assessment of clinical and predicted treatment outcomes of clear aligner treatment: An *in vivo* study. *Turk J Orthod* 2019;32:229-35.
79. Al-Nadawi M, Kravitz ND, Hansa I, Makki L, Ferguson DJ, Vaid NR. Effect of clear aligner wear protocol on the efficacy of tooth movement: *Angle Orthod* 2021;91:157-63.
80. Haouili N, Kravitz ND, Vaid NR, Ferguson DJ, Makki L. Has invisalign improved? A prospective follow-up study on the efficacy of tooth movement with Invisalign. *Am J Orthod Dentofacial Orthop* 2020;158:420-5.
81. Kudagi V, Shivakumar S, VMN, Nitin P. Aligners in orthodontics: A review. *Int J Appl Dent Sci* 2021;7:187-9.
82. Baxmann M, Timm LH, Schwendicke F. Who seeks clear aligner therapy? A european cross-national real-world data analysis. *Life* 2022;13:65. doi: 10.3390/life13010065.
83. Wajekar N, Pathak S, Mani S. Rise & review of invisalign clear aligner system. *IP Indian J Orthod Dentofac Res* 2022;8:7-11.
84. Gogna N, Irving M, Nandhra K. Aligner orthodontics: A literature review. *Orthod Update* 2023;16:33-8.
85. Sabouni W, Muthuswamy Pandian S, Vaid NR, Adel SM. Distalization using efficient attachment protocol in clear aligner therapy—A case report. *Clin Case Rep* 2023;11:e6854. doi: 10.1002/ccr3.6854
86. Milovanović A, Sedmak A, Golubović Z, Mihajlović KZ, Žurkić A, Trajković I, *et al.* The effect of time on mechanical properties of biocompatible photopolymer resins used for fabrication of clear dental aligners. *J Mech Behav Biomed Mater* 2021;119:104494. doi: 10.1016/j.jmbbm.2021.104494.
87. Al-Zainal MH, Anvery S, Al-Jewair T. Clear aligner therapy may not prevent but may decrease the incidence of external root resorption compared to full fixed appliances. *J Evid Based Dent Pract* 2020;20:101438. doi: 10.1016/j.jebdp.2020.101438.
88. Pariyatdulapak N, Churnjitapirom P, Sriksirin T, Viwattanatipa N. Bond strength of orthodontic buttons on clear aligner materials. *Orthodontic Waves* 2021;80:224-31.
89. Ma Y, Li S. The optimal orthodontic displacement of clear aligner for mild, moderate and severe periodontal conditions: An *in vitro* study in a periodontally compromised individual using the finite element model. *BMC Oral Health* 2021;21:109.
90. Martina S, Martini M, Bordegoni M, Razionale AV. Predictability of root movements using virtual root setup in a patient with periodontal disease treated with clear aligners. *Open Dent J* 2021;15:605-11.
91. Zhang J, Li J, Peng Y. Orthodontic treatment with clear aligners for a patient with chronic periodontitis. *Korean J Orthod* 2022;52:439-50.
92. Dianiskova S, Rongo R, Buono R, Franchi L, Michelotti A, D'Antò V. Treatment of mild class II malocclusion in growing patients with clear aligners versus fixed multibracket therapy: A retrospective study. *Orthod Craniofac Res* 2022;25:96-102.
93. Cardoso PC, Espinosa DG, Mecnas P, Flores-Mir C, Normando D. Pain level between clear aligners and fixed appliances: A systematic review. *Prog Orthod* 2020;21:3.
94. Kalia S, Reginald M, Birte M. Clear aligners and their role in orthodontics. *Adult Orthodontics*. Wiley; 2022. p. 379-91.
95. Flores-Mir C. Clear aligner therapy might provide a better oral health environment for orthodontic treatment among patients at increased periodontal risk. *J Evid Based Dent Pract* 2019;19:198-9.
96. Yassir YA, Nabbat SA, McIntyre GT, Bearn DR. Clinical effectiveness of clear aligner treatment compared to fixed appliance treatment: An overview of systematic reviews. *Clin Oral Investig* 2022;26:2353-70.
97. Jaber ST, Hajeer MY, Burhan AS. The effectiveness of in-house clear aligners and traditional fixed appliances in achieving good occlusion in complex orthodontic cases: A randomized control clinical trial. *Cureus* 2022;14:e30147. doi: 10.7759/cureus.30147.
98. Bilello G, Fazio M, Amato E, Crivello L, Galvano A, Currò G. Accuracy evaluation of orthodontic movements with aligners: A prospective observational study. *Prog Orthod* 2022;23:12.
99. Fiori A, Minervini G, Nucci L, d'Apuzzo F, Perillo L, Grassia V. Predictability of crowding resolution in clear aligner treatment. *Prog Orthod* 2022;23:43.
100. Grünheid T, Tasca AW, Kanyusik JS, Walters SA, Larson BE. Assessment of orthodontic treatment efficacy of clarity aligners using the peer assessment rating index and the American Board of Orthodontics Cast-Radiograph Evaluation. *Am J Orthod Dentofac Orthop* 2022;162:861-9.
101. Ciavarella D, Fanelli C, Suriano C, Cazzolla AP, Campobasso A, Guida L, *et al.* Occlusal plane modification in clear aligners treatment: Three dimensional retrospective longitudinal study. *Dent J*. 2022 Dec 27;11:8. doi: 10.3390/dj11010008.
102. Palone M, Baciliero M, Cervinara F, Maino GB, Paoletto E, Cremonini F, *et al.* Class II treatment of transverse maxillary deficiency with a single bone-borne appliance and hybrid clear aligner approach in an adult patient: A case report. *J World Fed Orthod* 2022;11:80-94.
103. Jiang T, Wu RY, Wang JK, Wang HH, Tang GH. Clear aligners for maxillary anterior en masse retraction: A 3D finite element study. *Sci Rep* 2020;10:10156. doi: 10.1038/s41598-020-67273-2.