FUNDAMENTALS OF ALIGNER THERAPY: A COMPREHENSIVE REVIEW

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ABSTRACT

Aligner therapy has emerged as a widely accepted orthodontic treatment modality, driven by digital advancements, advanced material science, and changing patient priority for esthetic and comfortable options of treatment. The use of aligner therapy is initiated from early vacuum-formed appliances to modern computer-aided design and manufacturing based clear aligner systems, which provide more precise and accurate tooth movement. Clinical indications for aligner treatment include mild to moderate malocclusions cases such as crowding, spacing, minor rotations, and relapse cases, while these are not advised in cases requiring complex orthodontic movements, need significant vertical control, severe skeletal discrepancy cases, and cases with poor patient compliance. As the aligners are removable, which means patients could eat, brush, and floss as normal, without having to navigate around brackets and wires. 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. This comprehensive review outlines the fundamental aspects of aligner therapy including historical evolution of aligners, clinical indications, contraindications, and the materials used. Understanding the advantages and limitations of different materials is essential for optimal treatment planning and predictable outcomes.

Keywords: Aligners, malocclusion, maxilla, mandible.

INTRODUCTION

Variety of malocclusion such as crowding, spacing, rotations or discrepancy in maxilla and mandible size and position compromises functions and also esthetics of face and smile of individual. So most of patients seek orthodontic treatment to correct these malocclusions. Orthodontic treatment focuses on correcting teeth and jaw alignment resulting in improved appearance of face and smile of patients. Orthodontic treatment involves movement of teeth, for which force is applied via different types of appliances. Most commonly used fixed orthodontic appliances that are brackets and bands in which wire is ligated for application of force. To overcome the shortcomings of these appliances, advancements are continuously happening. Initially the metal brackets were used but due to their appearance, some patients especially adult patients are reluctant for treatment. So esthetic brackets such as plastic and ceramic brackets, esthetic archwires were introduced. Also there was introduction of lingual system in which brackets are placed on lingual surface of teeth providing esthetic appearance to patients. Another esthetic alternative was clear aligners which are removable plastic trays instead of brackets.

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 are removed for eating and brushing.[1]

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.[2] The process began with a digital scan or impression of the patient's teeth, which is then used to create a virtual model of the patient's bite. This virtual model is used to plan the sequence of aligners and to determine the exact movements that would be necessary to achieve the desired final result.[3]

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.[4] 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 are self-conscious about their

appearance.[5]

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, deep bite, 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 the teeth. Additionally, the aligners are removable, which meant that patients could eat, brush, and floss as normal, without having to navigate around brackets and wires. 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. Additionally, research is being conducted to develop new materials and manufacturing techniques that will make aligners even more comfortable and durable.[6]

HISTORY

Contrary to popular belief, clear aligners are not a new find. 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 move from traditional braces, which used metal brackets and wires to achieve the same goal.[7]

The chronology leading up to their present-day use dates to 1945, when Dr. Harold D. Kesling first advocated a rubber appliance for moving teeth. In 1945, Herald D. Kesling designed a simple device to guide teeth into their ideal positions . The tooth positioner device intended to correct mild discrepancies. It was an active orthodontic appliance used in the finishing and retention phases. Even today, its modern version is available at TP orthodontics, Inc, a company founded by Kesling.

Robert John Pointz developed a clear plastic appliance in 1971 for the retention of orthodontic cases. He proposed that the tooth can be moved or repositioned using the appliance. The main advantage of Ponitz' invisible retainer is the ease of fabrication, insertion, and minimum chair side adjustments of the appliance. They were used for bruxism cases and as splints for trauma cases.[8,9]

NASA's Advanced Ceramic Research worked with Ceradyne Inc. to develop polycrystalline alumina (TPA). The material is strong, smooth, and transparent and was initially used to make infrared antennae in missile trackers. In 1986, Unitek contacted them when searching for a transparent material for orthodontic treatment. Ultimately, in 1987, Ceradyne and Unitek worked together and developed the first invisible braces.[10]

In 1963 when Shanks developed a technique for producing mouth guard style transparent retainers, with a machine capable of producing them. In 1964, Nahoum fabricated the dental contour appliance in what was to be the first thermoformed plastic sheet for moving teeth.

At the end of the 1980s, Elasto devices were developed that were made from highly flexible silicon that could be used for either one or two teeth quadrants. Tooth movements were possible with several setups that were built in different plastics, depending on the clinician's needs, after fixed appliances.

In 1994, Sheridan developed an aligner system, which he called ESSIX, using clear, polymeric shell appliances with thermoplastic divots to reposition teeth, which was meant to solve minor anterior malpositions. In 1997, together with Schwartz, they standardized this by patenting a system that would be implemented in many dental offices until now, an 'in office' vacuum system.[10]

Sheridan modified the same in 1993, calling it the Essix Appliance. However, fabricating the appliance was a laborious process requiring impression-making at every successive appointment. The solution arrived in the form of a clear aligner system created digitally by two Stanford graduates – Zia Chishti and Kelsey Wirth. Called Invisalign®, it was launched in 1997 by Align Technology© (Santa Clara, CA) and is credited with bringing a comfortable alternative to braces to mainstream orthodontics.11-13

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.14

In 2005, a competitor emerged in the form of OrthoClear® – a clear aligner system developed independently by one of the original founders Zia Chishti. However, it was withdrawn a

year later due to lawsuits alleging patent infringement. Many practicing clear aligner users suffered as a result, one of whom was Dr. Willis Pumphrey whose 400 patients were stranded mid-treatment. He responded by developing ClearCorrect(ClearCorrect, Round Rock, TX, USA), an Invisalign® alternative that quickly gained popularity. An onslaught of clear aligner systems has since followed that are being used to correct minor to complex malocclusions.15

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.

ADVANTAGES OF ALIGNERS

Patients prefer aligners because of their advantages, these are:

- More esthetic as compared to traditional brackets.
- There is no irritation or discomfort which is caused by brackets and wires.
- More comfortable with smooth edges and reduced tissue irritation and soft tissue ulcers.
- As aligners are removable, so patients can easily maintain oral hygiene, this reduces plaque deposition hence reduces chances of cavity formation and gingival and periodontal diseases.
- With brackets patient have to face diet restriction due to brackets, but in case of aligners patients are free to enjoy all types of food.
- In person visits needed in case aligners are less as compared to traditional braces. So it gives positive and motivating experience for busy patients.
- There is no emergency visits as needed in breakage of brackets.
- The incorporation of recent advances, increases treatment predictability. 16,17
- It was also observed that root resorption is less prevalent and less severe with aligner therapy.
- Gao et al.17 reported Lower level of pain, reduced anxiety, and improved quality of life in CAT compared to fixed orthodontic treatment.
- The available evidence would lead us to suggest that in terms of optimal treatment duration for mild malocclusions, treated on a non-extraction basis, aligner therapy results in clinically significant shorter treatment duration (range: 3-6 months) compared to conventional fixed appliance treatment and could be the appliance of choice.18

INDICATIONS

Aligners use for moderate to severe malocclusion cases is still under debate. Some case reports demonstrated that moderate to difficult malocclusion cases can be managed by aligners. The main limitation of aligners is inability to control root movement which is main restriction in use of aligners in extraction cases. It was observed in literature that in cases of premolar extraction there is need of fixed appliance to straighten the molars, premolars and canines at the end of aligner therapy. Honn and Goz provided a case study of a successful Invisalign premolar extraction therapy. The effectiveness of Invisalign therapy is highly dependent on which tooth movements are necessary to address the clinical condition, as well as comprehending the appliance's indications. In following conditions aligner therapy indicated:

- Cases with mild crowding and malaligned teeth having discrepancy of 1-5mm.
- Cases where treatment can be possible with expansion, interproximal reduction or removal of lower incisor.
- These can be used in spacing cases up to space of 1-5mm
- Class II division 2 cases where management of deep bite is possible by incisor intrusion and advancement.
- In patients with narrow arches and minor rotations.
- Patients having relapse after orthodontic treatment can be retreated with aligners.19

CONTRAINDICATIONS

- Crowding and spacing greater than 5 mm.
- Discrepancies between Centric-relation and centric-occlusion.
- Teeth that have been severely rotated (greater than 20 degrees).
- Anterior and posterior open bites that must be closed.
- Teeth extrusion.
- Teeth that are tipped more than 45 degrees.
- Teeth with clinical crowns those are too short.
- Arches with a many missing teeth.20

GENERATIONS OF ALIGNERS

First-generation aligners

Initially used aligner systems were solely reliant on the thermoformed plastic aligner material and no auxillary is used along with aligners to attain desired results. The first case report was published in 2000 using 1st generation Invisalign to treat mild crowding and space closure cases.21 The material used to fabricate Invisalign aligners before September 2001 was a polymer mixture and the brand name was Proceed30 (PC 30), which failed to meet all the physical, chemical, and clinical requirements for orthodontic tooth movement.22 Clinicians encountered some difficulties and limitations with the usage of these clear aligners.23,24

Second-generation aligners

With advances in aligner systems, manufacturers incorporated the use of attachments to provide better control of planned tooth movement. Clinicians can also use composite buttons to be bonded on the teeth and utilize inter-maxillary elastics. Other features, including SmartForce™ attachments, Power Ridge™, Velocity Optimization, and interproximal reduction (IPR) became universal in the Invisalign system. A single layered polymer material Exceed30 (EX 30), an implantable medical-grade polymer made of polyurethane methylene diphenyl diisocyanate 1.6-hexanediol, tested for safety and biocompatibility by the United States Pharmacopeia, Class IV, was used to fabricate the aligners. The EX30 material provided 1.5 times greater elasticity and 4 times more adaptability than PC 30 and facilitated easier insertion and removal of the trays for the patient.25,26

Third-generation aligners

In 2010, the third-generation aligners included SmartForce™ features, such as optimized attachments, designed and placed automatically by commercial software as well as indentations in the polyurethane plastic that placed increased pressure on specified points on the crown to produce a moment of a couple and root torque. Further, the clinician could also prescribe non-precision attachments to be placed on the teeth wherever needed, to improve movements such as derotation and extrusion. New precision cuts were introduced to help with Class II and Class III interarch elastics.27

Fourth-generation aligners

In 2011, G4 attachments were introduce which facilitate the clinical results in open bite cases with better optimized extrusion attachments on multiple teeth. Movement in different planes can be possible for upper laterals to enhance extrusion along with rotation and/or crown tipping. Optimized attachments for root control were incorporated for better mesiodistal root control of canines and central incisors.28 Since 2013, EX 30 has been replaced by a new multi-layer aromatic thermoplastic polyurethane/co-polyester material, called SmartTrack™ (LD30). This new material provides better performance, such as a gentle and more constant force, increased long-term action and improved adhesion, which eases the use for patients. Compared with EX30, LD30 has greater consistency of application of orthodontic forces, greater elasticity, chemical stability and an even more precise and comfortable aligner fit.29.30

Fifth-generation aligners

In late 2013, fifth-generation enhancement improved the predictability of deep bite correction by introducing pressure areas on the lingual of the upper and lower anterior teeth, precision bite ramps on the lingual of the upper incisors, and bevelled dome-shaped retention attachments on the premolars . However, a recent study by Blundell et al. found that the use of precision bite ramps does not appear to significantly improve the ability of SmartTrack™ material to predictably open the bite compared with EX30 materials.31,32

Sixth-generation aligners

In late 2014, sixth-generation clinical innovation for orthodontic treatment of first premolar extractions was introduced using new SmartStage™ technology and SmartForce™ features to provide vertical control and root parallelism that optimize the progression of tooth movements for extraction treatment planned for maximum anchorage.33

Seventh-generation aligners

Invisalign G7, a set of features designed to deliver greater control of tooth movements and improved treatment outcomes was released in 2016, particularly for teenage patients. It aimed to deliver better upper lateral incisor control, and improve root control and features to address the prevention of posterior open bites.34

Eighth-generation aligners

Around late 2020, the eighth-generation enhancements were announced aiming to further improve the predictability of deep-bite correction with SmartForce™ aligner activation for

anterior intrusion and improvements in the ClinCheck virtual proprietary software setup to level the Curve of Spee. G8 also minimizes unwanted crown tipping during posterior arch expansion with optimized expansion support and rotation attachments to reduce the potential for buccal crown tipping.35

Cutting-Edge Materials in Contemporary Aligners

1. Smart Polymers

- Shape Memory Polymers (SMPs): These materials adapt to intraoral temperature changes, permitting aligners to "self-adjust" during wear. A study reported that SMP-based aligners reduced mid-treatment adjustments by 40%.36
- 4D-Printed Materials: Time-responsive polymers enable aligners to modify their shape or stiffness in response to physiological conditions, such as pH or moisture.37

2. Nanocomposite Reinforcements

- Graphene Oxide (GO): Aligners infused with GO consists antimicrobial properties and a 40% increase in tensile strength and reducing bacterial biofilm formation.38
- Cellulose Nanocrystals (CNCs): These materials derived from renewable sources, CNCs enhance aligner transparency while decreasing impact on environment.39

3. Biocompatible and Sustainable Alternatives

- Bio-Based Polyurethanes: Aligners made from castor oil-derived polyurethanes are biodegradable and hypoallergenic, catering to eco-conscious patients.
- Polylactic Acid (PLA): PLA-based aligners, though still experimental, show promise in balancing strength with compostability.40

CONCLUSION

In conclusion, clear aligner therapy has transformed the landscape of modern orthodontics by offering an effective, esthetic, and patient-centered alternative to conventional braces. With advances in digital technology, precise treatment planning, and improved aligner materials, clinicians can now address a wide range of malocclusions with greater predictability and comfort. Patients benefit from removable appliances that support better oral hygiene, reduced chair time, and minimal disruption to daily life, while still achieving reliable orthodontic outcomes.

However, the success of aligner treatment depends heavily on careful case selection, accurate diagnosis, and strict patient compliance. Not all orthodontic problems are ideally suited for aligners, and the clinician's expertise remains critical in determining when aligners are appropriate and how they should be staged. As research continues and innovations such as attachments, optimized force systems, and AI-assisted planning evolve, the scope and effectiveness of aligner therapy will continue to expand. Ultimately, clear aligners represent a significant step forward in orthodontic care, blending technology with patient comfort and aesthetics. When used judiciously and guided by sound clinical judgment, aligner therapy can deliver excellent functional and aesthetic results, reinforcing its role as a valuable tool in contemporary orthodontic practice.

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