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Invisalign System – Contemporary Orthodontic Treatment Solutions

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Abstract
Invisalign is the most advanced and revolutionary technology ever in orthodontics and is the first treatment method based exclusively on 3D digital technology. It is a set of discreet and comfortable, clear plastic aligners which fit perfectly and intimately on the teeth and the patients can easily remove them for eating and brushing their teeth. They do not damage the teeth or periodontal tissues and not lead to root resorption. They work by pushing the teeth, not pulling them. The system incorporates the biological principles of tooth movement, reciprocal forces, biomechanics, and anchorage.
Attachments with precise size, design and position are used, made of composite resin bonded to the teeth for better attach and deliver greater force. Interproximal reduction is often a necessary procedure and intermaxillary elastics or mini-implants are also used to facilitate the vertical and sagittal movements that need to be achieved.
Initially, the indications referred only to moderate crowding, but today with the use of attachments, the list has been expanded and moderate crowding, crossbite, mild open and deep bite and some extraction cases can be successfully corrected.
The use of aligners facilitates oral hygiene, which improves periodontal status, reduces the level of plaque and gingival inflammation. Efficacy depends on the patient's cooperation and regularly wear as prescribed.
Key words: *Invisalign, orthodontic therapy, biomechanics*

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I. Introduction

Invisalign, as the most well-known aligner system, is the generic name for high-quality systems that use CAD-CAM technology, as the most sophisticated and commonly used technology [1]. As modern treatment option in orthodontics, Invisalign is a mobile appliance that overcomes the problems of orthodontic appliance visibility. It is a set of discreet and comfortable, clear plastic aligners that the patients can easily remove for eating and brushing their teeth0[2].

The concept of tooth movement as a series of planned, individual steps using set-up models and elastic appliances was first described by Kesling in 1945, the inventor of the first tooth positioned. Later, Henry Nahoum developed a vacuum-formed appliance in the late 1950s, often called "invisible." Pontiz introduced the Essix appliance, which he claimed produced minimal tooth movement and in 1985 McNamara and colleagues introduced invisible retainers. An improvement was made by Sheridan in 1993 with interproximal reduction and progressive leveling [3]. The main limitation of these described methods is that only relatively small magnitudes of change were possible due to the technical difficulty of evenly dividing the required large movements into small, precise steps.

Invisalign system is the most advanced and revolutionary technology ever in the world of orthodontics. These orthodontic appliances were invented in 1997 by Zia Chishti and Kelsey Wirth, graduate students at Stanford University who started Align Technologies with the help of several forward-thinking orthodontists. Combining 3D technology with a retainer, they designed a new state-of-the-art appliance. Align Technologies (San José, CA, USA) received FDA approval for Invisalign in August 1998, and commercial operations began a year later. The system involve CAD-CAM technology, combined with laboratory techniques, to create a series of aligners made of polyurethane [4].

Computer technology takes images and models of the patient's teeth and dental arches, and shows the progression needed to straighten the teeth. Based on this, a set of transparent appliances are manufactured that the patient wears for a certain period of time to straighten the teeth.

They are similar to the splints that cover clinical crowns and the marginal gingiva. Each individual aligner is designed to move the teeth a maximum about 0.25 - 0.3 mm over a period of 2 weeks and is worn in a specific sequence. Of course, they require responsibility, cooperation and commitment from the patient[5,6].

The therapy represents a completely different orthodontic technique and technology. In the beginning, the main feature and benefit were aesthetics, but today, with the accumulation of knowledge and clinical experience, other more priority attributes have been confirmed that increase the level of use and efficiency. The revolutionary thing is that this therapy acts proactively, not reactively as in traditional techniques and protocols. The movement of the teeth is not random, but according to a digitally determined path and map.

These tooth movement appliances have minimal impact on skeletal structures, and are not an appropriate therapeutic choice for transverse skeletal problems, pronounced sagittal anomalies and misaligned skeletal structures [7]. Of course, there are certain limitations and disadvantages, which include the need for patient cooperation and discipline, they are not recommended for patients with dental implants, crowns and bridges, patients with impacted teeth or in whom orthognathic surgery is necessary. The high cost of the treatment is also added to this list.

The duration of treatment varies depending on the complexity of the malocclusion. It usually lasts between 6 and 18 months in most cases.

The purpose of this paper is to sublimate the development of scientific thought in the modern therapy with Invisalign; to investigate the possibilities and advantages of use, indications and the age range of patients who can be treated according to the individual growth potential; and to present their dental and skeletal effect, range of movements, biomechanics and mode of action, duration of therapy as well as periodontal implications and recommendations for retention.

II. Material And Methods

To achieve the set goals, we used literary publications and conclusions from scientific and clinical studies, by searching the modern scientific databases PubMed, PMC, NLM, Web of Knowledge, Scopus, Google Scholar, and LILACs, which cover the period of the last 20 years, on the topic of our interest, using the keywords: Invisalign, orthodontic therapy, manufacturing, biomechanics.

III. Discussion

In 1999, the Invisalign system was introduced to the orthodontic market for the treatment of mild malocclusions only; however, the development of various accessories and aids now allows the Invisalign system to perform large tooth movements and treat more complex cases such as those requiring premolar extraction [8,9,10].

This is unique orthodontic technique in which the teeth move through the bone medium according to previously subtly programmed protocols and has already been implemented in more than 18.9 million patients worldwide [11,12].

According to Invisalign Treatment Planning, the fundamental principles of Invisalign are: aligners work by pushing the teeth, not pulling them and must fit intimately on all teeth and attachments; they allow multiple movements simultaneously; anchorage is required for effective movement; teeth need space to move and ClinCheck is mandatory [13].

This modern therapeutic option has its own indication area and certain limitations and contraindications in its use. In the literature, it is stated that they are indicated for adults and adolescents with fully erupted permanent teeth and patients with mild non-skeletal malocclusions. Until 1998, these devices were used only for small dental movements, usually at the end of orthodontic treatment or minor correction of relapse after orthodontic therapy. Since 2008, improvements such as precision cutting, the precision bite ramp, and smart force attachments have resulted in innovations in up to Invisalign G8, allowing for a greater range of tooth movement.

Today, the indication area has been expanded to include crowding and overjet of 1-5mm [14], deep overbite where the mild vertical overlaping can be reduced by intrusion of the incisors; non-skeletal compression of the dental arches that can be widened by mild tooth tipping.

Although the number and complexity of cases treated with this system continues to increase, it is not possible to treat all types of malocclusions. They are suitable for mild to moderate crowding or diastema, posterior expansion of the dental arches, intrusion of a group of teeth, cases with extraction of a lower incisor, and distal tipping of molars. Extrusion, rotation, torque, and closure of extraction spaces are more challenging. However, incisal extrusion, molar transition, and space closure are possible with the use of Invisalign appliances. [8,15].

Regarding the indication area, of course there are limits. Invisalign does not work in every case, so the orthodontist determines the candidates depending on the complexity and severity of the malocclusion and the

dental status. The list of contraindications includes: pronounced crowding and oj over 6mm; skeletal anomalies; Diastema over 4mm; rotated teeth more than 20^0; deep bite over 6mm; open bite over 2mm; teeth with short clinical crowns or periodontal problem and mobility; TMJ problems and existing implants and prosthetic abutments and bridges.

A deep bite is a limitation, not only because of the limited intrusion capability, but also further limits the ability to pronate the lower incisors and the possibility of correcting mandibular crowding. For these patients, additional treatment, such as microimplants, may be necessary.

In contrast, a pronounced open bite is a limitation of treatment, due to the inability to allow excessive dental extrusion. The most inaccurate movements are incisor intrusion and canine rotation [16].

According to Chan and Darendelier, extraction treatment with the Invisalign system is challenging and potentially the least predictable [17]. In treatments involving premolar extraction it is crucial to implement strategies to counteract roller coaster effect caused by aligner and it is imperative to enhance torque control in the anterior teeth and protect anchorage in the posterior teeth [18].

The advantages of Invisalign are numerous and include [19,20]: they are virtually invisible, so can be worn confidently in public and during sports, without the risk of injury the teeth, oral tissues or tongue; and do not damage the teeth or periodontal tissues, not lead to root resorption; they are highly effective, comfortable and do not cause allergies; the material used to make them offers greater predictability and controlled tooth movement; wearing them does not cause pain at any stage of the treatment; the results are easy to monitor at each stage of the orthodontic treatment; no additional time and effort is required to clean, just brush and rinse with lukewarm water; they can be easily removed to enjoy the favorite foods without any restrictions. Also, the treatment requires fewer visits to the orthodontist and is therefore suitable for even those patients with the busiest schedules. Additionally, after completion of treatment the last set is used as a retention appliance to prevent relapse.

According to the manufacturing methods, aligners can be grouped into two categories:
1. Aligners made of thermoplastic materials with manual set up
2. Aligner systems that use CAD-CAM technologies [21]

Manually fabricated aligners

The manual approach is a specific process that requires patience, exceptional manual skill and the ability to manually separate and reposition the teeth in the desired position, place and fix them on a wax base and produce vacuum-formed aligners using a pressure molding machine or a vacuum machine.

Aligners manufactured with CAD-CAM technology

The incorporation of digital technology has revolutionized appliances and techniques in orthodontics, as well as in other areas of dentistry.

The Invisalign aligners are designed and manufactured using CAD-CAM technology [21]. The unique combination of computer-aided virtual treatment planning and stereolithography prototyping technology for manufacturing has given Invisalign® a leading role in dental alignment therapy [22,23,24,25].

Today, Align Technology continues to be the market leader, and Invisalign has remained the household name for computer-aided aligners, with more than 18 million people treated with the system. Meanwhile, a 2015 literature review revealed approximately 27 different systems on offer, a number that continues to grow rapidly [2,15,26,27,28].

The list of companies that manufacture them is expanding daily and currently includes Invisalign, eCligner, Angelalign, SmartTrack, iORTHO, MasterForce, Orthero, EON Aligner, Smile Direct Club, 3M, Dentsply Sirona and Clear Correct [29].

Manufacturing technique

After summarizing the results of the first decade of use, the need for extremely precise impressions that the manufacturer converts into digital data using industrial 3D radiography was prioritized. The advent of intraoral scanners has simplified the digitization process and eliminated the need for a third party to convert the impression into a virtual model [30].

The instant virtual model from the intraoral scanner, combined with multiple software platforms, allows the orthodontist to manipulate the teeth without the need for a technician. Together with a three-dimensional printer, it allows the easy fabrication of aligners. The software must accomplish two tasks. First, it must fill in any gaps created during the scan itself to obtain a working model; second, it must allow for tooth segregation and three-dimensional manipulation to produce the planned final placement.

Furthermore, the amount of movement per aligner, or phase, must be determined either by the orthodontist with a 3D digital orthodontic system (Orchestrate Orthodontic Technologies, Rialto, CA) or programmed into the software in the form of a proprietary algorithm.

All 3D printers build an object (model) in layers. The height of the model and the thickness of each layer determine how long it takes to print. Objects can be printed from a variety of materials, depending on the printer and the intended use of the object, by stereolithography, fused deposit modeling (FDM), digital light processing (DLP) or poly-Jet photopolymerization (PJP).

In 2013, a new material, SmartTrack, a highly elastic, biocompatible multilayer aromatic thermoplastic polymer of polyurethane and copolyester, was introduced [2,31]. One study showed that the SmartTrack material allows significantly greater movement than the previous Exceed-30 (Align Technology) [32]. The main component among other manufacturers is polyethylene terephthalate glycolmodified (PET-G), but polypropylene, polycarbonate (PC), thermoplastic polyurethanes (TPU), ethylene vinyl acetate, and many other materials have also been used [33].

Thanks to technological advances, particularly in computer-aided design and manufacturing technologies, as well as biomaterials, now is possible to manufacture direct to print aligners (DPAs) in-office [34].

ClinCheck software

The virtual setup is checked by the orthodontist in a software program called ClinCheck, which is not a treatment plan, but rather a 3D virtual interpretation of the treatment plan prescribed by the orthodontist and reflects the phases of treatment. The orthodontist is the one who incorporates the biological principles of tooth movement, anchorage, reciprocal forces, and biomechanics. ClinCheck provides analysis and navigation tools to enable better treatment planning and relevant clinical decision-making [35]. The purpose of the virtual setup is to produce the individual tooth movements depicted in ClinCheck. Particular attention is paid to each crown and to the movement of the roots in all three planes of space. If a movement is not represented in ClinCheck, it will not be present in the aligner and will not manifest clinically.

The five basic steps in the ClinCheck Guide review are: final position, interproximal reduction, stage analysis, attachments and over correction. [35].

Final position should be approved by the orthodontist before the start of therapy.

Interproximal reduction (IPR) of teeth is often a necessary procedure to compensate the crowding. There is a table (Reproximation Chart), a template with directives on when, where and how much IPR to do. If the recommended amount of enamel reduction is not done at the correct stage and time during the treatment, the treatment will not progress. The total reduction for each tooth should be carefully studied and whether the shape can accommodate the stripping. The location, mesial and/or distal to fillings or intact surfaces, whether on the posterior teeth and how the appropriate surface can be accessed is also considered. The timing is also carefully analyzed, e.g. if it is indicated in phase 5-9, it means in any interphase from 5 to 9, with careful monitoring of that region.

"Staging" is the sequence of stages movement and the speed at which the teeth move. Each aligner represents a stage. Aligners allow movement of 0.25-0.33mm per tooth in a single phase. The number, type and sequence of stages are individual for each patient and are important for the course and outcome of the treatment. For example, first distalization of the second molar, then of the first molar, expansion, intrusion, derotation, etc. An alternative to segmented stages, which mimics treatment with fixed appliances, is simultaneous, overlapping stages (simultaneous staging). The basis for simultaneous movement is that all teeth in each arch move together from the initial to the final phase. Moving all teeth simultaneously reduces the speed of movement and increases predictability without increasing the total number of aligners.

The tooth that moves the most dictates the total number of phases.

Attachments, power ridge, power arms or pontics are often required. Attachments are composite attachments bonded to the teeth, far enough from the gingival margin, using a template. Their purpose is to improve fixation and deliver greater force and accurate design and precise placement are necessary. They provide a polygon for holding the aligner that is perpendicular to the force direction. Different shapes of attachments have been designed for better retention and easier performance of complex movements, such as rotation [8]. According to Martines, optimized attachments slightly enhance the effectiveness of dental movement compared to conventional attachments [36]. The timing of placement of the attachments must also be planned [37].

An alternative to attachments that help facilitate torque control are the power ridge. They are constructed corrugations, thickenings placed near the gingival margin. They function by strengthen the gingival third of the aligner to make it more resilient and provide additional force close to the gingival margin to increase the effect of the aligner.

Gingival extensions (power arms) can also be used as an additional force system, which move the force application closer to the center of resistance.

Pontics are spaces built into the aligner that narrow during treatment as the spaces close. In the case of missing teeth (due to extraction or hypodontia), they are filled with composite and are an aesthetic option. They are also called virtual teeth.

As an auxiliary maneuver in straightening teeth, especially extrusion, the so-called Buttons & Elastic technique can be used, which consists of placing composite balls gingivally on the corresponding tooth and its antagonist, freed from the aligner, and then connected with an elastic. Class II and Class III elastics are often required, just as with fixed appliances. They can be attached directly to the aligner or to buttons bonded to the teeth.

Miniscrews can be effectively used in combination with aligners in the same way as with fixed appliances. Miniscrews are applied to facilitate the vertical and sagittal movements that need to be achieved [38,39].

Over correction is the planning of tooth movement beyond ideal. Predicting in advance of treatment which teeth may need overcorrection is difficult and uncertain. Therefore, it is recommended that overcorrection, as part of Refinement, be sought once the patient has reached the final aligner.

Australian orthodontists Chan and Darendelier emphasize that sometimes the progress of therapy is not as easy and predictable as computer animation suggests. Following factors influence the predictability of treatment: anatomy of the dentition and malocclusion, patient's individual growth potential or lack of, the ability to place attachments (based on aesthetic and biomechanical requirements), and specific dental movements [37].

Biomechanics of Invisalign Treatment

Invisalign aligners encapsulates the teeth and must provide both retention over the archwire and active dental movement. In general, the natural tooth contours provide retention and stabilization. The elastic deformation of the material initiates tooth movement, but it must not be greater than the retentive force. At the same time, certain directions allow for a greater possibility of elastic deformation. In summary, only sequences of aligners move individual teeth in a single phase. The number of aligners, or phases, depends on the range of movements to be achieved [40].

Clear-Aligner (Scheu Dental, Iserlohn, Germany) for example, offers aligners in three different thicknesses (0.5 mm, 0.625 mm, and 0.75 mm) for each treatment phase. Similar to the material from which they are made, this also affects the orthodontic biomechanical properties and influences tooth movement.

Caruso and all examined 24 reviews and meta-analyses and found that there is still a shortage of high-quality evidence concerning the treatment modality [41].

Chewing efficiency test in subjects with clear aligners reveals that there was no substantial difference between chewing with or aligners [42].

Mechanical properties of the aligner material deteriorate with time. Microcracks, delaminated areas, calcified biofilm deposits and loss of transparency were reported after 2 weeks aligners worn. A change in fit of the appliance and resultant orthodontic forces can be seen as a result of intraoral hygroscopic expansion. Water absorption of thermoplastic materials increases with time, showing the highest absorption followed by PET-G20 [43,44].

Efficacy and effectiveness

There is consistency among studies that the Invisalign system is a viable alternative to conventional orthodontic therapy in the correction of mild to moderate malocclusions in non-growing patients that do not require extraction. Aligners can predictably level, tip, and derotate teeth except for cuspids and premolars; limited efficacy is identified in arch expansion through bodily tooth movement, extraction space closure, corrections of occlusal contacts, and larger antero-posterior and vertical discrepancies [45,46,47,48].

Predictability of tooth movements and clinical effectiveness of aligners compared to conventional fixed appliances is considered to be low to moderate and it tends to yield less accurate results [49].

Time Efficiency of Aligners

Time efficiency is an important consideration and depends on the frequency and duration of follow-ups and the overall treatment duration [50].

Buschang et al. [51] investigated the difference between conventional fixed appliances and the Invisalign system and found that the total treatment time was 67% shorter in the Invisalign group. The shorter treatment duration is supported by the absence of the finishing and detailing phase, which can take up to 6 months with fixed appliances.

In contrast, in cases of extraction, the treatment duration with Invisalign is 44% longer compared to fixed appliance treatment [52].

Patients with aligners are required to visit the orthodontist at 10-12 week intervals, while 4-6 week intervals are unavoidable when treated with fixed appliances. Therefore, more follow-ups are required with

fixed appliance treatments. Also, the duration of follow-ups is significantly shorter, allowing the clinician to treat more patients [51,53].

Effects of Invisalign on Periodontal Status and Oral Health

As the number of adults treated has increased, the literature has described the positive periodontal effects and benefits of this treatment [54,55].

The use of aligners facilitates oral hygiene, which improves periodontal status and causes a decrease in plaque levels, gingival inflammation, bleeding on probing; reduce development of white spot lesions and pocket depth [56].

Other aspects of Invisalign therapy are also discussed in the literature. Micro plastic release by plastic aligners has emerged as a significant human health and environmental concern. Studies indicate that minuscule non-biodegradable plastic particles can lead to adverse health effects upon ingestion or inhalation, potentially causing systemic inflammation and health risks [57].

IV. Conclusions

Invisalign are comfortable, transparent plastic aligners that fit perfectly and intimately on the teeth, and the patient can easily remove them for eating and maintaining hygiene. It is effective and safe orthodontic solution for correcting dental misalignment using subtle biomechanical force, based exclusively on 3D technology combined with laboratory techniques. Each aligner is designed to move the teeth a maximum of 0.25 - 0.3 mm over a period of 2 weeks and is worn in a specific sequence. It is indicated for moderately pronounced crowding and OJ of up to 5 mm, spacing, deep bite, open bite and non-skeletal compression of the dental arches; but is not indicated for skeletal discrepancies, severely rotated teeth, pronounced open bite and periodontally compromised teeth. The system incorporates the biological principles of tooth movement, reciprocal forces, biomechanics, and anchorage. Attachments with precise design, size and position are used, made of composite resin bonded to the teeth using a template, for better attach and deliver greater force. Interproximal reduction is often a necessary procedure and intermaxillary elastics or mini-implants are also used. The use of aligners facilitates oral hygiene, which improves periodontal status, reduces the level of plaque and gingival inflammation. Efficacy depends on the patient's cooperation and regularly wear as prescribed.

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