Invisalign update: A review of articles

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Abstract

Although clear aligners have long been introduced, the use of them was revived by Invisalign™ in 1999. With strong development and marketing, it has gained popularity and acceptance. Despite its soaring popularity, there is a lack of evidence-based studies with strong evidence on it. The objective of this article was to critically analyze recent relevant documents on Invisalign™. For systematical comparison between Invisalign™ and conventional orthodontic fixed appliances, this article was categorized as follows. First, the biological response of the tooth and periodontium to tooth movement caused by both techniques were discussed. Following which, detailed comparisons were done in terms of force magnitude and duration, types of tooth movement, pain and oral functions, root resorption, and clinical success.

Key words: invisalign, aligner, removable orthodontic appliances, orthodontic appliance, bracket, orthodontic wire

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Introduction

Orthodontic treatment utilizing clear appliance based on computerized 3-dimensional images of teeth and related tissue has been introduced since 1999 (Invisalign™; Align Technology, Santa Clara, Calif, US).[1] Although similar clear plastic aligners have been introduced for a relatively long period, it is distinctly apparent that this computerized technique is now the most popular. The company has the most number of patents and products. Moreover, the technology has been evolving and lately, novel techniques have been introduced, namely attachment. Instead of relying only on the clear plastic aligner, this new technique was designed to direct force to the teeth through both the clear plastic aligner and the attachment. These attachments can be used to modify the method of force delivery, or to improve specific tooth movements.[2] Recently, with the latest innovations, they are further enhanced and are smaller than the conventional attachment. These innovated attachments were claimed to provide optimized root control, multi-plane movement, and extrusion.[3] To extrapolate these issues, the company claimed that aligner and attachment act like archwire and bracket.[4] Albeit its success, popularity and advanced attachment design, the scientific basis to support this clear plastic aligner technology is not as advanced, or prevalent. The review of literatures with strong scientific evidence is still lacking. To shed light on this particular aspect, it is the aim of this review of the literatures to compare this orthodontic clear appliance with fixed appliance. They will be compared in these 6 topics: biological response, force magnitude and duration, types of tooth movement, pain and oral functions, root resorption, and clinical success.

Biological response

First of all, to provide essential basis to tooth movement by clear aligner, basic biological response to orthodontic force is required. When pressure is continuously directed against a tooth, it causes the tooth to shift position in the periodontal space and results in compression of the ligament at some areas where as stretching at the others. Blood flow decreases in the compression side, but it is maintained or increased in the tension side. Changes in blood flow create alterations in the chemical environment, then promote cellular differentiation and result in tooth movement.[5] This phenomenon can be determined via a histological study.

Study of early histological changes in response to a clear plastic appliance to move a left upper first molar mesially in rats was conducted and histological changes were evaluated on day 1, 4 and 7. It was demonstrated that after 4 days of clear plastic insertion, periodontal ligament (PDL) was stretched at the mesial side of the roots, while compression was observed at the distal side. These were in contrast to the expectation that moving molar mesially would result in stretching of the PDL on the distal side. Moreover, mesiobuccal root of the upper left second molar also had the PDL compressed at the apical area. Osteoclast cells which are usually followed by active undermining bone resorption were observed on the pressure side at the bifurcation, interdental septum, and inter-radicular alveolar bone septum areas.

In the same study, comparison of the clear appliance with a close-coiled spring was also conducted. As expected, the result revealed that the PDL fibers in response to a close-coiled spring were compressed at the mesial and apical aspects of the mesiobuccal and distal roots after day 1 of force application while the stretched fibers were observed at the

distal aspects. Moreover, hyalinized area of the PDL could also be seen in the compression area on day 1.

First, a possible explanation for these findings can be that to move the upper left first molar forward, there might be a piece of plastic material distally to it. It might huddle up on the distal occlusal surface of the tooth and the mesial surface of the second molar, resulting in intrusion of the first molar.

Second, one limitation of the clear appliance design was that it required extension to the anterior teeth area for retention. Assumingly physiologic eruption of the rat incisors could cause the appliance not to be fully seated, it might result in distal tipping of the molar instead of moving it mesially. According to these assumptions, with the intention of moving the molar mesially, the initial tooth movement by clear plastic appliance would possibly be intrusion and distal tipping and then mesial tipping.[6]

Force duration and magnitude

Force duration plays an important role in producing optimal tooth movement. With many orthodontic devices, the force maybe exerted strongly at start then drop down in the end, however, with different duration. From this perspective, force duration is classified by the rate of decay. Both continuous and interrupted forces can be produced by fixed appliances.[5] However, the aligners produce intermittent forces because the force is removed when the appliance is removed. Theoretically, if a patient wears the aligners for 16 to 20 hours per day, clinically effective tooth movement will occur. This is based on the aim that aligners are constructed to move teeth 0.25 mm per tooth per stage.[4]

According to Vardimon in 2010, forces are related to the strains that developed on the aligner surface (Invisalign™; Align Technology), so von Mises strains, which is based on the 3-dimension distortion of the energy of a structure, was analyzed. Von Mises strains were monitored during aligner wear of days 1, 2, 9 and 15. In this study, maxillary aligners were examined in 61 aligners of 3 patients. While retraction of maxillary incisor was the active unit, premolars were the anchor teeth. The result showed the mean incisor von Mises (IVM) strains on day 1 were significantly higher than day 2 and all other days. No statistical differences were found between days 2, 9, and 15. The results meant that all aligners had a peak force at day 1, then it decreased by day 2 and plateaued through day 15. Premolar von Mises (PVM) strains also showed similar results. During day 2 to day 15, the strain did not decrease to zero. It could probably be suggested that the passive aligner of this study exerted some pressure to all surfaces of the teeth. The authors also suggested that an undersized aligner might cause this strain to teeth even in the passive stage. This undersize of the aligner would probably be the result of the technique and material of the aligner company (polyurethane from methylene diphenyl diisocyanate and 1,6-hexanedial, additives). However, the authors speculated that no exact extent day of wearing appliance or magnitude of force could be inferred from this study. Further, despite inherent anchorage property, anchorage loss was not predictable. Attachment reinforcement is recommended for cases with demanding anchorage requirements.[1]

Fixed appliance can produce either “light” or “heavy” forces. Light forces are gentler and more physiologic than heavy forces. The reason for this is that light force can theoretically evoke frontal bone resorption and result in smooth continuous tooth movement. Unlike light forces, heavy forces cause hyalinization of the PDL and undermining bone resorption and then the tooth jumps to a new position.[5] But,

the orthodontic clear appliance was assumed that over time as the aligners were worn, the magnitude of applied force would diminish. This could be a consequence of material fatigue through the distance that teeth had moved.[4]

Unlike Invisalign™, ClearSmile™ technique manually sets up the teeth and constructs the aligner using 0.8 mm-thick polyurethane (ClearSmile™; Woolongong, Australia). According to Barbagallo and colleagues in 2008, the magnitude of the force generated by ClearSmile™ removable thermoplastic appliance was measured using Pressurex system (Fuji Photo Film Co.,Ltd., Tokyo, Japan) and the exact magnitude of force was reported. Forces exerted were measured by placing the Pressurex film in between the teeth and the aligner. This color sensitive film indicated the pressure distribution and quantification. Eight patients with palatally mal-positioned upper first premolar was corrected by wearing a series of four ClearSmile™ aligners over a duration of 8 weeks with one new appliance for every 2 weeks and the amount of movement was 0.5 mm per each appliance for buccal tipping movement. After subtracting the irrelevant forces, the mean initial force of the appliance to move the premolar for 0.5 mm was 5.12 N and the mean force exerted over the 2-week period was 1.12 N. This magnitude of force diminished rapidly in an exponential pattern during each aligner wear.[7]

Type of tooth movement

In case of fixed appliance, the magnitude of force delivered to a tooth and the PDL area to which force is distributed are important when determining the types of tooth movement. This fixed appliance incorporated with implant anchorage system enables almost all types of tooth movement including intrusion, rotation correction, and root movement (namely torque).[5] However, with clear appliance, it is speculated that the forces are dissipated over the majority of the crown and over more of the root surface than with fixed appliances. As mentioned, when mesial movement of molar was attempted, distal tipping and intrusion occurred. At this stage, evidence based studies demonstrating the type of tooth movement of clear appliance based on force delivery system with solid background of biomechanics are few and far between.

Kravitz and colleagues evaluated the efficacy of tooth movement as per type of tooth movement in 2009. They investigated the efficacy of tooth movement using Invisalign™ in 401 anterior teeth. The result showed that the highest accuracy was achieved during lingual constriction, and the lowest accuracy was during extrusion. More specifically, the most accurate tooth movements were lingual constriction of the mandibular canines and lateral incisors, followed by rotation of the maxillary central incisors. The least accurate tooth movements were extrusion of the maxillary and mandibular central incisors, followed by mesiodistal tip of the mandibular canines. Moreover, the accuracy of upper canine rotation was lower than other teeth, followed by lower canine tooth. Lingual crown tip was significantly more accurate than labial crown tip, particularly for the maxillary incisors. To summarize, the most accurate tooth movement was lingual constriction and the least accurate was extrusion.[8]

Pain and Oral Function

It is worthy to acknowledge the patient about pain perception when a clear appliance is worn. Moreover, it is intriguing to understand how the patients feel when they compare the pain level of clear appliance to other different types of orthodontic appliances. Shalish *et al*. tested and revealed this particular comparison

of pain perception using Health-Related Quality of Life parameter. The pain levels were examined after insertion of three-type appliances that were buccal bracket, lingual bracket and Invisalign™. The result showed that, on day 1, the highest percentage of pain levels was found in the Invisalign™ group. It significantly decreased from the first to the seventh day. The pain levels also were consistently higher in the Invisalign™ and Lingual groups compared to the Buccal group, but there were no statistically significant differences between the groups.

The maintenance of oral function is also another absorbing issue regarding clear appliance. The authors also conducted the comparison of the oral function impacted by different orthodontic appliances and weighed it against the clear appliance. The result showed that the levels of eating disturbances were significantly higher in the Lingual group compared to the Buccal group and the Invisalign™ group, respectively. In summary, Invisalign™ group complained of relatively high levels of pain in the first day, however, this group showed the lowest level of oral symptoms and oral dysfunction especially when compared to the Buccal appliance.[9]

Root resorption

To measure the root resorption affected by the invisible thermoplastic appliances (ClearSmile™; Woolongong, Australia), these appliances were worn and the effects on premolar cementum were thoroughly investigated. Thermoplastic appliances were used on one side to move premolar tooth in a buccal direction at a rate of 0.5 mm every 2 weeks and comparisons were made between the following groups.

Group 1 : untreated control group

Group 2 : heavy force from a 225-g beta-titanium alloy cantilever spring

Group 3 : light force from a 25-g cantilever spring. A tipping tooth movement was expected to be generated by these springs.

The treatment duration was 8 weeks and the thermoplastic appliances were changed every 2 weeks whereas the springs were not reactivated. At the end of the study period, premolar teeth were extracted. Root resorption was measured with an x-ray microtomograph. The control teeth had the least amount of resorption. The light-force teeth had approximately 5 times more resorption than the control teeth. The thermoplastic-appliance teeth had similar or slightly greater resorption than the light-force teeth, or approximately 6 times greater than the control teeth. The heavy-force teeth had the most resorption, which was about 9 times greater than the control teeth.

In the same study, cube root volume of the resorption cavities for the 6 root surfaces of tooth was measured. The result indicated that the teeth in the heavy-force, thermoplastic appliance, and light-force groups had the most resorption on the buccal-cervical and lingual-apical. These correspond to regions of compression generated by the tipping force.[10] The authors also mentioned that Invisalign™ company was contacted but did not agree to participate in the study. Therefore, it will be mandatory to look forward to the results of studies with similar testing on Invisalign™.

Clinical success

In the study by Clements and colleagues in 2003, each component of the Peer Assessment Rating (PAR) score (anterior alignment, buccal occlusion, overjet, anterior crossbite, overbite, openbite, and midline) was examined independently to determine which aspects of occlusion were the most clinically successful treatment component treated by aligners. Fifty-one randomized patients were

stratified based on high versus low PAR score and extraction versus non-extraction. The percentages of patients who stayed the same, improved, or worsened showed that anterior alignment was the most improved component, and buccal occlusion was the least improved.[11]

By the same group of investigators, Bollen *et al*. evaluated the effects of activation time (1 week and 2 weeks) and material stiffness (hard and soft) on the improvement of malocclusion by using PAR scores. For this study, Align Technology fabricated the "hard" aligners, which were twice as stiff as their commercially available material. The "soft" aligners, however, were one-tenth as stiff as the commercial ones. The result of this study showed no significant difference in the proportion of patients completing hard and soft appliances. Comparison of subjects with activation time of 1-week and 2-week, the 2-week subjects had a greater tendency to have completed the initial series of aligners than 1-week subjects (37% versus 21%). However, the overall completion of this initial treatment was only 29 per cent.[12]

In 2005, Djeu *et al*. assessed the treatment outcomes between Invisalign™ and fixed appliance by using pre- and post-treatment dental casts and lateral cephalograms in non-extraction cases, treated by an American Board certified orthodontist. To classify patients by severity of malocclusion, the pre-treatment records were analyzed by using the Discrepancy Index (DI) score of the American Board of Orthodontists (ABO) Phase III clinical examination. The result showed no statistically significant differences between the 2 groups for any of the 10 DI categories. Further, post-treatment records of 2 groups were scored by using the Objective Grading System (OGS). The result showed 4 OGS categories that were buccolingual inclination, occlusal contacts, occlusal relationships, and overjet had scores with a statistically significant difference between the groups. In these categories, the Invisalign™ group lost more points than the braces group. Therefore, Invisalign™ was deficient in its ability to correct large anteroposterior discrepancies and occlusal contacts. Invisalign™ and fixed appliances had similar scores on alignment, marginal ridge correction, interproximal contacts, and root angulation. It should be stressed here that most malocclusions in this study started with relatively well-aligned root, and they were all non-extraction cases.

When analyzing the average treatment duration for the 2 groups, the treatment time for the braces group was significantly longer than the Invisalign™ group. But there were no statistically significant correlations between treatment duration and any of the DI categories for either group.[13]

In conclusion, summaries of Invisalign™ treatment from these studies are : Early histologic changes in response to the clear plastic appliance were intrusion and distal tipping despite the intended mesial movement. Aligner should be worn close to 24 hours in the first 2 days, with the time subsequently reduced to 16-20 hours per day. Two-week activation times might lead to a higher degree of success. The most accurate tooth movement was lingual constriction. The least accurate tooth movement was extrusion. Invisalign™ has the highest pain levels in the first days after insertion; however, it has the lowest level of eating disturbances and a similar level of general activity disturbances compared to the fixed appliance. Clear aligners have similar effects on root cementum as light orthodontic forces. Invisalign™ did not treat malocclusions as well as braces, especially deficient in its ability to correct large anteroposterior discrepancies and occlusal contacts.

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