The efficacy of clear aligners in tooth movement

Master thesis

Master of Science in Specialized Orthodontics

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Summary

Objectives:

This literature review study aims to evaluate the effectiveness of clear aligners in tooth movements, to understand what factors affect the efficacy of clear aligners and how to improve the efficacy of clear aligners.

Methods:

Used Pubmed to search of electronic database in English and using filters "Clinical trial" to find topic related articles published up to now. Three books were also cited.

Results:

There were 105 articles found with the keyword "Invisalign", 27 articles with "clear aligners", 52 articles with "thermoplastic Orthodontic appliance", 27 articles with "clear plastic appliance", and 21 articles with "sequential removable Orthodontic appliance". Thirteen clinical studies related to this topic were found. The accuracy of tooth movements for clear aligners was studied in 3 articles.

Conclusions:

Not enough evidence-base articles for statistical conclusions about the effectiveness of clear aligners, but it seems that clear aligners can move teeth effectively in some tooth movements. The mean accuracy of tooth movement of clear aligners ranged from 41% (1) to 56% (2) comparing between predicted and actual achieved results . However, clear aligners are new treatment methods that also affected by many different factors from traditional braces and need to combine with some auxiliaries to increase treatment efficacy.

Key words:

" invisalign", " clear aligners", " thermoplastic orthodontic appliance", " clear plastic appliance", "sequential removable orthodontic appliance".

Contents

1 Introduction

The number of adult orthodontic patients is increasing significantly, therefore new aesthetic orthodontic therapies such as lingual braces or clear aligners are needed to meet the demands. The clear aligners use a series of clear thermoplastic customized aligners to move teeth to new positions. Clear aligners are the ideal choice for adult orthodontic patients who are hesitant to wear fixed braces, especially patients with mild to moderate crowding or spacing .

The thermoplastic sheet has been produced long ago, however it was not used in orthodontics before 1950. Air pressure, vacuum, pressurized steam and hot oil has been used to shape the heat – softened thermoplastic sheets on the patient's models to create thermoplastic appliances. The improvements in machinery, materials and computer aid has helped the production and application of thermoplastic aligners easier, more efficient and accurate (3) .

Due to differences in the properties of plastic, as well as thickness, the purposes of the appliances are different. It can be used to make the retainer that prevents the movement of teeth after orthodontic treatments, or it can be used to move teeth in orthodontic treatment (3) .

The orthodontic treatment with traditional fixed braces has had a long history with the methods confirmed effective in clinical studies, on the contrary, clear aligners have only just been used as an alternative to braces, since Invisalign has been introduced in 1997 by Kelsey Wirth and Zia Chisti, the founders of Align Technology in California (4).

Invisalign uses ClinCheck software as the technical key of system to predict treatment outcome and as a tool to communicate with clinicians, the software allows the clinician to evaluate all the 3D virtual treatments from the beginning to the end and can be changed by the clinician through communication with the company. However, the accuracy of the predicted and achieved results ranges between from 41% and 80%. The different tooth movements have different average accuracy (1, 2) .

The Invisalign treatment is challenging for clinicians. Experienced clinicians can treat some selective complex cases successfully. Generally, Invisalign is used to treat mild to moderate malocclusion cases, relapses and in cases where patients who do not want to wear fixed braces.

According to the Align Technology company, Invisalign can be used to treat most orthodontic cases (5). Some cases can be effectively treated with Invisalign such as patients with crowded teeth or gaps smaller than 5 mm , a deep bite or narrow dental arches (6). The Invisalign treatment is more difficult with moderate to severe malocclusions such as patients with crowded teeth or gaps greater than 5 mm, anterior/posterior skeletal discrepancies more than 2 mm, centric occlusion discrepancies, more than 20 degrees of rotation of teeth, open bites, extrusion, severe missing teeth, teeth needed to upright more than 45 degree (6) .

Some experienced clinicians have reported treating complex clinical cases by coordinating Invisalign with fixed orthodontic treatments for surgical class III patients (7), open bite patients (8), moderate to severe overjet, premolars extraction (9), and to control the torque of the incisors (10).

However, the passing rate of Invisalign group was found to be less than braces group when compared using the standard Objective Grading System (OGS) of the American Board of Orthodontics (ABO) in Djeu and colleagues' study (11) and the relapsing rate of Invisalign group was significantly higher than braces group in the maxillary anterior teeth using the American Board of Orthodontics Objective Grading System (ABO, OGS), according to the study of Kuncio and colleagues (12).

Dentists should be aware of the efficacy of clear aligners in tooth movements, so that they may consult their patients and propose the proper treatments that best fit their needs. Although the Align Technology company suggested that Invisalign can be used to treat a large ranges of orthodontic cases (5). However, there is still a controversy about the effectiveness of clear aligners in orthodontic treatments.

Thesis objective

The aim of this study was a literature review of the effectiveness of clear aligners in tooth movements, understanding which factors are related to the efficacy of clear aligners and how to improve the efficacy of clear aligners.

Research questions

1.   Which tooth movements are possible using clear aligners?

2.   What are the factors related to the efficacy of clear aligners?

3.   How can the efficacy of clear aligners be improved?

2 Material and methods

Used Pubmed to search electronic databases in English, with keywords such as "invisalign", "clear aligners", "thermoplastic appliances", "clear plastic appliances", "sequential removable orthodontic appliances ", " clear aligners tooth movement" and using filters "Clinical trial" . Three books were also cited.

After reading through the abstracts, articles in English that related to the effectiveness of clear aligners, the accuracy of clear aligners and the factors related to the effectiveness of clear aligners were selected. In addition, some relevant information on the website of the company that manufactured clear aligners are also used for reference.

Due to the limited number of articles related to the effectiveness of clear aligners , all articles published so far are considered as materials for this study.

Finally, the articles of the clinical studies including prospective, retrospective, randomized studies were chosen.

3 Results

There were 105 articles found with the keyword "Invisalign", 27 articles with "clear aligners", 52 articles with "thermoplastic Orthodontic appliance", 27 articles with "clear plastic appliance" , 21 articles with "sequential removable Orthodontic appliance". Thirteen clinical studies related to this topic were found.

Author	Study design	Sample
Krieger et al. 2012	Retrospective	50 patients (16 males and 34 females, mean age 33+_ 11.19 years)
Krieger et al. 2011	Retrospective	35 patients (11 males and 21 females, mean age 33 years)
Kravitz et al. 2009	Prospective	37 patients (14 males, 23 females, mean age 31 years)

Author	Study design	Sample
Kravitz et al. 2008	Prospective	31 patients (13 males, 18 females, mean age 19.4 years)
Duong et al. 2006	Prospective	14 patients (6/20 drop- out and/or poor compliance)
Bollen et al. 2003	Randomized	51 patients (15 males, 36 females, mean age 34 years)
Clements et al. 2003	Randomized	51 patients
Vlaskalic et al. 2002	Prospective feasibility	38 patients
Drake et al. 2012	Prospective single- center	15 patients (6 males, 9 females, adult)
Nguyen and Cheng 2006	Internal retrospective	38 patients
Pavoni et al. 2011	Prospective	40 patients (19 males, 21 females)
Kuncio et al. 2007	Retrospective cohort	22 patients
Djeu et al. 2005	Retrospective cohort	96 patients

Table 1: Clinical studies used in this thesis.

3.1 The clear aligners systems

Nowadays, there are many clear aligners systems, however the listed products below are the popular and well known.

3.1.1 Exxis system

The Exxis system is based on the manufacturing of single aligners to move teeth according to the treatment goals. In order to move teeth with the Exxis system, two types of space needed to be created: space within the appliance and space within the dental arches. The space within the appliance is created by blocking out the cast or cutting out a window in the plastic thermoformed appliance. The space within the dental arches can be created by expansion, IPR or extraction. With Exxis appliances, the

clinician can apply force to the tooth, anywhere on the surface. There are two ways to create force with Exxis system: using Hilliard pliers to create the spot on the appliances or mounding technique, placing thin layers of composite on the surface of the tooth (13).

3.1.2 Invisalign

Invisalign is a series of aligners produced by Align Technology Company to move teeth in orthodontic treatment. Firstly, the dentist or orthodontist takes a patient's dental impressions with PVS (Polyvinyl siloxane) and fills out the Invisalign forms, then submit and send all records to Align Technology company via the company's website and UPS. The company's technician scans the impressions into 3D models, using Invisalign software to separate all the teeth, manipulate and correct them individually according to the treatment plan and then virtual treatment plan is sent to the clinician through the " ClinCheck" program. The Clinician can change the treatment plan or " steps" in ClinCheck and can communicate with the technician to get the best treatment plan. After that, the clinician clicks " approve" button on the ClinCheck window and then Align technology produces the aligners using 3D printers and a pressure molding machine before sending all the aligners to clinician (4) .

3.1.3 Clear-Aligner ®

The Clear Aligner® (CA) is an orthodontic treatment using a series of sequential esthetic, removable, and progressive transparent aligners as an alternative for a fixed orthodontic treatment.

The technical steps of the CA is made with new impressions and include: a set up plaster model, 0.5mm of CA Soft, 0.65mm of CA medium, and 0.75mm of CA hard. Each step of treatment is about one month , where the patient is provided with three aligners. The patient must wear the soft aligner for the first week, the medium aligner for the second week, hard aligner for the third week. Aafter that, the patient will go back for new impressions in order to perform the next step.

During the fourth week, the patient wears the hard aligner while the laboratory performs the next step. After the fourth week, a new set of aligners are provided for the patient to use for the next step of treatment. All soft, medium and hard aligners are made on the same set up model . Aligners cover 3mm of gingival tissue. Since the aligners have different thicknesses, they create different forces that move the teeth and are stable for

one month. Patients should wear aligners for at least 17 h per day and follow their dentist's appointments (14).

3.1.4 Other

These kinds of clear aligners are either less popular or have just been newly introduced into the field.

3.1.4.1 MTM® Clear•Aligner

MTM ® Clear Aligner uses the clear removable plastic aligners to treat the mild misalignments such as crowding or spacing. Minor Tooth Movement (MTM) should only be used to treat the cases that need to minimally align teeth. The average treatment time with MTM ® Clear Aligner is from three to six months (15).

3.1.4.2 ClearCorrect

ClearCorrect straightens the teeth using a series of clear, custom, removable aligners. Each aligner moves teeth incrementally.

After the clinician sends the patient's records and prescription form to ClearCorrect, those records are used to create 3D digital models of teeth. ClearCorrect creates a "treatment setup" representing final desired position of the patient's teeth. ClearCorrect provides a "phase zero" passive aligner to help patients get accustomed to wearing aligners. After clinician agrees with "treatment setup", then ClearCorrect creates every steps to move teeth incrementally and uses a 3D printer to produce a 3D model of the patient's teeth to make aligner. The patient wears the aligners all the time, except when they are eating or caring their teeth(16).

3.1.4.3 Simpli5

Simpli5 is a simple aligner system that consists of 5 sequential aligners used in the treatment of mild to moderate crowding or spacing. It was developed by Ormco AOA Lab, clinicians simply send impressions or a dental cast and prescription to AOA Lab. Afterwards, AOA Lab technicians create digital virtual treatment plan. Each tray generates up to 0.5 mmm of tooth movement (17).

3.1.4.4 Ecligner

Ecligner is a combination of a clear aligner and digital 3D scan, design and print software developed by Dr. Kim Tae Won. After the clinician takes the patient's dental impression and pours the cast, the cast is sent to the company's agent, who will scan the

cast and send the digital dental images to the company. The company's staff uses special software to make a virtual treatment plan step by step and sends that data back to the clinician. The clinician can change the virtual treatment plan by communicating with the company's staff to make a final plan. Then, the company prints a 3D cast and makes a series of clear aligners. Each step has three aligners: a soft, medium and hard aligner on the same cast for each week of treatment (18).

3.2 The efficacy of clear aligners in tooth movements

3.2.1 Mechanics of tooth movements.

Tooth movement is due to the response of the periodontal system to the direction, angle, distribution and time of the forces applying on the tooth. It is hard to recognize and evaluate them as there are many forces that are affected in the dynamic environment of the mouth. The movement of the teeth due to selective forces sometimes produces good outcomes but also creates adverse effects on teeth. Understanding this helps clinicians choose the proper forces as well as auxiliary tools to limit the adverse forces (19).

There are many different forces that can be used for tooth movement: translation, root torque, rotation and extrusion all need heavy forces of 50-150g, tipping needs 50-75g, and intrusion needs lighter forces of 10-25g. Ideal forces should ensure that blood vessels in the periodontal ligament that are not blocked. Tipping needs only a single force, while bodily movement needs 2 or more force systems. In the oral environment, as the impact of many different forces in the three-dimensional space, the accurate force systems in fixed braces have not been reported .

3.2.2 Clear aligners in tooth movements.

The use of plastic, transparent polyurethane aligners as a solution to replace orthodontic metal braces raises questions about its effectiveness in moving the teeth as well as the accuracy of the software that simulates and predicts the tooth movements.

 The invisalign system is complicated by the uncertainty of where the exact point the forces reach. Invisalign covers all surfaces of the teeth, so the point of force application depends on the tooth geometry, the materials' properties, the fit over the teeth and programmed activation (20).

3.2.3 The accuracy of tooth movement with clear aligners.

There were three clinical studies that are relevant to this issue, one Invisalign company's internal retrospective and two prospective clinical trials (see table 2).

Author	Study type	A T Mov	Exp [%]	Con [%]	Int [%]	Ext [%]	Tip [%]		Tor [%]	Rot [%]	Mes/ Dis [%]
Nguyen and Cheng	Intr Retr	56			I 85 A 79	I 26 A 29 P 52	C Tip 44 Pm Tip 55		I 67 A 62 P 42	I 60 Pm 47 M 52	Pm Mes 52 M Dis 43
Kravitz et al. 2009	Pros Cli trial	41	A 40.5	A 47.1	A 41.3	A 29.6	MD Tip A 40.5	LL Tip A 44.		A 43.2	
Kravitz et al. 2008	Pro Cli trial									C 35.8	

Table 2: Accuracy of tooth movements for Invisalign. (A) Anterior; (T) tooth; (Mov) movement; (Exp) expansion; (Con) constriction; (Int) intrusion; (Ext) extrusion; (Tip) tipping; (Tor) torque; (Rot) rotation; (Mes) mesial; (Dis) distal; (Intr) internal; (Retr) retrospective; (I) incisor; (P) posterior; (C) canine; (Pm) premolar; (M) molar; (Pros) prospective; (Cli) clinical; (MD) mesialdistal; (LL) labiallingual.

In those three clinical studies, the accuracy of tooth movements was measured by comparing predicted with actual achieved outcomes. While the ClinCheck software program predicts the movements of the teeth, achieved outcomes could not be exactly the same.

The average accuracy of tooth movements for anteriors was found to range from 41% (1) to 56% (2). The amount of concordance was only 14.3% when comparing the predicted outcomes with the achieved outcomes(21).

The tooth movements include: expansion, constriction, intrusion, extrusion, tip, rotation, torque and bodily movement.

3.2.4 Expansion

Expansion is used to create the space needed for orthodontic treatment . Sometimes transverse maxillary expansion and protrusion on the anteriors can create enough space for orthodontic treatment without the need of extraction. No expansion are done on patients with gingival recessions , periodontal pockets greater than 2 mm , gingival thin biotype , thin labial cortical bone, or the incisors and molars with high torque (22).

The change of transverse dento- alveolar width by self- ligating braces was found to be statistically better results than Invisalign in the study of Pavoni et al. In the Invisalign group, the first intermolar widths (lingual and cusp), the second intermolar widths (lingual) and the intercanine widths (lingual and cusp) showed no statistically significant change. In general, no significant expansions in maxillary arches in all of the measurements were shown in Invisalign group (23).

On the contrary, the Invisalign treatment of crowded anteriors showed satisfactory success in all subjects by protrusion on the anteriors, distalization, and IPR in the study by Krieger et al.2012. Noteworthy finding was that 47% of the mandibular crowding subjects were treated successfully by a combination of IPR and protrusion (24).

However, in the study of Kravit et al. 2009, while comparing the predicted treatment outcomes in ClinCheck with the achieved outcomes, the average accuracy of labial expansion of the maxillary central incisors was 48.5%, the maxillary lateral incisors was 49%, the maxillary canines was 36%, the lower incisor was 27.4%, the mandibular incisors was 50.8%, and the mandibular canines was 29.9%. The average accuracy of anterior labial expansion was 40.5% (1).

3.2.5 Constriction

Constriction is used to reduce the alveolar arch length, so it can reduce the discrepancy dento-alveolar (25). There was one study on the accuracy of constriction so far.

The invisalign move teeth with the most accuracy with the lingual constriction (47.1%). The highest accuracy was the lingual constriction of the mandibular canines (59.3%) and the lowest accuracy was the lingual constriction of the maxillary canines (34.7%). This suggests that Invisalign can be successfully treated with the highest accuracy in anterior spacing cases (1).

3.2.6 Intrusion

To intrude the teeth, a labio-lingual inclination (torque) should be corrected, then the intrusion can be done in the spongy bone. Maintaining torque control in the process of intrusion is very important, because if the root apex contacts with the labial or lingual cortical bone, a root resorption can be produced (26).

The accuracy of anterior intrusion was found to be 79% (2) and 41.3% (1).

Author	Intrusion
Nguyen and Cheng	Incisor 85% Anterior 79%
Kravitz et al. 2009	Anterior 41.3%

Table 3: Accuracy of intrusion for Invisalign

The mandibular central incisors had the highest accuracy (46.6%) and the maxillary lateral incisors had the lowest (32.5%) accuracy for intrusion(1). Nguyen and Cheng however, reported that incisor intrusion showed high achievement of 85%. Canine intrusion was above the average achievement (64%) (2). This study is consistent with Joffe's opinion that the deep overbite (Class II division 2) can be treated by anterior intrusion and protrusion (27).

It is more difficult to move teeth vertically than transversely or sagitally (21). Krieger et al.2011 reported that the mean difference in the treatment of overbites between the post-treatment cast and the final position in the ClinCheck was 0.9 mm (from 1mm to 3mm) and that "the amount of concordance between predicted and actual treatment results was 14.3%" (21).

3.2.7 Extrusion

Due to lack of retention for extrusion, it is difficult to extrude the teeth by Clear Aligner (26). Extrusion is unpredictable by Invisalign, but using attachments can overcome this difficulty (28).

The mean accuracy of anterior extrusion is similar in the study of Kravitz (29.6%) and of Nguyen and Cheng (29%) (1, 2).

Author	Extrusion
Nguyen and Cheng	Incisor 26% Anterior 29% Posterior 52%
Kravitz et al.2009	Anterior 29.6%

Table 4: Accuracy of extrusion for Invisalign

According to the study of Kravitz (et al.), only 13 of the 64 teeth that protruded was greater than 1 mm and none protruded more than 2 mm. That is consistent with Joffe's idea that invisalign has a limitation in tooth extrusion(27).

It was interesting that the accuracy of posterior extrusion was 52%, which is higher than the prediction (2).

The alignment of the marginal tooth edges that requires vertical control of tooth movement in the Invisalign group and fixed braces was equivalent. This suggests that Invisalign can actually level arches as successfully as fixed braces. But Invisalign can not create a proper occlusion compared to fixed braces. Perhaps this is due to the fact that aligner has a limitation to extrude the teeth, unless there is a significant undercut. Besides, Invisalign covered occlusal surfaces of teeth preventing the settling of the occlusion (11).

3.2.8 Tip

The tipping movement can be done with Invisalign regularly (28). The removable aligners showed the ability to move teeth up to 6mm by tipping incrementally into the spaces (11). In Pavoni's study, invisalign showed the ability to tip crowns easily (23). Invisalign can easily tip crowns but cannot tip roots because of the lack of control of teeth movement (23). The role of uncontrolled tipping and loss of anchorage complicate the progression of programmed aligners.

The accuracy of tipping for Invisalign was found to be range from 40.5% to 55%.

Author	Tip	
Nguyen and Cheng	Canine tipping 44% Premolar tipping 55%	
Kravitz et al.2009	Mesialdistal tip Anterior 40.5%	Labiallingual tip Anterior 44.7%

Table 5: Accuracy of tipping for Invisalign

According to Nguyen and Cheng's study, the mean accuracy of premolar tip was 55% and of canine tip was 44% (2).

3.2.8.1 Mesiodistal tip

Clear Aligner is not effective in controlling teeth mesiodistal tipping unless being used with special attachments. There are two types of attachments: Clear Aligner power grip 2 (MDI-mesial / distal inclination) to help move the crowns mesially and move the roots distally; and power grip 3 (DMI - distal / mesial inclination) to move the crowns distally and move the roots mesially (29).

The average accuracy of anterior mesialdistal tip was 40.5%. The highest accuracy was achieved by the maxillary lateral incisors (43.1%) and the lowest was achieved by the mandibular canines (26.9%) (1).

Boyd reported a case of distalization more than 3 mm in Class II division 2 patient (Boyd), but Djeu (et al) and Clements (et al) concluded that it was difficult to use invisalign to correct anteroposterior discrepancies (11, 30).

3.2.8.2 Labiolingual tip

The accuracy of labiolingual tip was evaluated according to two groups: labial crown tip and lingual crown tip. Only the labial crown tip of the mandibular canines had a higher accuracy (44.8) than lingual crown tip (42.5%), while the other anterior labial crown tips were was less accurate than the lingual crown tip. The average accuracy of anterior lingual crown tip was 53.1%, while labial crown tip was only 37.6%. The pretreatment malocclusion affected the accuracy of the labiolingual crown tip (1).

3.2.9   Torque

Torque force generated by Essix aligners is more effective than braces because the distance between the opposing moments is only limited by the length of the crown, rather than the width of the bracket slot (0.016 or 0.022 inch). For example, these forces will generate a couples mechanical force that will move the incisal edge lingually and the root labially (13). About 3 degrees of torque can be adjusted by Clear Aligner with CA power edge, so that in those teeth the aligner should cut the gingival part to avoid compression (29).

The accuracy of incisal torque was 67%, the anterior torque was 62% and the posterior torque was 42% (2).

In the study of Castroflorio (et al), 12 upper anterior teeth in six patients were the subjects of research, but only nine teeth showed greater root movement than the crown when analyzed. The results showed that an average torque of nine teeth at T0 (beginning) was 20.95 degrees in virtual setup and 21.12 degrees in the scan cast. At T1 (end) the average change of torque between T1 and To was 10.4 degrees. This shows that the Invisalign with power ridges is a good alternative for the control of root torque of upper anteriors in some selective cases (10).

The fixed braces had OGS scores significantly higher than the Invisalign scores in labiolingual tip (11). This suggests that Invisalign can not create the appropriate root torque, especially in the posterior (11).

3.2.10 Rotation

Before rotating the teeth, a space must be created between the teeth by IPR or expansion. The flat surfaces of the incisors labially and lignually support the rotation, while the rounded teeth, like premolars and canines, make rotating movement more difficult. So for the rounded teeth, the attachments should be bonded on the teeth before taking the impressions (29).

Invisalign can be treated successfully with straightening arches by derotating teeth (23). Rotating the teeth with Invisalign showed a difference between the different shapes of teeth. The accuracy of rotation for Invisalign was found to be ranged from 35.8 to 60%.

Author	Rotation
Nguyen and Cheng	Incisor 60% Premolar 47% Molar 52%
Kravitz et al.2009	Anterior 43.2%
Kravitz et al.2008	Canine 35.8

Table 6: Accuracy of rotation for Invisalign

The average accuracy of anterior rotation was 43.2%. The highest accuracy of rotation was 54.2% for the maxillary central incisors and the lowest accuracy of rotation was 29.1% for the mandibular canines (1).

Invisalign had a limitation in rotating teeth. (27). At the rotation more than 15 degrees, the accuracy of the canine rotation decreased significantly, the accuracy of the maxillary canine rotation was only 18.8%, and the mandibular canine was only 33.2%. However at the rotation where it was less than 15 degrees, the accuracy increased to 35.8% for the maxillary canines and 27.9% for the mandibular canines (1).

In another study, Kravitz et al. 2008 assessed the influence of attachments and interproximal reduction (IPR) on the accuracy of canine rotation with Invisalign, made comparisions on the rotations of canines between the virtual pretreatment model and the virtual posttreatment model using ToothMesure for model superimposition. The study included 38 patients over 18 years old who were treated with Invisalign at the University of Illinois-Chicago, the sample was divided into 3 groups: one group using attachments only (AO), another group using interproximal reduction (IPR) only (IO) and the last group received no intervention (N).

The average amount of programmed rotation was 11.8 degrees. The average accuracy of canine rotation was 35.8%, in which the IO group had the highest accuracy (43.1%), and the lowest was the N group (30.8%). The AO group had the average accuracy of canine rotation (33.3%). However, there were no significant difference statistically (P = .343) between the 3 groups in the accuracy of canine rotation between maxillary and mandibular canines (31).

Invisalign was also successful with straightening teeth by rotation, and the alignment by Invisalign had the same OGS points with fixed braces (11).

According to the prospective study of Nguyen and Chang, the achievement of the maxillary left lateral incisor mesiodistal rotation was 56.2%. (11.9/20.1 degrees of rotation) (2).

In another retrospective study of Nguyen and Cheng, the mean accuracy of the incisor rotation was 60%, the molar rotation was 50%, the premolar rotation was 47% and the rounded teeth (canine and premolar) was 39% (2).

3.2.11 Bodily movement

Although the translational movement is programmed, the results still showed the uncontrolled tipping that created some clinical implications (32).

The translational movement used to close extraction spaces is poorly predicted (28). None of the patients completed the initial treatment with two or more extractions of premolars because of the excessive tooth tipping in the locations of extractions (33). Because translational movements with aligners are difficult, the tooth extraction should be considered as a final option (6). Although the gap caused by tooth extraction may be closed completely, achieving the parallelism of the roots is still a major challenge, especially in the lower jaw (33).

3.3 The factors related to the efficacy of clear aligners

There are many factors related to the effectiveness of aligners, however in this study, there are three main factors to be considered: compliance, activation time and materials.

3.3.1 Compliance

Patients are advised to wear aligners for at least 20 hours per day (34). The compliance of patient is critical factor to the treatment of Invisalign. To control for the patient's compliance, a compliance indicator can be used (35). However, there is currently no clinical studies on this issue.

3.3.2 Activation time

Currently, the majority of patients are recommended to change aligners every two weeks ever though there is not enough evidence for this. There were no significant differences between the change of aligners every week or two weeks. Orthodontic teeth

movement during the first week is more than 4.4 times the second week for two- weeks prescribed wear time (32).

Successful rate of completing the initial set of aligners is higher at two-weeks activation time (37%) than one-week activation time (21%) (33).

3.3.3 Materials

There were no significant differences between hard and soft materials in the completion of series of aligners (30, 33) . However, in four different groups of treatment protocols, the combination of hard materials and two-weeks activation times had the best results in all the measurements of occlusal improvement and alignment (30).

Although, the aligner degradation has not been fully studied, it seems that the aligner's ability of force magnitude is reducing over time. Research on material fatigue did not detect any difference in tooth movement between the two-weeks activation time group and the group who wore a new aligner after one week of two weeks prescribed activation time (32).

4   Discussion

Clear aligners are used by many clinicians over the world as an alternative for traditional fixed orthodontic treatments, especially in adult patients for aesthetic reasons. According to Align Technology, Invisalign has a "broad applicability based on level of experience, including comprehensive treatments" (5). However, not all cases are treatable with clear aligners, and the clinician should be aware of the advantages, disadvantages, limitations and difficulties of using clear aligners. Due to the accuracy of the tooth movements that ranges from 26% to 85%, the clinician should be prepared to make mid-course corrections and refinements in the treatment process or to combine with other auxiliaries to complete the treatment.

According to searching results, there were two randomized, six prospective and five retrospective studies, which all had their own limitations. (Table 1)

In the retrospective study, the authors can not control the compliance of the patients. Furthermore, each clinician has difference experiences and various treatment methods with Invisalign.

Studies of Bollen (et al) and Clements (et al) on the same sample were designed to be random. These two studies mainly evaluated activation time and material stiffness (30, 33). However, these studies had small sample size, and the materials used were not the same types of material used by the Align Technology company. Although the cases of tooth extraction were random, these studies did not consider the types of tooth extraction, thus the group that wore the hard aligners and followed two- weeks wear time had a higher rate of success, which could be due to having fewer premolar extractions. In addition, the rate of overall completion of the initial set of aligners was only 29%. This low rate may be due to failure of the patients following strict protocol for the activation time (33).

So which tooth movements are possible using clear aligners?

There are three studies about the accuracy of tooth movements (1, 2, 31). The study by Nguyen and Cheng was an Align Technology company's internal study, so its objectivity was not high. However, they also concluded that clinicians should use overcorrection and refinement to complete treatment goals. In this study, the mean accuracy of anterior tooth movement was 56%. On the other hand, in the study of Kravitz, the mean accuracy of anterior tooth movement was lower at 41%. The accuracy of most tooth movements was lower than 50%, except for the labial expansion of mandibular lateral incisors, the lingual constriction of maxillary central incisors, mandibular lateral incisors, mandibular canines, the rotation of maxillary central incisors, mandibular lateral incisors. These studies concluded that Invisalign was less effective and unpredictable in the extrusion. This is also consistent with the opinions of Joffe and Boyd (27, 9).

When analyzing the accuracy of each tooth movement, rotation was the only tooth movement that showed significant difference between the teeth. It was thought that the attachments would increase the undercut and geometrical retention of the teeth and make the tooth rotaton better (31). The use of vertical-shaped ellisoid attachments placed in the middle of the tooth crown, showed little clinical improvement compared to the rotation of teeth without attachments (31).

Due to the difficulty in rotating teeth, Align technology advised clinicians to use attachments, interproximal reduction, thermopliers, overcorrection and auxiliaries to support the tooth rotation. (Invisalign reference guide). In particular, the average accuracy of canine rotation is higher with interproximal reduction. However, clinicians

should consider that tooth rotation can somtimes stop, and any overcorrection can not improve the accuracy of rotation (31).

The study of Vlaskalic (et al) was a feasibility study of the University of the Pacific contracted with the Align Technology company. The study concluded that although Invisalign can be an alternative for removable or fixed orthodontic appliances in select cases, by comparing the results and the effectiveness of Invisalign treatment with traditional orthodontic treatments, it is clear that more studies are needed that have further clinical prospective, controlled studies with appropriate sample sizes and the use of assessment objective methods to evaluate the results (28). According to Joffe, clinician should be cautious when using Invisalign to treat patients with the discrepancies of crowding and spacing of more than 5mm, anterioposterior discrepancies of more than 2mm, tooth rotation of more than 20 degrees, anterior, posterior openbite, extrusion, tooth tipping of more than 45 degrees, short crown teeth; and severe missing teeth (27). This is similar to the above results that show that the limitation of clear aligners is controlling the vertical movements, especially extrusion and the translational movements because it has a low accuracy of tooth movement.

Currently, the histologic mechanisms of tooth movement with clear aligners has not been fully studied. The histologic changes of periodontal tissue in rats showed the intrusion and distal tipping of molars even though the initial treatment plan was to move molars mesially. The resorption of root surfaces is similar to the criteria used by close - coil spring (36) .

There are some factors that affect treatment outcomes by clear aligners.

One of the important reasons that makes Invisalign less effective than fixed appliances seems to be the patient's compliance. Invisalign patients are recommended to remove aligners when eating, but clinicians find it hard to control the patient's wear time and this causes biomechanical disadvantages (23). Recommended activation time is two-weeks, but if the aligners are not entirely passive, because the teeth have not yet moved to the programmed position, the patient can take longer time, for example 3 weeks. A compliance indicatior can be used to control the patient's compliance (35). According to the study by Bollen (et al), a two-weeks activation time had better completed results (33).

Since the effectiveness of clear aligners is still limited in some tooth movements, especially in the vertical movements, there is a need to use auxilarries as well as new treatment methods in order to increase the effectiveness of clear aligners .

Accoding to the Clinical Advisory Board (CAB) of Align Technology , a new treatment protocol is recommended for all cases treated after January 1, 2007. The protocol advices clinicians to move all the teeth at the same time by using 1mm horizontal, rectangular, beveled attachments for premolars in intrusion, extrusion and controlling the longitudinal axis of the tooth; using 1 mm vertical rectangular attachments to rotate round teeth and canines or translational movements, reducing less than 0.25 mm of standard velocity in some tooth movements such as rotaion, extrusion, torquing and translational movement, maintaining approximately 0.1 mm gap between the teeth when one tooth moves past another: primary use of the expansion to create needed spaces for the treatment of crowding and using interproximal reduction after the teeth are aligned (9).

The treatment with clear aligners is also continuously improved by clinicians as well as the company, although it still needs improvements. For example Bollen found that patients with two or more extracted premolars had the highest failure rate and none of those 21 patients could complete the initial regimen of aligners (33). However, with various auxiliaries, many authors have reported successful treatments of more complex cases. With the use of miniscrews, Choi (et al) treated one bialveolar premolar protrusion case successfully by combining retraction by segmental fixed appliances and clear aligners. They state that patient selection for treatment is also important cases such as: a mild skeletal class I or class II bialveolar protrusion, a stable posterior occlusion, mild to moderate crowded teeth and slight overbite can be treated (37).

In surgical orthodontic cases, Invisalign can be used in conjunction with segmental fixed braces or full fixed braces before and after surgery (38).

More randomized clinical studies are needed to confirm the effectiveness of clear aligners in tooth movement. Due to the current lack of scientific evidence, clinicians should be careful when choosing the appropriate cases to combine with fixed appliances or auxillaries to complete treatment goals. Although the clear aligners treatment is effective in certain cases, there have been cases of inaccuracy in predicting of the achievement in tooth movement.

5 Conclusion

Perhaps because clear orthodontic aligners are just beginning to use recently, there is not enough evidence-base articles for statistical conclusions about the effectiveness of clear aligners, but it seems that clear aligners can move teeth effectively in some tooth movements. The mean accuracy of tooth movement of clear aligners ranged from 41% (1) to 56% (2) comparing between predicted and actual achieved results. However, clear aligners are new treatment methods that are also affected by many different factors from traditional braces and need to combined with some auxiliaries to increase treatment efficacy.

6 List of tables

7 List of abbreviations

ABO	American Board of Orthodontics
OGS	Objective Grading System
A	anterior
T	tooth
Mov	movement
Exp	expansion
Con	constriction
Int	intrusion
Ext	extrusion
Tip	tipping
Tor	torque
Rot	rotation
Mes	mesial
Dis	distal
Intr	internal
Retr	retrospective
I	incisor
P	posterior
C	canine
Pm	premolar
M	molar
Pros	prospective
Cli	clinical
MD	mesialdistal
LL	labiallingual

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Declaration of academic integrity

I declare that I independently completed this thesis and this thesis was not previously submitted to another academic institution. I also confirm that no other sources have been used than those indicated in this thesis and the thoughts taken directly or indirectly from external sources are properly marked as such.

Ho Chi Minh City, 12th August 2014

Dr. Nguyen Quang Tien