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A systematic review of the accuracy and efficiency of dental movements with Invisalign®

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We are currently living in an era where the use of computer-aided design/computer-aided manufacturing has allowed individualized orthodontic treatments, but has also incorporated enhanced digitalized technology that does not permit improvisation. The purpose of this systematic review was to analyze publications that assessed the accuracy and efficiency of the Invisalign® system. A systematic review was performed using a search strategy to identify articles that referenced Invisalign®, which were published between August 2007 and August 2017, and listed in the following databases: MEDLINE, Embase, Cochrane Library, Web of Knowledge, Google Scholar, and LILACS. Additionally, a manual search of clinical trials was performed in scientific journals and other databases. To rate the methodological quality of the articles, a grading system described by the Swedish Council on Technology Assessment in Health Care was used, in combination with the Cochrane tool for risk of bias assessment. We selected 20 articles that met the inclusion criteria and excluded 5 due to excess biases. The level of evidence was high. Although it is possible to treat malocclusions with plastic systems, the results are not as accurate as those achieved by treatment with fixed appliances.
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Key words: Clear aligners, Invisalign®, Invisible orthodontics, Treatment outcomes

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INTRODUCTION

The use of braces, ligatures, archwires, and other elements of conventional orthodontic treatment make dental hygiene difficult; this interferes with aesthetics and causes patient discomfort.[1-3] With the significant recent improvements in computer-aided design/computer-aided manufacturing (CAD/CAM) and dental materials, we have seen an increase in the demand for plastic systems. Subsequently, plastic orthodontics, specially designed for adult patients, have been developed.

Proffit et al.[4] proposed that the ideal orthodontic appliance should not interfere with occlusion or hygiene, and should not damage the oral tissues. It should be light but capable of withstanding masticatory forces, be firmly retained, apply a controlled force between visits, and allow good control of the anchorage.

In 1945, Kesling[5] first introduced the use of multiple aligners to correct crowding. Later, Ponitz[6] reported the use of a removable plastic retainer (Essix®; Dentsply, York, PA, USA); in the 1990s, Sheridan et al.[7] popularized these retainers by combination with interproximal reduction (IPR).

In 1997, two students from Stanford University, Zia Chishti and Kelsey Wirth, together with a computer specialist, founded Align Technology in Palo Alto, CA, USA. After approval by the Food and Drug Administration, their technology (Invisalign®) was presented at the American Congress of Orthodontists in 1999; 2 years later, it was introduced in Europe.[8]

The primary focus of the Invisalign® system was initially to solve cases of low and moderate crowding and to close small spaces. However, its ongoing research and development has allowed treatment of more complex malocclusions. Currently, it is one of the most used systems among the aligners.

Invisalign® asserts that it can resolve, without the use of additional techniques, rotations of 40° in upper and lower central incisors, 45° in canines and premolars, 30° in lateral incisors, and 20° in molars. Extrusions and intrusions of 2.5 mm can be achieved in anterior teeth; radicular movements of 4 mm and 2 mm can be achieved in posterior teeth. However, few studies have been published to support the effectiveness and total correction that is asserted by proponents of these plastic systems.

Since Lagravère and Flores-Mir[9] published the first systematic review in 2005, several authors have updated evidence on this subject.[10-12] Therefore, we investigated the available scientific evidence in the literature to assess whether the Invisalign® system exhibits similar effectiveness to that of conventional orthodontics. Therefore, we focused on dental changes and effectiveness, compared with fixed appliances.

MATERIALS AND METHODS

Protocol and registration

The protocol for this review was registered on the international prospective register of systematic reviews (www.crd.york.ac.uk/prospero, protocol number: CRD42018074337).

Eligibility criteria

The following inclusion and exclusion criteria were used:

Study design: meta-analysis, systematic reviews, randomized and non-randomized clinical trials, cohort studies, and control cases were included. Prospective, retrospective, and cross-sectional studies were reviewed.

Participants: adult patients over 16 years old.

Intervention: articles that studied dental movement of cases treated with Invisalign® and Smartrack® (Align Technology, San Jose, CA, USA) material were included.

Exclusion criteria: articles older than 10 years, samples with adolescent patients, articles written in a language other than Spanish or English, *in-vitro* studies, surveys, engineering articles, author opinions, reviews of literature, letters to the editor, isolated cases, series of cases, surgical cases, or reports of patients with syndromes.

Results: studies were included that evaluated dental movement, superimposing virtual models or radiographs in 2 or 3 dimensions.

Information sources, search strategy, and study selection

A systematic search was performed of articles published between August 2007 and August 2017 in the following databases: MEDLINE, Embase, Cochrane Library, Web of Knowledge, Google Scholar, and LILACS. The search strategy comprised use of the following terms; "(Humans* OR adult* OR malocclusion* OR male* OR female*) AND (invisalign OR clear aligners OR aligners OR transparent aligners OR orthodontic appliances, removable*) AND (braces* OR orthodontic brackets* OR fixed appliances) AND (cephalometry* OR dental changes OR treatment outcome*)."

Additionally, a manual search was conducted in orthodontic journals of interest, such as the American Journal of Orthodontics, European Journal of Orthodontics, The Angle Orthodontist, Journal of Orthodontics, Journal of Clinical Orthodontics, and Journal of the World Federation of Orthodontists.

In addition, studies that were not yet published, listed in the national clinical trials database ClinicalTrials.gov (www.clinicaltrials.gov) and the National Research Register (www.controlled-trials.com), were queried with the terms "clear aligner" or "Invisalign."

RESULTS

Determination of relevance, validation, and data extraction

An independent search was performed by two of the authors (L.G.L. and E.P.) and existing disagreements were discussed with the third author (J.B.G.). The researchers were not blinded with respect to search results or authors.

Twenty-five articles were considered relevant and 5 were excluded because they had minimal scientific evidence. Finally, 20 articles were included in the analysis (Figure 1).[13]

Data items and collection

The following information was determined for all articles: year of publication, names of the authors, study design, number and groupings of participants, type of intervention, comparative groups, and results obtained (Table 1).

Risk of bias and quality assessment in the studies

All studies were analyzed and attempts were made to identify existing biases[14] (Table 2) with the exclusion of the systematic review article by Rossini et al.[10] All studies with a score lower than 5 were discarded (Kravitz et al.,[15] 2009; Kassas et al.,[16] 2013; Zhang et al.,[17] 2015; Ravera et al.,[18] 2016; Grünheid et al.,[19] 2017). Therefore, 15 articles remained for analysis, together with the systematic review published by Rossini et al.[10] in 2015.

To determine the methodological quality and level of evidence, the classification system described by the Swedish Council of Technological Assessment in Health Care[20] was considered (Table 3).

Results of individual studies and additional analyses

Dentoalveolar changes

This was the subject analyzed most frequently in the included studies.

- Transversal movements:

• Intercanine, interpremolar and intermolar width: several authors[21,22] demostrated that Invisalign® increases dentoalveolar width when the crowding is mild or severe. This increase was significantly lower when compared with treatments involving self-ligating brackets,[23] and was significantly higher when compared with conventional treatments.[22]

- Rotations:

• Canines: IPR favored precision movement, especially with respect to maxillary and mandibular canines.[24] The predicted rotation was 11.8°, but only 35.8% was expressed.

• Premolars: the accuracy of the correction was significantly reduced when it reached values > 15°. It is not recommended to correct > 1.5° per aligner.[25]

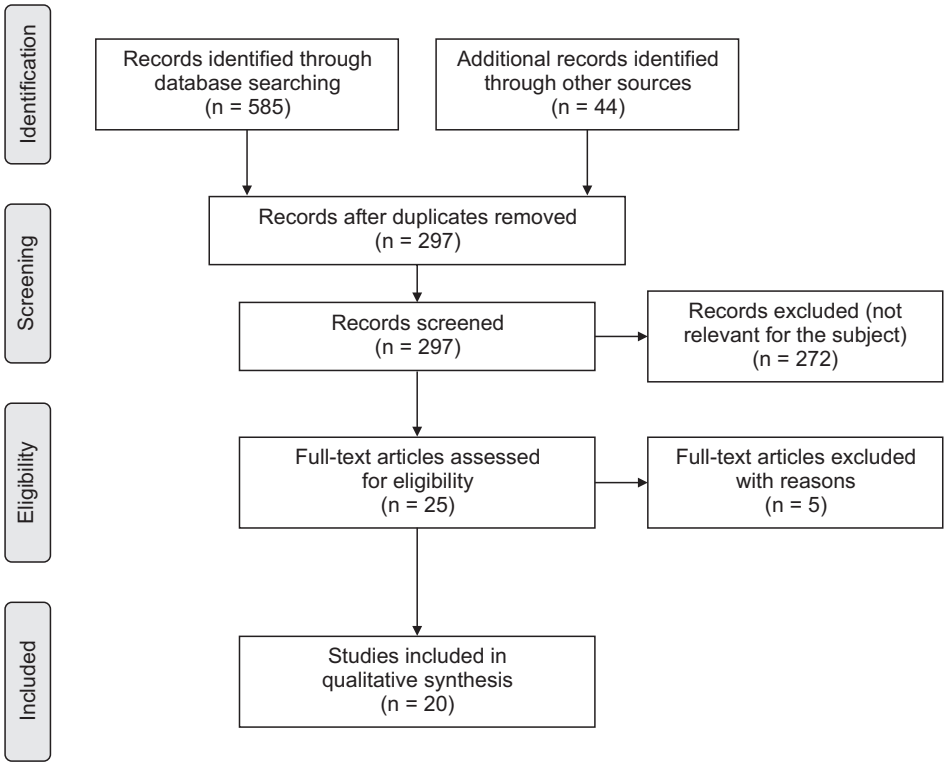

Figure 1. PRISMA diagram.

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Table 1. Design, participants, type of intervention, and observation period included in the qualitative analysis (*statistically significant)

Study	Study design	Participants	Intervention	Results (*significant outcomes)
Kuncio et al.,[33] 2007	Retrospective CT	22 pts · 11 fixed appliance · 11 Invisalign®	Final and retention evaluation casts using ABO score system	Relapse anterior alignment in retention* · Invisalign®: Mx and Md · Braces: Md
Kravitz et al.,[24] 2008	Prospective CT	31 pts · 17 canines attachment gruop · 18 canine IPR group	Canine rotation by virtual model superposition	Canine rotation accuracy: · Attachment: Mx 34.9, Md 21.0 · IPR: Mx 40.3, Md 45.9 · None: Mx 34.2, Md 27.5
Kravitz et al.,[15] 2009	Prospective CT	37 pts	Virtual model accuracy of expansion, constriction, intrusion, extrusion, mesiodistal tip, labiolingual tip and rotation	Highest accurate movement: · Lingual constriction (47.1%) Lowest accurate movement: · Extrusion (29.6%) · Mx and Md canine rotation (> 15° less accuracy)*
Pavoni et al.,[23] 2011	Prospective CT	40 pts · 20 self-ligating · 20 Invisalign®	Dental casts evaluation	Large intercanine width in brackets patients* Same treatment time
Drake et al.,[29] 2012	Prospective CT	52 pts · 15 change aligner every week · 37 change aligner every 2 weeks	Orthodontic tooth movement	4.4 times more orthodontic tooth movement in the first week* 55% of movement prescription was found
Krieger et al.,[26] 2012	Retrospective cohort study	50 pts	Pre- and post-treatment digital cast evaluation: arch length, intercanine distance, overjet, overbite, midline, irregularity index Accuracy of achieved and predicted outcome	Minimum scan discrepancies Minimal differences between achieved and predicted tooth movement, except for overbite (0.71 mm) Vertical movements are difficult to achieve Correlation between arch length and crowding
Kassas et al.,[16] 2013	Retrospective case series	31 pts	Pre- and post-treatment evaluation casts using ABO score	Invisalign® alignment and buccolingual inclination was successful*
Chisari et al.,[30] 2014	Prospective CT	30 pts · 15 young adults · 15 adults	CBCT and digital models evaluation Influence of sex, age, root length, bone quality	Achieved tooth movement 57% No relationship between variables but there is a complex relation age-tooth movement-sex Most tooth movement occurred in the first week
Simon et al.,[25] 2014	Retrospective CT (split-mouth design)	30 pts (4 dropout) · Incisor torque - Attachment - Power ridge · Premolar derotation - Attachment - None · Distalization - Attachment - None	Pre- and post-treatment superposition of dental casts	59.3% efficacy movement between planed and achieved None attachment/power ridge relation founded Accuracy of derotation reduces > 15° Molar distalization was recorded as the highest accuracy movement and premolar derotation as the lowest

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Table 1. Continued

Study	Study design	Participant	Intervention	Results (*significant outcomes)
Rossini et al.,[10] 2015	Systematic review	11 studies	Scientific evidence	Invisalign® is not effective in extrusion, rotation, distalization > 1.5 mm
Li et al.,[34] 2015	Prospective multicenter RCT	182 pts · 76 fixed appliance · 76 Invisalign®	ABO score in extraction cases with Invisalign® and braces	Longer treatment with Invisalign® Superior scores with braces in correcting occlusal contacts and buccolingual inclination*
Zhang et al.,[17] 2015	Retrospective case series	32 pts	Dental movements evaluating CBCT	· Crown average movement 2.5 mm · Minimal root movement
Duncan et al.,[21] 2016	Retrospective cohort study	61 pts · 20 mild Md crowding · 22 moderate Md crowding · 19 severe Md crowding	Digital study models and lateral cephalometric radiographs	Change of intercanine, interpremolar and intermolar widths in all groups* In severe crowding, proclination and protrusion of lower incisor
Grünheid et al.,[22] 2016	Retrospective cohort study	60 pts · 30 fixed appliance · 30 Invisalign®	CBCT evaluation of: · Buccolingual canine inclination · Intercanine distance	· Invisalign® increases intercanine distance* · Fixed appliances upright mandibular canines*
Hennessy et al.,[32] 2016	Prospective RCT	40 pts · 20 self-ligating · 20 Invisalign®	Cephalometric evaluation of mandibular incisor inclination	No significant statistic differences between braces and clear aligner patients · Invisalign® proclination: 3.4° · Self-ligating appliances proclination: 5.3°
Ravera et al.,[18] 2016	Retrospective multicenter case series	20 pts	Cephalometric evaluation of Class II patients	Distalization: · Second upper molar: 2.52 mm · First upper molar: 2.25 mm · Upper incisor: 2.23 mm No vertical changes
Grünheid et al.,[19] 2017	Retrospective cohort study	30 pts	Digital models superposition between predicted and achieved tooth positions	Arch expansion not fully correct, even second molars have more torque than predicted* Low accuracy of mandibular canine (torque and rotation)
Gu et al.,[27] 2017	Retrospective cohort study	96 pts: · 48 fixed appliance · 48 Invisalign®	Evaluation of Peer assessment index	Shorter treatment time for Invisalign®* Better scores with braces
Houle et al.,[31] 2017	Retrospective cohort study	64 pts	Digital model superposition to measure transverse dimensional changes between achieved and predicted movements	72.8% accuracy of upper arch 87.7% accuracy of lower arch More movement of cuspids tan gingival margins
Khosravi et al.,[28] 2017	Retrospective multicenter case series	120 pts · 68 normal overbite · 40 deep bite · 12 open bite	Cephalometric evaluation of overbite correction	No vertical differences in regular overbite Deep bite is corrected due to proclination, upper incisor intrusion, 0.5 mm of posterior extrusion Open bite was accomplished by incisor extrusion

CT, Clinical trial; pts, patients; ABO, American Board of Orthodontists; Mx, maxillary; Md, mandible; IPR, interproximal reduction; CBCT, cone-beam computed tomography; RCT, randomized controlled trial.

Table 2. Risk of bias of the studies included in the qualitative analysis

Study (first author, year)	Random	Prospective	Blind	Sample size (> 40)	Control/ comparative group	Defined sample	Orthodontist experience	Interexaminer reliability	Complete outcome	Others	Score
Kuncio,[33] 2007	X	X	X	X	Y	X	Y	Y	Y	Y	5
Kravitz,[24] 2008	X	Y	X	X	Y	X	X	Y	Y	Y	5
Kravitz,[15] 2009	X	Y	X	X	X	Y	X	Y	Y	X	4
Pavoni,[23] 2011	X	Y	X	Y	X	Y	X	Y	Y	Y	6
Drake,[29] 2012	X	Y	X	Y	Y	Y	Y	Y	Y	Y	8
Krieger,[26] 2012	X	Y	X	Y	X	Y	Y	Y	Y	X	6
Kassas,[16] 2013	X	X	X	X	X	Y	Y	Y	Y	X	4
Chisari,[30] 2014	X	Y	X	X	Y	Y	Y	X	Y	X	5
Simon,[25] 2014	X	X	X	X	Y	Y	Y	X	Y	Y	5
Li,[34] 2015	Y	Y	Y	Y	Y	Y	X	Y	Y	Y	9
Zhang,[17] 2015	X	X	X	X	X	Y	X	X	Y	X	2
Duncan,[21] 2016	X	X	X	Y	Y	Y	X	Y	Y	Y	6
Grünheid,[22] 2016	Y	X	X	Y	Y	Y	Y	Y	Y	Y	8
Hennessy,[32] 2016	Y	Y	X	Y	Y	Y	Y	Y	Y	X	8
Ravera,[18] 2016	X	X	X	X	X	Y	Y	Y	Y	X	4
Grünheid,[19] 2017	X	X	X	X	X	Y	X	Y	Y	X	3
Gu,[27] 2017	X	X	Y	Y	Y	Y	X	Y	Y	X	6
Houle,[31] 2017	Y	X	X	Y	X	Y	Y	Y	Y	X	6
Khosravi,[28] 2017	X	X	X	Y	Y	Y	Y	Y	Y	Y	7

X, No; Y, yes.

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Table 3. Evidence grade according to Swedish Council on Technology Assessment in Health Care

Study (first author, year)	Evidence level
Kuncio,[33] 2007	B
Kravitz,[24] 2008	C
Kravitz,[15] 2009	C
Pavoni,[23] 2011	B
Drake,[29] 2012	B
Krieger,[26] 2012	C
Kassas,[16] 2013	C
Chisari,[30] 2014	B
Simon,[25] 2014	C
Li,[34] 2015	A
Zhang,[17] 2015	C
Duncan,[21] 2016	B
Grünheid,[22] 2016	B
Hennessy,[32] 2016	A
Ravera,[18] 2016	C
Grünheid,[19] 2017	C
Gu,[27] 2017	C
Houle,[31] 2017	C
Khosravi,[28] 2017	B

The incorporation of an attachment to stimulate derotation is not supported by any author.[24,25]

- Vertical movements: Krieger et al.[26] stated that vertical movements were more difficult to accomplish than transverse or sagittal movements. They found that overbite was the most difficult parameter to predict and correct. Gu et al.[27] agreed with this statement. Rossini et al.[10] reported 0.72 mm of true intrusion. In general, 1.5 mm can easily be resolved.[28]

• Open bite: this is primarily corrected by extrusion of incisors without changes in the mandibular plane.[28]

• Deep bite: its rectification results from proclination of the lower incisors, minimum intrusion of upper incisors, and 0.5 mm extrusion of molars with a 0.5° opening of the mandibular plane,[28] similar to those reported by Rossini et al.[10]

- Sagittal movements:

• Anterior: most treatments that do not require extractions use IPR and protrude the incisor to reach a correct alignment of the anterior sector.[26]

• Posterior: the effectiveness of molar distalization does not increase if we incorporate an attachment and its accuracy movement rounds 87.65%.[25]

• Overjet: total correction of overjet with Invisalign® is not reported in all cases.[27]

Accuracy of movement

The accuracy of movement among the studies was 55% to 72%, and was reportedly dependent on whether the aligner was changed weekly or biweekly.[29] Chisari et al.[30] revealed accuracy of 57%. In contrast, Kravitz et al.[24] obtained an accuracy of 35.8% in a sample where only canines were assessed. Simon et al.[25] reported an average accuracy of 59.3% for anterior torque movements (50.3%), premolar derotation (39.95%), and molar distalization (87.65%). Houle et al.[31] achieved good transverse expansions regarding Clincheck® (Align Technology) prediction of 72.8% for the maxillary arch and 87.7% for the mandibular arch, with statistically significant results. However, in recent studies, they did not find clinically significant differences between what was expected and what was achieved.[26,31]

Variables that influence dental movement

Chisari et al.[30] identified sex and age as variables that may affect the movement of teeth with aligners. Drake et al.[29] reported that, in addition to sex and age, bone quality, tooth length, location of the resistance center, and systemic factors should be considered.

Cephalometric changes

There were two studies[21,32] that analyzed the results of treatment by lateral cephalometric radiography. They observed that when crowding was > 6 mm, the incisor tended to procline and protrude.[21] Invisalign® produces less average proclination than that observed with fixed appliances in moderate crowding: 3.4° ± 3.2° and 5.3° ± 4.3°, respectively[32]; this difference was not statistically significant.

Cone-beam computed tomography (CBCT)

Only two studies evaluated patients treated with Invisalign® using images with CBCT.[19,29] They demonstrated that uncontrolled dental inclination occurred with aligners[19,29] and asserted that brackets provided superior root control.[19] In contrast, a systematic review in 201510 asserted 17° of root control, with greater control in lateral incisors, compared with canines or central incisors, as evaluated by dental cast.

Aligners change

In an uncontrolled clinical trial, Drake et al.[29] showed that a large part of the movement occurs in the first week. Chisari et al.[30] revealed similar findings.

American Board of Orthodontics (ABO)

Only two articles have compared the results of treatment with Invisalign® and treatment with fixed appliances using the objective classification system of the ABO.[33,34] The trial by Li et al.[34] consists of a much larger

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sample (182 patients), using a randomized and prospective approach. Conversely, Kuncio et al.[33] used retrospective analysis. Both treatment modalities provided significant resolution, fulfilling all ABO objectives. However, buccolingual inclination and occlusal contacts were inferior with Invisalign®, which conflicts with the findings of Rossini et al.[10] In addition, relapse is greater in the maxillary arch than in the mandible in patients treated with plastic systems, 3 years following completion of orthodontic treatment.

Treatment duration

The durations of treatment according to the degree of crowding were: 13.4 ± 5.28 months (mild), 15.93 ± 5.17 months (moderate), and 17.92 ± 4.07 months (severe).[21] Krieger et al.[26] reported 13 months of treatment to correct moderate crowding. An randomized controlled trial found that the treatment time is longer with Invisalign® than with brackets.[34] In contrast, Gu et al.[27] reported a significantly shorter treatment time with Invisalign® than with fixed appliances. Notably, Pavoni et al.[23] achieved a treatment duration of 21.6 months in both groups.

DISCUSSION

Although the level of evidence was high because we incorporated two A-grade studies, we found 7 studies with moderate evidence and 5 with low evidence; these incorporated biases into the results of this review. Unlike the systematic review published by Rossini et al.[10] in 2015, the current study evaluates the treatment of more complex malocclusions treated with transparent systems. They only included 11 studies, whereas we initially began with 20. Our results are thus more precise and involve additional aspects.

Alteration of the intercanine and intermolar widths is primarily included in treatments without extractions; because it favors alignment and has an aesthetic effect on the smile,[35] the orthodontist can control this through Clincheck®. It is important to note that the control of these buccolingual inclinations is greater with brackets.[34]

There has been no study regarding retroclination with Invisalign® treatment. However, the least predictable movements are rotation[25] and vertical movements.[26] For rotational movements, IPR and no more than 1.5° rotation per aligner are recommended. Additional techniques should be incorporated when corrections greater than 15° are required.[24,25] In contrast, vertical problems are solved exclusively by anterior extrusion or intrusion movements, with minimum change in the posterior area.[28] Thus, the incorporation of attachments is recommended to improve results.

Recently, Align Technology has indicated that weekly changes of aligners can be made; however, we recommend that this must be individualized, depending on the complexity of the case and the degree of desired movement. In addition, the tooth requires a period of adaptation to recover from the force exerted,[30] in order to stabilize movement[29] and subsequently help retention.[33]

The precision of movement and correction of dental parameters has improved exponentially in recent years, reaching values of 70% to 80%. This change is due to the continuous research performed by Align Technology and the new products that have been released. The lack of consensus among results is likely because many of the articles published do not include new technologies launched after G5 in 2014.[36] However, it has been proven that brackets remain more accurate than plastic systems.[23,27,34]

The great majority of authors[24,25,28,31] recommend overcorrecting with Invisalign® because the movement is not total and there is little root control, which produces uncontrolled tipping of the tooth and can affect relapse.[22,23,29] However, good root parallelization has been confirmed when Invisalign® is used in treatments with extractions.[34]

Many variables influence dental movement, but very few studies have analyzed these parameters in treatments with plastic systems. In those studies, only age and sex have been consistently related to orthodontic tooth movement influences.[30]

The vast majority of studies that include a comparative group always involve a significantly older sample in the group treated with Invisalign®.[27,32,33] It is important to consider that both movement accuracy and treatment time can be altered by this fact.

Compliance is not an analyzed factor, but several authors have remarked on its influence with respect to treatment success.[23,30]

CONCLUSION

- Invisalign® and fixed appliances are able to alter intercanine, interpremolar, and intermolar width in the presence of crowding. Moreover, incisors tend to procline and protrude when crowding is > 6 mm.
- Vertical movement and derotation are difficult movements to accomplish with aligners. And IPR is recommended, especially in canines.
- It is not necessary to incorporate an attachment when molar distalization is required in Invisalign® treatment.
- The expression of the programmed movement is not fully accomplished with Invisalign®.
- Sex and age affect tooth movement in both modalities.
- There is better root control with fixed appliances.

- The majority of tooth movement occurs during the first week with plastic systems.
- Buccolingual inclination and occlusal contacts are worse with Invisalign®.

Although this is a more complete systematic review than that presented in 2015,[10] further studies with good methodological design are needed to confirm some of the aspects addressed in this review. Although it is possible to treat complex malocclusions with plastic systems, the results are less accurate than those achieved with fixed appliances.

CONFLICTS OF INTEREST

No potential conflict of interest relevant to this article was reported.

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