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REVIEW ARTICLE

Clinical Effectiveness of Using Clear Aligners in Orthodontic Treatment

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ABSTRACT

Purpose: **To assess the clinical treatment effectiveness of clear aligners in orthodontic tooth movements.**

Methods: **The database of Cochrane Central Register of Controlled Trials, Embase, PubMed, Web of Science, and Scopus were searched from Jan 2015 to Jan 2020. The National Institute for Health and Clinical Excellence assessment tool was used for the methodological quality of included studies.**

Results: **The literature review yielded 166 articles after removal of duplicates, and an additional 2 articles were included from hand search of the bibliographies of included articles and relevant reviews. Fifteen studies were included in the systematic review. One study was randomized controlled trial, one study was prospective case−control study, two studies were retrospective case−control and eleven studies were retrospective cohort studies.**

Conclusion: **The clear aligner treatment (CAT) is effective in managing minor malocclusion. CAT could achieve a comparable treatment outcome to that of the fixed orthodontic appliance in nongrowing patients with mild malocclusion. There are weak evidences to support the efficacy of CAT in extraction orthodontics. The results should be interpreted with caution due to heterogeneity in studies.**

Keywords: Orthodontic tooth movement; Clear aligner treatment (CAT); Aligners; Treatment effectiveness

INTRODUCTION

With the increasing esthetic and comfortable demands in patients seeking for orthodontic treatment, CAT nowadays has been a popular alternative to traditional fixed orthodontic appliances in orthodontic society. The modern CAT has been considered a modified form which could be to date back 1940s. Kesling first introduced a series of clear tooth positioners which could progressively align minor mispositioned teeth after fixed orthodontic treatment.[1] Later, many experts adopted the concept and tried their efforts to use transparent overlays to achieve minor tooth movements. With the advent of dental materials and hi-tech 3D technology, the Invisalign@ system (Align Technology@, Santa Clara, Calif) was commercially released to the orthodontic market to treat misaligned teeth in 1998. The modern computer-aided design/computer-aided manufacturing (CAD/CAM) system, incorporating orthodontic virtual planning and stereolithographic prototyping technology, manufactures a series of individualized thermoplastic clear aligners. The custom-made aligner was

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programmed to move a tooth or a small group of teeth by 0.25–0.33 mm in every 14 days.[2] Since the patent of Invisalign® expired in 2017, to date, numerous clear aligner systems, even some without the intervention of a dental profession are available in the orthodontic market.[3] All those orthodontic treatment with removable transparent aligners is characterized as CAT.

Clear aligners were initially introduced to resolve mild to moderate dental crowding and close mild spacing. At present, there are numerous publications and experts' experiences showed in more complex malocclusion such as extraction cases, could be corrected with CAT. Advantages of CAT were reported for better aesthetics, comfort at early stage, easier oral hygiene maintenance, improved periodontal health, and less root resorption as compared with fixed appliances.[4–6] In addition to aforementioned issues, the treatment efficiency is another one major concern for orthodontic professions. Recently, there have been many investigations and few reviews conducted to assess the predictability of tooth movement with CAT. With the continually evolution in the field of materials, algorithms of tooth movement planning and the apparatus design of CAT are constantly updating. The aim of this review was to investigate the latest relevant evidences about the precision of tooth movement and clinical effectiveness with CAT.

MATERIAL AND METHODS

Study design

The implement of this study was in accordance with the Preferred Reporting Items for Systematic Review and Meta-analysis (PRISMA) guidelines.[7] The main question guided the systematic search of the literature was: what's the clinical effectiveness of clear aligners in orthodontic treatment?

Search strategy

The Cochrane Central Register of Controlled Trials, Embase, PubMed, Web of Science, and Scopus databases were searched for relevant English-language literature from Jan 2015 to Jan 2020 using the following keywords: "clear aligner" OR "invisible orthodontic" OR "Invisalign" OR "Clear Aligner" OR "clear aligner therapy" OR "CAT" AND "effectiveness" OR "efficacy" OR "accuracy" OR "treatment effectiveness" OR "treatment outcome". Unpublished literature was searched using Google or Google Scholar search engine. The bibliographies of review articles and all the studies included for data extraction were searched.

Inclusion and exclusion criteria

The inclusion criteria were as follows: (1) prospective and retrospective studies including randomized clinical trials, controlled clinical trials and cohort studies; (2) studies on human subjects with permanent teeth; (3) studies on individuals undergoing extraction or non-extraction orthodontic treatment with CAT; (4) studies that providing data regarding to dental movement or treatment outcome assessment by evaluating dental models, radiographs, or validated scoring system. The exclusion criteria were as follows: (1) case series, case reports, review articles; (2) studies on subjects with craniofacial anomalies or syndromes, or those who were medically compromised; (3) in vitro studies.

Data extraction

The following data were extracted: authors, publication date, study design, number and groupings of study subjects, types of malocclusion, comparative groups, types of intervention, time points of measurements, methodology of outcome assessment, outcomes, and key findings.

Assessment of methodological quality

The National Institute for Health and Clinical Excellence (NICE) was used to assess the methodological quality of included studies.[8] The instrument consists of eight items that are assessed for the individual study.

RESULTS

After removal of duplicates, the database search yielded 127 articles. Hand search of the bibliographies of the selected articles and relevant reviews identified one additional article. After screening full-text articles, fifteen relevant studies met the eligible criteria were included in the analysis. Figure 1 provided the details of the search strategy.

Characteristics of included studies

The characteristics and details of the included fifteen studies presented in Table 1. In terms of study design, one study was randomized controlled trial, one study was prospective case–control study, two studies were retrospective case–control and

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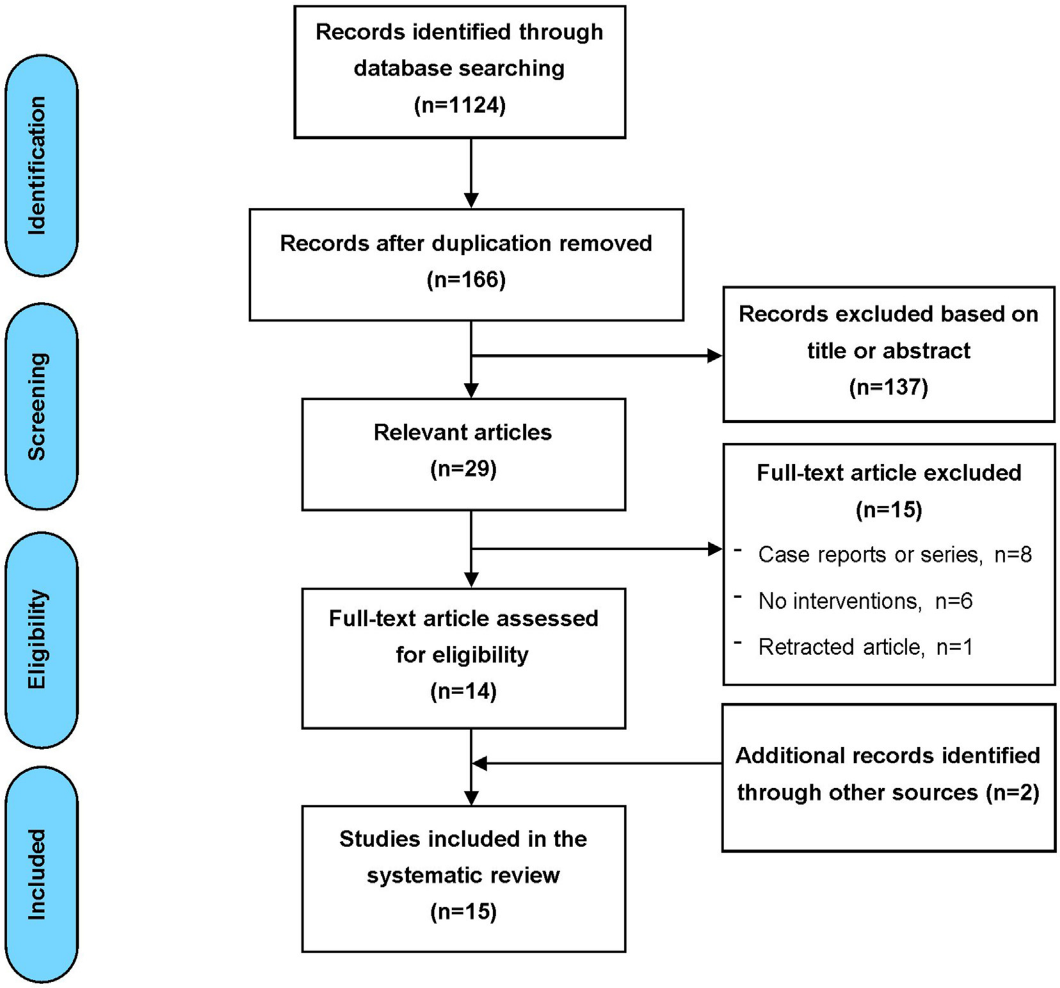

Figure 1. PRISMA flow diagram demonstrating the results of the systematic literature search.

eleven studies were retrospective cohort studies.[9–23] Three of them were comparative studies to investigate the differences between CAT and conventional fixed appliances. Invisalign@ was used in twelve studies, and Clear aligners@, F22@ and Nuvola@ were applied in the other studies.

Regarding to the methodology of outcome assessment: (1) two study analyzed plaster models with validated grading tools, which were American Board of Orthodontics (ABO) Objective Grading System (OGS) scores or Peer Assessment Rating (PAR) index; (2) five studies investigated the tooth movement from lateral cephalogram; (3) nine studies studied superimposed digital models; and (4) one study inspected the reconstructed 3D craniofacial models with a combination of the digital dental model and cone-beam computed tomography (CBCT) data. Meanwhile, the data representation which was varied among different studies included (1) size of difference between predicted and achieved dental movements in millimeters or degrees; (2) percentage of accuracy (accuracy = 100% - [(|predicted − achieved|)/|achieved|]x100%); and (3) scores with the grading tools. Among them, only one study reported the result of extraction cases with CAT.

Methodological quality of the included studies

All the fifteen included studies satisfied five to seven of the eight NICE quality assessment tool items (Table 2). The limits of evidences and sources of bias were as follows: (1) investigations conducted in a single institution or not reported; (2) the data were not collected prospectively; (3) the studies did not report that patients were recruited consecutively.

Results of CAT interventions

Anteroposterior dimension

Sfondrini et al. compared the buccolingual inclination of upper incisor treated with CAT,

Table 1. Characteristics of included studies.

Study	Study design	N, age	Appliance	Type of malocclusion	Time points	Method	Measures	Result
Buschang[14]	Prospective case −control	27, NR	Invisalign@	NR	Pre (T0), post (T1), setup (Ts)	Plaster models, software (CC)	ABO-OGS score: alignment, marginal ridge, inclination, occlusal contact, OJ, interproximal contact	1. CC models do not accurately reflect final occlusion. 2. CC overestimated alignment, BL inclination, occlusal contacts, and occlusal relations 3. The vertical components (marginal ridges and occlusal contacts) showed the largest differences.
Zhang[15]	Retrospective cohort study	32, 26.7	Clear aligners@	Complete permanent dentition, nEXT, Angle Class I or no AP change	Pre (T0), post (T1), setup (Ts)	CBCT, scanned PVS impression, software (OrthoDS 4.6/EA)	Crown and root position of anterior teeth	Crowns but not roots can be moved to designated positions by tilting motion
Duncan[16]	Retrospective cohort study	61, NR	Invisalign@	Md crowding, nEXT	Pre (T0), post (T1)	Digital models (iTero), LA ceph	Md incisor position, arch width, OB, OJ	1. Md incisors tend to procline and protrude in severe crowding cases 2. Buccal arch expansion and IPR have significant effect on resolution of crowding
Henessay[17]	RCT	44, 26.4	Invisalign@ and C	Mild md crowding <4 mm, nEXT, ANB 1-4°	Pre (T0), post (T1)	LA ceph	Lower incisor inclination	No difference in Md incisor proclination produced by CAT and C in mild crowding cases.

(continued on next page)

Table 1. (continued)

Study	Study design	N, age	Appliance	Type of malocclusion	Time points	Method	Measures	Result
Houle[18]	Retrospective cohort study	64, 31.2	Invisalign@	nEXT	Pre (T0), post (T1), setup (Ts)	Digital models (iTero), software (CC)	Intercanine width, interpremolar width, intermolar widths	1. The accuracy of expansion with CAT was 72.8% for Mx and 87.7% for Md. 2. Less accuracy toward the posterior region 3. More dental tipping than bodily movement.
Ravera[19]	Retrospective cohort study	20, 29.7	Invisalign@	Bilateral molar Class II end-on, skeletal Class I ~ II, normal divergent, Mx mild crowding (<4 mm)	Pre (T0), post (T1)	LA ceph	Cephalometric values	CAT is effective in distalizing Mx molars 2–3 mm without significant vertical and tipping movements.
Grünheid[20]	Retrospective cohort study	30, 21.6	Invisalign@	Full permanent dentition, nEXT	Post (T1), setup (Ts)	Scanned alginate impression (3-shape), software (Orthoanalyzer/3 shape)	MD, BL, OG position (mm); tip, torque, rotation (°)	1. Mx arch expansion was not fully achieved 2. More occlusal position of Md incisors 3. Incomplete rotation of round teeth
Gu[21]	Retrospective case −control	96, 24.0	Invisalign@ and C	Full permanent dentition, nEXT	Pre (T0), post (T1)	PAR index	PAR index: upper anterior/lower anterior alignment, AP, transverse, vertical, OB, OJ, midline	1. Final occlusal scored di not differ between the 2 systems 2. CAT finished 30% faster (5.7 months) than C
Khosravi[22]	Retrospective cohort study	120, 33.0	Invisalign@	nEXT	Pre (T0), post (T1)	LA ceph	Overbite, cephalometric values	1. CAT is relatively successful in managing OB 2. CAT improved deep bites primarily by proclination of Md incisors.

Lombardo[23]	Retrospective cohort study	16, 28.0	F22@	Crowding < 5mm/ arch, no rotation >35°, no diastema > 5 mm, nEXT	Pre (T0), post (T1), setup (Ts)	Digital models (3-shape), software (Orthoanalyzer/3 shape)	BL tip and MD tip of anterior teeth, rotation	1. The mean accuracy was 73.6% 2. MD tipping was the most predictable movement (82.5%) 3. The least predictable movement was rotation of lower canines (54.2%)
Charalampaski[24]	Retrospective cohort study	20, 37.6	Invisalign@	NR	Pre (T0), post (T1), setup (Ts)	Digital models, software (CC)	Horizontal, vertical, width, rotation	Rotations of canines and intrusions of incisors were the most inaccurate movements.
Sfondrini[25]	Retrospective case −control	75, 25.5	Invisalign@, C and SLB	Permanent teeth, dental Class I or mild Class II & III	Pre (T0), post (T1)	LA ceph	Cephalometric values	All the three systems showed good clinical reliability in the upper incisor torque control
Tepedino[26]	Retrospective cohort study	39, 30.0	Nuvola@	Crowding up to 6 mm, nEXT	Pre (T0), post (T1), setup (Ts)	Digital models (3-Shape), software (Maestro 3D Ortho Studio)	Inclination of anterior teeth	Nuvola@ produce outcome comparable to Ts in pt up to 6 mm crowding
Caruso[27]	Retrospective cohort study	10, 22.7	Invisalign@	Bilateral Class II molar or End-on (needs Mx molar distalization), mild Mx crowding	Pre (T0), post (T1)	LA ceph	Cephalometric values	Mx molar distalization allow good control of vertical dimension and Is torque
Dai, 2019[28]	Retrospective cohort study	30, 19.4	Invisalign@	Extraction first premolars	Post (T1), setup (Ts)	Scanned alginate impression (iTero), software (Orthoanalyzer/3 shape)	Mx incisors and first premolars position and angulation	In first premolar extraction cases with CAT, first molar anchorage control and central incisor retraction were not fully achieved

N, number of patients; NR, not reported; pre, pre-treatment; post, post-treatment; CC, ClinCheck; nEXT, non-extraction; CBCT, cone-beam CT; PVS, polyvinyl siloxane; Md, mandibular; LA ceph, lateral cephalogram; C, conventional fixed labial appliance; AP, anterioposterior; MD, mesiodistal; BL, buccolingual; OG, occlusogingival

Table 2. Methodological quality of included studies.

Study	Methodological quality of included studies[a]							
	1	2	3	4	5	6	7	8
Buschang et al.[14]	NR	Y	N	Y	Y	Y	Y	Y
Duncan et al.[15]	N	Y	Y	Y	N	N	Y	Y
Zhang et al.[16]	N	Y	Y	Y	N	N	Y	Y
Hennessy et al.[17]	NR	Y	Y	Y	Y	N	Y	Y
Houle et al.[18]	N	Y	Y	Y	N	N	Y	Y
Ravera et al.[19]	NR	Y	Y	Y	N	N	Y	Y
Grunheid et al.[20]	N	Y	Y	Y	N	Y	Y	Y
Gu et al.[21]	N	Y	Y	Y	N	N	Y	Y
Khosravi et al.[22]	Y	Y	Y	Y	N	Y	Y	Y
Lombardo et al.[23]	N	Y	Y	Y	N	N	Y	Y
Charalampakis et al.[24]	N	Y	Y	Y	N	N	Y	Y
Sfondrini et al.[25]	NR	Y	Y	Y	N	N	Y	Y
Tepedino et al.[26]	Y	Y	Y	Y	N	N	Y	Y
Caruso et al.[27]	NR	Y	Y	Y	N	N	Y	Y
Dai et al.[28]	N	Y	Y	Y	N	N	Y	Y

NR, not reported; Y, Yes; N, No.

[a] Quality Assessment of cases series studies checklist from National Institute for Health and Clinical Excellence (NICE): 1) Was the case series collected in more than one center, i.e. multicenter study? 2) Is the hypothesis/aim/objective of the study clearly described? 3) Are the inclusion and exclusion criteria (case definition) clearly reported? 4) Is there a clear definition of the outcomes reported? 5) Were data collected prospectively? 6) Is there an explicit statement that patients were recruited consecutively? 7) Are the main findings of the study clearly described? 8) Are outcomes stratified? (e.g., by abnormal results, disease stage, patient characteristics).

conventional fixed brackets, and self-ligating brackets in nonextraction cases. All the three techniques showed good clinical reliability in the upper incisor torque and no significant difference was found among the various techniques.[20] Tepedino et al. stated Nuvola@ produced clinical outcomes comparable to the planning of digital setup relative to torque movements of anterior teeth in patients with moderate crowding up to 6 mm.[21] Henessay et al. founded that there was no statistically significant difference in the mandibular incisor proclination of the mild mandibular crowding patients (<4 mm) underwent the orthodontic treatment course either with Invisalign@ or conventional fixed orthodontic appliances.[12] Duncan et al. further indicated when there was <6 mm of mandibular crowding, Invisalign@ appliance used in non-extraction non-growing patients could successfully relieve crowding under a good control of lower incisor position and proclination. The buccal arch expansion and interproximal reduction dominated the relief of mandibular crowding.[11] Moreover, lower incisors tended to procline and protrude when the crowding is more than 6 mm.

In matter of the efficacy of molar distalization with CAT. Ravera et al. reported the maxillary molar could be averagely distalize 2.5 mm in the sequential distalization protocol. There was no significant tipping and vertical movement of the crown.[14] Caruso et al. followed the sequential distalization protocol of maxillary molars described by Ravera et al., presented the outcome could be ensured by concomitantly using Class II elastics and rectangular attachments on the upper molars and premolars in maxillary arch distalization.[22] The results indicated that orthodontic aligners could perform a bodily distal movement of maxillary molars up to 2–3 mm in the control of vertical dimension. Meanwhile, the axis of upper incisors showed a significant reduction of 13.2°.

Transverse dimension

Grunheid et al. documented that Invisalign@ was able to achieve predicted tooth positions in non-extraction individuals with 2±2 mm crowding other than rotation of mandibular lateral incisor, canine, and premolars.[15] The molar torque may not be fully achieved. However, only maxillary second molars had the clinically relevant magnitude of more buccal crown torque than predicted (−2.3°±4.9°, 95% CI [-2.85, −1.41], $P < 0.05$). The maxillary molar was positioned more lingually. Houle et al. reported that dental tipping rather than bodily movement was observed following dentoalveolar arch expansion with Invisalign@.[13] The average accuracy of arch transversal expansion from canine to first molar was 82.9% at the cusp tip and 62.7% at the gingival margin. In the mandibular arch, there was an average accuracy of 98.9% at the cusp tip and 76.4% at the gingival margin. In average, the errors existed between the predicted and achieved arch expansion at the gingival margin of maxillary first molar was 1.42 mm (SD, 1.9 mm; 95% CI [0.95, 1.90]) as an average 3.02 mm of bucco-lingual movement was prescribed. Meanwhile, Invisalign@ for arch expansion became less accurate going from the anterior to the posterior region. Zhang et al. assessed the integrated 3D craniofacial composite models with the CBCT data and the digitized dental model.[10] The results indicated that the tooth movement with CAT was a tilting motion rather than a bodily movement. The crowns but not roots could be moved to designated position.

Vertical dimension

Khosravi et al. indicated that the Invisalign@ appliance was relatively successful in managing overbite.[17] The cephalometric analysis revealed the overbite remained stable in patients with normal pretreatment overbite. A median 1.5 mm of overbite reduction in patients with deep bite and a similar increase of overbite in patients with open bite patients were reported. Furthermore, the posterior vertical dimension remained stable (for molar extrusion < 0.5 mm) in patients either with pre-treatment normal overbite, deep-bite, and open bite. Charalampakis et al. indicated vertical movements and particularly intrusions of maxillary central incisors were less accurate in all linear measurements, with a median difference of 1.5 mm ($P < 0.001$) between the predicted and the achieved amount.[19] The maxillary incisor showed a tendency of extrusion. On the other hand, Grünheid et al. found the mandibular incisors tended to be positioned more occlusally than predicted.[15]

Rotation

Regarding to the rotational movement, Lombardo et al. reported the least predictable movement was rotation of the lower canines (54.2%).[18] The prediction errors were 6.9° ± 5.4° at lower canines, 3.4° ± 2.5° at lower incisors, and 2.0° ± 1.8° at lower molars ($p < 0.05$). The result was in accordance with the study conducted by Grünheid et al. that rounded teeth such as mandibular canines and premolars, the rotation could not be fully corrected.[15] Charalampakis et al. reported that all achieved rotations were significantly smaller than predicted ones. The median differences ranged from 0.9° on maxillary premolars to 3.05° ($P < 0.001$) on maxillary canines.[19]

CAT in extraction cases

Dai et al. superimposed 4 digital composite models to assess the precision of tooth movement in extraction cases by Invisalign.[23] They concluded both upper first molar control and central incisor retraction did not fully achieve the predicted positions without using additional refinements, other fixed appliance or auxiliary appliances. Although maximum anchorage was planned (an average predicted mesial translation of 0.87 mm on the first molar) in their subjects, the first molars actually moved mesially by an average of 3.16 mm.

Scores in grading tools

Buschang et al. evaluated the predictability of ClinCheck model of Invisalign@ with ABO's OGS. They reported that there was a significant overall OGS point deduction in posttreatment model as comparing with the ClinCheck models (24 vs 15, $p = 0.16$). Among them, the vertical components of the OGS system, including marginal ridges and occlusal contacts, showed largest differences between the predicted treatment outcome and the post-treatment model. For both components, the posttreatment models lost 2 more points on average than the respective ClinCheck model ($p < 0.001$).[9] Gu et al. compared the CAT with fixed appliances by using the Peer Assessment Rating (PAR) index. The data concluded the final occlusal scores did not differ between the two systems.[16] Posttreatment weighted PAR scores were 4.08 ± 4.35 in the Invisalign patients and were 2.69 ± 2.23 in fixed appliances patients ($p = 0.7420$).

DISCUSSION

In the present analysis, the achieved tooth movement was inconsistent with prescribed movement by CAT. Since the mechanical properties of thickness and stiffness of clinical aligners, mismatch of the force system transmitted to the teeth and the biomechanical response of the affected teeth were quite diverse to be predicted as we manipulate tooth movement in the specific software. Meanwhile, we could not neglect the influences of manufacturing errors, staging of tooth movement, attachment design, or aging and distortion of each aligner after continually wearing.[24–28] In terms of patient-associated factors, patient's compliance and anatomic characteristics e.g. density and morphology of alveolar bone, or crown and root morphology of teeth were proposed to be related to the precision of tooth movement.[29,30] The difference between the prescribed and real amount of IPR performed by the clinician could not be overlooked.[31] In the in-vitro study, Simon et al. reported the initial force systems between consecutive aligners could show great variety even though constant tooth movements were planned. Thus, the resulting tooth movement might be inconstant with the predicted tooth movement.[32]

The current data agreed with previous reviews that the orthodontic tooth movement was predictable in nongrowing patients with mild to moderate malocclusion undergoing CAT. For those cases, the clear aligners could reposition the misaligned teeth through the mechanism of arch expansion, interproximal reduction and distalization of maxillary molar. Undoubtedly, the arch expansion was mostly achieved by a tipping movement. Therefore, the greater success is obtained with Invisalign@ when treating nonskeletal arch constriction as concluded by Phan and Ling.[33] Although the reported mean accuracy of maxillary and mandibular expansion was 72.8% and 87.7% respectively, 2 mm of transversal expansion was more predictable overall. The IPR procedure provided the space required to prevent excessive proclination of incisors in non-extraction orthodontic tooth movement. For all that clinicians could expect 2–3 mm of maxillary molar distalization as well as anterior retraction with good vertical control of posterior teeth, the rectangular attachments at the posterior teeth and usage of auxiliary appliances, e.g. Class II elastics were recommended. On the contrary, Simon et al. indicated the overall accuracy of upper molar distalization without the support of attachment were comparable to that with the attachment. Nevertheless, the influence of attachment on the movement pattern of molar distalization, which is either bodily movement or tipping movement, could not be clarified.[34]

Regarding to the effectiveness of vertical tooth movement with CAT, Rossini et al. in the systemic review indicated that CAT could be only recommended for mild deep overbite correction but not for treatment of open bite. CAT had less effects on controlling the vertical movement of incisors.[35] Charalampakis et al. agreed that intrusion of incisors was the most unpredictable linear tooth movement and showed a tendency of extrusion even though intrusion was planned.[19] On the basis of overbite changes, the present evidences supported the expected efficacy of managing deep overbite and open bite with CAT was 1.5 mm improvement. Overbite overcorrection, leveling the curve of Spee, and virtual bite ramp might be considered in the planning strategy of deep bite correction. By the contrast, extrusion attachments could be prescribed to extrude incisors. However, according to the cephalometric analysis, changes in the incisor position, either by proclination of mandibular incisors or extrusion of incisors, were responsible for the most improvements in the deep bite and open bite. Therefore, the potential of achieving true vertical movement of incisors with CAT merits further investigation.

In 2015, Align Technology, Inc. introduced InvisalignG6 system incorporating with SmartForce (optimized anchorage attachment on posterior teeth and optimized retraction attachment on the canine) features and SmartStage (optimized tooth movement stage) technology claimed to achieve predictable tooth movement and improve clinical outcomes in cases with severe crowding and extraction orthodontics.[36] The evidences for extraction cases with CAT were relatively weak to date. There was only one study reported the predictability of tooth movement in first premolar extraction cases with Invisalign@. As the result showed, notable mesial tilting and translation of molars after the first serials of aligners without using any fixed appliance and auxiliary appliance. In the meantime, upper incisors showed loss of torque control and more lingual tipping. The anchorage control of first molar and retraction of central incisor were not fully achieved as predicted. The loss of first molar anchorage showed as a moderate anchorage type with 3 mm of mesial translation. The inherent feature of anchorage with CAT is comparable to the traditional edgewise orthodontic treatment in first premolar extraction cases.[37] Consequently, utilization of auxiliary appliances e.g. mini-implants, prescribed horizontal attachment, and overcorrection with a setting of 6.6° distal tipping on the first molar could be considered as the maximum anchorage control was required in extraction orthodontic treatment with CAT.[23] Interestingly, the current data revealed that CAT provided a good posterior vertical control in patients undergoing maxillary molar distalization, nonextraction, or even extraction orthodontic treatment. Hence, it could be assumed that CAT was viable for posterior vertical control in patients with hyperdivergent facial patten.

The accuracy of individual tooth movement with CAT could not fully reflect the treatment effectiveness from the clinical perspective. Several quantitative indexes have been developed to evaluate the malocclusion severity and orthodontic treatment need or treatment outcome.[38,39] Differing from previous investigations, Buschchang et al.[40] indicated the average actual posttreatment model scores fell at the high end of the acceptable range of the ABO's OGS.[9] Moreover, both Invisalign@ and fixed appliances had the similar clinical treatment effectiveness to improve the malocclusion in nonextraction patients based on the PAR scores.[16]

In terms of treatment efficiency, the current evidences represented that the treatment duration was averagely 5.7 month less for Invisalign patients than for fixed appliance patients with mild to moderate crowding. However, the result of treatment efficiency should be interpreted with caution. The lower patient's expectation, lack of detailing and finishing stages, higher occlusal force, and less severity of malocclusion have been proposed to explain a shorter treatment duration for Invisalign patients. Currently, there are no ample evidences to conclude that CAT increases the treatment efficiency and particularly for more complicated cases, e.g. extraction treatment.

Interestingly, Gu et al. showed the refinement rate was half of previous report and decreased to 37.5% in their study subjects.[16] The result might exhibit the improvement in aligner material, attachment features, and planning algorithm, or indicate the clinicians should have more experiences with the system.

It was not surprising that up-to-date evidences agreed that CAT had difficulties in achieving adequate occlusal contacts and deficiencies in overjet and anteroposterior correction. Additionally, CAT had less efficacy in controlling orthodontic tooth movement of rotation and incisor intrusion. Consequently, clinicians might need auxiliary appliances (e.g. interarch elastics, temporary anchorage devices), midcourse correction, refinements, or even conversion to fixed orthodontic appliances to finish treatment.

There were several limitations of the review article. First, most of the included studies were retrospective studies which having difficulties to eliminate the confounding factors.[9,11,13,15–19,21,23] To elucidate the real effects, a well-controlled subgroup comparison is required. Second, the methodology for accuracy assessment could be the source of bias since the serial digital images were superimposed on the posterior teeth.[15,17–19] Although the reference teeth were assumed to be "stable", the forces from the flexibility of the material might exert certain reaction forces on the reference tooth. The assessment of tooth movement based on the superimposition on stable structures could be conducted in future investigations. To the best of our knowledge, there are still lack of evidences to support the long-term stability of CAT.

CONCLUSIONS

Based on the available evidences, CAT is effective in managing minor malocclusion. CAT could achieve comparable treatment outcome to that of the fixed orthodontic appliance in nongrowing patients with mild malocclusion. However, the fixed appliances are more effective in great improvement, including adequate occlusal contacts than CAT. CAT is more effective in control of incisor extrusion than in control of incisor intrusion and rotation of lower canine and premolar. Arch expansion with CAT primarily achieved by crown tipping and exhibits less accuracy on second molars. There is no consensus about the efficacy of CAT for complex malocclusion e.g. extraction. Well-controlled prospective studies and randomized control trials with rigorous methodology, proper sample size and recruitment should be conducted to increase the strength of evidence level for a more persuasive conclusion.

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