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Review

Clear Aligner Therapy Concerns: Addressing Discrepancies Between Digitally Anticipated Outcomes and Clinical Ground Realities

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Main Points

- The discrepancies between the digitally prescribed and clinically achieved outcomes are comprehensively reviewed.
- Achieving predictability, efficacy, and efficiency requires a multifaceted approach.
- More robust researches are needed to bridge this gap.

ABSTRACT

Expeditious strides in the fields of biomaterials, computer-aided design, and manufacturing have catapulted clear aligner therapy (CAT) to become a comprehensive orthodontic treatment modality. The efficiency of achieving planned tooth movement with clear aligners is a significant consideration while setting up the final treatment goals, as well as calculating treatment times and costs based on the available evidence. Contemporary research outcomes confirm that one of the most commonly reported clinical concerns with CAT is the discrepancy between the prescribed outcome in the digital treatment plan and the clinically achieved outcome from a given series of aligners. Inaccurate prediction of tooth movements may not only lead to a prolonged duration of aligner treatment with an additional need for refinement strategies; but it may also cause other concerns, such as patient burnout and increased potential for relapse. The authors of this paper have elucidated some of the critical elements that may help address this discrepancy between digitally prescribed and clinical outcomes based on an evidence-based approach with regard to the predictability and accuracy of CAT. A strong diagnostic acumen, judicious case selection, solid biomechanical understanding of various types of orthodontic tooth movements, a research framework that keeps pace with technological and material developments and provides evidence-based knowledge of the limitations of CAT; and above all, the ability of the clinician to continually innovate as per different clinical scenarios, all contribute to attaining treatment predictability, efficacy, and efficiency with CAT.

Keywords: Clear aligners, predictability, efficacy, efficiency, treatment outcomes

INTRODUCTION

Expeditious strides in the fields of biomaterials, computer-aided design, and manufacturing have catapulted clear aligner therapy (CAT) into becoming a comprehensive orthodontic treatment modality. Clear aligners have witnessed an unprecedented demand over the last decade, possibly due to aggressive marketing by commercial clear aligner manufacturers and the widespread utilization of social media channels.[1] A recent market analysis

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report[2] revealed that the global clear aligner market size has surged to USD 5.13 Billion in 2023, and a survey conducted across North America reflected the sentiment that more orthodontists in the younger generations believe that clear aligners will be the main technique to treat malocclusions.[3]

The efficiency of achieving planned tooth movement with clear aligners is a significant consideration while setting up the final treatment goals, as well as when calculating treatment times and costs based on the available evidence. Compromised treatment outcomes after aligner use might be related to the inherent inability of the appliance to achieve the anticipated amount of tooth movement at the beginning of the treatment because this is prescheduled through prediction models or company-driven prediction software.[4]

Studies have identified specific tooth movements that are difficult to predictably attain in clinical settings, which relate to both the type of tooth being moved and the direction of tooth movement.[5,6] Inaccurate prediction of tooth movements may not only lead to a prolonged duration of aligner treatment but may also cause other concerns, such as patient burnout and increased potential for relapse.

A recent overview of systematic reviews (SRs) and meta-analyses examining the predictability and clinical effectiveness of clear aligners compared with fixed appliances (FAs) has indicated that the current evidence on this matter is of low quality. While CAT can be used for treating complex malocclusions, it tends to produce less precise outcomes than FAs.[7] Additionally, another SR, which evaluated the available evidence on the effectiveness and efficiency of CAT in complex cases involving premolar extractions compared with FAs, also suggested that FAs hold the advantage of achieving superior buccolingual inclination and occlusal contacts within a shorter treatment duration.[8] It is important to note that while previous studies, including the current paper, use "clear aligner therapy" or "CAT" as a broad term, the individual studies within the referenced SRs primarily focused on the Invisalign system. The exception is the study by Zhang et al.,[9] who evaluated custom aligners produced in a university laboratory; Lombardo et al.,[10] who investigated F22 clear aligners, and Tepedino et al.,[11] who studied Nuvola systems, Jaber et al.,[12] who compared in-house clear aligners with FAs. Although these other types of aligners may impact the presented results, the findings and subsequent discussion can generally be applied to the commercial brand Invisalign, with the terms "clear aligners" or "CAT" used interchangeably. The significant implications of this overview, which summarizes contemporary evidence on the predictability and effectiveness of CAT, are outlined below.

Contemporary CAT Research Outcomes: An Overview

Predicted versus Achieved Results for Different Types of Tooth Movement

The assessment of Computer-Aided Tooth movement (CAT) involves comparing predicted and actual tooth movements, typically expressed as a percentage or numerical measurement (in mm or °). This has led to numerous studies aiming to evaluate CAT's reliability. Most systematic reviews [13-17] included in analyses have shown low-quality evidence, except for one by Rossini et al.,[18] which was deemed moderate and focused on CAT's efficacy in controlling orthodontic tooth movement. Conflicting results regarding CAT predictability stem from varying software capabilities, tooth types, study methodologies, and outcome reporting (Table 1).

CAT appears relatively reliable for horizontal movements[13-15] but less so for rotations, particularly in canines and premolars, due to anatomical constraints.[13-15,17,18] Even with Invisalign attachments, canine accuracy may be compromised because the curved anatomical surface of the canine could reduce the dynamics of the attachment grip.[17] Interproximal reduction (IPR) of enamel and derotation direction also influence efficacy, with mesial movements being more predictable.[14,19] Torque control, especially in arch expansion and anterior teeth, remains challenging.[13,15] Invisalign's G8 enhancements improve posterior arch expansion and torque control,[20] however, further research is still needed.

Limited torque control for anterior teeth has also been observed.[13-16] CAT may produce clinically acceptable outcomes for minor buccolingual inclination of upper and lower incisors, albeit with a low level of evidence.[15] For extraction cases with Invisalign, power ridges and attachments on central incisors

Table 1. Summary of data synthesis from systematic reviews - predictability and/or accuracy (predicted versus achieved outcomes)

Treatment outcome	Summary of data synthesis from included systematic reviews
Predictability and/or accuracy (predicted vs achieved)	1. Teeth inclinations and occlusal contacts among limitations of Invisalign, when accuracy of planned movements achieved with aligners is concerned (Papadimitriou et al.,[13] 2018). 2. Expression of programmed movement is not fully accomplished with Invisalign (Galan-Lopez et al.,[14] 2019). 3. Most tooth movements with CAT not predictable enough except for minor horizontal movements. Predictability of minor extrusion of anteriors has increased compared to conclusions of previous SRs (Robertson et al.,[15] 2020). 4. Accuracy of movements for upper incisors ranges from 18.3% to 85%. For upper centrals: horizontal movements (especially rotation) most predictable and vertical movements less predictable. For upper laterals, horizontal movements (especially labiolingual tipping) most predictable and vertical movements less predictable (Collard et al.,[16] 2020). 5. Comparison between software-predicted and actual rotational movements showed low percentage accuracy for anteriors and premolars. Prediction of rotational movements with CAT not accurate, especially for canines. Selection of patients and malocclusions for CAT remains challenging (Koletsi et al.,[17] 2021).

CAT, clear aligner therapy; SRs, systematic reviews

were recommended, especially in adults, because incisor torque loss was more obvious in adults than in adolescents when the same predicted incisor torque was prescribed.[6]

Vertical movements pose greater challenges,[14-16,18,21] with maxillary anterior tooth extrusion being the least accurate.[18,22] Novel attachments may improve outcomes, with extrusion showing greater predictability than intrusion, particularly in anterior open bite cases.[13] Maxillary incisors may undergo unintended extrusion, whereas posterior teeth may be apically placed.[15] This could explain why the absence of occlusal contacts and posterior open bites are commonly observed during CAT. G8 enhancements target deep bite correction, suggesting potential benefits from pre-intrusion spacing for lower incisors.[20]

Overall, while CAT shows promise for certain movements, further research is crucial to enhance its efficacy and predictability, especially in complex cases.[8]

Effectiveness of CAT versus FAs

The summary of the clinical efficacy and effectiveness of CAT (Tables 2 and 3), primarily in contrast with traditional FAs, was drawn from evidence compiled from nine SRs[8,13-15,18,22-25] ranging from low to moderate quality.[7] The clinical effectiveness of clear aligners varied across these SRs due to diverse factors, including differences in study designs. It is important to note that treatment outcomes may not solely hinge on the appliance but also on unexplored patient and clinician factors.[26]

Table 2. Summary of data synthesis from systematic reviews - Effectiveness or efficacy of CAT versus FA

Effectiveness or efficacy of CAT vs FA	1. Low to moderate level evidence exists regarding efficiency of CAT for certain movements. Whole array of malocclusions to be efficiently treated with CAT has not been covered by included studies. CAT may produce clinically acceptable outcomes comparable to FA for minor buccolingual inclination of upper and lower incisors. Treatment time required to achieve results comparable to FA has not been investigated yet (Robertson et al.,[15] 2020). 2. Orthodontic treatment with CAT is associated with worse treatment outcomes compared to FA in adult patients. Current evidence does not support clinical use of aligners as a treatment modality equally effective to gold standard of braces. No significant differences seen for treatment duration. Treatment duration not defined by appliance alone, and patient or treatment-related factors might come into play (Papageorgiou et al.,[25] 2020). 3. CAT had an advantage in segmented movement of teeth and shortening treatment duration. Braces were more effective in achieving great improvement, producing adequate occlusal contacts, controlling teeth torque, and increasing transverse width and retention than aligners (Ke et al.,[24] 2019). 4. Vertical movement and derotation are difficult movements to accomplish with aligners. IPR is recommended, especially in canines and in cases of crowding. There is better root control with fixed appliances. Buccolingual inclination and occlusal contacts are worse with Invisalign. Although it is possible to treat complex malocclusions with plastic systems, results are less accurate than those achieved with FA (Galan-Lopez et al.,[14] 2019). 5. Clear aligners: a. are effective in correcting dental crowding; b. present limitations regarding intrusion and extrusion of teeth, and in not promoting proper occlusal contact; c. Higher recurrence of crowding observed with Invisalign compared to FA; d. Little difference in treatment duration compared to braces (Pithon et al.,[22] 2019). 6. Invisalign might treat mild non-extraction cases faster but requires more time than FA for more complex cases. Invisalign can safely straighten dental arches in terms of levelling and derotating teeth (except for canines and premolars, where a small inadequacy was reported). Crown tipping can be easily performed. Teeth inclinations and occlusal contacts seem limitations of Invisalign (Papadimitriou et al.,[13] 2018). 7. Both CAT and FAs are effective in the orthodontic treatment of premolar extraction-based cases. FAs have the advantage of achieving better buccolingual inclination and occlusal contacts in a shorter treatment duration (Jaber et al.,[8] 2023).

CAT, clear aligner therapy; FA, fixed appliance; IPR, interproximal reduction

Table 3. Summary of data synthesis from systematic reviews - effectiveness or efficacy of CAT- the role of attachments and auxiliaries

Effectiveness or efficacy of CAT- the role of attachments and auxiliaries	1. Anterior root torque can be improved by using auxiliaries, such as power ridges and attachments. However, these may still be insufficient to ensure the right root control. 2. Posterior anchorage seems important to ensure greater control during anterior teeth retraction, which can be improved by adding attachments on greater number of teeth (from canine to second molar). Optimized and rectangular horizontal attachments have shown best results. 3. Evidence of influence of attachments on intrusion and extrusion is lacking, although attachments seem to improve intrusion. 4. Conflicting results about ability of attachments to improve rotational control. Majority of studies showed positive influence of attachments on derotation, although not statistically significant. Using two attachments on buccal and palatal sides or adding attachments on adjacent teeth may not improve rotation. Larger attachments with sharper edges showed better outcomes. 5. Use of attachments could increase molar mesiodistal movement efficacy; however, this improvement may not be clinically significant. 6. No clinical studies evaluated posterior buccolingual tipping/expansion. 7. Further clinical studies necessary to confirm above findings and increase knowledge about influence of attachments on different types of movement. (1-7 from Nucera et al.,[23] 2022). 8. CAT is not based on aligners alone and requires use of auxiliaries (attachments, interarch elastics, IPR, altered aligner geometries) to improve predictability. (Rossini et al.,[18] 2015).

CAT, clear aligner therapy; IPR, interproximal reduction

CAT demonstrates effectiveness in aligning and straightening dental arches, particularly beneficial for mild to moderate crowding in non-growing patients compared with FAs.[15,18,22] However, if crowding exceeds 6 mm, the incisors may tend to procline and protrude after alignment with CAT.[14] The ability of CAT to modify intercanine, interpremolar, and intermolar widths is comparable to that of FAs and aids in resolving crowding.[14,22] However, arch expansion through bodily tooth movements remains a limitation according to some SRs.[13,14,24] In addition, CAT is noted to have an advantage in treating segmented tooth movements.[24]

Current evidence, ranging from low to moderate certainty, suggests that CAT may yield inferior treatment outcomes compared with FAs, particularly in larger anteroposterior/vertical corrections and achieving adequate occlusal contact.[8,13,14,18,22,24,25] However, because of limited evidence and small sample sizes, definitive conclusions on CAT's superiority or inferiority to FAs are elusive.[23] CAT has been observed to produce acceptable outcomes similar to FAs for minor buccolingual inclination of upper and lower incisors, albeit with limited evidence.[15]

Treatment duration comparisons between CAT and FAs have yielded mixed results over the years. Some SRs suggest a shorter treatment duration with CAT for mild-to-moderate cases, especially for non-extraction treatments and segmented movements.[13,23] However, inconsistencies exist, possibly due to CAT's evolving role in treating complex cases[8] and variations in patient-related factors. The scarcity of randomized controlled clinical trials (RCTs) comparing treatment times between CAT and FAs underscores the need for further investigation in this area.[15]

Limitations of Current Studies and Unavailability of Robust Research Outcomes

The overview[7] evaluated the quality of the individual SRs using the AMSTAR-2 quality assessment tool[27] and found the level of evidence to be variable. Three out of 18 (16.66%) SRs were considered to have moderate-quality evidence, eight out of 18 (44.44%) were considered to have low-quality evidence, and seven out of 18 (38.88%) were considered to have critically low-quality evidence. Thus, none of the SRs included in the mentioned overview were evaluated to provide a high level of evidence as per the AMSTAR-2 assessment tool. A recent SR was classified as having low-quality evidence because it incorporated a retracted RCT[28] among the six trials it synthesized.[8]

The number of prospective RCTs included in individual SRs was minimal, with most studies being retrospective, non-randomized, cross-sectional, or observational in design. Furthermore, the included studies could be influenced by different types of bias, such as those arising from the absence of randomization and/or concealment of allocation (selection bias); or due to the lack of blinding protocols (detection bias), and lack of standardization of treatment protocols (performance bias). In addition, several confounding factors were not considered in the included studies, such as the severity of the malocclusion, the commercial brand of the clear aligner, the specifics of the clear aligner material, patient's compliance with aligners, the total number of aligners, the use of additional or refinement aligners, and protocol for aligner change. These factors could generate bias due to the absence of standardization. Furthermore, the elevated laboratory costs associated with the fabrication of commercially available clear aligners may pose an impediment to research. Finally, rapid advances in the field of aligner materials and prediction software may prevent a direct comparison between older studies and the most recent ones.

In addition to the above general variables, data regarding the efficacy of specific features of Invisalign, such as the effects of various geometries of bonded attachments, and aligner alterations, such as power ridges and pressure points, are still lacking, despite these features having been a part of Invisalign for many years. Similarly, the possibility of using variable modulus aligners in CAT is poorly studied.

In summary, different aligner brands and materials, movement protocols, wear regimens, attachment prescriptions, and altered aligner geometries make concise analysis of generic CAT challenging for researchers. This combined with the rapid evolution of CAT means that clinicians often have to rely on inadequate or out-of-date data when making the decision to use CAT for the treatment of their patients. The need for well-designed individual clinical trials for mapping the robust evidence on CAT cannot be overemphasized.

Ground Realities of Cat Clinical Performance

This review has endeavored to focus on studies that highlight the clinical performance of aligners and evaluate the achieved outcomes relative to either FA norms or CAT digitally prescribed norms, other than the previously discussed SRs or RCTs.

Orthodontists' Perceptions of the CAT

In a recent survey of orthodontists in Australia,[29] respondents indicated particular concerns regarding the finishing of CAT cases, specifically movements that included root torque, bite opening, extrusion, and rotations. Although several SRs have been conducted and provided detailed information regarding the clinical efficacy of CAT;[13,15,18,25] unfortunately, both the rapid evolution of CAT and the plethora of more recently published studies providing increasing data demonstrate that these existing SRs lack breadth and tend to be outdated.

Occlusal Outcomes

Studies report an overall loss of posterior contact from both initial numbers of contact and those predicted, while Bowman et al.[30] highlighted a significantly greater loss of contact from the maxillary buccal occlusal surfaces than from the palatal occlusal surfaces for cases of mild-to-moderate malocclusion treatment.

Deep Bite

Research into deep bite correction using CAT has provided some most clear outcomes. In non-growing subjects, Invisalign has been routinely reported as clinically achieving 39-52% of the digitally predicted bite opening.[31-36] Possible explanations for this shortfall include a posterior bite-block effect of aligners and an inability to adequately direct apically directed intrusive forces, along with a reported shortfall in the ability to extrude posterior teeth. The only strategy for bite opening that offers moderate predictability is relative intrusion by the proclination of incisors.[37]

Open Bite

The treatment of open bite has been promoted as a strength of CAT; on the other hand, claims of relatively good predictability. Although several case reports and retrospective studies have demonstrated successful management of mild anterior open bites with CAT, primarily by incisor extrusion,[38-41] maxillary central incisor extrusion efficacy with CAT was reported by Haouili et al.[19] as 56% in a non-AOB sample, with similar efficacy for the mandibular central incisor.

Rotational Corrections

While several studies have reported shortfalls in the achieved versus predicted outcomes for rotational movements, the need to examine large samples and the requirement to separate rotational movements from other movements make a definitive assessment of predictability difficult. Haouili et al.[19] reported an overall rotational efficacy of 56% for all rotations. Studies on samples limited to individual specific tooth rotations have shown efficacy in the order of 75% for upper central incisors and lower canines. An interesting finding is that teeth are sometimes reported to rotate in a direction opposite to that intended.[42,43]

Labiolingual Crown Inclination and Torque

Although research is sparse, the conclusions of most studies indicate a shortfall in clinically achieved torque or labial crown inclination relative to that prescribed. The prescribed lingual crown tip is much more predictable than the prescribed labial crown tip in both arches and may frequently be overexpressed. Tooth movement in directions opposite to those prescribed has also been reported.[44,45]

Transverse Dental Expansion

Maxillary transverse expansion is one of the most comprehensively studied movements for CAT.[30,46-48] Shortfalls in achieved expansion versus predicted outcomes in the order of 70-80% are common findings, with efficacy declining from the canines to the more posterior teeth. Lower arch expansion is less well studied, although it appears to be slightly more predictable. Transverse expansion is routinely reported as a tipping movement rather than bodily translation.

Mesiodistal Root Tip

Studies of prescribed mesiodistal root uprighting using CAT are very rare. Two studies related to specific tooth types have found efficacy of 35% (lower incisors)[49] and 70% (upper central incisors)[41] in non-extraction treatments. Unprescribed crown tipping after premolar extraction has been reported in several studies.[6,50,51]

Addressing Discrepancy Between Anticipated Outcomes and Clinical Reality

Contemporary evidence highlights that one of the most commonly reported clinical concerns with CAT is the discrepancy between the prescribed outcome in the digital treatment plan and the clinically achieved outcome from a given series of aligners.[13,15,18,25] The current paper elucidates some of the critical elements that may help narrow the gap

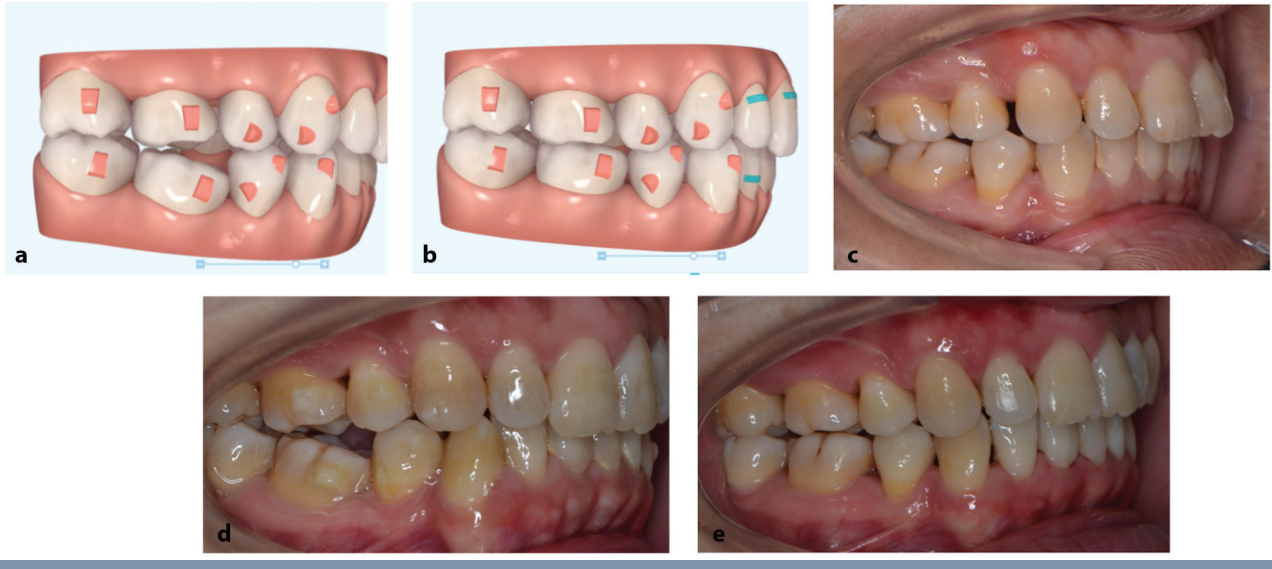


Figure 1. The discrepancy between anticipated digital outcomes and ground clinical realities, which warrants the need for refinement strategies to eventually achieve desired tooth movement. **a)** Anticipated digital outcome; **b)** Clinical ground reality; **c)** Pre-treatment photo; **d)** Molar dumping due to inappropriate biomechanical control and attachment design; **e)** Desired result post-refinement strategies

between digitally prescribed and clinical outcomes based on an evidence-based approach with regard to the predictability/accuracy of CAT. Figure 1 illustrates the discrepancy between anticipated digital outcomes and ground clinical realities, along with the need for refinement strategies to eventually achieve desired tooth movement.

Case Selection

Once a case has been adequately diagnosed, the suitability of a given case for an acceptable response to proposed orthodontic mechanotherapy is one of the most important elements to consider if treatment is to be timely and successful. All appliance systems have strengths and weaknesses, as do our clinical decisions regarding whether to extract or not, and patient biology adds a further level of discrimination. If we assume that a competent level of diagnosis and case selection is attained, our focus then shifts to the ability of our chosen mechanotherapy to achieve the desired treatment goals. As CAT is a relatively recent treatment modality, our knowledge of the strengths and weaknesses of CAT and the strategies we need to employ to overcome its weaknesses is far less complete than our knowledge of FA therapy.

Two simple considerations that apply to even basic CAT are: first, for treating mild-to-moderate crowding, evidence exists that the best results are likely to come if a) IPR is not relied upon as the primary means of space gain, as IPR is commonly underdone by approximately 50%;[52,53] b) Transverse dental expansion is either minimized or avoided, as it is commonly underexpressed in the maxilla in particular, is unstable in retention, and appears to lead to poor occlusal outcomes, including posterior open bites.[29,46-48,54] Thus, it would seem reasonable to avoid, wherever possible, both IPR and posterior expansion for the best clinical outcomes. Second, CAT tends to fail to achieve the prescribed labial crown torque to a significant degree.[43,44] This may leave the incisors visually more upright and more prone to incisor interference and posterior open bites.

Variable Modulus Aligners

Variable modulus archwire are regularly utilized in FA treatment. There is some evidence that variable modulus aligners may offer improved outcomes, with softer aligners providing improved alignment (analogous to the use of nickel-titanium archwires in fixed orthodontics) and harder aligners providing superior outcomes for bite opening,[32,33] torque,[48] and posterior intrusion.[48] Some commercial manufacturers offer variable modulus aligners, including 3M, Angel Align, and CA Clear Aligner.

Time-sensitive Aligner Change Regimes

Employing a "one-size fits-all" approach to aligner change regimens is contrary to biology. Different patients and different movements are likely to require different amounts of time. Some evidence exists that a 1-week aligner change protocol is as effective as a 2-week change for lower canine rotation, but that a 2-week aligner change is more effective for bite opening[33] and bite closing.[42] With FAs, archwire are changed as and when the desired movement has been expressed. Remote monitoring apps such as Dental Monitoring may offer a solution, particularly when monitoring alignment; however, the accuracy of these apps in determining the satisfactory progress of labiolingual root torque, bite opening, and mesiodistal root tip is yet to be proven.

Overcorrection

The overcorrection feature offered by Invisalign for desired tooth movements that are routinely known to be underexpressed is yet another facet for bridging the gap between the digital and clinical realities of clear aligner treatment. For overcorrection to be successful, it is essential to know the routine shortfalls expected of the tooth movement;[19,31,34,38,41-49] whether these movements reliably express shortfalls or whether they may express movements opposite to that prescribed;[42,43,49] and finally the appropriate timing of the overcorrections. For example, transverse expansion overcorrection is probably best placed at the end of the aligner treatment, while bite opening is necessary to permit incisor retraction and needs to be corrected early in such cases.

Attachments, Altered Aligner Geometries and Force Application to Teeth

Bonded resin attachments and altered aligner geometries are considered necessary by Invisalign to enhance the ability of Invisalign aligners to deliver appropriately directed forces to achieve desired tooth movement. However, despite the use of Invisalign attachments for more than two decades, our knowledge of the efficacy of the various proposed attachment types is limited. Evidence exists that the difference between the standard conventional attachments and the optimized attachments (the proprietary attachments from Align) is not clinically significant, at least for some tooth movements. It may also be inferred that in adults, bite ramps are ineffective at opening deep bites.[32,35,36] The clinical efficacy of Invisalign power ridges for palatal root torque is unproven even more than a decade after their introduction.

Biomechanical Considerations

Upadhyay and Arqub[55] presented the efficiency of aligners (in %) for different types of orthodontic tooth movement graphically to depict the consensus from the available literature on how good aligners actually are at moving teeth. Tipping has been demonstrated to be the most predictable tooth movement, whereas root movement or torquing was shown to be the least predictable movement, with recent literature demonstrating the mean efficiency of aligners to be around 50%. They have also succinctly summarized how achieving orthodontic tooth movement with CAT is more complex than it is with FAs, and this can be attributed to the absence of specific points of force application, variations in tooth anatomy, properties of aligner materials, mismatch between aligner and dentition geometries, slipping motions between contact shapes, and other biomechanical factors.[56] Accurate treatment prediction has long been a challenge not only for orthodontists

but also for the plethora of prediction algorithms employed by multiple commercial aligner manufacturers. A practical solution for improving predictability and optimizing treatment duration is the addition of a predictable and customized adjunct to clear aligners.

Incorporation of Clinical Adjuncts into CAT

Clear aligner systems are biomechanically inadequate for achieving complex orthodontic movements on the basis of aligner use alone. The incorporation of adjuncts such as composite attachments, IPR, power ridges, auxiliary anchorage devices such as brackets, buttons, mini-screws (or similar temporary skeletal anchorage devices), and intraoral elastics, especially in scenarios such as mesialization, distalization, expansion, and/or extrusion, can help improve the predictability of CAT. Vaid et al.[57] inspired by the "Golden Circle Model", addressed questions such as the "Why, How and What" of adjuncts used in combination with CAT and have elucidated an "inside out" approach (from Why to What) to present the rationale, stepwise clinical workflow, and advantages of these adjuncts. An astute clinician who wishes to expand the repertoire of malocclusions that can be successfully managed by CAT should plan the inclusion of such adjunct appliances in their aligner treatment planning. This may help reduce the overall treatment duration and provide more predictable treatment results than those attained with clear aligners alone.

Robust Research Framework for Consistent Clinical Outcomes

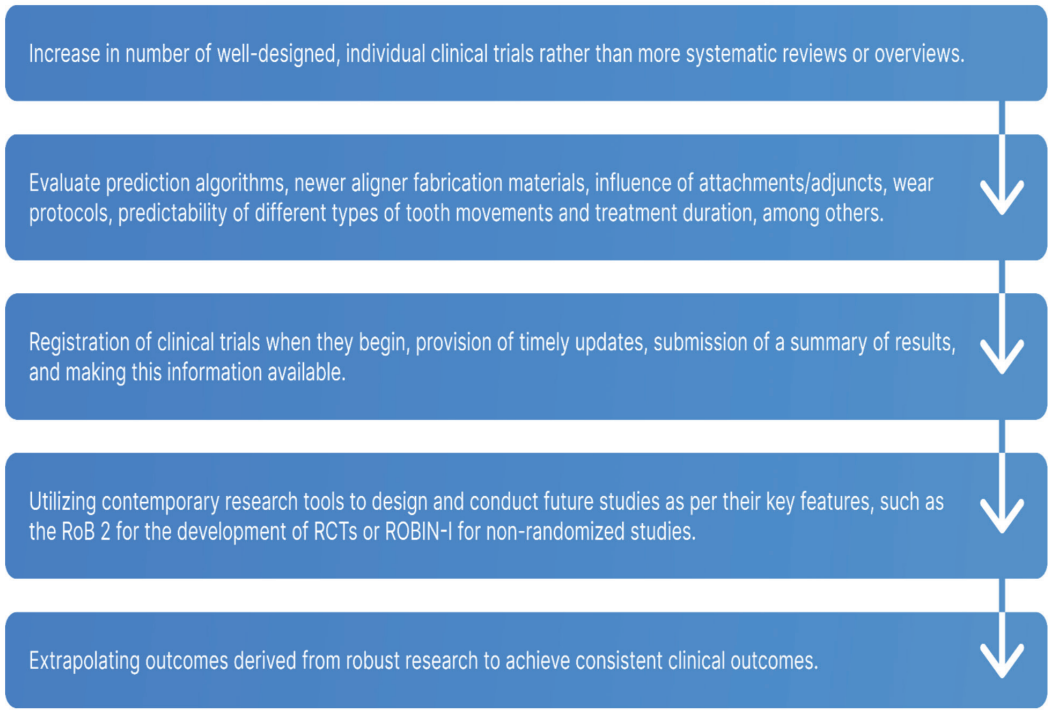
Technological advancements and their integration into any profession are essential. As clinicians we must leverage these advancements to enhance patient outcomes and shape the future of clear aligner applications in orthodontics.[58] Well-designed, individual clinical trials that thoroughly evaluate but are not limited to prediction algorithms, newer aligner fabrication materials, attachments/adjuncts, wear protocols, predictability of different types of tooth movement, and treatment duration are imperative to provide robust evidence and answer questions arising from the broad range of malocclusions that CAT is currently used to treat and to address the discrepancy between the digital and clinical reality.

Over the last two decades, research tools have considerably evolved to assess the quality of individual SRs included within an overview of SRs as well as the quality of individual clinical trials included within a single SR. These tools and methods clearly assist in categorizing the evidence obtained from individual studies, ranging from high to critically low, and inform the clinician about he degree of confidence in the information provided by a specific study. Another way of using these research tools is to plan and conduct future studies as per the key features outlined by the evidence evaluation tools, which may help in the development of a more robust research framework for the evaluation of multiple attributes of CAT and eventually lead to more consistent clinical outcomes. The current paper summarizes some of the defining steps for conducting robust studies on CAT and elucidates the essentials of some of the tools of evaluation of the evidence below.

Registration of clinical trials when they begin, provision of timely updates, submission of a summary of results, and making this information publicly available serve several purposes and benefit varied segments of the population. A results database likewise helps provide a public record of basic study results in a standardized format, promotes the fulfillment of ethical obligations toward the participants and the overall contribution of research results to medical knowledge, reduces publication and outcome reporting biases, and facilitates SRs and other analyses of the research literature.

RCTs constitute the gold standard for gleaning information on healthcare interventions. In 2019, Sterne et al.[59] developed and piloted a revised tool for assessing the risk of bias in randomized trials (RoB-2), which allows researchers to assess the risk of bias in five distinct domains. Although the role of non-randomized studies of the effects of interventions (NRSI) in determining treatment decisions remains controversial, NRSI continues to constitute an integral component of the evaluation of multiple disciplines in the field of healthcare.[60] Sterne et al.[61] (2016) described the development of ROBINS-I ("Risk of Bias in Non-randomized Studies of Interventions"), which evaluates the risk of bias in estimates of the effectiveness or safety (benefit or harm) of interventions from studies that did not use randomization to allocate interventions. Shea et al.[27] In 2017, AMSTAR 2 was devised as a critical appraisal tool to evaluate SRs that include randomized or non-randomized studies of healthcare interventions, or both. A thorough understanding of the various research tools at our disposal and the planning and subsequential conduct of clinical trials on CAT based on key fundamentals outlined by these tools will help clinical research teams design, conduct, and report the findings of clinical trials to achieve the most reliable findings possible that will eventually improve the predictability, efficacy, and effectiveness of CAT. Figure 2 outlines suggested guidelines for the development of a robust research framework for CAT studies to achieve consistent clinical outcomes.

Figure 2. Suggested guidelines for the development of a robust research framework for CAT studies to achieve consistent clinical outcomes



CAT, clear aligner therapy; RCT, randomized controlled clinical trial

CONCLUSION

Clear aligners represent one of the most significant advancements in orthodontics, exerting a growing influence in the orthodontic market. What began as an alternative appliance two decades ago has evolved into a comprehensive treatment solution.[57,58,62] The data collected from millions of patients over the past 20 years underscores the inadequacy of relying solely on a series of plastic aligners to address the diverse range of malocclusions routinely encountered in our specialty. Despite remarkable advancements in software, manufacturing, prediction algorithms, and materials, clear aligners alone are insufficient.[57,63-65]

Achieving predictability, efficacy, and efficiency with CAT requires a multifaceted approach. Strong diagnostic skills, careful case selection, a thorough understanding of biomechanics, ongoing research to keep pace with technological advancements, and a keen awareness of CAT's limitations are essential. Moreover, clinician innovation tailored to individual clinical scenarios is paramount.[55,57,66] These factors collectively contribute to bridging the gap between digitally anticipated outcomes and the clinical reality associated with CAT.

Ethics

Author Contributions: Concept – B.Z., Y.M.B., S.A., N.R.V.; Design – T.W., B.Z., S.A., N.R.V.; Data Collection and/or Processing – Y.M.B., T.W., B.Z.; Analysis and/or Interpretation – T.W., B.Z., S.A., N.R.V.; Literature Review – Y.M.B., T.W., B.Z.; Writing – Y.M.B., T.W., B.Z.; Critical Review – B.Z., S.A., N.R.V..

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