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# Optimising clear aligner therapy: What current evidence says about materials, attachments, and protocols

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A B S T R A C T

Recent years have seen an increase in aligner use by orthodontists and an increase in corresponding research. Potential deficiencies in aligner and auxiliary material properties and design, and wear protocols have been suggested as contributory factors in sub-optimal clear aligner therapy (CAT) outcomes. The aim of the present narrative review was to summarise the evidence regarding five specific factors to be considered in the choice of a clear aligner system. The findings indicated that the use of aligners with variable moduli of elasticity may offer the potential for improved treatment outcomes, with simple alignment using softer materials and more complex movements with higher modulus materials. CAT using straight extended trimlines provide better, larger areas of contact with tooth surfaces. This potentially improves force delivery to achieve more ideal tooth movement. The findings of the present review indicated that optimised attachments do not confer significant clinical advantages over conventional attachments. Aligner wear protocols should be determined by the case-specific features of biology and the type of tooth movement to be performed. Bite ramps and torque ridges are not efficacious in managing deep overbite and lingual root torque.

## Introduction

The popularity of clear aligner therapy (CAT) as a treatment modality is reflected in its use by 65–95 % of orthodontists in several countries according to multiple recent surveys.[1–6] Its prominence within the orthodontic landscape is also manifested by the increasing number of CAT systems available to orthodontists,[7] following the introduction of the Invisalign (Align Technology, Santa Clara, Calif.) appliance in the late 1990s, and the increase in relevant research published over the last 10 years.[8,9]

Notwithstanding the appliance's purported advantages, such as its aesthetic appeal and patient acceptance, potential deficiencies in aligner and auxiliary material properties and design, and wear protocols have been suggested as contributory factors in sub-optimal treatment outcomes.[10–12] Consideration of evidence in this regard may help clinicians in the choice of appliance and wear protocols in the management of malocclusion.

The aim of the present article was to provide an overview of the evidence regarding five specific factors to be considered in the choice of a clear aligner system.

## Literature search

The Scale for the Assessment of Narrative Review Articles (SANRA) guided the design and reporting of the present narrative review. The Web of Science database was searched on June 1st, 2025, with terms related to the five factors under review.

### *Factor I. Aligner Material*

Several materials are employed in the manufacture of clear aligners. The two main groupings comprise thermoplastic and direct printed. Since the available evidence regarding the clinical efficacy of direct-printed materials is minimal, the focus of this review will be on thermoplastic materials. While a wide range of thermoplastic materials are available, each with potentially different mechanical characteristics, the present review will relate to two general groups – "hard" and "soft".

Ho et al.[13] examined the effects of aligner materials with different moduli of elasticity (MOE) in-vitro and concluded that materials with a higher modulus may provide better control for some orthodontic tooth movements (OTMs), particularly where tooth translation without unwanted tipping is planned.

Clinical studies comparing CAT treatments employing materials of varying moduli are lacking. In 2013, Align Technology discontinued the use of the harder EX30 material in the manufacture of its Invisalign aligners in favour of SmartTrack, a material promoted as more closely matching the performance of nickel-titanium archwires than the preceding EX30 material, and was considered to being analogous to stainless steel archwires in performance.[11,14]

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Two clinical studies carried out in 2009[15] and 2020,[16] employing closely matching methodologies, enabled comparison of the clinical efficacy of each material. Notwithstanding the evolution of movement protocols, attachment types and altered aligner geometries in the interim, the newer material showed a mean accuracy of 50 % for OTM. This, however, was not dissimilar to the 41 % in the 2009 study,[15] and with ongoing evolution of movement protocols, attachment types and altered aligner geometries, casts doubt on claims for marked superiority of the new material.

In 2021, Griffiths et al[17] compared the two materials using the Peer Assessment Rating index to assess treatment outcomes among 94 adult patients and concluded that both materials resulted in similar amounts of malocclusion improvement. A study by Blundell et al[18] found that, when comparing achieved versus planned bite opening in 68 adult deep bite patients following wear of an initial series of aligners employing a 2-weekly aligner change protocol, those treated with EX30 had a bite opening efficacy of 52.8 %. This compared with a 42.8 % efficacy in those treated with SmartTrack and bite ramps, and 39.2 % in patients treated with SmartTrack alone. In a 2023 study of maxillary dental expansion in 120 adults treated with Invisalign, O'Connor et al[19] found that the greatest accuracy in prescribed buccolingual changes for posterior teeth was achieved by the EX30 group, with a 2-week aligner wear protocol. The SmartTrack/2-week wear protocol subgroup was only superior in the efficacy of canine inclination.

The limited evidence available appears to show that, for movements that traditionally require archwires with higher MOE, such as bite opening, arch expansion and torque, use of a higher modulus aligner material may be appropriate. Consequently, there may be value in incorporating aligners of varying MOE into treatment plans where complex OTMs are planned. This may enable the use the appropriate material for the type of tooth movement being undertaken at specific timepoints in the treatment sequence, just as the use of archwires with differing MOE or archwires with variable moduli built into the archwire, with stiffer posterior segments and more flexible anterior segments.

Currently, the ability to incorporate variable moduli aligners into a CAT treatment sequence appears to be available from three main manufacturers only – Solventum (Saint Paul, Minnesota), Angel Aligner (Angelalign Technology Inc, China), and CA-Clear Aligner (SCHEU-DENTAL GmbH Iserlohn, Germany). Data, however, regarding the efficacy of their appliances are lacking.

### *Factor II: Aligner Trimlines*

Aligner trimline design has been little studied, particularly regarding its effect on OTM efficacy.[20] Scalloped trimlines are primarily employed to improve appearance by following the clinical gingival margins to hide the aligner edge. This trim requires polishing which can weaken the material, with increasing flexibility in the gingival area resulting in poorer retention and OTM control.[21–23]

For optimal delivery of a desired force to a tooth, the aligner must be adequately retained and fit closely to the tooth surface. The in-vitro study by Cowley et al[23] found that aligner retention is essential for efficient OTM. They compared the effect of three trimline designs – scalloped, straight cut at the gingival zenith and straight cut 2 mm above the gingival zenith on the retention of thermoformed aligners. The study concluded that straight cuts reduced aligner flexibility and showed increased retention compared to scalloped margins for the materials tested. Further, the 2 mm straight gingival margin design had the highest retentive forces when compared to aligners of the same material and attachment type.

OTM with CAT is characterised by the direction and amount of force transmission that occurs because of the designed geometric 'mismatch' between the fitting aligner surface and the tooth crown.[11,24,25] The closer the adaptation of the aligner to the tooth crown, the more likely that the planned force transmission can occur.

In an in-vitro scanning electron microscopy (SEM) study, Mantovani et al[26] investigated the adaptation of Invisalign and CA-Clear Aligners to tooth surfaces. They found both systems provided similar fit, with Invisalign fitting better at gingival margins and the CA-Clear Aligner recording better adaptation to complex occlusal surfaces. However, considering that the default maximum linear displacement, applied to the tooth that has the furthest to move in most CAT systems is 0.25 mm per aligner, and most teeth are moved at speeds below that level, it is noteworthy that Mantovani and colleagues found tooth-aligner gaps measuring between 0.1 mm and 0.35 mm on the tooth surfaces investigated. This space may serve to diminish the applied force upon the tooth.

An in-vitro study by Elshazly et al[20] investigated how geometry and extension of the aligner trim line impacted stress distribution and forces transmitted from Invisalign aligners to tooth surfaces. Four trimlines designs were assessed – two scalloped and two straight cut. One of each type was trimmed at the gingival margin and the other 2 mm above. In relation to pressures and forces over the facial surface of an upper right central incisor, straight cuts provided more contact between aligner and tooth surface than scalloped designs at the same gingival trim height, and trimlines 2 mm above the gingival margin proved superior to those at the gingival margin. The research determined that more uniform force transfer and stress distribution across the tooth was seen with the extended straight cut, implying the potential for better control of the tooth with aligner-directed forces. While the authors concluded that trim line design could have a significant impact on the outcome of CAT, this has yet to be studied clinically.

### *Factor III: Attachments*

Attachments are geometric shapes of composite resin (CR) bonded to tooth surfaces, with the intention of enhancing aligner retention and facilitating certain types of OTM.[27,28]

The two primary attachments are conventional and optimised. Attachments are reliant on close adaptation of the aligner and optimal aligner retention for their effectiveness. However, attachments suffer potential drawbacks in this regard[29] in addition to deficiencies recently categorised by Nash et al. in an in-vitro study.[30]

These deficiencies include variation in attachment shape, and volume (including over- and underfill) and attachment placement errors. Errors of up to 0.4 mm were found. Given the default maximum for linear OTM described earlier, this may render movements reliant on attachments ineffective. Given these issues, several CAT manufacturers apparently plan to produce preformed attachments with more precise bonding jigs. At the present time, only Solventum has commercially released such a product – the Precision Grip™ attachment. Its accuracy and effect on clinical efficacy require investigation.

Conventional attachments are used in most commercially available CAT systems. There is wide variation in shapes and sizes, and their precise position on teeth can generally be adjusted by the treating doctor to suit the perceived requirements of the treatment plan. Optimised attachments have been progressively introduced by Align Technology since 2009 and are specific to that company. These attachments were intended to help increase the predictability of desired OTM. They incorporate an "active surface" where the shape of the attachment bonded to the tooth is different from the shape of the aligner engaging the attachment, with the objective of generating an active force in a desired direction.

Clinical studies comparing the efficacy of tooth movements when conventional or optimised attachments have been used have steadily increased. Table 1 provides a summary of the findings.

### *Factor IV: Aligner Wear Frequency*

In 2016, based on internal data from 200 patients, Align Technology recommended a change to a weekly wear protocol for each aligner with

**Table 1**
Summary of findings of studies comparing the efficacy of tooth movements with conventional or optimised attachments.

| |
|---|
| G6 attachments do not outperform conventional horizontal attachments.[31] |
| Horizontal attachments (any) were 22 % better than optimised for extruding maxillary lateral incisors.[32] |
| Conventional attachments just as effective as Invisalign's proprietary optimized attachments for rotations of canines and premolars, and extrusion of incisors and canines.[33] |
| Conventional attachments just as effective as Invisalign's proprietary optimized attachments for moderate to severe rotations of mandibular canines.[34] |
| Optimized attachments are no more effective than using conventional attachments in reducing deep OB.[35] |
| Optimized attachments for upper canines and lower premolar rotation seem to not work properly.[36] |
| Key. OB: overbite. |

all Invisalign Full & Teen product treatments from the previous 2-weekly wear protocol.[37] It is noteworthy that this recommendation was not made for aligner products with limited aligner numbers, such as the 14 aligner Lite product.[38] These recommendations were accompanied by the caveats that the decision to prescribe weekly changes is at the doctor's discretion and that doctors were encouraged to monitor more complex OTMs such as rotations, extrusions and significant root movements. Further, the recommendation was tempered with the statement that depending upon the patient response to treatment, particularly older adults, doctors should consider longer periods between aligner changes.

Despite this relatively cautious recommendation, suggesting large numbers of patients and OTMs were not necessarily ideally suited to weekly changes, recent surveys indicated the widespread adoption of the weekly change protocol as standard.[1–4,6] However, orthodontists should be aware of the lag phase - a period of minimal or no tooth movement that occurs after the initial application of orthodontic force, when considering the rate of aligner change earlier in the treatment process. The lag phase is the second of three associated with OTM following the application of orthodontic force[39]:

1. Initial: Characterised by rapid, significant movement, lasting from 24 h to 2 days, as the periodontal ligament is compressed and stretched.
2. Lag: OTM slows down or stops altogether, as PDL compression causes the tissue to die and harden, resulting in hyalinization and temporarily obstructing movement. Movement can stop for 20−30 days.
3. Post Lag: OTM resumes as the hyalinized tissue is cleared, although often movement occurs more gradually than the initial phase. Movement gradually or suddenly increases and is usually seen after 40 days following the initial force application.[40]

Consequently, it appears that a weekly wear protocol may not align with a desired response in the first 40 days after OTM is initiated. In 2018, one of the first articles to discuss the weekly change recommendation noted that "..we are unaware of any peer-reviewed, published study supporting this new guideline (weekly aligner change), whereas there is some evidence that a 2-week change regimen is more likely to result in higher completion rates using earlier aligner materials".[41]

Studies regarding OTM efficacy with varying aligner wear protocols report conflicting outcomes.[42] A 2021 randomised clinical trial[43] reported OTM efficacy with 7-, 10-, and 14-day wear protocols. It concluded that 14-day wear resulted in greater accuracy for some posterior tooth movements, which while statistically significant, did not exceed the >0.5 mm or >2.0° threshold for clinical significance. The authors suggested that clinically similar accuracy was found between 7- and 14-day changes, with the former achieving outcomes in half the time and making a 7-day wear protocol acceptable. However, doctors suggested to 'slowing' to a 14-day protocol if challenging posterior movements are required. A 2023 investigation[36] on the predictability of tooth movements with CAT among 79 adult patients reported that 14-day changes reduced the lack of correction by 12 % compared to 7-day changes.

The efficacy of specific OTMs related to different wear protocols has been evaluated. An in-vitro SEM study concluded that a 15-day wear protocol may be optimal as it showed the best adaptation and least gap width between aligner and attachment, while the 7-day group generally showed the worst adaptation.[29] Table 2 provides a summary of findings of studies comparing the efficacy of specific OTMs related to varying wear protocols.

Overall, it appears that different types of OTM with CAT may require varying wear protocols. The evidence supporting a routine 1-weekly aligner change regimen is lacking and indeed does not correspond with the original recommendation from Align Technology. Weekly wear protocols may be appropriate for simple movements, such as minor tipping, rotations and anterior tooth extrusion, especially in younger patients. For the resolution of the lag phase at the initiation of orthodontic treatment, in addition to more complex movements of tooth roots through bone − including torque, posterior dental expansion, and open bite correction a two-week protocol is recommended.

### *Factor V: Altered Aligner Geometries*

In addition to bonded CR attachments, many CAT manufacturers have produced a variety of altered aligner geometries (AAGs), including cutouts to allow placement of buttons or power arms, cutouts for intermaxillary elastic wear, posterior occlusal bite blocks, anterior bite ramps and torque ridges. The present review will focus on the efficacy of the latter two.

Anterior bite ramps were introduced by Align Technology in 2009.[46] While the limited number of studies regarding the efficacy of overbite reduction with and without bite ramps have mostly been carried out on non-growing patients, the evidence for superior overbite reduction efficacy with the use of anterior bite ramps appears to be lacking for both adults and adolescents (Table 3).

Torque ridges were introduced by Align Technology in 2009 as "Power Ridges", with the intention of improving lingual root torque efficacy.[46] As with bite ramps, Table 4 shows that the few clinical studies performed have indicated that torque ridges do not enhance lingual root torque efficacy.

**Table 2**
Summary of findings of studies comparing the efficacy of specific OTMs related to varying wear protocols.

| Comparison | Conclusion |
|---|---|
| Moderate to severe lower canine rotation correction in 75 patients[34] | 1-week wear and 2-week wear equally efficacious |
| Labio-palatal movements of the maxillary central incisors in 46 adults[44] | No differences between 7- and 14-day aligner change protocols |
| Movement of maxillary posterior teeth undergoing planned expansion in 120 adults[19] | Buccolingual inclination accuracy was worse for all posterior teeth with 1 week wear. |
| Efficacy of anterior open bite closure in 76 adults[45] | Improved by a mean of 0.5 mm, when a 2-weekly wear protocol was employed over a 1-weekly change. |
| Key. OTM: orthodontic tooth movement. | |

**Table 3**
Summary of findings of studies comparing the efficacy of tooth movements with and without anterior bite ramps.

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| No statistically significant differences between bite ramps and non-bite ramp groups.[47] |
| CAT without bite ramps had a 39.2 % bite opening efficacy in adults, whereas those with bite ramps had a 42.75 % efficacy.[18] |
| OB reduction efficacy with bite ramps in adults was 38.4 % while OB reduction without bite ramps was 31.7 %.[48] |
| OB reduction in adults with fixed appliances, CAT without bite ramps and with bite ramps was 3.1 mm, 3.8 mm and 3 mm respectively. Differences not statistically significant.[49] |
| OB reduction efficacies in adolescents were 37.6 % with bite ramps and 46 % without bite ramps in adolescents.[50] |

Key. CAT: clear aligner therapy. OB: overbite.

**Table 4**
Summary of findings of studies comparing the efficacy of tooth movements with and without torque ridges.

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| Planned lingual root torque changes of at least 10° in maxillary central incisors in adults were found to have torque efficacies of 41.4 % for those with Power Ridges and 42.6 % for those without.[51] |
| No differences were found in planned lingual root torque changes of at least 10° in mandibular central incisors in adults prescribed Power Ridges and those who were not.[52] |
| No statistically significant differences in predictability were found between the Power Ridges group and the attachments group in adults with Class II division 2 malocclusions.[53] |

## Limitations

Caution in the interpretation of the findings of the present review is advised as most relevant research relate to invitro or retrospective clinical investigations. The employment of randomised clinical trials is required to explore further the factors covered in the present review.

## Conclusions

Following a review of the literature, it appears that the selection of a specific clear aligner system and the method of its employ to provide the best possible movement efficacy should involve consideration of the following factors:

1. Just as variable MOE archwires are used in fixed appliance treatment to perform different types of movement, rather than relying on a single archwire only, the use of variable modulus CAT systems offers the potential for improved treatment outcomes. Simple alignment using softer materials and more complex movements such as arch expansion, bite opening and root movements performed with higher modulus materials appear to be appropriate.
2. CAT using straight extended trimlines provide better, larger areas of contact with tooth surfaces thus potentially improving force delivery to achieve more ideal tooth movement. In addition, such trimlines reduce the need to attachments purely for retention of the appliance
3. It appears that optimised attachments do not offer significant clinical advantages over conventional attachments, with some studies showing that optimised attachments are inferior.
4. Aligner change frequency should be dictated by the case-specific features of biology and the type of tooth movement to be performed. A "one size fits all approach" is not supported by the literature, and a combination of aligner change frequencies would appear to have supporting evidence.
5. There is no definitive evidence to support the use of AAGs, such as anterior bite ramps or torque ridges as aides to enhance OTM efficacy with CAT.

## Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Tony Weir is an editorial board member but had no role to play in the review and final decision on manuscript.

## CRediT authorship contribution statement

**Tony Weir:** Writing – review & editing, Writing – original draft, Visualization, Validation, Methodology, Investigation, Formal analysis, Conceptualization. **Maurice J Meade:** Writing – review & editing, Writing – original draft, Visualization, Validation, Methodology, Investigation, Formal analysis, Conceptualization.

## Patient consent

This study did not involve any human participants or patient data, so patient consent is not required.

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