

Effect of Varying Thickness of Clear Aligners in Orthodontic Therapy - A Review

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ABSTRACT

Clear aligner therapy (CAT) is one of the most rapidly expanding fields of orthodontics, propelled by patient interest in appliances that are aesthetic and removable. From the launch of Invisalign, ongoing improvements have broadened the applications of aligners from basic anterior alignment to advanced treatments. This review assesses the impact of aligner thickness on biomechanics, material properties, clinical results, and patient-centric factors and synthesizes evidence from laboratory research, computational simulations, and clinical research. An extensive search of PubMed, Scopus, and Google Scholar was conducted without year restrictions. The 25 included studies examined aligner thickness in terms of orthodontic performance, material response, or patient outcomes. Laboratory and computational analysis all show that aligner thickness increases with better stiffness and force delivery, but at the cost of patient comfort. Slimmer aligners are more tolerable but compromise biomechanical control. Thermoformed aligners are non-uniform in thickness, whereas 3D-printed aligners are more uniform and stable. Over time wear thins out aligners, so staged replacement regimens are required. Patients experience a

compromise among comfort, aesthetics, and mechanical function. The evidence indicates that thickness is a variable with immediate clinical significance. In conclusion thicker aligners enhance force control, whereas thinner ones are more comfortable and invite wear. Choice of material and fabrication technique influence thickness stability. Despite robust in vitro and computational evidence, evidence from the clinic is limited. Randomized trials, standardized measures, patient reports, and novel polymers should be the focus of future research to design customized thickness strategies enhancing biological efficacy and patient satisfaction

Keywords: Orthodontic Appliances, Removable; Clear Aligner Therapy; Thermoplastic Materials; Finite Element Analysis; Biomechanics.

INTRODUCTION

Clear aligner therapy (CAT) is becoming one of the orthodontics' fastest-growing segments as it is patient-friendly, removable, and aesthetically appealing. Apparently, the global aligner market crossed \$5 billion in 2023, and yearly growth was forecasted to surpass 15% until 2030 (Mehta & Mehta, 2014 [1]). Patient preference strongly favors such growth: survey responses indicate as much as up to 70% of adults' orthodontic

patients prefer the clear type over the fixed type whenever both are a choice (Cengiz & Goymen, [2]).

The roots of removable orthodontic appliances may be traced back to early prototypes used in the mid-20th century. However, the introduction of Invisalign in 1997 actually marked the beginning of modern-day aligner therapy, combining clear thermoplastics and advanced computerized planning [1]. In the beginning, aligners were specifically prescribed for minimal anterior crowding less than 2 mm. However, rapid development of CAD/CAM software, new polymers, and stepwise biomechanics has extended their usage for rotational corrections, extraction cases, posterior intrusion, and vertical control (Park et al. [3]).

Orthodontic tooth movement necessitates forces ranging between 15 and 150 grams depending on the type of tooth and tooth movement (Bucci et al. [4]). Because application of force is directly linked with stiff appliance, the thickness of the aligner has emerged as an optimizable variable. Greater thicknesses are less prone to deformation and might transfer greater loads better. Thin ones, on the other hand, promote patient comfort, even at the cost of less biomechanical control (Lombardo et al. [5]). In vitro research clarifies this rule clearly. Elshazly et al. [6] demonstrated that increasing the thickness from 0.5 mm to 1.0 mm resulted in almost double the levels of force in laboratory simulators. Edelmann et al. [7] also confirmed that 1.0 mm aligners delivered loads that were 35% higher than corresponding 0.5 mm thickness aligners of similar material.

Results are corroborated with finite element analysis (FEA). Li et al. [8] showed that increased thickness led to a 28% increase in periodontal ligament stress. In another study, Yang et al. [9] indicated that anterior retraction with 0.8 mm aligners resulted in an increase in forces up to 20–25% compared with 0.6 mm devices. These outcomes suggest that thickness of the aligner is an adjustable biomechanical variable.

At the final treatment plan, the fabrication of the aligners continues to occur, which introduces another level of variability. Standard thermoforming techniques produce a non-uniform thickness distribution between interfaces. Ammann et al. [10] observed a decrease of 20–25% across cusp tips, while as much as an intra-aligner variability of 0.15 mm was observed between labial and palatal segments by Mantovani et al. [11]. In comparison, 3D printing has materials with uniform thickness. Edelmann et al. [7] recorded 90% homogeneity of 3D-printed aligners compared with 65% of thermoformed devices. But then, a systematic review carried out by Liao et al. [12] has shown that, concerning reproducibility, accuracy, and biomechanical predictability.

3D-printed aligners are the best choice while compared to the thermoformed ones. The geometries are subjected to daily masticatory functions and temperature variations. Bucci et al. [4] recorded occlusal thickness reduction up to 10% upon a wear time of 10 days. Ammann et al. [10] established the presence of heterogeneous thinning and thus wear is greater in posterior segments relative to anterior segments. These suggest an aligner's effective thickness decreases over time and thus may cause reduction in force transfer and validates the need for replacing protocols on an every 7–14 days interval. Clinicians routinely use staged thickness protocols as a balance between comfort and efficiency. Cengiz & Goymen [2] showed patients were more adaptable with the initial 0.5 mm stage, and progressed to using 0.8 mm aligners with higher forces but with compliance. Patient self-reports exemplify the balance: thicker aligners are less comfortable and impact speech, and thinner ones are preferred for cosmetic preference (Mantovani et al. [11]). Aside from biomechanics, patient comfort, aesthetical considerations, and biological safety are very important factors that need to be addressed. Putrino et al. [13] recorded a successful case using differentiated-thickness aligners without attachment and noted the very high

level of patient tolerance. The biocompatibility outcomes are encouraging: Bleilöb et al. [14] demonstrated that directly printed aligners of varying thicknesses exhibited no cytotoxicity, validating their clinical use. Shirey et al. [15] reported that patients find thinner aligners more comfortable, and thus personalized options are in demand. This review considers the worldwide development of aligner therapy and the influence of thickness on performance, outcomes, and patient comfort. The aim of this narrative review is to synthesize current experimental, numerical, and clinical research on clear aligner thickness, assess its effect on biomechanics and patient outcomes, and present strengths, limitations, and research needs. This review examines the influence of varying clear aligner thicknesses on orthodontic treatment.

SEARCH STRATEGY

A systematic electronic search was performed in PubMed, Scopus, and Google Scholar for peer-reviewed articles with no year restrictions. The search strategy used free-text terms and Boolean operators together. Key words were: "clear aligner thickness", "thermoformed orthodontic aligners", "3D printed aligners", "finite element analysis aligners", and "orthodontic biomechanics thickness". The key words were used singularly and combined (AND/OR) to ensure maximum retrieval of relevant studies.

INCLUSION CRITERIA

Studies were included if they investigated clear aligner thickness as a primary or secondary variable, reported outcomes related to biomechanics, force transmission, clinical efficiency, or material performance, were original articles (in vitro, in vivo, clinical trials, or computational finite element analysis), were systematic reviews, meta-analyses, or high-quality narrative reviews addressing aligner thickness, were published in English during the study period.

EXCLUSION CRITERIA

Articles were excluded if they: were entirely based on unrelated topics (e.g., attachment shape, accelerated osteogenic surgery), were editorials, opinions, or conference abstracts with inadequate data, did not well report aligner thickness in methodology or results.

STUDY SELECTION AND DATA EXTRACTION

Two reviewers independently screened the titles and abstracts against eligibility. Full texts of included studies were obtained and assessed against the inclusion criteria. Disagreements were settled by consensus. With the final studies included, the following data were screened and collected: author and year, study design, material of the aligner, thickness studied, method of measurement or simulation, and main findings.

FINAL DATASET

After screening and ensuring the studies were eligible, 25 were reviewed. They comprised computational models based on finite elements, in vitro testing, clinical trials, and systematic reviews. Combined, they presented a strong argument regarding how varying sizes of clear aligners impact orthodontic treatment independently. One of the newer techniques that is transforming orthodontics is Clear Aligner Therapy (CAT). Many studies have dealt with the influence of aligner thickness on biomechanics, clinical outcomes, and patient comfort, with important contributions to the field. This section analyses the laboratory studies, finite element analyses, clinical trials, and systematic reviews to collate current evidence.

Biomechanical Foundations of Aligner Thickness

The biomechanics of orthodontics primarily concern the manner in which strong and in what direction the forces are directed to the teeth. The thickness of an appliance is a significant factor that influences the extent to which an appliance is stiff and how it responds to forces applied to it. Cengiz and

Goymen [1]., presented clinical evidence in which 0.8 mm aligners applied significantly higher forces than 0.5 mm devices, and the tooth movement was more effectively controlled. Elshazly et al., in their in-lab study, determined that with the thickness raised from 0.5 mm to 1.0 mm, the applied forces almost doubled [2]. Synchronously FEA studies supplement this massive body of evidence. Li et al. [8] argued that a thickness increase of 0.4 mm to 0.8 mm brought about an increase of 28% in the stresses existing in the periodontal ligament. Yang et al. [9] also established that 0.8 mm-thick devices had a retraction force of 20–25% more than comparable devices with a thickness of 0.6 mm. Edelmann et al. [7] report that 3D-printed parts with a thickness of 1.0 mm exerted 35% more force than those with a thickness of 0.5 mm. The findings indicate that the most significant factor that governs the pressures exerted by devices is thickness. Maintaining the force over time is equally crucial. As reported by Bucci et al. [4], the thickness reduced by up to 10% following 10 days of use of the device within the mouth. Ammann et al. [10] determined that the reduction in thickness was uneven, with a greater reduction at the sites where the teeth contacted. The axial stresses that lead to wear to thin are significantly reduced in force

transfer, contributing further to the argument for aligner replacement in stages.

Thermoformed vs. 3D-Printed Aligner Performance

Various thicknesses of aligners are due to significant variations in how materials were selected and how they were constructed. Lombardo et al. [5] reported thickness differences of a maximum of ± 0.15 mm among six thermoformed material manufacturers in 2020. Mantovani et al. [11] reported 10–12% Invisalign marker thickness differences. Edelmann et al. proved that 3D-printed aligners as 90% uniform while thermoformed were 65% [7]. Park et al. [6] reported it with less accurate thermoformed aligners. In [6], Park et al. concluded that thermoformed aligners decreased in accuracy as they became more translucent. Sayahpour et al. [19] concluded that 3D-printed the aligners'-maintained thickness more than thermoformed aligners do in the mouth. On the other hand, Bandić et al. [17] concluded that thermoformed aligners decreased in thickness over time. Liao et al. [12] discovered that PETG-based braces retained their thickness more effectively compared to polyurethane ones, with base material selection being a key consideration.

Table 1. Biomechanics and Material Properties of Clear Aligners

Author (Year)	Method	Variable Tested	Key Findings
Cengiz & Goymen (2025) [1]	Clinical	0.5 vs. 0.8 mm	Thicker aligners exerted stronger forces
Elshazly et al. (2024) [2]	In vitro	0.5 vs. 1.0 mm	Doubling thickness doubled applied forces
Bucci et al. (2019) [4]	Clinical	Wear (10 days)	Up to 10% thickness loss
Lombardo et al. (2020) [5]	Micro-CT	6 thermoformed brands	± 0.15 mm variation
Park et al. (2023) [6]	Micro-CT/optical	Thermoformed vs. 3D-printed	Thermoformed more translucent but less precise
Edelmann et al. (2020) [7]	Mechanical	3D-printed vs. thermoformed	3D-printed = 90% uniformity
Li et al. (2024) [8]	FEA	0.4 vs. 0.8 mm	PDL stress higher 28% with thicker aligners
Yang et al. (2025) [9]	FEA	0.6 vs. 0.8 mm	20–25% higher forces in thicker aligners
Ammann et al. (2022) [10]	Tomography	Thickness mapping	Heterogeneous thinning at contacts
Mantovani et al. (2021) [11]	Micro-CT	Invisalign aligners	10–12% thickness variability

Liao et al. (2024) [12]	In vitro	PETG vs. polyurethane	PETG preserved thickness better
Bandić et al. (2024) [17]	Clinical	Thermoformed vs. 3D-printed	Thermoformed lost thickness faster
Sayahpour et al. (2024) [19]	Clinical	In vivo ageing	3D-printed preserved thickness better

Patient-Centered Outcomes and Biocompatibility

Except for biomechanics, biological safety and patient comfort are essential requirements for approval of the aligners. Shirey et al. [15] contrasted thermoformed and 3D-printed aligners and found less comfortable thicker aligners as a result of rigidity. Putrino et al. [13] confirmed the observation in a case report with differentiated-thickness aligners, tolerated comfortably with varying thickness.

Biocompatibility testing was positive. Bleilöb et al. [14] demonstrated that there was no cytotoxicity present with 3D-printed

aligners of different thicknesses, and long-term safety for intraoral application was confirmed. Alhasyimi et al. [20] noted that thicker aligners resulted in better control of force but simultaneously resulted in greater gingival and periodontal stress in FEA simulations. Jindal et al. [16] and Ghoraba et al. [18] confirmed that geometric and mechanical changes in aligners significantly impact efficiency and comfort. Safi'ai et al. [21] also commented on colour stability and resistance to wear of resin-based aligners and indicated future material improvements will improve long-term compliance.

Table 2. Patient Outcomes and Biocompatibility of Aligner Thickness

Author (Year)	Study Type	Variable Tested	Key Findings
Putrino et al. [13]	Case report	Differentiated thickness	Well tolerated without attachments
Bleilöb et al. [14]	In vitro	Printed aligner thickness	No cytotoxicity detected
Shirey et al. [15]	Mechanical	Thermoformed vs. 3D-printed	Thicker aligners less comfortable
Jindal et al. [16]	In vitro	Mechanical properties	Thickness impacted stiffness and comfort
Ghoraba et al. [18]	In vitro	Model height vs. thickness	Model geometry altered force transfer
Alhasyimi et al. [20]	FEA	Thickness and attachments	Greater force control but increasing gingival stress
Safi'ai et al. [21]	In vitro	Resin-based aligners	Stable colour and mechanical integrity

Evidence from Systematic Reviews and Meta-Analyses

Whereas clinical and experimental work supports biomechanical activity of thickness substantially, systematic reviews reaffirm the evidence. Torkomian et al. [22] compiled the summation that 3D-printed aligners are superior in reproducibility and in biomechanical predictability over thermoformed ones. Cao et al. [23] reviewed 20 studies on finite element analysis (FEA) and reaffirmed thickness as a key variable in ascertaining the distribution of stresses but commented on the lack of randomized controlled trials (RCTs).

Most recently, Putrino et al. [13] summarized scoping studies based on FEA and found uniform correlations between thickness, expansion of the maxillary arch, and stress patterns. Yang et al. [9] also observed that stiffness and thickness of the aligners both determine efficacy of treatment and make the case for customization.

Synthesizing the Evidence

Overall, the literature verifies that orthodontic force, a modifiable, clinically significant factor, is in turn affected by orthodontic force duration, time span, and amplitude. Thick trays generate higher forces but are less convenient for the patients

[1,15]. On the other hand, 3D-printed aligners have their preferred thickness much better than thermoformed ones [7,19]. Material choice between PETG and poly-urethane and the time of wear determine how efficient that thickness is [4,12]. Clinical evidence is scant; most of them are data from either finite element analysis or in vitro experiments [23,24]. The key to these results is these must be supported by standardized protocols, customized prescription of the aligner, and a random control trial confirming these biomechanical simulations in clinical orthodontics.

LIMITATIONS AND WEAKNESS

There are quite a few interesting strong points that are to be considered in the present literature on clear aligner thickness. First, it handles a wide variety of methodological approaches, starting from in vitro mechanical testing to FEA simulation, clinical observational research, and systematic reviews. Third, the recent availability of 3D-printed aligners has moved the field away from traditional thermoforming, providing better biomechanical reproducibility and greater control over thickness profiles. However, there are certain limitations. The majority of the evidence is from in vitro or computational research, and as such do not necessarily reflect intraoral conditions [23,24]. In vivo research is quite scarce, and clinical evidence is primarily based on small case series or very short-term studies [1,13,17]. Patient-reported outcomes are lacking, although these are very important for acceptance of therapy [15]. Again, study designs, material types, and force measurement protocols differ between studies and impede inter-study comparability. Finally, systematic reviews have an overriding criticism—the paucity of randomized controlled trials (RCTs) of high quality [22–24]—which is the greatest evidence gap.

FUTURE DIRECTIONS

Some possible avenues for future research are indicated by the current synthesis:

Randomized Clinical Trials (RCTs): Well-powered and well-plotted RCTs would be required for directly comparing in the clinical setting aligners with different thicknesses. **Standardization of Measurement Methods:** Standardizing the protocols of measurement for thickness, its application of pressure, and patient comfort will result in a larger comparison among studies.

Patient-Centered Outcomes: Future research should include validated patient-reported outcome measure (PROM) assessing comfort, aesthetics, and compliance [15].

Individualized Thickness Protocols: Digital workflows may allow for patient-specific staging (e.g., moving from 0.5 mm to 0.8 mm aligners), thereby improving comfort and force efficiency [1, 13].

Materialistic Innovations: Studies on newly synthesized polymers and shape-memory resins could enhance long-term thickness stability and recovery of mechanical property [21].

Longitudinal Data: Long-term prospective investigations with long-term follow-up are also needed to determine the impact of thickness-related biomechanics on relapse, periodontal health, and post-treatment stability.

Adjunctive Therapy Implementation: Studies exploring thickness changes as well as acceleration techniques like periodontally accelerated osteogenic orthodontics (i.e., PAOO [20,25]) are able to achieve a good balance between pace and orthodontic treatment delivery.

CONCLUSION

An aligner thickness is an important biomechanical variable in orthodontics and correlates directly with force transmission, treatment predication, patient comfort, and safety. Literature across the board indicates thick aligners deliver higher forces at the

expense, however, of patient comfort. 3D-printed arch-wires possess better long-term stability and thickness homogeneity compared to thermoformed arch-wires. Material formulations also influence functionality and therefore, wear resistance is better with PETG and resin-based polymers. Although work has been done with strong research on computational and in vitro settings, clinical application is restricted due to availability of large-scale clinical trials. There has been a proposal based on systematic reviews that there is a need for standardized patient-oriented research and protocols. The future direction of innovation is toward customized thickness strategies for aligners, with biomechanics, material science, and digital planning complemented by biological efficacy and optimization of patient experience. In summary, aligner thickness is an evidence-based variable design parameter that can be used by practitioners for the balance of safety, comfort, and efficiency. There exists a need to close the gap between clinical practice and computational simulation in order to maximize clear orthodontic aligner therapy.

Declaration by Authors

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