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In Vitro Mechanical Performance of Orthodontic Auxiliary Photopolymerisable Resins under Simulated Oral Conditions

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ABSTRACT

The growing use of clear aligners in orthodontics has stimulated the advancement of biomechanical materials designed to enhance treatment effectiveness. The clinical success of these systems depends largely on their mechanical characteristics. This study aimed to assess the Young's modulus of Clear-Blokker® (Scheu Dental), a photopolymerisable resin employed for bonding clear aligners, and to analyze its mechanical response under varying curing durations (5 s and 10 s) and storage environments (dry condition versus immersion in artificial saliva at 37 °C). Forty-eight cylindrical samples were fabricated and tested under quasistatic compression after a 14-day period. Statistical evaluation was conducted using multifactorial ANOVA with a 5% significance threshold. Specimens aged in artificial saliva demonstrated a notably lower Young's modulus than those maintained in dry storage ($p = 0.0213$), whereas curing duration had no significant effect. Clear-Blokker® exhibits mechanical behavior comparable to that of clear aligner materials, indicating its potential suitability as a biomechanical support in orthodontic applications. Nonetheless, additional clinical investigations are necessary to validate its durability and long-term performance under intraoral conditions.

Keywords: Restorative materials, Aligners, Photopolymerisable resin, Orthodontics

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Introduction

The popularity of clear aligner therapy has risen substantially in recent years as patients increasingly seek orthodontic treatments that are both comfortable and aesthetically discreet [1-3]. These systems comprise a sequence of transparent polymer trays that snugly fit over the teeth, worn continuously except during eating or oral hygiene activities, and typically replaced every one to two weeks to facilitate progressive tooth movement. The growing clinical use of aligners has driven notable advancements in their design and associated technologies, enhancing treatment outcomes and expanding their clinical indications [4, 5]. However, aligner therapy often extends beyond the use of the trays themselves; complex cases may require auxiliary features such as resin attachments, divots, precision cuts, bite ramps, power ridges, or anchorage elements to optimize biomechanics [6, 7]. To further refine tooth movement and minimize discrepancies between predicted and actual outcomes, a supplementary elastic resin layer can be applied to specific teeth, as illustrated in **Figure 1**. For instance, a small resin elevation placed on the lingual surface can help promote buccal displacement of a tooth.

This additional layer—referred to as a "Hill"—is designed to modify the mechanical response of the aligner by providing a gentle, continuous force, thereby improving the efficiency of the biomechanical system. Since the physical properties of the aligner material play a pivotal role in determining the magnitude and consistency of applied forces, they have been the focus of extensive research [8]. Modern aligner systems worldwide predominantly rely on thermoformed transparent polymers, whose mechanical reliability directly influences treatment efficacy. External factors such as water absorption, temperature fluctuations, and repetitive loading cycles can progressively alter these mechanical characteristics, potentially affecting performance over time.

The present study investigates the mechanical behaviour of Clear-Blokker® (Scheu Dental), a photopolymerisable resin used as a biomechanical adjunct to enhance clear aligner function. Specifically, it examines its Young's modulus—a key indicator of stiffness and elastic response—under conditions simulating the oral environment. Evaluating this property under varying factors, including curing duration, artificial saliva immersion, and environmental changes, allows assessment of the material's stability, polymerisation behaviour, and resistance to degradation. The study tests the null hypothesis that no statistically significant difference exists between the Young's moduli of specimens stored in dry conditions and those immersed in artificial saliva.

Figure 1. Clinical picture of the "Hill" (red circle)

Materials and Methods

This experimental in vitro investigation was conducted jointly at the UOC Dental Clinic and the Faculty of Materials Engineering, University of Padua, Italy, following the ISO 604 standard [9]. The material under examination was Clear-Blokker® (SCHEU-DENTAL GmbH, Iserlohn, Germany), a light-curing dental resin (360–420 nm) composed of 40–70 percent urethane dimethacrylate (UDMA), 20–50 percent tricyclodecane dimethanol diacrylate (TCDDMDA), and less than 10% 1,4-butanediol dimethacrylate (1,4-BDDMA). This resin was selected due to its elasticity, transparency, mouldability, and ease of handling, as well as its photopolymerisable nature. Because the manufacturer does not provide detailed mechanical specifications and no prior studies have examined its mechanical performance under oral-like conditions, this work represents the first assessment of its Young's modulus.

Reusable cylindrical moulds, each measuring 6.3 mm in both internal diameter and height, were fabricated using a 3D printer. Matching stoppers of the same material were designed to close one end of the mould during resin injection. To prevent adhesion after curing, the interior of each mould and stopper was uniformly coated with Vaseline, which does not interfere with the light-curing process. The resin was injected into the moulds using a syringe equipped with a 0.4 mm diameter cannula, ensuring the exclusion of air bubbles. Excess resin was carefully removed to achieve a level surface. Polymerisation was performed for either 5 seconds or 10 seconds using a VALO™ Corded LED curing light (intensity: 1000 mW/cm^2; wavelength: 385–515 nm).

Following curing, specimens were extracted by detaching the stopper and gently pushing them out with a plastic cylinder. Any residual resin was cleaned from the mould before reuse. The procedure was repeated 48 times by a single operator, producing 24 specimens for each curing duration (5 s and 10 s). Within each group, 12 specimens were stored at room temperature in numbered envelopes (NB), while the remaining 12 were placed in labelled test tubes and submerged in a Thermo Scientific™ Precision™ GP 02 water bath containing artificial saliva at 37 °C (B), simulating oral conditions for 14 days. The composition of the artificial saliva (pH 6.5) is presented in

Table 1 [10]. A 14-day period was deemed sufficient for analysis, as plastic materials typically absorb most fluids within the initial 72–168 hours [11-13].

Table 1. Chemical composition of the artificial saliva used to recreate the biochemical conditions of human saliva [9]

Component	Content (g/L)
NaCl	0.6
KCl	0.72
$CaCl_2 \cdot 2H_2O$	0.22
KH_2PO_4	0.68
$Na_2HPO_4 \cdot 12H_2O$	0.856
KSCN	0.06
$NaHCO_3$	1.5
$C_6H_8O_7$	0.03

After the 14-day conditioning period, the specimens were measured for both height and diameter using a precision digital calliper (±0.01 mm accuracy). Each specimen was then tested under quasistatic compression at ambient temperature utilizing an MTS Acumen 3 electrodynamic testing apparatus (MTS Systems Corporation, Eden Prairie, MN, USA) fitted with a 3 kN load cell, as illustrated in **Figure 2**.

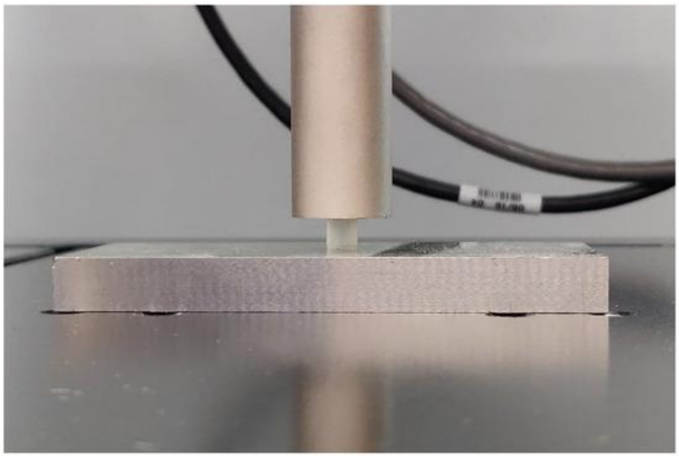

Figure 2. Configuration of the experimental apparatus used to perform the compression test on a Clear-Blokker® cylindrical specimen

For all tests, a data acquisition rate of 5 Hz and a deformation speed of 1 mm/min were applied. The yield strength was determined using the 0.2% offset method with a straight-line approach. Testing was concluded near the machine's mechanical limit, around 2400 N (83 MPa), without affecting the calculation of Young's modulus or the material's yield point. The system recorded the applied force (N), displacement (mm), and elapsed time (s) for each specimen. Using Microsoft Excel (Office 2021), the recorded data along with the measured sample dimensions were used to compute stress (MPa) and compressive strain (mm/mm). These values were then employed to plot the stress–strain curves for each test **(Figures 3–6)**.

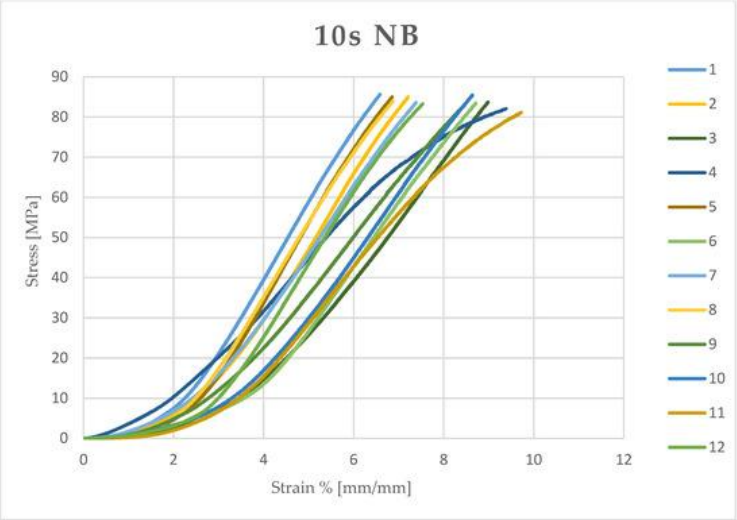

Figure 3. Stress–strain curves for the 12 specimens cured for 10 seconds (10 s) and stored under dry conditions (NB)

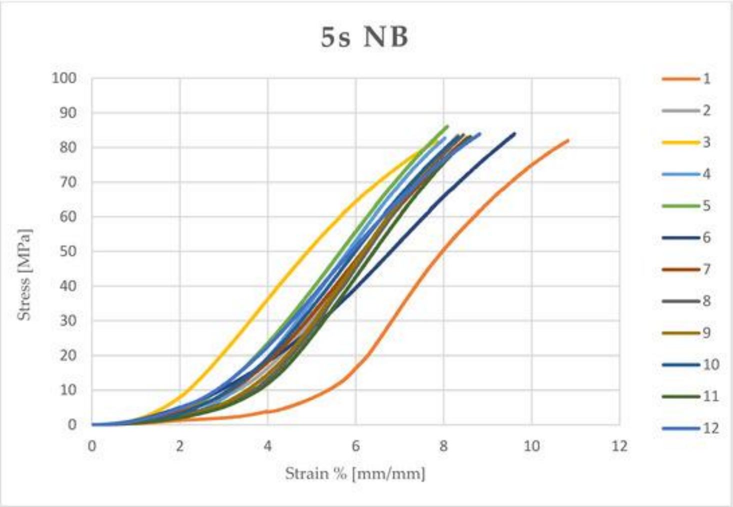

Figure 4. Stress–strain curves for the 12 specimens cured for 5 seconds (5 s) and maintained in a dry environment (NB)

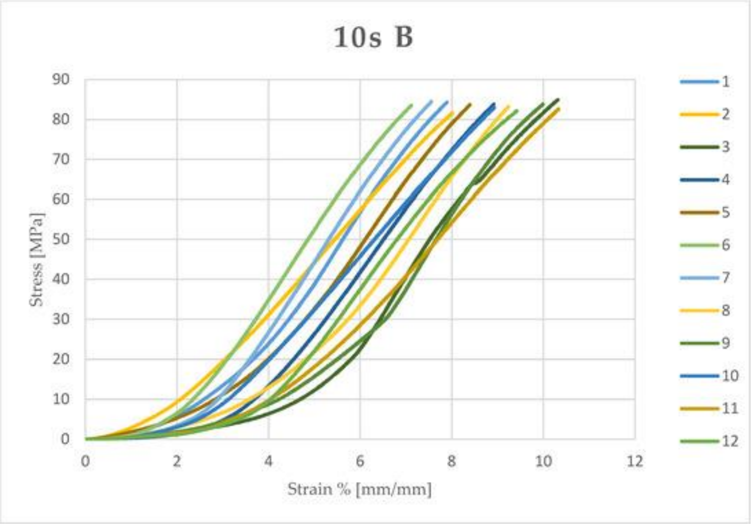

Figure 5. Stress–strain curves for the 12 specimens cured for 10 seconds (10 s) and immersed in artificial saliva (B)

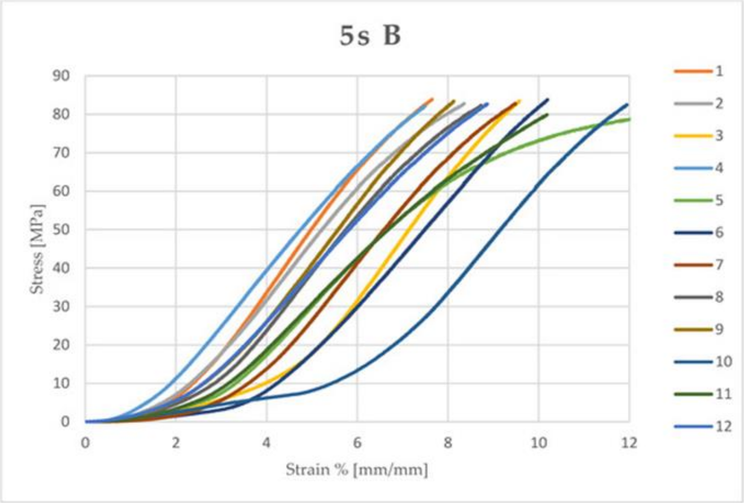

Figure 6. Stress–strain curves of the 12 specimens cured for 5 seconds (5 s) and immersed in artificial saliva (B)

The elastic portion of each stress–strain curve was manually identified, and a linear fit was applied to determine the Young's modulus (MPa). Additionally, the yield load (MPa) and corresponding yield strain (mm/mm) were calculated.

The study comprised 48 cylindrical specimens, divided into four groups of 12 based on curing duration (5 s or 10 s) and storage condition (NB or B): 5 s NB, 5 s B, 10 s NB, and 10 s B.

Statistical analysis

Sample size was established with reference to prior studies on dental material mechanics [14, 15] to ensure sufficient statistical reliability while minimizing variability. All analyses were performed using Statgraphics Centurion 19 (v. 19.2.02). Data normality was assessed via the Shapiro–Wilk test, and homogeneity of variances was checked using Levene's test. The influence of curing time and saliva immersion on Young's modulus was examined with a two-way ANOVA, followed by Tukey's post hoc test for pairwise comparisons. A significance threshold of $p < 0.05$ was applied, and results are reported as mean ± SD with 95% confidence intervals.

Results and Discussion

Young's modulus values obtained from the compression tests were analyzed using Statgraphics Centurion 19 (v. 19.2.02, ©2023 Statgraphics Technologies Inc., The Plains, VA, USA). Data for yield load and strain at yield were not presented, since the forces required to reach the yield point are higher than those typically exerted by clear aligners in clinical orthodontics. The distribution of the results is shown in a box plot **(Figure 7)**.

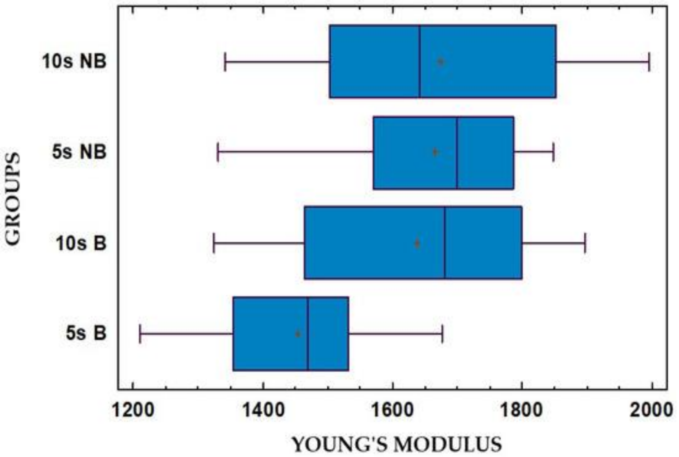

Figure 7. Box plot illustrating the Young's modulus (MPa) of all specimens, divided into four groups

according to curing TIME (10 s = 10 seconds, 5 s = 5 seconds) and storage BATH (NB = no bath, B = bath), with the "+" sign indicating the mean value

For each group, the mean, standard deviation, and value range were calculated **(Table 2)**. Notably, the 5 s B group showed a lower average Young's modulus compared to the other three groups. While all groups exhibited some variability—likely due to factors in sample preparation such as uneven photopolymerisation or microscopic air bubbles—no outliers were detected based on the Dixon test at a 1% significance level. After confirming normality with the Shapiro–Wilk test and verifying variance homogeneity across groups, a multifactorial ANOVA was performed at a 5% significance level to compare the group variances.

Table 2. Means, standard deviations, minimum values, maximum values, and value ranges of the Young's moduli (Mpa) of the four groups of samples

Group	Mean (MPa)	Standard Deviation (MPa)	Minimum (MPa)	Maximum (MPa)	Range (MPa)
10 s NB	1673.6	210.1	1340.6	1996.0	655.4
5 s NB	1665.9	154.6	1331.4	1847.1	515.7
10 s B	1638.1	203.2	1324.3	1897.1	572.8
5 s B	1454.5	137.7	1210.4	1676.7	466.3

The factors were treated as independent variables, and a multifactorial ANOVA was conducted using the experimentally measured Young's moduli as the dependent variable. The results indicated a statistically significant influence of the bath factor ($p = 0.0213$ *), whereas the curing time factor did not show a significant effect ($p = 0.0710$). No significant interaction between the two factors was observed ($p = 0.0960$). **Table 3** presents the means and confidence intervals of Young's modulus for the samples grouped by the factors under investigation. Since determining these average values was a key objective of the study, they are of particular importance.

Table 3. The mean Young's modulus for each factor and the standard error of each mean, which is a measure of its sampling variability. The two rightmost columns show the 95.0% confidence intervals of each of the means

Factors	Count	Mean (MPa)	Standard Error (MPa)	Lower Limit (MPa)	Upper Limit (MPa)
Bath					
NO	24	1669.7	36.6	1596.1	1743.4
YES	24	1546.3	36.6	1472.6	1620.0
Time					
5 s	24	1560.2	36.6	1486.5	1633.9
10 s	24	1655.9	36.6	1582.2	1729.5
bath × time					
NO—5 s	12	1665.9	51.7	1561.7	1770.1
NO—10 s	12	1673.6	51.7	1569.4	1777.8
YES—5 s	12	1454.5	51.7	1350.3	1558.7
YES—10 s	12	1638.1	51.7	1533.9	1742.3
OVERALL MEAN	48	1608.0			

This study investigated how immersion in artificial saliva, light-curing duration, and their combined effect influence the Young's modulus of Clear-Blokker®. The results indicate that exposure to artificial saliva significantly reduces the Young's modulus, reflecting the material's susceptibility to water absorption and solubility, which is typical of dimethacrylate-based resins. These changes are clinically meaningful, as they simulate the conditions the material encounters in the oral cavity, potentially affecting its long-term performance. Young's modulus quantifies the relationship between an applied axial force and the resulting deformation, with higher values indicating greater rigidity. Understanding this property is crucial for predicting the elasticity of aligners and auxiliary devices, ensuring accurate force delivery during treatment, and providing reliable insight into material behavior under simulated oral conditions.

Compression tests were used to evaluate the response of Clear-Blokker® to quasistatic compressive stress. Quasistatic deformation occurs slowly enough for the system to remain in equilibrium throughout the test, effectively passing through numerous intermediate equilibrium states between the initial and final positions.

Because orthodontic tooth movements typically occur at very slow rates, a quasistatic model is considered an appropriate approach for estimating the Young's modulus.

For the bath factor, samples were immersed in artificial saliva (pH 6.5) at 37 °C, closely replicating oral biochemical conditions and allowing evaluation of structural changes caused by the aqueous environment, temperature, and pH. Dimethacrylate-based photopolymerisable resins absorb water and release unreacted monomers during immersion. In glassy polymers, water uptake can be described by a dual-mode model: absorption occurs both at polymer matrix sites following Henry's law and within microvoids regulated by the Langmuir isotherm [16, 17]. Polydimethacrylates are cross-linked glassy polymers; cross-linking generally decreases solvent permeability, although in some cases higher cross-link density has been associated with increased water absorption [18]. Previous studies have measured the water absorption and solubility of UDMA, the primary component of Clear-Blokker®, reporting values of 29.46 ± 0.16 µg/mm³ and 6.62 ± 0.12 µg/mm³, respectively, while a resin containing UDMA and TCDDMDA showed absorption of 1.87 ± 0.01% and solubility of 0.22 ± 0.03% [16]. The type of methacrylate influences the resin's physical and chemical properties, and water absorption has been shown to negatively impact wear resistance, tensile and flexural strength, and the elastic modulus [19–22].

While a slightly acidic medium realistically simulates clinical conditions, its effects on the resin manifest slowly [23]. Temperature, however, has a significant impact on water absorption and solubility of dental resins [24].

The findings of this study demonstrate that the investigated factors induce measurable changes in mechanical properties. Samples exposed to the simulated oral environment had a statistically lower mean Young's modulus (1546.3 MPa) compared to those stored dry (1669.7 MPa), closely approaching the modulus of PET-G, the most common clear aligner material, under similar conditions (1870 MPa) [25]. Consequently, the null hypothesis was rejected at a 95% confidence level (p= 0.0213*).

Regarding the effect of light-curing time, the ANOVA analysis showed no significant correlation between the two curing durations and the Young's modulus. Changing the curing time from 5 s to 10 s did not produce statistically meaningful differences in the elastic modulus of the samples. While varying light exposure alters the energy delivered to the resin, influencing the degree of polymerisation and Knoop microhardness [26, 27], and given that Young's modulus correlates with Knoop hardness [28], the lack of significant differences may result from the small variation between the two curing times. For many materials, depending on the photoinitiator and irradiation intensity, most polymerisation occurs within the first 5 seconds, with only minor additional polymerisation afterward [29–31]. Experimental errors may also have partially masked any minor differences. Additionally, ANOVA indicated no significant interaction between curing time and bath condition at the 5% significance level.

The Young's modulus values obtained align with expectations, with the most clinically relevant data being those from specimens immersed in a simulated oral environment. The reduction in mechanical properties observed for Clear-Blokker® after saliva immersion is similar to changes reported for common clear aligner materials [32], suggesting the resin is suitable for clinical orthodontic applications. Therefore, this transparent material could be applied to the surfaces of teeth targeted for movement with a clear aligner, providing an elastic interface (1546.7 MPa) that enhances the effectiveness of the orthodontic forces compared to the much stiffer tooth surface.

Conclusion

The Young's modulus of Clear-Blokker®, evaluated in terms of light-curing duration and immersion in artificial saliva, was slightly lower than that of PET-G. Immersion in a simulated oral environment caused a significant reduction in its mechanical properties, as demonstrated by quasistatic compression testing. The mean modulus of samples stored in artificial saliva was lower than that of dry-stored specimens, closely resembling PET-G and considerably lower than the modulus of natural tooth structure. No significant effect of curing time (5 s vs. 10 s) was observed on Young's modulus. Due to its elastic characteristics, Clear-Blokker® shows potential as a biomechanical aid, improving the force transmission between aligner and tooth surface and offering a practical solution to enhance treatment outcomes in complex orthodontic cases.

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