MATERIALE PLASTICE
https://revmaterialeplastice.ro
https://doi.org/10.37358/Mat.Plast.1964

Mechanical Property Assessment of Polyacid-Modified Composite Resins: An *In Vitro* Approach

LEILA ABDELGADER, CHAFAA HAMROUNI*
Department of Computer sciences Alkhurmah, Khurma University College, Taif University, Khurma, 2935, Saudi Arabia

Abstract: *This in vitro study performed a comparative mechanical evaluation of three classes of direct restorative materials: resin composites, polyacid-modified composite resins (components), and Glass Ionomer Cements (GICs). The objective was to clarify the mechanical position of components relative to composites and glass ionomer cements (GICs). Specimens from two materials per class including the components Dyract AP and Dyract Extra were fabricated using standardized molds. Compressive, diametral tensile, and three-point flexural strength tests were conducted according to ADA and ISO specifications, followed by statistical analysis using ANOVA and Tukey's HSD test. Results established a consistent mechanical hierarchy: composite resins exhibited the highest strength values in all tests, followed by components, with GICs demonstrating the lowest. Within the component group, the third-generation Dyract Extra showed superior properties compared to Dyract AP. The findings confirm that components occupy an intermediate mechanical position, offering significantly greater strength than GICs but not matching composites. Thus, components suit low-to-moderate stress applications where fluoride release and handling ease are beneficial, while composites remain indicated for high-stress areas. This study provides clear evidence for evidence-based clinical material selection.*

Keywords: *Adhesive interface, compomer restorative systems, dental biomaterials, fluoride-releasing resins, hybrid resin technology, pediatric restorative dentistry, polyacid-modified composite materials*

1. Introduction

The high prevalence of dental caries, which remains the leading cause of coronal tooth damage, has stimulated continuous research efforts to improve and diversify restorative materials and techniques for morpho-functional rehabilitation of teeth [1]. With the ongoing expansion of restorative biomaterials and the parallel development of amelodentinal adhesive systems, direct intraoral restoration has become increasingly preferred over indirect methods that require laboratory fabrication steps. This shift is primarily driven by the demand for efficient, minimally invasive, and aesthetically pleasing solutions in restorative dentistry. Dental composites, widely recognized as synthetic resin-based restorative materials, have undergone significant technological advancements over the past decades, including improvements in filler technology, polymerization efficiency, and bond strength [2,3]. Their most common application is in light curable restorations, where their ability to mimic the natural appearance of teeth represents a major advantage compared with traditional materials such as dental amalgam. The performance of modern composites has been enhanced through multiple innovations: increasing nanofiller concentrations to improve wear resistance without compromising translucency, employing more stable polymerization systems to preserve color stability, incorporating radiopacifying agents to facilitate diagnostic imaging, and integrating advanced adhesive systems to improve bonding efficacy. Together with glass ionomers, dental composites currently dominate the spectrum of aesthetic restorative materials for the treatment of carious lesions. Glass ionomer cements (GICs) are known for their acid-base reaction setting mechanism, which occurs within 2–3 min and produces a material of acceptable mechanical strength and esthetics [4], though their mechanical limitations are well-documented [5,6]. Their bioactive properties, including fluoride release, make GICs valuable for caries management and

email: cmhamrouni@tu.edu.sa

long-term prevention. Over time, they form a durable ion-exchange layer at the tooth–material interface, ensuring strong and chemically mediated adhesion. However, despite these advantages, limitations in wear resistance and esthetic stability under functional stress have restricted their widespread replacement of composite resins in posterior restorations. To bridge the gap between composites and glass ionomers, compomers also known as Polyacid-Modified Composite resins (PMCs) were introduced in the early 1990s. Their development was motivated by the desire to combine the mechanical strength and esthetic appeal of composites with the bioactivity and fluoride release of glass ionomers, thereby creating a versatile restorative option suitable for a broad range of clinical applications. However, the scientific and clinical community has debated their classification. Some literature argues that compomers do not represent a truly distinct class of restorative materials but are rather a modified subset of resin composers, marketed under a distinct nomenclature [7], while others classify them as a separate category with unique properties [8,9]. From a compositional perspective, compomers resemble resin composites but incorporate selected components of glass ionomer cement. Upon maturation, they exhibit a limited acid–base reaction facilitated by the uptake of moisture, a process that also enhances their fluoride-releasing capacity [10]. The presence of hydrophilic monomers in their formulation allows post-curing water sorption, which is responsible for initiating this secondary reaction. Clinically, this property provides a preventive benefit by releasing fluoride ions at concentrations sufficient to contribute to caries resistance in adjacent dental tissues. Given their intermediate position between two well-established material classes, compomers represent an attractive alternative in restorative dentistry. Their ease of handling, esthetic outcomes, and fluoride release potential make them particularly relevant in pediatric dentistry, where minimally invasive and durable restorations are essential.

The aim of the present study is to perform a comparative evaluation of the physicochemical and mechanical properties of three major classes of direct restorative materials composites, compomers, and glass ionomers. By conducting a series of laboratory tests, this research seeks to determine the material-specific qualities that dictate clinical performance and durability in the oral environment. The findings will contribute to clarifying the position of compomers within the hierarchy of restorative biomaterials and to assessing their long-term suitability as an alternative to established restorative systems.

2. Materials and methods

2.1. Materials

The present investigation focused on the comparative evaluation of six restorative dental materials, selected from three distinct classes: components, resin composites, and glass ionomer cements (GICs). Within the component category, two products manufactured by Dentsply were chosen to represent successive generations of development: Dyract AP, a second-generation light-curable component, and Dyract Extra, a third-generation material designed to enhance both clinical performance and handling properties. From the composite class, two light-curable resins were investigated. The first, (Kerr Corporation), is a commercially available micro hybrid composite. The second, Radopacril, is an experimental composite material developed by the Raluca Ripan Institute of Chemistry in Cluj-Napoca, Romania. For the glass ionomer class, two widely recognized self-curing materials were selected: Ketac Molar (3M ESPE) and Kavitan Plus (Spofa Dental).

2.2. Specimen preparation and storage

Specimen fabrication was carried out using precision-engineered Teflon molds. For compressive and diametral tensile tests, a cylindrical cavity (0.3 cm diameter, 0.6 cm height for compression; 0.6 cm diameter, 0.4 cm thickness for tension) was used. For flexural strength tests, a parallel-piped cavity (25 mm length, 2 mm thickness, 2 mm depth) was used. The molds were secured with a metal ring, and restorative materials were condensed into the cavity. For light-curable materials, polymerization was achieved using a calibrated dental curing lamp for 180 s through both glass plates placed at the ends of the mold, with an additional 60-s exposure along the midsection for flexural bars. Self-curing glass

ionomers were held under compression until the setting reaction was complete. A total of five replicates per material were prepared for each of the three mechanical tests. After demolding and deburring, all specimens were conditioned by immersion in distilled water at 37 ± 1°C for 24 h, followed by 50 h at 23°C.

2.3. Mechanical testing protocols

2.3.1. Compressive strength test

Compressive strength was tested in accordance with ADA Specification No. 27 using a universal mechanical testing system (Instron). Tests were performed at a crosshead speed of 0.5 mm/min. The compressive strength was calculated based on the maximum load at failure and the original cross-sectional area of the specimen.

2.3.2. Tensile strength test

Tensile strength was evaluated indirectly via the diametral compression test. Specimens were compressed vertically at a crosshead speed of 1 mm/min. The tensile strength (Rt) was calculated using the formula: $Rt = 2F/\pi DT$, where F is the fracture load (N), D is the specimen diameter (mm), and T is the thickness (mm).

2.3.3. Flexural strength test

Flexural strength was determined via a three-point bending test according to ISO 4049/2000. Specimens were supported on a 20 mm span and loaded centrally at a crosshead speed of 1 mm/min. The flexural strength (σ) was calculated using the formula: $\sigma = 3Fl/2bh^2$, where F is the fracture load (N), l is the span length (mm), b is the width (mm), and h is the height (mm).

2.4. Statistical analysis

All mechanical property data (compressive strength, tensile strength, and flexural strength) were analyzed using statistical software. For each property, a one-way analysis of variance (ANOVA) was performed to detect significant differences among the mean values of the different material groups. Upon identifying a significant effect from the ANOVA, post-hoc comparisons were conducted using Tukey's Honest Significant Difference (HSD) test. A p-value of less than 0.05 was considered statistically significant for all tests. The results are presented as mean ± standard deviation. All data are presented as the means of five independent replicates (n = 5) for each material in each of the three mechanical tests. Separate specimens were fabricated and used for each test protocol.

Figure 1 schematically illustrates the application of compressive force and the resulting deformation of a cylindrical specimen. The specimen preparation process, utilizing custom Teflon molds (see Figure 1, a Schematic representation from this study), was standardized for all materials. To assess the mechanical behavior of the selected materials, three key properties were investigated: compressive strength (Figure 1), tested in accordance with ADA Specification No. 27; tensile strength (Figure 2a), evaluated under the same ADA standard; and flexural strength (Figure 2b), determined according to ISO 4049/2000. By applying standardized testing protocols, the study ensures the comparability and reproducibility of results, allowing for a rigorous assessment of how compomers position themselves mechanically between composites and glass ionomers.

Figure 2 depicts the loading configurations for the (a) tensile and (b) three-point bending tests. The specimen preparation process, utilizing custom Teflon molds (see Figure 2, a Schematic representation from this study), was standardized for all materials. Specimens were fabricated by means of a custom-designed Teflon mold consisting of two detachable halves, each shaped into a disk of 0.8 cm thickness.

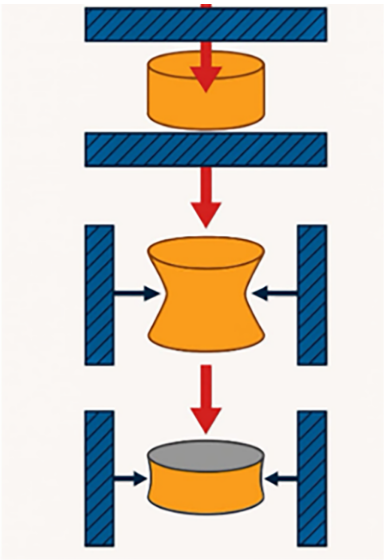

Figure 1. Schematic of compressive test setup and deformation stages

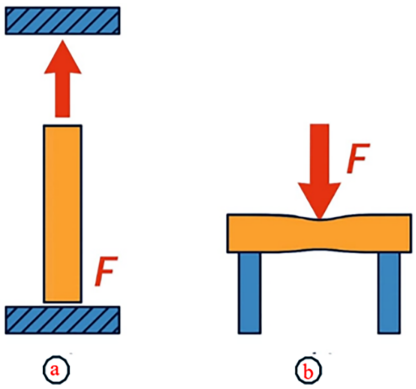

Figure 2. Schematic diagrams of the (**a**) diametral tensile and (**b**) three-point bending test configurations

The force 'F' is placed at the arrowhead in both schematics for clarity. At the center of the mold, a cylindrical cavity with a diameter of 0.3 cm and a height of 0.6 cm was prepared to define the specimen geometry. The two halves of the mold were tightly secured with a surrounding metal ring, ensuring precise alignment and containment of the restorative material during filling and curing. To seal the mold and provide smooth specimen surfaces, 1 mm glass plates were placed at both ends of the cavity, and a small vise was employed to apply uniform compression. The restorative materials under investigation composites, compomers, and glass ionomers were introduced into the cylindrical cavity. For the light-curable materials, polymerization was initiated and reinforced by applying visible light for 180 s through both glass surfaces, using a calibrated dental curing lamp to achieve uniform polymerization depth [11]. For the glass ionomers, the glass plates remained under compression until the setting reaction was complete, allowing the acid–base reaction to fully stabilize the structure. This procedure yielded cylindrical specimens with precise dimensions of 0.3 cm in diameter and 0.6 cm in height.

The light intensity of the curing lamp was verified to be 800 mW/cm² using a handheld radiometer (provide model and manufacturer, e.g., Model X100, Curing Monitor Inc.) prior to specimen fabrication

to ensure consistent polymerization energy delivery. To ensure consistency, five replicates of each material were prepared. A total of five replicates per material were prepared specifically for the compressive strength test. After demolding achieved by detaching the metal ring and carefully separating the glass plates the specimens were deburred to eliminate excess material and achieve smooth, standardized edges (Figure 3). The specimen preparation process, utilizing custom Teflon molds (see Figure 3, a Schematic representation from this study), was standardized for all materials:

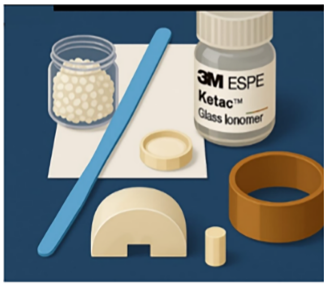

Figure 3. Materials, tools, and specimens used in mechanical testing

Figure 3 illustrates the key materials, molds, and prepared specimens used in the standardized specimen fabrication process. For light-curable specimens, an additional 60-s light exposure was applied along the midsection to ensure complete polymerization throughout the bulk of the material [12]. Once finalized, all specimens were subjected to a storage protocol designed to simulate intraoral conditions: immersion in distilled water at 37 ± 1°C for 24 h, followed by transfer into a second distilled water bath maintained at 23°C for 50 h. This aging process allowed water uptake and equilibrium stabilization, which are critical for evaluating the true in-service mechanical performance of restorative materials. Dimensional verification of each specimen was performed with a high-precision micrometer prior to testing, ensuring that deviations from nominal geometry were within acceptable tolerances. Compressive strength testing was then carried out using a universal mechanical testing system (Instron, VEB Thüringer Industriewerk Rauenstein). The machine was equipped with an electronic data acquisition system for continuous monitoring of applied force and specimen deformation, as well as a mechanical system for precise control of clamp displacement. Tests were performed at room temperature (23°C) within a force measurement range of 0–400 kgf. The crosshead speed was maintained at 0.5 mm/min, providing controlled and reproducible loading conditions. During testing, the load at failure (F) was recorded at the moment of specimen crushing and the compressive strength was calculated relative to the specimen cross-sectional area, with the average of at least five determinations reported for each material. To preserve statistical integrity, any specimen deviating by more than 15% from the mean was excluded. If more than two specimens in a series exceeded this threshold, the entire batch was discarded, and the series was repeated. This rigorous quality control ensured that the final reported compressive strength values accurately reflected the intrinsic material properties and not experimental variability.

The determination of tensile strength for the studied restorative materials was conducted using an indirect mechanical evaluation, known as the diametral compression test. This method was selected because it provides a reliable way to assess tensile performance in brittle or small-scale dental materials, which are difficult to test under conventional uniaxial tension due to their geometry and fracture-prone nature. Specimen fabrication was carried out with the aid of a precision engineered Teflon mold, consisting of two detachable halves encircled by a robust metal ring that ensured tight alignment during specimen preparation. The mold was designed with a cylindrical cavity measuring 0.6 cm in diameter and 0.4 cm in thickness, thereby standardizing the geometry of the test specimens. A central shaft within the mold further sealed one end during assembly, while glass plates of 1 mm thickness were employed to compress the restorative material and produce smooth specimen surfaces.

The entire process was supported by a thermostated water bath to simulate intraoral conditions and a calibrated tensile strength testing device. For the light-curable materials (Kerr Corporation) (microhybrid composite, Kerr), Radopacril (experimental composite, Raluca Ripan Institute), and the compomers Dyract AP and Dyract Extra (Dentsply) the fabrication process began with careful insertion of the material into the mold cavity until excess material refluxed, ensuring complete filling (Figure 4). The specimen preparation process, utilizing custom Teflon molds (see Figure 4, a Schematic representation from this study), was standardized for all materials. To ensure consistency across test groups, five replicates per light-curable material were prepared specifically for the diametral tensile test.

Figure 4. Specimen preparation workflow showing tools, molds, and test pieces

The second glass plate was then applied to close the mold, and the specimens were irradiated with visible light from a curing lamp for 180 s on both ends. After the setting reaction was completed, the mold was disassembled, the specimens were extracted, and excess material was removed by deburring. To ensure consistency across test groups, five replicates were prepared from each light-curable material. As in the compressive strength protocol, the samples were conditioned in a thermostatic bath for 24 h at 37 ± 1°C to achieve equilibrium before testing. For the self-curing glass ionomers, Kavitan Plus (Spofa) and Ketac Molar (3M ESPE), preparation began by mixing powder and liquid according to manufacturer specifications. The resulting paste was condensed into the cylindrical cavity of the Teflon mold (previously sealed at one end) using a plastic spatula, ensuring the elimination of voids and proper adaptation (Figure 4). Once filled, a glass plate was applied to the opposite end, and the entire assembly was held firmly until the acid–base setting reaction of the glass ionomers was completed. Five specimens per glass ionomer were prepared for tensile testing.

Five standardized specimens were prepared for each glass ionomer following this procedure. Mechanical testing involved placing each specimen between the plates of the tensile testing device and applying compressive loading along the vertical axis of the cylinder. Under these conditions, the applied force F generates internal tensile stresses along the vertical diameter of the disc-shaped specimen. Failure thus occurs due to indirect tensile stress rather than compressive stress. Testing was performed at a crosshead speed of 1 mm/min, consistent with standard mechanical testing protocols for brittle restorative materials. The tensile strength by diametral compression, R_t (MPa), was calculated using the formula:

$$R_t = \frac{2 \cdot F}{\pi \cdot D \cdot T} \tag{1}$$

where F represents the maximum applied load at fracture (in Newtons), D is the specimen diameter (in millimeters), and T is the specimen thickness (in millimeters). The final tensile strength values for each material were determined by averaging at least five replicates [13]. Outliers deviating significantly from the group mean were excluded to preserve statistical validity.

This methodology provided an accurate and reproducible measure of the tensile performance of the restorative systems studied, enabling direct comparison of composites, compomers, and glass ionomers under clinically relevant conditions.

The evaluation of bending strength was performed to assess the resistance of restorative materials to flexural forces, which simulate the complex stress conditions encountered *in vivo* when restorations are subjected to simultaneous compressive and tensile loads [14]. Unlike compressive or tensile strength tests that focus on a single stress mode, bending tests provide a more comprehensive measure of the material's ability to withstand functional stresses, incorporating both elasticity and fracture resistance. Bending strength is particularly significant in dental materials because it directly reflects the performance of the hybrid layer and marginal integrity at the tooth restoration interface, both of which are critical to long-term clinical success. The specimens were fabricated using a custom engineered disc-shaped Teflon mold, 0.8 cm thick and 2.5 cm in diameter, designed in two detachable halves for ease of manipulation. At its core, the mold contained a parallel-pipped-shaped cavity with standardized dimensions of 25 mm in length, 2 mm in thickness, and 2 mm in depth (Figure 5). The specimen preparation process, utilizing custom Teflon molds (see Figure 3, a Schematic representation from this study), was standardized for all materials:

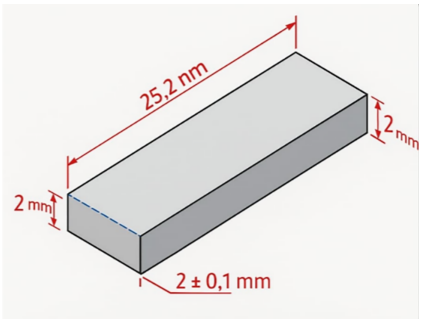

Figure 5. Dimensions of rectangular specimen for flexural testing

The dimensions of the rectangular specimen used for bending tests are provided in Figure 5. To ensure precise ceiling and dimensional stability during specimen preparation, the mold was reinforced with a metal retaining ring (Figure 6):

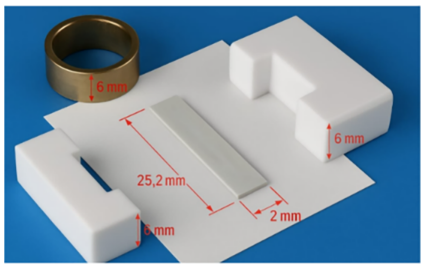

Figure 6. Finalized composite specimen with disassembled mold

A representative composite specimen and the associated mold components are shown in Figure 6. The specimen preparation process, utilizing custom Teflon molds (see Figure 6, a Schematic representation from this study), was standardized for all materials. The restorative materials were condensed into this cavity and flattened between two glass plates (1 mm thickness each) to obtain smooth, parallel surfaces. A vise was employed to maintain constant pressure, preventing void formation during curing.

This step was critical for controlling internal defects, as voids act as stress concentration points that can significantly lower the measured mechanical strength and increase data variability. By applying this protocol, we minimized void content, enhancing result reliability. (Specify the actual method used if known, e.g., vibration). The prepared specimens were subsequently conditioned in a thermostatic water bath at 37 ± 1°C for 24 h, simulating intraoral humidity and temperature conditions prior to mechanical testing. five replicates per material were fabricated and tested for flexural strength. Bending strength testing was carried out using a calibrated three-point bending apparatus, capable of applying controlled flexural loads. Each specimen was positioned horizontally on two cylindrical supports, each with a diameter of 2 mm, placed symmetrically such that the distance between their axes (span length) was 20 mm. A third cylindrical loading pin of the same diameter was applied centrally to the specimen, delivering a uniaxial load at a constant crosshead displacement rate of 1 mm/min. This configuration ensured uniform stress distribution and minimized edge effects. During loading, the applied force (F) induced tensile stresses on the lower surface and compressive stresses on the upper surface of the specimen, eventually leading to fracture once the material's flexural strength was exceeded. The recorded maximum load was used to calculate bending strength (σ, in MPa) according to the standardized formula:

$$\sigma = \frac{3 \cdot \mathrm{F} \cdot \ell}{2 \cdot \mathfrak{b} \cdot h^2} \tag{2}$$

F is the fracture load (N), l is the support span length (20 mm), b is the specimen thickness (mm), and h is the specimen height (mm), both measured precisely prior to testing. The use of at least five replicates per material ensured statistical reliability, with outliers beyond 15% of the mean excluded from the dataset. This rigorous methodology provided reproducible measurements of bending strength, allowing for accurate comparison between composites, compomers, and glass ionomers.

2.5. Statistical analysis

All mechanical property data (compressive strength, tensile strength, and flexural strength) were analyzed using statistical software (e.g., SPSS Statistics, Version X; IBM Corp.). For each property, a one-way analysis of variance (ANOVA) was performed to detect significant differences among the mean values of the different material groups. Upon identifying a significant effect from the ANOVA, post-hoc comparisons were conducted using Tukey's Honest Significant Difference (HSD) test. A p-value of less than 0.05 was considered statistically significant for all tests. The results are presented as mean ± standard deviation.

3. Results

The mechanical properties of the tested restorative materials are summarized in Figures 7–9 and Tables 1–3. A consistent performance hierarchy was observed across all three tests.

The numerical data presented in the tables and the corresponding graphical representations in the figures have been cross verified to ensure absolute accuracy and consistency. Composite resins exhibited the highest mean values for compressive, tensile, and flexural strength. Compomers demonstrated intermediate properties, with values significantly lower than composites but significantly higher than glass ionomer cements (GICs). The GICs consistently recorded the lowest mechanical values in all tests. Within the compomer group, Dyract Extra showed superior mechanical properties compared to Dyract AP.

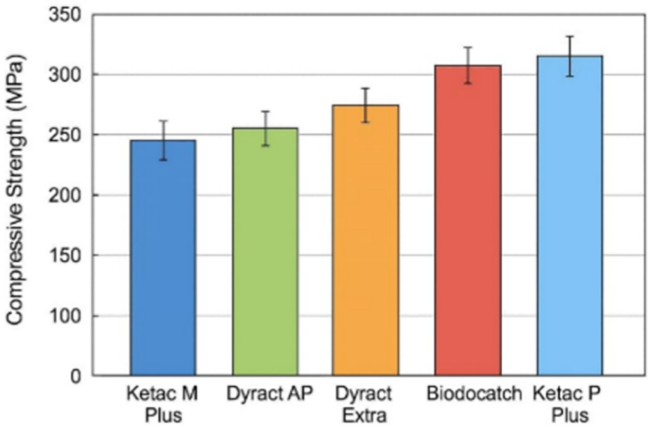

Figure 7. 3D cone chart comparing compressive strength

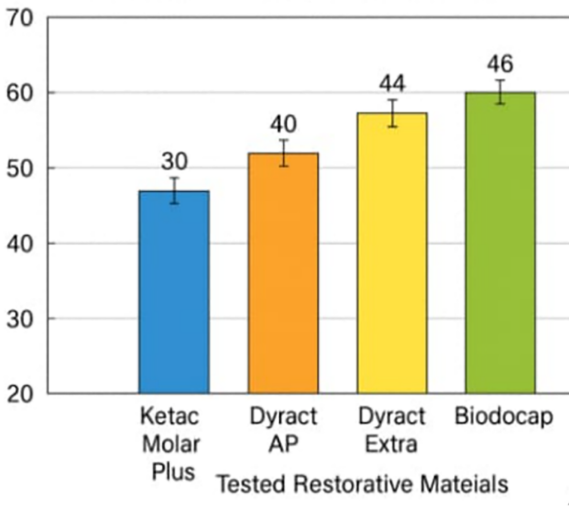

Figure 8. 3D cone chart comparing tensile strength

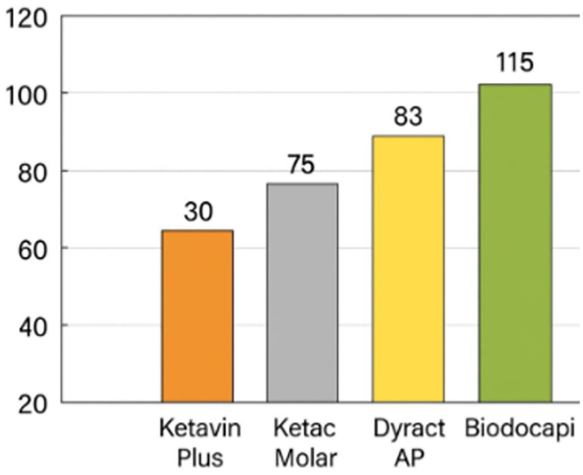

Figure 9. 3D cone chart comparing flexural strength

Table 1. Measured compressive strength values of selected compomers

Material	Mean ± SD (MPa)	Statistical grouping
(Kerr Corporation)	285 ± 15.0	A
Radopacril	260 ± 14.0	A
Dyract extra	217 ± 12.0	B
Dyract AP	210 ± 11.0	B
Ketac molar	165 ± 10.0	C
Kavitan plus	150 ± 9.0	C

Table 2. Tensile strength values of the tested restorative materials

Material	Mean ± SD (MPa)	Statistical grouping
(Kerr Corporation)	53 ± 3.5	A
Dyract extra	46 ± 3.0	B
Radopacril	44 ± 2.8	B
Dyract AP	40 ± 2.5	C
Ketac molar	27 ± 2.0	D
Kavitan plus	25 ± 1.8	D

Table 3. Flexural strength values of the tested restorative materials

Material	Mean ± SD (MPa)	Statistical grouping
(Kerr Corporation)	115 ± 8.0	A
Radopacril	95 ± 7.0	B
Dyract Extra	83 ± 6.0	C
Dyract AP	75 ± 5.5	C
Kavitan Plus	32 ± 3.0	D
Ketac Molar	30 ± 2.8	D

4. Discussion

The findings of the present investigation emphasize that the analyzed restorative materials have reached a level of bending strength that makes them clinically applicable in both anterior and lateral regions, consistent with recent studies on modern components [15,16]. This mechanical progress broadens the spectrum of clinical indications for components, highlighting their suitability in situations where resistance to flexural forces is essential for long-term stability. The cumulative outcomes of the *in vitro* analyses of compressive, tensile, and bending strength demonstrate a clear mechanical hierarchy. The superior mechanical strength of components like Dyract compared with glass ionomer cements can be directly attributed to its composite-like nature and its more robust resin–filler interactions. Within the component group, the improvement from Dyract AP to Dyract Extra highlights the evolution between the two components, which is mainly attributed to modifications in the inorganic composition and to the more uniform distribution of glass filler particles within the resin matrix. In the case of the composites (Kerr Corporation) and Radopacril, the microstructural organization plays a fundamental role: small powder particles dispersed between larger filler particles minimize interstitial voids and

allow the fine particles to assume part of the compressive load, thereby enhancing the overall resistance to fracture. These variations are strongly influenced by several microstructural factors such as the homogeneity of filler distribution within the polymer matrix, the proportion of inorganic phase loading, and the morphology of the filler particles. However, fracture strength remains lower in components than composites. This deficiency reflects a reduced resistance to crack propagation and underscores the need for caution in applying components to high-stress clinical areas. In agreement with this observation, El-Kalla Ibrahim and Garcia-Godoy Franklin reported in their comparative study that the compressive and flexural strengths of three components exceeded those of resin-modified glass ionomers but remained inferior to those of composites. This aligns with El-Kalla and Garcia-Godoy, who reported components occupy an intermediate position and mechanical performance for components [17]. For instance, they recorded flexural strengths for components in the range of 70–85 MPa, which is consistent with our results for Dyract Extra (83 MPa) and Dyract AP (75 MPa), and confirms their performance remains below that of conventional composites, which often exceed 100 MPa. Such findings clearly delineate a mechanical hierarchy among restorative materials [18]: composites consistently exhibit the highest values, followed by components, then Resin-Modified Glass Ionomer Cements (RMGICs), and finally conventional glass ionomer cements (GICs), which occupy the weakest position [19]. Our results strongly support the microstructural analysis of Cattani-Lorente et al., who attributed the superior mechanical strength of Dyract to its composite-like nature and robust resin-filler interactions. The higher compressive strength we observed for Dyract Extra (217 MPa) compared to the values reported in their earlier study may be attributed to subsequent generational improvements in filler technology and resin matrix formulation, leading to a more homogeneous microstructure and reduced void content. Supporting evidence from Cattani-Lorente and colleagues demonstrates that the superior mechanical strength of Dyract compared with glass ionomer cements can be directly attributed to its composite-like nature and its more robust resin filler interactions. Taken together, these findings confirm that while components represent a significant mechanical improvement over glass ionomers and resin-modified ionomers, they still cannot fully match the superior resistance of composites. Their clinical application must therefore be carefully tailored to the mechanical demands of the oral environment, with composites remaining the gold standard in stress-bearing areas and glass ionomers retaining a role in situations where their unique adhesive and fluoride-releasing properties outweigh their mechanical limitations. Overall, the absolute values for compressive, tensile, and flexural strength obtained in this study for all material classes fall within the ranges reported in the broader literature, confirming the validity of our experimental methodology. The consistent hierarchical trend observed across these studies underscores the fundamental relationship between material composition and mechanical performance. The mechanical properties measured in this study align well with performance ranges reported in the literature [20,21], thereby validating our experimental results and supporting the reliability of our testing protocols.

For instance, the compressive strength of Dyract Extra (217 MPa) falls within the typical range of 200–250 MPa reported for other commercial components in recent studies. Similarly, the flexural strength of the tested composites, Kerr Corporation (115 MPa) and Radopacril (95 MPa), is comparable to, and in some cases superior to, values reported for other micro-hybrid composites, which often range between 90–120 MPa. This comparative analysis underscores that the components tested, particularly the advanced formulation Dyract Extra, possess mechanical properties that are competitive within their category. However, it also reaffirms the established performance gap, showing that while components have improved, they still reside in the lower segment of the performance spectrum occupied by modern composite resins, which can achieve flexural strengths exceeding 130 MPa in highly filled systems. This direct comparison solidifies the intermediate positioning of components within the restorative materials hierarchy.

5. Clinical relevance

The mechanical hierarchy established in this study provides clear guidance for clinical material selection. Composite resins remain the material of choice for permanent restorations in high stress bearing areas, such as large Class II cavities, due to their superior overall strength and long-term clinical performance. Modern compomers, particularly third-generation formulations like Dyract Extra, present a versatile option for restorations in low-to-moderate stress environments, including Class I, III, and V cavities, as well as small Class II restorations. Their additional benefits of fluoride release make them especially suitable for pediatric dentistry. Conventional glass ionomer cement is best indicated for non-load bearing applications such as Class V restorations, cavity liners, and bases, where their chemical adhesion and bioactive properties are most advantageous.

Figure 7 provides a three-dimensional cone chart illustrating the comparative compressive strength of several restorative materials, highlighting not only their values but also their relative performance. The vertical axis spans from 0 to 350, enabling a clear visualization of differences between materials. As shown in Figure 7 and Table 1, the composite resins (Kerr Corporation) and (Radopacril) demonstrated the highest compressive strength, followed by the compomers (Dyract Extra and Dyract AP), with the glass ionomer cements (Ketac Molar and Kavitan Plus) exhibiting the lowest values. The results obtained from the compressive strength tests, presented in Figure 7 and Table 1, demonstrate clear differences among the three categories of restorative materials analyzed.

Statistical analysis revealed that the compressive strength of the composite resins (Kerr Corporation), (Radopacril) was significantly higher than that of both compomers and glass ionomers ($p < 0.05$). The compomers (Dyract AP, Dyract Extra) formed an intermediate group, demonstrating significantly greater compressive strength than the glass ionomers (Ketac Molar, Kavitan Plus) but lower than the composites.

Figure 8 provides a detailed visual comparison of the tensile strength of five different restorative materials, represented by color-coded cones in a three-dimensional chart. The vertical axis, labeled in megapascals (MPa), ranges from 0 to 70, which is sufficient to cover the maximum values recorded in the tests. The cone heights directly reflect the tensile strength of each material, while the exact numerical values are placed above the cones for clarity. The tensile strength results (Figure 8, Table 2) followed a similar hierarchy, with composites outperforming compomers, which in turn were superior to glass ionomers. By presenting these results in a 3D cone format with contrasting colors, the chart makes it easy to observe both the absolute values and the relative ranking of each material. From a practical standpoint, these differences highlight the importance of material selection in restorative dentistry: higher tensile strength materials, such as Radopacril or Dyract Extra, may be more reliable in high-stress clinical applications, while materials with lower tensile strength may be better suited for non-load-bearing restorations.

The tensile strength results, illustrated in Figure 8 and Table 2, confirm a similar pattern of performance.

The tensile strength of glass ionomers was statistically the weakest ($p < 0.05$). While the compomers performed significantly better than the glass ionomers, their values were statistically lower than those of the composite resins. Among the materials studied, the Kerr Corporation composite achieved the highest tensile strength. The differences between generations of compomers are also evident in this test: Dyract Extra exhibited superior tensile behavior, suggesting better *in vitro* resistance to the types of traction forces that occur under clinical conditions. These variations are strongly influenced by several microstructural factors such as the homogeneity of filler distribution within the polymer matrix, the proportion of inorganic phase loading, and the morphology of the filler particles [22]. Such parameters have direct clinical implications, as tensile strength values guide the clinician in the appropriate selection of restorative materials based on the location and functional demands of the cavity.

Figure 9 provides a detailed comparison of the bending strength values of five restorative materials, presented in the form of a three-dimensional cone chart. The vertical axis, measured in megapascals

(MPa), extends from 0 to 120, and the relative heights of the cones illustrate the performance differences among the tested materials. Flexural strength testing (Figure 9, Table 3) revealed that the compomers, particularly Dyract Extra, approached the performance of composites, while the glass ionomers again displayed significantly lower resistance to bending forces. Overall, the chart not only shows the numerical results but also visually emphasizes the hierarchical ranking of materials in terms of bending strength. From a clinical and engineering perspective, this comparison underscores how material choice directly impacts the longevity and performance of restorations under functional stress. Biodocapil is consistent with earlier naming (likely Radopacril), while weaker ones like Ketac Molar and Kavitan Plus may be limited to non-load-bearing applications. The bending strength tests, summarized in Figure 9 and Table 3, provide additional insight into the mechanical profile of these materials.

A consistent statistical hierarchy was observed in flexural strength: composites > compomers > glass ionomers ($p < 0.05$). Notably, the flexural strength of the third-generation component (Dyract Extra) was not statistically different from one of the composite resins (Radopacril), indicating a closing of the mechanical performance gap.

This observation highlights the progressive refinement of compomers, which now possess mechanical properties much closer to those of composites. Such an evolution enhances their usability not only in anterior restorations but also in posterior regions exposed to more intense mechanical stresses. Taken together, the compressive, tensile, and bending strength results underline a consistent trend: composites remain the most reliable restorative materials due to their superior resistance across all mechanical tests, while compomers occupy an intermediate position, outperforming glass ionomers but not yet reaching the full strength of composites. The evolution observed particularly in Dyract Extra demonstrates the positive effect of compositional optimization, making it a clinically viable material for a broader range of applications. These findings also confirm that the mechanical properties of restorative materials are strongly dictated by their microstructure, particularly the particle size distribution, filler morphology, and resin filler interactions. The progression from glass ionomers to compomers and ultimately to composites reflects a continuous improvement in the ability of dental materials to withstand the complex masticatory forces within the oral cavity, thereby offering clinicians an expanded and more reliable choice for long-term restorative success [23]. The findings of the present investigation emphasize that the analyzed restorative materials have reached a level of bending strength that makes them clinically applicable in both anterior and lateral regions of the oral cavity under conditions closely comparable to those of conventional composites. This mechanical progress broadens the spectrum of clinical indications for compomers, highlighting their suitability in situations where resistance to flexural forces is essential for long-term stability. The cumulative outcomes of the *in vitro* analyses of compressive, tensile, and bending strength. Tensile strength, compressive resistance, and the dimensional characteristics of restorative materials are critical since they often substitute a significant proportion of lost tooth structure and must endure the repetitive action of masticatory forces over many years. A substantial body of research has documented the mechanical performance of compomers with respect to compressive strength, diametral tensile strength, fracture resistance, and surface hardness. Generally, these properties approximate those of conventional composite resins, suggesting that compomers have evolved into a promising intermediate restorative category. The mechanical performance of components is fundamentally governed by their composite-like microstructure. The particle size distribution of the inorganic fillers plays a critical role; a bimodal or multimodal distribution, where smaller particles fill the interstices between larger ones, leads to a higher filler load and a more densely packed resin matrix. This directly enhances resistance to deformation under load, as reflected in the higher compressive and flexural strength of Dyract Extra compared to earlier formulations. Furthermore, the filler morphology, whether spherical or irregular, affects stress distribution within the material. Spherical fillers minimize stress concentration points and facilitate a higher packing density, thereby improving overall strength and fracture resistance compared

to irregular, sharp-edged particles that can act as crack initiation sites. Finally, the integrity of the resin-filler interface is paramount. A strong, stable bond, often achieved through silane coupling agents, ensures efficient stress transfer from the relatively soft polymer matrix to the rigid, reinforcing filler particles. A weak interface can lead to debonding, which serves as a failure nucleus and explains the characteristically lower fracture toughness of components compared to conventional composites, where interface optimization has been more extensively developed. The evolution in composer technology can thus be viewed as a progressive refinement of these three microstructural elements.

However, one key mechanical parameter fractured strength remains markedly lower in compomers compared with composites. This deficiency reflects a reduced resistance to crack propagation and underscores the need for caution in applying compomers to high-stress clinical areas. In agreement with this observation, El-Kalla Ibrahim and Garcia-Godoy Franklin reported in their comparative study that the compressive and flexural strengths of three compomers exceeded those of resin-modified glass ionomers but remained inferior to those of composites. Such findings clearly delineate a mechanical hierarchy among restorative materials: composites consistently exhibit the highest values, followed by compomers, then Resin-Modified Glass Ionomer Cements (RMGICs), and finally conventional glass ionomer cements (GICs), which occupy the weakest position. Supporting evidence from Cattani-Lorente and colleagues demonstrates that the superior mechanical strength of Dyract compared with glass ionomer cements can be directly attributed to its composite-like nature and its more robust resin–filler interactions. GICs remain confined to indications where shortcomings like low abrasion resistance, insufficient hardness, moisture sensitivity, and porosity do not compromise performance. The therapeutic success of these materials is therefore strongly dependent on their careful protection against both dehydration and overhydration during and after placement, a requirement emphasized in multiple clinical studies.

Taken together, these findings confirm that while compomers represent a significant mechanical improvement over glass ionomers and resin-modified ionomers, they still cannot fully match the superior resistance of composites. Their clinical application must therefore be carefully tailored to the mechanical demands of the oral environment, with composites remaining the gold standard in stress-bearing areas and glass ionomers retaining a role in situations where their unique adhesive and fluoride-releasing properties outweigh their mechanical limitations.

6. Conclusions

The findings of this research clearly highlight the progressive evolution of compomers across successive generations, steadily advancing toward mechanical characteristics that approximate those of conventional composite resins. This development reflects significant improvements in their formulation, particularly in terms of filler distribution and resin filler interaction, which collectively enhance their resistance to functional stresses encountered in the oral cavity. Among the investigated materials, Dyract Extra, representing the third generation of compomers, distinguished itself by exhibiting remarkably high values of tensile, compressive, and flexural strength. These enhanced properties position it as a clinically reliable option not only for aesthetic anterior restorations, where superior appearance and durability are essential, but also for posterior restorations in lateral areas, where restorative materials are subjected to more substantial occlusal forces. The performance of Dyract Extra thus demonstrates the potential of modern compomers to bridge the gap between traditional ionomer-based materials and composites, combining mechanical durability with the added advantages of adhesion and fluoride release.

Despite the clear insights provided, this study has certain limitations. As an *in vitro* investigation, it assessed immediate mechanical properties under standardized conditions, which may not fully simulate the complex oral environment characterized by variable pH, temperature fluctuations, and long-term cyclic loading. Furthermore, the study focused on bulk mechanical properties and did not evaluate the long-term aging of the adhesive interface or the material's wear resistance.

Future studies should include long-term aging under oral conditions, including thermocycling and fatigue. Additionally, clinical trials are recommended to validate these laboratory findings and assess the real-world performance, survival rate, and failure modes of modern components, particularly Dyract Extra, in various clinical scenarios. Investigations into the synergistic effects of different filler technologies and resin matrix compositions could also guide the development of next-generation components with enhanced fracture toughness.

By contrast, the studied glass ionomer cements exhibited significantly lower mechanical values when compared with both composites and compomers. Their reduced resistance to tensile, compressive, and bending stresses confirms their limited applicability in stress-bearing regions of the dentition. These findings reinforce their primary clinical indication as restorative agents in Class V cavities, where occlusal pressures are minimal, or as base and liner materials placed beneath stronger restorative systems such as composites, compomers, or even amalgams. In such roles, glass ionomers continue to provide valuable benefits through their biocompatibility, ease of handling, and fluoride release, but their mechanical shortcomings prevent them from being viable alternatives in areas of high masticatory demand. In conclusion, the present study emphasizes that compomers, particularly advanced formulations such as Dyract Extra, represent a significant step forward in restorative material science, narrowing the mechanical gap with composites and expanding their clinical applicability. Glass ionomers, while still indispensable in specific therapeutic contexts, remain restricted by their mechanical limitations, confirming their complementary rather than competitive role in contemporary restorative dentistry.

Acknowledgement: The author would like to acknowledge the Taif University Department of Scientific Research in the Saudi Arabia for assistance and motivation to accomplish the research work.

Funding Statement: The authors received no specific funding for this study.

Author Contributions: Leila Abdelgader: Conceptualization, Methodology, Formal Analysis, Investigation, Writing—Original Draft Preparation. Chafaa Hamrouni: Supervision, Project Administration, Resources, Validation, Writing—Review & Editing. All authors reviewed the results and approved the final version of the manuscript.

Availability of Data and Materials: The datasets generated and analyzed during the current study are available from the corresponding author C.H. upon reasonable request.

Ethics Approval: Not applicable.

Conflicts of Interest: The authors declare no conflicts of interest. The founding sponsors had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, or in the decision to publish the results.

References

1. Nicholson JW. Polyacid-modified composite resins (“compomers”) and their use in clinical dentistry. Dent Mater. 2007;23(5):615–22. doi:10.1016/j.dental.2006.05.002.
2. Yan L, Xu H. Lightweight composite materials in automotive engineering: state-of-the-art and future trends. Alex Eng J. 2025;118:1–10. doi:10.1016/j.aej.2024.12.002.
3. Feldens CA, dos Santos IF, Kramer PF, Vítolo MR, Braga VS, Chaffee BW. Early-life patterns of sugar consumption and dental caries in the permanent teeth: a birth cohort study. Caries Res. 2021;55(5):505–14. doi:10.1159/000518890.
4. Xu X, Burgess JO. Compressive strength, fluoride release and recharge of fluoride-releasing materials. Biomaterials. 2003;24(14):2451–61. doi:10.1016/S0142-9612(02)00638-5.
5. Zhang Y, Fu Y, Li KC, Ekambaram M, Dai R, Cooper PR, et al. A scoping review of hydroxyapatite-modified glass ionomer cements used for restorative dentistry. J Dent. 2025;163:106149. doi:10.1016/j.jdent.2025.106149.

6. Sidhu S, Nicholson J. A review of glass-ionomer cements for clinical dentistry. J Funct Biomater. 2016;7(3):16. doi:10.3390/jfb7030016.
7. Cattani-Lorente MA, Dupuis V, Payan J, Moya F, Meyer JM. Effect of water on the physical properties of resin-modified glass ionomer cement. Dent Mater. 1999;15(1):71–8. doi:10.1016/S0109-5641(99)00016-0.
8. Gladys S, Van Meerbeek B, Braem M, Lambrechts P, Vanherle G. Comparative physico-mechanical characterization of new hybrid restorative materials with conventional glass-ionomer and resin composite restorative materials. J Dent Res. 1997;76(4):883–94. doi:10.1177/00220345970760041001.
9. Xiong Y, Huang M, Luo L. Improving the low-temperature degradation (LTD) resistance of pure 3 mol% yttria-stabilized tetragonal zirconia polycrystal (3Y-TZP) ceramics by defect engineering. Ceram Int. 2025;51(25):43566–74. doi:10.1016/j.ceramint.2025.07.089.
10. Shaw AJ, Carrick T, McCabe JF. Fluoride release from glass-ionomer and compomer materials: one-year data. J Dent. 1998;26(4):355–9. doi:10.1016/S0300-5712(97)00016-X.
11. Cattani-Lorente MA, Godin C, Meyer JM. Mechanical behavior of resin-modified glass-ionomer cements and compomers. Dent Mater. 1999;15(4):263–71. doi:10.1016/0109-5641(94)90020-5.
12. Wang XY, Yap AUJ, Ngo HC. Effect of early water exposure on the strength of glass ionomer restoratives. Oper Dent. 2006;31(5):584–9. doi:10.2341/05-106.
13. Ferracane JL. Resin composite—state of the art. Dent Mater. 2011;27(1):29–38. doi:10.1016/j.dental.2010.10.020.
14. Nicholson JW, Sidhu SK, Czarnecka B. Enhancing the mechanical properties of glass-ionomer dental cements: a review. Materials. 2020;13(11):2510. doi:10.3390/ma13112510.
15. Ilie N. Relationship between fracture toughness and fracture mirror in modern polymer-based dental composites. J Funct Biomater. 2025;16(8):290. doi:10.3390/jfb16080290.
16. Lohbauer U, Belli R, Ferracane JL. Factors involved in mechanical fatigue degradation of dental resin composites. J Dent Res. 2013;92(7):584–91. doi:10.1177/0022034513490734.
17. Cattani-Lorente M, Scherrer SS, Ammann P, Jobin M, Anselm Wiskott HW. Low temperature degradation of a Y-TZP dental ceramic. Acta Biomater. 2011;7(2):858–65. doi:10.1016/j.actbio.2010.09.020.
18. Cramer NB, Stansbury JW, Bowman CN. Recent advances and developments in composite dental restorative materials. J Dent Res. 2011;90(4):402–16. doi:10.1177/0022034510381263.
19. Ilie N, Hilton TJ, Heintze SD, Hickel R, Watts DC, Silikas N, et al. Academy of dental materials guidance—resin composites: part I—mechanical properties. Dent Mater. 2017;33(8):880–94. doi:10.1016/j.dental.2017.04.013.
20. Osiceanu G, Negru R, Porojan L. Effect of water sorption on the mechanical properties of direct and CAD/CAM subtractive dental resin composites. J Phy Conf Ser. 2025;3153:012009. doi:10.1088/1742-6596/3153/1/012009.
21. Lempel E, Lovász BV, Bihari E, Krajczár K, Jeges S, Tóth Á, et al. Long-term clinical evaluation of direct resin composite restorations in vital *vs*. endodontically treated posterior teeth-retrospective study up to 13 years. Dent Mater. 2019;35(9):1308–18. doi:10.1016/j.dental.2019.06.002.
22. Cattani-Lorente MA, Dupuis V, Moya F, Payan J, Meyer JM. Comparative study of the physical properties of a polyacid-modified composite resin and a resin-modified glass ionomer cement. Dent Mater. 1999;15(1):21–32. doi:10.1016/s0109-5641(99)00010-x.
23. Olander J, Kowar J, Barkarmo S. Long-term clinical outcomes for single dental crowns versus extensive direct restorations: a register-based cohort study with up to 10 years of follow-up in a swedish population. J Dent. 2025;17(3):106267. doi:10.1016/j.jdent.2025.106267.

Received: 26 September 2025; Accepted: 22 December 2025