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EFFECT OF BEVERAGE EXPOSURE ON THE COLOR STABILITY OF CAD/CAM PMMA ENDOCROWNS VERSUS PREFORMED ZIRCONIA CROWNS IN PRIMARY MOLARS: AN IN VITRO STUDY

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Abstract

Objectives: To evaluate and compare the effect of different beverages (cola, orange juice, apple juice) on color stability of PMMA endocrown and preformed zirconia crowns as restorations of pulpotomized primary molars. **Materials and Methods**: The study included unidentified fifty-six freshly extracted human mandibular second primary molars underwent pulpotomy procedure. Teeth were randomly subdivided into two main groups according to the type of coronal restoration each comprising twenty-eight specimens: CAD/CAM Milled PMMA endocrown, and preformed zirconia crown. Afterward, specimens in each group were randomly subdivided into four subgroups seven on each according to the different treatment modalities. Specimens were subjected to thermocycling and pH cycling to evaluate color stability using reflective spectrophotometer. The collected data were examined for outliers and tested for normality using Shapiro-Wilk and ANOVA test at 0.05 significance level. **Results**: There was highly statistically significant difference between the four subgroups regarding color stability in PMMA endocrown and zirconia crown with the highest impact for cola ($p < 0.001$*) and lowest impact for artificial saliva ($p < 0.001$*). Intergroup comparison demonstrated highly statistically significant differences between both groups in all beverages ($p < 0.001$*). **Conclusion**: PMMA endocrown revealed noteworthy changes under oral conditions, while zirconia crowns remained more stable, highlighting the need for selection of good material for durable, minimally invasive pediatric restoration and limitation of the consumption of carbonated and fruit juices for durable, minimally invasive pediatric restorations.

Keywords: Color Stability, Endocrown PMMA, Primary, Zirconia.

1- INTRODUCTION

Deciduous teeth offer several functions such as mastication, phonetics, and aesthetics, while also preserving space for the proper eruption and alignment of permanent teeth and contributing to jaw and facial growth.[1] When carious or traumatic pulp exposures confined to the coronal portion, pulpotomy is commonly performed vital pulp therapy procedure,[2] However, these treated teeth tend to be more prone to fracture due to weakened structural integrity.[3] Consequently, the selected restorative material should effectively replace lost tooth structure while enhancing mechanical strength, functional performance, esthetics, and providing an optimal coronal seal.[4]

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Stainless steel crowns (SSCs) have been standard restoration for pulpotomized primary teeth because of their durability and affordability. Nevertheless, their unesthetic appearance and the risk of metal hypersensitivity have limited their acceptance among parents.[5] Subsequently, the rising need for esthetic restorations, has led to the growth of zirconia crowns. that offer superior esthetics, biocompatibility, and excellent mechanical properties.[6] However, they have some disadvantages such as higher cost, limited shades, require excessive tooth preparation, and may cause wear of opposing teeth.[7]

Endocrowns have gained attention as a conservative an aesthetic restorative option for primary teeth. Theorized by **Bindl et al.** [8] These restorations combine the post and core into a single unit, to produce a full-block prosthesis. They are especially beneficial in cases with reduced clinical crown height or limited interocclusal space or insufficient thickness for conventional ceramic restorations especially in pulpotomized primary molars.[9, 10]

Endocrowns were mostly fabricated from ceramic materials, recently advances in CAD/CAM technology compared with conventional crown fabrication in terms of time, precision, and laboratory skill dependency as they decrease chairside time and therefore, increase the cooperation of children have expanded material options to include CAD/CAM milled hybrid ceramics, resin composites, polymers such as PMMA.[11] polymethylmethacrylate (PMMA) is characterized by its accuracy, biocompatibility, economic affordability, ability to match color of teeth and gums, good thermal conductivity, co-efficiency of thermal expansion similar to teeth, good mechanical properties, and relatively lower toxicity.[12, 13]

2. METHODS

2.1. Study design:

The study's procedures received approval from the Research Ethics Committee (REC) of the Faculty of Dentistry, Suez Canal University, under the authorization number 746/2023, in accordance with the Helsinki Declaration of the World Medical Association (2008 Version). This study included fifty- six, unidentifiable, primary, mandibular second molars, that were extracted in the Pediatric Dentistry and Oral and Maxillofacial Surgery Departments, Suez Canal University, for reasons unrelated to this research, such as natural exfoliation or orthodontic interventions. All the patients under 16 years old who presented to these above-mentioned departments had their parents or legal guardians sign informed consent forms to use their removed teeth for study purposes.

2.2. Sample Size Calculation:

The sample size was determined using G*power version 3.1.9.4 to calculate sample size based on effect size of 0.7825, 2-tailed test, α error =0.05 and power= 90.0% Consequently, the calculated minimum number of samples required was fifty-six (twenty-eight samples in each group). The sample size is in accordance with.[14]

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2.3. Sample selection

Extracted mandibular second primary molars were selected regarding the following eligibility criteria:

Inclusion criteria:

1- At least one-third of the root structure remaining intact, molars with an intact pulpal floor.

2- The presenting had at least three intact axial walls with a minimum of 1 mm of sound tooth structure,

3- A similarity in dimensional standardization was ensured using a digital micrometer, with buccolingual and mesiodistal variations not exceeding ±1 mm.

Exclusion criteria:

Molars with macroscopic defects (cracks, hypoplasia, hypo mineralization) were excluded with the aid of operating microscope.[15]

2.4. Sample storage and disinfection

All primary molars were wiped of blood, debris, and soft tissue. Disinfection was done using 0.1% thymol solution for a maximum of one month, then they were stored in distilled water till their use.[16]

2.5. Sample Mounting

Acrylic resin served to secure specimens within prefabricated polypropylene tubes measuring 5 by 8 centimeters. Positioning each tooth correctly in its mold relied on a mounting surveyor for accuracy. With pink wax, individual teeth attached to the surveyor's pin in an upright position. After alignment, they were lowered slowly, placed at the center and kept vertical until the resin surface reached 2 millimeters beneath the cementoenamel junction.[17] **Fig (1)**

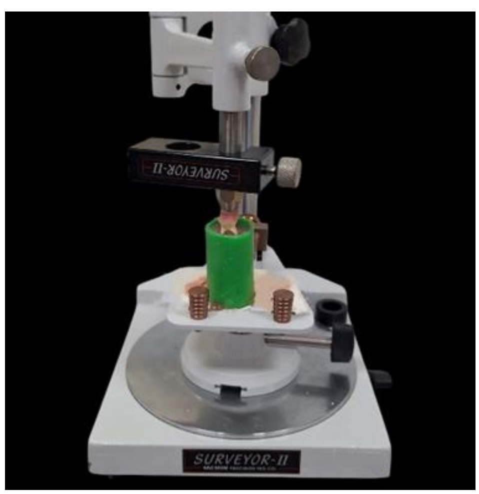

Fig. (1): Showed primary molar mounting in acrylic resin using surveyor

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2.6. Pulpotomy procedure

All mounted molars were pulpotomized according to the guidelines outlined in reference.[17], following these steps:

All Caries was removed with a high- speed hand piece with round diamond bur no 46 under copious irrigation. Then, access to the pulp chamber obtained with carbide fissure bur **(No. FG.57)**. All access cavity walls were flared to allow complete exposure of the pulp chamber.

Upon pulp exposure, the roof of the pulp chamber was removed with a high-speed diamond round bur and pulp remnants were removed with large spoon excavator. The pulp chamber was thoroughly irrigated with saline, then hand thick mix of zinc-oxide and eugenol (ZOE) **(I dental, AUB, Lithuania)** was applied to the prepared cavity to seal the orifices.[17] **Fig (2)**

Fig. (2): Showed cavity preparation for pulpotomy

2.7. Sample randomization and grouping

Each specimen was assigned a number from 1-56, using an online randomizing program (www.randomizer.org), specimens were then randomly allocated into two study groups each group received a different restoration.

Group I: Twenty-eight pulpotomized molars were restored by PMMA Endocrown

Group II: Twenty- eight pulpotomized molars were restored by preformed zirconia crowns.

Each group was randomly subdivided into four subgroups (n=7) according to types of submersion beverages for an hour in each beverage for 30 days

Subgroup A: artificial saliva (freshly prepared) (control)

Subgroup B: Cola (Coca- Cola company)

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Subgroup C: orange juice (Juhayna company)

Subgroup D: Apple juice (Juhayna company)

2.8. Restoration of the pulpotomized molars

1) Endocrown tooth preparation:

Preparations for endocrown restorations were standardized using a specially modified milling machine (AF30) as follows:

A) Occlusal reduction

A wheel stone was attached to milling surveyor performing an occlusal reduction of 2mm. The vertical arm was calibrated to control the depth of reduction, while the horizontal arm was adjusted to ensure even clearance over the entire surface. The preparation was subsequently refined using a diamond disc.

To achieve a butt joint cervical margin, the tapered stone was oriented along the major axis of the tooth and held parallel to the occlusal plane.[18, 19]

B) Axial reduction

The axial walls were prepared with 6° to 8° divergence toward the occlusal surface, and a 96° to 98° angle between the pulpal floor and pulpal walls was obtained by using tapered stone. Gingival seat was prepared 1mm above the cemento-enamel junction**.**

Internal angles were smoothened and rounded. The cavity floor sealed with a layer of glass ionomer followed by flowable composite to isolate the ZOE from the successive resin-based restorations and adhesives**.** [17] **Fig (3 A, B)**

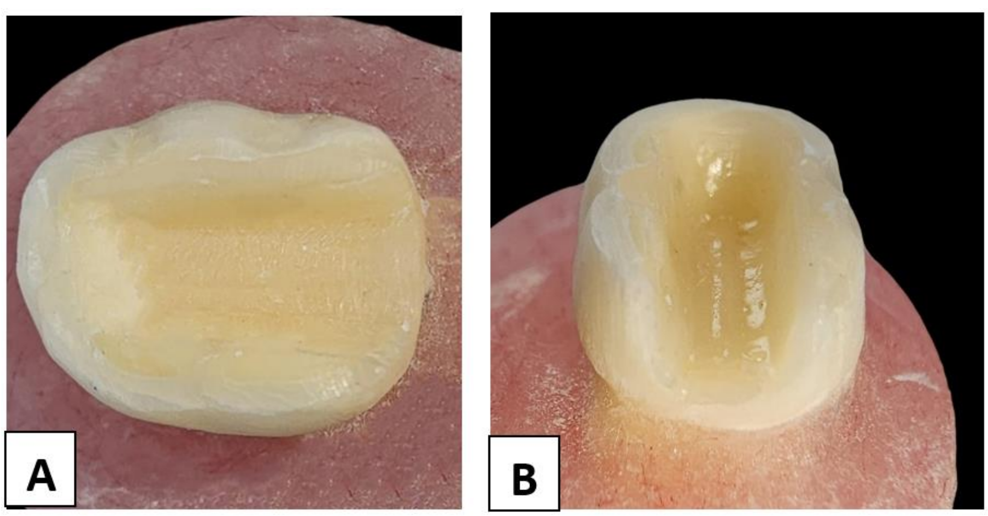

Fig. (3): Showed sealing the final prepared cavity for endocrown with flowable composite (A: occlusal view, B: proximal view)

C) Tooth Scanning for CAD/CAM Endocrown and Cementation:

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A digital workflow guided the process using Exocad 3.2 software from GmbH, Germany. Scanning occurred next - each specimen captured through an Auto Scan-DS-EX Pro 3D device to generate precise optical data. From that point, a virtual die emerged for close evaluation. Software tools removed undesirable undercuts automatically, which designed the restoration's path of insertion..**[20]**.Once the endocrown design was displayed, minor refinements followed as needed

CAD/CAM milling machine (Roland Dwx 52 di 5 Axes d milling machine) was used to design and fabricate the endocrowns. Each tooth had its own numbering and each endocrown had taken the same numbering for the same tooth so that each tooth corresponded to its endocrown and overlapping between samples was minimized. **Fig (4 A, B)**

Once the correct grinding tools arrived, activation of the milling sequence began. Inside the machine's chamber, placement of the chosen block preceded its shaping through abrasion. Following this phase, refinement occurred – finishing and polishing was achieved according to manufacturer instructions

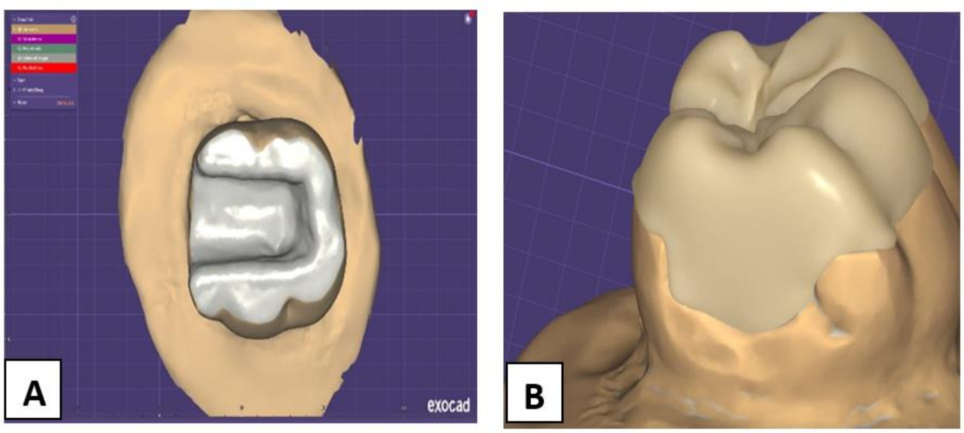

Fig. (4): Showed designing and fabrication of endocrown by exocad (A:Occlusal view of preparation B: Proximal view,)

Cementation was done using a self-adhesive resin that coated both the inner face of the endocrowns and the prepared tooth surfaces. Placement followed, with each restoration positioned precisely over its matching prepared tooth. After applying steady finger pressure, rest for five minutes while briefly exposing to light cure - just two seconds. A scaler removed excess cement before continuing. Each surface receives forty seconds of additional light curing afterward.**[20]** **Fig (5)**

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Fig. (5): Cementation of endocrown (A: Occlusal view of cemented endocrown)

2) Zirconia Crown group preparation:

Second primary molar preparation standardization was achieved by using a specially modified milling machine (AF30) as follows:

The cavity was filled with reinforced glass ionomer to the top.

Teeth were prepared according to manufacturer's recommendations for preparation of primary molars to receive zirconia crowns.[17]

A) Occlusal reduction

A tapered stone attached to the milling surveyor was used for reduction of the occlusal surface and central grooves to a depth of 1mm from central portion of the tooth

B) Occlusal finishing

Occlusal finishing with diamond disc.

C) Proximal and axial reduction A tapered stone was used for axial walls preparation and proximal reduction for 1–1.5 mm to ensure a passive fit of the selected crown, eliminating the height of contour. This reduction was performed gradually and, on all planes of the tooth.

D) Circumferential reduction

The expected edge resulting from the circumferential reduction was finished into a featheredge. This was done to facilitate the passive fitting of the zirconia crown. **Fig (6)**

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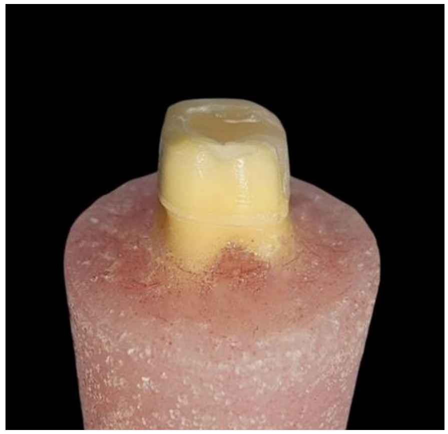

Fig. (6): Showed Final preparation for zirconia crown

E) Preformed Zirconia Crown Cementation:

For cementation of preformed zirconia crown, resin modified glass ionomer cement was employed to cement zirconia crowns. Excess cement was removed with a scaler after setting time of glass ionomer.[17] **Fig (7)**

Fig. (7): Showed zirconia crown cementation

2.9. Thermocycling Aging:

All specimens before submersion period in beverages were exposed to a thermocycling aging procedure for 5000 cycles with a dwell period of 10 sec and at a temperature range of 5–55°C (60min).[21] **Fig (8)**

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Fig. (8): Showed specimens in thermocycler

2.10. Submersion of Specimens in Different Beverages and pH Cycling Protocol:

Before submersion, baseline readings for surface roughness and color were recorded for all specimens. Specimens were divided into 4 subgroups (n = 7) and submersed separately in 40 ml of either artificial saliva (Freshly prepared), Coca-Cola (Coca-Cola Company, Egypt), orange juice (Juhayna Company), or apple juice (Juhayna Company). According to different treatment modalities. Specimens were submersed in a demineralizing solution (pH 4.5) for 7 hours daily, containing 50 mM acetic acid, 2.2 mM NaH_2PO_4, and 2.2 mM $CaCl_2$.

After demineralization, specimens were transferred to a remineralizing solution (pH 7.0) for 16 hours daily, consisting of 0.15 M KCl, 1.5 mM $CaCl_2$, and 0.9 mM NaH_2PO_4.

Submersion was carried out in sealed plastic containers, each beverage was changed every 24 hours to prevent bacterial or yeast contamination, submersion for (1 hour/ daily) at 37 °C in an incubator. A pH meter was used to assess the pH of each beverage daily. **Fig (9)**

This pH cycling process was repeated daily for 30 days in conjunction with the beverage submersion.[22, 23]

All specimens were rinsed under running filtered water and stored in distilled water for 24 hours before final surface roughness and color measurements.[24]

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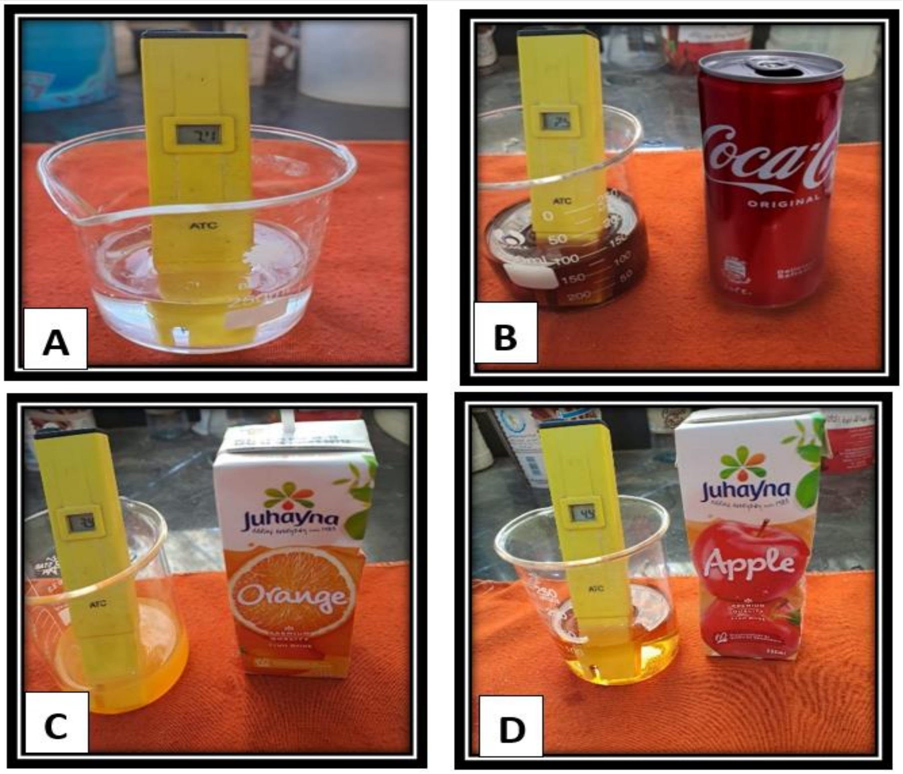

Fig. (9): Showed pH measuring using pH meter (A: Artificial saliva B: Coca-Cola C: orange juice D: apple juice)

2.11. Evaluation Methods:

Evaluation of Color stability

The color tone was measured before the specimen submersed in the beverage (T0). All color tone measurements were made by one experimenter in a treatment room with sufficient natural light on a day with abundant sunlight.[25] Color stability was measured for 28 specimens for each material. 7 specimens from each group were measured before being submersed in each beverage, (artificial saliva (control), cola, orange juice, and apple juice), respectively, and stored in an incubator at 37°C till were evaluated again after 30 days (T30).

A Reflective spectrophotometer **(X-Rite, model RM200QC, Neu-Isenburg, Germany)** was used for color estimation of all specimens, at the beginning (T0) and after 30 days (T30) of submersion. The aperture size was set to 4 mm and the specimens were lined up with the device. A white background was used, and Color changes of endocrowns and zirconia crowns were assessed according to Commission Internationale de l'Eclairage (CIE) L*, a*, b* (LAB) color scale (shading space comparative with CIE standard illuminant D65). This scale quantitatively determines color by using 3 coordinates; L*, a* and b*.[25] This procedure was done at a private dental laboratory.

The color changes (ΔE) of the specimens were assessed utilizing the following equation:

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ΔE CIELAB = (ΔL*2 + Δa*2 + Δb*2) ½ Where:

ΔE* = Overall color difference

ΔL* = Difference in lightness (L* ranges from 0 = black to 100 = white)

Δa* = Difference on the red-green axis (positive = red, negative = green)

Δb* = Difference on the yellow-blue axis (positive = yellow, negative = blue)

3. Statistical Analysis

Statistical analysis was performed using SPSS software (IBM SPSS version 29.0). Data were organized using Microsoft Excel 2016. Normality was assessed using the Shapiro–Wilk test ($p \leq 0.05$). Parametric data were analyzed using two-way ANOVA to evaluate the effects of material type and beverage on surface roughness and color stability, followed by Bonferroni-adjusted post hoc tests for pairwise comparisons. One-way ANOVA was used to assess differences within each group. Paired t-tests were applied for intra-group comparisons (baseline vs. after immersion), while independent t-tests were used for intergroup comparisons. Correlation between variables was assessed using Spearman's test. Statistical significance was set at $p \leq 0.05$.

4. RESULTS

Intra group comparison:

Changes in mean values (ΔE) and standard deviation (SD) of color stability of group I and II after submersion in different beverages were presented in **Table (1) and Fig. (10)**.

In PMMA endocrown (group I) mean of color change between artificial saliva(control) and cola was highly statistically significant difference ($p<0.001^*$). Also, between orange and apple juice there was highly statistically significant difference ($p<0.001^*$).

When comparing mean of color change of specimens in PMMA endocrown (group I) between cola and orange juice, the difference was statistically non-significant ($p=0.129$), however between cola and apple juice, there was highly statistically significant difference ($p<0.001^*$)

Within PMMA endocrown (group I), the variation in mean of color change between artificial saliva (control) and orange juice was highly statistically significantly different ($p<0.001^*$). Likewise, a highly statistically significant difference was observed between artificial saliva(control) and apple juice ($p<0.001^*$).

On comparing the mean of color change of specimens in zirconia crown (group II) between artificial saliva(control) and cola, the difference was highly statistically significant ($p<0.001^*$), however between orange juice and apple juice, there was highly statistically significant difference ($p<0.001^*$).

According to current results evaluating the mean of color change in zirconia crown (group II), the comparison between cola and orange juice revealed a statistically non-significant

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difference (p= 0.102). In contrast, the difference between cola and apple juice was highly statistically significant ($p<0.001^*$).

Within zirconia crown (group II), the mean of color change between artificial saliva (control) and orange juice was highly statistically significantly different ($p<0.001^*$). Likewise, a highly statistically significant difference was observed between artificial saliva (control) and apple juice ($p<0.001^*$).

Inter group comparison:

The mean of color change ∆E in PMMA endocrown (group I) and zirconia crown (group II) increased by 7.09 ± 0.44 and 4.04 ± 0.19 respectively after submersion in artificial saliva (control). This change was a highly statistically significant difference between both groups ($p<0.001^*$).

The mean of color change ∆E in PMMA endocrown (group I) was 23.36 ± 0.99 and in zirconia crown (group II) was 11.75 ± 1.02 change after submersion in cola, there was highly statistically significant difference between both groups ($p<0.001^*$).

PMMA endocrown (group I) showed a mean of color change ∆E of 22.43 ± 0.76, while zirconia crown (group II) exhibited a change of 10.30 ± 0.94 after submersion in orange juice. A highly statistically significant difference was noted between both groups (p < 0.001*).

The mean values of ∆E of PMMA endocrown (group I) and zirconia crown (group II) recorded 11.87 ± 0.23 and 8.26 ± 0.22 change respectively after submersion in apple juice. The difference between both groups was highly statistically significant ($p<0.001^*$).

Factorial ANOVA was performed to assess the effects of restorative material, beverage type, and their interaction on color stability. The results demonstrated that the overall model was highly statistically significant, with an F-value of 892.395 and a p-value $<0.001^*$, indicating that the combination of factors significantly influenced color changes.

The main effect of material was highly statistically significant (F = 2116.556, $p<0.001^*$), confirming that different materials exhibit significantly different color stability. The type of beverage also had a highly statistically significant main effect (F = 1149.268, $p<0.001^*$), showing that beverage composition plays a critical role in influencing color change. Importantly, the interaction between material and beverage was highly statistically significant (F = 227.468, $p<0.001^*$), suggesting that the effect of a particular beverage on color stability depends on the specific restorative material. Denoting that material might exhibit more discoloration in a particular beverage than another, in our study it was PMMA endocrown.

The mean square error was relatively low (0.392), which, combined with the high F-values, supports the robustness of the findings. **(Table 2), Fig (11)**

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Table (1): Comparison of mean color change between the tested groups before and after submersion in different beverages

ΔE	Artificial Saliva (n=7)	Cola (n=7)	Orange juice (n=7)	Apple juice (n=7)	p value
	Mean ±SD	Mean ±SD	Mean ±SD	Mean ±SD	
Group I	7.09 ± 0.44	23.36 ± 0.99	22.43 ± 0.76	11.87± 0.23	<0.001*
	P_1<0.001, p_2<0.001*, p_3<0.001*, p_4=0.129, p_5<0.001*, p_6<0.001*				Significance between groups
Group II	4.04 ± 0.19	11.75 ± 1.02	10.64 ± 0.37	8.26 ± 0.22	<0.001*
	p_1<0.001*, p_2<0.001*, p_3<0.001*, p_4=0.102, p_5<0.001*, p_6<0.001*,				Significance between groups

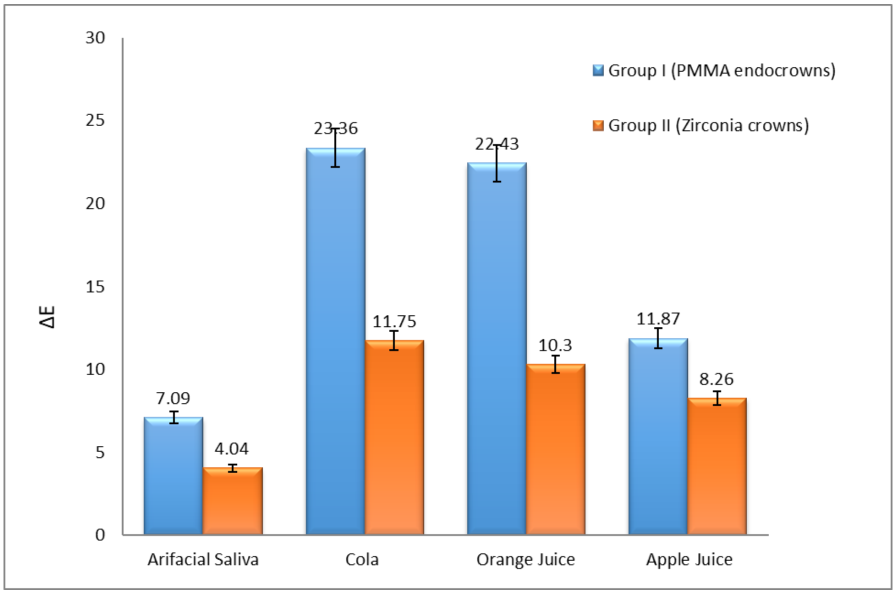

Fig. (10): Showed bar chart presenting the mean of color change between both tested groups after submersion in different beverages

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Table (2): Factorial ANNOVA outcome for color stability

Source	Type III sum of squares	Df	Mean square	F	sig
Corrected Model	2448.005[a]	7	349.715	892.395	<0.001*
Intercept	8661.226	1	8661.226	2201.509	<0.001*
Material	829.444	1	829.444	2116.556	<0.001*
Beverages	1351.139	3	450.380	1149.268	<0.001*
Material*Beverages	267.423	3	89.141	227.468	<0.001*
Error	18.810	48	0.392		
Total	11128.042	56			
Corrected Total	2466.816	55			

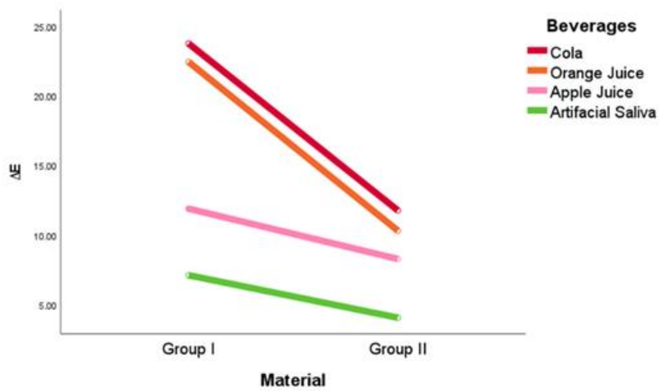

Fig. (11): line Chart showing the interaction between material and beverages on color stability

5. DISCUSSION

The purpose of this study was to evaluate and compare the effect of different beverages (cola, orange juice, and apple juice) on color stability of PMMA endocrown and preformed zirconia crown as restorations of pulpotomized primary molars.

This study was in vitro as it, offered a controlled environment that mitigates the variability inherent in clinical studies involving human subjects. Moreover, in vitro methods are less time-consuming, more cost-effective, and highly repeatable, making them indispensable

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in the evaluation of devices and dental materials performance and biocompatibility under standardized conditions.(26)

The extracted primary second mandibular molar was chosen and standardized for this study as, it is the last molar to erupt, important for the appropriate jawbone's, muscles development, and it is critical for mastication, proper occlusion, and correct alignment of permanent teeth which influence children's overall health.[1]

The selected teeth were individually mounted using surveyor (SAESHIN) in self-curing acrylic resin, guaranteeing that the acrylic resin surface was positioned 2 mm below and parallel to cemento-enamel junction (CEJ), to simulate the height of healthy alveolar bone, providing adequate support and retention throughout the study procedures.[20, 27]

Teeth preparations were done using a specially modified milling machine(surveyor) to standardize the preparation for all the teeth and make all steps machinable and reproducible to save time and effort. This was in coincidence with.[20]

Prefabricated zirconia crown was used as restorative option in this study since it is the most commonly aesthetic crown used by many pediatric dentists[17]**,** while endocrown was selected as it requires less circumferential tooth reduction than zirconia crowns, also preparation terminates supragingival, which removes any potential discomfort or gingival stress,[19]

Three different beverages were used (cola, orange juice, apple juice) in addition to artificial saliva as a control medium, since (cola and orange juice) are the most commonly consumed beverages by children and teenagers in the Middle East.[28] All specimens were submersed in these beverages at 37°C using an incubator to replicate the oral conditions and asses the material performance.[29]

Thermocycling aging procedure was done for specimens for 5000 cycles with a dwell period of 10 sec and at a temperature range of 5–55°C (60min) to appropriately replicate the oral cavity environment around six months of clinical care.[21]

Assessing color stability is essential to ensure that the restoration maintains its aesthetic appearance over time. Exposure to various beverages can cause discoloration, compromising the visual appeal of the crowns. By conducting these tests, it could predict how both materials maintain stable in color in the oral environment, guiding the evolution of more durable and aesthetically stable dental materials.[23]

Reflective spectrophotometer was used in this study to evaluate change in color. It measures the wavelength that is reflected or transmitted from one object at a time, without being influenced by the subjective interferences of the color (CIELab) system estimates chromaticity and characterizes the shade of an object in a uniform 3-dimensional space. This was in agreement with.**Dawood et al.** [30] who evaluated the effect of staining beverages and surface finishing on color stability and surface roughness of translucent zirconia using reflective spectrophotometer.

In current study, there was high significant difference with the superiority toward zirconia group with all beverages, although they all displayed discoloration over the clinically

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acceptable threshold. However, the used beverages had little impact on the color stability of the zirconia specimens. This could be explained by the acid-resistant property of zirconia, which could have shown less vulnerability for discoloration [31]

Similar to the outcome of the present study,**Colombo et al.** [32] observed clinically acceptable color values with zirconia specimens following one week of storage in a cola beverage., Also**,** [33] results were supporting to ours since they found that zirconia specimens submersed in the energy and acidic drinks(cola) showed perceivable color changes at the end of a 28-day study period while specimens stored in artificial saliva shown slight color changes .On the other hand, **Arindham et al.** [34] reported that Zirconia also exhibited notable color alterations after submersion in artificial saliva. Moreover, **Demir Sevinç et al.** [35] agreed with current finding and concluded that zirconia exposed to staining liquids (cola, citric acid) had introduced color change. Also **Gheytasi et al.** [36] who demonstrated color change of monolithic zirconia with orange juice submersion.

This color change in all specimens may be attributed to presence of artificial colorants and citric acid that facilitate discoloration of teeth and restorations. Moreover, the acidic pH of these soft drinks causes discoloration of dental restorations [33]

In this study, thermal alterations as a result from thermocycling may be a cause of discoloration of monolithic zirconia restorations. Thermal stresses applied to polycrystalline materials with anisotropic crystals, such as zirconia ceramics, intensify the mechanical stresses due to differences in the expansion of crystals or their different phases. This would enhance water sorption and uptake of pigments and stains from colored foods and beverages.[36]

The current study findings for color stability were agreed with **Dimitrova et al.** [37] who found that, water accumulation and photo oxidation has also been reported to be accountable for internal color alteration. Water plays an imperative role in chemical degradation process such as oxidation and hydrolysis and the consequent shift of the optical properties of provisional restorative materials. Incomplete polymerization, water sorption. chemical reactivity, diet, oral hygiene and surface smoothness of the restoration can affect the degree of color changes. Color is the result of light waves reflected by restorative materials which could be opaque or translucent.

Moreover**, Alfouzan et al.** [38] concluded that the chromogenic agent in (cola, orange) specially is the most contributing factor in color change of PMMA restorations, followed by the material type and surface treatment. Sorption (water or oral fluid uptake) takes place while PMMA was submersed and due to the molecular polarity, the water molecules infiltrate through the polymer chains.[39]

The present study in line with, **Wayakanon et al.** [40] who concluded that there is significant color change in PMMA restorations after submersion in artificial saliva, cola and orange juice.

Zirconia crown group exhibited better color stability performance in our study, this could be explained by highly resistant properties of zirconia to chemical reactions. This is due

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to its dense, non-porous structure. It can also withstand significant temperature changes without displaying remarkable discoloration. Additionally, the smooth surface of zirconia crowns reduces the accumulation of chromogenic stains, helping to maintain their color over time. It could also be due to the glazing procedures designed to provide esthetic and hygienic surfaces.[31, 34]

Findings here match those found by with **Alzanbaqi et al.** [41] where a systematic review of nine separate analyses focused on how well zirconia crowns resist discoloration. In their work, little change in shade appeared over time. Despite differences across methods, consistent outcomes emerged regarding material performance.

One reason findings vary across investigations lies in the distinct material microstructures involved. Another stems from shifts in erosion-testing approaches taken. Temperature changes add yet another layer of difference. Measurement techniques also shift from one study to the next. Each approach uses its own set of variables. These variations together shape the range of results seen.[29] .

Limitations

1. In-vitro study: The study was conducted in a laboratory setting, which does not perfectly replicate the oral environment in terms of salivary enzymes, bacterial flora, and patient habits like brushing and diet.
2. Limited beverage types: Only three beverages (cola, orange juice, and apple juice) were used. Other commonly consumed beverages such as coffee, tea, and milk, were not evaluated.
3. No mechanical loading: The effect of chewing forces and wear due to mastication was not simulated, which could affect surface roughness and restoration durability over time.

CONCLUSION

The current study concluded that there was significant difference in color stability of pulpotomized primary molars among the tested groups (PMMA endocrowns, Preformed zirconia crowns). Although zirconia crowns offer superior long-term stability and aesthetics, PMMA endocrowns remain a viable, cost-effective, and conservative alternative for restoring pulpotomized primary molars when esthetics and long-term durability are less critical. The choice of restoration should be individualized based on clinical needs, esthetic demand, and patient cooperation.

Recommendations

Future research should include clinical trials with extended follow-up periods, a wider variety of beverages, and the incorporation of mechanical loading and brushing simulation to better reflect real intraoral conditions.

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Author's Contributions

SMM and MNE conceived the idea and designed the study. MAO wrote the main manuscript text. MNE prepared the figures. All listed authors participated in experiments and data collection. All authors have read and approved the final manuscript.

Data availability

The datasets generated and analyzed during the current study are available from the corresponding author on reasonable request.

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