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EVALUATION OF MICROHARDNESS AND COLOR CHANGE OF TOOTH-COLORED RESTORATIVE MATERIALS AFTER CYCLIC IMMERSIONS IN SPORT AND ENERGY DRINKS: IN VITRO STUDY

Aya Omar Tawfik*, Heba Arafa Abd El Wahab*, Mona El Deeb** *and* Mennat Allah Atef Aboulnaga***

ABSTRACT

Aim of the study: This research aimed to examine the impact of sport and energy beverages on the surface hardness and color stability of nanohybrid resin composite (Zirconfill) and universal nanocomposite (Filtek Z350 XT) , and also to assess the PH and acid concentration of sport and energy beverages.

Methods: Samples of each resin based composite material were fabricated using a polytetrafluoroethylene mold with a diameter of 10 mm and a thickness of 2 mm. These specimens were categorized into three groups: sports beverage, energy beverage, and deionized water (serving as a negative control). They underwent an alternating immersion process, being placed in the test solution for 5 seconds, followed by artificial saliva for another 5 seconds, for a total of 24 cycles. Afterward, they were stored in artificial saliva for 24 hours. The immersion cycle was conducted daily for a duration of two weeks. Hardness and color measurements were conducted using a Vickers microhardness tester and a reflective spectrophotometer, respectively, at baseline (before immersion), as well as after 7 and 14 days (n=14).

Results: After beverages insertion, the Filtek Z350 XT Nanofilled resin composite exhibited significantly lower hardness, and greater color alterations compared to the other materials ($P < 0.05$). Additionally, energy beverage groups led to more pronounced color alteration than sport beverage groups, with statistical significance ($P < 0.05$).

Conclusion: The novel nanohybrid composite Zirconfill BM4 demonstrated excellent mechanical properties, high microhardness values, and lower susceptibility to discoloration in sports and energy drinks. This suggests that Zirconfill BM4 could be a promising alternative as a filler for nanohybrid dental composites.

KEYWORDS: Zirconfill BM4 composite, Filtek Z350 XT nanocomposite, Energy beverage, Sport beverage, Surface hardness, Color.

* Operative Department, Faculty of Dentistry , Beni-seuf University.
** Biomaterials Department, Faculty of Dentistry, Cairo University, Cairo, Egypt
*** Restorative Department, Faculty of Oral and Dental Medicine, Modern University For Technology and Information

INTRODUCTION

Resin based restorative materials are extensively used and continuously improved to meet the growing demand for enhanced aesthetics. Resin composites possess mechanical properties similar to those of natural teeth, making them a popular choice over amalgam [1-4]. These materials consist of a polymer-based matrix and inorganic fillers, with coupling agents strengthening the bond between them [5]. Resin composites are designed to satisfy both the aesthetic requirements of anterior restorations and the functional durability needed for posterior teeth [6]. Recently, nanocomposites have emerged as an advanced class of dental composites, offering superior physical, mechanical, and aesthetic qualities due to their high filler content [7,8]. Nanocomposites are categorized into two types: nanohybrid composites, which contain processed glass fillers and distinct nanoparticles (40–50 nm), and nanofilled composites, which include nano-sized filler particles, known as nanomers, along with agglomerated clusters of these particles called “nanoclusters” [7]

Sports and energy beverages are popular flavored beverages that contain a combination of minerals, and electrolytes such as sodium, potassium, calcium. These beverages are often consumed to enhance physical performance and to restore fluids and electrolytes lost through perspiration, making them widely used by athletes aged 18–35 years [9-11].

Despite their benefits, these beverages have a low pH due to the presence of acids like citric acid and malic acid [12]. Their acidic nature can contribute to tooth demineralization and degradation of restorative materials by displacing fillers from the resin matrix, which increases surface roughness [13-15]. Additionally, research has shown that exposure to sports and energy beverages significantly decreases the surface hardness of restorative materials [16, 17]. Studies suggest that low-pH liquids can negatively impact the mechanical properties of resin based materials. Moreover, the synthetic colorants present in energy drinks may lead to staining of tooth-colored restorative materials through absorption and adsorption processes.

In an effort to enhance nanohybrid dental composites, porous fillers known as diatomite have been integrated into the matrix [18]. Diatomite, a porous silicate derived from diatomaceous algae, is distinguished by its large surface area and low density [19]. Recently, it has been introduced as an inorganic filler in the Zirconfill® resin composite [20]. Its structure, consisting of nanometric pores, allows the monomeric matrix to infiltrate, resulting in improved optical properties. This prevents the direct exposure of the organic matrix to the oral environment, reducing staining and maintaining long-term color stability. Additionally, the ability to incorporate a higher filler content enhances mechanical properties such as compression strength, diametral compression resistance, flexural strength, microhardness, and wear resistance. Although Lins et al. reported high linear shrinkage values in Zirconfill® sticks, the overall impact of diatomite on mechanical properties and color stability remains unclear [20].

Various studies have explored the effects of different beverages, including Cola, Pepsi, and Red Bull, on resin composites. Research findings indicate that microhybrid and nanohybrid resin composites exhibited noticeable color changes after 15 days of immersion [21]. Another study demonstrated that nanohybrid resin composites had superior color stability compared to giomer restorative materials after exposure to tea and coffee for 7, 30, and 90 days [22]. Similarly, nanohybrid composites showed greater resistance to discoloration than microhybrid composites when immersed in Yemeni beverages such as qat, tea, and coffee [23]. Additionally, studies have found a correlation between color measurements obtained using a spectrophotometer and the Vita classical shade guide [24].

The focus of this research was to assess the impact of sports and energy beverages on the surface hardness and color stability of nanohybrid resin based composite and universal nanocomposite. The null hypothesis proposed that exposure to these beverages would not alter the surface hardness or color of the tested materials.

MATERIALS AND METHODS

The restorative materials used in this investigation are presented in **Table 1 and Figure 2 (a,b)** , while the beverages selected for testing are listed in Table 2.Research approval was granted by the research ethics committee at the Faculty of Dentistry, Cairo University, Egypt (Research approval #: 55924).

Sample size estimation

The sample size for this research was estimated using the G*Power software (version 3.1.9.7, Heinrich-Heine-Universität Düsseldorf, Düsseldorf, North Rhine-Westphalia, Germany). The calculation was performed with a statistical power of 80% and a Type I error probability of 0.05. Mean and standard deviation values were derived from prior research[25]. Each subgroup consisted of a total of 14 samples.

Samples Preparation

A total of 84 flat disc-shaped sample were prepared from resin based restorative materials and divided into two groups: 42 specimens from the nanohybrid composite (Zirconfill BM4) and 42 from the universal nanocomposite (Filtek Z350 XT). The samples were formed using a circular Teflon mold surrounded by a metallic ring, with dimensions of 10 mm in internal diameter and 2 mm in thickness. This mold was placed between two microscopic slides , each coated with a clear celluloid Mylar strip. To ensure a uniform surface and remove excess material, a 20 N stainless steel weight was applied on top. The resin composite was incrementally inserted into the mold, and the glass slides were carefully pressed together to minimize porosity and eliminate any surplus material (Figure 1 a).

TABLE (1) Materials used for the research.

Restorative material	Composition	Average particle size (um)	Manufacturer	Lot number
Zirconfill Nanohybrid composite shade Enamel A2	Bis-GMA, Bis-EMA, TEGDMA, and UDMA, photoinitiatior, Diatomite, Silica, Zirconia/Silica, Mixed oxide and colorants The total filler load is 80% by Wt	15.8 um	BM4, Maquira dental group, Brazil	749422
Filtek Z350 XT Universal nano composite shade Enamel A2	Bis-GMA, UDMA, TEGDMA, PEGDMA, Bis-EMA, non-agglomerated/ non- aggregated silica and zirconia fillers The total filler load is 78.5% by Wt	0.6 to 10 um	3M ESPE, St Paul, MN, USA	NE35959

TABLE (2) Sport and energy beverages used for testing.

Beverage	Proprietary name	Structure	Producer
Sport beverage	CR7	Vitamins B3, B6 and B12, sodium, calcium, potassium, magnesium, color (E160 a)	Generic, Egypt
Energy beverage	Power Horse	Carbonated Water, Sucrose, Glucose, Citric Acid, Taurine, Glucuronolactone (240mg/100ml), Artificial Flavor (Tutti-frutti); Caffeine, Color (Caramel E150a), Inositol(20mg/100ml), Niacin, Pantothenic Acid, Vit B6, Vit. B12 and Riboflavin.	Power Horse Energy Drinks, GmbH, spitz, Austria

Fig. (1) (a, b): (a) Composite resin filling material packed into the Teflon mould, (b) The disc-shaped specimen after removal from the mould.

Samples were subsequently cured with an LED light-curing device (Elipar 3M, ESPE) emitting a wavelength of 470 nm and an intensity of 1000 mW/cm² for 20 seconds prior to removal from the mold (Figure 1 b). The top surfaces were further refined and polished using fine and superfine polishing discs (Sof-Lex, 3M, ESPE) for 15 seconds. To ensure complete polymerization, all samples were stored in distilled water at room temperature for 24 hours

Fig. (2) (a, b): (a) Nano-hybrid resin composite (Zirconfill BM4), (b) Nanofilled resin composite (Filtek Z350 XT 3M)

Grouping of the specimens

The 84 samples were equally categorized into two groups based on the type of material: Group (A1) included universal nanocomposite, while Group (A2) consisted of nanohybrid composite. Each group (42 specimens) was further divided into three subgroups, with 14 specimens in each, based on the immersion solution: (B1) deionized water as a negative control, (B2) sport beverage, and (B3) energy beverage. Measurements were conducted at three different time intervals: before immersion (T0), after 7 days (T7), and after 14 days (T14).

pH and Acid concentration Assessment

The pH levels of both the sports and energy beverages were measured five times using a pH meter, and the average values were computed and documented. Following this, each beverage underwent titration using a 0.1 N sodium hydroxide (NaOH) solution. NaOH was incrementally added while continuously measuring the pH until it reached 5.5, 7, and 10. The collective volume of NaOH required to reach each pH level was documented. Each titration procedure was repeated ten times for accuracy, and the mean values were determined [26].

Sample Submersion and Analysis

Prior to immersion, the surface hardness and color alterations values of each sample were recorded as baseline measurements using a Vickers microhardness tester and a spectrophotometer. The immersion solutions used in the study included deionized water (serving as a negative control), a sports beverage, and an energy beverage. Each specimen underwent alternating immersion in 25mL of the assigned solution for 5 seconds, followed by immersion in 25 mL of artificial saliva for another 5 seconds, with this process repeated for a total of 24 cycles [27]. Following immersion, the specimens were stored in artificial saliva at room temperature (approximately 25°C) for 24 hours. This cycle was repeated daily for a total of 2 weeks.

For each immersion group (14 specimens), the samples were divided into two subgroups (7 specimens each) to assess surface microhardness and color stability. These measurements were performed at both 1 week and 2 weeks [27,28].

Surface Hardness Evaluation

The surface hardness (VHN) of the samples was determined using a Vickers microhardness tester, which applied a 0.3 μm rectangular-based pyramidal stylus under a load of 0.5 N for a duration of 10 seconds. Measurements were taken at five different points on each specimen, and an average value was calculated [29].

Color Assessment

Color evaluation was conducted at specific time intervals using a portable reflective spectrophotometer (X-Rite, model RM200QC, Neu-Isenburg, Germany). The device was configured with a 4 mm aperture, ensuring accurate alignment with each sample. A white background was utilized for consistency, and measurements were performed following the CIE L*ab** color system, referenced against the CIE standard illuminant D65.

The extent of color variation (ΔE) was determined using the following equation:

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

- **L*** represents lightness (ranging from 0 to 100)
- **a*** corresponds to the red-green color axis shift
- **b*** refers to the yellow-blue color axis shift

To ensure reliable data, three separate measurements were taken from different areas of each sample, and an average value was calculated[30].

Statistical Evaluation

The collected data were subjected to statistical analysis, with normality assessed using the Shapiro–Wilk test. Mean values for surface hardness and color variation were analyzed using a one-way ANOVA test, followed by Tukey's post hoc test for multiple comparisons. A significance level of 0.05 was applied.

RESULTS

The average pH and acid concentration of the sports and energy beverages are shown in **Table 3**. Both drinks had acidic pH levels, but CR7 (the sports drink) had a higher pH than Power Horse (the energy drink). When measuring titratable acidity, more NaOH solution was needed to neutralize Power Horse to pH levels of 5.5, 7, and 10 compared to CR7, indicating that the energy drink had higher acidity.

This table presents the mean pH values (± standard deviation) of the tested sports and energy drinks, along with the volume of sodium hydroxide (NaOH) solution (in mL) required to adjust the pH to 5.5, 7.0, and 10.0. Acid concentration was determined by incrementally adding NaOH and recording the amount needed to reach each specified pH level.

TABLE (3) Mean pH (± SD) and acid concentration of Tested Sports and Energy Beverages

Sport drink & Energy beverages	Mean PH ± SD	Collective volume of NaOH used to titrate to each PH (ml)		
		5.5	7	10
CR7	3.55 ±0.05	6.71 ±0.05	8.21 ±0.06	9.16 ±0.03
Power Horse	3.05 ±0.05	17.92 ±0.07	32.99 ±0.10	41.93 ±0.13

Tables [4-5] presents the surface hardness and color changes of restorative materials before and after being immersed in the drinks. The data highlight how exposure to the beverages affected the materials, with noticeable differences in hardness and color alteration after immersion.

Total effect of composite material group on surface microhardness mean value:

Regardless to evaluation time, totally it was found that there was a significant difference between them, there was a significant difference between them only in 7 days- 14 days and baseline -14 days of sport drink and energy drink (P=0.0001) as micro hardness changes in Filtek Z350 XT Nanofilled resin composite (control) was significantly higher than Zirconfill BM4 Nanohybrid resin composite intervention group.

Effect of evaluation Time on microhardness mean value:

Comparison between micro hardness changes of different immersion solutions was performed by using One Way ANOVA test followed by Tukey's Post Hoc test for multiple comparisons and presented in **table 4 and figure 3**. There was a significant difference between them regarding all measurements as P<0.05, except baseline-7 days of control group (P=0.72) and intervention group (p=0.28) as:

In Filtek Z350 XT control group: At 7 days -14 days and baseline -14 days energy drink was significantly the highest, then sport drink, while deionized water was significantly the least (P=0.0001).

In Zirconfill BM4 intervention group: At 7 days -14 days and baseline -14 days energy drink was significantly the highest, then sport drink, while deionized water was significantly the least (P=0.0001)

Total effect of composite material group on color change mean value:

Regardless to evaluation time, totally it was found that there was a significant difference between them (changes in Filtek Z350 XT group was significantly higher than Zirconfill BM4 group) regarding all measurements as revealed by using independent t test P<0.05, except 7-14 days of sport drink (P=0.32) and 7-14 days of energy drink (P= 0.64)

TABLE (4) The mean surface hardness (± SD) of materials tested immersed in sport and energy drinks at different times:

		Deionized water (B1)		Sport drink (B2)		Energy drink (B3)		P value
		Mean	Standard Deviation	Mean	Standard Deviation	Mean	Standard Deviation	
Filtek Z350 XT control group (A1)	Baseline-7days	-1.36 [a]	1.11	-1.58 [a]	1.14	-1.64 [a]	0.66	0.72
	7 days-14 days	-0.87 [a]	0.19	-3.25 [b]	0.58	-5.31 [c]	0.71	0.0001*
	Baseline- 14 days	-2.24 [a]	1.19	-4.83 [b]	1.15	-6.95 [c]	1.30	0.0001*
Zirconfill BM4 intervention group (A2)	Baseline-7days	-1.02 [a]	1.19	-1.76 [a]	0.89	-1.51 [a]	0.43	0.28
	7 days-14 days	-0.96 [a]	0.28	-1.32 [b]	0.38	-3.08 [c]	0.35	0.0001*
	Baseline-14 days	-1.98 [a]	1.12	-3.08 [b]	0.81	-4.59 [c]	0.62	0.0001*

Significant difference as P≤ 0.05.
Means with different superscript letters were significantly different as P<0.05.
Means with the same superscript letters were insignificantly different as P>0.05.

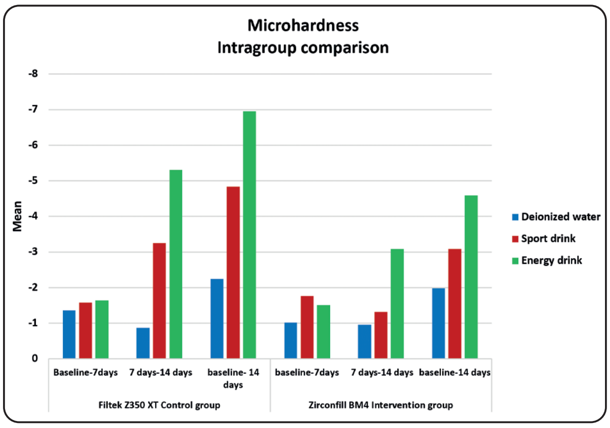

Fig. (3) Bar chart showing comparison between immersion solutions effect on microhardness.

Effect of evaluation Time on color change mean value

Comparison between color changes of different immersion solutions was performed by using One Way ANOVA test followed by Tukey's Post Hoc test for multiple comparisons and presented in **table 5 and figure 4**. There was a significant difference between them regarding all measurements as P<0.05, except baseline-7 days of control group (P=0.19) as:

In Filtek Z350 XT control group: At baseline – 7 days and at baseline -14 days energy drink was significantly the highest, then sport drink, while deionized water was significantly the least changes (P=0.0001). At 7 days – 14 days sport drink was significantly the highest, while there was insignificant difference between energy drink and deionized water (P=0.0001).

In Zirconfill BM4 intervention group: At 7 days -14 days energy beverage was significantly the highest, then sport drink, while deionized water was significantly the least (P=0.0001). At baseline -14 days energy drink was significantly the highest while there was insignificant difference between sport drink and deionized water (P=0.0001). between sport drink and deionized water (P=0.0001).

TABLE (5) Color change (▲E) results (Mean± SD) for composite groups as a function of evaluation time:

		Deionized water (B1)		**Sport drink (B2)**		**Energy drink (B3)**		**P value**
		Mean	Standard Deviation	Mean	Standard Deviation	Mean	Standard Deviation	
Filtek Z350 XT Control group (A1)	Baseline-7days	14.42^{a}	0.50	17.81^{b}	0.19	15.86^{c}	0.63	0.0001*
	7 days-14 days	7.96^{a}	0.71	5.69^{b}	0.46	8.50^{a}	0.95	0.0001*
	Baseline-14 days	22.38^{a}	0.54	23.49^{b}	0.38	24.36^{c}	0.49	0.0001*
Zirconfill BM4 Intervention group (A2)	Baseline-7days	10.80^{a}	0.79	10.36^{a}	0.96	10.85^{a}	0.47	0.19
	7 days-14 days	5.06^{a}	0.61	6.14^{b}	1.61	8.34^{c}	0.84	0.0001*
	Baseline- 14 days	15.86^{a}	0.71	16.49^{a}	0.94	19.19^{b}	0.59	0.0001*

Significant difference as P≤ 0.05.

Means with different superscript letters were significantly different as P<0.05.

Means with the same superscript letters were insignificantly different as P>0.05.

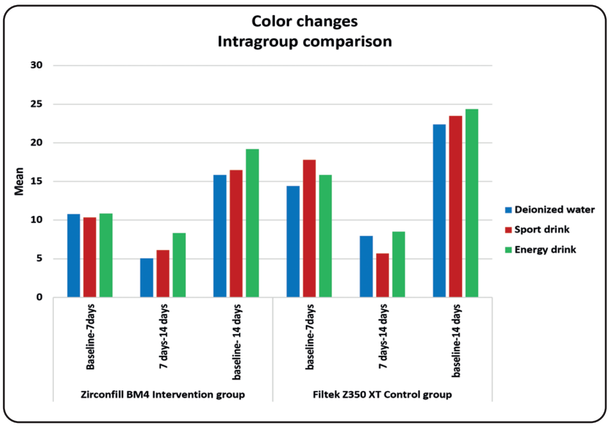

Fig. (4) Bar chart showing Comparison between different immersion solutions.

The study found that the energy drink Power Horse had a stronger impact on dental materials than the sports drink CR7. Specifically, it caused a more noticeable drop in surface hardness and a greater change in color. Among the restorative materials tested, Filtek Z350 XT (a nanofilled composite) was more affected than Zirconfill (a nanohybrid resin), showing a greater reduction in hardness and more visible discoloration. These differences were statistically significant ($P < 0.05$).

DISCUSSION

In this research, the effects of different beverages on the surface hardness, and color stability of three different resin-based materials were investigated. The null hypothesis of this study proposed that the surface hardness and color properties of resin-based materials would remain unchanged after repeated exposure to sports and energy beverages. However, the findings from this research indicate that this hypothesis should be rejected.

The research entailed the sequential immersion of samples in drinks and artificial saliva at ambient temperature, simulating the conventional drinking process in which saliva aids in the rinsing of the beverage within the oral cavity. Since the expected duration for ingesting a beverage is around 2 minutes, the research simulated this timeframe by applying approximately 24 immersion cycles. Saliva was considered an important factor affecting hardness of the material. Furthermore, temperature plays a role in material degradation, so the research was conducted at ambient temperature to minimize temperature-related effects.

The surface microhardness showed that the Zirconfill nanohybrid composite was superior to the 3M Nanofilled resin composites. The constructor indicated enhanced qualities of Zirconfill were targeted towards improved mechanical performance and better matrix/filler interaction. This is accomplished by adding certain porous fillers to the nano-hybrid dental composites. One of such fillers, diatomite, has recently been incorporated as an inorganic filler in Ziconfill BM4 Nanohybrid resin composite. Diatomite has the ability to incorporate monomeric matrix because of its unique structure with nanometric pores. Furthermore, greater amounts of filler in Zirconfill BM4 improve mechanical properties such as compression resistance, diametral compression resistance, flexural strength, microhardness, and wear resistance bladder. These properties surpass those of other composites currently available on the market. [20] In this study, the most pronounced change in microhardness was the Filtek Z350 XT Nanofilled resin composite. This is probably due to the presence of citric acid in energy drinks, which is commonly added to food and beverages to enhance sourness. It is a well-known fact that citric acid is destructive since it has the potential of chelating calcium from artificial saliva. Hence, drinks containing low pH and citric acid are likely to have greater erosive potentials. The unreacted monomers of the resin can also be released due to the softening action of acidic liquids. The softening effects are probably due to the combined action of the unreacted monomers and the water which is known to plasticize the resin and absorb water. Thus, the composite becomes softer because of polymer network swelling and reduced cohesion between polymer chains.

Color can greatly enhance optimum aesthetics [31]. The growing patient's expectations toward better aesthetics have led to the emergence and enhanced use in dental practices of restorative materials with superior aesthetic claims. In any case, one of the biggest problems associated with resin composites is that they can be discolored, which is perhaps the preeminent reason for restorations to be replaced [32, 33].

Hence, the restorative material needs to be in harmony with the original shade and meet the aesthetic requirements in the tooth after restoration[31]. The staining of the composite materials was found to be linked to the type of resin filler, the type of resin matrix, and the type of staining agent used [34]. Even resin composite materials that are hydrophilic can become really dark. Water is presumed to be a vehicle for the pigment penetration into the resin matrix[35-36]. Nonetheless, while the resin matrix of the resin based materials is capable of taking in water from the surrounding environment, inorganic glass fillers are incapable of taking in water to the interior bulk of the material, they can only sorb water on their surface. Excessive water retention might shorten the life expectancy of a resin composite by expanding and plasticizing the resin components, hydrolyzing the silane, and inducing microcrack formation. Therefore, microcracks or interfacial gaps at the filler-matrix interfacial region may facilitate the ingress of the stain and cause discoloration of the material [35]. The Zirconfill BM4 nanohybrid resin composite showed the least amount of color change statistically (P<0.05). This could be due to the inclusion of diatomite as an inorganic filler in the Zirconfill® resin composite. Diatomite's nanometric porous structure allows the monomeric matrix to penetrate its pores, enhancing key properties. This penetration reduces the "wedge" effect of the filler within the matrix, improving mechanical retention compared to traditional inorganic fillers. As a result, the organic matrix—typically responsible for color instability is less exposed to the oral environment, helping to prevent staining and maintain color longevity. However, external factors can still contribute to color changes by causing chemical degradation. Pigments from food, beverages like tea and coffee, or cigarette smoke may adhere to the surface or be absorbed into the resin matrix, impacting the composite's appearance. Among these, extrinsic staining is the most significant factor affecting the long-term color stability and durability of resin based materilas.[37] The sport drink (CR7) and energy drink (Power Horse) used in this research contained artificial pigments, which played a role in altering the color of the restorative materials. The energy drink included caffeine along with Caramel E150a, a synthetic pigment that ranges from yellow to red. On the other hand, the sport drink contained only E160 a (i), a carotene-based pigment derived from carrots, giving it a yellow-orange hue. Besides these synthetic dyes, the drinks' low pH levels also contributed to color changes. This aligns with findings from Azer et al.[38], who highlighted that while pigments in food and drinks are external elements, their pH levels significantly impact the extent of color change.

To measure these changes, the study used the CIELAB system, known for its precision, sensitivity, and ability to detect even the slightest shifts in color. The results showed that Filtek Z350 XT underwent more noticeable color changes when exposed to sport and energy drinks compared to Zirconfill BM4. Among the Filtek Z350 XT samples, the energy drink caused the most significant color change at both (baseline – 7 days) and (baseline – 14 days), followed by the sport drink, while deionized water resulted in the least change (P=0.0001). Between (7 days – 14 days), the sport drink caused the highest color alteration, while the difference between the energy drink and deionized water was not statistically significant (P=0.0001). The material's color shifts were primarily influenced by changes in the a* and b* values, making it appear more red and yellow consistent with the synthetic dyes present in both drinks.

This reserach found that Power Horse energy drink had the most significant impact on reducing the hardness of composite materials immersed in it. This is likely due to its lower pH compared to CR7 sport drink, as confirmed by pH and titratable acidity measurements. Higher acidity leads to greater erosion, which can weaken the mechanical properties of composite resin. Among the tested materials, Filtek Z350 XT universal nanofilled composite showed the highest decrease in hardness across all drinks. This could be due to the softening of the composite caused by polymer network swelling and reduced friction between polymer structures, a result of low pH and citric acid's strong erosive effect.

Despite advancements in tooth-colored restorative materials, the findings of this research suggest that consuming sport and energy beverages can negatively impact both the microhardness and color stability of these materials. Clinically, Zirconfill BM4 Restorative was identified as the most suitable option for patients who frequently consume these beverages. While manufacturers of sport and energy drinks promote them as sources of energy and enhanced physical performance, regular consumption may have unintended consequences for both oral and overall health.

The findings of this study align with those of De Souza Aroujo et al. [39] who demonstrated that the presence of nanohybrid particles, such as diatomite and zirconia, in Zirconfill BM4 composite contributed to its higher microhardness values. Similarly, our results support the research by Dos Santos Melo et al. [40], which found that Zirconfill BM4 exhibited significantly better mechanical properties than Filtek Z250 XT and Filtek Z350 XT. Additionally, our results are compatible with AlGhamdi et al. [41], who reported that Filtek Z350 XT showed reduced microhardness values regardless of the storage medium after four weeks. Their study also confirmed that energy drinks had a more damaging impact on microhardness compared to soft drinks.

However, our results contrast with those of Eredemir et al. [42], who found that nanofilled composites exhibited less color change over a six-month period. Additionally, our study does not align with the findings of Nazish Fatima and Mehwish Hussain [43], who reported that Filtek Z350 XT showed less reduction in microhardness over time compared to VitroFil and Vitremer. These discrepancies could be attributed to differences in immersion duration and the amount of storage solution used. In their study, samples were immersed in 10 mL of energy drink for two minutes daily at 37°C, with microhardness testing conducted at various intervals (1 day, 7 days, 14 days, and 30 days). In contrast, our study involved alternating immersion in 25 mL of the storage agent for 5 seconds and 25 mL of artificial saliva for 5 seconds, with 24 cycles repeated over 14 days. Surface microhardness and color changes were measured at both 7 and 14 days, which may explain the differences in outcomes.

This research aimed to replicate the effects of consuming sports and energy drinks on dental restorations. However, there are some limitations that should be considered. The immersion period in these beverages lasted only 14 days, which is relatively short compared to long-term, real-life consumption. In a clinical scenario, only one side of a dental restoration is typically exposed to the oral environment, whereas in this research, the entire sample was submerged, allowing both sides to come into contact with the beverages. Additionally, real-world factors such as fluctuations in pH and heat level in the oral cavity, as well as the natural aging of materials, were not fully simulated. Since this was an in vitro study, it did not account for the impact of other food and beverages consumed daily, which may also influence the features of resin based materials. Therefore, further in vivo research is necessary to better understand the long-term effects of sports and energy beverages on dental restorations.

CONCLUSIONS

Within the constraints of this study, the following conclusions were drawn:

- Repeated exposure to sports and energy beverages significantly affected the surface hardness and color stability of resin based materials, leading to reduced hardness and increased discoloration ($P < 0.05$).
- Energy drinks had a more pronounced impact, causing a greater decrease in surface hardness and a higher degree of color change compared to sports drinks ($P < 0.05$).
- The novel nanohybrid composite Zirconfill BM4, which contains diatomite, demonstrated excellent mechanical properties, high micro-hardness values, and lower susceptibility to discoloration in sports and energy drinks. This suggests that Zirconfill BM4 could be a promising alternative as a filler for nanohybrid dental composites.

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