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Research Article

The Effect of Staining Solution on Colour Stability of Feldspathic Porcelains and Monolithic Zirconia

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ABSTRACT

Background: The great aesthetics and high wear resistance have promoted the ceramics to the most favourable material for dental restorations. However, they are still associated with the complication of discoloration. This study aimed to measure the discoloration of two monolithic zirconia and a feldespathic porcelain immersed in colorant solutions.

Methods: Ceramic disc samples were made of DD Cube X2, DD Bio ZX2, and Vita VMK 95 (each group=48, total 144). The groups were then subdivided into four subgroups (n=12) to be immersed in coffee, tea, sour cherry juice, and distilled water at room temperature for two weeks. The colour was measured at the baseline, 7 and 14 days later. The CIE L*a*b* system was used to calculate the colour changes within 14 days.

Results: Different staining solutions were found to leave significantly different discoloration effects on the tested materials (p 0.001). Moreover, the colour change of each material was significantly different in various staining solutions.

Conclusion: The highest staining potential was observed in coffee, followed by tea and sour cherry juice. Besides, the staining effect was time dependent in all materials and increased over time.

Keywords: Restorative Material, Porcelain, Monolithic Zirconia, Staining, Discoloration

INTRODUCTION

Restoration of smile is one of the most challenging and aesthetically satisfying services a dentist can render to a patient. The smile is affected by several factors like tooth shape, texture, position, and colour. Currently, various types of aesthetic material with different physical characteristics and colours are available. (1-3) Dental ceramics, due to their excellent aesthetics, wear resistance, chemical inertness, low thermal conductivity, diffusivity and well be characterized as tooth sturcure, is one of the most popular dental aesthetic materials.. (4) Because of allergy to metals, metal-free restorations such as full ceramic types are more used currently. (5) The appropriate mechanical properties and biocompatibility of 3 moll% yttrium stabilized tetragonal zirconia polycrystalline (3Y-TZP) makes it suitable to be used as restoration. However the whitish-opaque appearance of 3Y-TZP as well as the metal should be covered with a more translucent ceramic layer. (5-7) The improved translucency and various colouring technologies make it possible to match the natural tooth colour. Thereby, zirconia ceramic is being vastly used in dentistry as a monolithic design. (8, 9) The restoration colour, as the material properties, determines the success or failure of prosthetic treatment. Discoloration of porcelain restoration may be endogenous or exogenous. Chemical instability of the material may lead to endogenous colour change. The exogenous staining may occur due to the ability of the restoration to adsorb or absorb stains in the oral cavity. [10]

Several studies investigated the effects of diet and habits on colour instability of different aesthetic materials. [10-13] Guler *et al.*'s research on composite resin showed that colour changes due to red wine is more than cola drinks, water, tea, and coffee. Moreover, due to the sticky nature of sugar, sweet tea and coffee caused more changes than the sugar-free coffee and tea. They also found that the acidic nature of sports drinks caused discoloration. [11]

Garoushi *et al.* noted that the tea and cola caused, respectively, the most and the least discoloration in composite resins. [14] However, the results of Karaman *et al.*'s research on methacrylate-based composite showed the same colour change in groups of coffee and cola. [15] The research in relation to porcelain has been limited to feldspathic porcelain, so far. Jain *et al.* reported higher staining caused by coffee compared with any other solution. Thus it was concluded that the colour change depends more on the type of immersion solution rather than the restorative material. [10] The purpose of this study was to measure the colour change of two monolithic zirconia with two different translucencies and one feldespathic porcelain faced with staining solutions. The CIELAB colour-difference formula ($\Delta E = [\Delta L2+ \Delta a2+ \Delta b2]$**1/2**) provided numeric data (ΔE) to represent the magnitude of the discoloration in the two objects.

MATERIALS AND METHODS

A total of 144 ceramic samples were fabricated in disc form. They were divided into three groups (n=48) as following; group I (Dental Direkt Cube X2, 49% translucency), group II (Dental Direkt Bio ZX2, 40% translucency), and group III (Vita VMK 95). Each group was then subdivided into four subgroups (n=12) according to the basis solutions used for immersion as following. (Table 1)

For group I and II, 96 disks of 10×0.7 mm (diameter×thickness), were prepared of pre-sintered cube X2 and Bio ZX2 zirconia blank (Dental Direkt GmbH), mounted on the Cercon Brain unit and milled with tungsten carbide burs of 2.8 and 1.0 mm in diameter. Then, the milled ceramic disks were fired at 1450°C for 6 hours. The disks were trimmed, and before cleansing, they were machine-polished to 0.5±0.05mm thickness with wet silicon carbide papers of 320, 400, 600, 800, 1000, and 1200 grades sequentially.(Fig.1)

Fig.1: milled zirconia sample

For group III, 48 wax discs of 10×0.7 mm (diameter×thickness) were prepared. Then the wax discs were investing and casted, following the manufacturer's instructions. The castings were divested and the residual surface investment was removed by sandblasting with 100 µm aluminum oxide abrasive particles. The metal discs were finished with carborundum discs and metal trimmers. Then, they were sandblasted to achieve a uniform final thickness of 0.7 mm for each sample. (Fig2)

Fig.2: metal disks for feldespathic porcelin group

The prepared cast samples were ready to be applied by Vita (VMK 95) porcelain over the cast samples. Two coats of opaque paste were applied, and the ceramic was fired. For the application of dentine layer, the powder and liquid were mixed and a layer was applied over the samples. The enamel layer was, then, applied by using the same technique as for the dentine layer. The samples were fired and finished with a diamond bur to achieve a uniform thickness of 2.5 mm. The samples were finally glazed. The procedures were all performed according to the manufacturers' instruction.(Fig3)

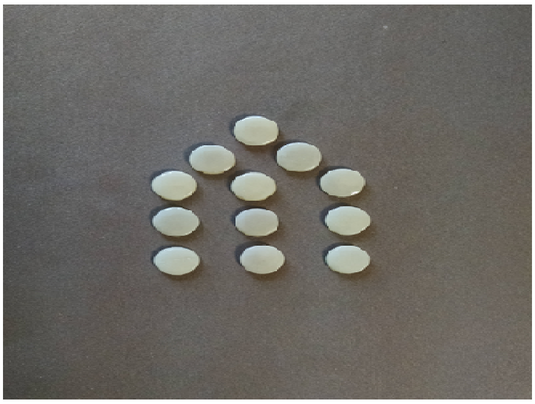

Fig.3: feldespathic porcelain group

To remove any surface remnants, the disks were placed in 75% ethanol in an ultrasonic bath for 10 minutes and then dried. Samples of each group were randomly divided into 4 subgroups to be immersed in coffee, tea, sour cherry juice, and distilled water as the control group. Accordingly, the subgroups were as following; *-W (Control group): Water, *-C: Coffee, *-T: Tea, and *-S: Sour cherry juice (*: I, II or III).

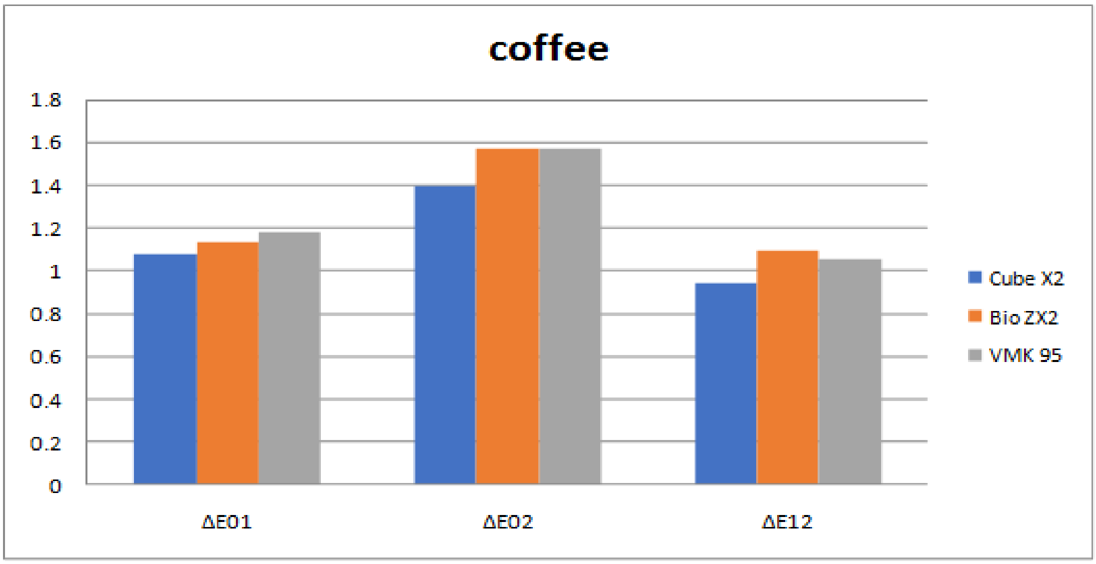

Fig.4 The mean discoloration of each material after immersion in coffee

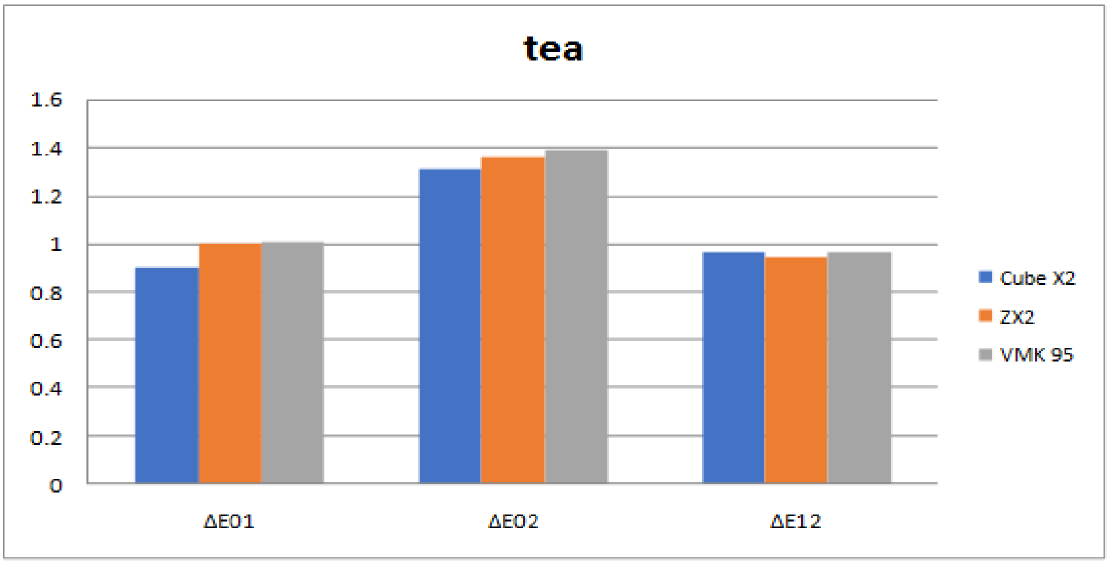

Fig. 5 The mean discoloration of each material after immersion in tea

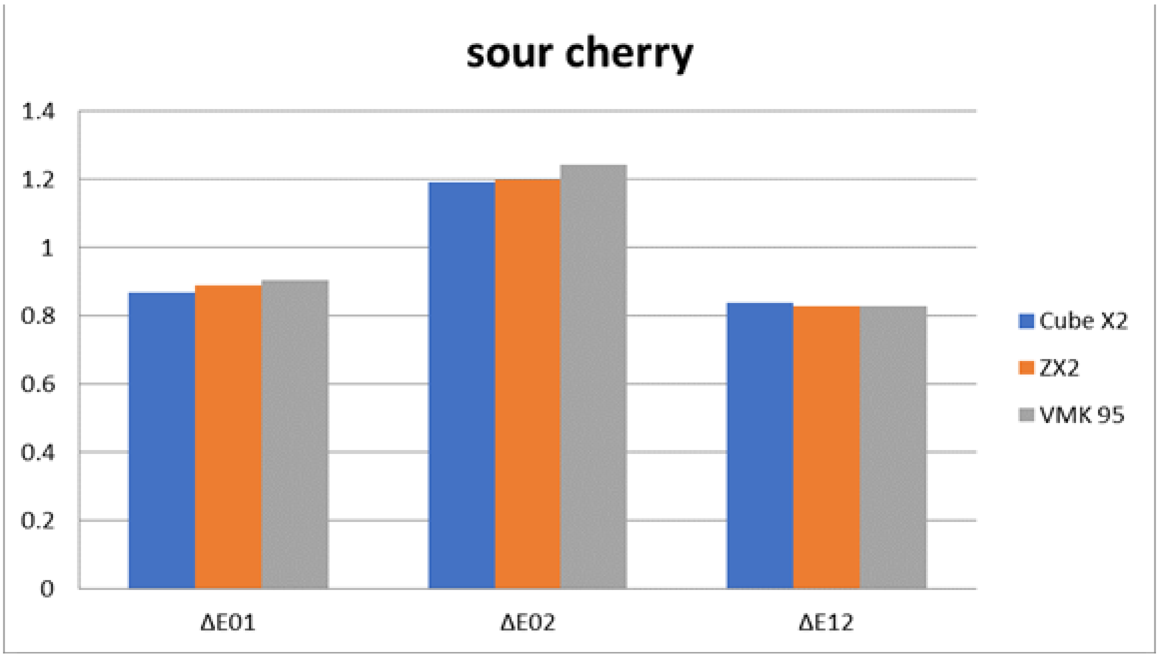

Fig. 6 The mean discoloration of each material after immersion in sour cherry juice

Each sample was immersed in 10ml of liquid at room temperature for two weeks. To prevent evaporation, sealed containers were used and the liquid was replaced daily.

The baseline colour of samples was measured through reflectance spectrophotometry (spectral reflection) according to CIE L*a*b*, by using a calibrated device (SpectroShade, Handy Dental Type, MHT, Arbizzano, Italy). The device had a built-in aiming routine that enabled a reproducible positioning (perpendicular to the sample's surface) to ensure equal measurement conditions for all samples. Before each measurement, the spectrophotometer was calibrated according to the manufacturer's recommendations. The measurements were performed by the same operator under a D65 light source **(**GL OptiLight LED 127 CLC, USA). [16]

CIE L*a*b* is a three-dimensional system in which L represents lightness, a and b describe the chromatic characteristics; i.e., a is the green/red coordinate and b is the blue/yellow coordinate (-a=green, +a=red; -b=blue, b+=yellow). In VMK 95 group, the samples were covered with metal on one side and only one side was exposed. However, in Cube X2 and Bio ZX2 groups, due to the samples shape, both sides of the disks were in touch with staining solutions; it affected the colour as a colored background. In order to eliminate the effect of lower surfaces stain when measuring the colour by spectrophotometer, one side of the samples in Cube X2 and Bio ZX2 groups was polished by 600, 800, 1200 grit disks for 10 seconds; then the colour measurement was performed. The colour measured before immersion was recorded as the baseline. Colour measurement was repeated 7and 14 days later. Before measurements, each sample was rinsed with distilled water and dried with paper.

Numeric data were obtained by using CIELAB colour-difference formula; i.e., ΔE = [ΔL2+ Δa2+ Δb2]1/2; ΔE represented the magnitude of colour-difference between two objects. Three times of colour measurement (baseline, day 7, and day 14) yielded 3 ΔEs; i.e., ΔE01 was from the baseline to the 7^{th} day, ΔE02 from the baseline up to the 14^{th} day, and ΔE12 between the 7^{th} and the 14^{th} day. The obtained data were subjected to statistical analysis by suing SPSS software. Mann-Whitney U test and Kruskal-Wallis were used as appropriated (P>0.05).

RESULTS

This *in vitro* study was performed on 144 samples were made of three types of materials, samples of which were immersed in coffee (c), tea (T), sour cherry juice (S), or distilled water (W) based on the subgroups (Table 1).

Table 1. The study groups and subgroups according to the materials and beverages

Groups according to the materials	Subgroups according to the beverages				
	Coffee	Tea	Sour cherry juice	Water	Total
DD(Cube X2)	12	12	12	12	48
DD(Bio ZX2)	12	12	12	12	48
Vita(VMK 95)	12	12	12	12	48
Total	36	36	36	36	144

Tables 2, 3, and 4 represent the mean and standard deviations (SD) of discoloration (ΔE) between the baseline and the 7th day, the baseline and the 14th day, and the 7th and 14th days. The statistical analyses of ΔE values in each column represent the result of a comparison between the materials in each staining solution, and those at the end of each row show the result of comparisons between the staining solutions on each material.

Table 2. The mean (SD) of discoloration (ΔE) from the baseline to the 7th day

ΔE01	**Coffee**	**Tea**	**Sour cherry juice**	**Water**	**P**
Cube X2	1.0818(.23360) A,a	.9045(.06413) A,b	. 8674(.03924) A,bc	.4153(.29788) A,c	0.001
Bio ZX2	1.1336(.0222) B,a	.9976(.14293) B,b	.8913(.04405) A,b	.4064(.23617) A,c	0.001
VMK 95	1.1785(.10039) B,a	1.0053(.05727) B,b	.9047(.17322) A,b	.3872(.19549) A,c	0.001
p	0.002	0.001	0.164	0.831	

* A: The same superscript capital letters in the same column and the same superscript small letters in the same row mean statistically not significant groups from Tukey's multiple range test (*p*> 0.05)

Table 3. The mean (SD) of discoloration (ΔE) from the baseline to the 14th day

ΔE02	**Coffee**	**Tea**	**Sour cherry juice**	**Water**	**P**
Cube X2	1.3963(.08514) A,a	1.3121(.04819) A,ac	1.1926(.15497) A,bc	.6378(.41361) A,b	0.001
Bio ZX2	1.5715(.02295) B,a	1.3577(.14605) B,b	1.1976(.04000) A,b	.5577(.12591) A,c	0.001
VMK 95	1.5723(.02235) B,a	1.3895(.05354) B,b	1.2412(.15741) A,b	.4839(.11186) A,c	0.001
P	0.001	0.005	0.245	0.433	

* A: The same superscript capital letters in the same column and the same superscript small letters in the same row mean statistically not significant groups from Tukey's multiple range test (*p*> 0.05).

Table 4. The mean (SD) of discoloration (ΔE) from the 7th to the 14th day

ΔE12	**Coffee**	**Tea**	**Sour cherry juice**	**Water**	**P**
Cube X2	.9425(.04642) A,ab	.9638(.03572) A,a	.8383(.23611) A,b	.4910(.40364) A,c	0.001
Bio ZX2	1.0917(.03428) B,a	.9448(.11987) A,b	.8294(.02969) A,b	.3759(.19831) A,c	0.001
VMK 95	1.0560(.08494) B,a	.9670(.03865) A,a	.8298(.06611) A,b	.2919(.19977) A,c	0.001
P	0.001	0.557	0.457	0.169	

* A: The same superscript capital letters in the same column and the same superscript small letters in the same row mean statistically not significant groups from Tukey's multiple range test (*p*> 0.05).

The effect of staining agents

Diff[redacted]ent staining solutions showed significant discoloration between the tested materials (p 0.001). Coffee had the highest staining potential, followed by tea, sour cherry juice. Within the first seven days (ΔE01), there were significant differences between C/T, C/S, C/W, and T/W subgroups in samples made of Cube X2; C/T, C/S, C/W, T/W and S/W in Bio ZX2 samples, and C/T, C/S, C/W, T/W, and S/W in VMK 95 samples. Within the fourteen days (ΔE02), significant differences were observed between the C/S, C/W, and T/W in Cube X2 samples, C/T, C/S, C/W, T/W, and S/W in Bio ZX2 samples, and C/T, C/S, C/W, T/W, and S/W in VMK 95 samples. Measuring the discoloration from the day 7 to 14 (ΔE12) revealed significant differences between C/W, and T/W in Cube X2 samples, C/T, C/S, C/W, T/W, and S/W in Bio ZX2 samples, and C/T, C/S, C/W, T/W, and S/W subgroups in VMK 95 samples.

The effect of materials: The colour changes of each material immersed in coffee, tea, and sour cherry juice from the initial measurement up to 14 days of storage are shown in Figs. 4, 5 and 6. The VMK 95 group showed the highest staining susceptibility followed by Bio ZX2 and Cube X2. In ΔE01 there were significant differences between I/II, and I/III groups in coffee subgroups, I/II, and I/III groups in tea subgroups. In ΔE02, significant differences were observed between I/II, and I/III in coffee subgroups, I/II, and I/III in tea. In ΔE12, the differences were significant between I/II, and I/III in coffee subgroups.

The effect of time

The effect of staining was time-dependent in all groups; i.e., staining increased as the time passed. The samples showed more instability in the first 7 days of immersion. In most subgroups like I-C, II-C, III-C, II-T, III-T, I-S, II-S, and III-S, the ΔE01>ΔE12; however the I-T was the only subgroup with higher discoloration in the second 7-day period.

DISCUSSION

Due to its natural appearance and colour stability, porcelain has been established as an aesthetic restorative material. One of the primary factors contributing to the failure of these restorations is discoloration, which is undesirable for both patient and the dentist.

Discoloration of the restorative materials has been attributed to both intrinsic and extrinsic factors. Intrinsic factors include the changes within the material itself; while, the extrinsic factors include staining by adhesion or penetration of colorants as a result of contamination from exogenous sources such as coffee, tea, and other stain-producing beverages and solutions. [17] Several studies showed the effect of diet and habits on discoloration of different materials. [10-14]

Colour determination in dentistry is performed visually and instrumentally. Instrumental colourimetry can potentially eliminate the subjective errors. Colourimetry is more exact than the naked eye in measuring slight differences in colored objects on flat surfaces. [18] The CIE Lab system was chosen for measuring the chromaticity and recording the colour differences since it is so precise that and well suited that determines the minor changes in colour. [19]

The ΔE<1 is not perceptible to most subjects with normal colour vision. Meanwhile, the restorations with a ΔE as high as 3.3-3.7 require replacement as such a discoloration is clinically perceptible. [20, 21] The measured colour depends on both the actual colours of the surface and the lighting conditions. In the present study, according to koishi article, a standard light was used against a white background. [11, 22]

The effect of the background on colour perception is a controversial issue as mentioned in the literature. White background is widely used as a standard background. [23, 24] Alharbi *et al*. reported a significant difference between ΔE values measured against white and black backgrounds; being higher against white ones. [25] Nevertheless, Ardu *et al*. in their recent study declared the black background as the ideal background for the anterior teeth, compared with grey and white ones. [26] The present study made use of white background to prevent the effect of the stain on the other sides in measuring; mentioning that one side of the samples in monolithic groups were polished before measurement.

Within the testing conditions of this *in vitro* study, the ΔE values of all the studied materials were below 3.3 in all colorant solutions. It was lower than what was reported by Jain et al. [10] The difference could be due to the different immersion periods, which was 90 days in Jain et al.'s research and 14 days in the present study.

Regarding the staining intensity, coffee had the highest staining potential compared to sour cherry juice and tea. These results were similar to the previous investigations. [10, 11, 27] Besides, Jain evaluated the coffee, tea, and water at 50±1°C, and coca cola and orange juice at room temperature, which can justify the higher discoloration caused by coffee. [10] While, the effect of temperature on colour stability was eliminated, since all the solutions were assessed at room temperature.

In the current study, the highest discoloration in all materials and all the timespans was observed in coffee subgroups, followed by tea and sour cherry juice. It was in agreement with the findings of previous studies.(11, 23, 28)

Nonetheless in this study, ΔE12 was the highest for the tea in Cube X2 group; the same as what was reported by Garoushi *et al*. for composite resins. [14]

Because of the significance of colour stability in aesthetic dental materials, several studies have been performed on these materials. In a study by Guler *et al*. on composite resin, discoloration in red wine was higher than the other solutions; this could happen due to the softening effect of alcohol on composite resins. They also checked the effect of sugar since they had separate groups of coffee and tea with or without sugar. The discoloration was higher in sugar-containing groups due to the sticky nature of sugar. [11]

Alharbi *et al*. reported the same result; i.e., the red wine made the most change in the colour of CAD/CAM direct resin composites.(25) However, Karaman *et al*. found that cola and coffee caused the same changes in silorane and methacrylate-based composite resins.(15)

In the current and some other studies, the rate of colour change increased over time. However, there were several studies in which the subgroup with higher discoloration was not affect by time.(28-30) Crispin *et al*. noted that at the end of the first month, the discoloration was the highest in coffee and tea groups; whereas, at the end of the second month the grape juice group caused the greatest colour changes.[31] In the present study, the staining was the highest in the coffee group. In fact, within the first seven days (ΔE01) in Cube X2, coffee caused more changes in colour, but in the final seven days (ΔE12), tea caused the highest staining.

yannikakis *et al*. reported that all the provisional resin restorative materials had observable colour changes (>3.3) after 7 days of immersion. [28] But in the present study, discoloration of all samples was below 3.3; which is due to the materials structure. Some studies showed that ceramics were colour resistant in comparison with resin composites. [25, 32] According to Samra *et al*., the discoloration was higher in both direct and indirect resin composites than in porcelains. [32]

Researches about resin composites proved that colour change depends on the amount and type of resin due to the higher susceptibility of water absorption.[14] Ertas *et al*. found that the discoloration of microhybrid resin composite was less than that in nanohybrids.[27] Moreover, Bis-GMA-based resin composites were found to undergo more colour changes than UDMA-based resin composites.[14]

In the present study, feldspathic porcelain used in PFM (porcelain-fused-to-metal) was less stain-resistant compared to monolithic zirconia in most staining solutions. However, colour measurement from day 7 to 14 showed that Bio ZX2 group was the least stain-resistant; which might be due to the difference in the materials structure. Except for the tea subgroups from 0 to 7 days, and coffee from 0 to 14 days and 7 to 14 days, there were no significant differences between the studied materials. However, the discoloration rates were all below 3.3; so, the discoloration was clinically acceptable in all the study groups.

CONCLUSION

The results of this study showed the highest staining potential in coffee, followed by tea and sour cherry juice. Besides, the staining effect was time dependent in all materials and increased over time. The discoloration rates were all below 3.3, which were clinically acceptable.

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