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Color stability of different zirconia ceramics for crowns with feather edge preparations after aging.

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Abstract:

Background: to evaluate the color stability and marginal gap of different types of zirconia crowns with two preparation designs.

materials and methods: two upper left centrals typodonts were prepared with two different preparation designs; vertical preparation and horizontal preparation with shoulder finish line0.5mm depth. Each typodont was scanned for designing full coverage crowns and duplication to 3D printed dies (n=21).21 crowns were milled for each preparation design and furtherly divided according to the material into three groups(n=7) as follows; zirconia YZ XT, IPS e-max zircad prime and vita suprinity then each crown is cemented to its corresponding die.

Marginal gap analysis for both vertical and horizontal crown samples were measured using stereomicroscope with (300X) power. Color analysis of the crowns was performed by means of Agilent Cary 5000 spectrophotometry before and after 5000 thermal cycles to calculate ΔE, the data were analyzed statistically significant using two-way anova at significance value ($p \leq 0.05$).

Results: the type of the material($p<0.001$) as well as the preparation type($p=0.004$) resulted in significant change in ΔE, zircad crowns with horizontal finish lines showed the highest color stability with $\Delta E=2.51$, regarding the marginal gap analysis the preparation type only showed significance ($p<0.001$) with higher gap values to vertical preparations samples.

Conclusion: the color stability before and after thermocycling is affected with both the type of material and preparation type, yet the marginal gap only affected by the preparation type with no correlation with color stability.

Key words: color stability, marginal gap measurement, monolithic zirconia, Verti preparation.

Introduction:

Over the past four decades, there have been significant technological advancements in dental ceramics.[1]. As with all contemporary restorations, zirconia ceramic monolithic crowns target the optimum shape, function, and color of natural teeth. The objective nowadays of different studies is to evaluate monolithic translucency and to what extent recent generations have achieved aesthetic optimization.

Dental Zirconia can be divided into three main groups based on the concentration of yttria. The initial group is the most rigid, consisting of 3 mol.% Y-TZP (predominantly tetragonal). The second group, comprising 4 mol.% Y-TZP, possesses greater transparency, while the third group contains 5 mol.% Y-TZP and displays reduced mechanical properties. The variation in mechanical and physical characteristics within each Zirconia class is influenced by the mole percentages. Opaque Zirconia, with approximately 3 mol.% yttria (85-90% tetragonal phase), is the strongest. Transparent Zirconia, with around 5 mol.% yttria exhibits approximately 50% cubic phase.[2]

This most recent innovation of 50% cubic zirconia (zirconia YZ XT) is used in several clinical applications, ranging from singular anterior crowns to three-unit bridges. [3]

Further development in manufacturing technology was performed in gradient technology, utilizing of a single blank comprising diverse generations of zirconia was adopted to attain the advantageous attributes of conventional and extra-translucent zirconia. This approach combines the esteemed high-flexural strength 3Y-TZP in the dentin/body region, which augments stability, with the high-translucency 5Y-TZP in the incisal or occlusal area, thus improving appearance.[3] similarly, since 2016, manufacturers incorporated lithium disilicate with zirconia particles to gain benefit from both materials by launching Vita Suprinity ceramic material.[4]

The longevity of monolithic zirconia crowns is influenced by various factors related to tooth preparation, such as total occlusal convergence (TOC), presence of undercuts, amount of occlusal reduction, finish line form and depth, line angle form, and surface texture. In the case of computer-aided design/computer-assisted manufacture (CAD/CAM) crowns, additional principles become important. These include the quality of the finish line form, the line angle form, and the design of the occlusal surface preparation (anatomical, semi-anatomical, or non-anatomical).[5]

There are two main approaches for tooth preparation: Horizontal preparation (preparations with defined margins) and vertical (or feather edge) preparations. [6]

the horizontal preparation technique with chamfer and shoulder finish lines has been widely accepted as the preferred method for preparing the teeth to receive all-ceramic restoration, yet the introduction of high-strength polycrystalline materials has permitted the use of vertical preparation as a less extensive alternative to the traditional horizontal approach (chamfer and shoulder). Vertical margins offer the advantage of providing the most conservative restoration with minimal removal of sound

tooth structure. This is particularly important for vital teeth and teeth with root canal fillings, as it helps reduce stress on the abutment tooth when restored with a crown.[7]

For the horizontal preparations, several margin designs have been utilized, such as the chamfer margin, which adds volume to the cervical limit. Also, the shoulder margin, one of the oldest cervical limits, with various angulations (90 degrees, obtuse angles of 120 to 135 degrees, and rounded internal angles with or without a bevel. For the vertical preparations, also known as a shoulder-less approach, is a technique where the abutments are prepared by using a diamond rotary instrument in the sulcus to remove the cementoenamel junction and establish a new prosthetic cementoenamel junction determined by the prosthetic margin.[8]

Color stability is an inevitable factor in prothesis success. The quality and life span of dental prothesis depend partially on the color stability of the restoration .[9]

The final color and the translucency of the highly translucent zirconia restorations not only influenced by the restoration thickness due to different finish line design but also with tooth shade background as well as the type of ceramic material selected [9]

clinical implementation for full crown preparations, the Verti preparations are the future of highly translucent full coverage crowns not only for the conservation of tooth structure but for the color stability and optimum translucency of the restoration [10,11]. Use of monolithic zirconia for fabrication of all-ceramic crowns eliminates several drawbacks of layered zirconia crowns.

Long-term success of prothesis highly depends on the marginal fit. The crown thickness is one of the most important factors that affect marginal integrity. The marginal fit is affected by several factors such as different preparation designs, fabrication methods, sintering techniques, and CAD-CAM systems.[12]One of the influencing factors is the material thickness, Controversies exist about the effect of zirconia thickness on the marginal fit of zirconia-based crowns.[12,13].Conclusively the color stability as well as the marginal gap both affected with the preparation type and the restoration thickness as well as type of ceramic material used [14]

Due to the aforementioned reasons, these materials were selected to assess their color stability before and after thermocycling with different finish line preparations with correlation with the marginal gap regarding each preparation design.

The aim of this study:

1.To determine the effect of change in preparation design and different zirconia crown material on color stability after aging.
2.evaluating the marginal gap of different zirconia crown material with different margin designs.
3.determining the correlation between color stability and marginal gap.

The null hypothesis of this study was that there would be no difference in color stability nor the marginal gap by varying the type of zirconia crown material or the preparation.

Materials and methods

Sample preparation:

Two upper left central typodont were prepared for a full coverage crown with two finish line designs. The first one was prepared with horizontal preparation design with 90° shoulder finish line (0.5mm depth) were prepared using diamond burs flat end cylinder. The axial wall was 12° convergent. The other typodont was prepared with vertical preparation design using a batt bur with a 1 mm noncutting end to utilize 8° taper.

To achieve standardization, preparations were performed with the same operator using a dental surveyor (AF 30 Nouvag AG, Switzerland) with straight hand piece for axial wall preparation for each sample to ensure consistent degree of taper [15].

The two typodonts were finished by rubber cups followed by scanning with a laser scanner (3 Shape D810; 3 Shape, Copenhagen, Denmark) to digitize the dies. The data was transferred to computer software exo-cad in lab designing software (EXOCAD, GmbH, Darmstadt, Hessen, Germany) for designing a model for each typodont.

The digitalized dies were transferred to a 3D printer (Any cubic, any cubic technologies, hongkong) to print the model for each die type with polyetherimide resin (pro shape digital solutions,Cairo,Egypt)The designed shade A2 models were subjected to an accuracy check with the help of a digital protractor and a stereomicroscope (Amscope, CA, USA).

All models were first powdered using the scan spray (VITA CEREC; Bad Sackingen, Germany) with the aid of a propellant that offered an even, thin powder layer. Then scanned by DZ Mizer extra oral scanner for generating STL files which were then transferred to CAD software (EXOCAD, GmbH, Darmstadt, Hessen, Germany) for designing the crowns with the same parameters [16]

Crown fabrication was done Using a 5-axis computerized numerically controlled (CNC) milling machine (Shera eco-mill 5x). (14) zirconiaYZ_XT and (14) IPS zircad prime crowns divided evenly according to the type of their respective materials CAD/ CAM blanks under dry milling. To eradicate any potential effects of translucency on color measurement, all specimens were obtained in the same

color (shade A2) across all materials. To standardize the surface quality, 600, 800, and 1200 grit silicon carbide paper was used to refine all sides of the crowns for 60 seconds after milling.[17]

Zirconia YZ-XT, Ips e-max zircad prime crowns were then rapidly sintered with IvoclarVivadentProgramat S1 Sintering Furnace (Fürstentum, Liechtenstein) as per manufacturer instructions. The specimens were then cleaned with steam. Ultra-fine diamond bur (Diamond bur; Microdont) was used for surface smoothing under water cooling using a high-speed dental micro motor and standard movements followed by glazing (Ivocolorfluor, Ivoclar, Schaan, Liechtenstein). The burs were changed after three specimens and then rubber abrasive cups were used.[17]

While For vita suprinity crown samples, 14 crowns(n=7) for each finish line type were milled under wet milling using (Shera eco-mill 5x) milling machine then the crowns further crystallized using a ceramic furnace (programat p310, ivoclarvivadent) as per manufacturer instructions to accomplish full crystallization.[18]
Materials details and specifications are on table (4).

Marginal gap analysis:
Marginal gap measurements were taken before cementation. Measurements were taken by connecting a stereo microscope to a PC with a USB with 300× magnification Amscope, CA, USA. Using the definition of the marginal gap the perpendicular distance from the margin of the finishing line preparation to the margin of the restoration were measured [19]. The digital microscope was positioned so that its long axis lined up with the long axis of the tooth. The handle was secured, preventing it from being changed vertically without altering the microscope's horizontal tilt. Image-processing application (Image J 1.50i, USA) allowed for the measurement of the marginal gap in pixels after Dino-capture software 50i was used to process two photographs for each surface of the tooth sample. The measurements were taken at four spots on each tooth's surface [20]. The largest gap was selected to reflect the sample's marginal gap [21]. All measurements were carried out by the same researcher. All estimated measurements were transformed from pixels to µm.[22] figure (1)
The mean ± standard deviation (SD) values were calculated for each sample.

The crowns were cemented to corresponding 3D printed dies with transparent self-adhesive resin cement. (breeze self- adhesive resin cement). The cement was injected into the respective crowns using the Auto mix syringe system, as provided by the manufacturer, and removal of excess cement was done with a scalier tip and cotton pellet. Each crown was subjected to a standard load of 5.0 newton (N)to optimize standardization.[23,24] figure (2)

Color analysis:

Specimens were chromatically analyzed using (Agilent gray 5000) spectrophotometer (Agilent technologies, USA) for color coordinates calculation (L, A, B). All the crowns were exposed to the light at the same location throughout the study period. The calibration parameters of the spectrophotometer included a slit of 1.5 nm, a scan speed of 600 nm/min, light range of 300–900 nm (visible and ultra-violet) with a data interval of 1 nm, resolution 0.02/nm and dwell time of 0.1 s. We used an internal diameter of 110 mm. For calculation, we used the wavelengths in the range of 380–700 nm (visible light) [25]. The Integrated Sphere accessory can measure both the diffused and specular light waves, meaning that no light will be lost in our measure. [25]

The measurements were established in mathematic coordinates referred to the international color space Commission Internationale de l'Eclairage L* a* b*. For each crown, three readings at the labial surface cervically were taken. The average L*, a*, and b* values for the three readings were calculated and tabulated as the baseline color measurements [26]

Aging of the specimens:

After initial color measurements, samples were individually immersed in Thermocycler (SD mechatronic, feldkirchen-westerham, Germany) all crowns were subjected to cold water bath immersion for 30 seconds at 5 degrees and hot water bath immersion for 30 seconds at 55 degrees dwell time 10 seconds for 5000 cycles for 5 days equivalent to 6 months intra oral.[27]

After the aging process, new color measurements were performed in the same way as described previously, the color stability of the restorations was calculated using the formula.

$$\Delta E=\sqrt{(L1-L2)} +(a1-a2)2+(b1-b2)2$$

Statistical analysis:

Numerical data was represented as mean and standard deviation (SD) values. Normality and variance homogeneity assumptions were validated by viewing data distribution and by using Shapiro-Wilk's and Levene's tests respectively. Data were analyzed using two-way. ANOVA. Statistical analysis was performed with R statistical analysis software version 4.3.2 for Windows1.

Results:

Results of two-way ANOVA presented in table (1), showed that for color change there a was a significant interaction between both tested variables (p=0.012), while for marginal gap only the effect of preparation type was statistically significant (p<0.001). Summary statistics and Comparisons of simple effects for color change are presented in table (2) and in figure (3) . Results showed that, regardless of preparation type, there was a significant difference between tested materials with Vita Suprinity samples having the highest change, ΔE followed by Vita YZ XT Zirconia and with the lowest color change found with Zircad (regular) (p<0.001). For Vita Suprinity, color change measured in samples with vertical preparation was significantly higher than those with horizontal preparation. While for other materials, the difference was not statistically significant (p>0.05). Summary statistics and comparisons of main effects for marginal gap are presented in table (3) and in figure (4). Results showed that samples made with vertical preparation had significantly higher gap values (p<0.001) and that there is no significant difference between materials regardless the preparation design(p=0.476). There was no significant correlation between color change and marginal gap values (rs=0.218, p=0.247). Scatter plot for the correlation between both variables is presented in figure (5)

Discussion:

The objective nowadays to the different studies evaluated monolithic ZrO2 translucency and to what extent its recent generations have achieved aesthetic optimization.[3] As with all contemporary restorations, zirconia (ZrO2) ceramic monolithic crowns target the optimum shape, function, and color of natural teeth [4]

In this study, we compared the cumulative effect of material type, preparation type, and thermocycling on color stability and marginal gap of zirconia crown before and after cementation and thermocycling.[28]

Tooth preparation with horizontal finish line requires aggressive tooth reduction at the cervical area which affects the remaining tooth structure [29]. Therefore, more conservative preparation design such as Verti preparation or biologically oriented preparation technique (BOPT) might be needed to save tooth structure at the cervical area [12] , the Verti preparations are the future of highly translucent full coverage crowns not only for the conservation of tooth structure but for the color stability and optimum translucency of the restoration Łabno(2020)[11]andCarlos A. Jurado(2024) et al.[7] claimed that the color and the translucency of the highly translucent zirconia restorations was influenced by both

restoration thickness and tooth shade background[6].The selection of the A2 shade of the 3D printed model and milled crowns in the present investigation was based on its prevalence as one of the most commonly observed tooth shades. [30]

Measurement of color was calculated with ΔE1976 because it's the most commonly used in color measurement and Various studies on acceptable ΔE and ΔE00 values in clinical and in vitro studies have been published [31], Agilent cary 5000 spectrophotometers for optimum color measurement with low percentage of errors& record minute color change.Perroni AP(2017) [32]

Marginal gap analysis was done using stereomicroscope for 300X magnification before cementation as the cement layer has been reported to interfere with measurements of the gap due to variations in cement type and cementations techniques [31].

The null hypothesis was rejected.

Regarding the results of color stability, zircad crowns had the best color stability results with ΔE (2.51) this was explained by the gradient technology as a multi composition material which help in natural light performance and the effect of the chemical composition of each type on the microstructure.[32]

The ΔE value indicates the extent of color change: 0-2 signifies no observable color change, 2-3 indicates a slight change, and 3-8 or higher suggests a noticeable color change. Values of ΔE equal to or below 3.7 are considered clinically acceptable [33], which makes the IPS e-max zircad prime (2.51) and zirconia YZ XT (3.10) within the acceptable range.

The preparation type considered insignificant for all tested materials except for vita suprinity, vertical preparations samples were higher in color change than horizontal samples. vita suprinity had least color stability as well, the significant color change may be related to its zirconia content. Zirconia may undergo phase transition from tetragonal to monoclinic phases when it is contained in water (low thermal degradation). This will be accompanied by displacement of particles from the surface of the material, leading to surface roughness and the infiltration of the solution into the material. This transformation can occur after a week of exposure [34] beside the glazing procedure, high temperature exposure, and the high crystalline content. Moreover, the presence of metal oxide in the Vita Suprinity may have resulted in the increased color change.[35]

regarding thermocycling, there is significant color change in color before and after aging in all tested materials, these results was in agreement with Aljanoubi et al(2020)[36]as well, but in contrast to hamza et al.(2017)[37]that all thermocycling didn't have significant effect on ΔE.

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Regarding the marginal gap results, it was affected by the preparation type with more gap values related to vertical preparation which was in accordance with Jalalian et al(2014)[38] who found that increasing the zirconia core thickness reduces the marginal gap. These results are in agreement with Comlekoglu et al(2009)[39]and Almahdy et al(2022)[40] but in contrast with Nasir mq(2023)[41] as he concluded that the vertical preparation design illustrated better marginal adaptation than the horizontal preparation design, this may be due to milling discrepancies and scanner accuracy. While Eldamaty et al(2020)[42] concluded that there no statistically significant differences in the marginal accuracy of monolithic zirconia crowns with chamfer and vertical margins this may be attributed that they used metal dies.

Marginal gaps that were less than 120 µm were considered clinically acceptable as claimed by Nizaroglu et al(2024)[43], Our results revealed that the marginal gap was 121.35±6.81 µm when vertical preparation is applied and 102.30±7.08µm for horizontal preparation making the letter in the clinically acceptable range and the vertical preparations slightly inacceptable.[44]

Limitations:

Mentioning the limitations of This study, it was carried out in vitro with typodonts as the substrate, which may vary in size and form from natural teeth. Even though in vitro studies can provide controlled conditions, other aspects associated with the aging of the restoration, such as low-temperature degradation and stress-induced toughening of zirconia as well as the presence in oral cavity due to the presence of saliva. Plus, under clinical conditions, as the restorations are bonded to the tooth, they are exposed to the staining liquids unequally. Additionally, oral hygiene maintenance habits (toothbrushing, use of mouthwash) could also affect the color stability of restorations in vivo.[44]

Figures:

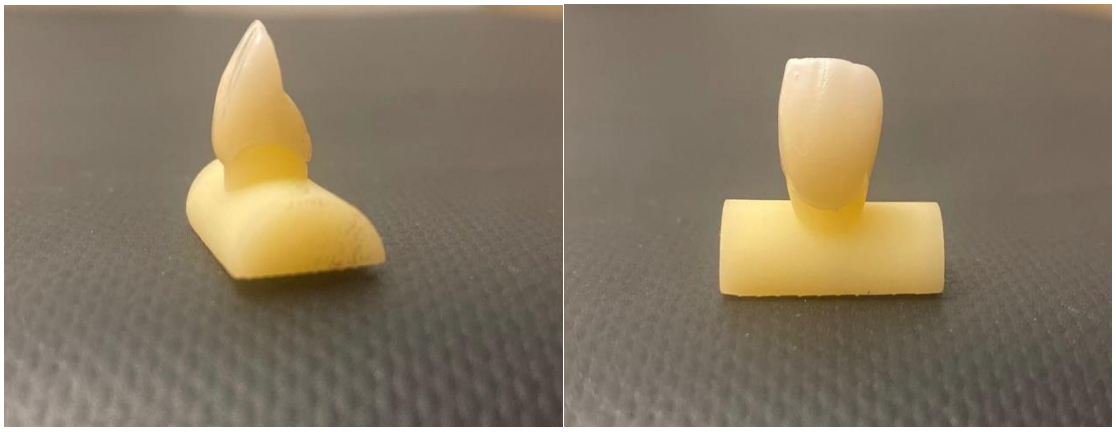
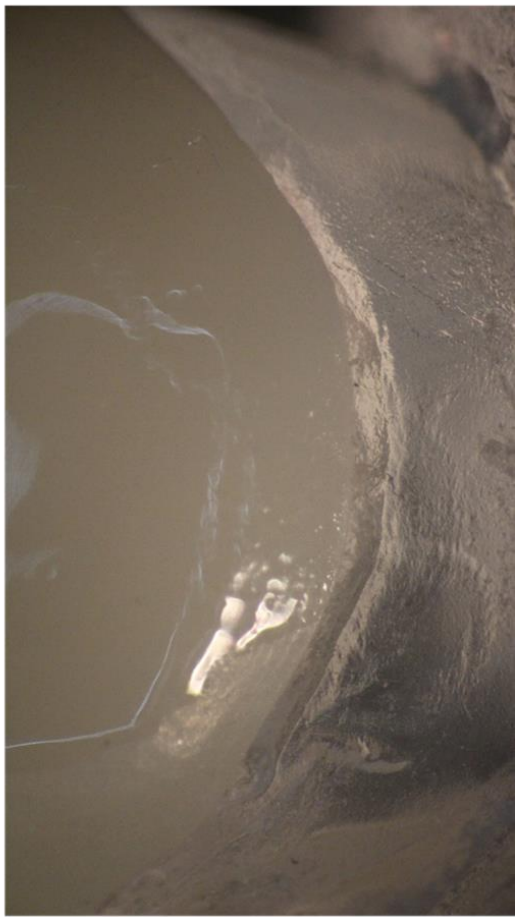


Figure (1): milled crown checking over 3D printed die prior cementation procedure.



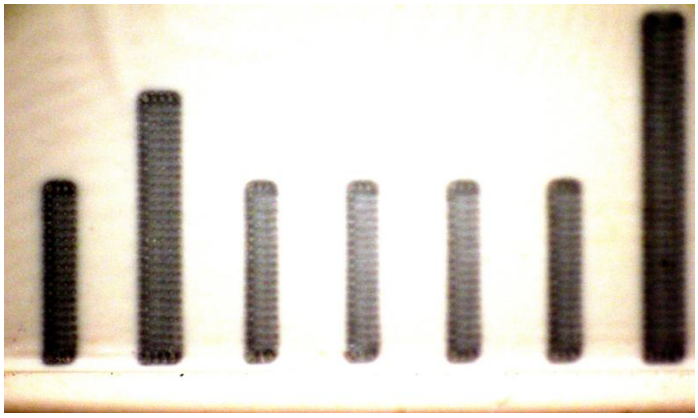


Figure (2): marginal gap analysis under X300 stereo microscope with measuring caliper.

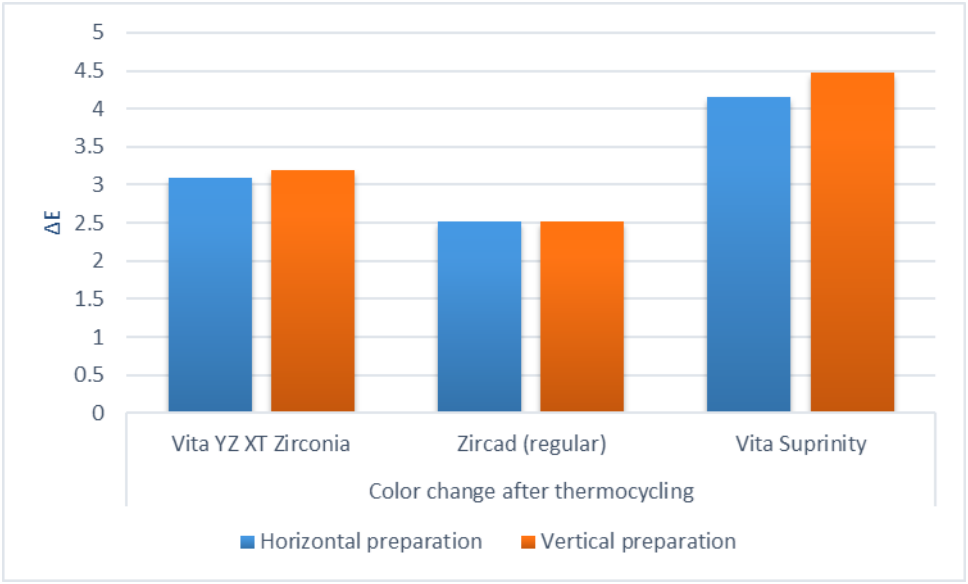


Figure (3): Bar chart showing average color change (ΔE) after thermocycling for different materials and preparation designs (B)

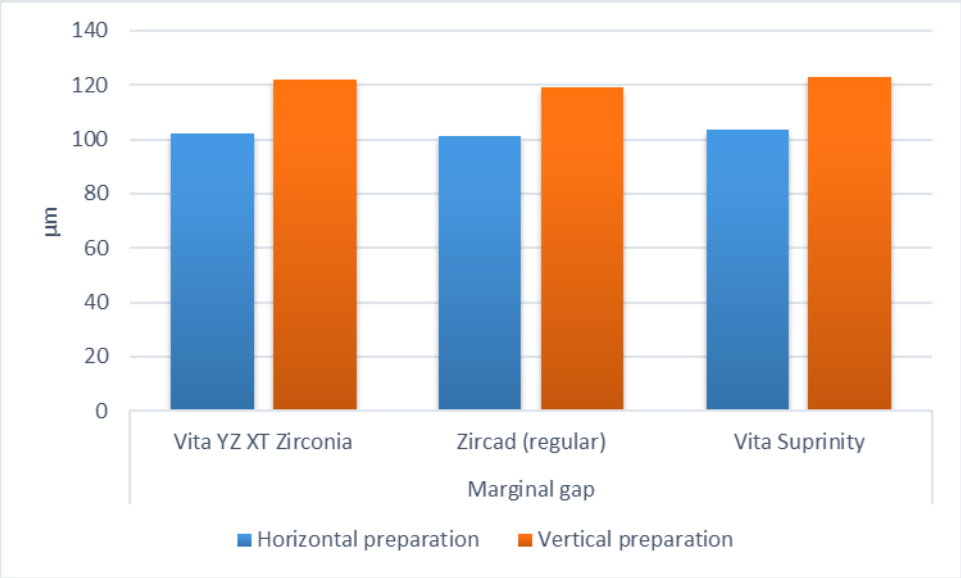


Figure (4): bar chart showing average marginal gap for different materials and preparations designs

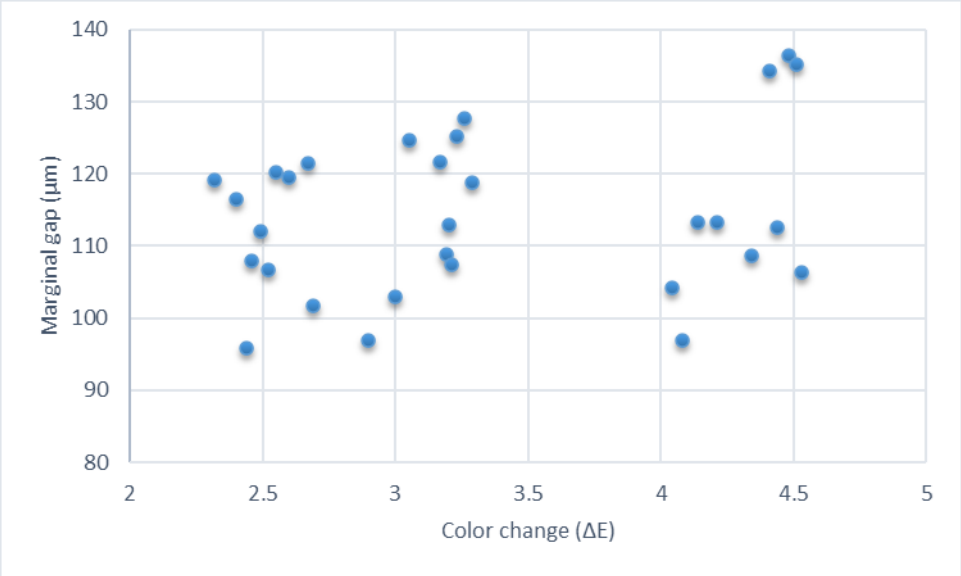


Figure (5): Scatter plot showing the correlations between color change and marginal gap.

Tables:

Table (1): Two-way ANOVA test results for color change (ΔE).

Measurement	Parameter	Sum of squares (II)	df	Mean square	f-value	p-value
Color change (ΔE)	***Material***	16.74	2	8.37	**658.17**	**<0.001***
	Preparation	0.13	1	0.13	**10.48**	**0.004***
	Material* Preparation	0.14	2	0.07	**5.32**	**0.012***
Marginal gap (µm)	***Material***	76.61	2	38.31	**0.76**	**0.476**
	Preparation	4352.35	1	4352.35	**85.84**	**<0.001***
	Material* Preparation	13.41	2	6.70	**0.13**	**0.877**

*Significant ($p<0.05$).

Table (2): Summary statistics and simple main effects comparisons for color change

Material / Preparation	Color change (ΔE) (Mean±SD)			f-value	p-value
	Vita YZ XT Zirconia	***Zircad (regular)***	***Vita Suprinity***		
Horizontal	3.10 ± 0.14^{B}	2.52 ± 0.10^{C}	4.16 ± 0.12^{A}	**272.56**	**<0.001***
Vertical	3.20 ± 0.09^{B}	2.51 ± 0.14^{C}	4.47 ± 0.05^{A}	**390.93**	**<0.001***
f-value	**1.97**	**0.03**	**19.13**		
p-value	**0.226**	**0.882**	**<0.001***		

Values with different superscript within the same horizontal row are significantly different

*Significant ($p<0.05$)

Table (3): Summary statistics and main effects comparisons for marginal gap.

Parameter		Marginal gap (µm) (Mean±SD)	f-value	p-value
Material	***Vita YZ XT Zirconia***	112.10±11.78	**0.76**	**0.476**
	Zircad (regular)	110.16±10.35		
	Vita Suprinity	113.22±13.68		
Preparation	***Horizontal***	102.30±7.08	**129.99**	**<0.001***
	Vertical	121.35±6.81		

Table (4): different materials used in the study

Table (4): Different materials, brand name, manufacturer and composition used in the study.

Material	Brand name	Manufacturer	Composition	Lot number
Extra translucent ZrO_2.	Vita YZ-XT Zirconia	VITA Zahnfabrik, Bad Säckingen, Germany	ZrO_2 (86 - 91 %), Y_2O_3 (8 - 10 %), HfO_2 (1 - 3%), Al_2O_3 (0 - 1%) and pigments (0 - 1%).	XZM21 29004
Multi-layered ZrO_2	IPS e.max® ZirCAD Prime	Ivoclar Vivadent, Zurich, Switzerland	ZrO_2 (88.0 – 95.5 %), Y_2O_3 (> 4.5 % – ≤ 7.0 %), HfO_2 (≤ 5.0%), Al_2O_3 (≤ 1.0%) and oxides (≤ 1.5 %)	Z03M3 3
Zirconia reinforced lithium silicates	Vita suprinity	VITA Zahnfabrik, Bad Säckingen, Germany	ZrO_2 (8-12 %), SiO_2 (56-64%), Li_2O (15-21%), La_2O_3 (0.1%), pigments (<10%) and various (>10%)	66613

Duel cured resin cement	**Breeze** resin cement	Breeze Pentron USA	Mixture of BISGMA ,UDMA,TEGDMA,HEMA&4-MET resins , silane treated barium-borosilicate glasses ,silica with initiators ,stabilizers &UV absorber ,organicand inorganic pigments ,opacifiers	609425

Conclusion:

With limitations of this study, the following conclusion can be drawn:

1.color stability before and after thermocycling is affected with both the type of zirconia crown material and preparation type.

2.zirconia crown with horizontal preparations has less marginal gap than with vertical preparations.

3.no correlation between marginal gap and color stability.

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Ethical matter:

This research has been exempted from ethical reviewing as it’s quite laboratory research i.e no patients or experimental animals.moreover,the research does not include any human samples.

the exemption of research ethics committee auditing for master’s degree no. is (FDASU-Rec IM092202)

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