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FLEXURAL STRENGTH, SHEAR BOND STRENGTH, AND COLOR CHANGE OF VENEERING DENTAL PORCELAIN MODIFIED BY SILVER NANOPARTICLES ON ZIRCONIA AND METAL CORES

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ABSTRACT

Aim: Evaluation the effect of modification of veneering porcelain bonded to metallic and zirconia cores by silver nanoparticles (SNP) on flexural strength, shear bond strength (SBS), and color change. **Materials and methods:** A total of sixty samples were constructed and divided into two groups in accordance with the core material type (n=30). Group I: Zirconia core, while group II: Metal core. Each group was classified into 3 sub-groups (n=10) in accordance with the test performed: flexural strength, SBS, and color change, each subgroup was subdivided into two classes (n=5), according to incorporation of SNP. A control class (class I) and Class II: Modified samples. Fracture strength and SBS were tested utilizing a universal testing machine, while color change was measured using a spectrophotometer, Data were tabulated and analyzed statistically. **Results:** Flexural strength test results showed a significant increase in modified classes on both metal~~lic~~ and zirconia cores (2904±76.4, 1318±58.1MPa) compared to unmodified classes (2542±71.9, 1066.8±47.2 MPa) respectively. Where SBS mean values showed a significant increase in control classes for both metal~~lic~~ and zirconia cores (42.5±0.5, 27.6±0.4 MPa) compared to modified classes (41.4±0.5, 25.7±0.3) respectively. Color change results showed significantly higher mean values (ΔE=10.75±1.1) in Zirconia core group than those in metal group (1.65±0.6). **Conclusions:** Incorporation of SNP into the veneering porcelain significantly increased flexural strength in both groups while SBS was significantly decreased. Color change of veneering porcelain on metal core was within the acceptable clinical range, while on zirconia core showed higher mean values & was not clinically accepted.

KEYWORDS: Silver nanoparticles, flexural strength, color change, shear bond strength, veneering porcelain, zirconia core, metal core

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INTRODUCTION

The usage of porcelain in esthetic dentistry aims to create cosmetic restoration in order to fulfill the aspired optical transparency. Nevertheless, in terms of porcelain requirements, they must meet more than cosmetic standards; also, it needs to be adequately strong in order to bear the functions of mastication and to have durability. [1]

The incorporation of bioactive agents to limit both microbial destruction and recurrence of caries meanwhile sustaining the capability of load-bearing is highly recommended to enhance restorations' long service without compromising load-bearing capacity & bonding properties. [2]

The large variety of biomedical applications adopted the use of materials containing substances exhibiting antimicrobial activity. Elementary and ionized silver forms are well documented to provide potent antimicrobial and substantial bactericidal properties against up to 16 bacterial species. That's why silver nanoparticles have been used in a broad scale in various bactericidal applications, as silver-based compounds. [3)), (4)

Prosthetic dentistry largely depends on core veneered restorations. The incorporation of a substantial core with an esthetic veneering ceramic has proved effective for several decades. Because of its high-quality esthetics and mechanical endurance, veneered ceramic and metal-ceramic restorations are commonly utilized in dentistry, Ceramic or metal copings are fused with porcelain to create these restorations. Nevertheless, restorations may sometimes be replaced due to veneering porcelain fracture or chipping. When excessive forces of occlusion forces are applied as in cases of bruxism, porcelain breaks or cracks promptly with almost no deformity; unlike metals, porcelain is a brittle material, i.e., neither ductile nor malleable. This brittleness renders veneering porcelain susceptible to chipping or fracture that sometimes necessitates the removal of restorations. Inhibition of veneer porcelain chipping or fracturing as well as boosting restorations' mechanical dependability can be performed by adding ductile metal particles that improve glass ceramics' toughness by enhancing crack deflection & bridging. [5,6]

A fracture toughness of 9-10 MPa and a flexural strength of 900-1200 MPa are evidence of the mechanism of transformation toughening, which is shown by the incorporation of partly stabilized yttria tetragonal zirconia polycrystals. Zirconia has the mechanical characteristics to tolerate significant stresses of occlusion [7,8]. Nevertheless, zirconia FPDs often fail due to minor chip-off fractures or delamination of the veneering porcelain. As a result, the bond between the veneer and core, or even within the material of the veneer itself, is among the vulnerabilities in layered zirconia-based restorations and takes a crucial role in their longevity [9,10]. So, in order to make the materials more usable in clinical settings, research into the bond shear strength between the widely used ceramic and core materials is necessary. [11]

As dental restorations are continually subjected to different pressures from the oral environment which modify the structure of the restorations, both chemically and physically, stability of color is just as critical as mechanical characteristics for clinical success in the long term. [12]

Metal and zirconia veneered cores, share the same common type of failure; delamination or chipping of the veneering porcelain, compromising esthetics by exposing the core material. Therefore, restoration flexural strength and bond shear strength in between the widely utilized core materials and veneering ceramic require study to ensure restoration longevity. [13] The objective of this research is to assess the effect of veneering zirconia and metal cores with veneering porcelain modified by silver nanoparticles on, flexural strength, shear bond strength, and the influence on color change.

Hypothesis

The current study's premise was that the modification of veneering porcelain by SNP will affect flexural strength, bond shear strength and color change in both core materials.

MATERIALS AND METHODS

1- Sample grouping

A power calculation using information from earlier research was used to establish the required samples number needed in every group. [14] In that research, the flexural strength mean was (64.2 ±11.28 Mpa) in the control group and (100.2± 18.41Mpa) in the modified group. Using G Power 3.1 9.2 software, it was found that a sample size of 5 samples in each group would offer 80% power for an independent Samples T-test at the threshold of 0.05 significance.

A total of sixty samples were constructed with three different designs and divided into three groups (n=20) according to the design & type of test they will be subjected to. Group I: Rods with dimensions 25 mm × 3 mm × 1 mm with veneering porcelain 1mm thickness in the center with dimensions 8mm X 3mm for the flexural strength test. Group II: Rods with dimensions 9 mm × 4 mm × 4 mm veneered with porcelain 3mm thick for the shear bond strength test. Group III: Discs 10 mm in diameter with a 0.5 mm thickness veneered with 1mm veneering porcelain for color change test. Each group was then divided into 2 subgroups in accordance with the sort of core (n=10). Subgroup M: metal core, subgroup Z: zirconia core. Each subgroup was then divided into 2 classes(n=5) according to the modification of veneering ceramic with silver nanoparticles (SNP). Class C: Control class (veneering porcelain without any modification) Class S: Modified group (SNP modified veneering porcelain).

2- Preparation of silver nanoparticles modified dental porcelain

Silver nanoparticles (SNP) powder having the size of 20-40nm (Nano-Tech. Company, Giza, Egypt) was weighed using an electronic sensitive balance (AOSTE Model Number. HS China) and added in a ratio 1:100 to each type of veneering dentin porcelain VITA VM 13 (Vita Zahnfabrik, Badsackingen, Germany) and Vita VM 9, (Vita Zahnfabrik, Bad Säckingen, Baden-Württemberg, Germeny) used for both core materials metal and zirconia cores, respectively.

3- Construction and preparation of core/veneer samples:

a- Preparation of cores:

Stainless steel templates were prefabricated to standardize the construction of wax patterns for metal cores and composite patterns to be scanned for the construction of zirconia cores. The template for the flexural strength test, was 25 mm × 3 mm × 1 mm according to the ISO 9693:1999 standards, [15] The template used for the construction of samples for the shear bond strength test, template had the dimensions of 9 mm × 4 mm × 4 mm. [16] while for color change testing, 10 mm in diameter with a 0.5 mm thickness. [2]

Preparation of zirconia core Three composite models were constructed in different templates, one model in each template. Each composite model was constructed & scanned for zirconia cores construction (ceramill Zolid fx, AUSTRIA). Cores were designed using CAD-CAM system (imes-icore^{R}, Germany). Samples designs were confirmed and exported to the CAM system to be milled by (VHF, CAM 5- S1 Impression Germany) and then, sintered in a dental ceramic oven (Tabeo-1/M/ZIRKon-100 Germany) following the manufacturer's instructions. The design took into consideration the percentage of shrinkage documented by manufacturers as 20-22%. Twenty cores were fabricated per design.

Preparation of metallic core:

Twenty wax patterns were fabricated using inlay wax (YETI DENTAL, Germany) in each prefabricated stainless-steel template. After the patterns of wax were made, they were invested in a phosphate-bonded investment substance (BellavestR SH, Germany). When the investment mould underwent setting, it was placed in a furnace. Ni-Cr alloy ingots (MoguCeraN, S&S Schefter GmbH, Mainz, Germany) underwent heating to the point the ingots transformed to the molten state and of procedure casting was accomplished using a centrifugal casting machine (BEGO Fornax German). Afterward, it was allowed to the investment to cool to room temperature. Divestment was completed and casting was reclaimed.

Preparation of core/veneer samples

For metal & zirconia cores, the surfaces to be veneered underwent the procedure of sandblasting with 50μ Al_2O_3 particles and steam cleaning. Metal surfaces were veneered with one layer of 0.2mm of opaque porcelain and then 0.8 mm of dentine porcelain VITA VM 13 (Vita Zahnfabrik, Badsackingen, Germany) either modified or unmodified for flexural strength & color samples while 2.8 mm for shear bond strength samples. Using the layering technique, zirconia surfaces were veneered with modified or unmodified dentin porcelains Vita VM9, (Vita Zahnfabrik, BadSäckingen, Baden-Württemberg, Germany). The porcelain powder was mixed with porcelain molding liquid to form a past. A moistened brush was used to apply each porcelain layer in small increments until it reached its step level in the mold. The samples were dried by heating slowly in the open entrance of the furnace. This is carried out in order to drive off excess water before it has a chance to form steam. Once the compact has been dried. All samples were fired following the manufacturers' recommendations, in a porcelain furnace (Programat P500, Ivoclar Vivadent AG, Schaan, Liechtenstein). To standardize samples of group III, the porcelain shade used was 2M3. the thickness of the veneering layer was 1mm for flexural strength & color samples and 3 mm for shear bond strength samples. For flexural strength samples porcelain was applied in the center of the surface with dimensions 8mm X 3 mm X 1 mm thickness. Dimensions were checked using the digital caliper to confirm the thickness of the veneering layer. Samples were then finished and polished and dimensions were re-checked again using a digital caliper.

Flexural strength test:

Samples of group I were subjected to a flexural strength test. A three-point bending test was performed using a compressive load under displacement control (cross-head feed rate equal to 0.5 mm/min) with a 5 kN load cell. in a universal testing machine (Instron, industrial production, USA(Norwood) using computer software (Instron, Bluehill 2014) as shown in figure (1).

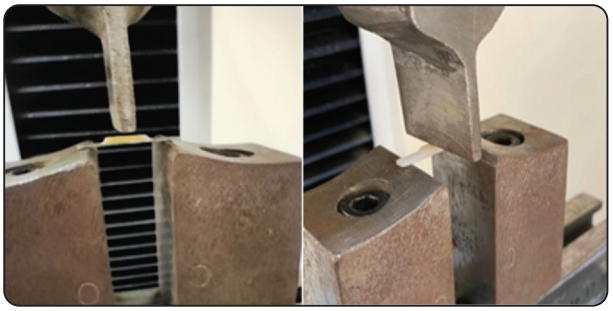

Fig. (1) Flexural strength measurement using universal testing machine

Shear bond strength test:

Samples of group II were mounted in self-cure acrylic resin) Acrostone dental factory, England). A specially designed teflon mold was constructed. The proper self-curing acrylic resin powder/ liquid ratio was measured according to the manufacturer's instructions and then poured into the mold. When the acrylic resin had achieved the dough stage, the samples were immersed in it. The excess acrylic resin was rapidly removed with a metallic wax carver and the assembly was left for complete chemical curing. The mold was then opened and the acrylic block containing the sample was removed.

Shear bond strength testing was performed with a universal testing machine (Instron, industrial production, USA(Norwood) using computer software (Instron, Bluehill 2014) as shown in figure (2). Shearing force was applied with the aid of a chisel shape blade, with a 0.6 mm thick edge. The machine's beveled blade was parallel to the interface of the core veneer. The samples were loaded using a 5000 N load cell at a cross-head speed of 0.5 mm/min till failure takes place. The maximum loading force of each sample was recorded in Newton. Shear bond strength was calculated as shear bond strength (MPa) = shear bond force (N)/surface area (mm^2).

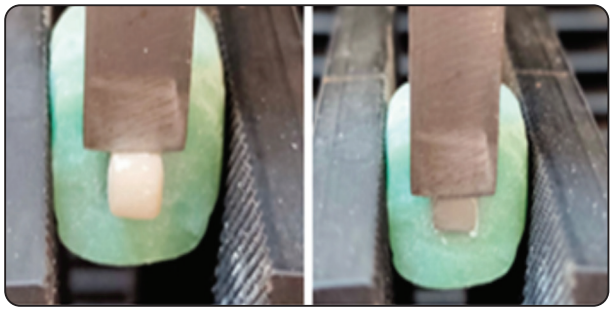

Fig. (2) Shear bond strength measurement

Color measurement test:

All samples underwent color parameters measurement using the Spectrophotometer (UV-Shimadzu 3101 PC Spectrophotometer, Japan). The means of following formula was utilized to calculate the change of color. $(\Delta E) = [(\Delta L)^2 + (\Delta a)^2 + (\Delta b)^2]^{1/2}$; in which ΔE= change of color; ΔL= difference of lightness (L*), such that the higher L* values, the greater the sample brightness; Δa=axis a* difference; such that high value for Δa indicates additional red samples and negative values, means a greener shift of the values. Δb=axis b* difference; such that positive values for Δb indicate yellower samples and negative values mean more shifted towards the bluer side, where: ΔL=L*F–L*I; Δa=a*F–a*I Δb=b*F–b*I, where L*I, a*I e b*I are referenced to as the control color measurement and L*F, a*F and b*F as the measurement of modified color.

Statistical analysis

The SPSS program (Statistical Package for Social Sciences) software version 25 was used to code, tabulate, and statistically analyze the acquired data. Meanwhile, mean, standard deviation (SD), and minimum and a maximum of the range were used to perform descriptive statistics for parametric (normally distributed) quantitative data. Distribution of the data was done by ***Shapiro Wilk test***

Analyses were carried out between both groups for the parametric quantitative data utilizing the Independent **Samples T-test**. The significance level was chosen at (P value ≤ 0.05)

RESULTS

Flexural strength test results (Group 1):

TABLE (1) The flexural strength (MPa) ± SD of veneered porcelain on both metal and zirconia core.

		Control	Modified	P value
Flexural strength in MPa (Subgroup M) (Metallic core)	*Range* *Mean ± SD*	(2450-2640) 2542±71.9	(2800-3000) 2904±76.4	***<0.001****
Flexural strength in MPa (Subgroup Z) (Zirconia core)	*Range* *Mean ± SD*	(1000-1120) 1066.8±47.2	(1250-1400) 1318±58.1	***<0.001****

The flexural strength of modified samples (2904±76.4, 1318±58.1Mpa) showed a significant increase compared to control samples (2542±71.9, 1066.8±47.2Mpa) on both metallic and zirconia cores respectively.

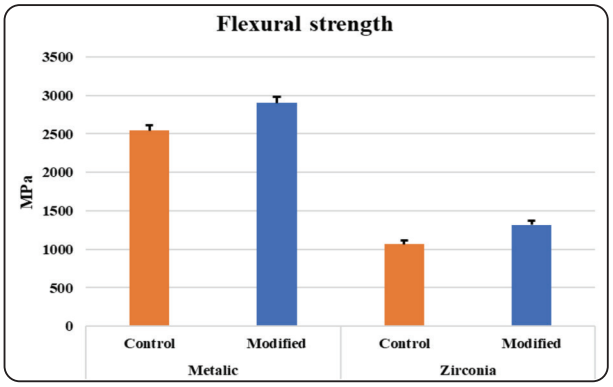

Fig. (3) Histogram showing flexural strength of veneered porcelain on both metal and zirconia core.

Shear bond strength test results (Group II):

TABLE (2) The shear bond strength (MPa) ± SD of veneered porcelain on both metal and zirconia core

		Control	Modified	P value
Metallic core (Subgroup M)	*Range*	(41.9-43)	(40.8-42)	***0.012****
	Mean ± SD	42.5±0.5	41.4±0.5	
Zirconia core (Subgroup Z)	*Range*	(27.1-28)	(25.1-26)	***<0.001****
	Mean ± SD	27.6±0.4	25.7±0.3	

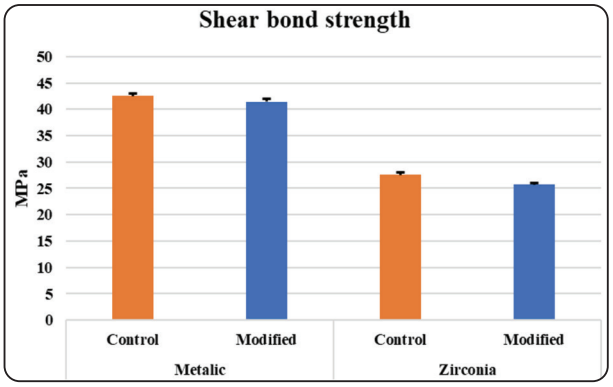

Fig. (4) Histogram comparing the mean shear bond strength of modified and control classes of both metal and zirconia subgroups

Results recorded a significant decrease in shear bond strength of both metal and zirconia-modified subgroups (41.4±0.5, 25.7±0.3 Mpa) compared to control subgroups (42.5±0.5, 27.6±0.4Mpa) respectively.

Color change test results (Group III):

TABLE (3) Comparison between mean (ΔE) of veneered porcelain in both metallic and zirconia cores.

		Metallic	Zirconia	P value
ΔE	*Range*	(0.97-2.72)	(9.82-12.4)	***<0.001****
	Mean ± SD	1.65±0.6	10.75±1.1	

The color change in Zirconia core group showed a higher statistically significant mean (ΔE) value (10.75±1.1) which is clinically un-acceptable than the metallic group (1.65±0.6) which is clinically acceptable.

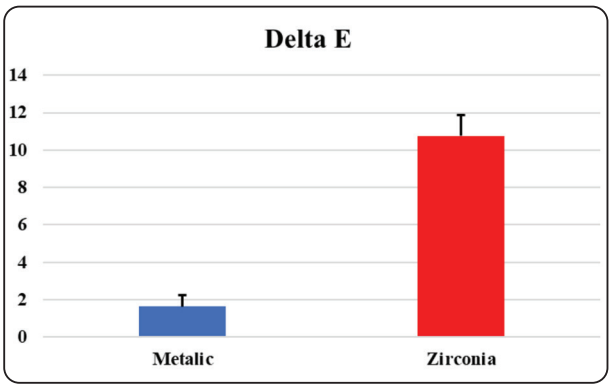

Fig. (5) Histogram compared the mean color change (ΔE) of veneered porcelain in both metallic and zirconia subgroups.

DISCUSSION

Nanoparticles had been provided as materials that have the capability for wide-ranging biological and medicinal uses. It is known that nanoparticles have the feature of insolubility as well as are smaller than 100nm in terms of size. Their significance is in the smaller particle size that demonstrates anti-bacterial activity as a result of their greater ratio of

surface area to volume. Because of their anti-viral, antifungal, and antimicrobial characteristics, nanoparticles show great promise. These nanoparticles enhance the mechanical properties of restorative material [17].

Since silver nanoparticles are very efficient in terms of antimicrobial efficiency against bacteria, viruses, and other microorganisms, they have become the gold standard for antimicrobial agents. Nanoparticles' potential benefits to biomedicine arise from their small size, which increases their biocompatibility. [18]

The need for better esthetic, biocompatibility, and strength in fixed prosthodontics is the reason for the greater use of yttrium-stabilized zirconia as core material for fixed restorations. In recent years, the use of zirconia and all-ceramic crowns has become increasingly widespread in esthetic dentistry. A zirconia crown may consist of a zirconia ceramic core and a porcelain layer as a veneering material. This is a highly predictable restorative treatment that resists chipping and breakage in the oral cavity. However, it offers limited predictability for sites that are subjected to stress. [10]

The vast majority of bond failures in metal-ceramic restorations occur when the layer of ceramic chips off, therefore subjecting the metal surface that compromises the esthetics. Therefore, the use of zirconia-based restorations in the dental field follows naturally. Complications with delamination or porcelain chipping away from the zirconium core are unfortunately prevalent even with zirconium coping. As a result, research into the shear bond strength between the widely utilized core materials and ceramic is necessary to allow the materials' usage in clinical settings for durability. [19]

Although, esthetic dentistry adopted the use of dental porcelain due to its excellent optical properties, yet its durability and strength to withstand masticatory forces are essential and very critical. [20]

Three different molds were used to prepare the test samples, Stainless steel templates were prefabricated to standardize the construction of wax patterns for metal cores, and composite patterns were constructed to be scanned for the construction of zirconia cores. [2,15,16]

In this study, flexural strength and shear bond strength was measured using a universal testing machine that can apply forces up to 5KN in tension and direct compression. An encoder of high-resolution is utilized for the purpose of measuring the sample extension as well as providing high-accuracy speed control. A high-precision servo motor and DC servo system power the cross-head, allowing it to achieve a variable range of speeds across the full load range. [21]

Results of flexural strength showed that nano-silver modified veneering porcelain (2904±76.4, 1318±58.1Mpa) on metal and zirconia cores significantly increased their flexural strength compared to their control subgroups (2542±71.9, 1066.8±47.2Mpa) respectively. This increase might be attributed to the presence of ductile silver nanoparticles with a coefficient of thermal expansion higher than that of the glassy matrix, creating radially directed tensile stresses and tangentially directed compressive stresses with the particles. This inhibits the extension of cracks towards silver particles causing crack deflection. As agreed by many researchers, the strength of porcelains with dispersed particles in the glass matrix is enhanced by the crack suppression by deflection and bridging mechanisms. [22-24]

In this study, flexural strength results were in accordance with De la Fuente et al (2016) [25], and Karthikeyan et al (2019). [26] They recorded an increase in fracture toughness of sintered porcelain due to the incorporation of silver nanoparticles. They reported that porcelain toughening occurred due to the incorporation of fine metal particles in the porcelain matrix and explained how the lamella structures hold the fracture surfaces together after

the crack propagation through the porcelain matrix and that microcracks and cracks form around the main crack resulting in stress relieve at the crack tip. by effectively increasing the material's compliance and transformation toughening. In addition, Mohsen et al [2] and Pal et al [27], compared the effects of silver nanoparticles on the color and fracture strength of dental ceramics, and they concluded incorporation of silver nanoparticles increased the fracture strength of dental ceramics.

As discussed by Dlouhy et al. [28], If the particles and the glass matrix are perfectly bonded, there may be an effective crack/ particle interaction between them. Inhibition of the running crack propagation through nanoparticles can be carried out by utilizing the inherent ductility of the metallic phase; in other forms, stretching nanoparticles can bridge the crack. Hydrostatic stress generation in the glass matrix after the incorporation of metal nanoparticles is a further potential mechanism. Hydrostatic stress is proportional to the difference between the coefficients of thermal expansion of the added metal and the matrix.

The results of this study indicated a significant decrease in shear bond strength of both metal and zirconia-modified subgroups (41.4±0.5, 25.7±0.3 Mpa) compared to control subgroups (42.5±0.5, 27.6±0.4 Mpa) respectively. This decrease in shear bond strength may be due to agglomeration and aggregation of nanoparticles. The agglomerated compounds can act as stress-concentrating centers and adversely affect the shear bond strength of the material. [29]

Shilpa et al (2019) **[30]**, tested the shear bond strength of veneering ceramic on metal and zirconia cores. They recorded that the metal-ceramic samples had greater shear bond strength compared to veneered zirconia cores. Using SEM analysis, they traced combined failure modes due to cracks originating inside the veneering porcelain in both the zirconium and metal samples. They drew attention to the importance of the mechanical properties of veneering porcelain.

In earlier studies, Dundar et al. [31] recorded a shear bond strength within the range of 23-41 M Pa, and Al-Dohan [32] reported shear bond strength within the range of 22-31 M Pa for commercially available core-veneer all ceramic systems (zirconium). In this study, the value of shear bond strength (SBS) veneering ceramic to a zirconium core was 27.10 M Pa, emphasizing on the earlier studies' findings.

For optimal esthetics, restorative materials should mimic the natural tooth structure's optical properties as much as possible. However, as mentioned by Mohsen et al. [2] al and Hatem et al. [33] that the dental ceramic color may alter due to the most common form of ceramic strengthening, the dispersion of reinforcement particles.

In this study, color was assessed using a spectrophotometer to eliminate individual interpretations of visual color similarity. CIElab system was used to detect a minor difference in color where ΔE represents the numerical values between the 3 coordinates L*a*b* and demonstrates the color change values. **[34]**

Color change (ΔE) of group II samples (veneered metal cores) was within the acceptable clinical range while for group I (veneered zirconia cores) was detectable by human eyes

The addition of silver to a veneering ceramic very rich in SiO_2 resulted in the formation of greyish AgO due to the reaction between Ag and SiO_2. [35] Also, Koutayas et al (2008) [36], found that core material was the most influential factor for the final color of glass-infiltrated veneer restoration. This might explain the great color change in zirconia samples as this greyish coloration of the veneering ceramic over a whitish zirconia core as a background results in a high ΔE that is detectable to human vision, while in the case of metallic samples the background is already greyish in color. This comes in contrast with **Al Ben Ali et al (2014)** **[37]**, who concluded that changing the underlying background color to a darker one caused an increase in ΔE of the ceramic compared to a lighter background.

From the above discussion, the hypophysis of our study was partially accepted.

There may be some possible limitations in this study regarding the size and shape of the samples, they do not simulate those in the patient's mouth, and in addition, the samples were not exposed to the same environment or forces in the oral cavity. As the forces in the oral cavity are subjected to a different type of stress analysis. Also, the samples didn't subject to any type of aging which lead to unpredictable long-term Serviceability of the modified provisional materials.

CONCLUSIONS

The following finding was reached within the constraints of this study:

1. Modification of veneering porcelain using silver nanoparticles increases fracture resistance while decreasing shear bond strength to the underlying core
2. The color change of the modified veneering material depends upon the material of the underlying core

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