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# MARGINAL ADAPTATION OF VARIOUS CAD/CAM ALL-CERAMIC SUPERSTRUCTURES CEMENTED ON READY AND CUSTOM MADE ZIRCONIA ABUTMENTS

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## *ABSTRACT*

**Statement of the problem:** In spite of the varied materials and techniques available for fabricating implant-supported superstructures, reaching an abutment/crown combination that provides standardized results and an accurate fit is still of utmost importance for the success of implant-supported restorations.

**Purpose of the study:** This study aimed to evaluate the marginal adaptation of various CAD/CAM fabricated all-ceramic superstructures cemented on both ready and custom made zirconia abutments.

**Materials and methods:** A total of 30 implant samples were divided into two main groups *(n=15)* according to the received zirconia abutment design as follows; ***Group I***: readymade zirconia abutments with scalloped 0.5 mm chamfer finish line and ***Group II***: custom made zirconia abutments with uniform 1mm deep chamfer finish line. According to the received ceramic superstructure material each group was further subdivided into three subgroups *(n=5)* namely; *subgroup1*: Vita Enamic, *subgroup2*: IPS e. max CAD and *subgroup3:* Zirconia. Vertical marginal gap measurements for different groups were carried before cementation using a digital microscope; measurements were repeated again after cementation of the superstructures each on its corresponding abutment. Data were statistically analyzed.

**Results:** Regardless of ceramic superstructure material or cementation, it was found that the ready-made abutments recorded a statistically significant higher mean vertical marginal gap than the custom made abutments. Regardless of abutment designs or superstructure material; it was found that there was a statistically significant increase in mean marginal gap distance after cementation at *P*-value ≤ 0.05.

**Conclusions**: Based on the clinical acceptability of 120 µm as a marginal gap, the results of the three all-ceramic superstructures were within the acceptable range for both tested abutments. Marginal gap values increased after cementation of various superstructures on different abutments.

**KEYWORDS*:*** marginal adaptation, all-ceramic superstructures, custom abutment, cement-retained restorations, lithium disilicate, zirconia, vita Enamic.

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## INTRODUCTION

Single implant-borne crowns and fixed dental prostheses (FDPs) have become a widely accepted and reliable treatment option for the rehabilitation of partially edentulous patients [(1)]. The success of single-implant therapy relies not only on their high survival rates, but also on the quality of survival, which is determined by adequate osseo-integration, proper implant's functional load-bearing capacity together with improved esthetic results [(2)]. Although, titanium abutments have been well-documented for their biocompatibility and mechanical properties [(3)], yet they have limited indications in esthetically delicate areas [(4)]. Even when placed subgingivally, their dark gray color, may give the peri-implant mucosa an unnatural bluish appearance [(5)]. Moreover, gingival discoloration may also be partially attributed to thin gingival tissue that is incapable of blocking reflective light from the metal abutment surface [(4,5)].

Therefore, in an effort to achieve optimal muco-gingival esthetics and as an alternative to metal abutments [(6)], high strength ceramics became used for the fabrication of implant abutments and superstructures. The most widely used materials are densely sintered high-purity alumina ($Al_2O_3$) and yttria ($Y_2O_3$) partially stabilized zirconia ($ZrO_2$). Compared to metal abutments, these new abutments offered optically favorable characteristics, low corrosion potential, high biocompatibility, and low thermal conductivity [(7)].

Ceramic abutments are available either in prefabricated or customizable forms. Due to their cylindrical form, prefabricated abutments often cannot improve the appearance of the peri-implant soft tissue leaving the emergence profile modifiable only by the final restoration [(8)]. Moreover, the finish line is located according to average values which might not necessarily coincide with the existing mucosal contour [(9,10)].

From that point of view, the use of customized abutments could be considered an option to imitate the natural looking appearance of teeth. They offer harmony with the mucosa around the adjacent teeth and the implant-supported crown as well as with the neighboring dentition [(11)].

Recent developments in computer-aided designing / computer-aided manufacturing (CAD/CAM) technique made it possible to use high strength ceramics (mainly zirconia) to fabricate implant-supported all-ceramic abutments with customized contour that match carefully the clinical situation[(12,13)].In addition, Lithium disilicate ceramic (E max cad) was also used for custom made implant abutments [(14)] . The ceramic CAD/CAM abutments combine most of the advantages of stock and cast custom abutments. Added to its predictable fit and durability, all the prosthesis parameters can be easily adjusted including the emergence profile, finish line thickness and location as well as external contour which results in improved final esthetics of implant supported restorations [(8,15)].

The combination of a high-strength ceramic abutment and a high-strength all-ceramic superstructure system has been described in the literature in anterior and posterior regions of the arch[(12,16,17)] either in the form of high strength ceramic core to be veneered with a more esthetic ceramic or most recently in the form of monolithic restoration using the CAD/CAM technology[(18)]. Among the ceramic systems used are glass ceramics[(16,19)] , densly sintered Alumina[(20)], zirconia[(20,21)], feldspathic ceramics[(22)] , hybrid ceramics[(19,22,23)] , and zirconia reinforced lithium silicate [(24,25)].

Unfortunately, under tensile stresses ceramic materials are susceptible to fracture as a result of their brittleness, surface and bulk defects as well as crack propagation under oral function[(25)]. In order to improve the reliability of ceramics, a novel polymer infiltrated ceramic (hybrid ceramic) was developed[(26)]. Due to its low modulus of elasticity, the hybrid material absorbs more energy than ceramics and therefore leads to more damping of occlusal forces, as found in an earlier study [(27)].

Since marginal fit and mechanical fatigue failure are prime factors that affect the long-term biological and mechanical success of fixed prosthodontic restorations [28], thus, it is necessary to minimize the marginal discrepancy between the abutment and the restoration, as a significant gap will expose the luting material to the oral environment, resulting in cement dissolution[29]. The misfit may also act as a trap for bacteria colonization, which may possibly cause inflammatory reactions in the peri-implant soft tissues [30].

In addition to biologic issues, it has been shown that marginal misfit between an implant and an abutment is able to cause screw loosening and facilitates the risk of abutment fracture[31]. In fact, marginal misfit results in the transmission of high stresses to the alveolar bone and dental implant components [32].

Similar to conventional fixed dental prostheses, the fit of all ceramic crowns cemented on implant abutments may be influenced by several factors such as the ceramic material, the associated manufacturing technique, finish line design, or the luting procedure[33].

Various techniques have been reported to examine the marginal gap, such as; direct viewing, sectioning, impression taking to make replicas, and explorative and visual examinations[34,35]. Moreover, several types of microscopes have been suggested by investigators for evaluation of the marginal gap among which are, digital microscopes, stereomicroscopes, light microscopes, and electron microscopes that have been used with various magnifications[34,35].

Since marginal adaptation of a ceramic restoration is considered as an important parameter which can compromise the marginal fit and can affect the longevity of a restoration, therefore the aim of this study was to evaluate the marginal adaptation of different monolithic CAD/CAM all-ceramic superstructures cemented on ready and custom made zirconia abutments.

Three null hypotheses were tested within this study; the first assumed that the marginal adaptation of different all-ceramic superstructures would not be influenced by their materials while, the second postulated that there is no effect of the abutment design whether ready or custom made on the marginal adaptation of the tested superstructures and for the third, it supposed that cementation of the superstructure would not affect the marginal adaptation of the various superstructure/abutment combinations.

## MATERIALS AND METHODS

In this study, a total of 30 implant samples were randomly divided into two main groups *(n=15)* according to the received zirconia abutment design as follows; ***Group I***: readymade zirconia abutments with scalloped 0.5 mm chamfer finish line and ***Group II***: custom made zirconia abutments with uniform 1mm deep chamfer finish line. According to the received ceramic superstructure material each group was further subdivided into three subgroups *(n=5)* namely; *subgroup1*: Vita Enamic, *subgroup2*: IPS e. max CAD and *subgroup3:* Zirconia.

### i) Preparation of implant samples models:

Thirty internal connection titanium dummy implants with 3.7mm diameter, 13 mm length and 3.5mm platform diameter (Legacy 1 system, Implant direct, Sybron International, USA) were used throughout the study. In order to ensure secure holding of the implants during fabrication of the models, transfer copings (3.5mm platform diameter) supplied by the implant manufacturer, were screwed to all implants using the implant system's hex tool. Each implant-transfer coping assembly was centrally placed in a machine crafted copper box by the aid of a specially constructed parallelometer. Self cured acrylic resin was proportioned and mixed according to the manufacturer instructions then injected around the implant up to its first thread. The assembly was left 24 hours till complete polymerization of the resin then retrieved from the copper box. This strategy was adopted to all of the tested samples, and finally, all transfer copings were unscrewed from the implants.

For ***Group I***: each of the 15 implant samples received a readymade two-piece zirconia abutment with gold anodized titanium base and internal connection (Implant direct, Sybron International, USA). All abutments had standardized dimensions of 3.5mm platform diameter, 7.6 mm length above the collar height at the buccal side and 6.1mm at the lingual side as well as 8° total convergence angle [19]. The abutments had a 0.5mm chamfer finish line with scalloped pattern[36] (Figure 1).

According to the manufacturers' recommendations, abutments were torqued to implants at 30Ncm using calibrated torque wrench (Implant direct, Sybron International, USA). All abutments were shortened by a single operator to have 1.6 mm occlusal reduction so their final height was 6 mm above the collar height at the buccal side. This was carried out using cylindrical stone(Zirconia Bur Block shaping and polishing kit, Implant direct ,Sybron International, USA) mounted at a high speed hand piece under copious air/water spray, then the length was checked by digital caliber. Finally, abutments were polished with the low speed polishing tools of the kit.

While, for ***Group II*** each of the other 15 implants received a custom made zirconia abutment. The abutment consisted of a titanium base compatible with the implant system (Ti base, Osteoseal Co.USA) that was adhesively luted to a CAD/CAM fabricated zirconia structure .The zirconia structure was designed by the DOW CAD software (dental wings Inc. Montreal, Canada) in the form of an anatomically prepared maxillary right first premolar with , 6mm occluso-cervical length above the collar height, 12° total convergence angle and 1mm deep chamfer finish line with uniform pattern all around the abutment surfaces as recommended by the ceramic manufacturers preparation guidelines to receive an all-ceramic crown[37]. (Figure 2).

The designed abutments were milled from KATANA Zirconia HT disc (Kuraray Noritake Dental Inc, Japan) by a 5 axis milling machine (SHERA eco-mill 5 axis, Shera, Germany) then sintered in a furnace (Nabertherm HTC, Shera, Germany) at 1500° C for 7 hours as recommended by the manufacturer. Prior to bonding, the outer surface of the ceramic structure as well as the screw access hole and the emergence profile of the

Fig. (1) Readymade abutment with scalloped 0.5mm chamfer finish line.

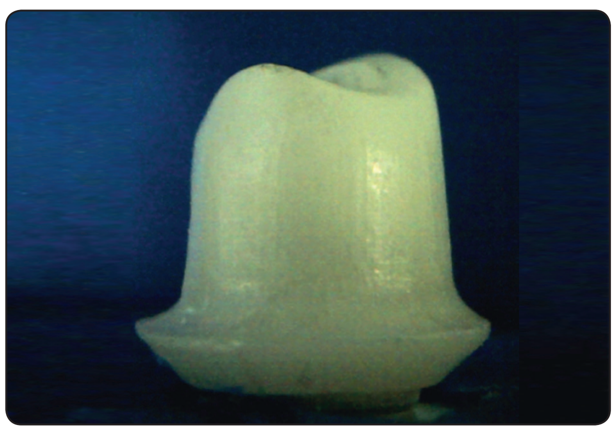

Fig. (2) Custom made zirconia abutment with uniform 1mm deep chamfer finish line titanium base were protected with modeling wax (Cavex Holland BV, Netherlands), followed by air borne particle abrasion of the bonding areas of the two components by 50 $\mu$m $Al_2O_3$ particles at 1 bar pressure. Wax was then removed and the components were ultrasonically cleaned in distilled water and dried with oil free air spray. Conditioning of the abraded bonding areas of the two components took place with a universal primer (Monobond Plus, Ivoclar Vivadent ,Schaan , Liechtenstein) which was allowed to react for 60 seconds then air dispersed. In order to be able to receive the ceramic structure, the surface treated titanium base was screwed to an implant analogue and a thin layer of self curing automix opaque adhesive resin cement (Multilink Hybrid Abutment HO 0, Ivoclar Vivadent, Schaan, Liechtenstein) was applied to the bonding areas then the zirconia structure which was lightly pressed onto the titanium base. Excess cement at the cement joint and at the screw channel was removed by microbrush (Microbrush International, USA) and glycerin gel (Liquid strip, Ivoclar Vivadent, Schaan, Liechtenstein) was applied on the cement joint (to prevent the formation of oxygen inhibited layer) and left for 7 minutes till complete polymerization of the cement following the manufacturer's instructions then rinsed with water spray. Finally, the cement joint was polished with rubber polishers (Dedeco International Inc, USA) at low speed and the custom made abutment was unscrewed from the implant analogue. By the aid of the titanium screw of the osteoseal titanium base, each custom made zirconia abutment was screwed to its corresponding implant and torqued to 30Ncm as recommended by the manufacturer using the calibrated torque wrench and hex tool (Implant direct, Sybron International, USA).

**ii) CAD/CAM fabrication of all-ceramic monolithic superstructures:**

All superstructures in this study were CAD/CAM fabricated according to a standardized protocol started by scanning of ready as well as custom made abutments by In Eos scanner (Sirona Dental Systems GmbH, Bensheim, Germany) after being sprayed with titanium dioxide powder (Cerec Optispray, Sirona Dental Systems GmbH, Bensheim, Germany)and the resultant 3D images were saved on the computer. (Figure 3).

By the aid of the in Lab 4.3CAD software, all superstructures were individually designed onto their corresponding 3D abutment models. Each superstructure was designed in the form of fully contoured monolithic maxillary right first premolar with 2mm ceramic thickness at the occlusal surface and1.5 mm at the axial walls as well as 80m$\mu$ cement space following the ceramic manufacturers guidelines. This design was adopted to all the tested

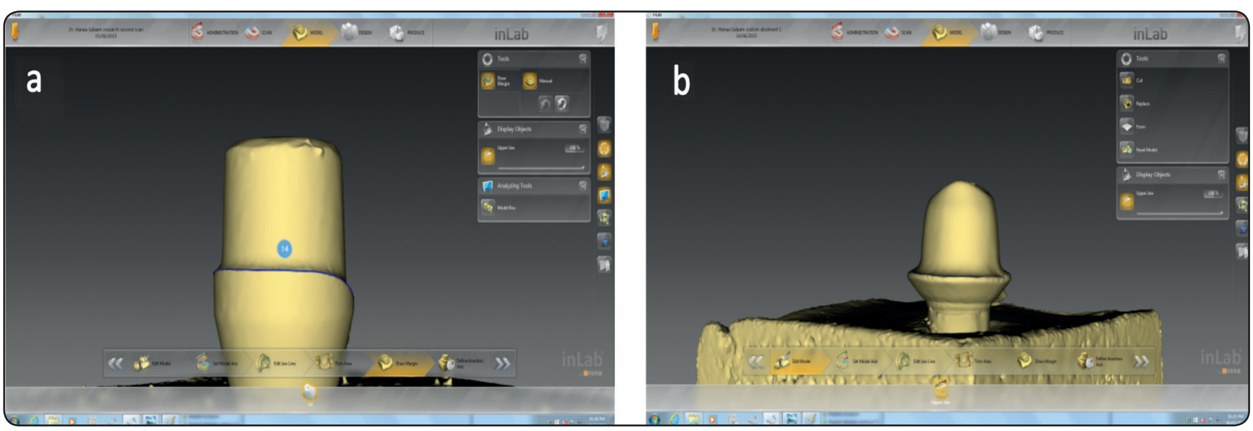


Fig. (3) Scanned images of zirconia abutments a: Readymade b: Custom made

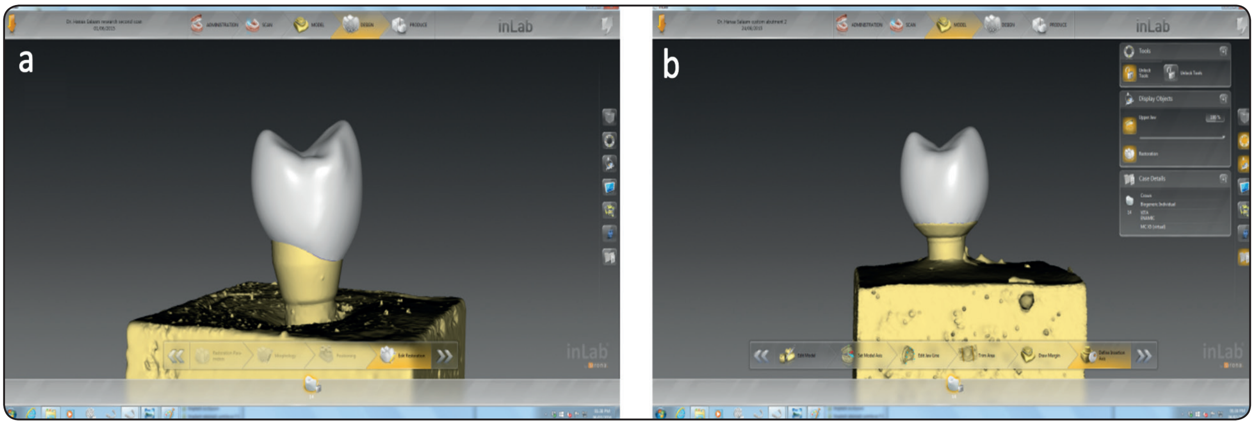


Fig. (4) Superstructure design on scanned zirconia abutments, a: Readymade b: Custom made

superstructures to have standardized identical dimensions and shape (Figure 4). Exceptionally for zirconia superstructures, this design was enlarged by 25% to compensate for the zirconia sintering shrinkage as recommended by the manufacturer.

The in Lab 15 CAM software was used for the milling procedure which was carried out in the in Lab MC X5 milling machine (Sirona Dental Systems GmbH, Bensheim, Germany). After completion of the milling procedure, the milled zirconia superstructures were sintered in the furnace (inFire HTC super speed Sirona Dental Systems GmbH, Bensheim, Germany) for 7 hours at 1500$^{o}$ C following manufacturer's instructions. After sintering, the superstructures were polished using a special diamond polishing system for zirconia (EVE DIACERA Set HP 321, EVE Ernst Vetter GmbH, Germany).

While for Vita Enamic, the milled superstructures were polished with the pink followed by the grey polishers of the Vita Enamic polishing kit (VITA Zahnfabrik, Germany).

Regarding IPS e.max CAD, the milled superstructures were polished while they were in the pre-crystallized blue state with a diamond polishing system for silicate ceramics (EVE DIAPRO Set HP 360, EVE Ernst Vetter GmbH, Germany) followed by ultrasonic cleaning in distilled water for two minutes. The cleaned superstructures were then subjected to a crystallization cycle in the Programat P310 furnace (Ivoclar Vivadent, Schaan, Liechtenstein) at 850$^{o}$C for a total firing time of 25 minutes according to the manufacturer's recommendations.

Finally, polished superstructures of all groups were ultrasonically cleaned in distilled water for two minutes and dried by oil free air spray. Prior to their cementation onto their corresponding abutments, the different crowns were subjected to their manufacturer's recommended surface treatments as follows: for zirconia crowns the fitting surfaces were air abraded by 50 $\mu$m $Al_2O_3$ particles at 1 bar pressure then ultrasonically cleaned and air dried. The intaglio surfaces of Vita Enamic and IPS e.max CAD crowns were subjected to acid etching by hydrofluoric acid 5% (IPS Ceramic Etching Gel, Ivoclar Vivadent) 60 seconds for Vita Enamic crowns and 20 seconds for IPS e max CAD ones, then thoroughly rinsed with water and air dried. For crowns of different groups a ceramic primer (Clearfil Ceramic Primer, Kuraray, USA) was applied to their treated fitting surfaces and was allowed to react for 60 seconds then air sprayed. The screw access holes of ready and custom made abutments of all groups were sealed with cotton pellets and temporary filling material (Cavit, 3M ESPE, USA).

**iii) Marginal gap measurements:**

Vertical marginal gap distance between all abutments and their corresponding superstructures was measured before their cementation using USB digital-microscope (Scope Capture Digital Microscope, Guangdong, China) at X 90 magnification. Images of all surfaces were analyzed by the Image-tool software (Image J 1.43U, National Institute of Health, USA). The measurements were made at 16 predetermined reference points around the abutment before cementation (four equidistant measurements /surface)[38]. A specially designed wooden holder was fabricated to hold the superstructure on the abutment during the measurement procedure.

After finishing of the vertical marginal gap distance measurements, all superstructures were cemented to their corresponding abutments. A specially constructed cementing device was used to standardize the cementing procedure for all samples. An automix dual cure self adhesive resin cement (Panavia SA cement Plus, white, Kuraray, USA) was dispensed from the automix syringe and applied to the treated fitting surfaces of all superstructures by the aid of the mixing tip. Each superstructure was immediately seated onto its corresponding abutment under finger pressure then placed in the cementing device under constant axial load of 5 Kg[39]. Excess cement at the margins was light cured for two seconds by LED curing unit (LED curing unit LY-B 200, LIANG YA Dental, China) then removed by dental explorer. The cement was photo-polymerized for 10 seconds /surface by the LED curing unit on all surfaces of the superstructure. All samples were kept at 100% humidity and 37°C for 24 hours. Then the vertical marginal gap distance of all samples were measured again following the same measurement protocol used before cementation. All recorded readings were then statistically analyzed.

**Statistical Analysis**

Data were presented as mean, median, standard deviation (SD), range (Minimum – Maximum) and 95% Confidence interval (95% CI) for the mean values. Data were explored for normality by checking the data distribution and using Kolmogorov-Smirnov and Shapiro-Wilk tests. Marginal gap data showed non-parametric distribution.Mann-Whitney U test was used to compare between the two abutment designs. Kruskal-Wallis test was used to compare between the three superstructure materials. Mann-Whitney U test with Bonferroni's adjustment was used for pair-wise comparisons when Kruskal-Wallis test is significant. Wilcoxon signed-rank test was used to compare between marginal gap distances before and after cementation.

The significance level was set at $P \leq 0.05$. Statistical analysis was performed with IBM (IBM Corporation, NY, USA), SPSS (SPSS, Inc., an IBM Company) Statistics Version 20 for Windows.

**RESULTS**

Table (1), shows the descriptive statistics of marginal gap distance values of different groups and sub-groups

***i) Effect of superstructure material regardless of other variables***

Regardless of abutment design or cementation, it was found that e.max CAD group recorded the statistically significant highest mean vertical marginal gap (44.9 ± 21.3). There was no statistically significant difference between Vita Enamic and Zirconia; both showed the statistically significant lowest mean marginal gap values (39.2 ± 20.4 and 40.7 ± 16.6) respectively at *P*-value ≤ 0.05. Table (2).

TABLE (1) Descriptive statistics of marginal gap distance values of the different groups

| Superstructure material | Abutment design | Cementation | Mean | SD | Median | Minimum | Maximum | 95% CI | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | Lower bound | Upper bound |
| Vita Enamic | Ready made | Before | 24.0 | 3.9 | 20.5 | 16.5 | 28.5 | 20.6 | 44.2 |
| | | After | 68.5 | 19.4 | 63.3 | 40.5 | 84.2 | 51.5 | 120.3 |
| | Custom made | Before | 13.5 | 1.9 | 12.5 | 11.1 | 17.8 | 11.8 | 25.1 |
| | | After | 50.7 | 20.6 | 44.7 | 36.4 | 74.1 | 32.6 | 84.6 |
| e.max CAD | Ready made | Before | 21.1 | 3.4 | 20.5 | 18.5 | 26.3 | 18.1 | 38.9 |
| | | After | 61.9 | 24.3 | 52.4 | 45.5 | 80.1 | 40.6 | 103.9 |
| | Custom made | Before | 17.7 | 2.9 | 17.0 | 13.2 | 21.5 | 15.2 | 32.6 |
| | | After | 78.9 | 13.3 | 74.2 | 62.4 | 90.0 | 67.2 | 145.1 |
| Zirconia | Ready made | Before | 20.1 | 2.8 | 19.5 | 15.5 | 23.6 | 17.6 | 37.4 |
| | | After | 79.8 | 26.3 | 68.6 | 60.8 | 94.3 | 56.7 | 137.5 |
| | Custom made | Before | 21.9 | 5.7 | 19.2 | 10.6 | 29.8 | 16.9 | 38.8 |
| | | After | 41.0 | 13.2 | 35.6 | 26.4 | 55.3 | 29.4 | 70.9 |

TABLE (2) Comparison between vertical marginal gap distances of the three superstructure materials regardless of other variables

| **Superstructure material** | Mean ± SD | *P*-value |
|---|---|---|
| Vita Enamic | $39.2 \pm 20.4^{B}$ | 0.042* |
| e.max CAD | $44.9 \pm 21.3^{A}$ | |
| Zirconia | $40.7 \pm 16.6^{B}$ | |

***: Significant at P ≤ 0.05, Different superscripts are statistically significantly different***

## ii) Effect of abutment design regardless of other variables

Regardless of ceramic superstructure material or cementation, it was found that the ready-made abutments recorded a statistically significant higher mean vertical marginal gap (45.9 ± 23.2) than the custom made abutments (37.3 ± 14.9) at *P*-value ≤ 0.05. Table (3).

TABLE (3) Comparison between vertical marginal gap distances of the two abutment designs regardless of other variables

| **Abutment design** | Mean ± SD | *P*-value |
|---|---|---|
| Ready made | 45.9 ± 23.2 | 0.022* |
| Custom made | 37.3 ± 14.9 | |

***: Significant at P ≤ 0.05***

## iii) Effect of cementation regardless of other variables

Regardless of abutment designs or superstructure material, it was found that there was a statistically significant increase in mean marginal gap distance after cementation. Table (4).

Table (4) Comparison between vertical marginal gap distances before and after cementation regardless of other variables

| **Cementation** | Mean ± SD | *P*-value |
|---|---|---|
| Before cementation | 19.7 ± 5.3 | <0.001* |
| After cementation | 63.5 ± 21.4 | |

***: Significant at P ≤ 0.05***

## iv: Interaction of variables

Table (5) and Figure (5), show a detailed comparison between the vertical marginal gap distances with different interactions of the different groups.

### *a) Comparison between superstructure materials*

As regards readymade abutments before cementation; there was no statistically significant difference between the three superstructure materials tested.

While for custom made abutments before cementation; it was found that Zirconia sub-group recorded the statistically significant highest mean vertical marginal gap values (21.9 ± 5.7). Whereas, e.max CAD sub-group showed a statistically significant lower mean value(17.7 ± 2.9) and Vita Enamic showed the statistically significant lowest mean marginal gap distance (13.5 ± 1.9) at *P*-value *≤ 0.05*.

As regards readymade abutments after cementation; it was found that Zirconia sub-group recorded the statistically significant highest mean vertical marginal gap values (79.8 ± 26.3). Vita Enamic sub-group showed a statistically significant lower mean value (68.5 ± 19.4). While, e.max CAD showed the statistically significant lowest mean marginal gap distance values (61.9 ± 24.3). For the custom made abutments after cementation; it was found that e.max CAD sub-group recorded the statistically significant highest mean vertical marginal gap (78.9 ± 13.3). Vita Enamic sub-group showed a statistically significant lower mean value (50.7 ± 20.6). Whereas, Zirconia sub-group showed the statistically significant lowest mean marginal gap distance values (41.0 ± 13.2) at *P*-value *≤ 0.001*

***b) Comparison between abutment designs:***

It was found that readymade abutments recorded statistically significant higher mean vertical marginal gap distance than custom made abutments except with Zirconia superstructure before cementation where there was no statistically significant difference between the two abutment designs. For the e.max CAD superstructure after cementation, readymade abutments recorded statistically significant lower mean vertical marginal gap distance than custom made abutments. It was found that there was a statistically significant increase in mean marginal gap distance after cementation in all groups.

TABLE (5) Comparison between vertical marginal gap distances with different interactions

| Cementation | Superstructure material | Ready made | Custom made | *P*-value *(abutment designs)* |
|---|---|---|---|---|
| | | Mean ± SD | Mean ± SD | |
| Before | Vita Enamic | 24.0 ± 3.9 [A] | 13.5 ± 1.9 [B E] | <0.001* |
| | e.max CAD | 21.1 ± 3.4 [A] | 17.7 ± 2.9 [B D] | 0.048* |
| | Zirconia | 20.1 ± 2.8 [A] | 21.9 ± 5.7 [C] | 0.485 |
| | *P*-value *(Between materials)* | 0.060 | <0.001* | |
| After | Vita Enamic | 68.5 ± 19.4 [A D] | 50.7 ± 20.6 [B D] | <0.001* |
| | e.max CAD | 61.9 ± 24.3 [B E] | 78.9 ± 13.3 [A C] | 0.001* |
| | Zirconia | 79.8 ± 26.3 [A C] | 41.0 ± 13.2 [B E] | <0.001* |
| | *P*-value *(Between materials)* | <0.001* | <0.001* | |
| *P*-value *(Changes after cementation)* | Vita Enamic | <0.001* | <0.001* | |
| | e.max CAD | <0.001* | <0.001* | |
| | Zirconia | <0.001* | <0.001* | |

***: Significant at P ≤ 0.05,***

***A,B superscripts in the same row indicate significant differences between abutment designs.***

***C,D,E superscripts in the same column indicate significant differences between superstructure materials***

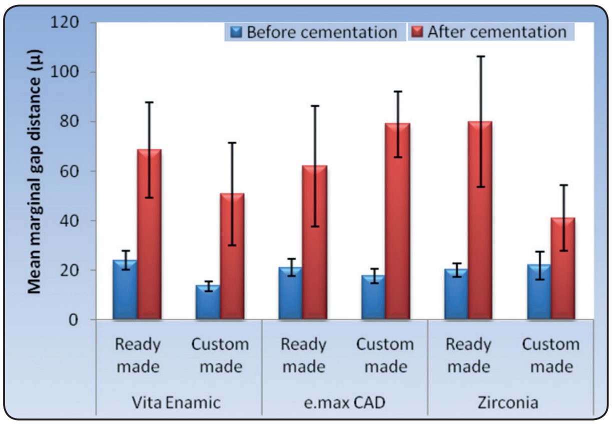


Fig. (5): Bar chart representing mean and standard deviation values for marginal gap distances of the different groups.

## DISCUSSION

With the evolution of implant dentistry, the clinical use of osseointegrated implants for single tooth replacement has been well documented[40]. Despite, numerous modifications to the fabrication and design of titanium abutments, there is still the disadvantage of metallic components showing through when such abutments are used [41,42].

Tooth-colored alumina and zirconia, abutments have been proposed as an alternative to Ti for abutments to overcome this esthetic problem [6]. Several authors reported that all ceramic abutments made of alumina had unfavorable behavior after aging and possessed less favorable properties than zirconia and titanium abutments [43]. From studies available, it is postulated that zirconia abutments not only induce significantly less mucosal discoloration than metal abutments8 but also allow less bacterial adhesion than Ti [44].

As reported by Glauser et al [45] and Canullo[46] the clinical performance of zirconia implant abutments has been very promising. Furthermore, a 100% survival rate for the ceramic abutments after 3 years has been reported by Zembic et al in a randomized-controlled clinical trial (RCT) of zirconia and titanium abutments supporting single crowns in posterior regions [47]. Accordingly, zirconia was the abutment material of choice in this study.

From various studies CAD/CAM technology has been found to be a simpler technique and less time-consuming with improved accuracy that provides standardized results, decreased processing time, low cost, and an accurate fit[48,49] . Hence, CAD/CAM was adopted throughout this study.

Ceramic abutments are available either in pre-fabricated or customizable forms and can be prepared in the dental laboratory either by the technician or by utilizing computer-aided design/computer-aided manufacturing techniques. Firstly, prefabricated all ceramic abutments were totally made of zirconia including the internal connection with the titanium implant. This ceramo-metal connection became prone to wear and led to abrasion of the metallic part[50]. Moreover, as a consequence of seating and reseating of ceramic abutments during the fabrication process, rounding of the corners of the implant external hexagon has been observed[51]. This imprecise fit between abutment and implant can lead to screw loosening and other clinical problems such as bone loss due to subsequent microbial infection[6]. To overcome the wear problem at the abutment/implant interface, an all ceramic zirconia abutment which is sintered onto titanium base that covers the implant platform and hexagon had been developed [52,53]. Based on this available knowledge, readymade zirconia abutments with titanium base were selected in the present study.

Implant prosthetic components should exhibit a natural emergence profile that mimics natural tooth contour to support the peri-implant soft tissues [9,10]. As the contours of readymade abutments are rarely anatomic and do not support the surrounding soft tissues, this makes it difficult in managing the emergence profile of an implant restoration[8].

CAD/CAM engineering principles were adopted to fully customize the abutment contour to match carefully the clinical situation[54]. Custom CAD/

CAM abutments combine most of the advantages of stock and cast custom abutments[55]. In addition to a predictable fit and durability, all the prosthesis parameters are modifiable including the emergence profile, finish line location, thickness, and external contour [55,56].

Again, to overcome the wear at the implant body/ ceramic abutment interface, a custom made hybrid design was developed in which a zirconia abutment body is adhesively bonded to a titanium base[57]. Thus, in the current study custom made zirconia hybrid abutments were fabricated.

The restoration of ceramic abutments with all ceramic crown systems has been described in the literature, as it would enhance the overall resistance of the restoration and will allow for better aesthetics [58,59]. Continuous improvements to CAD/ CAM technology made it possible to use high strength ceramics to fabricate implant-supported all-ceramic restorations, instead of using conventional methods [60,61].

Throughout the procedural steps conducted in this study, all the implant supported crowns tested, were fabricated in the form of monolithic crowns as recommended by many authors [16,22-24]. The most frequent clinical complication with zirconia-based crowns was chipping of the veneering porcelain. Fabrication of monolithic full-contour zirconia crown is an alternative that might avoid chipping of veneering [62]. Beuer et al [63] reported that anatomic contoured zirconia crowns in a laboratory conducted study demonstrated higher resistance to static loading tests than veneered zirconia ones. Additionally, monolithic IPS e max cad and Vita Enamic crowns fabrication procedure became simplified; moreover they demonstrated satisfactory results within the in-vitro studies [16,24,25] Based upon this data, the three selected all-ceramic superstructure materials to be investigated throughout this study belonged to the different ceramic families as categorized by Gracis et al [64] according to the presence or absence of glass-matrix into (glass-matrix ceramics), (polycrystalline ceramics) or whether the material contains an organic matrix highly filled with ceramic particles (resin-matrix ceramics). IPS e max CAD belongs to the glass-matrix ceramics and it is characterized by improved physical properties and translucency due to the high concentration of refined lithium disilicate crystals [65]. While, Katana zirconia ML blocks belonged to the polycrystalline ceramics family, which are partially sintered zirconia and were selected as they are softer than the fully sintered zirconia blocks and this not only shortens the milling time but also reduces the wear of the milling tools[65]. Whereas, Vita Enamic belonged to resin-matrix ceramics; the material combines the properties of ceramic and polymer. It consists of a hybrid structure with two interpenetrating networks of ceramic and polymer. The most remarkable property of Vita Enamic is the precise milling of the material which takes the leading position among all blocks used to date[64].

In accordance to Pjetursson and Lang[66], and Salinas and Eckert [67] who have proposed the use of cement-retained all-ceramic restorations for esthetic rehabilitation of single-tooth implants, this abutment/superstructure combination was chosen in this study.

This choice was supported by other authors who have emphasized the advantages of the cement retained restoration including its greater versatility for aesthetics, simplicity of the technique and the potential for complete passivity of the cemented restoration [68,69]. On the contrary, several authors advocate that the screw-retained restoration offers reversibility and more stability and security at the implant-abutment interface[70,71] .

As it has been demonstrated that marginal configuration does become an important consideration when CAD/CAM systems are used for restoration fabrication[72]. Komine et al[33] and Comlekoglu et al [73] recommended a rounded shoulder or a chamfer preparation for the finish line design of CAD/CAM fabricated restorations. In this study chamfer finish line was adopted for all zirconia abutments, in order to receive all ceramic superstructures, as mentioned by Sannino et al [74] who reported that chamfer finish line configuration was found to minimize the localized stress as indicated by a 3D finite element analysis than the shoulder one.

Marginal fit of a cemented implant crown is one of most important criteria in its long-term success [35,75]. It has been proposed that an accurate fit of the implant components will minimize bacterial leakage and the strains within the implant components and the peri-implant bone. Subsequently, the biological and mechanical complications, such as bone loss and components loosening or fracture, will be reduced [28,76].

On the contrary, lack of adequate fit is potentially detrimental to the supporting periodontal tissues [29,77]. The gap between the crown and the abutment can act as a trap for bacteria, and thus, possibly cause inflammatory reactions in the peri-implant soft tissues [30,78].

Absolute marginal discrepancy is defined as: "the linear distance from the cavo surface finish line of the preparation to the margin of the restoration"[79]. The marginal gap distance of a restoration may be estimated by either invasive or noninvasive methods. [10]. In this study, marginal adaptation was evaluated by a direct method through microscopic analysis performed with a digital microscope with X90 magnification at 16 predetermined points. This noninvasive method has the advantage of leaving the restoration intact therefore useful to determine the precision of fit of the whole restoration at different stages. However, it does not provide any information about internal fit of the restoration, microleakage, and disintegration of the cement layer[80].

To date, there is no consensus on what constitutes a clinically acceptable maximum marginal gap width in both tooth- and implant-supported fixed prostheses. The values reported in the literature range from 50 to 200 μm [81]. Most investigators continue to use the criteria established by McLean and von Fraunhofer[82] who, after examining more than 1,000 restorations, concluded that 120 μm was the maximum tolerable marginal opening.

In this study, firstly, marginal gap measurements were recorded before cementation, as differences in accuracy of measurements for marginal gap were reported to be independent of whether the crowns were cemented or not[83] and the cement layer has been reported to interfere with measurements of primary precision[80]. Then, measurements were repeated again after cementation to simulate the condition intra-orally.

Based on the results of this study, the first null hypothesis that assumed that the marginal adaptation of the three all-ceramic superstructures would not be influenced by their materials was partially rejected, as regardless of the abutment type or cementation, vita Enamic and Zirconia superstructures showed the lowest values with insignificant difference between them, while e.max CAD recorded the highest mean vertical marginal gap values. (Table.2). These findings may be explained on the basis that the variation in the manufacturing process of the three materials is mainly dependant on the variation in their structural composition.

Moreover, as a result of the interaction of abutment design and cementation, regarding readymade abutments before cementation; the following was revealed for the different superstructures, measurements of marginal fit ranged from (20.1 ± 2.8) to (24.0 ± 3.9) with no significant difference between the three superstructure materials tested. These results were probably related to the accuracy and reproducibility of the CAD/CAM milling procedure, that has the benefit of producing predictable and consistent superstructures in terms of strength, marginal fit, and esthetics [12, 14, 16, 84, 85, 86].

While for custom made abutments before cementation; it was found that the Zirconia superstructures recorded the statistically significant highest mean vertical marginal gap values (21.9 ± 5.7). This can be explained on the basis of, the cumulative effect of the two zirconia shrinkage processes that took place. At first a variable percentage of zirconia shrinkage during the sintering process of the custom made zirconia abutment occurred that might have lead to slightly distorted abutment dimension[87] then, shrinkage took place again when the CAD/CAM fabricated zirconia superstructures were subjected to their sintering process. All this resulted finally in increased marginal gap values. These findings were coinciding with the findings of Abdou J et al[49].

For the e.max CAD a statistically significant lower mean value (17.7 ± 2.9) was recorded. This is attributed mainly to the manufacturing process, as the crowns were milled from partially crystallized lithium disilicate blanks. After milling, the restorations were crystallized at high temperature to reach their final strength and the desired esthetic properties. The crystallization process does not cause any major shrinkage and thus does not require any compensation process[88].

Whereas, Vita Enamic superstructures showed the statistically significant lowest mean marginal gap distance (13.5 ± 1.9). These findings could be based on material science advancement, as polymer-infiltrated ceramics were not subjected to further steps as sintering or crystallization, after the definite milling of the material[89].

Concerning the second null hypothesis, it was totally rejected as the readymade abutments revealed statistically significant higher mean vertical marginal gap values than custom made ones. (Table3). The ready-made abutments recorded a statistically significant higher mean vertical marginal gap (45.9 ± 23.2) than the custom made abutments (37.3 ± 14.9).This may be attributed to the difference in the abutment geometry in terms of total occlusal convergence where the readymade abutments having 8° total occlusal convergence become more or less cylindrical in form than the custom made abutments resulting in hindering excess cement escape during cementation and entrapment of cement occlusally, thus, increasing the marginal gap measurements. While, for custom made abutments having a 12° total occlusal convergence allowed free escape of excess cement along the inclined axial walls allowing proper seating, that will decrease the vertical misfit and enhance the marginal adaptation. These findings were in accordance with Meijer[11] Moreover, difference of margin configuration for both ready and custom made abutments in form of thickness and scalloping indirectly affected the cement film thickness that in turn affected the restoration's marginal adaptation. This can be elucidated by the fact that the scalloping and a 0.5mm thickness of the chamfer finish line of readymade abutments hindered the escape of excess cement which lead to increased marginal discrepancy, whereas, the custom made abutments possessed a uniform 1mm thick deep chamfer finish line that allowed proper seating with less marginal discrepancies. This coincided with the findings of [9, 10, 33].

Finally, the third null hypothesis which supposed that cementation of the superstructure would not affect the marginal adaptation of the various superstructure/abutment combinations was totally rejected. Regardless of abutment designs or superstructure material evaluated, the mean marginal gap values showed an increase after cementation for all the tested groups that ranged from (19.7 ± 5.3) before cementation to (63.5 ± 21.4) after cementation, which was statistically significant for all groups.(Table 4). Such an increase can be explained by the volume required for the cement used and by the role of the internal fit of the restoration. These findings were in accordance with the results reported by Tsukada et al [90]. On the contrary, the post cementation marginal discrepancies results differed than those obtained by Att et al[75]. This difference might be caused by differences in the type and film thickness of cement used. Such an increase can be explained by the volume required for the cement used and by the role of the internal fit of the restoration[90]. In addition, the results were different to those of Sutherland et al[91] due to the difference in the procedural steps as they cemented the all-ceramic crowns to Ti abutments using zinc phosphate, which has a lower film thickness than resin cements. Consequently, the luting agents used in these two studies might have caused different post cementation marginal gaps.

The current standards of the International Organization for Standardization require a film thickness at the time of seating not greater than 25 µm for water-based luting cements[92] and not greater than 50 µm for resin-based cements [93].

In the present study, according to the ceramic manufacturers' guidelines, the cement space was set as 80m$\mu$ during the CAD/CAM designing of the different superstructures. Considering that a marginal gap in the scale of 50 to 100 $\mu$m is ideal for resin cements and seems to optimize performance as reported by Wu and Wilson[94] ,and by taking into account the physical and clinical properties of resin-based luting agents, the obtained results were found to be within the mentioned limits, and the increase after cementation seems to be clinically accepted. The increase in the marginal gap value after cementation can be explained by the volume requirement of the cement used, depending on particle size, flow properties and viscosity.[95]

The clinically acceptable values defined for marginal gap after cementation were reported to be <120 $\mu$m [96]. While, studies consider marginal gap between 50 and 100 mm as the clinically acceptable limit [97]. Other in-vitro studies conducted by Sutherland et al[35] and Att et al [75], considered the 120$\mu$m. marginal gap values clinically acceptable.

In principle, a luting agent must maintain a minimum film thickness over a sufficient period of time to allow seating of indirect restorations.

A possible limitation of this study, was being in-vitro with limited sample size. Additionally, all the vertical marginal gap measurements were performed without artificial aging of the samples, which represents the clinical condition and may affect the results.

## CONCLUSIONS

Within the limitations of this in vitro study, the following conclusions were drawn:

1. Based on the clinical acceptability of 120 µm as a marginal gap, the results of the various all-ceramic superstructures were within the acceptable range and met the clinical requirements for both tested abutments, with the superiority of the vita Enamic superstructures on custom made abutments before cementation.
2. Marginal discrepancies increased significantly after cementation for different abutment-crown combinations

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