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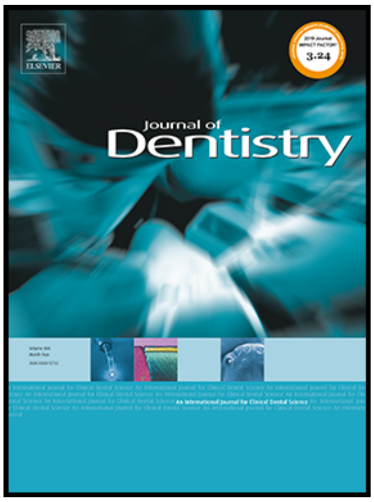

Marginal gap and fracture resistance of implant-supported 3D-printed definitive composite crowns: an in vitro study

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Highlights

- 3D printed implant-supported composite crowns presented lower marginal gap values than clinically acceptable threshold.
- 3D printed implant-supported composite crowns could endure occlusal forces of the posterior region.

Marginal gap and fracture resistance of implant-supported 3D-printed definitive composite crowns: an in vitro study

Original article

Full Title: Marginal gap and fracture resistance of DLP based implant-supported 3D-printed definitive composite crowns: an in vitro study

Short title: Characteristics of CAD-CAM crowns

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ABSTRACT

Objectives: To compare the marginal gap and fracture resistance of implant-supported 3-dimensional (3D) printed definitive composite crowns with those fabricated by using 3 different millable materials.

Material and Methods: A prefabricated abutment was digitized by using a laboratory scanner (E4 Lab Scanner) and a complete-coverage maxillary first premolar crown was designed (Dental Designer). Forty crowns were fabricated either by 3D printing (Saremco Print Crowntec, SP) or milling (Brilliant Crios, BC; Vita Enamic, VE; Cerasmart 270, CS) (n=10). Baseline marginal gap values were evaluated by measuring 60 predetermined points on an abutment (15 points for each side) with a stereomicroscope at ×40 magnification. Marginal gap values were reevaluated after adhesive cementation. Load-to-fracture test was performed by using a universal testing machine. Two-way analysis of variance (ANOVA) was used to evaluate the effect of material type and cementation on marginal gap values. While Tukey HSD tests were used to compare the materials' marginal gap values before and after cementation, the effect of cementation on marginal gap values within each material was analyzed by using paired samples t-tests. Fracture resistance data were analyzed by using 1-way ANOVA (α=.05).

Results: Material type and cementation significantly affected marginal gap values (*P*<.001). Regardless of cementation, SP had the lowest marginal gap values (*P*<.001), while the differences among milled crowns were nonsignificant (*P*≥.14). Cementation significantly increased the marginal gap values (*P*<.001). Material type did not affect fracture resistance values (F=1.589, *P*=.209).

Conclusion: Implant-supported 3D-printed composite crowns showed higher marginal adaptation compared with the milled crowns before and after cementation. In addition, all crowns endured similar forces before fracture.

Clinical Significance

Implant-supported composite crowns fabricated by using the 3D-printed definitive resin tested showed higher marginal adaptation than those fabricated by milling. Considering this result and the similar fracture resistance values among materials, tested 3D-printed definitive resin may represent a valuable alternative to millable materials with comparable chemical compositions.

1. INTRODUCTION

Computer aided design-computer aided manufacturing (CAD-CAM) technology has long been associated with dentistry. Until recently this method was synonymous with subtractive manufacturing or milling [1], which is based on computer controlled devices milling prefabricated blocks to obtain the desired product [2]. However, milling has its disadvantages such as the amount of excess raw material that cannot be reused, wear of the burs, and the dependence of the milling detail to the size of the burs and the number of axis of the milling device [3-5]. In addition, this technique is incapable of producing complex geometries. However, additive manufacturing or 3-dimensional (3D) printing facilitates manufacturing of more complex products with less waste material [1] as objects are fabricated in consecutive layers. This technology has made its impact on dentistry and it is used for the fabrication of various dental products [2].

One of the essential factors defining the clinical success of a restoration is marginal gap [5, 6, 7], which is the distance between the finish line and the margin of the restoration [8]. A suitable marginal adaptation ensures minimal cement film thickness [9] and prevents microleakage that could lead to prosthesis failure [5, 6, 8-13]. Furthermore, a thick cement layer increases polymerization shrinkage and interfacial stresses, which may decrease the fracture resistance of restorations [6, 10]. Previous studies have shown that the marginal adaptation of CAD-CAM restorations is material dependent [6, 7, 9, 11]. No consensus has been reached regarding the marginal gap width [5], yet a previous research has reported clinically acceptable marginal gap as 120 μm [14].

Implant-supported restorations are a viable treatment option to reestablish function, esthetics, and phonetics by replacing missing teeth [15, 16]. Resin-based materials have a shock absorbent nature and might be an alternative for implant-supported restorations [15, 17]. CAD-CAM composites have the advantage of ease of intraoral repair, high marginal stability, and straightforward post-processing [18-22]. In addition, recent studies have reported definitive composite restorations fabricated by using 3D-printing [18, 19, 23, 24]. However, those studies were based on the fracture resistance of tooth-supported restorations and to authors' knowledge, no study has investigated 3D-printed implant-supported definitive composite crowns. Therefore, the purpose of this study was to compare the marginal adaptation and the fracture resistance of 3D-printed definitive composite crowns with 3 CAD-CAM millable materials (polymer-infiltrated ceramic network, force absorbing hybrid ceramic, and reinforced composite). The null hypotheses were that i) marginal gap of implant-supported crowns would not be affected by material type and cementation and ii) fracture resistance of implant-supported crowns would not be affected by material type.

2. MATERIALS AND METHODS

2.1. Specimen preparation

A prefabricated abutment (ø=5.5 mm, *h*=5.5 mm, and 1.5 mm of gingival height, EZ Post Abutment; Megagen Implant, Daegu, Republic of Korea) was screwed to an implant replica (ø=4.3 mm, *h*=12 mm, Megagen Implant, Daegu, Republic of Korea) and was digitized by using a laboratory scanner (E4 Lab Scanner; 3Shape, Copenhagen, Denmark). A full contour maxillary first premolar was designed (Dental Designer; 3Shape, Copenhagen, Denmark) in standard tessellation language (STL) format (Figure 1). The height of the crown was 9 mm from the buccal aspect and 8.5 mm from the palatal aspect, while the thickness of the restoration was 2 mm in the proximal surfaces, 2.5 mm in the buccal and palatal surfaces, and the minimum occlusal thickness was 1.5 mm. The cement gap (the distance between the margin of the abutment and the restoration) used was 25 μm, while the extra cement gap (cement spacer) was set to 50 μm [25]. In addition, drill radius was set to 650 μm and drill compensation offset was set to 660 μm.

Power analyses based on the results of previous studies on 3D-printed definitive resin crowns [18, 23] were performed to determine the number of specimens in each group. However, the results of the power analyses yielded a relatively low number of specimens, due to large effect sizes of those studies. Thus, the number of specimens in each group was determined according to previous studies [5, 15, 18, 23], in which significant differences were reported. Forty crowns were fabricated from 4 different CAD-CAM materials (n=10): SP (Saremco Print Crowntec; Saremco Dental AG, Rebstein, Switzerland), BC (Brilliant Crios; Coltene/Whaledent AG, Altstätten, Switzerland), VE (Vita Enamic; VITA Zahnfabrik, Bad Säckingen, Germany), and CS (Cerasmart 270; GC Corporation, Tokyo, Japan). Table 1 presents detailed information regarding the materials used in the present study. BC, VE, and CS crowns were fabricated by using a milling unit (inLab MC XL; Dentsply Sirona, Bensheim, Germany) and the same milling strategy. A new set of burs (Step Bur 12S and Cylinder Pointed Bur 12S; Dentsply Sirona, Bensheim, Germany) was inserted before the milling process of each restorative material and all crowns were cleaned in distilled water ultrasonically (Cleanex 2801; Everest Elektromekanik, İstanbul, Turkey) following the fabrication process to remove any remaining residues from the intaglio surfaces.

SP crowns were printed by using a digital light processing based 3D printer (MAX UV; ASIGA, Sydney, Australia). Parameters were set to slice thickness of 50 μm, exposure time of 1.8 s, maximum light intensity of 12.14 mW/cm^2, z compensation of 0 μm, and xy compensation of 0 μm. Following the printing process, the external surfaces of the crowns were cleaned with an alcohol-soaked (96%) cloth, while the internal surfaces were cleaned with a brush soaked in an alcohol solution until all resin residues were completely removed. Then, crowns were dried by using an air syringe and were light cured with 4000 lighting exposures by using a Xenon lamp-curing device (Otoflash G171; NK Optik, Baierbrunn, Germany) under nitrogen oxide gas atmosphere. Polishing was not performed after fabrication [18, 19].

2.2. Marginal gap and fracture resistance evaluation

Fifteen points were identified on each side (buccal, mesial, distal, and palatal) of the abutment for the measurement of marginal gap values, which resulted in a total of 60 reference points [13, 26]. A single researcher (Y.O.) evaluated the marginal gap of the crowns before cementation by using a stereomicroscope (Olympus SZ61; Olympus Corp, Tokyo, Japan) under ×40 magnification [13], and photographed by using an image analysis software (Olympus DP2-SAL; Olympus Corp, Tokyo, Japan).

Crowns were then pretreated either with airborne particle abrasion (Rotaks Sandblasting Machine; Rotaks Dent, İstanbul, Turkey) or hydrofluoric etching gel as per manufacturers' recommendations for adhesive cementation (Table 2). After isolating the abutment margins with wax, the abutments were sandblasted with 50μm Al_2O_3 from 10 mm for 60 s (15 s per surface) at 1 bar (Figure 2) [27].

Dental implant replicas were fixed by using a custom-made apparatus with an approximately 3-mm clearance between the fixation screw and the margin of the abutment. Prefabricated abutments were fixed with a torque wrench driver at 35 Ncm as recommended by the manufacturer and the screws were retightened 10 mins later to prevent screw loosening [28]. Screw access holes were sealed with a Teflon tape and a flowable composite material (Filtek Ultimate Flowable Restorative A3; 3M ESPE, St. Paul, MN, USA) was used to secure the screw access holes. Thereafter, a single operator (Y.O.) adhesively seated all crowns by using a self-adhesive resin cement (Panavia SA Cement Universal; Kuraray Noritake, Kurashiki, Okayama, Japan) under finger pressure [29]. Excess cement was removed immediately and a light-emitting diode polymerization unit (1000 mW/cm^2, SmartLite Focus;

Dentsply Sirona, Konstanz, Germany) was applied for 40 s on the buccal, occlusal, and palatal surfaces. Marginal gap of the crowns was then reevaluated by using the same procedure (Figure 3). All crowns were stored in distilled water at 37 °C for 24 hours.

Fracture loading was performed by using a universal testing machine (TSTM 02500; Elista, İstanbul, Turkey). A 6-mm-diameter stainless steel ball at a crosshead speed of 1 mm/min applied the force vertically on buccal and palatal cusps of the crowns. Maximum load at failure was recorded in Newton (N). Thereafter, all crowns were analyzed by using a stereomicroscope (Olympus SZ61; Olympus Corp, Tokyo, Japan) under ×6.7 magnification and one sample from each group was further analyzed with scanning electron microscopy (SEM, EVO LS-10; Zeiss, Cambridge, UK) under magnifications ranging from ×54 to ×100 depending on the area investigated.

2.3. Statistical analysis

Shapiro-Wilk and Levene tests were used to assess the normal distribution of data and homogeneity of variances, respectively. Two-way analysis of variance (ANOVA) was used to evaluate the effect of material type and cementation on marginal gap values. Tukey's HSD post-hoc tests were performed to compare the marginal gap values of materials before and after cementation, while paired samples t-tests were used to resolve any significant relevancies between pre- and post-cementation marginal gap values within each material. Material type's effect on maximum load at failure was analyzed by using 1-way ANOVA. All statistical tests were performed by using a statistical analysis software (SPSS v 21.0; IBM, Armonk, NY, USA) at a significance level of $\alpha = 0.05$.

3. RESULTS

Two-way ANOVA showed that material type and cementation had a significant effect on the marginal gap of the crowns (*P*<.001), whereas the effect of their interaction was nonsignificant (*P*=.086) (Table 3). Among the materials tested, SP presented the lowest marginal gap values before (*P*<.001) and after (*P*<.001) cementation. However, no significant differences were observed among the other restorative materials tested before (*P*≥.729) and after (*P*≥.14) cementation. Marginal gap values of all materials tested increased significantly after cementation (*P*<.001) (Table 4).

Table 5 summarizes the descriptive statistics of the fracture resistance data. One-way ANOVA showed that the differences among the test groups were nonsignificant (df=3, F=1.589, *P*=.209). In addition, all crowns showed non-repairable fragmented crown fractures with at least one part of crown remaining on the abutment. However, no damage was observed in any of the abutments or prosthetic screws (Figure 4). Figure 5 illustrates the representative SEM images of the tested materials for fractographic analysis. Fractured SP, BC, and CS surfaces showed similar topography, which was characterized by dominant hackle and arrest lines. However, VE surfaces were relatively smoother when compared with the other materials tested.

4. DISCUSSION

SP crowns had the lowest marginal gap values before and after cementation, while cementation increased the marginal gap values of all materials. Therefore, the first null hypothesis was rejected. To the authors' knowledge, the present study was the first to evaluate the marginal gap of implant-supported 3D-printed definitive composite crowns. Therefore, the results of the present study could not be compared. However, both 3D-printed and milled specimens showed higher marginal gap values than the predetermined cement gap of 25 µm. This may be attributed to the layer thickness of 3D-printed specimens (50 µm) and the diameters of the burs used (1.3 and 1.8 mm) for the fabrication of milled specimens.

Finger pressure was used in the present study during cementation as clinicians commonly use this method [30]. Considering that the difference in mean marginal gap values before and after cementation ranged from 12.6 to 16.5 µm, which are similar to or slightly higher than the film thickness of the resin cement used (14 µm) [31], it can be stated that the effect of operator on the cementation process was minimized. Mean marginal gap values ranged from 33 to 57.1 µm before cementation and from 47.1 to 69 µm after cementation. Even though these values are lower than 120 µm [14], cementation statistically increased the marginal gap values of all materials. This finding substantiates previous studies [8, 13, 29, 32] and might be related to the volume requirement of the cement used, which is related to its consistency, particle size, and flow properties [29]. Nevertheless, future studies should investigate the effect of thermomechanical aging on the marginal gap of 3D-printed definitive composite crowns as contradictory results have been reported [8, 29]. In addition, surface treatments might have also affected marginal gap values [29], even though all materials received recommended surface treatments.

The present study aimed to compare the marginal gap of different CAD-CAM materials before and after cementation. Thus, instead of a destructive method or replica technique, visual examination by using a stereomicroscope and an image analyzing software was preferred. In addition, this nondestructive method was previously used in dental studies [8, 12, 13, 16]. In the present study, 60 measurements were made for each crown before and after cementation, which resulted in a total of 4800 measurements. Nevertheless, the difficulty of repeating measurements and identifying the actual marginal gap rather than its projection while using direct view with a stereomicroscope has been reported [8]. Considering that the standardized technique for the examination of marginal gap is controversial [29], the knowledge on the fit of 3D-printed implant-supported definitive resin crowns should be corroborated with more advanced measurement methods such as x-ray microtomography [10].

The differences among the fracture resistance values of tested materials were nonsignificant. Therefore, the second null hypothesis was accepted. The materials tested in the present study endured fracture loads that were considerably higher than the reported maximum masticatory forces in the premolar region (200-445 N) [33]. Moreover, considering that the maximum masticatory forces in the molar region may reach up to 900 N [34], it can be speculated that the materials tested may also be used to rehabilitate single implants in molar region. A recent study showed that 3D-printed composite crowns resisted higher loads than BC for each occlusal thickness tested (0.5, 1, and 1.5 mm), while increasing the restoration thickness resulted in significantly higher fracture resistance values for both materials [23]. Contrarily, Zimmermann et al [18] showed that 3D-printed crowns endured similar loads with BC and CS after thermomechanical aging regardless of the occlusal thickness (0.5, 1, and 1.5 mm), while only 1.5 mm-thick VE showed similar values to all 3 of these materials. However, a direct comparison between the present study and those studies [18, 23] could be inaccurate due to the differences in test design.

It is possible to enhance the mechanical properties of a restorative material through advancements in fabrication processes as they are related to the material's distinct matrix and filler arrangement [21, 22]. The materials tested in the present study contain fillers of different ratios. Even though non-repairable crown fractures were seen in all specimens, SEM images showed that VE had a different fracture pattern due to non-complex crack propagation and the presence of main deformation being dominant at the occlusal region. Except from this area, the incidence of hackles was considerably low compared with the other materials. This could be associated with VE's chemical composition that comprised of higher amount of ceramic than the other materials as well as its higher elastic modulus. Considering this finding, it can be speculated that VE might have a different fatigue behavior in clinical use, which should be corroborated with in vivo findings. Nevertheless, no significant differences were found among the fracture resistance values of the materials tested, which may be attributed to the absence of aging or to the adequate occlusal thickness of the restorations. Zimmermann et al's [18] study substantiates the results of the present study as 1.5 mm-thick VE, BC, and CS crowns were reported to show similar fracture resistance values after thermomechanical aging. Moreover, the authors [18] showed that none of the 0.5 mm-thick VE crowns survived the thermomechanical aging and 1 mm-thick BC crowns endured statistically higher loads than VE crowns of same thickness. Contrarily, Rosentritt et al [17] showed that VE resisted higher fractural loads than CS, which was corroborated by another study [9].

Even though the present study solely focused on the effect of material type and cementation on tested parameters, absence of thermal or mechanical aging is a limitation. In addition, only one type of restoration design was tested and other prosthetic designs such as screw-retained crowns with titanium base abutments may lead to different results. Another limitation of the present study was the absence of other restorative materials that are well-known and proven to be successful such as lithium disilicate or monolithic zirconia. Considering these aspects, the results of the present study should be interpreted as preliminary and further supported with studies with diverse parameters.

5. CONCLUSIONS

Considering the limitations of the present study, it can be concluded that implant-supported crowns fabricated by using 3D-printed definitive resin had better marginal adaptation than those of fabricated from millable restorative materials, along with similar fracture resistance values. Even though the results of the present study are promising, tested 3D-printed resin should be further investigated with materials that are scientifically and clinically proven to be successful.

Declaration of interest

The authors declare no conflict of interest. The authors do not have any financial interest in the companies whose materials are included in this article.

Acknowledgement

All other authors have no conflicts of interest to declare. The authors do not have any financial interest in the companies whose materials are included in this article.

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Author Statement File

The authors of the manuscript contributed in the following ways to the submitted manuscript:

Mustafa Borga Donmez: Conceptualization, Resources, Writing - Original Draft, Writing - Review & Editing

Yener Okutan: Conceptualization, Investigation, Resources, Formal analysis, Writing - Review & Editing

Declaration of interests

☒ The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

REFERENCES

[1] A. Kessler, R. Hickel, M. Reymus, 3D printing in dentistry-state of the art, Oper Dent 45(1) (2020) 30-40. http://doi.org/10.2341/18-229-L

[2] R. van Noort, The future of dental devices is digital, Dent Mater 28(1) (2012) 3-12. http://doi.org/10.1016/j.dental.2011.10.014

[3] W. Wang, H. Yu, Y. Liu, X. Jiang, B. Gao, Trueness analysis of zirconia crowns fabricated with 3-dimensional printing, J Prosthet Dent 121(2) (2019) 285-291. http://doi.org/10.1016/j.prosdent.2018.04.012

[4] M.M. Methani, M. Revilla-León, A. Zandinejad, The potential of additive manufacturing technologies and their processing parameters for the fabrication of all-ceramic crowns: A review, J Esthet Restor Dent 32(2) (2020) 182-192. http://doi.org/10.1111/jerd.12535

[5] M. Revilla-León, M.M. Methani, D. Morton, A. Zandinejad, Internal and marginal discrepancies associated with stereolithography (SLA) additively manufactured zirconia crowns, J Prosthet Dent 124(6) (2020) 730-737. http://doi.org/10.1016/j.prosdent.2019.09.018.

[6] W.A. El Ghoul, M. Özcan, H. Ounsi, H. Tohme, Z. Salameh, Effect of different CAD-CAM materials on the marginal and internal adaptation of endocrown restorations: An in vitro study, J Prosthet Dent 123(1) (2020) 128-134. http://doi.org/10.1016/j.prosdent.2018.10.024

[7] E.I. Oguz, M.A. Kılıçarslan, M.E. Özgür, K. Orhan, S. Shujaat, Comparison of marginal adaptation of different resin-ceramic CAD/CAM crowns: an in vitro study, J Adv Oral Res 12(1) (2021) 112-118. http://doi.org/10.1177/2320206820975971

[8] D. Taha, S. Spintzyk, A. Sabet, M. Wahsh, T. Salah, Assessment of marginal adaptation and fracture resistance of endocrown restorations utilizing different machinable blocks

subjected to thermomechanical aging, J Esthet Restor Dent 30(4) (2018) 319-328. http://doi.org/10.1111/jerd.12396

[9] N. Naffah, H. Ounsi, M. Ozcan, H. Bassal, Z. Salameh, Evaluation of the adaptation and fracture resistance of three CAD-CAM resin ceramics: an in vitro study, J Contemp Dent Pract 20(5) (2019) 571-576.

[10] M.D. Gaintantzopoulou, H.M. El-Damanhoury, Effect of preparation depth on the marginal and internal adaptation of computer-aided design/computer-assisted manufacture endocrowns, Oper Dent 41(6) (2016) 607-616. http://doi.org/10.2341/15-146-L

[11] M. Bankoğlu Güngör, A. Doğan, B. Turhan Bal, S. Karakoca Nemli, Evaluation of marginal and internal adaptations of posterior all-ceramic crowns fabricated with chair-side CAD/CAM system: an in vitro study, Acta Odontol Turc 35(1) (2017) 1-8. http://doi.org/10.17214/gaziaot.306165

[12] A. Azarbal, M. Azarbal, R.L. Engelmeier, T.C. Kunkel, Marginal fit comparison of CAD/CAM crowns milled from two different materials, J Prosthodont 27(5) (2018) 421-428. http://doi.org/10.1111/jopr.12683

[13] B. Yildirim, Effect of porcelain firing and cementation on the marginal fit of implant-supported metal-ceramic restorations fabricated by additive or subtractive manufacturing methods, J Prosthet Dent 124(4) (2020) 476.e1-476.e6. http://doi.org/10.1016/j.prosdent.2020.03.014

[14] J.W. McLean, J.A. von Fraunhofer, The estimation of cement film thickness by an in vivo technique, Br Dent J 131(3) (1971) 107-11. http://doi.org/10.1038/sj.bdj.4802708

[15] P. de Kok, C.J. Kleverlaan, N. de Jager, R. Kuijs, A.J. Feilzer, Mechanical performance of implant-supported posterior crowns, J Prosthet Dent 114(1) (2015) 59-66. http://doi.org/10.1016/j.prosdent.2014.10.015

[16] H.H. Zaghloul, J.F. Younis, Marginal fit of implant-supported all-ceramic zirconia frameworks, J Oral Implantol 39(4) (2013) 417-24. http://doi.org/10.1563/AAID-JOI-D-11-00103

[17] M. Rosentritt, S. Hahnel, F. Engelhardt, M. Behr, V. Preis, In vitro performance and fracture resistance of CAD/CAM-fabricated implant supported molar crowns, Clin Oral Investig 21(4) (2017) 1213-1219. http://doi.org/10.1007/s00784-016-1898-9

[18] M. Zimmermann, A. Ender, G. Egli, M. Özcan, A. Mehl, Fracture load of CAD/CAM-fabricated and 3D-printed composite crowns as a function of material thickness, Clin Oral Investig 23(6) (2019) 2777-2784. http://doi.org/10.1007/s00784-018-2717-2

[19] M. Zimmermann, A. Ender, T. Attin, A. Mehl, Fracture load of three-unit full-contour fixed dental prostheses fabricated with subtractive and additive CAD/CAM technology, Clin Oral Investig 24(2) (2020) 1035-1042. http://doi.org/10.1007/s00784-019-03000-0

[20] E.T.P. Bergamo, S. Yamaguchi, P.G. Coelho, A.C.O. Lopes, C. Lee, G. Bonfante, E.B. Benalcázar Jalkh, E.N.S. de Araujo-Júnior, E.A. Bonfante, Survival of implant-supported resin-matrix ceramic crowns: In silico and fatigue analyses, Dent Mater 37(3) (2021) 523-533. http://doi.org/10.1016/j.dental.2020.12.009

[21] I.J.R. Lucsanszky, N.D. Ruse, Fracture toughness, flexural strength, and flexural modulus of new CAD/CAM resin composite blocks, J Prosthodont 29(1) (2020) 34-41. http://doi.org/10.1111/jopr.13123

[22] N.D. Ruse, M.J. Sadoun, Resin-composite blocks for dental CAD/CAM applications, J Dent Res 93(12) (2014) 1232-4. http://doi.org/10.1177/0022034514553976

[23] K. Corbani, L. Hardan, H. Skienhe, M. Özcan, N. Alharbi, Z. Salameh, Effect of material thickness on the fracture resistance and failure pattern of 3D-printed composite crowns, Int J Comput Dent 23(3) (2020) 225-233.

[24] K. Corbani, L. Hardan, R. Eid, H. Skienhe, N. Alharbi, M. Özcan, Z. Salameh, Fracture resistance of three-unit fixed dental prostheses fabricated with milled and 3D printed composite-based materials, J Contemp Dent Pract 22(9) (2021) 985-990.

[25] R. Sadid-Zadeh, A. Katsavochristou, T. Squires, M. Simon, Accuracy of marginal fit and axial wall contour for lithium disilicate crowns fabricated using three digital workflows, J Prosthet Dent 123(1) (2020) 121-127. http://doi.org/10.1016/j.prosdent.2018.11.003

[26] N. Kaleli, D. Saraç, Influence of porcelain firing and cementation on the marginal adaptation of metal-ceramic restorations prepared by different methods, J Prosthet Dent 117(5) (2017) 656-661. http://doi.org/10.1016/j.prosdent.2016.08.016

[27] M. Weyhrauch, C. Igiel, H. Scheller, G. Weibrich, K.M. Lehmann, Fracture strength of monolithic all-ceramic crowns on titanium implant abutments, Int J Oral Maxillofac Implants 31(2) (2016) 304-9. http://doi.org/10.11607/jomi.4601

[28] W. Al-Zordk, A. Elmisery, M. Ghazy, Hybrid-abutment-restoration: effect of material type on torque maintenance and fracture resistance after thermal aging, Int J Implant Dent 6(1) (2020) 24. http://doi.org/10.1186/s40729-020-00220-y

[29] W. Att, T. Hoischen, T. Gerds, J.R. Strub, Marginal adaptation of all-ceramic crowns on implant abutments, Clin Implant Dent Relat Res 10(4) (2008) 218-225. http://doi.org/10.1111/j.1708-8208.2007.00079.x

[30] M. Falahchai, Y.B. Hemmati, H.N. Asli, M.N. Asli, Marginal adaptation of zirconiareinforced lithium silicate overlays with different preparation designs. J Esthet Rest Dent 32(8) (2020) 823-830. http://doi.org/10.1111/jerd.12642.

[31] The Kuraray Noritake website https://www.kuraraynoritake.eu/pub/media/pdfs/20038_1_Panavia_SA_Cement_Universal_Brochure_LR.pdf accessed on 03.02.2022

[32] J.K. Sutherland, R.W. Loney, S. Syed, Marginal discrepancy of all-ceramic crowns cemented on implant abutments, J Prosthodont 4(3) (1995) 173-7. http://doi.org/10.1111/j.1532-849x.1995.tb00336.x

[33] W. Al-Zordk, A. Elmisery, M. Ghazy, Hybrid-abutment-restoration: effect of material type on torque maintenance and fracture resistance after thermal aging, Int J Implant Dent 6(1) (2020) 24. http://doi.org/10.1186/s40729-020-00220-y.

[34] S. Varga, S. Spalj, M. Lapter Varga, S. Anic Milosevic, S. Mestrovic, M. Slaj, Maximum voluntary molar bite force in subjects with normal occlusion, Eur J Orthod 33(4) (2011) 427-33. http://doi.org/10.1093/ejo/cjq097

TABLES

Table 1. List of the materials tested

Material	Classification	Chemical Composition	Flexural Strength	E-modulus
Saremco Print Crowntec (SP)	3D-printed composite resin	Bis-EMA, Dental glass and silica fillers (30 - 50%), Initiators, Inhibitors and color pigments	>130 MPa	> 4 GPa
Brilliant Crios (BC)	Reinforced composite	70.7 wt% barium glass (<1 µm) and amorphous silica (SiO_2; <20 nm), Cross-linked methacrylates (Bis-GMA, Bis-EMA, TEGDMA)	198 MPa	10.3 GPa
Vita Enamic (VE)	Polymer-infiltrated ceramic network	86 wt% ceramic and 14 wt% polymer (UDMA and TEGDMA)	150-160 MPa	30 GPa
Cerasmart 270 (CS)	Force absorbing hybrid ceramic	Bis-MEPP, UDMA, DMA, Silica (20 nm), Barium glass (300 nm), (filler: 71 wt%)	246 MPa	9.6 GPa

Table 2. Surface treatment of the materials

Material	Surface Treatment
Saremco Print Crowntec (SP)	Airborne particle abrasion by using 110µm Al_2O_3 (Korox; Bego, Bremen, Germany) particles at 1.5 bar
Brilliant Crios (BC)	Airborne particle abrasion by using 50µm Al_2O_3 (Shera Aluminium Oxide; Shera Material Technology, Lemförde, Germany) particles at 1.5 bar
Vita Enamic (VE)	4.5% hydrofluoric acid (IPS Ceramic Etching Gel; Ivoclar Vivadent, Schaan, Liechtenstein) etching for 60 s
Cerasmart 270 (CS)	4.5% hydrofluoric acid (IPS Ceramic Etching Gel; Ivoclar Vivadent, Schaan, Liechtenstein) etching for 60 s

Table 3. Two-way ANOVA results of marginal gap measurements

	Type III Sum of Squares	df	Mean Square	F	P
Corrected Model	6761.007	7	965.858	108.532	<.001
Intercept	230143.602	1	230143.602	25860.893	<.001
Material	2438.519	3	812.84	91.338	<.001
Cementation	4261.492	1	4261.492	478.857	<.001
Material x Cementation	60.996	3	20.332	2.285	.086
Error	640.749	72	8.899		
Total	237545.357	80			
Corrected Total	7401.756	79			

R Squared = .913 (Adjusted R Squared = .905); df: degrees of freedom

Table 4. Mean ±standard deviations (95% confidence intervals) of the marginal gap values

	Before Cementation (µm)	After Cementation (µm)
SP	35.9 ±1.8^{aA} (34.6-37.1)	52.4 ±2.3^{aB} (50.7-54)
BC	50.7 ±3.6^{bA} (48.1-53.3)	63.3 ±2.8^{bB} (61.3-65.3)
VE	49.3 ±3.3^{bA} (46.9-51.6)	65.5 ±2.7^{bB} (63.5-67.4)
CS	49.5 ±3.3^{bA} (47.1-51.9)	62.6 ±3.5^{bB} (60.1-65.1)

*Different superscript letters present significant differences (lowercase letters for columns, uppercase letters for rows) (*P*<.05)

Table 5. Mean ±standard deviations (SD), confidence intervals (CI), minimum, and maximum values of fracture resistance of the test groups

	Mean ±SD (N)	95% CI (N)	Min (N)	Max (N)
SP	1413.91 ±140.49	1313.41-1514.41	1193.45	1607.51
BC	1333.23 ±144.73	1229.7-1436.77	1144.86	1526.31
VE	1359.25 ±159.63	1245.05-1473.44	1150.8	1587.08
CS	1274.32 ±135.8	1177.18-1371.47	1101.98	1493.96

FIGURES

Figure 1. Proximal and occlusal aspect of the crown design

Figure 2. Pretreatment of the standard abutment (A: Isolation of the margins; B: After sandblasting)

Figure 3. Representative stereomicroscope images (×40) of each material (Pre: Before cementation; Post: After cementation)

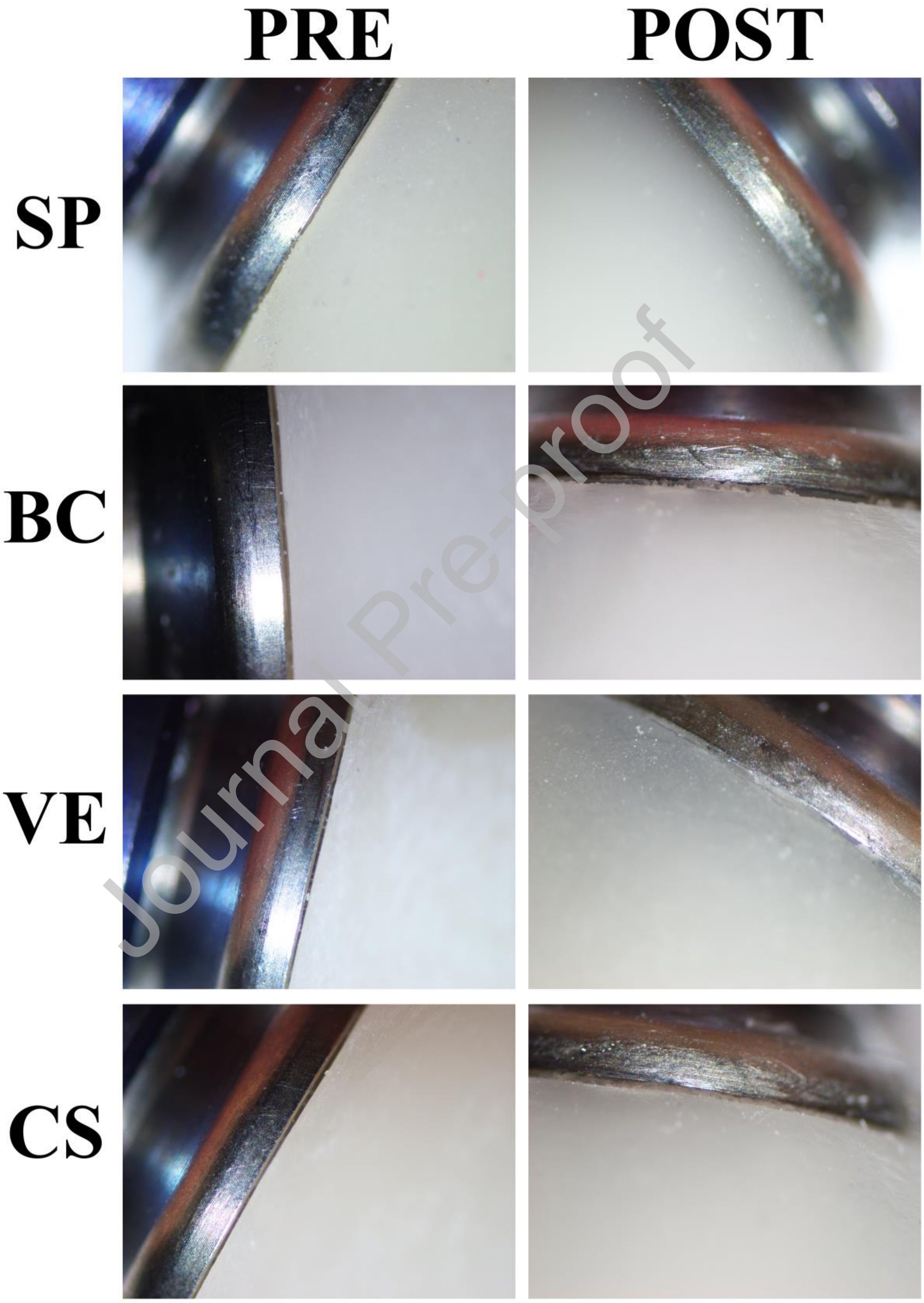

Figure 4. Crown fractures observed in each group

Figure 5. Representative SEM images of fractured specimens (A: Abutment; AL: Arrest line; CL: Cement layer; HL: Hackle line; O: Origin of fracture; White arrows: Direction of crack propagation). Images on the left have magnifications ranging from ×54 to ×59 and images on the right have ×100 magnification. SEM images on the right depict magnified images of red squares on the left.