Article published online: 2024-03-20

Digital Evaluation of the Trueness and Fitting Accuracy of a Three-Unit Fixed Zirconium Bridge Fabricated from Different Types of Zirconia and Different Marginal Cement Space Thickness

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Eur J Gen Dent 2024;13:30–36.

Abstract

Objective The aim of this study was to measure the internal, marginal fitness, and trueness of a three-unit fixed zirconium bridge fabricated using two types of zirconia and different marginal cement space thicknesses.

Methods and Materials Thirty-two aluminum master models, constructed by computer numerical control (CNC) milling machines using aluminum rod, representing two prepared aluminum abutments (the upper first premolar and the first molar) were chosen due to differences in shape and dimensions, which may affect adaptation. It may also be considered one of the most common cases in clinical practice and a missing second premolars were used to fabricate a three-unit fixed partial zirconium bridge. A master model was scanned with an intraoral scanner. Fixed dental prostheses (FDPs) were fabricated with two designs (single-layer high-translucent [HT] Katana and ultra-translucent multilayer (UTML] zirconia Katana) and two marginal cement space thicknesses (0 and 25μm for HT and ML). These specimens are divided according to marginal cement space and type of zirconia into four groups, each containing eight samples. Group A: 25-μm marginal cement space with single-layer HT zirconia. Group B: 25-μm marginal gap with UTML zirconia. Group C: 0 μm marginal gap single-layer HT zirconia. Group D: 0 μm marginal gap with UTML zirconia. Fitness and trueness of the fabricated three-unit FDPs were evaluated by scanning the silicone replica of the cement space and analyzing the thickness of the silicone replica in the three-dimensional inspection software (Geomagic Control X, Morrisville, North Carolina, USA).

Results Highest mean value of internal gap was recorded at the molar abutment of group D (95.05, ± 3.42 μm), while the lowest was recorded at the premolar abutment of group A (57.12, ± 2.43μm). For marginal gap, the lowest marginal gap was also recorded at the premolar abutment of group A (36.14, ± 3.94μm), and the highest was at the molar abutment of group D (84.74, ± 2.98 μm).

Keywords
- zirconium bridge
- trueness
- internal fitness

DOI https://doi.org/10.1055/s-0043-1777010.
ISSN 2320-4753.

For trueness, group A showed the lowest root mean square (RMS) of mean with both abutments compared with group D, which recorded the highest RMS of mean for trueness.

Conclusion The marginal cement space thickness affects the FPD internal, marginal fitness, and trueness; single-layer HT (Katana) zirconia shows better fitness and trueness than UTML (Katana).

Introduction

The maintenance of prosthetic restorations is dependent upon achieving a high level of accuracy in terms of fit. The trueness of the manufactured prosthesis is a significant determinant in influencing fitness.[1–4] The degree of marginal accuracy has a significant role in determining the success of a restoration in clinical performance. Trueness refers to the degree of similarity between the initial computer-aided design (CAD) reference model of prosthesis and the final CAD test model of the manufactured prosthesis.[5–10] The presence of an inaccurate inner surface of the prosthesis is among several factors that impact the marginal and internal fit. Therefore, it is imperative to conduct a trueness evaluation.[11,12] The presence of internal fit disorders can have an impact on the long-term retention and resistance of the prosthesis. The decline in the marginal fit of dental restorations leads to the accumulation of bacteria, which in turn gives rise to a range of biological complications such as microleakage, hypersensitivity, secondary decay formation, infection, periodontal diseases, and bone resorption.[13–17] All-ceramic systems have the potential to serve as viable substitutes for metal ceramic systems in the context of esthetic restorative materials for crowns and fixed partial dentures (FPDs).[18] The utilization of zirconia in digital dentistry is experiencing a growing trend in popularity.[19,20] Zirconia exhibits remarkable strength, thereby highlighting a limitation of conventional ceramic materials.[21] To achieve aesthetic outcomes comparable to natural teeth, the application of veneering porcelain onto the zirconia framework is necessary. Nevertheless, a deficient configuration of the underlying structure and a significant disparity in the occlusal surface the occurrence of delamination and fracture of the veneering porcelain can be attributed to certain factors.[22] The CAD/CAM system with ZrO2 material exhibited a satisfactory level of marginal fit.[23] Recently, there have been advancements in the development of zirconia materials that exhibit high translucency and possess a multilayered structure capable of replicating the diverse range of colors observed in natural teeth, spanning from the cervical region to the incisal edge. These materials are commonly referred to as highly translucent (HT) zirconia and multilayer (ML) zirconia, respectively. Using these materials, it has become feasible to manufacture a visually pleasing monolithic zirconia restoration without the need for veneering porcelain. This advancement not only reduces the likelihood of fracture but also simplifies the laboratory process.[24–28] Nevertheless, there is a shortage of research examining the characteristics of ML zirconia with high translucency, and the accuracy of fit for fixed dental prostheses (FDPs) made from this material remains uncertain. There exist two distinct approaches for the production of zirconia FDPs: the first involves milling from a zirconia disk that has undergone complete sintering (fully sintered zirconia), while the second entails milling from a zirconia disk that has undergone partial sintering (pre-sintered zirconia). Presintered zirconia can be efficiently produced due to its comparatively modest flexural strength range of 31 to 50 MPa.[29] The observed variation in the chemical composition of CAD/CAM materials appears to be correlated with the disparity in their postmilling firing requirements, which may in turn be indicative of the divergence in the marginal, internal, and overall fitness of the produced all ceramic crowns.[30] In this study, we conducted an in vitro study to examine the impact of varying marginal cement gap thicknesses (0 µm, 25 µm) and two types of zirconia (HT and UTML Katana) on the trueness and FPDs fit. The factors contributing to the improved fit of FDPs are clarified. The null hypothesis stated that there would be no significant impact on the trueness and internal fit of three-unit fixed zirconium bridges when considering the marginal cement space thickness (0 µm, 25 µm) and two varieties of zirconia (HT, ML) used by the FDP.

Materials and Methods

This study employed an aluminum master die featuring two abutments, namely the maxillary first premolar and the first molar, as well as a single missing tooth, specifically the maxillary second premolar. The three-unit all-ceramic bridge was prepared with a 360 degree chamfer on each abutment tooth, as depicted in ►**Fig. 1**. An even application of dental scan spray (Optispray, Sirona Dental Systems GmbH, Bensheim, Germany) was administered to the upper dentoform arch, followed by the use of the InLab inEos X5 extra-oral scanner device (manufactured by Sirona Dental System, Bensheim, Germany) to capture the Standard Triangle Language (STL) file required for the design of a dental bridge. Two different types of zirconia, namely monolithic HT and UTML Katana , were manufactured. Subsequently, the determination of the thickness of the marginal cement space was conducted utilizing CAD software. The marginal gap of 0 µm was observed in two types of zirconia, namely HT and ML. Similarly, the marginal gap of 25 µm was also found in two types of zirconia, HT and ML; to get a cement space of 25 µm at the marginal area of the finishing line, the inlay/onlay parameter is utilized. The "marginal adhesive gap" is then selected and adjusted to a value of 25 µm. Next, the morphology of the crown should be adjusted, followed by the precise arrangement of the

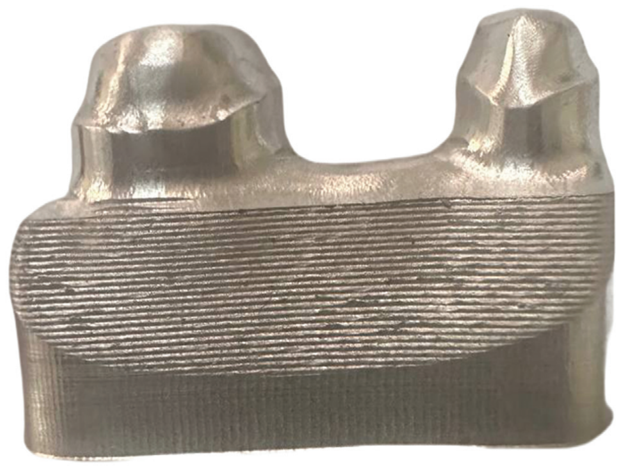

Fig. 1 An aluminum master die featuring two abutment teeth, specifically the maxillary first premolar and first molar, as well as a vacant space in the second premolar region.

buttons. Finally, the "Edit restoration" option should be selected to let the program to compute all the necessary information before exporting it to the milling machine.[31]

Trueness and Internal Fit Analysis

Using an optical scanner, specifically the Medit T710 desktop scanner manufactured in Seoul, South Korea, the inner surface of each abutment was scanned. Prior to each utilization, the scanner underwent calibration to guarantee accurate scanning. Every scan was converted into an STL file to be stored and used for the purpose of evaluating its accuracy[32] as shown in ►**Fig. 2**.

The three-dimensional (3D) inspection software employed in this study was Geomagic Control X, developed by 3D Systems Inc., based in Rock Hill, South Carolina, United States. The Coping Designed Model (CDM) file and the Coping Scanned Model (CSM) file were imported into the software, and the two files were aligned through initial and best-fit alignment techniques. Subsequently, the 3D comparison feature was chosen to assess the disparities in dimensions between CDM and CSM. The established tolerance for this analysis was ± 10 µm, with a maximum and minimum range of ± 100 µm. Each data point within the inner region of each scan is comprised of three coordinates, namely X, Y, and Z. To determine the accuracy of the data, the Euclidean distance between each data point in the Control Data Matrix (CDM) and its corresponding point in the Comparison Data Set (CSM) files was computed.[15,33]

The utilization of root mean square (RMS) values is employed to characterize the standard deviation of the scanned data. A small RMS value indicates a high level of 3D agreement among the overlapping data. The color difference maps are presented for every 3D comparison in cases where the CSM file data are positioned above the CDM file data. In these maps, the red area represents the range of 10 to 100 µm. This implies that the manufacturing process failed to achieve the desired outcome. When the data in the CSM file is situated below the data in the CDM file, as denoted by the blue zone spanning from −10 to −100 µm, it implies that the manufacturing process has exceeded the intended position. The regions were precisely aligned with the green region, which measures less than 10 µm. If the RMS value is high, the color difference map will exhibit an increased presence of red and blue regions (►**Fig. 3**). This observation suggests that the 3D alignment of the overlay data is characterized by a suboptimal level of agreement.

Fig. 2 Scanning of the inner surface of each abutment.

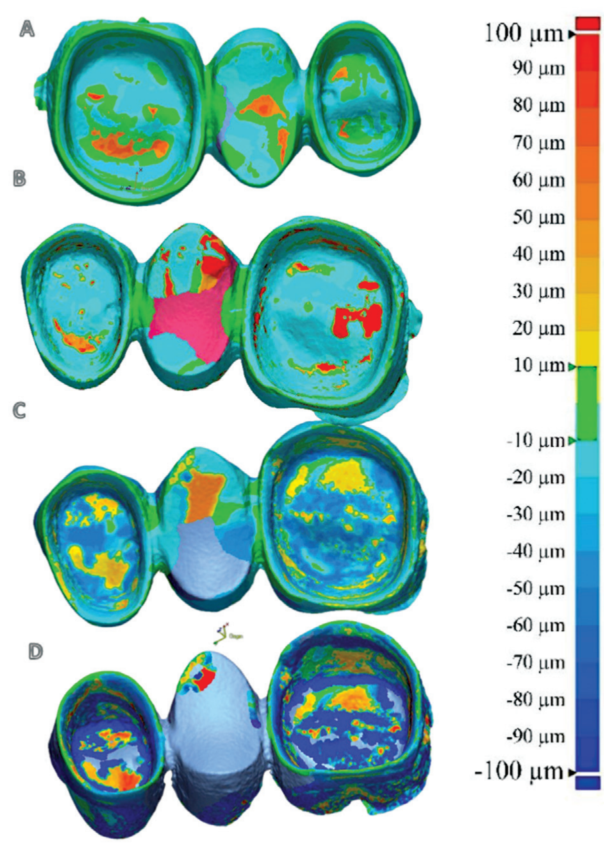

Fig. 3 Color difference map with three-dimensional compare option. Positive deviations are visually represented by a color spectrum ranging from yellow to red, whereas negative deviations are visually represented by a color spectrum ranging from cyan to blue.

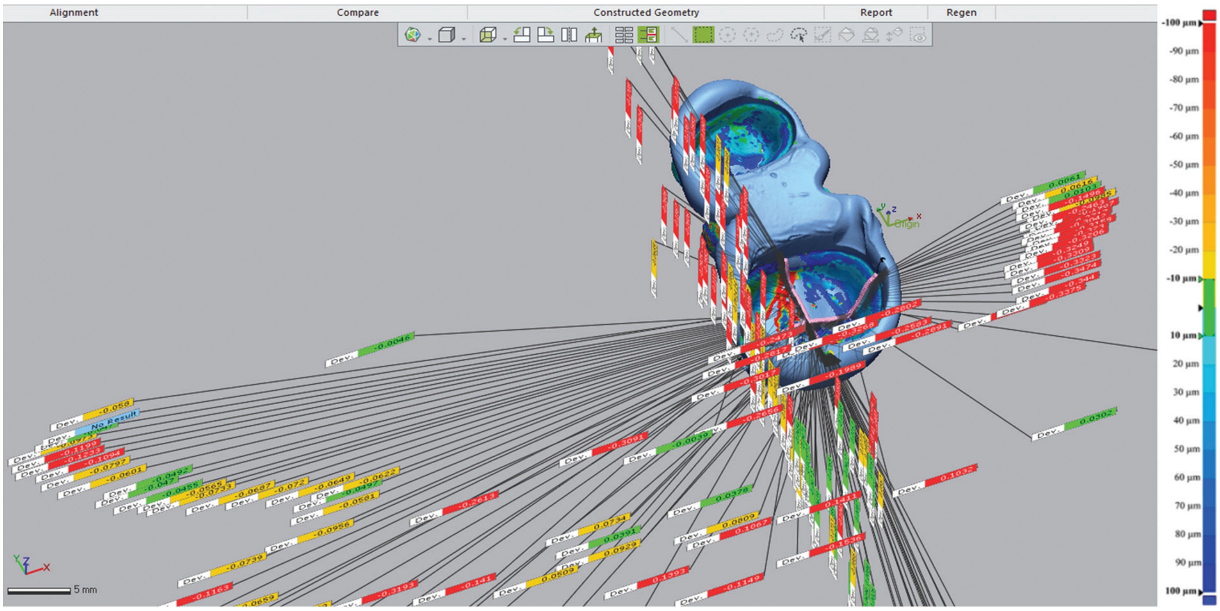

Fig. 4 The assessment of marginal and internal fit within a theoretical plane.

The Express Light Body, Fast Set, 3M ESPE material was utilized to fill the intaglio surface of the copings. Subsequently, the coping was placed on the model and subjected to finger pressure. Each coping was positioned on the model with an occlusal force of 5 kg (50 N). To simulate the biting forces generated by the mandible during the process of measurement, it is necessary to model those forces and for more standardization.[34,35] The removal of the material after its complete polymerization from the die was subsequently undertaken.[36,37]

The inner surface of each coping, both with and without the impression material, was scanned using an optical scanner (Medit T710, Seoul, South Korea). The STL files obtained from the scans were saved and subsequently imported into the software Geomagic Control X, developed by 3D Systems Inc.. These files were then overlaid with initial and best-fit alignment. The superimposed files were divided into hypothetical planes along the mesiodistal and buccolingual directions, and the fitness was assessed along these planes. In each sample, a total of 600 points were systematically chosen along the theoretical planes, with equal spacing between the points within each sample (►**Fig. 4**). The data analysis was conducted using IBM SPSS Statistics, version 26.0 (IBM Corp., Armonk, New York, United States). The statistical tests employed for assessing significant differences between the groups were one-way analysis of variance (ANOVA) and Tukey's honestly significant difference test.

Results

The mean RMS value for trueness was the highest for the molar abutment of group D (63.25, ± 3.67 µm), while the lowest RMS value was for trueness for the premolar abutment of group A (29.63, ± 5.13 µm) as shown in ►**Table 1**.

For the internal fit, the premolar abutment of group A showed the lowest mean of internal gap (57.12, ± 2.43µm), while the highest mean of internal gap was recorded at the molar abutment of group D (95.05, ± 3.42 µm). And for the marginal gap, also the molar abutment of group D had the highest mean value (84.74, ± 2.98 µm) and the lowest mean

Table 1 Mean RMS value (µm) for trueness of the four groups

Groups	Abutment	Mean	SD	Minimum	Maximum
A	Premolar	29.63	5.13	20.34	37.34
	Molar	35.61	3.76	28.45	40.91
B	Premolar	32.94	2.72	29.14	35.92
	Molar	36.73	2.69	32.44	40.11
C	Premolar	47.90	4.04	42.11	52.92
	Molar	54.16	4.46	48.12	59.82
D	Premolar	55.25	2.99	50.45	60.89
	Molar	63.25	3.67	57.91	67.11

Abbreviations: RMS, root mean square; SD, standard deviation.

Table 2 Mean internal and marginal gaps (μm) of the four groups

Measure	Group	Abutments	Mean (μm)	SD	Minimum	Maximum
Internal fitness	A	Premolar	57.12	2.43	53.65	60.12
		Molar	72.47	1.51	70.11	74.17
	B	Premolar	66.72	1.40	64.78	68.89
		Molar	78.53	2.03	75.47	81.21
	C	Premolar	74.97	2.00	72.65	77.91
		Molar	90.08	1.50	87.95	92.42
	D	Premolar	80.93	4.04	75.14	86.17
		Molar	95.05	3.42	88.21	98.74
Marginal fitness	A	Premolar	36.14	3.94	29.96	42.54
		Molar	60.33	3.55	52.98	64.11
	B	Premolar	45.01	3.14	40.11	50.17
		Molar	70.88	4.42	62.19	75.11
	C	Premolar	65.85	2.51	62.67	69.12
		Molar	82.58	2.25	78.11	85.11
	D	Premolar	72.30	3.69	68.11	78.91
		Molar	84.74	2.98	80.92	89.11

Abbreviation: SD, standard deviation.

for marginal was recorded for the premolar of the abutment of group A (36.14, ± 3.94μm) and the highest mean marginal fitness was recorded for the molar abutment of group D (84.74, ± 2.98μm) showed in ►**Table 2**.

The results of the one-way ANOVA test revealed a statistically high significant difference at a significance level of $p = 0.000$ for both the mean RMS value of trueness and the mean internal gaps.

The Tukey's test was conducted to perform multiple comparisons between various pairs of groups to investigate the underlying source of the observed differences. The Tukey's test showed there is statistically highly significant difference between all groups in the marginal and internal fitness. Except molar abutment of group C and molar abutment of group D there was nonsignificant difference. As for mean RMS values trueness, there is statistically nonsignificant difference between group A and except between premolar and molar abutments of group A is statistically significant difference and between premolar of group A and molar abutment of group B there is statistically high significant difference. A high significant difference between group C and D except between premolar and molar abutments of group C is statistically significant difference. Between molar abutment of group C and premolar abutment of group D is nonsignificant difference.

Discussion

The null hypothesis was rejected due to the presence of a statistically significant difference in trueness ($p = 0.000$) and fitness ($p = 0.000$) between two types of zirconia HT and ML fabricated with different types of cement space thickness (0 and 25 μm).

Internal Fit

In this study, the results showed that the FDPs' design and different marginal cement space thickness (0–25μm) had an effect on the marginal and internal fit when compared with the results obtained when we used a 0 μm cement space at the marginal area of preparation. The results of this study showed that using a 25μm cement space around the marginal area of preparation results in a thinner cement film thickness than the set cement space at all areas of measurement according to the mean marginal gap of premolar and molar abutments, as groups A and B had the lowest mean marginal gap than C and D, as shown in ►**Table 2**. This may be explained by the fact that by using a 25μm cement space at the margin, the frictional resistance that results from the seating of crown restorations may be reduced, and this is agreed with.[38,39]We thought about the possibility that the ML structure of zirconia could cause a change in size. By including FDPs made from single-layer HT zirconia in the experimental group, we could see how the ML structure affected the marginal and internal fit. The single-layer HT zirconia with a marginal gap of 25μm in group A had the lowest mean marginal and internal gap for both abutments premolar and molar as when compared with UTML zirconia with the same marginal gap of 25 μm, which was also the same for Groups C and D, which were fabricated with the same marginal cement space thickness 0μm and from different types of zirconia (HT for Group C and UTML for Group D), which revealed that Group C had a lower marginal and internal gap than Group D. Thus, these groups fabricated from single layer HT zirconia had a better fit than groups fabricated from ML zirconia, and this happens because the amounts of metal oxide particles in each layer are different, and the amount and timing of shrinkage in each layer during secondary firing differed. This could have resulted in layer distortion. Because the company did not provide the authors with any information regarding the coloring particles, the influence of various metal oxides and their amount on the fit cannot be revealed.[40] Furthermore, it is believed that the process utilized to create the ML zirconia affects the degree of distortion. As a result, more research on this topic is required.[41]

Trueness

According to Cho et al 2019, the acceptable RMS value of the trueness is below 50µm; so based on the results of this study, the mean RMS values for trueness were 29.63, ± 5.13µm for premolar abutment and 35.61, ± 3.76µm for molar abutment of group A and for group B, RMS values were 32.94, ± 2.72µm for premolar abutment and 36.73, ± 2.69 µm for abutment; while in group C only premolar abutment was below the acceptable range, which was 47.90, ± 4.04 µm, though molar abutment showed greater RMS value of 54.16, ± 4.46 µm, and in group D, RMS values for premolar and molar were 55.25, ± 2.99 µm and 63.25, ± 3.67 µm, respectively, were above the accepted range; so these groups had a greater deviation from the design.[41] Therefore, the decreased trueness can be ascribed to various factors, including the dimensions and configuration of the milling burs, the quality of the CAD data collected by the CAM system, and the processing capabilities. The formation of rounded edges is a consequence of the limited resolution of the CAD-CAM imaging system, as well as the challenges associated with scanning acute angles during the image acquisition process and subsequent reconstruction by the software program. During the process of reading, the phenomenon of light reflection is observed to occur with greater intensity compared with flat areas and this agreed with other Majeed ZA and Jasim HH in 2023.[33]

Conclusion

Given this study's limitations, the findings showed that:

1. HT Katana zirconia had the lowest mean RMS of trueness and the lowest internal and marginal gap, which means it had the least amount of deviation from the design and a better fit.
2. ML Katana Zirconia had a greater amount of deviation from the design due to its highest mean RMS for trueness and high mean internal and marginal gaps.
3. Marginal cement space thickness affects the internal fit; a 25 µm marginal cement space thickness showed a better fit than a 0 µm.

Conflict of Interest
None declared.

Acknowledgment
The authors would like to thank Baghdad University and Mustansiriyah University (www.uomustansiriyah.edu.iq), Baghdad, Iraq, for its support in the present work.

References

1 Lövgren N, Roxner R, Klemendz S, Larsson C. Effect of production method on surface roughness, marginal and internal fit, and retention of cobalt-chromium single crowns. J Prosthet Dent 2017;118(01):95–101
2 Ortega R, Gonzalo E, Gomez-Polo M, Lopez-Suarez C, Suarez MJ. SEM evaluation of the precision of fit of CAD/CAM zirconia and metal-ceramic posterior crowns. Dent Mater J 2017;36(04):387–393
3 Gaikwad BS, Nazirkar G, Dable R, Singh S. Comparative evaluation of marginal fit and axial wall adaptability of copings fabricated by metal laser sintering and lost-wax technique: an *in vitro* study. J Indian Prosthodont Soc 2018;18(01):47–52
4 Rödiger M, Schneider L, Rinke S. Influence of material selection on the marginal accuracy of CAD/CAM-fabricated metal-and all-ceramic single crown copings. BioMed Res Int 2018;2018: 2143906
5 Behnam N. Effect of different surface treatments on shear bond strength of zirconia bonded to dentin with two resin luting cements. Mustansiria Dent J 2013;10(02):167–175
6 Ali AAA, Sabea NR. Comparison of marginal adaptation, internal fitness and microleakage of Zolid, Zirconia and Empress 2 all-ceramic crown materials (an in vitro study). Mustansiria Dent J 2013;10(02):184–192
7 Patzelt SB, Bishti S, Stampf S, Att W. Accuracy of computer-aided design/computer-aided manufacturing-generated dental casts based on intraoral scanner data. J Am Dent Assoc 2014;145 (11):1133–1140
8 Kim C-M, Kim SR, Kim JH, Kim HY, Kim WC. Trueness of milled prostheses according to number of ball-end mill burs. J Prosthet Dent 2016;115(05):624–629
9 Renne W, Ludlow M, Fryml J, et al. Evaluation of the accuracy of 7 digital scanners: An in vitro analysis based on 3-dimensional comparisons. J Prosthet Dent 2017;118(01):36–42
10 Jasim Kahdim AK. Comparison the marginal and internal fitness of veneered and anatomical zirconia crowns milled by two different CAD/CAM systems (an in vitro study). Mustansiria Dent J 2022;18(02):238–244
11 Kirsch C, Ender A, Attin T, Mehl A. Trueness of four different milling procedures used in dental CAD/CAM systems. Clin Oral Investig 2017;21(02):551–558
12 Kalberer N, Mehl A, Schimmel M, Müller F, Srinivasan M. CAD-CAM milled versus rapidly prototyped (3D-printed) complete dentures: an in vitro evaluation of trueness. J Prosthet Dent 2019;121(04):637–643
13 Kim D-Y, Kim JH, Kim HY, Kim WC. Comparison and evaluation of marginal and internal gaps in cobalt-chromium alloy copings fabricated using subtractive and additive manufacturing. J Prosthodont Res 2018;62(01):56–64
14 Lee K-B, Park CW, Kim KH, Kwon TY. Marginal and internal fit of all-ceramic crowns fabricated with two different CAD/CAM systems. Dent Mater J 2008;27(03):422–426
15 Park J-Y, Bae SY, Lee JJ, Kim JH, Kim HY, Kim WC. Evaluation of the marginal and internal gaps of three different dental prostheses: comparison of the silicone replica technique and three-dimensional superimposition analysis. J Adv Prosthodont 2017;9(03): 159–169
16 Kane LM, Chronaios D, Sierraalta M, George FM. Marginal and internal adaptation of milled cobalt-chromium copings. J Prosthet Dent 2015;114(05):680–685
17 Park J-K, Kim HY, Kim WC, Kim JH. Evaluation of the fit of metal ceramic restorations fabricated with a pre-sintered soft alloy. J Prosthet Dent 2016;116(06):909–915
18 Al-Zubaidi Z, Al-Shamma A. The effect of different finishing lines on the marginal fitness of full contour zirconia and glass ceramic CAD/CAM crowns (an in-vitro study). J Dent Mater Tech 2015;4 (03):127–136

19 Mehl A, Hickel R. Current state of development and perspectives of machine-based production methods for dental restorations. Int J Comput Dent 1999;2(01):9–35
20 Borba M, Miranda WG Jr, Cesar PF, Griggs JA, Bona AD. Evaluation of the adaptation of zirconia-based fixed partial dentures using micro-CT technology. Braz Oral Res 2013;27(05):396–402
21 Zhang Y, Lee JJ, Srikanth R, Lawn BR. Edge chipping and flexural resistance of monolithic ceramics. Dent Mater 2013;29(12):1201–1208
22 Rezende CEE, Borges AF, Gonzaga CC, Duan Y, Rubo JH, Griggs JA. Effect of cement space on stress distribution in Y-TZP based crowns. Dent Mater 2017;33(02):144–151
23 Hmedat SJA, Ibraheem AF. An in vitro evaluation of fit of the crowns fabricated by zirconium oxide-based ceramic CAD/CAM systems, before and after porcelain firing cycles and after glaze cycles. J Baghdad Coll Dent 2013;25(01):43–48
24 Chun EP, Anami LC, Bonfante EA, Bottino MA. Microstructural analysis and reliability of monolithic zirconia after simulated adjustment protocols. Dent Mater 2017;33(08):934–943
25 Kolakarnprasert N, Kaizer MR, Kim DK, Zhang Y. New multi-layered zirconias: composition, microstructure and translucency. Dent Mater 2019;35(05):797–806
26 Wang F, Takahashi H, Iwasaki N. Translucency of dental ceramics with different thicknesses. J Prosthet Dent 2013;110(01):14–20
27 Zhang Y. Making yttria-stabilized tetragonal zirconia translucent. Dent Mater 2014;30(10):1195–1203
28 Øilo M, Kvam K, Gjerdet NR. Load at fracture of monolithic and bilayered zirconia crowns with and without a cervical zirconia collar. J Prosthet Dent 2016;115(05):630–636
29 Sachs C, Groesser J, Stadelmann M, Schweiger J, Erdelt K, Beuer F. Full-arch prostheses from translucent zirconia: accuracy of fit. Dent Mater 2014;30(08):817–823
30 Majeed MA, Al-Adel SK. Evaluation of the marginal and internal fitness of full contour CAD/CAM crowns made from zirconia, lithium disilicate, zirconia-reinforced lithium silicate and hybrid dental ceramic by silicone replica technique (A comparative In vitro study). J Genet Environ Resour Conser 2016;4(01):10–20
31 Hammond E, Ibraheem AF. Evaluate and compare the effect of different marginal cement space parameter setting in the CAD software on the marginal and internal fitness of monolithic zirconia crowns with different types of luting agents (a comparative in vitro study). J Res Med Dent Sci 2020;8:74–80
32 Park G-H, Son K, Lee K-B. Feasibility of using an intraoral scanner for a complete-arch digital scan. J Prosthet Dent 2019;121(05):803–810
33 Ali Majeed Z, Hasan Jasim H. Digital evaluation of trueness and fitting accuracy of Co-Cr crown copings fabricated by different manufacturing technologies. Cureus 2023;15(06):e39819
34 Abdulazeez MI, Majeed MA. Fracture strength of monolithic zirconia crowns with modified vertical preparation: a comparative in vitro study. Eur J Dent 2022;16(01):209–214
35 Balkaya MC, Cinar A, Pamuk S. Influence of firing cycles on the margin distortion of 3 all-ceramic crown systems. J Prosthet Dent 2005;93(04):346–355
36 Jang D, Son K, Lee K-b. A comparative study of the fitness and trueness of a three-unit fixed dental prosthesis fabricated using two digital workflows. Appl Sci (Basel) 2019;9(14):2778
37 Lee K, Son K, Lee K-b. Effects of trueness and surface microhardness on the fitness of ceramic crowns. Appl Sci (Basel) 2020;10(05):1858
38 Hoang LN, Thompson GA, Cho SH, Berzins DW, Ahn KW. Die spacer thickness reproduction for central incisor crown fabrication with combined computer-aided design and 3D printing technology: an in vitro study. J Prosthet Dent 2015;113(05):398–404
39 Hussien IM, Ibraheem AF. The effect of differentmarginal cement space thickness on the fracture strength of monolithic zirconia crowns using different luting agents. J Res Med Dent Sci 2020;10(04):48–52
40 Suzuki S, Katsuta Y, Ueda K, Watanabe F. Marginal and internal fit of three-unit zirconia fixed dental prostheses: effects of prosthesis design, cement space, and zirconia type. J Prosthodont Res 2020;64(04):460–467
41 Cho J-H, Yoon HI, Han JS, Kim DJ. Trueness of the inner surface of monolithic crowns fabricated by milling of a fully sintered (Y, Nb)-TZP block in chairside CAD–CAM system for single-visit dentistry. Materials (Basel) 2019;12(19):3253