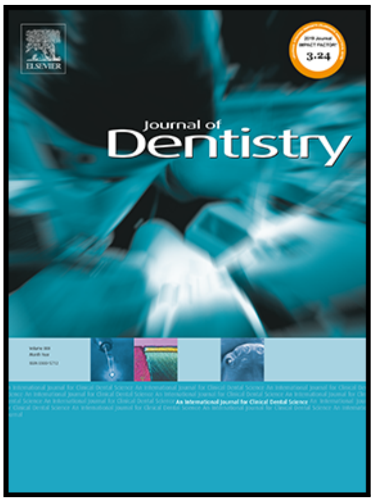
Journal Pre-proof



Additive or subtractive manufacturing of crown patterns used for pressing or casting: a trueness analysis

Gülce Çakmak , Mustafa Borga Donmez ,
Alfonso Rodrigues Cuellar , Çiğdem Kahveci , Martin Schimmel ,
Burak Yilmaz

PII: S0300-5712(22)00277-9
DOI: https://doi.org/10.1016/j.jdent.2022.104221
Reference: JJOD 104221

To appear in: *Journal of Dentistry*

Received date: 11 February 2022
Revised date: 5 July 2022
Accepted date: 8 July 2022

Please cite this article as: Gülce Çakmak , Mustafa Borga Donmez , Alfonso Rodrigues Cuellar , Çiğdem Kahveci , Martin Schimmel , Burak Yilmaz , Additive or subtractive manufacturing of crown patterns used for pressing or casting: a trueness analysis, *Journal of Dentistry* (2022), doi: https://doi.org/10.1016/j.jdent.2022.104221

Additive or subtractive manufacturing of crown patterns used for pressing or casting: a trueness analysis

Original article

Full Title: Additive or subtractive manufacturing of crown patterns used for pressing or casting: a trueness analysis

Short title: Trueness of milled or printed crown patterns used for pressing or casting

Authors: Gülce Çakmak, DDS, PhD,[a] Mustafa Borga Donmez, DDS, PhD,[b,c] Alfonso Rodrigues Cuellar, DDS, PhD,[d] Çiğdem Kahveci, DDS, PhD,[e] Martin Schimmel DDS, PhD,[f,g] and Burak Yilmaz DDS, PhD[h,i,j]

[a]Senior Research Associate, Department of Reconstructive Dentistry and Gerodontology, School of Dental Medicine, University of Bern, Bern, Switzerland; guelce.cakmak@zmk.unibe.ch

[b]Assistant Professor, Department of Prosthodontics, Istinye University Faculty of Dentistry, Istanbul, Turkey

[c]Visiting Researcher, Department of Reconstructive Dentistry and Gerodontology, School of Dental Medicine, University of Bern, Bern, Switzerland; mustafa-borga.doenmez@zmk.unibe.ch

[d]Periodontist, Private Practice, Mexico City, Mexico; alfonso_rodriguez@my.unitec.edu.mx

[e]Assistant Professor, Department of Prosthodontics, Giresun University Faculty of Dentistry, Giresun, Turkey; cigdem.kahveci@giresun.edu.tr

[f]Chairman, Department of Reconstructive Dentistry and Gerodontology, School of Dental Medicine, University of Bern, Bern, Switzerland

[g]Privat-Docent extra muros, Division of Gerodontology and Removable Prosthodontics, University Clinics of Dental Medicine, University of Geneva, Geneva, Switzerland; martin.schimmel@zmk.unibe.ch

[h]Associate Professor, Department of Reconstructive Dentistry and Gerodontology, School of Dental Medicine, University of Bern, Bern, Switzerland

[i]Associate Professor, Department of Restorative, Preventive and Pediatric Dentistry, School of Dental Medicine, University of Bern, Bern, Switzerland; burak.yilmaz@zmk.unibe.ch

[j]Adjunct Professor, Division of Restorative and Prosthetic Dentistry, The Ohio State University College of Dentistry, Ohio, USA

Corresponding author:

Dr Gülce Çakmak

Department of Reconstructive Dentistry and Gerodontology,

School of Dental Medicine, University of Bern,

Freiburgstrasse 7 3007

Bern, Switzerland

email: guelce.cakmak@unibe.ch

Keywords: 3D-printing, milling, resin pattern, trueness

HIGHLIGHTS

- Pattern fabrication technique affects the trueness of crown patterns.
- Milled crown patterns had higher trueness than printed patterns.
- Clinical fit might not be affected from pattern fabrication technique due to small deviations.

ABSTRACT

Objectives: To investigate the effect of subtractive and additive manufacturing techniques on the trueness of crown patterns used for pressing or casting.

Material and Methods: A complete-coverage mandibular right first molar crown was designed in standard tessellation language (STL) format. This STL served as the control (C-STL) and was used to fabricate 30 crown patterns in 3D-printed resin (PR, ProArt Print Wax), millable wax suitable for casting (BW, ProArt CAD Wax Blue), and millable wax suitable for pressing (YW, ProArt CAD Wax Yellow) (n=10). Subtractively manufactured patterns were fabricated by using a 5-axis milling unit (PrograMill PM7), while 3D-printed patterns were fabricated by using a digital light processing-based 3D printer (PrograPrint PR5; Ivoclar Vivadent, Schaan, Liechtenstein). All fabricated patterns were digitized by using an intraoral scanner (CEREC Primescan SW 5.2) to generate test-STLs. C-STL and test-STLs were transferred into a 3D analysis software (Medit Link v 2.4.4). Trueness evaluation was performed at 4 different surfaces (external, intaglio with margin, marginal, and intaglio without margin) and for complete scan meshes (overall) by using the root mean square (RMS) method. Data were analyzed with Kruskal-Wallis and Mann-Whitney U tests (α=.05).

Results: RMS values varied significantly at all surfaces ($P<.001$), except for marginal surface ($P=.151$). PR had the highest RMS values at external surface ($P\leq.007$), intaglio surfaces (with ($P\leq.003$) and without margin ($P\leq.005$)), and overall ($P\leq.01$). No significant differences were observed between YW and BW ($P\geq.223$).

Conclusion: Patterns fabricated by using subtractive manufacturing exhibited high trueness. The deviation values, in general, were small, particularly at intaglio and marginal surfaces; thus, clinical difference in crown-fit may be negligible using additive or subtractive technique.

Clinical Significance

The fit of definitive crowns may be similar when tested crown patterns are additively or subtractively manufactured. However, crowns fabricated by using tested 3D-printed resin patterns may require more chairside adjustments compared with those fabricated by using subtractively manufactured wax patterns.

1. INTRODUCTION

Conventional wax pattern fabrication is a technique-sensitive and time-consuming process, and the quality of the final product depends on the skill of technician [1, 2]. In addition, intrinsic features of wax such as thermal sensitivity, elastic memory, texture, and high coefficient of thermal expansion limit its use [3]. With advancements in computer aided design-computer aided manufacturing (CAD-CAM) technologies [4], fabrication of wax patterns has shifted from conventional to digital [2], which involves additive and subtractive manufacturing [5]. CAD-CAM fabricated wax patterns can be used to cast metal restorations or press restorations from pressable materials like lithium disilicate [6,7]. Not all dental laboratories or clinics have CAM units that can mill metals, and some continue using ceramic pressing technology, which has been reported to be successful [8].

Additive manufacturing through 3-dimensional (3D) printing is becoming increasingly popular in dentistry [9]. Among 3D printing technologies [10], digital light processing (DLP) is a commonly used method that is based on ultraviolet structured light photopolymerization of resin [11]. Additive manufacturing enables the fabrication of multiple products in complex geometries with less waste [9]. 3D printing facilitates wax pattern production in high quality and rate with reduced time and labor [2, 12]. In general, dental printers are more affordable than milling units that are capable of milling metals. Therefore, laboratories or clinics may consider using additively manufactured wax for efficient fabrication of cast or pressed restorations.

Trueness can be described as the closeness of a measurement to the actual dimensions of an object. Dimensional accuracy after fabrication is a key factor for the optimal fit of a fixed restoration [13]. Previous studies have focused on the marginal and internal fit of either additively manufactured copings or onlay patterns [1, 5] or definitive restorations fabricated from 3D-printed wax patterns [14-19]. However, the authors are unaware of any study that evaluated and compared the trueness of additively manufactured resin patterns with that of subtractively manufactured waxes suitable for casting and pressing techniques. Considering that any error in the pattern may be amplified in the final restoration due to potential casting or pressing related flaws, a study based on the trueness of additively manufactured crown patterns can focus on the direct effect of pattern fabrication technique on pattern trueness. Therefore, the present study aimed to compare the trueness of additively manufactured crown patterns with that of 2 subtractively manufactured (1 suitable for casting and 1 suitable for pressing) wax patterns. The null hypothesis was that there would be no difference in the trueness of wax crown patterns fabricated.

2. MATERIALS AND METHODS

2.1. Specimen preparation

A titanium die was sprayed with a thin layer of antireflective spray and digitized by using an intraoral scanner (IOS) (Cerec Primescan SW 5.2; Dentsply Sirona, Bensheim, Germany) [1, 20]. A complete-coverage mandibular right first molar crown was designed onto the standard tessellation language (STL) file of the die with a 30 μm cement space [21] by using a design software (3Shape Dental System; 3Shape, Copenhagen, Denmark). This design was saved in STL format (C-STL) and used for the fabrication of 30 patterns from a 3D-printed resin (PR, ProArt Print Wax; Ivoclar Vivadent, Schaan, Liechtenstein) and 2 CAD-CAM wax discs (BW, ProArt CAD Wax Blue and YW, ProArt CAD Wax Yellow; Ivoclar Vivadent, Schaan, Liechtenstein) (n=10). The number of specimens in each group was based on a previous study that investigated the trueness of additively manufactured crowns [11].

For the fabrication of additively manufactured resin patterns, C-STL was transferred into nesting software (3Shape CAMbridge; 3Shape, Copenhagen, Denmark) and its occlusal surface was positioned towards the build platform. After generating supports automatically, this configuration was duplicated 10 times for standardization, arranged on the build platform, and transferred into a DLP-based 3D printer (PrograPrint PR5; Ivoclar Vivadent, Schaan, Liechtenstein) with the software (PrograPrint Manager; Ivoclar Vivadent, Schaan, Liechtenstein). Printed specimens were placed into an alcohol bath (PrograPrint Clean; Ivoclar Vivadent, Schaan, Liechtenstein) containing 96% isopropyl alcohol and cleaned for 4 mins (2 mins of rough cleaning and 2 mins of fine cleaning at 850 rpm). Specimens were left to dry for 1 hour and post-polymerized by using a light-emitting diode curing unit (PrograPrint Cure; Ivoclar Vivadent, Schaan, Liechtenstein), which had a preset curing program for the resin used [22]. All processes were performed in a room specifically designed for printing, which had stabilized temperature (20 °C) and humidity (45%), controlled by building maintenance system. The 3D printer manufacturer has not disclosed specific requirements. After removing the patterns from the build platform by using a scraper, support structures were removed and surfaces were smoothened.

For the fabrication of subtractively manufactured wax patterns, C-STL was nested (PrograMill CAM V4; Ivoclar Vivadent, Schaan, Liechtenstein) in CAD-CAM wax discs (n=10), which were indicated either for casting (BW) or pressing (YW). Wax patterns were milled by using a 5-axis milling unit (PrograMill PM7; Ivoclar Vivadent, Schaan, Liechtenstein). After separating the subtractively manufactured patterns from the discs, surfaces were smoothened. One operator performed all fabrication processes (G.Ç.) and further evaluated the specimens under 3.5× magnification to detect potential defects. No surface adjustments were made on the intaglio surfaces of the specimens [11, 21] (Figure 1).

One operator (M.B.D.) with 4 years of experience in digital dental applications digitized the specimens to generate test-STLs by using the same IOS. IOS was calibrated before scanning each group and the operator took 5-min breaks in between each group to prevent fatigue-related deviations [23]. All scans were performed in the same temperature- and humidity-controlled room.

2.2. Trueness analysis

Deviation analysis was performed by using a software (Medit Link v 2.4.4; Medit, Seoul, Korea) and the root mean square (RMS) method [11, 24]. C-STL and test-STL files were imported into the software and the C-STL was selected as the reference with the assign data tool. The comparison tool of the software, which allows the simultaneous selection of 3 points from reference and target data, was used to superimpose the test-STL over C-STL (Figure 2). Similar to previous studies on trueness evaluation of 3D-printed crowns [11, 24, 25], color maps representing 3D deviations were generated with the maximum/minimum critical (nominal) values set at +50/-50 µm and the tolerance range set at +10/-10 µm. Overall RMS values were automatically calculated from the color maps. STL files were imported again for the evaluation of other surfaces (external, intaglio with margin, marginal, and intaglio without margin). These surfaces were virtually separated, dividing the patterns into 4 as previously reported [11, 25]. This superimposition process was repeated for each surface and the color maps generated were used for RMS calculations (Figure 3).

2.3. Statistical analysis

Statistical analysis of RMS data was performed by using the software (SPSS Statistics v22.0; IBM, Chicago, IL, USA). As the Kolmogorov-Smirnov test revealed a non-normal distribution, non-parametric Kruskal-Wallis and Mann-Whitney U tests were performed to analyze the data (α=.05).

3. RESULTS

Figure 4 represents the RMS values measured for each material-surface pair, while Table 1 lists the descriptive statistics of each material-surface pair. Except for marginal surface (*P*=.151), RMS values at all surfaces differed among the test groups (*P*<.001). Patterns fabricated with PR had the highest RMS values at external surface (*P*<.001 vs BW and *P*=.007 vs YW), intaglio surface with (*P*=.003 vs BW and *P*<.001 vs YW) and without margin (*P*=.005 vs BW and *P*<.001 vs YW), and overall (*P*<.001 vs BW and *P*=.01 vs YW). However, the differences between BW and YW were nonsignificant (*P*=.223 for overall, *P*=.322 for external, *P*=.851 for intaglio with margin, and *P*=.554 for intaglio without margin).

4. DISCUSSION

In this study, subtractively manufactured wax patterns had higher trueness than 3D-printed resin patterns at tested surfaces, except for marginal surface. Therefore, the null hypothesis was rejected.

Even though additively manufactured resin patterns showed marginal RMS values similar to those of subtractively manufactured wax patterns, clinical fit of the restorations fabricated by using additively manufactured resin patterns could be worse. Higher deviations observed at overall and external surfaces of resin patterns may lead to tighter or open interproximal and occlusal contacts of definitive restorations that would require adjustments for an optimal fit. When color maps were analyzed, blue color (undercontour) was significantly dominant for overall and external surface of PR, which might lead to open interproximal or occlusal contacts. However, red color (overcontour) was observed at the central fossae of the crowns, regardless of the material, which may increase the chairside time needed for occlusal adjustments. In addition, deviations at the intaglio surfaces might affect cement space and clinical fit. Color maps showed deviations at the intaglio surfaces of 3D-printed patterns, which showed both overcontoured and undercontoured areas. However, subtractively manufactured patterns showed a more uniform pattern at the intaglio surface. BW showed overcontoured areas at the intaglio occlusal surface that may affect clinical fit. Some differences were observed in the color maps of different crowns and the crown fit or contacts affected may differ depending on the location of the deviation. Even though statistical differences were detected for the effect of fabrication technique, all intaglio and marginal deviations were below 32 µm. In addition, the maximum difference between mean intaglio surface deviations was 19 µm, and the maximum difference in mean marginal surface deviations was 1 µm amongst the groups. These differences may be considered clinically small and the clinical fit of the crowns may be similar when tested fabrication techniques are used. A previous study has also reported no difference in the internal and marginal fit of pressed lithium disilicate crowns fabricated from additively and subtractively manufactured patterns [15]. Other studies on the effect of pattern fabrication technique on marginal fit have reported contradictory findings [1, 14, 17, 19, 20], which may be related to different definitive restorative materials used. However, the authors are unaware of a study on the occlusal analysis of restorations fabricated from different CAD-CAM fabrication techniques. Thus, future studies should investigate the effect of CAD-CAM fabrication technique on clinical fit and occlusal contacts of restorations fabricated by using various materials s.

Revilla León et al [5] investigated the effect of fabrication technique on the marginal and internal adaptation of onlay patterns. The authors [5] reported that subtractively fabricated patterns resulted in higher internal gaps, whereas no significant difference was observed in the marginal gap of additively and subtractively manufactured specimens. However, another study concluded that 3D-printed custom abutment patterns showed higher marginal gaps than subtractively manufactured patterns [16]. These contradictory findings may be due to the effect of restoration type/geometry on the marginal fit of wax patterns. Therefore, the results of the present study should be elaborated with studies evaluating the trueness of different types of restorations in varying geometries.

An IOS that has high resolution sensors and performs on shortwave light with optical high-frequency contrast analysis was used in the present study to digitize the crown patterns. IOSs allow digitizing crowns in one scan, whereas a laboratory scanner or an industrial-grade scanner needs further alignment of external and intaglio surface scans to generate one crown scan, which is a technique that relies on this alignment's accuracy. Therefore, IOS scans could be considered a more straightforward approach compared to using a laboratory scanner or an industrial-grade scanner to digitize single crowns. In addition, a previous study showed that scans performed using the IOS utilized in the present study resulted in similar congruence between the scan mesh and the design file when compared with a laboratory scanner [23].

The software (Medit Link) used in the present study allows the analysis of any STL output [24], and it has been reported that this software performed similarly to a commonly used metrology-grade software (Geomagic Control X) while measuring deviations between the meshes of a complete coverage crown and its corresponding design file [24]. However, other studies have shown the significant effect of 3D analysis software on the deviation analyses when metrology-grade software were used [26, 27]. Considering these contradictory findings, future studies should investigate the trueness of 3D-printed resin patterns by using different 3D analysis software. The results of such studies would widen the knowledge on the performance of additive manufacturing and the ability of 3D analysis software to detect deviations.

RMS calculation is commonly preferred in dental studies [28] and has been used for trueness evaluation of crowns [11, 24, 25]. However, the effect of calculation method on measured deviations has been shown in recent studies [29, 30]. Considering that present study was the first to analyze the trueness of complete-coverage crown patterns, future studies using different calculation methods such as absolute average value and (90–10)/2 percentile should substantiate the findings of the present study.

A limitation of the present study was the absence of a power analysis. However, considering that significant differences were found among test groups and the number of specimens in each group was based on a previous study on the accuracy of additively manufactured crowns [11], the authors believe that 10 specimens per group may be adequate. In addition, the materials used in the present study were limited to one brand and only one type of milling unit and 3D printer were used. Therefore, the results of the present study should be interpreted carefully and extrapolating these results to different brands of materials, milling units, and 3D printers may be misleading. Another limitation was that only one type of restoration was analyzed. However, different restoration geometries may lead to different results. One IOS was used to digitize the crown patterns and IOS type may affect the congruence between the scan meshes and the digital design file of crowns [23]. The results of this study should be elaborated with future studies that have varying parameters such as type of restoration, 3D-printed resins, subtractively manufactured waxes, fabrication, digitization, and deviation measurement methods. In addition, potential effect of these patterns on definitive lithium disilicate restorations should be investigated and compared with subtractively manufactured lithium disilicate restorations, which are reported to have high clinical success [31].

5. CONCLUSIONS

Within the limitations of the present study, it can be concluded that subtractively manufactured wax patterns resulted in high trueness at all surfaces except for the margins when compared with additively manufactured resin patterns. Therefore, definitive restorations fabricated with subtractively manufactured patterns may require less chairside occlusal and interproximal adjustments. Nevertheless, internal and marginal deviations of all crowns can be considered clinically small, which may result in similar clinical fit.

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.

Ivoclar Vivadent is gratefully acknowledged for supplying the materials used in this study. The authors also thank Marco Pannier for supplying the materials.

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

Gülce Çakmak: Design, Data collection, Drafting article, Critical revision of article

Mustafa Borga Donmez: Drafting article, Critical revision of article

Alfonso Rodrigues Cuellar: Design, Data collection

Çiğdem Kahveci: Data analysis, Data interpretation, Statistical analysis

Martin Schimmel: Design, Critical revision of the article

Burak Yilmaz: Critical revision of the article, Approval of the submitted and final versions

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.

☐The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:

References

[1] E. Farjood, M. Vojdani, K. Torabi, A.A. Khaledi, Marginal and internal fit of metal copings fabricated with rapid prototyping and conventional waxing, J Prosthet Dent 117(1) (2017) 164-170. http://doi.org/10.1016/j.prosdent.2016.04.010.

[2] J. Sun, F.Q. Zhang, The application of rapid prototyping in prosthodontics, J Prosthodont 21(8) (2012) 641-4. http://doi.org/10.1111/j.1532-849X.2012.00888.x.

[3] J. Abduo, K. Lyons, M. Swain, Fit of zirconia fixed partial denture: a systematic review, J Oral Rehabil 37(11) (2010) 866-76. http://doi.org/10.1111/j.1365-2842.2010.02113.x.

[4] 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.

[5] M. Revilla-León, M. Olea-Vielba, A. Esteso-Saiz, I. Martínez-Klemm, M. Özcan, Marginal and internal gap of handmade, milled and 3D printed additive manufactured patterns for pressed lithium disilicate onlay restorations, Eur J Prosthodont Restor Dent 26(1) (2018) 31-38. http://doi.org/10.1922/EJPRD_01733RevillaLeon08.

[6] F. Zarone, M. Ferrari, F.G. Mangano, R. Leone, R. Sorrentino,"Digitally oriented materials": Focus on lithium disilicate ceramics, Int J Dent 2016 (2016) 9840594. http://doi.org/10.1155/2016/9840594.

[7] F. Zarone, M.I. Di Mauro, P. Ausiello, G. Ruggiero, R. Sorrentino, Current status on lithium disilicate and zirconia: a narrative review, BMC Oral Health. 19(1) (2019)134. http://doi.org/10.1186/s12903-019-0838-x.

[8] F.A. Forrer, N. Schnider, U. Brägger, B. Yilmaz, S.P. Hicklin, Clinical performance and patient satisfaction obtained with tooth-supported ceramic crowns and fixed partial dentures, J Prosthet Dent 124(4) (2020) 446-453. http://doi.org/10.1016/j.prosdent.2019.08.012.

[9] J. Jockusch, M. Özcan, Additive manufacturing of dental polymers: An overview on processes, materials and applications, Dent Mater J 39(3) (2020) 345-354. http://doi.org/10.4012/dmj.2019-123.

[10] M. Revilla-León, M. Özcan, Additive manufacturing technologies used for processing polymers: current status and potential application in prosthetic dentistry, J Prosthodont 28(2) (2019) 146-158. http://doi.org/10.1111/jopr.12801.

[11] G. Çakmak, A.R. Cuellar, M.B. Donmez, M. Schimmel, S. Abou-Ayash, W.-E. Lu, B. Yilmaz, Effect of printing layer thickness on the trueness and margin quality of 3D-printed interim dental crowns, Applied Sciences 11(19) (2021) 9246. http://doi.org/10.3390/app11199246

[12] S. Witkowski, CAD/CAM in dental technology, Quintessence Dent Technol 28 (2005) 169-184.

[13] W. Pacquet, L. Tapie, B. Mawussi, P. Boitelle, Volumetric and dimensional accuracy assessment of CAD-CAM-manufactured dental prostheses from different materials, J Prosthet Dent (2021). http://doi.org/10.1016/j.prosdent.2021.05.024.

[14] S.Y. Kang, H.N. Lee, J.H. Kim, W.C. Kim, Evaluation of marginal discrepancy of pressable ceramic veneer fabricated using CAD/CAM system: additive and subtractive manufacturing, J Adv Prosthodont 10(5) (2018) 347-353. http://doi.org/10.4047/jap.2018.10.5.347.

[15] L. Shamseddine, R. Mortada, K. Rifai, J.J. Chidiac, Fit of pressed crowns fabricated from two CAD-CAM wax pattern process plans: A comparative in vitro study, J Prosthet Dent 118(1) (2017) 49-54. http://doi.org/10.1016/j.prosdent.2016.10.003.

[16] D. Taha, M. Nour, M. Zohdy, A. El-Etreby, A. Hamdy, T. Salah, The effect of different wax pattern fabrication techniques on the marginal fit of customized lithium disilicate implant abutments, J Prosthodont 28(9) (2019) 1018-1023. http://doi.org/ 10.1111/jopr.13112.

[17] F.R. Homsy, M. Özcan, M. Khoury, Z.A.K. Majzoub, Comparison of fit accuracy of pressed lithium disilicate inlays fabricated from wax or resin patterns with conventional and CAD-CAM technologies, J Prosthet Dent 120(4) (2018) 530-536. http://doi.org/10.1016/j.prosdent.2018.04.006.

[18] Y. Liu, H. Ye, Y. Wang, Y. Zhao, Y. Sun, Y. Zhou, Three-dimensional analysis of internal adaptations of crowns cast from resin patterns fabricated using computer-aided design/computer-assisted manufacturing technologies, Int J Prosthodont 31(4) (2018) 386–393. http://doi.org/10.11607/ijp.5678.

[19] L. Guachetá, C.D. Stevens, J.A. Tamayo Cardona, R. Murgueitio, Comparison of marginal and internal fit of pressed lithium disilicate veneers fabricated via a manual waxing technique versus a 3D printed technique, J Esthet Restor Dent (2020). http://doi.org/10.1111/jerd.12675.

[20] M. Vojdani, K. Torabi, E. Farjood, A. Khaledi, Comparison the marginal and internal fit of metal copings cast from wax patterns fabricated by CAD/CAM and conventional wax up techniques, J Dent (Shiraz) 14(3) (2013) 118.

[21] N. Alharbi, R.B. Osman, D. Wismeijer, Factors influencing the dimensional accuracy of 3D-printed full-coverage dental restorations using stereolithography technology, Int J Prosthodont 29(5) (2016) 503-10. http://doi.org/10.11607/ijp.4835.

[22] The Ivoclar website https://downloadcenter.ivoclar.com/#search-info-542=289117%2C1&details=21993, accessed on 09.02.2022

[23] F. Mangano, H. Lerner, B. Margiani, I. Solop, N. Latuta, O. Admakin, Congruence between meshes and library files of implant scanbodies: an in vitro study comparing five intraoral scanners, J Clin Med 9(7) (2020). http://doi.org/10.3390/jcm9072174.

[24] B. Yilmaz, V.R. Marques, M.B. Donmez, A.R. Cuellar, W.E. Lu, S. Abou-Ayash, G. Çakmak, Influence of 3D analysis software on measured deviations of CAD-CAM resin crowns from virtual design file: An in-vitro study, J Dent 118 (2021) 103933. http://doi.org/10.1016/j.jdent.2021.103933.

[25] 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.
[26] S. Peroz, B.C. Spies, U. Adali, F. Beuer, C. Wesemann, Measured accuracy of intraoral scanners is highly dependent on methodical factors, J Prosthodont Res (2021). http://doi.org/10.2186/jpr.JPR_D_21_00023.
[27] K. Son, W.S. Lee, K.B. Lee, Effect of different software programs on the accuracy of dental scanner using three-dimensional analysis, Int J Environ Res Public Health 18(16) (2021). http://doi.org/10.3390/ijerph18168449.
[28] S. O'Toole, C. Osnes, D. Bartlett, A. Keeling, Investigation into the accuracy and measurement methods of sequential 3D dental scan alignment, Dent Mater 35(3) (2019) 495-500. http://doi.org/10.1016/j.dental.2019.01.012.
[29] H. Lerner, K. Nagy, N. Pranno, F. Zarone, O. Admakin, F. Mangano, Trueness and precision of 3D-printed versus milled monolithic zirconia crowns: An in vitro study, J Dent 113 (2021) 103792. http://doi.org/10.1016/j.jdent.2021.103792.
[30] B.B. Yatmaz, S. Raith, S. Reich, Trueness evaluation of digital impression: The impact of the selection of reference and test object, J Dent 111 (2021) 103706. http://doi.org/10.1016/j.jdent.2021.103706.
[31] M. Imburgia, H. Lerner, F. Mangano, A retrospective clinical study on 1075 lithium disilicate CAD/CAM veneers with feather-edge margins cemented on 105 patients, Eur J Prosthodont Restor Dent, 29(1) (2021) 54-63. http://doi.org/10.1922/EJPRD_2248Mangano10.

TABLES

Surfaces

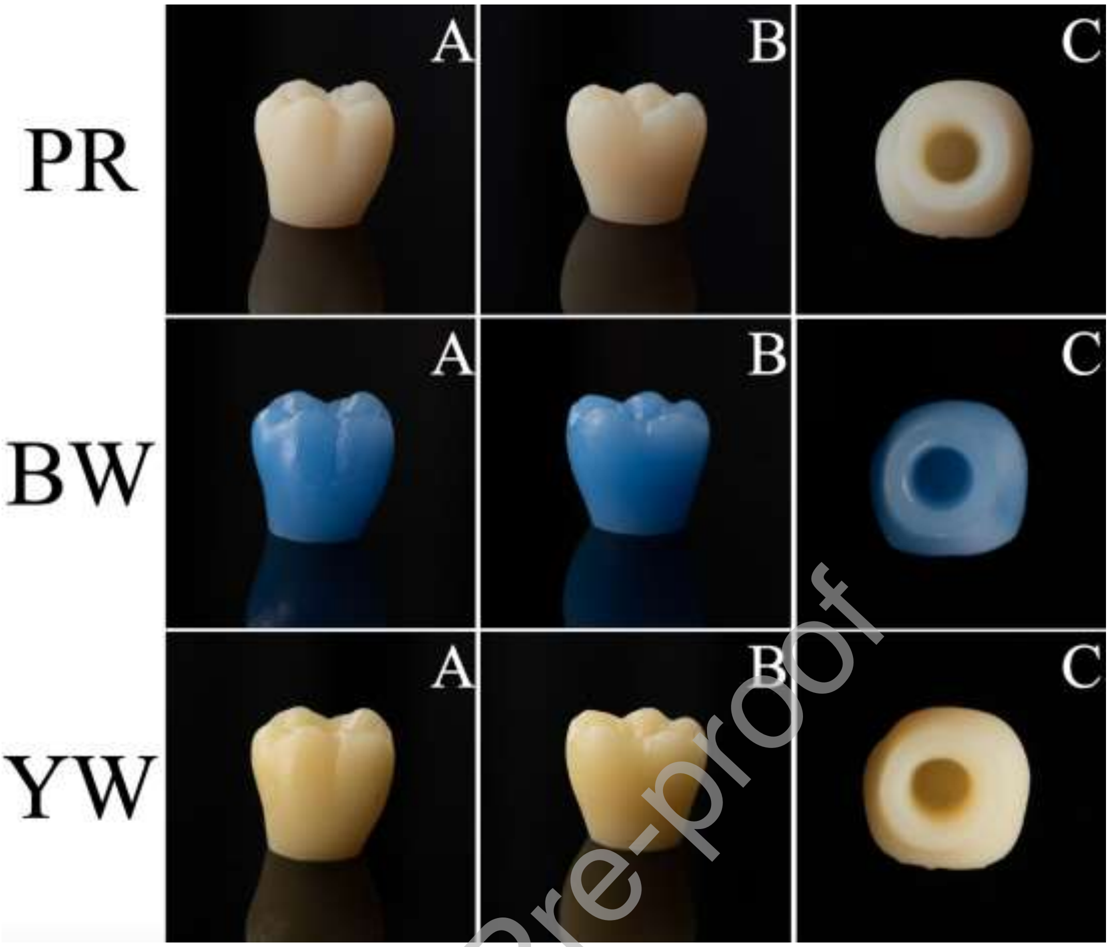
Material	Overall		External		Intaglio with margin		Marginal		Intaglio without margin	
	Mean ±SD	Median (Min-Max)	Mean ±SD	Median (Min-Max)	Mean ±SD	Median (Min-Max)	Mean ±SD	Median (Min-Max)	Mean ±SD	Median (Min-Max)
PR	49 ±3	50[b] (46 - 53)	54 ±5	55[b] (45 - 60)	28 ±7	27[b] (20 - 45)	10 ±2	10[a] (8 - 13)	32 ±6	30[b] (22 - 44)
BW	32 ±3	32[a] (28 - 37)	39 ±1	39[a] (37 - 40)	14 ±2	15[a] (11 - 17)	11 ±1	11[a] (8 - 12)	16 ±3	17[a] (10 - 19)
YW	36 ±3	37[a] (32 - 39)	40 ±3	41[a] (32 - 42)	13 ±2	13[a] (11 - 16)	10 ±1	10[a] (8 - 11)	13 ±2	12[a] (11 - 18)

Table 1. Descriptive statistics of the RMS values according to each material-surface pair

*Different superscript letters indicate significate differences among columns (*P*<.05)

FIGURES

Figure 1. CAD-CAM fabricated wax crown patterns (A: Buccal surface; B: Lingual surface; C: Marginal and intaglio surfaces)



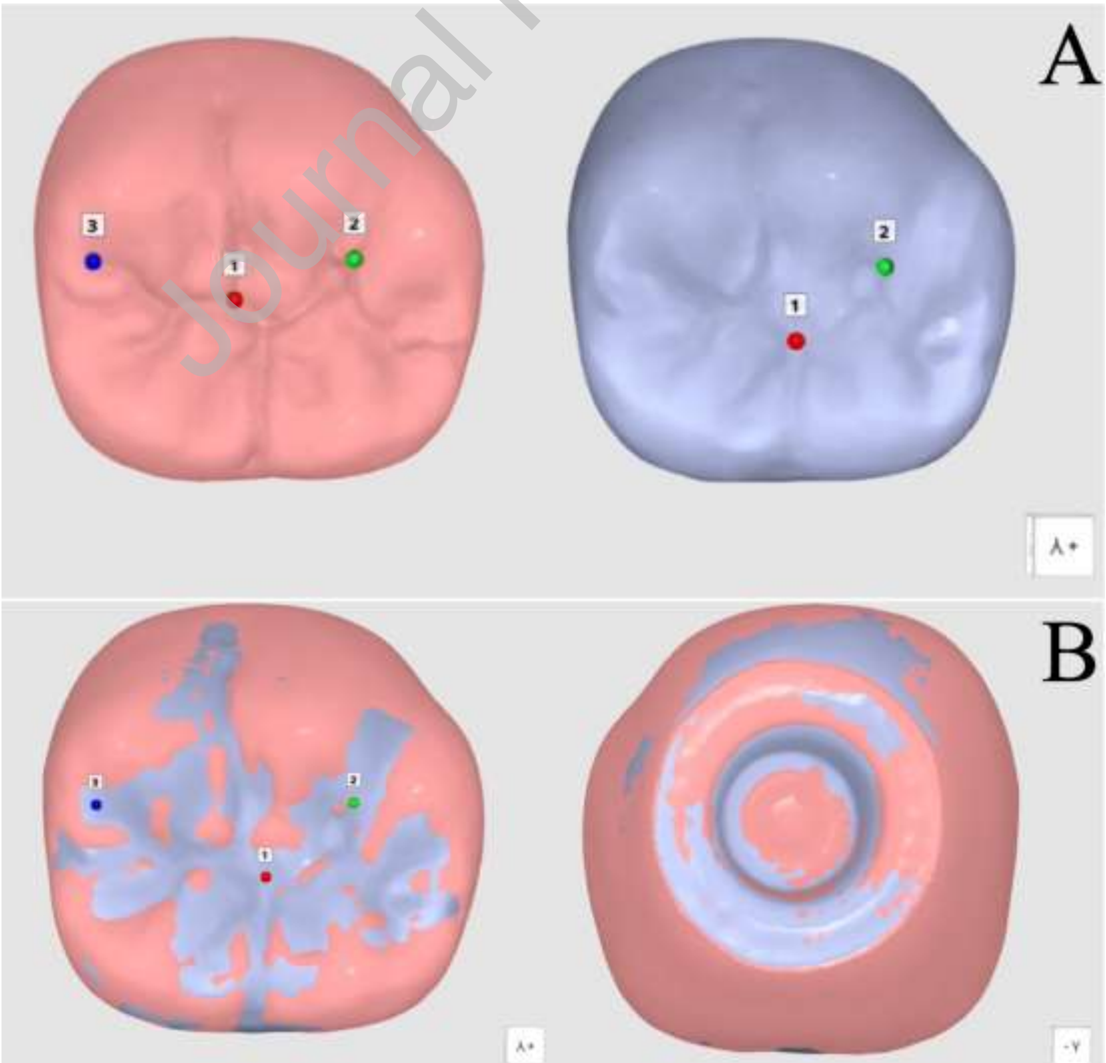


Figure 2.

Superimposition of test-STL (blue, target data) over C-STL (red, reference data) (A: Points selected for superimposition; B: Superimposed STLs from occlusal and intaglio surfaces)

Figure 3. Color maps generated by the superimposition of test-STL over C-STL for each surface (A: Overall RMS; B: External RMS; C: Intaglio RMS with margin; D: Marginal RMS; E: Intaglio RMS without margin)

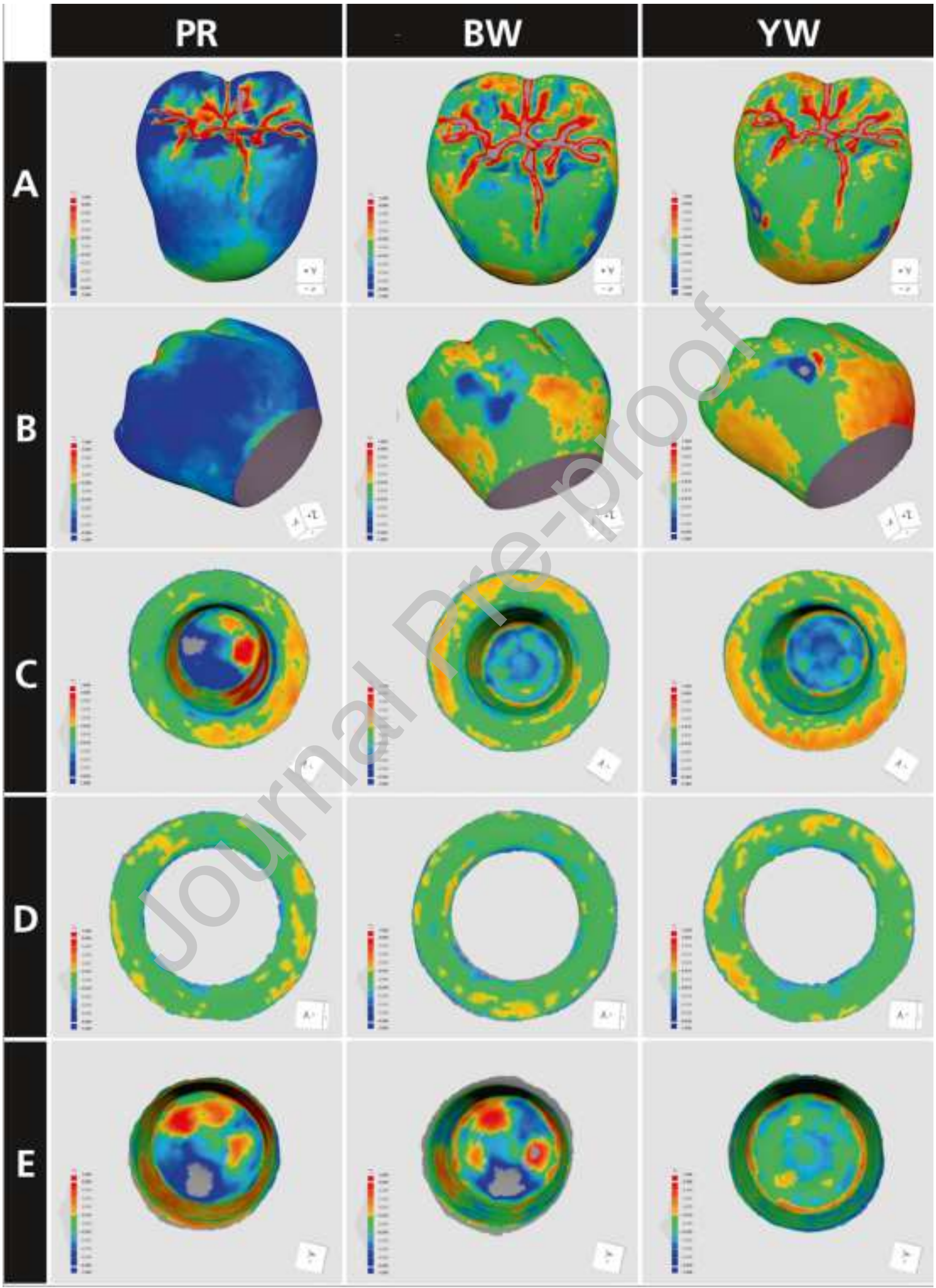


Figure 4. Box-plot graph of the RMS values calculated for each material-surface pair