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Marginal Adaptation and Surface Roughness of Indirect Composite Veneers: A Comparative Study of 3D Printing and Conventional Techniques

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ABSTRACT

Background and Objectives: Indirect composite veneers in restorative dentistry depend on precise marginal fit and ideal surface roughness for long-term success. Marginal fit refers to how closely the edge of the veneer adapts to the tooth margin, where smaller gaps indicate better accuracy. Comparing 3D printing to conventional manufacturing techniques, the growing usage of digital technology may result in improvements in surface quality and accuracy. This study aimed to evaluate how traditional methods compare with 3D printing in terms of the fit and surface texture of indirect composite veneers.

Materials and Methods: Twenty extracted human teeth were used for the marginal fitness test and twenty composite discs for the surface roughness test in this in vitro study. Each set was divided into two groups (n=10 per group): One group for 3D printed composite veneers and the other for conventional indirect composite veneers. For marginal fit, the extracted teeth were prepared and ten veneers were fabricated for each group, and a stereomicroscope was used to measure the vertical marginal gaps at twelve reference points per each fabricated veneer. To measure surface roughness, disc-shaped specimens per group were fabricated. A contact profilometer was used to measure surface roughness both before and after polishing.

Results: Both groups' marginal gaps fell into clinically acceptable limits. With a mean gap of 56.07 µm for the 3D-printed group and 59.61 µm for the conventional group, the difference in marginal gaps between the two groups was not statistically significant, indicating that both methods provided similar results ($p = 0.457$). Surface roughness was significantly reduced in both groups after polishing ($p < 0.0001$). The 3D-printed group demonstrated superior surface characteristics, showing significantly lower roughness values both before polishing ($p = 0.039$) and after polishing ($p < 0.0001$).

Conclusion: Indirect techniques for fabrication of veneers from 3D printed composite can provide clinically acceptable marginal fit, and smoother surface than traditional composite. These results support the potential of using 3D printing to create indirect composite veneers.

Keywords: Indirect composite veneers; 3D printing; Conventional fabrication; Marginal fit; Surface roughness.

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INTRODUCTION

Composite resin veneers are now standard in restorative dentistry, especially for younger patients seeking minimally invasive solutions. Their conservative approach and aesthetic benefits make them a popular choice. These restorations are preferred due to their cost-effectiveness and ease of repair, making them suitable for the correction of discolored, misaligned, or worn teeth. Nevertheless, the clinical efficacy of these restorations is contingent upon the utilization of fabrication techniques that guarantee optimal surface quality and marginal adaptation.[1]

By fabricating restorations in successive layers, additive manufacturing (3D printing) further refines this process, enabling the creation of customized designs and intricate geometries with minimal material waste.[2] 3D printing uses less material with almost no material loss, which is one of its benefits. It can also print a wide range of materials with accurate reproduction. has several benefits, including being less costly than the earlier approach, reducing the carbon footprint, and assisting in the conservation of resources and energy.[3]

It is imperative to achieve an optimal marginal fit, as marginal discrepancies are linked to complications. Research indicates that marginal gaps that are clinically acceptable fall within the range of 50 to 120 µm.[4] The choice of scanner system, preparation design, and material processing techniques are among the factors that influence marginal fit.[5] Inadequate marginal adaptation can also interfere with restoration integrity and affect gingival health.[6]

The evolution of composite resins utilized in veneer fabrication has been crucial. Microfilled composites enhanced surface smoothness at the expense of mechanical strength, while early macrofilled composites provided strength but poor polishability.[7] Nanofilled and nanohybrid composites have enhanced aesthetics and marginal integrity as a result of their optimized filler size and distribution.[8] It is necessary to assess whether if 3D printing provides indirect composite veneers of a quality that is similar to conventional methods, given the growing use of digital technology in restorative dentistry.

The null hypothesis in this study was that there are no significant differences in marginal fit and surface roughness between indirect composite resin veneers fabricated using the 3D printing technique and the conventional laboratory technique.

METHODS

Materials and Equipment

The marginal fit and surface roughness of veneers made with two different methods, conventional/ packable and 3D printing techniques were evaluated in this in vitro study

Detailed information about the materials and equipment used in this study are detailed in Table 1.

Table 1. Provides detailed information regarding the materials and equipment used in this study, including their generic names and expiry dates

N	Generic/commercial name	Batch/LOT number	Expire date
1	Transparent silicone material (GC, Exaclear, Japan)	2303201	N/A
2	Saremco Dental AG, els composite syringe, Switzerland	F237	2029-01
3	Saremco Print CROWNTEC , Switzerland	D600217	
4	Laboratory scanner, Zirkonzahn 2018, Italy	N/A	
5	Asiga Max 365 3D printer (Asiga, Sweden)	N/A	
6	Stereomicroscope, Motic, Kowloon, Hong Kong model ST-39 Series	N/A	
7	Imagej software, 1.52a, national institution of health, USA	N/A	
8	Hayear camera software (Electronic Co., version x64, Guangdong, China) model 4.11.22070.20230204	N/A	
9	Contact profilometer (Surface Roughness Tester), TIME®3200/3202 model TR200	N/A	

Tooth Selection criteria and Preparation protocol:
For marginal fitness, twenty human maxillary central incisors that were caries-free and in good condition had been selected from dental hospitals and private dental clinics. Teeth were cleaned using an ultrasonic scaler and stored in distilled water. Each tooth was mounted in standardized acrylic blocks using cold-cure acrylic. Mounts were constructed from custom-made X-ray film (3 × 2.5 × 2.5 cm), and every tooth was embedded 2 mm below the CEJ, as verified by a periodontal probe.[9]
The Scientific Research Ethics Committee of the College of Dentistry at Hawler Medical University in the Kurdistan Region of Iraq examined and approved this study (Meeting No. Pros 24302, Approval Date: 23 December 2024). Every procedure followed the guidelines set out in the 2013 edition of the Declaration of Helsinki. Following institutional protocols, extracted human teeth were used, and all specimens were confidential before analysis. The Zirkonzahn laboratory scanner was employed for capturing pre-preparation scans, which were subsequently saved in STL format.
A silicone putty index, was employed to standardize tooth reduction. The index was sectioned to facilitate lateral viewing. A veneer bur kit with incisal depth cut was employed to generate depth grooves. Depth was visually controlled by marking it with ink. The final preparations consisted of a 0.5 mm facial reduction, a 1 mm incisal reduction, and a 0.5 mm chamfer finish line cervically.[10, 11] Finishing burs were employed for finishing, and they were changed once every third preparation. A silicone guide and periodontal probe were employed to confirm the reduction. STL scans of post preparation were done and merged with original pre preparation scans in Exocad as another approach to confirm the standardized reduction. as illustrated in Figure 1.

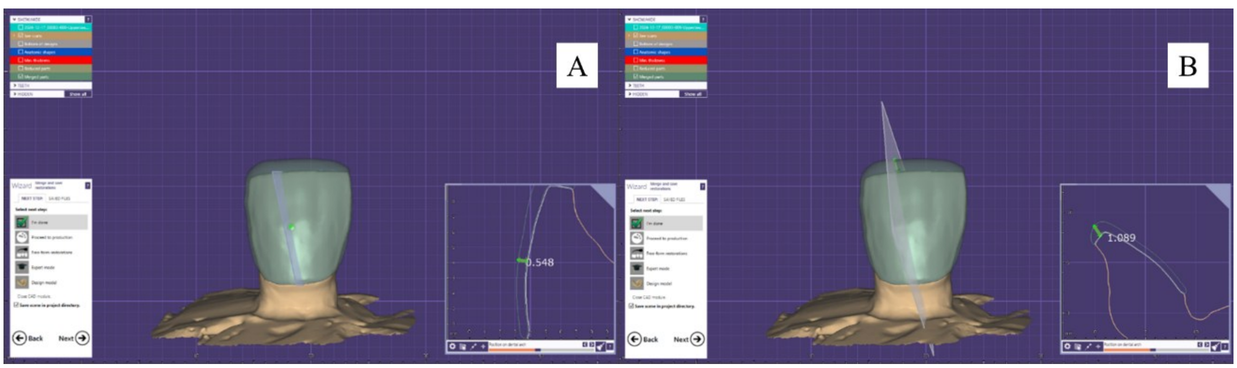

Figure 1. Tooth preparation double check by the Exocad software.
A: Verification of incisal dimension. B: Verification of facial dimension

Fabrication of Veneers
1. Conventional/Packable Composite Veneers: A laboratory scanner was used to digitally scan each prepared tooth in order to create a standardized digital model. In order to create a virtual wax -up design in STL format, the scan data was loaded into the Exocad DentalCAD program with a 0.5 mm facial and 1 mm incisal reduction. For each specimen, the STL files were transferred to a Creality 3D printer in order to create two resin models: one that represented the virtual wax-up and another that represented the prepared tooth that was ready for the following composite veneer fabrication.[12, 13] as illustrated in Figure 2.

Figure 2. Two models from each tooth for conventional composite were fabricated, virtual wax up and 3D printed die of prepared tooth

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Cement space was generated by applying a (Renfert Die Master) 50 µm on the 3D printed die of the prepared tooth. A guide with escape holes was fabricated by applying transparent silicone (Exaclear) to the virtual wax-up.

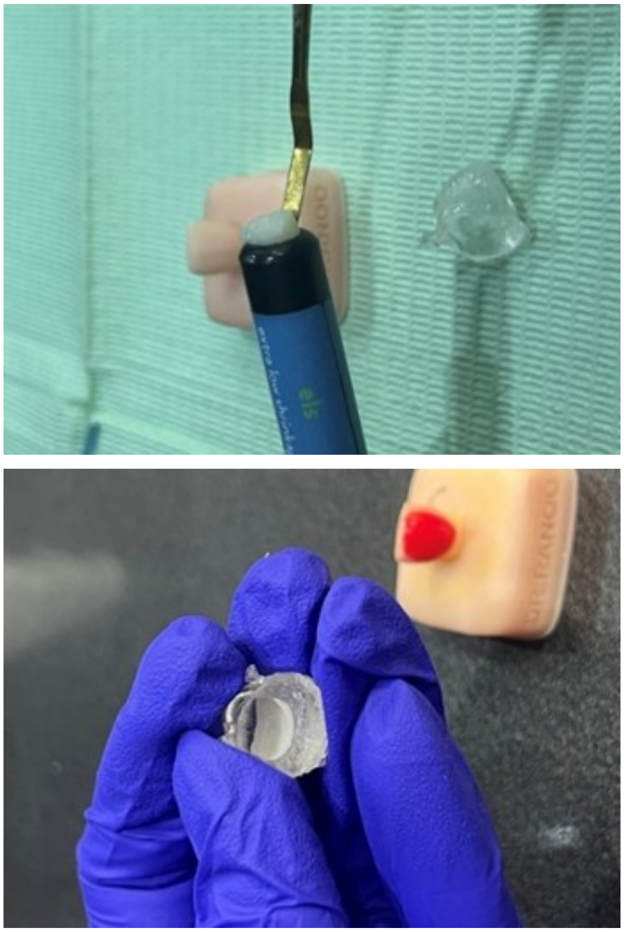

Figure 3. Composite application on silicon index

The composite (shade B1) was seated on the printed die and placed in the guide, as illustrated in Figure 3.

The Dentmate unit was employed to perform light-curing on each surface, with a power output of 1000 mW/cm² and a duration of 40 seconds according to the manufacturer recommendation. Next, polishing discs with water cooling were employed to eliminate any surplus following polymerization. Finally, a Vernier caliper was employed to verify the thickness of the veneer, to discard any malformed samples.

2. 3D-Printed Composite Veneers: Similar parameters described in the previous section were used to digitally design veneers in Exocad after scanning the prepared teeth.

Veneers STL files, were printed using an Asiga Max 365 printer with Saremco Print CROWNTEC resin (shade B1). The post-processing regimen comprised air drying, cleaning with 96% isopropyl alcohol, and light-curing with a Dentacolor XS unit at 1000 mW/cm² for 30 seconds. Polishing was conducted utilizing a low-speed handpiece at 6000 rpm.

Evaluation of Marginal Fit

Each veneer was affixed to its respective tooth. A horizontal force of 1 kg was applied on the veneers by a screw-retained holder to achieve standardized pressure.[14] After that an orthodontic elastic were offered an additional amount of stability while testing. Standardized three points have been measured per surface: mesial, distal, cervical, and incisal. Accordingly, each sample contained twelve points. A stereomicroscope (Motic ST-39) was employed at a magnification of 40×. Images were captured using Hayear camera software and calibrated in ImageJ (v1.52a) with a 0.5 mm ruler.[15] As illustrated in Figure 4.

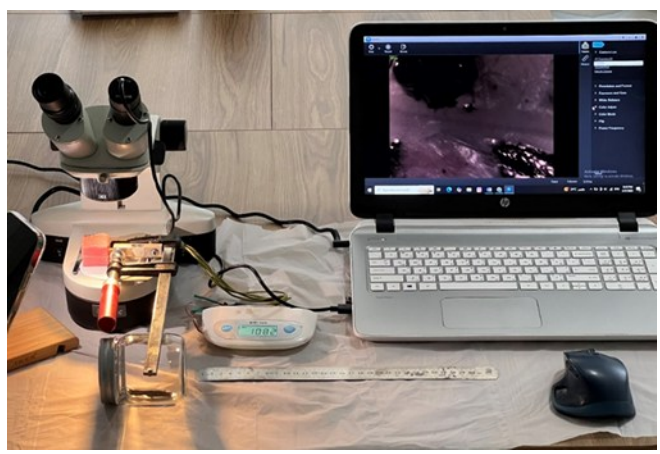

Figure 4. Marginal fit test with stereomicroscope 40x and Hayear camera software

Three measurements were taken per each point and the final marginal gap was calculated by averaging them using ImageJ software. A single operator executed all procedures. As illustrated in Figure 5.

Evaluation of Surface Roughness

Twenty disc specimens with dimensions of 8mm diameter and 2mm in thickness (10 conventional, 10 printed) were produced. Conventional group discs were cured utilizing the Dentmate light-

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curing device under a Mylar strip and glass slide. The same printing workflow as used in 3D printed veneers group was employed to produce printed discs.

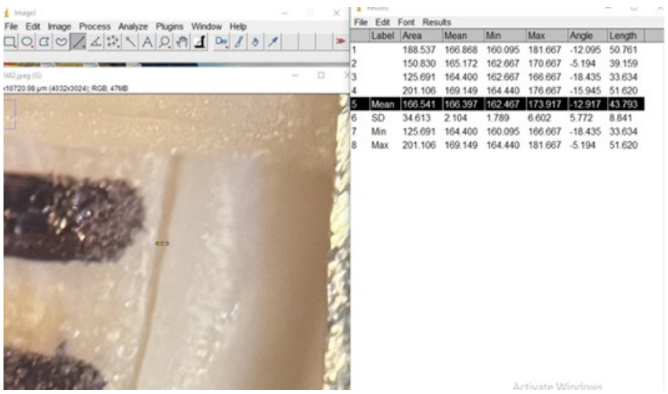

Figure 5. Marginal gaps were measured in ImageJ, with each point assessed three times to minimize error, and the mean value was calculated

Finishing and polishing were conducted using FLEXI-D HP discs (coarse to superfine) in order with a low-speed handpiece (10,000 rpm) for 10 seconds per grit. Each disc was used once for each veneer. In every aspect polishing was performed by a single operator.[16] The contact profilometer device (TIME®3200/3202 TR200) was employed to measure surface roughness (Ra). The average of two perpendicular measurements was calculated for each disc (30). As illustrated in Figure 6.

For statistical analysis: Normality of data distribution was tested using the Shapiro–Wilk test. Descriptive statistics (mean, standard deviation) were calculated using SPSS (IBM SPSS Statistics version 27).

Figure 6. Contact profilometer device

Independent samples t-tests were used to compare:

1-Marginal fit between groups.

2-Surface roughness between groups before and after polishing.

Paired samples t-tests were applied within each group to evaluate the effect of polishing on surface roughness. A p-value < 0.05 was considered statistically significant.

RESULTS

The present study evaluated the surface roughness and marginal fit of indirect composite veneers made with two distinct methods: conventional indirect fabrication and 3D printing.

Marginal Fit Analysis

Descriptive Statistics and Normality Test: This analysis utilized twenty extracted human central incisors, which were equally distributed between two groups. Marginal gap measurements at four reference points on each sample: mesial, cervical, distal, and incisal.

The 3D-printed group exhibited a slightly lower mean value of observed marginal fit 56.070 µm (SD = 12.16), while the conventional group exhibited a mean marginal gap of 59.110 µm (SD = 5.164), as confirmed by descriptive statistical analysis. Although the numerical difference in support of the 3D-printed group was crucial, the independent samples t-test did not reveal a statistically significant difference between the groups, with a corresponding p-value of 0.476 (a p-value shows whether the difference is due to chance; values above 0.05 mean no significant difference) (Table 2). This indicates that, in practical terms, both fabrication methods performed similarly in overall marginal accuracy. The data indicate that both techniques yielded marginal adaptations within a comparable range.

The incisal region showed the smallest mean marginal gap at (mean = 51.7 µm) within the conventional group, while the cervical surface presented the highest mean value at (mean = 73.6 µm). In contrast, the 3D-printed group exhibited the smallest gap at the mesial surface (mean = 51.6 µm), and the largest at the cervical surface (mean = 61.2 µm). These results suggest that cervical margins generally show higher discrepancies regardless of technique, likely due to access and geometry challenges.

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Table 2. Comparison of veneers marginal fitness (µm) between Conventional and 3D printed groups (n=10)

	Conventional (mean ±SD)	3D printed (mean ±SD)	p-value
Incisal	51.700 ±17.526	54.000 ±16.392	0.765
Mesial	54.250 ±9.474	51.600 ±19.835	0.708
Distal	56.880 ±15.313	57.540 ±16.503	0.927
Cervical	73.640 ±7.452	61.180 ±17.885	0.057
Mean	59.110 ±5.164	56.070 ±12.163	0.476

Analysis of Surface Roughness:

Disk-shaped specimens were created using both conventional and 3D-printed methods. Surface roughness measurements were conducted on each specimen at two different orientation angles, both prior to and following polishing. The average of the two values for each specimen has been calculated and employed for additional statistical analysis. The normal distribution of all surface roughness data sets was verified by the Shapiro–Wilk test. The mean surface roughness values of the 3D -printed group were 1.228 µm prior to polishing and dropped to 0.24 µm following polishing. The pre-polishing mean of the conventional group was 1.602 µm, while the post-polishing mean was similarly dropped to 0.39 µm. The data were normally distributed and could be used for parametric testing, as evidenced by the p-values of all subgroups exceeding 0.05 (Table 3).

Table 3. Comparison of veneer surface roughness (µm) between Conventional and 3D printed before and after polishing (n=10)

	Group	Mean ±SD	p-value
Before polishing	Conventional	1.228 ±0.306	0.039
	3D-Printed	0.241 ±0.070	
After polishing	Conventional	1.602 ±0.436	0.000012
	3D-Printed	0.390 ±0.037	

Note: $p < 0.05$ considered statistically significant

Intra-Group surface roughness comparison: Impact of Polishing

Using paired samples t-tests, the efficacy of polishing was assessed within each group. The polishing procedure resulted in statistically significant reductions in surface roughness in both fabrication groups. The p-value for the conventional group was 0.000031, whereas the p-value for the 3D-printed group was 0.000001

The polishing procedure significantly enhanced surface smoothness across both fabrication techniques, thereby confirming the utility of post-fabrication polishing, irrespective of technique.

Inter-Group Comparison: Before Polishing

An independent samples t-test was implemented to conduct a comparative analysis of surface roughness values prior to polishing. The pre-polishing roughness of the conventional group was significantly greater than that of the 3D-printed group, as evidenced by a p-value of 0.039 (Table 3).

This implies that the 3D printing technique inherently generates a smoother initial surface texture than the conventional indirect method, which may be attributed to variations in material layering precision and fabrication processes.

Inter-Group Comparison: After Polishing

In comparison to the conventional group, the 3D-printed group exhibited a significantly lower surface roughness value. The p-value of 0.000012 was highly significant in the independent samples t-test (Table 3).
These findings suggest that the 3D printing technique reacts more favorably to polishing procedures.

DISCUSSION

From the obtained result data, the null hypothesis is rejected for marginal fit, as there was non-significant difference between the tested groups for marginal fit test ($p < 0.05$), and accepted for surface roughness, as there were significant differences between the tested groups ($p > 0.05$).
The data from the marginal fit test addressed no statistically significant difference in marginal fit between the two groups ($p = 0.477$), suggesting that both methods can achieve clinically acceptable precision prior to cementation.
The marginal fit values observed in this study are similar with the clinical thresholds for acceptable marginal adaptation that have been previously established as in the study by Dolev et al., 2019 and Hanoon et al., 2023.[4,17] These thresholds typically refer to values of ≤100 µm as clinically reasonable. The data serve to substantiate the observation that both fabrication methods generate marginal fits that satisfy these clinical criteria when implemented under controlled conditions.
The results are in agreement with Alharbi et al.,[18] who conducted a comparison of 3D-printed and milled restorations and discovered that incisal regions exhibited the most significant gaps. However, present study reported even greater absolute marginal gaps. The variance may be the result of varying resin composite materials, sample types, or measurement protocols. It is important to note that the cervical region consistently exhibited the greatest discrepancy, which may be attributed to anatomical challenges and adaptation difficulties. Furthermore, STL file slicing errors and surface complexities may influence adaptation in 3D-printed restorations. In contrast, conventional method of veneer fabrication introduces variability through manual processes. Alharbi et al. discovered that the gaps in mid-axial areas of 3D-printed restorations were reduced. However, the current study demonstrated that the gaps were the smallest on mesial surfaces, which may be attributed to the advantageous scanning or geometric properties. These variations may be further influenced by factors such as software algorithms and printer resolution.
According to Daghrery et al. (2024),[19] the study's marginal gap, as determined by CBCT, did not significantly differ between the two groups. While internal and total discrepancies were greater for the 3D-printed group, their investigation comparing three methods of manufacturing (PVT, CAD/CAM, and 3D printing) also revealed no significant differences in marginal fit. In contrast to their reported maximum disparity of 500 µm in CAD/CAM veneers, our data showed more uniform marginal adaptation, with the largest site-specific gap at 73.6 µm (the conventional group's cervical margin). Differences in resin characteristics, post-curing procedures, printer settings, teeth geometry, and seating pressure can all account for these discrepancies. Despite these methodological variations, both investigations demonstrate that all fabrication techniques—including 3D printing—achieve marginal fittings that fall within clinically acceptable bounds, but our conventional group showed somewhat larger gaps at the cervical borders.
In the same way, Pott et al.[20] reported that the marginal gaps for CAD/CAM inlays were larger at 174.9 µm, while the gaps for conventionally fabricated inlays with plaster models were smaller at 58.2 µm. Despite the utilization of digital design and 3D-printed dies, the conventional group achieved a mean gap of 59.61 µm in the current study. Conversely, the 3D-printed group in the present study exhibited a marginal gap that was significantly smaller (56.07 µm) than the CAD/CAM group in the article. This difference may be attributed to the enhanced adaptation provided by the silicone guide in our workflow, differences in the application of spacers, or restoration design.
The standard polishing protocol's efficacy was demonstrated by a statistically significant reduction in surface roughness for both groups following polishing ($p < 0.0001$). The 3D-printed group exhibited significantly lower roughness both pre- and post-polishing ($p = 0.039$ and $p < 0.0001$, respectively), which partially deviating to Karaoğlanoğlu et al.,[21] who reported no signifi-

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cant differences between CAD/CAM and 3D-printed materials. The divergence may be attributed to the type of material, printer technology, and polishing systems.

The current study included Saremco packable and 3D-printable composites and a four-step disc-based polishing system, in contrast to Karaoğlanoğlu et al., which employed industrial CAD/CAM blocks and diamond-based polishers. This approach may have resulted in superior printed specimens. The uniformity of 3D-printed surfaces, the resolution of DLP printers, and the Mylar-strip finishing all contributed to the smoother baseline textures.

Vinagre et al.[22] reported that surface roughness was significantly influenced by composite type and polishing system ($p < 0.001$). The current study's findings partially agree with this finding. Nevertheless, the present study restricted variability by employing a single polishing method on standardized materials. Comparisons are also influenced by the type of profilometer (2D Ra vs. 3D Sa).

In accordance with our findings, Erturk-Avunduk et al.[23] also discovered that Crowntec exhibited the lowest surface roughness values. The observed variation may be attributed to variations in specimen dimensions, polishing systems, and post-processing. In the current study, the conventional group exhibited a higher level of roughness both prior to and following polishing (1.228 µm and 1.864 µm, respectively). Controlled polymer networks and filler distribution may contribute to the superior polishability of 3D-printed composites.

Finally, the present study substantiates the clinical viability of both conventional and 3D-printed indirect composite veneers. The utilization of digital workflows and standardized protocols may improve the quality of the surface and marginal fit, while 3D printing provides minor advantages in the initial smoothness and final polishability.

CONCLUSION

Indirect veneer fabrication utilizing 3D-printed composite resin has shown its potential in producing veneers with a smoother surface both before and after polishing and a marginal fit that is clinically acceptable when compared to veneers using conventional packable composite procedures. These results provide evidence to the prospective clinical use of 3D printing technology as a dependable alternative for conventional laboratory techniques, providing enhanced accuracy and surface quality when fabricating indirect composite veneers. Overall, these findings suggest that 3D printing may offer a practical and efficient option for indirect veneer fabrication in clinical settings, particularly where improved surface smoothness is desired. Future research should investigate the long-term clinical performance, durability, and patient outcomes associated with 3D-printed composite veneers to validate their broader clinical applicability.

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CONFLICT OF INTEREST

The authors declare that there are no conflicts of interest related to this study.

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