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Additively manufactured hybrid composite implant-supported restorations: A retrospective clinical study of 145 patients with up to 2 years of follow-up

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Abstract

Objective: To present the 2-year clinical outcomes of short-span implant-supported hybrid composite restorations, namely single crowns (SCs) and fixed partial prostheses (FPPs), produced using tilting stereolithography (TSLA).

Methods: This retrospective study was based on data from a cohort 145 patients, treated between June 2021 and June 2023, with 185 fixed short-span implant-supported hybrid composite restorations (Irix Max®, RD Printing, Thiene, Vicenza, Italy) produced using tilting stereolithography (TSLA). The restorations were manufactured through a fully digital, model-free workflow, which included intra-oral scanning, computer-aided design (CAD) and additive manufacturing with the TSLA system (Dfab®, RD Printing). Primary outcome measures included marginal fit, occlusal and interproximal contact quality and colour matching of the restorations, all evaluated by two experienced clinicians (a prosthodontist and a periodontist, who were not directly involved in the treatment of the patients). Each restoration was rated at the time of delivery, using a 5-point scale (5 being excellent, 4 satisfactory, 3 acceptable, and 2 or 1 indicating poor quality). The secondary outcomes assessed comprised the survival and success (i.e. absence of complications) rates of the restorations, during the entire follow-up period. Statistical analysis was performed on the collected data.

Results: Among the 3D-printed hybrid composite restorations, 95 had a 2-year follow-up, whereas 90 had only a 1-year follow-up. Overall, the restorations demonstrated excellent performance in terms of marginal fit and contact accuracy, both occlusal and interproximal. Their aesthetic integration was also deemed satisfactory. During the follow-up period, all restorations remained functional, with a low complication rate (1.0 % biological and 3.7 % prosthetic complications), resulting in an overall success rate of 95.1 %.

Conclusions: Implant-supported short-span hybrid composite restorations manufactured using TSLA technology demonstrated high clinical accuracy and showed a low rate of complications over a 2-year period.

Clinical relevance: TSLA printing technology shows potential for the definitive prosthetic treatment of small edentulous spaces.

Keywords: Accuracy; Additive manufacturing; Fixed partial prostheses; Hybrid composite restorations; Single crowns; Success; Survival.

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Influence of preparation design and build orientation on the accuracy of ceramic-filled composite veneers printed using Tilted Stereolithography technology. An in vitro study.

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Abstract

Aim: To evaluate the influence of preparation design, build orientation and interaction between these two factors on the accuracy of veneers 3D printed using tilted stereolithography technology (TSLA).

Methods: Three maxillary central incisor typodont models were prepared to receive a full veneer preparation with three finish line designs: Cl I; labial reduction, Cl II; labial with butt joint incisal reduction and Cl III; labial and incisal overlap design then digitized to design the restorations which were 3D-printed using ceramic filled composite material (Dfab; DWS) (Irix Max monochrome A2; DWS)(N=90). In each group, three subgroups were defined based on the build orientation (N =10): 90°, 75° and 45° angles. Accuracy was evaluated using metrology software. Two-way Analysis of Variance (ANOVA) test was used to detect the differences between the groups (α=0.05).

Results: Two-way ANOVA revealed a statistically significant interaction between different build angles and preparation design on RMSE trueness values (P = .003) and RMSE precision values (P = .001) Tukey post hoc test revealed that Cl II design had significantly lower RMSE values compared to both Cl I and Cl III designs (P<.001). 45° angle revealed significantly higher RMSE values compared to 75° and 90° build angles with P values .017 and .009 respectively.

Conclusions: Both preparation design and build orientation have an influence on the accuracy of TSLA printed laminate veneers. Butt-joint preparation design exhibited highest trueness compared to both window and incisal wrap designs. Among all finish line designs, 45° build angle exhibited the most significant deviation values and is not recommended for printing veneers using TSLA technology.

Keywords: Build angle; Finish line Design; Laminate veneers; Preparation design; Tilting stereolithography; Trueness.

Clinical significance: The preparation design that best fits a given clinical situation should be selected. The print angle that yields the highest accuracy relative to the clinically selected and executed tooth preparation design should be chosen. With different veneer preparation designs, 45° build angle provides the highest deviation values with chairside TSLA printers and should be avoided when printing resin-based, monochromatic laminate veneers.

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Marginal fit of nanocomposite 3D-printed crowns with horizontal and vertical preparation geometries: An in vitro comparative analysis

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Abstract

Aim: This study aimed to evaluate the marginal fit of crowns fabricated using a 3D-printer with either horizontal or vertical tooth preparation geometries.

Methods: Two abutments representing a standard maxillary first premolar were designed using CAD software, featuring either a horizontal (Ho) or vertical (Ve) tooth preparation. These abutments were milled in resin and positioned on a reference typodont. For each preparation design, ten crowns were 3D printed using a resin nanocomposite. Cementation was simulated for each crown on its corresponding tooth preparation geometry. The samples were then scanned using an industrial metrological machine, and the scans were analyzed with specialized software to assess marginal fit in micrometers (μm). Descriptive statistics, including a 95% confidence interval, were calculated, and an independent sample test ($\alpha = .05$) was performed to compare the two groups.

Results: The mean marginal fit values for both preparation geometries were below the clinically acceptable threshold of 120μm: Ho = 76.83μm, Ve = 84.37 μm. No statistically significant differences were found between the two groups (Ho: p = 0.58; Ve: p = 0.83).

Conclusions: The tested nanocomposite crowns exhibited similar mean marginal discrepancies for both vertical and horizontal preparation designs. Additionally, the marginal discrepancies observed in both cases were within clinically acceptable limits.

Keywords: marginal fit; 3D printer; printed crown; digital workflow; nanocomposite; vertical preparation; horizontal preparation

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Trueness of multichromatic versus monochromatic veneers printed using tilted stereolithography technology at different build angles? An in vitro study

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Abstract

Aim: To evaluate the influence of shade (monochromatic vs multichromatic) and build angle on the trueness of veneers printed using tilted stereolithography technology (TSLA).

Methods: A maxillary central incisor typodont tooth model was prepared to receive a butt-joint full veneer with 0.3 mm labial and 2 mm incisal reduction. The preparation was digitized using laboratory scanner (T310; Medit) to design the veneer restoration. Sixty veneers were fabricated using Tilting Stereolithography (TSLA) 3D-printing technique (Dfab; DWS). Thirty veneers were printed in monochromatic shade (N = 30) (Irix Max monochromatic A2; DWS) and thirty veneers in multichromatic shade (N = 30) (A1-A3.5) using hybrid resin-ceramic material (Irix Max Photoshade A1-A3.5; DWS). In each group, three subgroups were defined based on the build angle (N = 10): 90°, 75° and 45° angles. Trueness was evaluated quantitatively and qualitatively using metrology software (Geomagic Control v2020; 3DSystems). Two-way Analysis of Variance (ANOVA) test with Tukey post hoc test for multiple comparisons were used to detect the differences in root mean square estimate (RMSE) between the test groups (α =0.05).

Results: Two-way ANOVA revealed a statistically significant interaction between different build angles and material shade on RMSE in butt-joint veneer preparation design (P = .001). Multichromatic shade showed significantly higher RMSE values when printed at 45° (P=.010) compared to monochromatic one.

Conclusions: Build angles and material shade have an influence on the trueness of veneers printed using TSLA technique. 45° build angle with multichromatic shade material resulted in the highest RMSE deviation values. Therefore, clinicians should be cautious with the selected print angle when printing multichromatic resin-based veneers.

Keywords: TSLA Tilted Stereolithography Technology, 3D printing Three-Dimensional Printing, SLA Stereolithography, DLP Digital Light Processing, AM Additive Manufacturing, FPD Fixed Partial Dentures, ANOVA Analysis of Variance, RMSE Root Mean Square Estimate, CAD Computer Aided Design.

Clinical significance: Advances in material science and 3D-printers resulted in the introduction of a chairside TSLA 3D-printer that can be used for the fabrication of multichromatic, resin-based veneer restorations. Both build angle and material shade influence the dimensional accuracy of TSLA printed veneer restorations. To print highly accurate multichromatic restorations and increase the number of printed parts per print cycle, 45° build angle should be avoided.

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Corrigendum to **"Effect of manufacturing trinomial and preparation design on the fabrication and fit accuracy of additively and subtractively manufactured resin-based overlay restorations"**

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Effect of manufacturing trinomial and preparation design on the fabrication and fit accuracy of additively and subtractively manufactured resin-based overlay restorations

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Abstract

Aim: To evaluate the effect of the manufacturing trinomial (technology, printer, and resin) and preparation design on the fabrication and fit accuracy (trueness and precision) of additively manufactured (AM) resin-based overlays compared to subtractively manufactured (SM) overlays.

Methods: Six mandibular right first molar typodont teeth were prepared with varying designs: (A) 1 mm occlusal reduction, (B) 1.5 mm occlusal reduction, (C) B+contrabevel finish line, (D) B+chamfer finish line, (E) C+proximal box, and (F) D+proximal box. Overlays were fabricated using AM-IX (tilting stereolithography), AM-VS (digital light processing), or SM-EN and digitized for fabrication (overall, external, intaglio, marginal) and internal fit accuracy analyses. Data were analyzed with two-way analysis of variance and Bonferroni-corrected post-hoc tests (α=0.05).

Results: The interaction between the manufacturing trinomial and preparation design affected fabrication accuracy of overall, external, and intaglio surfaces, and the precision of marginal surface deviations and average gaps ($P \leq 0.034$). AM-IX overlays mostly had higher overall, external, and marginal fabrication accuracy, whereas SM-EN overlays mostly had lower accuracy across these surfaces ($P \leq 0.019$). Preparation designs A, B, and C mostly led to lower overall, external, and intaglio surface trueness within SM-EN overlays ($P \leq 0.014$). AM-IX overlays had the lowest and preparation design E led to the highest gaps ($P \leq 0.023$).

Conclusions: AM overlays fabricated with tilting stereolithography mostly had higher fabrication and fit accuracy. Increased axial preparation improved fabrication trueness but did not consistently enhance fit.

Keywords: accuracy, fit, manufacturing trinomial, overlay, preparation design.

Clinical significance: To maximize the fabrication accuracy and adaptation of AM resin overlays, the manufacturing trinomial with tested tilting stereolithography-based printer and its corresponding resin can be recommended. More invasive preparation designs (D, E, and F) may enable higher fabrication trueness. Tested overlays had acceptable fit when previous thresholds were considered.

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Effect of manufacturing trinomial and restoration thickness on the fabrication trueness, fit, and margin quality of additively manufactured resin-based ultrathin laminate veneers

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Abstract

Aim: To evaluate the effect of the manufacturing trinomial (manufacturing technology, three-dimensional printer, and material) and restoration thickness on the fabrication trueness, fit, and margin quality of additively manufactured resin-based ultrathin laminate veneers (LVs) by comparing them to those produced subtractively.

Methods: Reference LVs were designed from the scan files of two identical maxillary central incisor typodonts prepared for 0.3 mm and 0.5 mm LVs. LVs were manufactured additively with resins of different compositions, either using a tilting stereolithography (Irix Max [AM-IX] and Irix Plus [AM-IP]) or a digital light processing printer (VarseoSmile Crown Plus [AM-VS] and Tera Harz TC- 80DP [AM-GR]), and subtractively (Tetric CAD [SM-TC]) (n=10). All LVs were digitized to evaluate their fabrication trueness and fit. The margin quality was assessed through visual examination. The trueness and fit data were analyzed with two-way analysis of variance and Tukey tests, while the chi-squared test was used to evaluate the margin quality ($\alpha = 0.05$).

Results: The interaction between the main factors and the manufacturing trinomial affected the fabrication trueness and fit, while restoration thickness affected the fit of tested LVs ($P \leq 0.001$). AM-IP mostly had the lowest deviations, followed by AM-IX, and mostly had the lowest gaps ($P \leq 0.037$). Thinner LVs had lower gaps ($P < 0.001$). Tested LVs mostly had slightly rough margins with small defects.

Conclusions: LVs fabricated with the tilting stereolithography printer mostly had higher trueness. Using AM-IP or fabricating 0.3 mm LVs improved the fit. Nevertheless, all tested LVs had clinically acceptable fit.

Keywords: fit; laminate veneer; margin quality; thickness; tilting stereolithography; trueness.

Clinical significance: Ultrathin laminate veneers fabricated with the manufacturing trinomial involving tested tilting stereolithography printer and resins may require less clinical adjustments. In addition, one of the resins (AM-IP) within this manufacturing trinomial or fabricating 0.3 mm laminate veneers may improve the fit.

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Volumetric and Linear Adaptation of an Indirect Adhesive Restoration: Comparison of Chairside 3D Printing and Milling Techniques

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Abstract

Aim: The aim of this study was to evaluate volumetric and linear adaptation of an indirect adhesive restoration, comparing a novel chairside 3D printer to conventional milling techniques.

Methods: An intact upper premolar was selected, prepared for an overlay restoration, and replicated. A standardized overlay restoration was designed with CAD software (Cerec inLab CAD SW 4.5.2, Dentsply Sirona, Charlotte, NC, USA), maintaining equal morphology for each sample. Restorations were produced with three CAM processes: chairside 3D printer (D-FAB, DWS, Thiene, Italy), chairside milling unit (Cerec MCXL, Dentsply Sirona, Charlotte, NC, USA), and an industrial milling machine serving as control (Micro 5x, Aman Girrbach, Mäder, Austria). Once cemented, specimens were scanned using micro-computed tomography to assess volumetric, internal, and external adaptation. Data were statistically analyzed with ANOVA and post hoc Bonferroni tests.

Results: CAM technique significantly affected volumetric adaptation ($p < 0.001$), with the chairside 3D printer performing the best and chairside milling unit the worst. Concerning internal adaptation, the chairside milling unit performed significantly worse than the other groups ($p < 0.001$). No significant differences were reported for external adaptation ($p > 0.05$).

Conclusions: CAM technique influenced volumetric and internal adaptation, with the 3D printer showing optimal volumetric adaptation and chairside milling poor internal adaptation.

Keywords: chairside; 3D printing; micro-CT; interfacial adaptation; overlay; milling.

Featured Application The present study is significant in providing in vitro results about precision of volumetric and linear adaptation of indirect restorations produced by a new chairside printing machine.

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Artificial intelligence and mixed reality for dental implant planning: A technical note

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Abstract

Aim: The aim of this work is to present a new protocol for implant surgical planning which involves the combined use of artificial intelligence (AI) and mixed reality (MR).

Methods: This protocol involves the acquisition of three-dimensional (3D) patient data through intraoral scanning (IOS) and cone beam computed tomography (CBCT). These data are loaded into AI software which automatically segments and aligns the patient's 3D models. These 3D models are loaded into MR software and used for planning implant surgery through holography. The files are then exported and used to design surgical guides via open-source software, which are 3D printed and used to prepare the implant sites through static computer-assisted implant surgery (s-CAIS). The case is finalized prosthetically through a fully digital protocol. The accuracy of implant positioning is verified by comparing the planned position with the actual position of the implants after surgery.

Results: As a proof of principle, the present protocol seems to be to be reliable and efficient when used for planning simple cases of s-CAIS in partially edentulous patients. The clinician can plan the implants in an authentic 3D environment without using any radiology-guided surgery software. The precision of implant placement seems clinically acceptable, with minor deviations.

Conclusions: The present study suggests that AI and MR technologies can be successfully used in s-CAIS for an authentic 3D planning. Further clinical studies are needed to validate this protocol.

Keywords: accuracy; artificial intelligence; holograms; implant planning; mixed reality; static guided implant surgery.

Summary Box: What is known? Artificial intelligence (AI) and mixed reality (MR) are two modern technologies that have attracted general attention, and which have the potential to become increasingly established, even in the dental world**.**

What this study adds? The combined use of AI and MR may transform modern s-CAIS through the automated segmentation and alignment of 3D models and holographic 3D implant planning.

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Flexural Properties of Three Novel 3D-Printed Dental Resins Compared to Other Resin-Based Restorative Materials

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Abstract

Aim: To evaluate the flexural strength and flexural modulus of three recently introduced 3D-Printed resins and compare them with the flexural properties of other well known, already commercialized, and extensively used resin based dental materials.

Methods: Three 3D-printed dental resins, a fiber-reinforced epoxy resin, a heat-cured bis-acrylate-based composite resin, two conventional CAD/CAM PMMA, and a graphene-reinforced CAD/CAM PMMA, were selected for this study. Ten prismatic-shaped specimens (2 × 2 × 25 mm) were fabricated for each material (n = 10). All specimens underwent a three-point bending test using a universal testing machine and were loaded until fracture. Flexural strength (MPa) and flexural modulus (MPa) mean values were calculated and compared using the on ranks One-Way ANOVA test. Scanning electron microscope analysis of the 3D-printed resins was performed.

Results: Significantly different flexural properties were recorded among the tested materials. The fiber-reinforced epoxy resin exhibited the highest flexural strength (418.0 MPa) while, among the 3D-printed resins, the best flexural strength was achieved by Irix-Max (135.0 MPa). Irix-Plus and Temporis led to the lowest mean flexural strength values (103.9 MPa and 101.3 MPa, respectively) of all the CAD/CAM milled materials, except for the conventional PMMA by Sintodent (88.9 MPa). The fiber-reinforced epoxy resin also showed the highest flexural modulus (14,672.2 MPa), followed by the heat-cured bis-acrylate composite (10,010.1 MPa).

Conclusions: All 3D-printed resins had a higher flexural modulus than the conventional PMMA materials. CAD/CAM fiber-reinforced epoxy resin excels in flexural strength, with Irix-Max showing promising flexural properties, which could encourage its use for permanent restorations. Caution is needed with Irix-Plus and Temporis due to their lower flexural strength compared to other traditional materials.

Keywords: 3D-printed materials; CAD/CAM materials; fiber-reinforced epoxy; flexural modulus; flexural strength.

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3D-printed Short-span Hybrid Composite Implant-supported Restorations Fabricated Through Tilting Stereolithography: A Retrospective Clinical Study on 85 Patients with 1 Year of Follow-up

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Abstract

Purpose: To report the clinical results obtained with fixed short-span (single crowns [SCs] and fixed partial prostheses [FPPs]) implant-supported hybrid composite restorations fabricated through tilting stereolithography (TSLA).

Methods: This retrospective clinical study included 85 patients who had been restored with 95 fixed short-span implant-supported hybrid composite (Irix Max®, DWS Systems) restorations (70 SCs and 25 FPPs up to three units) fabricated with TSLA. The full-digital model-free workflow was based on intraoral implant scanning, computer-assisted design (CAD) and 3D printing using TSLA (Dfab®, DWS Systems). The primary outcomes were the marginal adaptation, the quality of the occlusal and interproximal contact points, and the chromatic integration of the restorations, assessed independently by two experienced operators (a prosthodontist and a periodontist). A score from 1 to 5 (with 5 as the highest value, 4 for satisfactory quality, 3 for acceptable quality, and 2 and 1 as the lowest values, expressing unsatisfactory quality) was assigned by each operator to each restoration at delivery. The secondary outcomes were the survival and success of the restorations at the 1-year follow-up. The restoration was defined as successful in the absence of any complications throughout the follow-up period. A statistical analysis was conducted.

Results: For the quality of the marginal closure and occlusal and interproximal contact points, the 3D-printed hybrid composite restorations scored highly; the aesthetic integration was satisfactory. One year after placement, all restorations survived, with a low incidence (4.2% overall, 5.7% SCs) of complications (two abutment screw loosenings, two decementation of the restorations, and one upper portion of the hybrid abutment decemented from the titanium base), for a success rate of 95.8%.

Conclusions: Within the limits of this study (retrospective design, follow-up limited to 1 year from the delivery, and only cemented restorations included) fixed short-span implant-supported hybrid composite crowns and bridges fabricated through TSLA were clinically precise, presenting a low incidence of complications at 1 year.

Statement of clinical relevance: The use of TSLA printing technology can open new perspectives for the treatment of small edentulous gaps with definitive implant-supported prosthetic restorations.

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Trueness, precision, time-efficiency, and cost analysis of chairside additive and subtractive versus lab-based workflows for manufacturing single crowns: An in vitro study

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Abstract

Purpose: To evaluate the trueness, precision, time efficiency, and cost of three different workflows for manufacturing single crowns (SCs).

Methods: A plaster model with a prepared tooth (#15) was scanned with an industrial scanner, and an SC was designed in computer-assisted-design (CAD) software. Ten SCs were printed with a hybrid composite (additive chairside) and a stereolithographic (SLA) printer (Dfab®), 10 SCs were milled in lithium disilicate (subtractive chairside) using a chairside milling unit (inLab MC XL®), and 10 SCs were milled in zirconia (lab-based) using a five-axis laboratory machine (DWX-52D®). All SCs were scanned with the same scanner after polymerization/sinterization. Each scan was superimposed to the marginal area of the original CAD file to evaluate trueness: absolute average (ABS AVG), root mean square (RMS), and (90˚-10˚)/2 percentile were calculated for each group. Marginal adaptation and quality of the occlusal and interproximal contact points were also investigated by two prosthodontists on 3D printed and plaster models. Finally, the three workflows' time efficiency and costs were evaluated.

Results: Additive chairside and subtractive lab-based SCs had significantly better marginal trueness than subtractive chairside SCs in all three parameters (ABS AVG, $p < 0.01$; RMS, $p < 0.01$; [90˚-10˚]/2, $p < 0.01$). However, the two prosthodontists found no significant differences between the three manufacturing procedures in the quality of the marginal closure ($p = 0.186$), interproximal ($p = 0.319$), and occlusal contacts ($p = 0.218$). Both time efficiency and cost show a trend favoring the chairside additive workflow.

Conclusions: Chairside additive technology seems to represent a valid alternative for manufacturing definitive SCs, given the high marginal trueness, precision, workflow efficiency and low costs.

Statement of clinical relevance: Additive chairside manufacturing of definitive hybrid composite SCs is now possible and shows high accuracy, time efficiency, and competitive cost.

Keywords: Additive technology; Chairside; Cost-analysis; Dental laboratory; Precision; Single crowns; Subtractive technology; Time-efficiency; Trueness.

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Influence of print orientation on the intaglio surface accuracy (trueness and precision) of tilting stereolithography definitive resin-ceramic crowns

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Abstract

Statement of problem: Vat-polymerization tilting stereolithography (TSLA) technology can be selected for fabricating definitive crowns; however, how the printing variables, including print orientation, influence its manufacturing accuracy remains unclear.

Purpose: The purpose of this in vitro study was to assess the influence of different print orientations (0, 45, 75, or 90 degrees) on the intaglio surface accuracy (trueness and precision) of TSLA definitive resin-ceramic crowns.

Material and methods: The virtual design of an anatomic contour molar crown was obtained in standard tessellation language (STL) file format and used to manufacture all the specimens by using a TSLA printer (DFAB Chairside) and a resin-ceramic material (Irix Max Photoshade single-use cartridges). Four groups were created depending on the print orientation used to manufacture the specimens: 0- (Group 0), 45- (Group 45), 70- (Group 75), and 90-degree (Group 90) print orientation (n=30). Each specimen was digitized by using a laboratory scanner (T710) according to the manufacturer's scanning protocol. The reference STL file was used as a control to measure the volumetric discrepancies of the intaglio surface with the digitized specimens by using the root mean square (RMS) error calculation. The trueness data were analyzed by using 1-way ANOVA followed by post hoc pairwise multiple comparison Tukey tests, and precision data were analyzed using the Levene test (α=.05).

Results: Significant mean trueness (P<.001) and precision (P<.001) value discrepancies were found among the groups tested. Additionally, all the groups were significantly different from each other (P<.001), except for the 45- and 90-degree groups (P=.868). Group 0 showed the best mean trueness and precision values, while the Group 90 demonstrated the lowest mean trueness and precision values.

Conclusions: The print orientations tested influenced the intaglio surface trueness and precision values of the TSLA definitive resin-ceramic crowns.

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Fracture Resistance of Three-unit Fixed Dental Prostheses Fabricated with Milled and 3D Printed Composite-based Materials

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Abstract

Aim: To evaluate the fracture resistance of three-unit fixed dental prosthesis (FDP) made of composite, high-density polymers (HDP), fiber-reinforced composite (FRC), and metal-ceramic (MC) using different fabrication methods.

Materials and methods: A typodont model was prepared to receive a three-unit FDP replacing a missing second maxillary premolar. The prepared model was digitally scanned using an intraoral scanner (Trios3, 3Shape, Denmark). In total, 60 FDPs were fabricated and divided into four groups (n = 15) according to the materials and fabrication method: the subtractive method was used for the FRC (Trilor, Bioloren, Italy) and the HDP (Ambarino, Creamed, Germany) groups; the HDP group was monolithic, whereas the FRC group was layered with a nanocomposite (G-aenial Sculpt, GC). The additive method was used for the 3D printed (3DP) nanocomposite (Irix Max, DWS, Italy) and the Cr-Co (Starbond CoS powder 30) infrastructure of the MC groups. The FDPs were adhesively seated on stereolithography (SLA) fabricated dies. All samples were subjected to thermomechanical loading and fracture testing. The data for maximum load (N) to fracture was statistically analyzed with one-way analysis of variance (ANOVA) followed by Games-Howell post hoc test (α = 0.05).

Results: The MC group reported the highest fracture resistance with a statistically significant difference (2390.87 ± 166.28 N) compared to other groups. No significance was noted between 3DP and HDP groups (1360.20 ± 148.15 N and 1312.27 ± 64.40 N, respectively), while the FRC group displayed the lowest value (839.07 ± 54.30 N). The higher frequency of nonrepairable failures was observed in the MC and FRC groups, while HDP and 3DP groups reported a high frequency of repairable failures.

Conclusion: Significant differences were found in fracture resistance between the tested groups. The load-bearing capacity of the composite-based FPDs exceeded the range of maximum chewing forces.

Clinical significance: 3D printed and milled composite-based materials might offer a suitable solution for the fabrication of FPDs.

Keywords: CAD/CAM; Fiber reinforced composite; Fixed dental prosthesis; Fracture resistance; High-density polymers 3D printing.

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Effect of material thickness on the fracture resistance and failure pattern of 3D-printed composite crowns

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Abstract

Aim: To evaluate the fracture resistance and failure pattern of 3D-printed and milled composite resin crowns as a function of different material thicknesses.

Materials and methods: Three typodont tooth models were prepared to receive a full coverage composite resin crown with different thicknesses (0.5, 1.0, and 1.5 mm). The prepared master casts were digitally scanned using an intraoral scanner, and the STL files were used to fabricate 60 nanocomposite crowns divided into two groups according to the material thickness (n = 10) and fabrication method: a 3D-printed group (3D) using an SLA printer with nanocomposite, and a milled group (M) using a milling machine and composite blocks. All crowns were adhesively seated on stereolithography (SLA)-fabricated dies. All samples were subjected to thermomechanical loading and fracture testing. The load to fracture [N] was recorded and the failure pattern evaluated. Data were statistically analyzed using a two-way ANOVA followed by a Bonferroni post hoc test. The level of significance was set at $\alpha = 0.05$.

Results: The 3D group showed the highest values for fracture resistance compared with the milled group within the three tested thicknesses ($P < 0.001$). The 3D and M groups presented significantly higher load to fracture for the 1.5-mm thickness (2383.5 ± 188.58 N and 1284.7 ± 77.62 N, respectively) compared with the 1.0-mm thickness (1945.9 ± 65.32 N and 932.1 ± 41.29 N, respectively) and the 0.5-mm thickness, which showed the lowest values in both groups (1345.0 ± 101.15 N and 519.3 ± 32.96 N, respectively). A higher incidence of irreparable fractures was observed for the 1.5-mm thickness.

Conclusion: 3D-printed composite resin crowns showed high fracture resistance at different material thicknesses and can be suggested as a viable solution in conservative dentistry.

Keywords: 3D printing; CAD/CAM; composite crowns; failure pattern; fracture resistance; additive manufacturing.

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A review on chemical composition, mechanical properties, and manufacturing work flow of additively manufactured current polymers for interim dental restorations

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Abstract

Objectives: Additive manufacturing (AM) technologies can be used to fabricate 3D-printed interim dental restorations. The aim of this review is to report on the manufacturing workflow, its chemical composition, and the mechanical properties that may support their clinical application.

Overview: These new 3D-printing provisional materials are typically composed of monomers based on acrylic esters or filled hybrid material. The most commonly used AM methods to manufacture dental provisional restorations are stereolithography (SLA) and material jetting (MJ) technologies. To the knowledge of the authors, there is no published article that analyzes the chemical composition of these new 3D-printing materials. Because of protocol disparities, selected technology, and parameters of the printers and material used, it is notably difficult to compare mechanical properties results obtained in different studies.

Conclusions: Although there is a growing demand for these high-tech restorations, additional information regarding the chemical composition and mechanical properties of these new provisional printed materials is required.

Clinical significance: Additive manufacturing technologies are a current option to fabricate provisional dental restorations; however, there is very limited information regarding its chemical composition and mechanical properties that may support their clinical application.

Keywords: 3D printing; additive manufacturing technologies; interim restorations; material jetting; stereolithography.

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Three-dimensional evaluation of marginal and internal fit of 3D-printed interim restorations fabricated on different finish line designs

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Abstract

Purpose To evaluate the influence of fabrication method and finish line design on marginal and internal fit of full-coverage interim restorations.

Methods Four typodont models of maxillary central-incisor were prepared for full-coverage restorations. Four groups were defined; knife-edge (KE), chamfer (C), rounded-shoulder (RS), rounded-shoulder with bevel (RSB). All preparations were digitally scanned. A total of 80 restorations were fabricated; 20 per group (SLA/3D-printed n=10, milled n=10). All restorations were positioned on the master die and scanned using micro-computed tomography. The mean gaps were measured digitally (ImageJ). The results were compared using MANOVA (α=.05).

Results Internal and marginal gaps were significantly influenced by fabrication method (P=.000) and finish-line design (P=.000). 3D-Printed restorations showed statistically significant lower mean gap compared to milled restorations at all points (P=.000). The mean internal gap for 3D-printed restorations were 66, 149, 130, 95μm and for milled restorations were 89, 177, 185, 154μm for KE, C, RS, RSB, respectively. The mean absolute marginal discrepancy in 3D-printed restorations were (30, 41, 30, 28μm) and in milled restorations were (56, 54, 52, 38μm) for KE, C, RS, RSB, respectively.

Conclusions The fabrication methods showed more of an influence on the fit compared to the effect of the finish-line design in both milled and printed restorations. SLA-printed interim restorations exhibit lower marginal and internal gap than milled restorations. Nonetheless, for both techniques, all values were within the reported values for CAD/CAM restorations. Significance3D-printing can offer an alternative fabrication method comparable to those of milled restorations.

Keywords: 3D-SLA printing; Additive manufacturing; Finish line design; Marginal and internal fit; Micro-CT.

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Effects of build direction on the mechanical properties of 3D-printed complete coverage interim dental restorations

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Abstract

Statement of problem: The application of 3-dimensional printing technology is emerging in dentistry and is being increasingly used to fabricate dental restorations. To date, scientific evidence is lacking regarding the effect of different factors on the mechanical properties of the printed restorations with the additive manufacturing technique.

Purpose: The purpose of this in vitro study was to evaluate the effect of build direction (layer orientation) on the mechanical properties of a novel 3-dimensionally (3D)-printed dental restorative material.

Material and methods: Based on the printing direction, 2 groups were tested. In the first group (n=20), the specimens were vertically printed with the layers oriented perpendicular to the load direction. In the second group (n=20), the specimens were horizontally printed with the layers oriented parallel to the load direction. All specimens were fabricated using the DW028D 3D-printer. The specimens were loaded with a universal testing machine at a crosshead speed of 1 mm/min with a 10-kN load cell. The test was performed at room temperature (22°C) under dry testing conditions. The compressive strength was calculated for both groups, and the results were compared using the unpaired t test (α=.05).

Results: The mean ±SD compressive strength for the vertically printed specimens was 297 MPa (±34) compared with 257 MPa (±41) for the horizontally printed specimens (P=.002).

Conclusions: Within the limitations of this study, the layer orientation was found to influence the compressive strength of the material. Vertically printed specimens with the layers oriented perpendicular to load direction have improved mechanical properties more than horizontally printed specimens with the layers oriented parallel to load direction.

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Factors Influencing the Dimensional Accuracy of 3D-Printed Full-Coverage Dental Restorations Using Stereolithography Technology

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Abstract

Purpose: The aim of the present study was to evaluate the effect of the build angle and the support configuration (thick versus thin support) on the dimensional accuracy of 3D-printed full-coverage dental restorations.

Materials and methods: A full-coverage dental crown was digitally designed and 3D-printed using stereolithography-additive manufacturing (SLA-AM) technology. Nine different angles were used during the build process: 90, 120, 135, 150, 180, 210, 225, 240, and 270 degrees. In each angle, the crown was printed using a thin and a thick support type, resulting in 18 specimens. The specimens were digitally scanned using a high resolution optical surface scanner (IScan D104i; Imetric 3D). The dimensional accuracy was evaluated by digital subtraction technique. The 3D digital files of the scanned printed crowns (test model), exported in standard tessellation language (STL) format, were superimposed with the STL file of the designed crown (reference model) using Geomagic Studio 2014 (3D Systems).

Results: The root mean square estimate value and color map results suggest that the build angle and support structure configuration have an influence on the dimensional accuracy of 3D-printed crown restorations. Among the tested angles, the 120-degree build angle showed a minimal deviation of 0.029 mm for thin support and 0.031 mm for thick support, indicating an accurate fit between the test and reference models. Furthermore, the deviation pattern observed in the color map was homogenously distributed and located further away from the critical marginal area.

Conclusions: Within the limitations of this study, the selection of build angle should offer the crown the highest dimensional accuracy and self-supported geometry. This allows for the smallest necessary support surface area and decreases the time needed for finishing and polishing. These properties were mostly observed with a build angle of 120 degrees combined with a thin support type.

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3D FOR PATIENTS

POSTER SECTION

POSTER section

Poster presented at the 2nd SIPRO (Italian Prosthodontics Society) National Congress. Florence, February 17-18, 2023 – full text

THE USE OF CHAIRSIDE 3D-PRINTING TECHNOLOGIES TO RESTORE A COMPROMISED PREMOLAR: A CASE REPORT

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Aim 3D printing technologies are increasingly being used in dentistry, especially for the fabrication of models and artifacts such as surgical templates, splints, or templates. More recently, the use of PMMA and composite resins has enabled the fabrication of temporary restorations. The rapid evolution of materials on the one hand and technologies on the other hand have allowed the introduction of hybrid ceramics that can be printed with laser-sintering technology in a short time, so that the clinician can be offered solutions that can be increasingly employed in the daily clinic. The purpose of this case report is to show the morpho-functional restoration of a highly compromised posterior dental element with chairside technique.

Materials and Methods A 64-year-old female patient came to the Restorative Department of the Dental School Lingotto, University of Turin, for post-endodontic reconstruction of first lower right premolar. The clinical examination showed a destructive distal carious lesion with invasion of the supracrestal connective attachment and the residual tooth structure was thin and full of enamel-dentinal cracks. Therefore, an indirect hybrid ceramic adhesive restoration was planned to be performed after surgical crown lengthening. After performing plexic anesthesia, cavity debridment was performed, which confirmed that the distal cavity margin was close to the bone crest. Therefore, a flap was opened with marginal incision and circumferential osteoplasty to reestablish the correct relationships between supporting tissues and cavity margins. The soft tissues are sutured, and the rubber dam is placed. A circumferential matrix is placed, and after application of a two-pass self-etch adhesive system, a build-up with composite resin is performed. Once photopolymerization is completed, the patient is discharged. After 7 days, stitch removal, preparation of 4.4 for an adhesive crown with 1mm deep butt-join margins and 1.5mm occlusal reduction is performed. An intraoral scan (Trios 3) and CAD fabrication of the prosthetic restoration is performed. The stl file is imported to NAUTA software where the procedure for 3D printing is set up, which is done using a hybrid ceramic (Irix Max, DWS) with a D-Fab 3d printer (DWS). At the end of the process, the artifact is cemented using etch-and-rinse adhesive procedure and dual resin cement.

Results The procedure employed allowed the morpho-functional restoration of an extremely compromised tooth element through an all-digital workflow finalized with 3D manufacturing of a state-of-the-art hybrid ceramic. The fitting and anatomical adaptation of the artifact proved to be optimal, mind the color integration still shows defects, such as excessive opacity of the restorative material and an inconspicuous color gradient.

Conclusion 3D printing technologies represent the future of indirect restorative care, ensuring a dizzying evolution of technologies and materials. Already, the method employed has enabled a single appointment management of CAD-CAM flow and the use of highly filled resin-based materials. Longer follow-ups and clinical studies are now needed to establish the efficacy of these procedures.

POSTER section

Poster presented at the 2nd SIPRO (Italian Prosthodontics Society) National Congress. Florence, February 17-18, 2023 – full text Special Mention for Research in Prosthetics

CAM-TECNIQUE EFFECT ON CEMENT VOLUME AND FATIGUE RESISTANCE OF POLYMER-INFILTRATED CERAMIC NETWORK (PICN) RESTORATIONS

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Aim To evaluate the cement volume and fatigue resistance of milled (in lab or chairside) or 3D-printed polymer infiltrated ceramic network restorations. The first null hypothesis was that cement volume and fatigue resistance were not affected by different CAM techniques.

Materials and Methods An intact upper premolar was selected and was prepared for an overlay restoration: occlusal reduction of 1,5 mm, two interproximal boxes and inclined chamfer margin on buccal and oral surfaces. After being scanned with lab scanner in Hi-Res mode (inEOS X5, Dentsply Sirona) a 3D model was created. To obtain the same specimen shape for all groups it was 3D printed by Solflex 170 HD (VOCO) in light-curing resin (V-Print Model, VOCO) at the highest resolution (layer thickness = 50 micron). All these 3D-printed specimens were scanned by an intraoral scanner (PrimeScan, Dentsply Sirona) and an overlay restoration was designed with a CAD software maintaining equal morphology and thickness. The so-obtained STL file was processed to produce the restoration with three different techniques (n=10 each): 3D-printing (D-FAB, DWS) (G1); milling procedure by a 4-axis chairside-milling machine (MCXL, Dentsply Sirona) (G2); milling procedure by a 5-axis lab-milling machine (DWX 51D, Roland) (G3). The material used for all the restorations was a polymer-infiltrated ceramic network (PICN): for G1 Irix Max (DWS), for G2 and G3 Vita Enamic (Vita). The same adhesive procedures were performed for all groups both on model and on restoration. Then a self-adhesive cement (Panavia SA Cem, Kuraray Noritake) was used. After removing the excess, specimens were cured 20 s on each side with LED lamp. Specimens were scanned using a Micro-CT (SkyScan 1172, Bruker) to measure the cement volume. Then, specimens were submitted to a fatigue protocol (1st step: 5.000 cycles at 200 N, 2nd step: 5.000 cycles at 400 N, 3rd step: 5.000 cycles at 400 N, 4th step: 10.000 at 600 N, 5th step: 10.000 at 800 N) and the number of cycles before the restoration fracture was detected. The volume in mm3 and the number of cycles were collected and statistically analyzed with one-way ANOVA test.

Results The mean cements volume and accelerated fatigue resistance (number of cycles), ±SD, of different groups are displayed in graph 1 and graph 2 respectively. The cement volume was significantly affected by the CAM-technique tested (p=0.00001), with the chairside-milling process showing higher values than 3D-printed and lab-milled ones. On the other hand, the 3Dprinted PICN showed a significantly higher fatigue resistance than lab-milled and chairside-milled specimens. The chairside-milling process was significantly worse than lab-milled one.

Conclusion Based on the obtained results, the 3D-printing process can reflex the indirect preparation design as a 5-axis milling machine does, while a 4-axis one produces an increase in cement layer which seems to affect the fatigue resistance or indirect adhesive PICN restorations. Thus, the initial null hypotheses were rejected.

POSTER section

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College of University Teachers of Dentistry disciplines
ETS - Modern dentistry between advanced technology and humanisation
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ACCELERATED FATIGUE RESISTANCE OF 3D PRINTED VS MILLED OCCLUSAL VENEERS

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Aim: to evaluate the biomechanics of the cement layer and different restorative materials (3D printed and milled) through accelerated fatigue.

Methods: a human second mandibular molar was prepared with anatomical reduction for an occlusal veneer restoration. After digitalization, 8 identical models of the prepared tooth were 3D printed (SolFlex 170, V-Print Model 2.0, Voco). All the obtained casts were individually scanned (Cerec Primescan, Dentsply Sirona), and restorations were designed with identical occlusal surfaces and uniform 1mm-thickness. Four restorations were 3D printed (Irix Plus, DFAB, DWS), four were milled (Grandio Blocks, Voco) with a chairside milling unit (Cerec MC X, Dentsply Sirona). Surface pretreatment was performed as follows, for both restorations and casts: sandblasting (30 µm Cojet Sand, 3M), Silane (Porcelain Silane, BJM LAB), Universal adhesive (Universal Bond Quick, Kuraray Noritake). Then a dual curing self-adhesive cement was used to cement all restorations with standardized pressure (Panavia SA, Kuraray Noritake). Cement excesses were removed before 3 min light-curing (VALO 1400mW/cm2). Accelerated fatigue was performed with Instron Machine, MTS, as follows: 200N-5000 cycles, 400N-5000 cycles, 400N-5000 cycles, 600N-5000 cycles, 600N-5000 cycles, 800N-5000 cycles. Samples were tested up to fracture and n° of cycles were recorded, as well as fracture pattern.

Results: Kaplan-Meier survival estimates showed that the 3D printed material performed significantly better than the milled material. Fracture patterns showed that 3D printed samples were more prone to wear and failure due to complete consumption of the material. On the other hand, milled material had more catastrophic failures with complete fracture of both the restoration and the substrate.

Conclusions: tested 3D printed material showed promising performances both on fatigue resistance and failure patterns. Further studies are necessary to confirm the results obtained and evaluate their interfacial behavior.

POSTER section

Conservative dentistry | Abstract - Pages 71-82
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ANTERIOR TEETH SHAPE MODIFICATION AFTER ORTHO TREATMENT TROUGH 3D-PRINTING TECHNOLOGIES

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Aim: the aim of this case report is to demonstrate the use of a digital workflow in achieving an aesthetically pleasing outcome for a patient who underwent orthodontic treatment and has lateral incisor agenesia.

Methods: a 20-year-old male patient visited the Restorative Department of the Dental School Lingotto, University of Turin, after receiving a two-year-long orthodontic treatment to correct malocclusion, microdontia, and lateral incisor agenesia. Due to the altered Bolton Index, multiple diastemas were present, and the canines were positioned as lateral incisors. As a result, indirect hybrid ceramic adhesive restorations were planned after Digital Smile Design (DSD) evaluation. After minimal preparation of teeth 1.3, 1.1, 2.1, and 2.3 to remove enamel undercuts, an intraoral scan was performed using Trios 3. The CAD fabrication of minimal veneer restorations was performed in cut-back mode, followed by importing the stl file to NAUTA software, which was used to set up the procedure for 3D printing. The restorations were printed using a hybrid ceramic (Irix Max, DWS) with a Dfab 3D printer (DWS). The veneers were then luted, and enamel layers with characterization were completed directly.

Results: the all-digital workflow employed in this case proved to be effective in achieving morpho-functional restoration using minimal thicknesses. The artifact was optimally fitted and anatomically adapted.

Conclusions: the use of 3D printing technologies in indirect restorative care represents the future, and the digital workflow can assist multidisciplinary approaches in orthodontic patients with altered Bolton indices or requiring shape modifications.

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3-BODY WEAR OF 3D PRINTED VS MILLED COMPOSITES: AN IN VITRO STUDY

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Aim: to evaluate the 3-body wear behavior of 3D printed vs milled materials in an acidic medium. The tested null hypothesis will be that the different materials are not able to equally resist to abrasive wear independently of the acidic medium.

Methods: the analyzed materials are 2 CAD/CAM milled composite (Cerasmart, GC; Grandio Block, Voco), a PICN (Vita Enamic, Vita) and a 3D printed composite (Irix Max, DWS). Square-shaped specimens of 2 mm thickness are obtained by using a cutting machine (Micromet, Remet) under water cooling or printed using a 3D printing machine (D-Fab, DWS). Once the specimen surface is finished with abrasive papers at sequential grit, they are fixed on the rotative wheel of the ACTA machine with a resin-based support. The wear test are performed with specimens continuously immersed in different mediums: pH 5.8 (distilled water), pH 3.3 (Redbull) and SEM analysis were performed. After the wear test the volumetric loss are evaluated through a 3D laser scanner. The obtained data are statistically analyzed through a 2-way ANOVA test and Tukey post-hoc test.

Results: after 3 body-wear test Irix Max showed significantly lower volume loss than other materials ($p = 0.00001$), while acidic medium induced an increased wear ($p = 0.0007$).

Conclusions: since 3D printed material had a lower wear rate than CAD/CAM ones independently of the acid medium, the initial null hypothesis was rejected.

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CEMENT GAP WITH 3D PRINTED VS MILLED OCCLUSAL VENEERS: A MICRO CT STUDY

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Aim: to evaluate the cement layer thicknesses in different manufacturing techniques through the use of the microCT.

Methods: a second mandibular molar was prepared with anatomical reduction for an occlusal veneer restoration. After digitalization, 16 identical models of the prepared tooth were 3D printed (SolFlex 170, V-Print Model 2.0, Voco). All the casts were scanned (Cerec Primescan, Dentsply Sirona) and restorations were designed with identical occlusal surfaces and uniform 1 mm-thickness. Half of the restorations (n = 8) were 3D printed (Irix Plus; Dfab, DWS) and half were milled (Grandio Blocks, Voco) with a chairside milling unit (Cerec MC X, Dentsply Sirona). Surface pretreatment was performed as follows, for both restorations and casts: sandblasting (30 µm Cojet Sand, 3M), silane (Porcelain Silane, BJM LAB), Universal adhesive (Universal Bond Quick, Kuraray Noritake). After that, a dual curing self-adhesive cement was used to cement all restorations, with standardized pressure (Panavia SA, Kuraray Noritake) and 3 min light-curing (VALO, 1400mW/cm^2). Micro-CT scans were taken to obtain high-quality 3D images (15 µm resolution), that were linearly analyzed to collect data of internal (24 points per sample) and marginal (16 points per sample) adaptation.

Results: no significant differences were found for marginal adaptation ($p = 0.154$), with an average of 0.11±0.067 in the 3D-printed group and 0.098±0.063 in the milled group. However, a significant difference was reported for internal adaptation ($p < 0.01$), with the 3D-printed group performing better.

Conclusions: the study showed that different manufacturing techniques have a significant influence on cement layer thickness in internal adaptation of different restorative materials.