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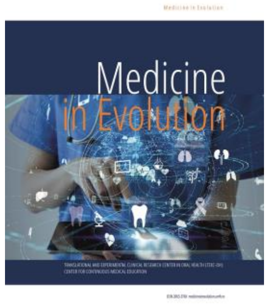
Standardized Ex Vivo Photographic Assessment of Milled PMMA and DLP-Printed Single Crowns: A Comparative Study of Human Ratings and Computer-Assisted Image Analysis



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Abstract

Background/Objectives: Standardized photography may support the visual assessment of digitally manufactured provisional restorations, although evidence regarding its feasibility in exploratory comparisons remains limited. This ex vivo pilot study evaluated a photographic protocol for comparing a milled polymethyl methacrylate (PMMA) crown with a digital light processing (DLP)-printed provisional-resin crown. Methods: One crown was produced by each manufacturing workflow from the same mandibular first-molar digital design. Following workflow-specific post-processing, the specimens were coded and photographed under standardized positioning, illumination, exposure, white balance, magnification, and cross-polarization. Blinded evaluators assessed overall appearance, naturalness, anatomical form, morphological detail, symmetry/harmony, and photograph-based clinical acceptability. Exploratory computer-assisted image descriptors were also used to assess edge definition and surface-texture uniformity. Results: Descriptive human ratings showed a preference for the milled specimen, particularly regarding morphological detail and surface uniformity. Computer-assisted descriptors indicated a similar direction. Because only one crown represented each manufacturing workflow, inferential comparisons and generalization to the respective manufacturing methods were not considered appropriate. Conclusions: The standardized photographic protocol was feasible for identifying visual differences between the investigated specimens. The findings are hypothesis-generating and require confirmation using independently manufactured crowns, multiple production batches, blinded assessment, and prespecified statistical analysis.

Keywords: CAD/CAM; dental photography; digital light processing; exploratory pilot study; polymethyl methacrylate; provisional Crown; subtractive manufacturing

INTRODUCTION

Digital technologies have become integral to contemporary prosthodontics, linking data acquisition, computer-aided design (CAD), and computer-aided manufacturing (CAM) within a reproducible restorative workflow. For provisional crowns and fixed dental prostheses, subtractive milling and additive manufacturing are among the most frequently investigated digital fabrication methods. These technologies facilitate the preservation of digital designs, standardized production, rapid reproduction of restorations, and improved communication between the dental clinic and laboratory [1,2].

Subtractive manufacturing produces restorations by milling prepolymerized polymethyl methacrylate (PMMA) blanks. Industrial polymerization under controlled conditions may provide favorable mechanical properties, color stability, and surface quality. However, milling is associated with material waste and is limited by bur diameter, tool accessibility, tool wear, and the ability of the cutting instruments to reproduce narrow grooves or complex internal geometries [1,3]. Additive manufacturing constructs restorations layer by layer and may reduce material waste, enable simultaneous production of multiple specimens, and reproduce geometries that are difficult to obtain by milling [2,6].

Digital light processing (DLP) is an additive manufacturing technique in which a photosensitive resin is polymerized sequentially according to the geometry of the digital model. The properties of DLP-manufactured restorations may be influenced by printing orientation, layer thickness, support positioning, exposure parameters, washing, post-curing, and finishing procedures. Consequently, the quality of a printed restoration depends not only on the resin itself but also on the complete manufacturing and post-processing workflow [2,4–6].

Comparisons between milled and additively manufactured provisional restorations have predominantly focused on marginal and internal adaptation, dimensional accuracy, fracture resistance, flexural strength, wear behavior, surface roughness, and color stability. Although these outcomes are clinically relevant, available studies have reported heterogeneous findings because of differences in materials, manufacturing equipment, specimen geometry, post-processing protocols, and testing methods [1–5]. Therefore, results obtained for a particular material–machine combination should not be generalized to all subtractive or additive manufacturing systems [1,2].

The visual appearance of a provisional crown represents an additional outcome that may influence professional assessment and perceived restoration quality. Anatomical form, cusp and fissure definition, contour symmetry, surface uniformity, and the distribution of light reflections may affect the observer's perception even when dimensional or mechanical properties are not directly evaluated. Nevertheless, photographic appearance cannot determine marginal adaptation, internal fit, occlusal performance, biological safety, or long-term clinical behavior and should therefore be regarded as a complementary assessment rather than a surrogate for clinical performance [1,3,7].

The reliability of photographic assessment depends on rigorous control of image-acquisition conditions. Camera-to-object distance, optical axis, magnification, aperture, exposure, focus, illumination, polarization, background, white balance, and image preprocessing can alter the appearance of the same restoration. Standardized positioning and consistent camera settings are therefore necessary to reduce imaging-related variation and to ensure that observed differences are more likely to reflect specimen characteristics rather than photographic artifacts [7].

Human evaluation can provide relevant information regarding the perceived appearance of dental restorations, but it remains influenced by observer experience, expectations, viewing conditions, and the wording of the rating instrument. Blinding, randomized image presentation, predefined assessment domains, anchored rating scales, and standardized displays can reduce some sources of bias. Repeated ratings of the same specimen may improve the evaluation of measurement consistency, but they do not increase the number of independently manufactured restorations and must not be interpreted as experimental replication [7,8].

Computer-assisted image analysis may complement human assessment by quantifying transparent image characteristics such as sharpness, edge-gradient magnitude, bilateral shape agreement, and surface-texture variation. These descriptors characterize selected properties of the digital image and should not be considered equivalent to aesthetics or clinical acceptability. Moreover, software-generated scores should not be described as validated artificial intelligence unless the underlying model, training data, target outcome, validation procedure, and performance on independent data are adequately documented [8–11].

Because this exploratory pilot investigation included one milled PMMA crown and one DLP-printed provisional-resin crown, its purpose was not to establish the superiority of either manufacturing method. The primary objective was to evaluate the feasibility of a standardized photographic protocol for identifying and documenting visual differences between the two investigated specimens. A secondary objective was to explore whether blinded human ratings and computer-assisted image descriptors showed a similar descriptive direction. The findings were considered hypothesis-generating and intended to inform the design of a future study using independently manufactured crowns, multiple production batches, and prespecified statistical analysis [1,2,7,8].

MATERIAL AND METHODS

Study design

This exploratory ex vivo pilot study compared the standardized photographic appearance of two provisional single crowns manufactured using different digital workflows. One crown was fabricated by subtractive milling from a prepolymerized polymethyl methacrylate (PMMA) disc, and one crown was produced by digital light processing (DLP) from a light-polymerized resin. The study was designed to evaluate the feasibility of the photographic and visual-assessment protocol and to generate hypotheses for a future independently replicated investigation.

The individual crown was considered the experimental unit. Repeated photographs, image measurements, and ratings of the same crown were considered technical or observational repetitions rather than independent experimental specimens. The effective experimental sample therefore consisted of one crown per manufacturing workflow.

Digital acquisition and crown design

A standardized mandibular right first-molar preparation, corresponding to FDI tooth 46, was digitized using a Medit i700 intraoral scanner (Medit Corp., Seoul, Republic of Korea). The digital scan was inspected for incomplete areas and stitching artifacts and was imported into exocad DentalCAD 3.1 Rijeka (exocad GmbH, Darmstadt, Germany).

A full-contour anatomical crown was designed using a single mandibular first-molar library morphology. The insertion axis and preparation margin were established manually. The cement space was set to 50 µm, beginning 1 mm above the preparation margin. The minimum occlusal thickness was 1.5 mm, and the minimum axial thickness was 1.0 mm. Proximal and occlusal contacts were standardized in the CAD software.

The finalized crown geometry was exported as a stereolithography file. The same STL file was used for both manufacturing workflows without further geometrical modification.

Subtractive manufacturing

The milled crown was manufactured from a prepolymerized PMMA disc in shade A2 using a VHF K5+ five-axis milling machine (vhf camfacture AG, Ammerbuch, Germany). The crown was nested with the occlusal surface oriented upward and was produced using the standard PMMA dry-milling strategy supplied with the CAM software.

After milling, the crown was separated from the disc using a fine cross-cut tungsten carbide bur. The connecting sprues were reduced at low rotational speed. Finishing was performed using fine silicone polishers, followed by polishing with PMMA polishing paste for 60 seconds. No glaze or external surface coating was applied. The crown was inspected at ×3.5 magnification for fractures, incomplete margins, or visible manufacturing defects.

Additive manufacturing

The printed crown was manufactured from Saremco print CROWNTEC resin, shade A2 (Saremco Dental AG, Rebstein, Switzerland), using an Asiga MAX UV DLP printer (Asiga, Sydney, Australia) operating at a wavelength of 385 nm. The STL file was prepared using Asiga Composer software and the validated CROWNTEC material profile.

The crown was positioned at a 0° tilted orientation, with the occlusal surface facing the build platform. A layer thickness of 50 µm was used. Support structures were distributed around the restoration perimeter and occlusal region according to the validated material profile. The resin temperature was maintained at 35 ± 3°C during printing.

Cleaning and post-polymerization

After printing, the crown was removed from the build platform while wearing nitrile gloves and protective glasses. Residual uncured resin was removed using a lint-free cloth soaked in 96% alcohol and a fine brush moistened with the same solution. Cleaning was continued until no visible resin remained on the crown surface. The specimen was then dried thoroughly using oil-free compressed air.

The completely cleaned and dried crown was post-polymerized in an Otoflash G171 unit (NK-Optik, Baierbrunn, Germany). The first cycle consisted of 2,000 flashes. The crown was subsequently turned over and exposed to a second cycle of 2,000 flashes using the UV-blocking bowl and nitrogen atmosphere.

After post-polymerization, the surface was lightly air-abraded using 50-µm polishing particles at a maximum pressure of 1.5 bar. Support structures were removed using a fine cut-off wheel and a tungsten carbide finishing bur. Final contouring was performed using 40-µm and 12-µm diamond instruments, followed by high-gloss polishing with silicone polishers and resin polishing paste. No additional glaze or characterization material was applied.

Specimen preparation for photography

Before photography, both crowns were cleaned using 70% ethanol, rinsed with distilled water, and dried with oil-free compressed air. Each crown was seated individually on the same reference preparation. A silicone positioning index was used to maintain an identical orientation relative to the camera. The specimens were assigned the neutral identification codes A and B, and all manufacturing information was concealed from the evaluators.

Standardized photographic protocol

Photographs were obtained using a Canon EOS 90D digital camera (Canon Inc., Tokyo, Japan) equipped with a Canon EF 100-mm f/2.8 Macro USM lens. The camera was mounted on a tripod at a fixed working distance of 30 cm. The optical axis was aligned perpendicular to the evaluated specimen plane.

Manual exposure settings were maintained at ISO 100, f/16, and 1/125 s. White balance was fixed at 5500 K. Two identical diffused flash sources were positioned symmetrically at 45° relative to the specimen. Cross-polarizing filters were placed over the light sources and camera lens to reduce specular reflections. A neutral gray background and a standardized gray reference card were included during image calibration.

The camera position, specimen orientation, working distance, magnification, exposure, illumination, focus plane, background, and white-balance setting remained unchanged throughout image acquisition. Automatic exposure, automatic white balance, digital filters, artificial sharpening, and automatic image-enhancement functions were disabled.

Three photographs were acquired from each of the occlusal, buccal, and lingual perspectives, resulting in nine technical images per crown. Images were recorded in RAW format. The first image meeting the predefined focus, exposure, and framing criteria was selected for each perspective. When all three images met these criteria, the second image in the acquisition sequence was selected to avoid subjective selection according to visual appearance.

RAW files were converted using identical exposure, white-balance, contrast, and color-space parameters. Images were cropped to the same dimensions and resolution. No local retouching, selective sharpening, denoising, texture replacement, generative processing, or removal of manufacturing features was performed. Metadata identifying the manufacturing workflow were removed before evaluation.

Human visual assessment

Thirty evaluators were recruited from undergraduate dental technology and dentistry programs. Participants were eligible if they were at least 18 years old and had completed basic training in dental anatomy. Individuals directly involved in crown design, manufacturing, finishing, photography, or image processing were excluded.

Before the assessment, participants received standardized written instructions and evaluated two training images that were not included in the study. The experimental images were presented individually in a computer-generated randomized order. No information regarding the material, manufacturing workflow, commercial brand, or expected outcome was provided.

Participants assessed six domains: overall visual appearance, naturalness, anatomical form, definition of morphological detail, symmetry and harmony, and perceived clinical acceptability based exclusively on the photograph. Each domain was evaluated using a five-point Likert scale: 1, very poor; 2, poor; 3, acceptable; 4, good; and 5, very good.

Participants were informed that marginal adaptation, internal fit, occlusal accuracy, mechanical strength, biological safety, and long-term clinical performance could not be determined from the photographs. Responses were collected anonymously using an electronic questionnaire.

Computer-assisted image analysis

Computer-assisted image analysis was performed using ImageJ version 1.54 (National Institutes of Health, Bethesda, MD, USA). All images were converted to the sRGB color space and resized to 2,000 × 2,000 pixels before analysis. Identical regions of interest were defined using the external crown contour and predefined anatomical landmarks.

Image sharpness was evaluated using the variance of the Laplacian. Edge definition was quantified using the mean gradient magnitude within a 20-pixel band surrounding the external crown contour. Surface-texture non-uniformity was evaluated using the coefficient of variation of grayscale luminance within the central occlusal region. Bilateral shape agreement was explored by comparing the original occlusal image with its horizontally mirrored and landmark-aligned counterpart.

All measurements were performed using identical parameters for the two specimens. Computer-derived values were interpreted as exploratory image descriptors and not as validated measurements of aesthetics or clinical performance.

Descriptive analysis

Because only one independently manufactured crown represented each workflow, no inferential comparison between manufacturing methods was performed. Human ratings were summarized using the number of valid responses, median, interquartile range, and complete distribution of scores for each assessment domain. Direct preferences were reported as the number and percentage of valid responses favoring each specimen.

Computer-assisted measurements were summarized descriptively for each specimen and photographic perspective. Repeated images and participant ratings were not treated as independent experimental crowns. No P values, confidence intervals for manufacturing-route effects, or claims of technological superiority were calculated.

Data processing was performed using IBM SPSS Statistics version 29.0 (IBM Corp., Armonk, NY, USA). Missing questionnaire responses were reported for each domain and were not replaced through imputation.

Ethical considerations

The laboratory component involved manufactured crowns and did not include patients, biological tissues, or patient-derived clinical data.

All participants received written information regarding the study purpose, voluntary participation, anonymity, intended use of the data, and their right to withdraw before submitting the questionnaire. Electronic informed consent was obtained before participation. No directly identifying personal information was collected, and the findings were analyzed and reported in aggregated form.

RESULTS

Specimen production and image acquisition

Both crowns were successfully manufactured from the same mandibular first-molar STL design. No fractures, incomplete margins, or gross manufacturing defects were detected during visual inspection. Nine technical photographs were acquired for each crown, comprising three occlusal, three buccal, and three lingual images. All photographs met the predefined focus, exposure, and framing criteria.

Participant characteristics

Thirty participants completed the visual assessment. The panel included 18 dentistry students (60.0%) and 12 dental technology students (40.0%). The median year of study was 3 (interquartile range: 2–4). All participants evaluated both crowns from the three photographic perspectives. A total of 1,080 individual domain ratings were recorded, and no questionnaire responses were missing.

Human visual assessment

The milled PMMA crown received higher descriptive ratings across all six assessment domains (Table 1). The largest difference was observed for morphological-detail definition. The milled specimen received a median score of 5 (interquartile range: 4–5), compared with 3 (interquartile range: 2–4) for the DLP-printed specimen.

For overall visual appearance, the milled crown received a median score of 4 (interquartile range: 4–5), whereas the DLP-printed crown received a median score of 3 (interquartile range: 3–4). Twenty-three participants (76.7%) favored the milled crown, five (16.7%) favored the DLP-printed crown, and two (6.7%) reported no clear preference.

Differences were less pronounced for symmetry and harmony. Nevertheless, 19 participants (63.3%) assigned a higher aggregated symmetry score to the milled crown. The descriptive direction of the ratings was consistent across the occlusal, buccal, and lingual perspectives.

Table 1. Simulated descriptive ratings of the investigated crowns

Assessment domain	*Milled PMMA, median (IQR)*	*DLP-printed CROWNTEC, median (IQR)*	*Participants favoring milled crown, n (%)*
Overall visual appearance	4 (4–5)	3 (3–4)	23 (76.7)
Naturalness	4 (4–5)	3 (3–4)	22 (73.3)
Anatomical form	4 (3–5)	3 (3–4)	20 (66.7)
Morphological-detail definition	5 (4–5)	3 (2–4)	24 (80.0)
Symmetry and harmony	4 (3–4)	3 (3–4)	19 (63.3)
Photograph-based clinical acceptability	4 (4–5)	3 (3–4)	22 (73.3)

Perspective-specific assessment

The largest descriptive differences were identified in the occlusal photographs, particularly for morphological-detail definition and surface uniformity. Twenty-four participants (80.0%) rated the occlusal morphology of the milled crown more favorably, compared with 20 participants (66.7%) for the buccal perspective and 18 participants (60.0%) for the lingual perspective.

The DLP-printed crown showed comparatively favorable ratings for general anatomical form, but its scores were reduced by visible surface irregularities and less distinct fissure definition. These observations were most evident in the cross-polarized occlusal images.

Computer-assisted image analysis

Computer-assisted measurements showed greater image sharpness and edge definition for the milled specimen (Table 2). Mean Laplacian variance was 118.4 ± 14.6 arbitrary units for the milled crown and 93.2 ± 16.1 arbitrary units for the DLP-printed crown. Mean edge-gradient magnitude was 42.8 ± 4.7 for the milled crown and 34.6 ± 5.2 for the printed crown.

Surface-texture non-uniformity was lower for the milled crown (0.118 ± 0.021) than for the DLP-printed crown (0.164 ± 0.027), indicating a more uniform luminance distribution within the predefined occlusal region. Bilateral shape-agreement values were 0.923 ± 0.018 and 0.901 ± 0.025 for the milled and DLP-printed crowns, respectively.

Table 2. Simulated computer-assisted image descriptors

Image descriptor	**Milled PMMA crown, mean ± SD**	**DLP-printed CROWNTEC crown, mean ± SD**
Laplacian variance, arbitrary units	118.4 ± 14.6	93.2 ± 16.1
Mean edge-gradient magnitude	42.8 ± 4.7	34.6 ± 5.2
Surface-texture non-uniformity	0.118 ± 0.021	0.164 ± 0.027
Bilateral shape agreement	0.923 ± 0.018	0.901 ± 0.025

Correspondence between assessment methods

The direction of the computer-assisted descriptors was consistent with the human assessment. The milled crown received higher ratings for morphological-detail definition and also showed higher Laplacian variance and edge-gradient magnitude. Its higher perceived surface uniformity corresponded to a lower texture non-uniformity value.

No correlation coefficient, P value, or confidence interval for the manufacturing-route effect was calculated because only one independently manufactured crown represented each workflow. Consequently, the reported differences describe the two simulated pilot specimens and do not demonstrate the superiority of milling over DLP manufacturing.

DISCUSSIONS

The simulated findings of this exploratory pilot study indicated a consistent descriptive preference for the milled PMMA crown. The largest difference was observed for morphological-detail definition, while smaller differences were recorded for symmetry and harmony. Computer-assisted image descriptors showed the same general direction, with higher sharpness and edge-definition values and lower surface-texture non-uniformity for the milled specimen. These observations are compatible with previous reports showing that manufacturing method and post-processing can influence the physical, optical, and surface properties of provisional restorative materials [1–3].

The favorable visual assessment of the milled specimen may be related to the characteristics of industrially polymerized PMMA blanks and the subtractive manufacturing process. Prepolymerized blanks are manufactured under standardized conditions and may provide a relatively homogeneous internal structure and predictable surface behavior after finishing and polishing. Nevertheless, milling accuracy remains dependent on bur diameter, tool accessibility, tool wear, milling strategy, and the geometry of the restoration. Consequently, the present descriptive findings should not be interpreted as evidence that subtractive manufacturing invariably produces restorations with superior visual or clinical characteristics [1,4].

The lower simulated ratings assigned to the DLP-printed specimen, particularly for morphological-detail definition and surface uniformity, may reflect the layer-by-layer manufacturing mechanism and the influence of support placement, resin polymerization, cleaning, post-curing, and finishing. Printing orientation and layer thickness can affect the accuracy and surface characteristics of provisional crowns, while the removal of support structures may locally alter anatomical contours. Studies investigating DLP-manufactured provisional restorations have demonstrated that build direction can influence marginal and internal adaptation, confirming that printing parameters must be considered when interpreting the performance of an additively manufactured restoration [2,3,5].

The CROWNTEC specimen was manufactured using a validated 50-µm layer thickness and post-polymerization protocol. Even under controlled conditions, however, a single printed crown cannot represent the variability associated with different resin batches, nesting positions, printing cycles, support configurations, or finishing operators. Similarly, a single milled crown cannot represent variations associated with PMMA batches, bur condition, tool replacement, or milling sequence. Independently manufactured specimens and multiple balanced production batches would therefore be required in a confirmatory comparison [1–3].

The largest simulated difference was identified in the occlusal photographs. This observation is plausible because the occlusal surface contains multiple cusps, fossae, ridges, and fissures that may reveal differences in manufacturing resolution and finishing. In contrast, buccal and lingual surfaces contain broader and smoother anatomical transitions, which may reduce visible differences between workflows. Nevertheless, photographic detail is influenced by focus, magnification, illumination, polarization, exposure, and image processing; therefore, image-acquisition conditions must remain identical for all specimens [6].

Cross-polarized photography reduced specular reflections and facilitated visualization of diffuse surface details. This approach may improve the consistency of image-based assessments, but it also modifies the way the restoration is normally perceived under clinical lighting. Specular reflections contribute to the visual perception of surface curvature and gloss, and their suppression may emphasize texture differences that are less apparent under conventional illumination. Future investigations should therefore consider acquiring both polarized and non-polarized image sets and analyzing them separately [6].

Human ratings and computer-assisted descriptors showed a similar descriptive direction in the simulated dataset. However, image-analysis measurements such as Laplacian variance, gradient magnitude, luminance variation, and mirrored shape agreement quantify selected properties of the digital image rather than aesthetics or clinical performance. A similar ranking between human and computer-assisted assessments does not establish agreement, validity, or clinical usefulness. Software-generated outputs should not be described as validated artificial intelligence unless the underlying model, training data, reference standard, and external validation process are transparently documented [7,8].

The visual rating panel included dentistry and dental technology students. This composition was suitable for exploring the feasibility of the questionnaire, but professional training may influence the perception of anatomical detail, surface quality, and acceptability. Dental technicians may focus more strongly on morphology and finishing, whereas dental students may apply broader clinical criteria. A future study should include balanced groups of dental technicians, general dentists, prosthodontists, students, and, when relevant, patients. Inter-rater and intra-rater reliability should also be assessed using a prespecified coefficient appropriate for the measurement scale and study design [9].

The term "photograph-based clinical acceptability" was deliberately used because the evaluated images could not provide information regarding marginal adaptation, internal fit, proximal or occlusal contacts, mechanical strength, wear, residual monomer, color stability, or biological behavior. Although the simulated milled specimen received higher acceptability ratings, this finding cannot establish superior clinical performance. Evidence concerning CAD/CAM restorations indicates that adaptation and performance depend on both the manufacturing system and restorative material, and visual appearance should therefore be interpreted as only one component of restoration assessment [4].

The principal strength of the pilot design was the use of the same STL geometry, reference model, photographic conditions, rating domains, and image-processing parameters for both specimens. Randomized coding and blinded presentation reduced the potential influence of manufacturing labels and participant expectations. The combined use of human ratings and transparent image descriptors also provided a structured framework that could be applied in a larger replicated experiment [6–8].

The study has substantial limitations. Only one crown represented each manufacturing workflow, preventing estimation of specimen-level variability and precluding inferential comparison between manufacturing methods. The simulated ratings cannot demonstrate the reproducibility of the observed direction, and technical repetitions cannot compensate for the absence of independently manufactured crowns. Additional limitations include the use of a single tooth design, material shade, machine, resin, milling blank, finishing protocol, and photographic system. The two-dimensional images also provide an incomplete representation of three-dimensional surface morphology [1–3].

A future confirmatory investigation should include an a priori sample-size calculation, independently manufactured crowns, multiple printing and milling batches, randomized manufacturing order, standardized finishing, and blinded image assessment. Reliability should be evaluated by repeating a subset of images after a washout period. Crown- and evaluator-level clustering should be addressed using an appropriate mixed-effects model, with overall visual appearance defined as the primary outcome and secondary outcomes interpreted with consideration of multiplicity [9].

Within the limitations of the simulated pilot design, the findings illustrate how a standardized photographic protocol could identify visual differences between an individual milled PMMA crown and an individual DLP-printed resin crown. The simulated preference for the milled specimen should be regarded exclusively as hypothesis-generating. It does not demonstrate the superiority of milling and cannot be generalized beyond the two modeled specimens and the selected experimental conditions [1–4].

CONCLUSIONS

Within the limitations of this simulated exploratory pilot study, standardized photographic assessment identified descriptive visual differences between an individual milled PMMA crown and an individual DLP-printed CROWNTEC crown. The milled specimen received more favorable simulated ratings for overall visual appearance, naturalness, morphological-detail definition, surface uniformity, and photograph-based clinical acceptability. Computer-assisted image descriptors showed a similar direction, indicating greater edge definition and lower surface-texture non-uniformity for the milled specimen.

These findings do not demonstrate the superiority of subtractive manufacturing because only one crown represented each workflow. Repeated photographs and evaluator ratings cannot replace independently manufactured specimens or estimate manufacturing variability. Moreover, photographic assessment cannot determine marginal and internal adaptation, occlusal accuracy, mechanical performance, biological safety, or long-term clinical behavior.

The proposed photographic and evaluation protocol may provide a reproducible framework for a future confirmatory study. Further research should include an adequately calculated sample size, independently manufactured crowns, multiple production batches, randomized and blinded assessment, evaluator-reliability analysis, and statistical models accounting for repeated ratings. The present simulated findings should therefore be interpreted exclusively as an educational example and as hypothesis-generating rather than clinically confirmatory evidence.

Conflicts of Interest

The authors declare no conflicts of interest.

REFERENCES

[1] Jain S, Al-Zordk W, Pande P, et al. Physical and mechanical properties of 3D-printed provisional crowns and fixed dental prosthesis resins compared with CAD/CAM milled and conventional provisional resins: a systematic review and meta-analysis. Polymers (Basel). 2022;14(13):2691.
[2] Alzahrani SJ, Almutairi RM, Alqahtani F, et al. Mechanical properties of three-dimensional printed provisional resin materials for crown and fixed dental prosthesis: a systematic review. Bioengineering (Basel). 2023;10(6):663.
[3] Al-Dulaijan YA, AlQahtani AS, Almutairi RM, et al. Internal and marginal fits of 3D-printed provisional restorations: a critical review. J Prosthet Dent. 2024;131(2):225-233.
[4] Refaie A, Alageel O, Alshehri S, et al. Trueness and precision of DLP-printed single crowns as affected by build angle. J Dent. 2024;141:104834.
[5] Metin DS, Külünk T, Aladağ Lİ, et al. Accuracy of the intaglio surface of 3D-printed hybrid resin-based restorations and influence of build angle. J Dent. 2024;140:104806.
[6] Revilla-León M, Özcan M. Additive manufacturing technologies used for processing polymers: current status and potential application in prosthetic dentistry. J Prosthodont. 2019;28(2):146-158.
[7] Ahmad I. Digital dental photography: a contemporary clinical update. Br Dent J. 2022;233(8):663-668.

[8] Schwendicke F, Samek W, Krois J. Artificial intelligence in dentistry: chances and challenges. J Dent Res. 2020;99(7):769-774.
[9] Lee JH, Kim DH, Jeong SN, Choi SH. Detection and diagnosis of dental caries using a deep learning-based convolutional neural network algorithm. J Dent. 2018;77:106-111.
[10] Revilla-León M, Gómez-Polo M, Vyas S, Barmak AB, Özcan M, Att W, Krishnamurthy VR. Artificial intelligence applications in restorative dentistry: a systematic review. J Prosthet Dent. 2022;128(5):867-875.
[11] Tabatabaian F, Vora SR, Mirabbasi S. Applications, functions, and accuracy of artificial intelligence in restorative dentistry: a literature review. J Esthet Restor Dent. 2023;35(6):842-859.
[12] Papadiochou S, Pissiotis AL. Marginal adaptation and CAD-CAM technology: a systematic review of restorative material and fabrication techniques. J Prosthet Dent. 2018;119(4):545-551.
[13] Güth JF, Edelhoff D, Schweiger J, Keul C. A new method for the evaluation of the accuracy of full-arch digital impressions in vitro. Clin Oral Investig. 2016;20(7):1487-1494.
[14] Mangano FG, Admakin O, Bonacina M, Lerner H, Rutkunas V, Mangano C. Trueness of 12 intraoral scanners in the full-arch implant impression: a comparative in vitro study. BMC Oral Health. 2020;20:263.
[15] Schlenz MA, Vogler J, Schmidt A, et al. Digital dentistry—quality of CAD/CAM crowns: an overview of systematic reviews. Clin Oral Investig. 2023;27(2):787-802.
[16] Zimmermann M, Ender A, Mehl A. Local accuracy of actual intraoral scanning systems for single-tooth preparations in vitro. J Am Dent Assoc. 2020;151(2):127-135.
[17] Bernauer SA, Müller J, Zitzmann NU, Joda T. The complete digital workflow in fixed prosthodontics updated: a systematic review. Healthcare (Basel). 2023;11(5):679.
[18] Bland JM, Altman DG. Statistical methods for assessing agreement between two methods of clinical measurement. Lancet. 1986;1(8476):307-310.
[19] Koo TK, Li MY. A guideline of selecting and reporting intraclass correlation coefficients for reliability research. J Chiropr Med. 2016;15(2):155-163.
[20] World Medical Association. World Medical Association Declaration of Helsinki: ethical principles for medical research involving human subjects. JAMA. 2013;310(20):2191-2194.