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ORIGINAL ARTICLE

Comparative Evaluation of Trueness and Precision of PMMA Three-Unit Bridges Fabricated Using Three Milling Devices

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Abstract

Aim This in vitro study aimed to evaluate the trueness and precision of three-unit bridge restorations fabricated using different milling devices.

Material and method A dental model prepared for bridge restorations in the right first premolar and first molar was scanned using a laboratory scanner (inEos X5, Dentsply Sirona). The data were imported into dental design software (DentalCAD 3.1 Rijeka; exocad GmbH) to create a bridge restoration design, saved as a reference (R-STL). Ten bridges were milled from polymethylmethacrylate blocks (Telio CAD LT A2 B55, Ivoclar Vivadent, Liechtenstein) using three milling devices: Cerec MC XL (C-STL), Cerec Primemill (P-STL), and inLab MC X5 (X-STL). The restorations were rescanned with an intraoral scanner (Cerec Primescan, Dentsply Sirona), and the datasets were analyzed using a 3D analysis program (Geomagic Control X v.2020.1, 3D Systems, NC, USA). Statistical analyses included one-way ANOVA, post hoc Tukey tests, and the Shapiro-Wilk test ($\alpha = 0.05$).

Results Significant differences in trueness were observed among the groups ($p < 0.001$), with the inLab MC X5 device (X-STL, RMS = 32 µm) showing the highest trueness and the Cerec MC XL group (C-STL, RMS = 44 µm) the lowest. No significant differences in precision were found ($p = 0.117$).

Conclusion The choice of milling device significantly affects the trueness of three-unit bridge restorations, with the inLab MC X5 device producing the most accurate results. However, precision did not differ significantly among the devices.

Keywords Milling devices, Polymethylmethacrylate, Precision, Three-unit bridge, Trueness

Introduction

The advent of computer-aided design/computer-aided manufacturing (CAD/CAM) technology has revolutionized restorative dentistry by improving the accuracy, efficiency, and reproducibility of dental prostheses (1,2). In contrast to conventional techniques, CAD/CAM systems allow for digital design and production of restorations, eliminating many manual steps and reducing potential errors (3). This digital workflow presents opportunities and challenges, particularly when evaluating the milling device performance (4).

In CAD/CAM workflows, milling accuracy is a critical determinant of the clinical success of the restorations. Two parameters, trueness and precision, are commonly used to evaluate milling quality. Trueness reflects how closely a milled object matches its original digital design, whereas precision indicates the consistency of repeated measurements or processes (5). Both factors directly affect the fit of restorations, which influences longevity, marginal integrity, and patient satisfaction (6). For instance, a poorly fitted restoration may lead to plaque accumulation, secondary caries, or marginal discoloration, compromising the long-term success of the prosthesis (4,7).

Polymethyl methacrylate (PMMA) is widely used in dental applications because of its biocompatibility, machinability, and aesthetic properties. It is frequently employed in temporary restorations and serves as a test material for evaluating milling systems. The relatively low hardness of the material makes it ideal for testing the capabilities of different milling strategies and devices under controlled conditions (8,9).

The performance of milling devices depends on several factors including the number of axes, spindle control, tool geometry, and milling strategies (10). Variations in the design of milling machines and implementation of distinct machining methodologies may significantly affect the outcomes of the milling process (11). In dental practice, three- or four-axis milling machines are predominantly employed, whereas in dedicated milling centres, five-axis machines are more frequently utilized. The prevalent machining methodology is the Z-level strategy, in which the restoration is machined based on two-dimensional curves analogous to contour lines (4,11).

This study aims to compare the trueness and precision of three milling devices, focusing on the fabrication of three-unit PMMA bridges. The hypothesis was that there would be no significant differences in the trueness and precision of the three milling devices.

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Material and Methods

Design of study

This in vitro study aimed to assess the trueness and precision of three-unit polymethylmethacrylate (PMMA) bridges fabricated using three distinct CAD/CAM milling systems: Cerec MC XL, Cerec Primemill, and inLab MC X5. The study adhered to the guidelines set forth in ISO 12836:2015 (12), which establish the accuracy criteria for digitizing devices utilized in dentistry. Thirty specimens were fabricated, with each milling system producing 10 bridges (n = 10 per group). Ethics committee approval was not required for this study as it was conducted in vitro using only CAD/CAM-fabricated PMMA specimens.

Digital Design and Specimen Preparation

A master dental model prepared for a three-unit bridge restoration involving the right first premolar and first molar served as the basis of this study. The reference model was digitized using a high-precision laboratory scanner (inEos X5; Dentsply Sirona). The bridge restoration was then virtually designed with dedicated dental CAD software (DentalCAD 3.1 Rijeka; Exocad GmbH), and the finalized design was saved as the reference standard STL file (R-STL).

Using the R-STL data, three-unit PMMA bridges were fabricated from prefabricated PMMA blocks (Telio CAD LT A2 B55; Ivoclar Vivadent) using three different milling systems. The resulting STL files were classified according to their respective milling devices: Cerec MC XL (C-STL), Cerec Primemill (P-STL), and inLab MC X5 (X-STL). All milling procedures were performed in accordance with the manufacturer's recommendations to ensure standardization. The milling systems employed in this study differed in their technological configurations and operational parameters (Table 1).

Table 1: Milling Devices

Milling System	Type	Spindle Speed (RPM)	Bur Type	Cooling System
Cerec MC XL	4-axis chairside milling system	20000	Dual cutting burs designed for milling ceramics, and hybrid materials PMMA	Air-based cooling system to prevent overheating
Cerec Primemill	Upgraded 4-axis milling system	22000	Enhanced diamond burs with optimized cutting edges for precision	Integrated liquid cooling to maintain material integrity
inLab MC X5	5-axis laboratory milling system	25000	Multi-directional cutting burs capable of milling complex geometries	Advanced liquid cooling system with continuous temperature monitoring

Following milling, each bridge was subjected to digital scanning using an intraoral scanner (Cerec Primescan, Dentsply Sirona). To ensure optimal data acquisition and minimize the influence of extrinsic variables, scanning was performed in an environment that was specifically controlled to eliminate dust and mechanical vibrations. The scanning protocol involved capturing multiple perspectives to generate high-resolution three-dimensional (3D) models, which were subsequently exported as STL files.

The obtained STL files were imported into a dedicated metrology software (Geomagic Control X; version 2020.1, 3D Systems, NC, USA) for accuracy assessment. The trueness and precision of the fabricated restorations were evaluated through a comparative analysis of the scanned STL data and the original reference STL model (R-STL).

Trueness was evaluated by calculating the root-mean-square (RMS) deviation between the scanned STL file of each fabricated bridge and the original reference STL (R-STL). This approach provides a quantitative assessment of the overall accuracy of milled restorations relative to their digital design. Each sample was analyzed at more than 50,000 data points to ensure a comprehensive evaluation, and the mean RMS deviation (µm) across the entire surface was recorded. The precision was assessed by determining the standard deviation of the RMS deviations within each milling group, reflecting the consistency of the milling process. Lower standard deviation values indicate greater reproducibility of the milling outcome.

Statistical Analysis

All measurements were statistically analyzed to determine significant differences among the three milling systems. Data distribution was assessed using the Shapiro–Wilk test to verify normality. One-way analysis of variance (One-Way ANOVA) was performed to identify overall differences between groups, followed by Tukey's post hoc test for pairwise comparisons, with the level of statistical significance set at $\alpha = 0.05$. Statistical analyses were conducted using SPSS Version 28.0 (IBM Corp., Armonk, NY, USA).

Results

The trueness of the fabricated PMMA bridges was assessed by evaluating the RMS deviation between the scanned STL models and reference STL file (R-STL). One-way ANOVA revealed significant differences between the three milling devices ($F = 29.345$, $p < 0.001$).

Among the three milling systems, inLab MC X5 demonstrated the highest trueness with an average RMS deviation of 32 ± 2.5 µm. Cerec Primemill exhibited moderate trueness, with an RMS deviation of 38 ± 2.8 µm. In contrast, Cerec MC XL showed the lowest trueness, with an RMS deviation of 44 ± 3.0 µm (Table 2). Post-hoc Tukey analysis confirmed that the inLab MC X5 group differed significantly from the other two groups ($p < 0.001$). Furthermore, a statistically significant difference was observed between Cerec Primemill and Cerec MC XL ($p = 0.017$) (Figure 1). Precision was evaluated by analysing the consistency of the RMS deviations within each group. One-way ANOVA indicated no statistically significant differences in precision between the three devices ($F = 2.146$, $p = 0.117$) (Figure 2). The inLab MC X5 exhibited the highest consistency, with a standard deviation of 2.5 µm. Cerec Primemill achieved similar precision, with a standard deviation of ±2.8 µm, whereas Cerec MC XL displayed the lowest consistency, with a standard deviation of 3.0 µm (Table 2).

Table 2: Comparison of Trueness and Precision Among Different Milling Systems

Milling System	n	Trueness (Mean ± SD, µm)	95% CI (Trueness	Range (Median)	p-value (Trueness)	Precision (Mean ± SD, µm)	95% CI (Precision)	Range (Median)	p-value (Precision)
inLab MC X5	10	32 ± 2.5	[29.5, 34.5]	27 – 39 (32)	<0.001**	2.5 ± 0.8	[1.8, 3.2]	1.8 – 3.5 (2.5)	0.017*
Cerec Primemill	10	38 ± 2.8	[35.0, 41.0]	35 – 42 (38)	–	2.8 ± 0.9	[2.0, 3.6]	2.0 – 4.0 (2.8)	–
Cerec MC XL	10	44 ± 3.0	[40.5, 47.5]	37 – 49 (44)	–	3.0 ± 1.0	[2.2, 3.8]	2.2 – 4.2 (3.0)	–
p-value	–	–	–	–	<0.001**	–	–	–	0.017*

*ANOVA Test *p<0,05 **p<0,01*

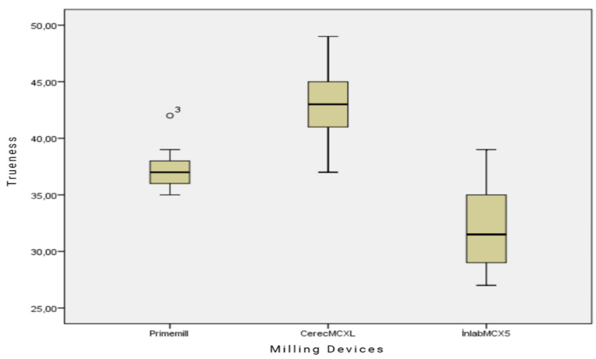

Figure 1: Box Plot Representation of Trueness Values for Different Milling Devices

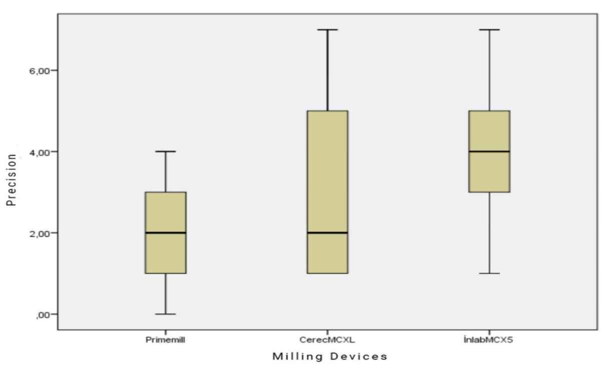

Figure 2: Box Plot Representation of Precision Values for Different Milling Devices

Discussion

This study evaluated the trueness and precision of three different CAD/CAM milling systems for the fabrication of three-unit PMMA bridges. The trueness exhibited significant differences among the milling systems (p <0.001), indicating that the accuracy of the fabricated restorations varied depending on the milling device used. In contrast, the precision analysis revealed minimal differences among the milling systems (p = 0.117), suggesting that all devices produced consistent results across multiple fabrications. Therefore, the null hypothesis was rejected for the trueness analysis but partially accepted for the precision analysis.

The use of digital workflow in the fabrication of provisional restorations has significantly enhanced manufacturing efficiency and improved clinical outcomes, particularly in terms of marginal adaptation and mechanical strength (13,14). One of the primary functions of a provisional bridge is to maintain proper occlusal function and tooth stability until definitive restoration is achieved (15). An optimally fabricated provisional bridge also plays a key role in preventing postoperative complications such as hypersensitivity, pain, and abutment mobility or migration (16,17). In this regard, CAD/CAM technology has become a widely adopted approach, owing to its precision and reproducibility. Subtractive manufacturing, which is the most commonly used CAD/CAM technique, relies on milling machines equipped with power-driven tools that mechanically shape material blocks into the desired geometry under computer-controlled conditions (18,19). Various materials are used for interim prostheses, with polymethylmethacrylate (PMMA) being one of the most established options owing to its high strength, colour stability, and ease of repair (20). In the present study, a PMMA-based provisional material was used to fabricate three-unit bridges, allowing for a standardized evaluation of milling accuracy among different CAM systems.

Among the three milling systems evaluated, Cerec MC XL and Cerec Primemill are both 4-axis chairside milling systems, with Primemill offering enhanced accuracy, whereas InLab MC X5 is a 5-axis laboratory milling system designed for high-accuracy restorations, allowing for greater flexibility in milling complex geometries. 5-axis milling units seem to result in better-adapted restorations compared with 3-axis (21,22) and 4-axis units (4,6,23). The design of 5-axis milling machines, which can move in the X, Y, and Z directions and rotate around two axes, typically the A-axis and C-axis, enables milling complex contoured surfaces and intricate geometries without repositioning the workpiece (3). Only one study reported better marginal integrity and smaller gaps for a 3-axis than for a 5-axis machine (24). Therefore, a milling unit with an additional axis achieves better angles, more effective and accurate processing, and better surface topography and finishing, particularly for multiunit restorations (4,6,21,25).

Trueness is a critical parameter for ensuring the proper fit of restorations, particularly in areas such as margins and occlusal surfaces. Poor trueness can result in overmilling or undermilling, leading to marginal gaps that compromise the long-term success of restoration. Marginal gaps facilitate plaque accumulation and increase the risk of secondary caries, gingival inflammation, and prosthetic failure (26). In this study, inLab MC X5 consistently produced bridges with minimal deviations, making it particularly suitable for complex restorative cases requiring high accuracy.

Studies comparing 3-, 4-, and 5-axis milling machines in the same context are lacking, making it impossible to rank the efficiency of the machines however, the inLab MC X5 showed superior trueness. All three systems demonstrated consistent precision, as indicated by the lack of significant differences in standard deviations across groups. This suggests that under standardized conditions, even 4-axis systems such as Cerec MC XL and Primemill can achieve reliable repeatability in milling results. Nonetheless, the limitations of 4-axis systems in accurately reproducing intricate features, particularly undercuts and marginal details, were evident in the trueness analysis (10, 22).

Moreover, the precision reflects the consistency of the milling process. While precision has a less direct impact on clinical fit compared to trueness, high precision ensures predictable outcomes and reduces variability in restorations produced by the same system (22). The comparable precision observed across all devices in this study underscores the reliability of modern CAD/CAM technologies in maintaining a consistent milling quality, even across different hardware configurations. For clinicians, the choice of milling system should be guided by the specific requirements of the restorative task. The inLab MC X5 is recommended for laboratory-based workflows and complex cases that require high trueness, such as full-arch restorations or prostheses with intricate features. Chairside systems such as Cerec MC XL and Primemill, while providing slightly less accuracy, offer sufficient precision for simpler restorations and convenience in same-day dentistry. Balancing accuracy, efficiency, and cost-effectiveness is key to optimizing patient care.

This study has several limitations. First, research was carried out in a controlled in vitro setting, which does not fully duplicate the complex intraoral environment, where occlusal forces, salivary exposure, and patient-specific anatomical variances can all impact on the long-term accuracy and longevity of dental restorations. Additionally, the study focused solely on PMMA discs, a material commonly used for temporary restorations; however, its mechanical properties differ significantly from definitive materials like zirconia and lithium disilicate. Another limitation is that the study utilized a standardized scanning protocol and a limited number of milling devices with different axis configurations. Variability introduced by different intraoral or laboratory scanners, scanning strategies, operator skills, and software settings was not assessed, which may impact clinical outcomes. Finally, the study employed a single Z-level milling strategy, whereas alternative strategies such as spiral, adaptive, or zigzag milling may yield different accuracy and surface characteristics.

To address these limitations, future research should focus on assessing milling accuracy under clinical loading settings, taking into account occlusal forces and salivary exposure. Expanding the range of restorative materials, including zirconia, lithium disilicate, and hybrid ceramics, would provide a broader understanding of milling system performance across different substrates. Additionally, further research should investigate the impact of various scanning devices, scanner types (intraoral vs. laboratory), scanning strategies on the trueness and precision of milled restorations. Another significant field for future research is comparing different milling processes, such as spiral, adaptive, and zigzag milling, to enhance digital workflows for a variety of clinical applications. Moreover, including a broader range of milling devices with different axis configurations (three-, four-, and five-axis systems) would help determine the influence of machine configuration on milling accuracy and efficiency. Finally, long-term clinical studies are needed to evaluate restoration survival rates, marginal adaptation, and patient satisfaction, ensuring that the findings of in vitro analyses translate effectively into real-world clinical applications.

Conclusion

Within the limitations of this in vitro study, restorations fabricated using the 5-axis milling system (inLab MC X5) demonstrated the highest trueness, achieving greater dimensional accuracy in reproducing complex geometries. In contrast, the 4-axis milling units (Cerec MC XL and Cerec Primemill) exhibited lower trueness, with Cerec MC XL showing the least accuracy. However, no significant differences were observed in the precision among the three systems, indicating consistent reproducibility across multiple fabrications. The findings suggest that the increased range of motion in 5-axis systems enhances milling accuracy, making them more suitable for cases requiring high precision, while 4-axis systems remain a viable option for less complex restorations where efficiency and chairside convenience are prioritized.

Declarations

Ethics Committee Approval: *Since this study did not involve the use of any live animals or human-derived materials, ethical approval was not required.*

Informed Consent: *Since no human-derived materials were used in this study, informed consent was not required.*

Peer Review: *Externally peer-reviewed.*

Author Contributions: *Conception/Design of Study- M.D.; Data Acquisition- M.D.; Data Analysis/Interpretation- G.D.; Drafting Manuscript- G.D.; Critical Revision of Manuscript- M.D.; Final Approval and Accountability- G.D.; Material and Technical Support- M.D.; Supervision- M.D.*

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