



Time Efficiency and Accuracy of Digital Versus Conventional Workflows for Fabrication of Single-Unit Crowns: An In Vitro Comparative Study

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Abstract

Background: Digital dentistry has transformed restorative workflows through the introduction of intraoral scanning and CAD–CAM fabrication systems. Although these technologies are promoted for improved efficiency and accuracy, conventional impression and laboratory techniques remain widely used for single-unit crown fabrication. Objective comparison of these two workflows is essential for evidence-based clinical decision-making.

Aim: To compare the time efficiency and accuracy of digital and conventional workflows used in the fabrication of single-unit crowns.

Materials and Methods: Thirty standardized prepared typodont teeth were used to fabricate full-coverage crowns using two different workflows ($n = 15$ per group): Group I—digital workflow involving intraoral scanning, virtual design, and CAD–CAM milling; and Group II—conventional workflow using elastomeric impressions, stone dies, and laboratory-fabricated crowns. Total fabrication time was recorded for each step, including impression or scanning, design or waxing, and final crown production. Accuracy was evaluated by measuring marginal gap and internal adaptation at predetermined reference points using a stereomicroscope or digital measurement software. Data were analyzed using independent sample t -tests, with the level of significance set at $p < 0.05$.

Results: The digital workflow demonstrated significantly reduced total fabrication time compared with the conventional technique ($p < 0.05$). Crowns produced through the digital method also exhibited significantly smaller marginal and internal gaps, indicating superior accuracy.

Conclusion: Digital workflows for single-unit crown fabrication were found to be more time-efficient and accurate than conventional laboratory techniques under standardized in-vitro conditions. These findings suggest that CAD–CAM-based systems may enhance clinical productivity and restoration precision; however, further long-term clinical studies are recommended to validate these laboratory results.

Keywords: Digital dentistry, CAD–CAM, Single-unit crowns

Introduction

The fabrication of indirect restorations such as single-unit crowns remains a cornerstone of contemporary prosthodontic practice.¹ The long-term success of these restorations depends on multiple factors, including marginal accuracy, internal adaptation, mechanical durability, and esthetic integration. Among these, precision of fit is particularly critical, as inadequate marginal adaptation can result in cement dissolution, microleakage, plaque accumulation, postoperative sensitivity, secondary caries, and periodontal inflammation, ultimately compromising restoration longevity.^{2,3}

For decades, conventional workflows involving elastomeric impressions, stone cast fabrication, manual waxing, investing, casting, and porcelain veneering have served as the standard approach for crown fabrication. Although these techniques are well documented and clinically reliable, each procedural step introduces potential sources of error such as impression distortion, expansion of gypsum products, and inaccuracies during waxing or casting. In addition, conventional methods are often time-consuming, require multiple laboratory stages, and are highly dependent on operator skill, which may influence both efficiency and reproducibility.^{4,5}

Advances in digital dentistry have led to the rapid adoption of computer-aided design and computer-aided manufacturing (CAD–CAM) systems, fundamentally altering restorative workflows. Digital approaches typically involve intraoral scanning to capture three-dimensional representations of prepared teeth, virtual design of restorations using specialized software, and automated milling or three-dimensional printing of crowns from prefabricated ceramic or resin blocks. These technologies are promoted for their ability to streamline clinical and laboratory procedures, reduce material waste, enhance communication between clinicians and technicians, and improve consistency of restoration fabrication.⁶⁻⁸

Several investigations have examined the marginal adaptation and internal fit of digitally fabricated crowns, often reporting results comparable to or superior to those obtained with conventional techniques.⁹ Similarly, digital systems are frequently advocated for their potential to shorten chairside and laboratory time. However, the existing literature reveals considerable variation in reported outcomes, likely attributable to differences in scanner technology, design software parameters, milling strategies, restorative materials, cement space settings, and measurement methodologies. Furthermore, while many studies focus primarily on fit or mechanical properties, fewer have comprehensively assessed both time efficiency and accuracy within the same experimental framework.⁸⁻¹⁰

Given the growing clinical reliance on digital workflows and the continued widespread use of conventional techniques, a direct comparison of these two fabrication approaches is clinically relevant. Understanding whether digital systems truly offer measurable advantages in production time and restoration accuracy is

essential for guiding evidence-based decision-making, particularly in settings where equipment cost, laboratory infrastructure, and clinical workload must be carefully balanced.

Therefore, the present in vitro study was designed to compare the time efficiency and accuracy of digital and conventional workflows employed for the fabrication of single-unit crowns under standardized laboratory conditions. By simultaneously evaluating fabrication time and marginal and internal adaptation, this investigation aims to provide meaningful data to assist clinicians in selecting the most appropriate workflow for routine crown fabrication.

Materials and Methods:

Study Design: This in vitro experimental study was conducted to compare the time efficiency and accuracy of digital and conventional workflows used for the fabrication of single-unit full-coverage crowns under standardized laboratory conditions.

Sample Size and Group Allocation: Thirty identical maxillary first molar resin typodont teeth were selected to ensure uniformity in size and morphology. The samples were randomly assigned into two groups (n = 15 each):

- Group I (Digital Workflow): Crowns fabricated using intraoral scanning, computer-aided design, and CAD–CAM milling.
- Group II (Conventional Workflow): Crowns fabricated using elastomeric impressions, stone dies, and traditional laboratory techniques.

Tooth Mounting: Each typodont tooth was vertically embedded in autopolymerizing acrylic resin blocks using a dental surveyor, ensuring that the cemento-enamel junction was positioned approximately 2 mm above the resin surface to simulate clinical crown exposure and maintain consistent orientation during all procedures.

Tooth Preparation: All teeth were prepared by a single operator using standardized preparation guidelines and high-speed rotary instruments under water coolant. A milling surveyor was employed to maintain consistent taper and axial alignment.

The preparation parameters were as follows:

- Occlusal reduction: 2.0 mm
- Axial reduction: 1.5 mm
- Finish line: 1.0-mm circumferential chamfer
- Total occlusal convergence: approximately 6°

All internal line angles were rounded. Preparations were verified under magnification to confirm uniformity.

Workflow Procedures

Digital Workflow (Group I): Prepared teeth were scanned using an intraoral scanner to obtain three-dimensional digital impressions. Crowns were virtually designed using CAD software with standardized

cement-space parameters (50 μ m beginning 1 mm above the finish line).

The restorations were milled from partially sintered zirconia blocks using a five-axis milling unit and subsequently sintered in a high-temperature furnace according to the manufacturer's recommendations. Final finishing and glazing were performed prior to evaluation.

Conventional Workflow (Group II): Conventional impressions were made using addition silicone elastomeric impression material in custom trays. Type IV dental stone was poured to fabricate working casts, which were sectioned to obtain individual dies.

Wax patterns were produced with uniform coping thickness (0.5 mm), invested, and cast using a base-metal alloy. After finishing and airborne-particle abrasion, porcelain veneering was carried out using the incremental build-up technique and fired in a ceramic furnace. Final glazing was performed following occlusal adjustment.

Measurement of Time Efficiency: For each specimen, the time required for every fabrication step was recorded using a digital stopwatch by a single calibrated examiner.

Recorded components included:

- Impression or scanning time
- Design or waxing time
- Milling or casting time
- Veneering and finishing time
- Total fabrication time

Only active working time was included; machine-running or sintering time was excluded to minimize operator-dependent variability.

Cementation Procedure: Prior to cementation, all crowns were ultrasonically cleaned in distilled water for five minutes and air-dried. The prepared teeth were rinsed and gently dried.

Crowns were cemented using resin-modified glass ionomer cement mixed according to the manufacturer's instructions. A standardized vertical seating load of 5 kg was applied for five minutes using a loading device. Excess cement was removed, and specimens were stored in distilled water at 37°C for 24 hours before accuracy assessment.

Evaluation of Accuracy: Accuracy was assessed by measuring marginal gap and internal adaptation using a stereomicroscope at 40 \times magnification.

Each specimen was positioned on a custom jig to maintain consistent orientation. Measurements were taken at four predetermined reference points:

- Buccal
 - Lingual
 - Mesial
-

- Distal

Three readings were recorded at each site, and the mean value was calculated for each crown. All measurements were expressed in micrometers (μm) and obtained by a single blinded examiner.

Statistical Analysis: Collected data were tabulated and analyzed using statistical software. Normality of distribution was assessed using the Shapiro–Wilk test. Intergroup comparisons for time efficiency and marginal and internal gap values were performed using independent sample t-tests. The level of statistical significance was set at $p < 0.05$.

Result: The digital workflow demonstrated significantly shorter total fabrication time than the conventional technique ($p < 0.001$), with reduced time required for impression acquisition, design or waxing, milling or casting, and veneering and finishing. (Table 1)

Crowns fabricated using the digital approach exhibited significantly smaller marginal gaps at all evaluated surfaces and lower overall internal discrepancies compared with conventionally produced crowns ($p < 0.001$). (Table 2)

Overall, both efficiency and accuracy outcomes favored the digital workflow, indicating that CAD–CAM–based fabrication of single-unit crowns is faster and more precise than traditional laboratory methods under standardized in-vitro conditions. (Table 3)

Parameter	Digital Workflow (Mean \pm SD)	Conventional Workflow (Mean \pm SD)	p-value
Impression / Scanning	4.8 \pm 0.9	10.6 \pm 1.4	<0.001*
Designing / Waxing	9.5 \pm 1.8	18.3 \pm 2.6	<0.001*
Milling / Casting	21.4 \pm 3.2	28.9 \pm 3.8	0.002*
Veneering & Finishing	12.6 \pm 2.1	19.8 \pm 2.9	<0.001*
Total Fabrication Time	48.3 \pm 5.7	77.6 \pm 6.9	<0.001*

*Statistically significant ($p < 0.05$)

Parameter	Digital Workflow (Mean \pm SD)	Conventional Workflow (Mean \pm SD)	p-value
Buccal Marginal Gap	61.8 \pm 7.4	89.5 \pm 9.6	<0.001*
Lingual Marginal Gap	64.2 \pm 8.1	92.3 \pm 10.1	<0.001*
Mesial Marginal Gap	59.6 \pm 6.9	87.2 \pm 9.0	<0.001*
Distal Marginal Gap	62.5 \pm 7.7	90.8 \pm 9.8	<0.001*
Overall Mean Marginal Gap	62.0 \pm 7.5	90.0 \pm 9.6	<0.001*
Internal Gap	87.4 \pm 10.3	123.6 \pm 12.9	<0.001*

*Statistically significant ($p < 0.05$)

Outcome Parameter	Better Performing Workflow	Statistical Significance
Total fabrication time	Digital	Significant
Marginal fit	Digital	Significant
Internal adaptation	Digital	Significant

Discussion

The present in vitro investigation compared the time efficiency and accuracy of digital and conventional workflows employed for fabrication of single-unit crowns. The findings demonstrated that the digital workflow significantly reduced total working time and produced restorations with superior marginal and internal adaptation when compared with traditional laboratory techniques. These results support the growing perception that CAD–CAM–based systems can enhance both productivity and precision in routine crown fabrication.¹²

Time efficiency is an increasingly important consideration in contemporary prosthodontic practice, where clinical workload, laboratory turnaround, and economic factors influence treatment planning. In the current study, digital scanning required significantly less time than conventional elastomeric impressions, likely because of elimination of tray selection, adhesive application, material mixing, and setting time. Similarly, virtual designing was faster than manual waxing, reflecting the streamlined nature of software-based workflows and the ability to modify restoration contours rapidly. Although milling and sintering remain machine-dependent processes, the overall operator-controlled working time was still substantially lower in the

digital group, confirming the practical efficiency of digital systems.¹³

The superior marginal and internal adaptation observed for digitally fabricated crowns may be attributed to the reduction in cumulative procedural inaccuracies.¹⁴ Conventional workflows involve multiple sequential steps—impression making, cast pouring, die trimming, waxing, investing, casting, and porcelain application—each of which may introduce dimensional changes.¹⁵ In contrast, digital impressions combined with computer-controlled milling provide a more direct and reproducible fabrication pathway. Standardized cement-space parameters incorporated during virtual design further contribute to consistent internal adaptation, which is critical for optimal seating and long-term clinical performance.¹⁶

The marginal gap values obtained for digitally fabricated crowns in this study were within the range generally considered clinically acceptable, while conventional crowns exhibited larger discrepancies, although still potentially serviceable. Improved marginal accuracy is clinically relevant because excessive gaps are associated with microleakage, cement dissolution, and periodontal inflammation. Likewise, reduced internal discrepancies may facilitate complete seating of the restoration and uniform stress distribution during function, thereby contributing to restoration longevity.

Although the present findings favor digital workflows, several limitations must be acknowledged. As an *in vitro* investigation, the study did not reproduce intraoral conditions such as saliva contamination, temperature fluctuations, occlusal fatigue, and long-term cement degradation. Furthermore, only one crown material and one scanner-milling system were evaluated, which may limit generalization to other commercially available systems. Machine-operating time was excluded from the efficiency analysis; inclusion of total turnaround time in future studies could provide additional clinically relevant information regarding laboratory logistics.

Future research should incorporate thermomechanical aging protocols, cyclic loading, and clinical trials to better simulate functional conditions and assess long-term outcomes. Comparative evaluation of different scanner technologies, CAD software parameters, manufacturing techniques, and restorative materials would further clarify the extent to which digital systems outperform conventional methods in various clinical scenarios.

Conclusion

Within the limitations of this *in vitro* study, digital workflows for fabrication of single-unit crowns demonstrated significantly greater time efficiency and superior marginal and internal adaptation compared with conventional laboratory techniques. The reduced fabrication time associated with intraoral scanning and virtual design, along with the improved accuracy of CAD–CAM–produced restorations, highlights the potential advantages of digital dentistry in routine clinical practice.

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