Internal Fit of Cobalt–Chromium Metal–Ceramic Crowns Fabricated by Conventional Casting and Selective Laser Sintering: An In Vitro Comparison of Three Measurement Techniques

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Abstract

1.Background/Objectives: *The purpose of this study was to compare the internal fit of cobalt-chromium metal-ceramic single crowns fabricated through conventional casting versus selective laser sintering (SLS), and to determinate the relative accuracy of three internal space measurement techniques.* ***2.Methods:*** *A standardized CAD design of a maxillary first molar was used to create two metal frameworks, one produced by was-pattern milling followed by casting and the other by SLS. Internal fit was assessed before and after ceramic firing using methods: differential micrometer measurements on frameworks with and without impression material, direct micrometer readings of detached silicons replicas, and digital microscopy of sectioned silicone specimens.* ***3.Results:*** *For the cast metal framework, mean internal gaps ranged from 0.08 to 0.09 mm with micrometer-based techniques and reached 0.1056 mm under digital microscopy. In contrast, the SLS framework showed larger discrepancies, with microscopic mean values up to 0.1806 mm and maximum occlusal gaps of 0.354 mm. After ceramic veneering, the cast crown maintained uniform internal fit (mean values of 0.08 mm with micrometers and 0.0784 mm with microscopy), whereas the SLS crown preserved higher variability and occlusal gaps up to 0.352 mm. Across all specimens, micrometer techniques yielded mean gaps of approximately 0.08–0.10 mm, while digital microscopy provided* *higher means of 0.1056–0.1806 mm, reflecting greater sensitivity to local irregularities.* ***4. Conclusions:*** *Within the limitation of the study, conventionally cast frameworks demonstrated a more favourable internal fit than SLS frameworks, and digital microscopy proved to be the most reliable method for evaluating internal adaptation in metal-ceramic crowns.*

Keywords: metal-ceramic crowns; internal fit; CAD/CAM, prosthodontics; selective laser sintering

INTRODUCTION

Metal–ceramic restorations remain a cornerstone of fixed prosthodontics due to their favourable combination of mechanical strength, versatility and long-term clinical performance [1-3]. Despite the increasing popularity of all-ceramic systems, metal–ceramic single crowns and fixed partial dentures continue to be widely prescribed, particularly in posterior regions where high masticatory loads require reliable frameworks [1-3]. In such clinical scenarios, the longevity of treatment is not determined solely by the intrinsic properties of the materials used, but also by how accurately the restoration reproduces the prepared tooth geometry. Among the multiple factors that influence success, the quality of the fit between the crown and the prepared abutment has been consistently identified as a key determinant of biological and mechanical outcomes.

Internal and marginal discrepancies may compromise the integrity of the luting cement, promote microleakage and plaque accumulation, and ultimately increase the risk of secondary caries, periodontal inflammation, loss of retention and biological or technical complications over time [5-7]. Even when restorations are fabricated from materials with excellent mechanical properties, an inadequate internal fit may produce unfavourable stress distributions within the cement layer and at the tooth–restoration interface, potentially predisposing to debonding, fracture or failure under functional loading [5-8]. Consequently, the assessment of internal fit has become an essential component in the evaluation of new restorative materials, manufacturing technologies and clinical protocols.

From a clinical perspective, internal fit is generally defined as the perpendicular distance between the internal surface of the restoration and the prepared tooth surface, measured at specific reference points. Optimal values should allow sufficient space for the luting agent to achieve complete seating and adequate flow, while avoiding excessive thicknesses that may weaken the cement layer or impair seating [5-8]. Previous investigations have suggested that internal gaps in the range of approximately 50–150 µm can be considered clinically acceptable, depending on the restorative material, cement type and loading conditions [5-8]. However, these thresholds are not absolute and may be influenced by the location of the discrepancy (axial versus occlusal), the type of finish line and the geometry of the preparation. Notably, many experimental studies report a wide variation of gap values for apparently similar restorative systems, reflecting not only differences in fabrication workflows but also substantial variation in measurement methodologies and evaluation criteria.

The evolution of computer-aided design and computer-aided manufacturing (CAD/CAM) has profoundly changed the traditional fabrication of fixed restorations. Subtractive milling of wax patterns or pre-sintered blocks and, more recently, additive manufacturing technologies such as selective laser sintering (SLS) and direct metal laser sintering (DMLS) have been introduced with the aim of reducing the technique sensitivity associated with manual wax-up and conventional casting [4,9-13]. These digitally driven workflows were developed to standardize production, minimize human error and improve the reproducibility of prosthetic frameworks. In particular, SLS technology allows the fabrication of cobalt–chromium (Co–Cr) frameworks directly from STL files, theoretically enabling a closer correspondence between the virtual design and the final metal infrastructure [4,9-13].

However, the translation of digital design into a physical restoration is influenced by a complex chain of events. In subtractive workflows, milling strategies, bur diameter, tool wear and material properties can all affect the dimensional accuracy of the wax pattern or pre-sintered framework [4,9-13]. In additive manufacturing, the layer-by-layer consolidation of metal powder, the characteristics of the alloy, build orientation, laser parameters and post-processing procedures (heat treatment, support removal, surface finishing) may introduce distortions and residual stresses, which can negatively influence marginal and internal adaptation [9-13,14-18]. As a result, the theoretical advantages of digital workflows do not automatically translate into superior internal fit in all clinical or laboratory situations.

The literature currently offers conflicting evidence regarding the comparative performance of additive and conventional fabrication techniques in terms of internal and marginal fit. Some in vitro and clinical studies suggest that SLS or DMLS frameworks may offer improved consistency and can achieve internal and marginal gaps within clinically acceptable ranges, comparable to or even better than those obtained with traditionally cast restorations [9-13]. Conversely, other investigations indicate that conventionally cast Co–Cr infrastructures still provide superior or more homogeneous internal adaptation, particularly in occlusal areas or in regions with complex preparation geometry [9-13,14-18]. These discrepancies may be explained, at least in part, by differences in study design (tooth type, preparation geometry, finish line configuration), scanner and software systems, alloy composition, cement space settings and the specific parameters used for additive manufacturing and post-processing [9-13,14-18]. As a consequence, direct comparison between studies is challenging, and clinicians receive mixed messages regarding which fabrication workflow offers more predictable internal fit in daily practice.

Methodological variability in the assessment of fit further complicates the interpretation of published data. A wide range of techniques has been used to evaluate marginal and internal adaptation, including direct sectioning of restorations and microscopic analysis, various adaptations of the replica technique, computed tomography and 3D digital evaluation [5-8,14-16]. Micrometer-based methods are relatively accessible, do not require sophisticated equipment and can be implemented in many laboratory settings; however, they are sensitive to operator handling, specimen positioning and potential elastic deformation of the silicone material used to reproduce the internal space [5-8]. Digital optical microscopy of sectioned replicas improves visualization and allows repeated measurements at standardized reference points, but it is more time-consuming and may yield higher gap values because of its greater sensitivity to local irregularities and minor surface defects [5-8,14-16]. The absence of a universally accepted gold standard, together with variations in replica thickness, sectioning protocols and calibration of measurement devices, can significantly influence the reported outcomes and contribute to apparent inconsistencies across studies.

In addition, internal fit may be affected not only by the framework fabrication process but also by the subsequent ceramic veneering procedures. Repeated firing cycles, differences in the coefficient of thermal expansion (CTE) between metal and ceramic, and residual stresses induced during cooling can all influence the final adaptation of the crown [14-18]. Some authors have reported minimal changes in internal and marginal gaps after veneering, while others have observed increased discrepancies in certain areas, especially at the occlusal surface [14-18]. Therefore, studies that assess internal fit both before and after ceramic firing provide more clinically relevant information than those restricted to framework analysis alone.

Given this complex background, there is a clear need for investigations that control the design and manufacturing variables as strictly as possible and, at the same time, systematically compare different measurement techniques within the same experimental setup. In particular, studies that derive both conventional and SLS frameworks from an identical CAD design, apply standardized cement space parameters, evaluate internal fit at predefined reference points and analyse changes induced by ceramic veneering can help clarify whether discrepancies arise primarily from the fabrication workflow, the veneering process or the evaluation method itself [9-18]. Such data are especially relevant for clinicians and dental technicians who must decide whether the transition to additive manufacturing technologies offers tangible benefits in terms of internal adaptation and long-term prosthetic performance.

Aim and objectives

The primary aim of this in vitro study was to evaluate and compare the internal fit of cobalt–chromium metal–ceramic crowns fabricated using two distinct production workflows, namely conventional casting based on a wax pattern and additive manufacturing through selective laser sintering (SLS). A further objective was to investigate the extent to which different internal space assessment protocols influence the recorded gap values and, consequently, the perceived accuracy and reliability of internal fit evaluation. By jointly analysing fabrication method and measurement technique, the study sought to generate more robust evidence regarding the internal adaptation of metal–ceramic crowns produced by conventional and additive technologies.

MATERIAL AND METHODS

This in vitro study evaluated the internal fit of two cobalt–chromium metal–ceramic single crowns fabricated using different production workflows: conventional casting and selective laser sintering (SLS). A maxillary first molar abutment (tooth 2.6) mounted on a mobilizable study model served as the substrate for all analyses.

This research was designed as an exploratory in vitro pilot study. Consequently, the experimental sample was intentionally limited to two cobalt–chromium frameworks per fabrication workflow (conventional casting and SLS), all derived from the same standardized CAD design. This restriction reflects both the laboratory constraints associated with the complex multi-step fabrication and measurement protocol and the primary objective of the study, which was to document qualitative trends and descriptive differences rather than to perform formal statistical inference. In line with this design, the results are presented as individual values, ranges and arithmetic means, and no inferential statistical tests were undertaken; therefore, the findings should be interpreted as preliminary data that may inform and support future studies with larger sample sizes.

The working model and the antagonist arch were scanned using the Medit T310 extraoral scanner (Medit Corp., version 2.5.1). A standardized crown design was created in Exocad DentalCAD (Exocad GmbH, version Galway 3.1), ensuring identical morphology and cement space parameters for both metal frameworks

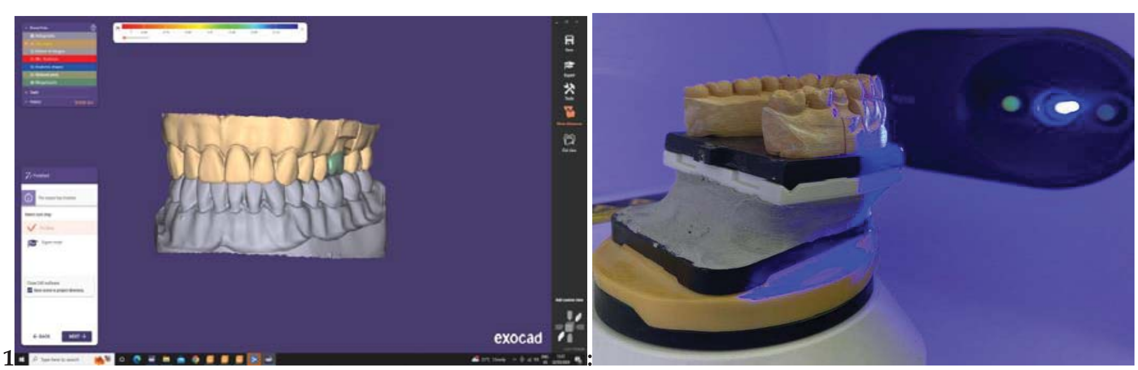
1 

Figure 1. Scan & CAD design

Fabrication of the Cast Framework

The STL design file was exported to the UpMill P53 UP3D milling unit to generate a wax pattern from a prefabricated CAD/CAM wax disc. The pattern was sprued, invested, and cast using a Co–Cr alloy (Realloy-C) in a vacuum-assisted induction casting machine (Galloni Fusus 72). Post-processing included divesting, sprue removal, finishing, and airborne-particle abrasion with 110 µm aluminum oxide.

Fabrication of the SLS Framework

Using the same STL file, a second framework was produced by selective laser sintering in the GE Additive M2 Cusing Lab 200R system, employing CoCrW alloy powder. Post-processing included controlled cooling, powder removal, heat treatment, support removal, finishing, and identical airborne-particle abrasion to standardize surface preparation.

Both metal frameworks were veneered using the IPS InLine ceramic system (Ivoclar Vivadent). The protocol included bonding application, opaque firing, dentin and incisal layering, correction firing, finishing, and final glazing performed in the Programat EP 3010 furnace, following manufacturer specifications.

Internal fit was evaluated before and after ceramic veneering using three distinct techniques at five predetermined reference points: vestibular, oral, mesial, distal, and occlusal.

At each of the five reference sites (vestibular, oral/palatal, mesial, distal and occlusal), three consecutive measurements were performed per specimen and per technique, and their arithmetic mean was calculated to obtain a single value for each point. The Ritter Dent micrometer and the wax micrometer used in this study had a nominal resolution of 0.01 mm and an accuracy of ±0.01 mm, according to the manufacturers' specifications, and both instruments were checked for zero error and proper function before each measurement session. All micrometer readings were carried out by the same operator, who was trained in the use of the devices and followed a standardized measurement sequence in order to minimize operator-dependent variability. The digital optical microscope was calibrated before data collection using a certified calibration slide, and linear distances were recorded with the dedicated software at fixed magnification under controlled room temperature conditions.

Using a Ritter Dent micrometer, the thickness of each metal framework was measured before and after injecting low-viscosity condensation silicone (Zhermack Oranwash L with Indurent Gel) into the crown and seating it on the abutment. The internal gap was calculated as the difference between the two measurements.

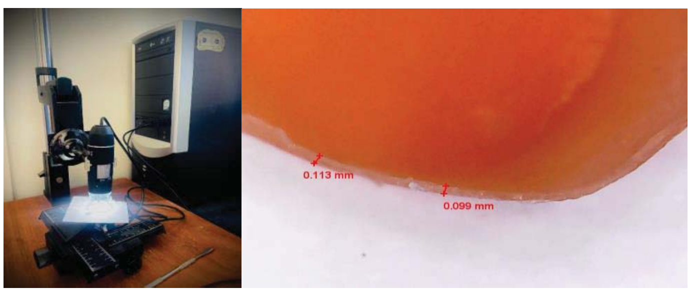


Figure 2. Measurement Procedure

After polymerization, silicone was carefully removed intact, sectioned vestibulo-orally, and measured directly with a wax micrometer to prevent perforation. Care was taken to preserve the integrity of the replica to avoid measurement errors.

For the replica-based assessments, low-viscosity condensation silicone (Zhermack Oranwash L with Indurent Gel) was injected into the crowns and allowed to polymerize fully before removal. After setting, the silicone films reproducing the internal space were carefully detached from the crowns, sectioned and inspected to exclude specimens with visible defects or tearing. The thickness of the silicone layer at the measured sites, corresponding to the local internal gap, ranged approximately between 0.05 and 0.35 mm, depending on the reference point and fabrication method. To reduce elastic deformation during measurement, replicas were handled with minimal manual stress, positioned in a reproducible manner between the micrometer anvils and on the microscope stage, and measured under constant, low contact pressure.

Sectioned silicone replicas were stabilized on the microscope support and analyzed using a digital optical microscope with dedicated software. Measurements were obtained directly from the digital interface to ensure precision.

Figure 3. Digital Microscopy Measurement

After ceramic veneering, the same three measurement techniques were repeated on the finished metal–ceramic crowns to determine whether firing induced changes in internal adaptation.

RESULTS

Internal fit measurements were performed on four cobalt–chromium specimens: two metal frameworks (P1—cast, P2—SLS) and their corresponding metal–ceramic crowns after veneering (P3—cast, P4—SLS). Three measurement techniques were applied: differential micrometer readings, direct silicone replica measurement, and digital optical microscopy. The numerical outcomes obtained through these methods are presented in Tables 1–4. Given that internal gaps between 0.05 and 0.15 mm (50–150 μm) are generally regarded as clinically acceptable for cemented crowns [5–8], the following results are described in relation to this threshold.

Given the extremely small sample size inherent to this pilot design, inferential statistical analysis was not performed. All results are therefore reported descriptively, as individual measurements, ranges and arithmetic means, without claims of statistical significance.

Overall, the internal gap values recorded with the two micrometer-based techniques were closely aligned, whereas digital microscopy consistently produced higher measurements and showed greater sensitivity to subtle variations in silicone thickness.

For the cast metal framework (P1), internal gap values ranged between 0.05 and 0.10 mm at the five reference points, with a mean value of 0.09 mm for both micrometer techniques. Digital microscopy revealed a slightly higher mean of 0.1056 mm, indicating that this method may detect finer discrepancies that are not captured manually. These findings are summarized in Table 1. All internal gap values recorded for the cast metal framework (P1), irrespective of the measurement technique, remained within the 0.05–0.15 mm clinically acceptable interval.

Table 1. Internal Fit Measurements for Cast Metal Framework (P1)

Measurement (mm)	Vestibular	Oral	Mesial	Distal	Occlusal	Mean
Differential micrometer	0.10	0.05	0.10	0.10	0.10	0.09
Direct silicone measurement	0.10	0.05	0.10	0.10	0.10	0.09
Digital microscopy	0.079	0.087	0.105	0.113	0.144	0.1056

In the SLS framework (P2), a similar distribution pattern was observed; however, the occlusal area exhibited notably larger discrepancies, reaching up to 0.354 mm under microscopic evaluation. This resulted in the highest mean internal gap among all frameworks (0.1806 mm). Such values suggest a lower precision of internal adaptation compared with the cast specimen, particularly in the occlusal region, where additive manufacturing processes are more susceptible to cumulative layering deviations, as shown in Table 2.

Table 2. Internal Fit Measurements for SLS Metal Framework (P2)

Measurement (mm)	Vestibular	Oral	Mesial	Distal	Occlusal	Mean
Differential micrometer	0.10	0.05	0.10	0.10	0.10	0.09
Direct silicone measurement	0.10	0.05	0.10	0.05	0.10	0.08
Digital microscopy	0.134	0.106	0.148	0.161	0.354	0.1806

Following ceramic veneering, both cast and SLS crowns (P3 and P4) demonstrated internal fit values consistent with those recorded at the metal stage. The cast crown (P3) exhibited the most uniform measurements, with mean values of 0.08 mm using micrometer techniques and 0.0784 mm under microscopy. This indicates that ceramic firing did not induce clinically relevant distortion of the cast infrastructure. The complete dataset for P3 is presented in Table 3**.**

All measurements obtained for the cast metal–ceramic crown (P3) were contained within the 0.05–0.15 mm clinically acceptable interval, confirming a favorable and homogeneous internal adaptation after ceramic veneering.

Table 3. Internal Fit Measurements for Cast Metal–Ceramic Crown (P3)

Measurement (mm)	Vestibular	Oral	Mesial	Distal	Occlusal	Mean
Differential micrometer	0.10	0.05	0.10	0.05	0.10	0.08
Direct silicone measurement	0.10	0.05	0.10	0.05	0.10	0.08
Digital microscopy	0.073	0.096	0.116	0.028	0.079	0.0784

In contrast, the SLS crown (P4) showed greater variation across measurement points, particularly at the occlusal surface, where microscopy again revealed values as high as 0.352 mm. These findings parallel those seen in the metal-only stage, indicating that the differences intrinsic to the two fabrication workflows persist even after ceramic application, as reflected in Table 4.

In the SLS metal–ceramic crown (P4), axial and proximal values generally remained within the 0.05–0.15 mm range, while the occlusal microscopic gap of 0.352 mm again exceeded this limit, suggesting that the main area of clinical concern is confined to the occlusal surface.

Table 4. Internal Fit Measurements for SLS Metal–Ceramic Crown (P4)

Measurement (mm)	Vestibular	Oral	Mesial	Distal	Occlusal	Mean
Differential micrometer	0.15	0.10	0.10	0.05	0.10	0.10
Direct silicone measurement	0.15	0.10	0.10	0.05	0.10	0.10
Digital microscopy	0.165	0.169	0.106	0.096	0.352	0.1776

When comparing manufacturing methods, cast specimens consistently demonstrated smaller internal gaps across all three measurement techniques. On average, cast restorations exhibited mean values between 0.08 and 0.09 mm, whereas SLS specimens showed higher means ranging from 0.10 to 0.18 mm, primarily influenced by the more pronounced occlusal discrepancies.

A comparison of the three measurement techniques showed that digital microscopy yielded the highest mean internal gap values (approximately 0.135 mm), whereas both micrometer-based methods produced lower and nearly identical means (approximately 0.09 mm). This confirms the superior sensitivity of microscopic evaluation, while also highlighting its tendency to detect micro-irregularities that may not be clinically significant.

DISCUSSIONS

The present study evaluated the internal fit of cobalt–chromium metal–ceramic restorations fabricated through two distinct manufacturing workflows: conventional casting based on wax patterning and selective laser sintering (SLS), a digital additive technique. Across all measurement methods, cast frameworks and their corresponding ceramic restorations demonstrated smaller and more uniform internal gaps compared with SLS specimens, indicating superior adaptation to the abutment surface. These findings align with the working hypothesis that conventional patterning techniques may still provide enhanced accuracy in marginal and internal fit relative to certain additive workflows [14;15].

The differences observed between fabrication methods are consistent with previously published data. Arora et al. reported that SLS crowns generally exhibited improved marginal fit but inferior internal adaptation compared with conventionally fabricated Co–Cr restorations, highlighting the influence of manufacturing technology on spatial accuracy. Likewise, Ullattuthodi et al. [15] demonstrated that conventional metal frameworks produced better internal fit values than DMLS restorations, with no significant differences observed in marginal adaptation. The results of the present study reinforce these findings by showing that SLS specimens displayed greater variability and more pronounced occlusal discrepancies, likely attributable to the layer-by-layer material consolidation characteristic of additive manufacturing.

In the current analysis, digital microscopy consistently produced higher internal gap values compared with micrometer-based techniques. This is unsurprising, as microscopy allows visualization and quantification of micro-irregularities not detectable manually. Although this confirms the superior sensitivity of microscopic evaluation, it also indicates that some discrepancies identified through microscopy may fall within clinically acceptable thresholds. Literature suggests that internal gap values between 0.05 and 0.15 mm are generally acceptable for cementation, depending on the restorative material used. Approximately half of the measurements obtained in this study fall within this interval, suggesting that both fabrication methods can produce clinically functional restorations, although the cast technique provides more predictable results [5-8].

From a clinical perspective, the pattern of internal adaptation observed in this study suggests that the main area of concern for SLS restorations is confined to the occlusal surface, where microscopic gaps exceeded the 0.15 mm upper limit of the commonly accepted interval. Localized occlusal discrepancies of approximately 0.35 mm may result in excessively thick cement layers, which could compromise complete seating in the presence of viscous luting agents or generate occlusal "pools" of cement that are more susceptible to void formation, dissolution and fatigue. Under functional loading, such non-uniform internal support may alter occlusal load distribution, increasing tensile and shear stresses within the cement layer and at the ceramic–metal interface, thereby predisposing to microcracking, loss of occlusal contact or chipping over time. By contrast, the more homogeneous internal fit of cast restorations, with all values remaining within the 0.05–0.15 mm interval, is expected to favour more predictable cementation, more uniform stress transfer and, potentially, more stable long-term prosthesis performance.

Ceramic firing did not introduce significant dimensional changes in either workflow, as indicated by the strong correspondence between values recorded for metal frameworks and those obtained for the final veneered restorations. This observation suggests that both Co–Cr alloys used—regardless of fabrication method—exhibit satisfactory thermal stability under the firing cycles applied. However, although global deformation was not observed, microstructural differences at the alloy level may still contribute to subtle changes in internal fit not easily detected without advanced metallurgical evaluation [11;16].

This study has several important limitations that should be acknowledged when interpreting the results. Only one anatomical region (a maxillary first molar) and a single crown design were investigated, which restricts the generalizability of the findings to other tooth morphologies, preparation geometries or multi-unit restorations. Moreover, the experimental sample was extremely small, with only two specimens per manufacturing technique, so the study was not powered for inferential statistics and all data must be regarded as exploratory. In addition, micrometer-based assessments are inherently operator dependent; although all measurements were performed by a single trained operator following a standardized protocol and with regularly calibrated instruments, subtle variations in specimen positioning and contact pressure cannot be entirely excluded. The replica technique also introduces potential sources of error related to silicone handling and elastic recovery, despite efforts to minimize deformation. Finally, the results reflect the performance of one specific combination of scanner, CAD software, Co–Cr alloys, SLS machine and ceramic system, and may not be directly transferable to other digital workflows or material configurations. Despite these limitations, the findings provide relevant insights into the performance of conventional and additive manufacturing workflows. The superior consistency of cast specimens suggests that traditional techniques remain highly reliable for achieving precise internal adaptation. However, continued advancement in laser-based powder fusion technologies may narrow the gap in accuracy, offering opportunities for workflow optimization in fully digital restorative dentistry [17;18].

CONCLUSIONS

This in vitro pilot study showed that cobalt–chromium metal–ceramic restorations fabricated through conventional casting exhibited smaller and more uniform internal gaps than those produced by selective laser sintering (SLS), with cast frameworks and their veneered crowns demonstrating superior internal adaptation, particularly in the occlusal region. Digital microscopy proved more sensitive than micrometer-based methods, revealing additional micro-discrepancies and underscoring the value of high-resolution assessment for evaluating restorative accuracy. Within the limitations of the small sample size and single tooth morphology, these findings reinforce the predictable precision of conventional casting and clarify current constraints of additive manufacturing in achieving uniformly optimal internal fit, providing clinically relevant guidance for selecting and refining manufacturing workflows.

Conflicts of Interest

The authors declare no conflict of interest.

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