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Original Article

Novel method for using a single impression and additive technologies to fabricate a metal post and core and metal coping

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Abstract

Purpose: To investigate a novel method that uses a single impression, facilitated by additive technologies, to fabricate a metal post and core and metal coping.
Methods: Twenty-four human single-rooted teeth were divided into two groups—one for use with a conventional two-appointment method (CT group) and the other for a novel, one-appointment method (OA group). The CT group required separate impressions and cast models for the metal post and core and coping. In contrast, the OA group used a novel single-impression method to obtain both the metal post and core and metal coping. Silicone replica technique was used to assess marginal and internal adaptation of the copings in each group. Statistical analysis was performed using the Mann-Whitney U test ($\alpha = 0.05$). Additionally, three-dimensional digital evaluation was used for comparison of teeth and coping internal areas.
Results: The mean marginal gap did not significantly differ between the CT group (83.77 ± 51.84 µm) and OA group (77.09 ± 31.65 µm) (P = 0.8835). However, the CT group had significantly larger internal gaps ($P < 0.05$).
Conclusion: The findings suggest that it is feasible to fabricate a metal post and core and metal coping from a single impression.

Keywords: CAD-CAM, dental impression technique, dental marginal adaptation, dental prosthesis

Introduction

From the advent of the process for casting gold inlays [1,2] to the development of digital dentistry [3,4], which includes the use of scanners [5] and additive manufacturing [6], new techniques and solutions have emerged to enhance the quality of dental rehabilitation. Restoration of endodontically treated teeth is one of the most researched areas in prosthetic dentistry, and numerous techniques are available to address the specific challenges of each case [7,8]. The complexity of such restorations increases when the post and core are combined with coronal rehabilitation. Factors such as preparation design [9], type of restorative material [10,11], manufacturing technique [12,13], and impression material technique [14] are all important.

Previous studies confirmed the clinical durability and reliability of restoring endodontically treated teeth with metal posts, cores, and crowns [8,13], although success rates decrease when there is a delay in completing the restorative treatment [15,16]. Prosthetic treatment for endodontically treated teeth typically requires multiple clinical appointments. The process begins with an impression for post and core fabrication, which is followed by a second appointment to obtain a second impression, for coping fabrication [17]. Because of the recent global pandemic and risk of cross-infection during dental consultations, adopting protocols that minimize intervention time and reduce exposure for patients and dental staff could help decrease the risk of contaminant spread among the persons involved [18,19]. Development of an alternative method that is clinically acceptable while minimizing the number of appointments requires investigation of marginal adaptation, as such adaption directly affects cement thickness [19], which in turn influences mechanical strength [20] and inflammatory reactions in periodontal tissues [21,22].

A clinically acceptable marginal gap is typically considered to be 120 µm [23,24]. To measure marginal adaptation, noninvasive two-dimensional (2D) methods such as the silicone replica technique (SRT) can be used. SRT involves creating a silicone replica by filling the space between the prosthesis and its die with a silicone impression material. The replica is then evaluated with a stereomicroscope [24,25]. An alternative approach involves three-dimensional (3D) analysis [26] that utilizes optical metrology software to complement conventional two-dimensional methods.

The aim of this study was to evaluate a novel method that uses a single impression and support by additive technologies to fabricate a metal post and core and metal coping. This method differs from the conventional approach, which, after cementation of the post and core, requires a new impression and a new cast model for fabrication of the coping. SRT and 3D analysis were used to evaluate marginal and internal adaptation for this new method.

Materials and Methods

Figure 1 shows an overview of the study workflow, outlines the procedural steps for the conventional two-appointment method (CT Group) and novel one-appointment method (OA Group), and highlights important methodological differences.

After obtaining approval from the ethics committee (protocol number CAAE:10379919.8.0000.0077), a total of 24 intact human single-root premolars were collected and embedded in standardized acrylic resin cylinders measuring 25 × 20 mm, with 5 mm of dental root structure extending above the resin base. A high-speed dental handpiece equipped with a cylinder diamond bur was used to precisely section the crowns of the teeth at 2 mm above the cementoenamel junction. Meticulous cleaning and filling of the root canals were then performed using gutta-percha.

A sloped shoulder finish-line was prepared (diamond burr #3118, KG Sorensen, Cotia, Brazil), and the top portion of each prepared tooth was shaped into a flat surface capable of supporting the core (diamond burr # FG 3053, KG Sorensen). The finish lines were meticulously refined using a low-speed contra-angle handpiece. To ensure the absence of any imperfections or cracks at the finish line and surrounding areas, which could potentially interfere with the study results, all teeth were thoroughly examined under a light stereomicroscope (Discovery V20, Zeiss, Oberkochen, Germany) at ×20 magnification. To ensure uniformity in the final shape and height of the root canals (10 mm), postspace preparation was carried out using Peeso reamers #1, #2, and #3 at low speed, employing a push and pull motion, followed by thorough cleaning of the post space.

The specimens underwent impression to obtain the cast post and core, using the indirect technique [14]. This method involved a two-step impression process that uses light-body and heavy-body silicone materials (Optosil Comfort Putty and Xantopren VL Plus, Kulzer, Hanau, Germany). Subsequently, the impressions were poured with Type IV stone (Fuji

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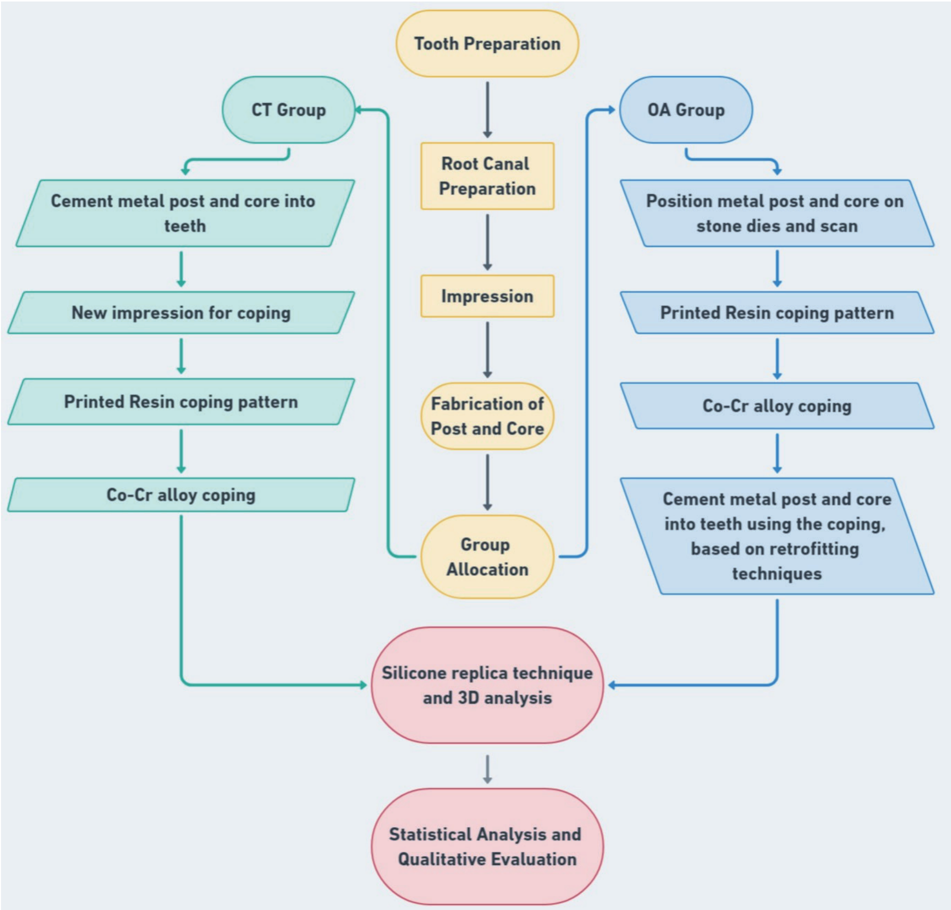

Fig. 1 Step-by-step overview of the workflow for metal post, core, and coping fabrication using conventional and single-impression methods in the CT and OA groups, respectively

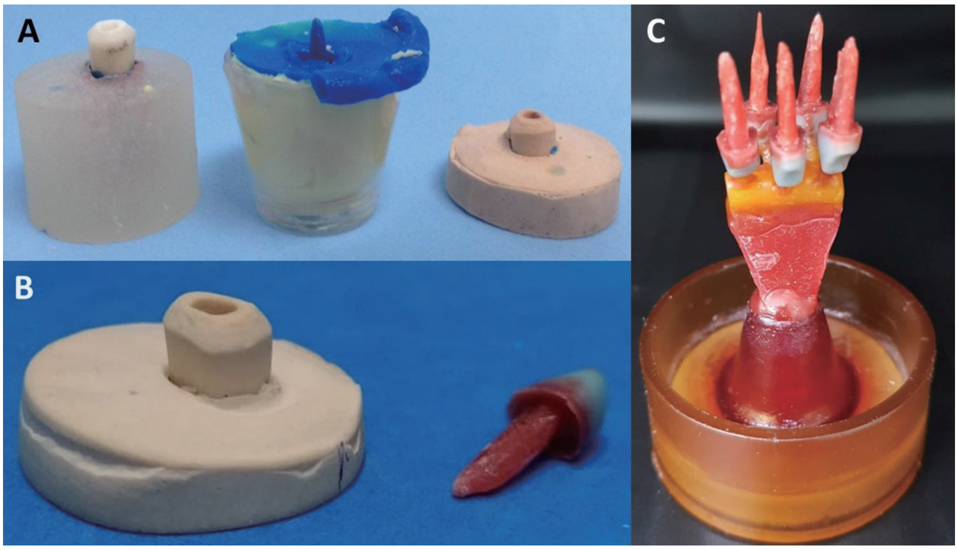

Fig. 2 Protocol sequence for fabricating a post and core: (A) prepared tooth, impression, and stones die; (B and C) fabrication of the post and core, using a resin pattern

Rock, GC Europe, Leuven, Belgium). All procedures were conducted in accordance with the manufacturers' guidelines and under standardized conditions. Using the stone dies produced from the impressions, wax patterns for the post and core were fabricated (Fig. 2), invested, and then cast in Co-Cr alloy (Fitcast Cobalto, Talmax, Curitiba, Brazil).

The specimens were randomly divided into two groups. The CT Group (n = 12) used the conventional two-appointment method, involving one impression for casting the post and core and another impression for casting the coping. The OA Group (n = 12) utilized a novel one-appointment method that uses a single impression to cast the post and core and obtain a cast metal coping.

For the CT Group, the metal post and core was cemented into the respective tooth with zinc phosphate cement (zinc phosphate cement, SS White Duflex, Rio de Janeiro, Brazil) under digital pressure, to simulate clinical practice. Then, two-step technique was used to produce a new impression, which was then poured into Type IV stone (Fig. 3). The stone dies were scanned by a dental lab scanner (Swing, DOF Inc., Seoul, Republic of Korea), and the resulting stereolithography (STL) files were generated and exported to computer-aided design (CAD) software (DentalCad, Exocad, Darmstadt, Germany) for coping design, with the cementation space set as

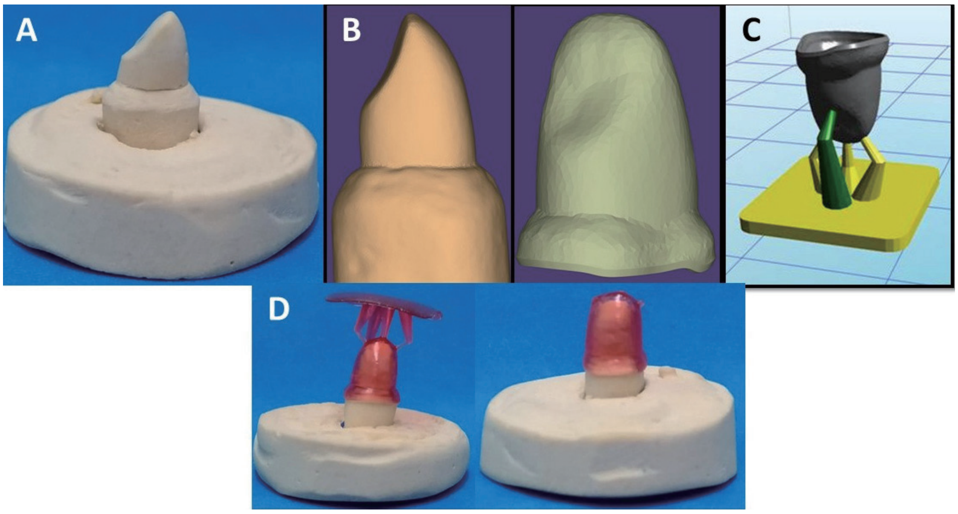

Fig. 3 CT group protocol sequence: (A) stone die; (B) digitized model and coping design; (C) preparation of supports for printing; (D) printed coping positioned on the stone die, with and without supports

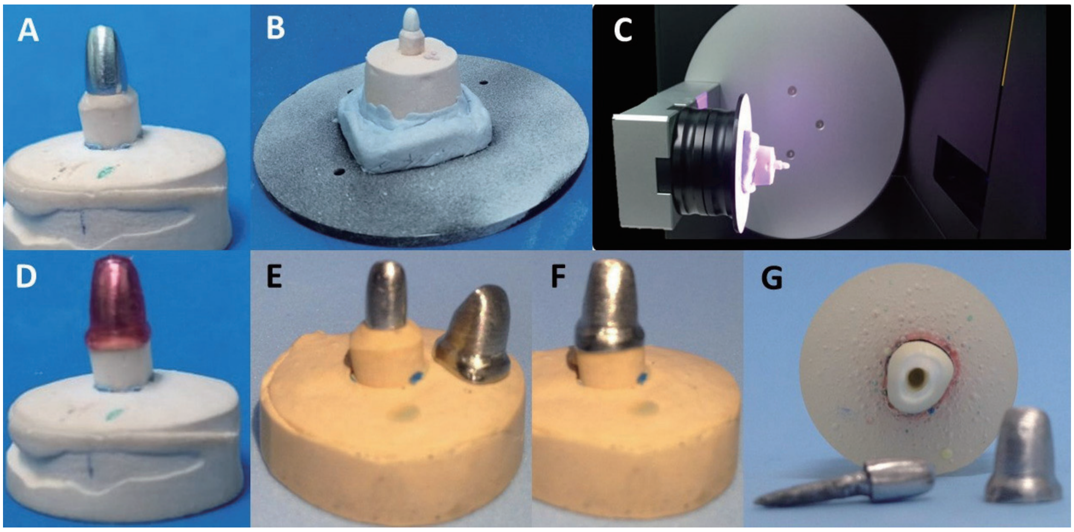

Fig. 4 OA group protocol sequence: (A) Cast and finished post and core positioned on the stone die; (B) preparation of the assembly, stone die, and cast post and core for scanning; (C) scanning of the assembly; (D) printed coping; (E-F) finished cast metal post and core and coping positioned on the stone die; (G) prepared tooth, post and core, and coping

50 µm and no spacer at the marginal band. The STL files of the designed coping were then transferred to a 3D printer slicer and host controller software (Creation Workshop, EnvisionLabs, n.d.) for support structure design. Printing was done with a digital light processing (DLP) 3D printer (Wanhao Duplicator7, Wanhao 3D printer, Jinhua, China). After printing, the resin copings (CM Resin - Red 400, Makertech Labs, Tatuí, Brazil) were cleaned in an ultrasonic bath with isopropyl alcohol, followed by a final polymerization process for 10 min under an ultraviolet (UV) lamp outside the printer. Finally, the supports were removed, and the patterns were invested for casting in Co-Cr alloy.

For the OA group, the obtained metal post and core were not cemented into their respective teeth, unlike the CT group (Fig. 4). The metal post and core were positioned on their respective stone dies, which were used to obtain the wax patterns for the post and core. After that, the stone die and cast metal post and core were scanned by a dental lab scanner, utilizing a nonaqueous developer (D70, Metal chek, Bragança Paulista, Brazil) to reduce glare interference from the shining surface of the metal post and core. The design, processing, and post-processing procedures for the coping were the same as those used for the CT group. Cementation for the post and core was based on retrofitting techniques, which are used when the crown has already been produced but the tooth eventually requires a post and core [27]. Using the coping as a positioning guide for the post (Fig. 5), all cementations were performed using digital pressure and by the same trained operator.

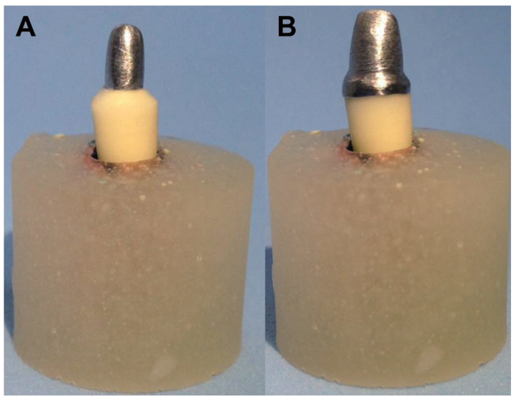

Fig. 5 Fitting of the structures in the OA group: (A) post and core in position; (B) post and core and coping in position

The marginal and internal fit of the metal coping in both groups was tested using SRT (Fig. 6). Copings were cleaned and filled with light-body silicone (Xantopren, Kulzer) before placement in the teeth. They were then placed in their respective teeth under digital pressure and, after polymerization, the silicone replicas were separated from the teeth. Then, a putty

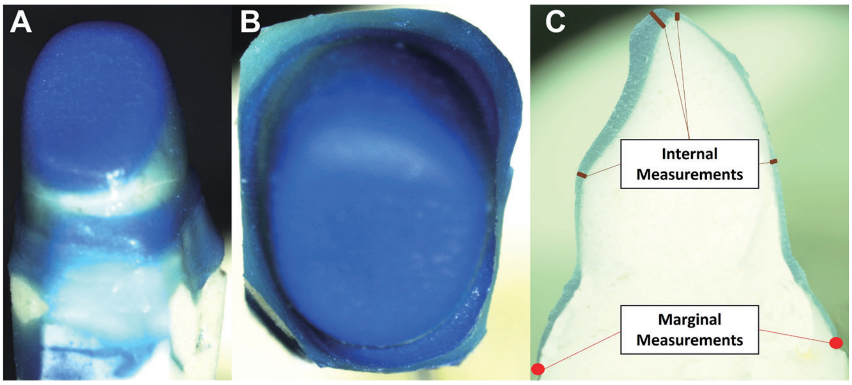

Fig. 6 (A and B) silicone replica before sectioning; (C) cross-section with standardized points for marginal and internal measurements

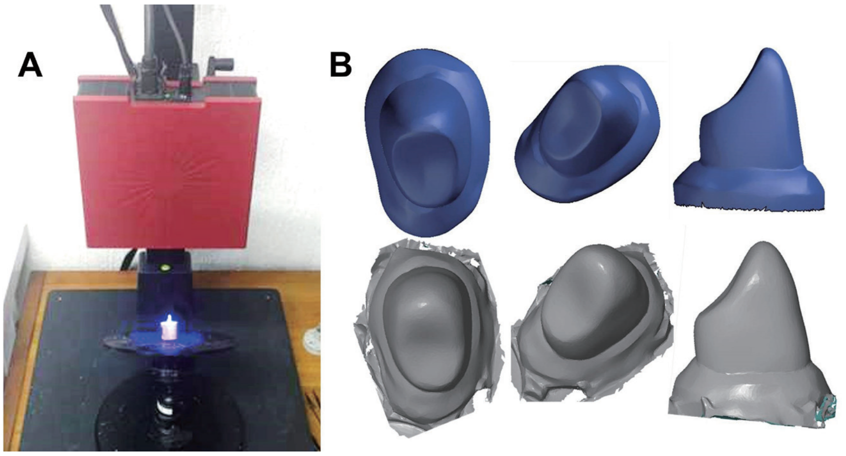

Fig. 7 Digital analysis: (A) industrial scanner ATOS Core 80 (GOM); (B) the upper row shows scans of dental samples; the lower row shows scans of the internal silicone replica of the coping

silicone material (Putty Optosil, Kulzer) was mixed and placed inside the light-body silicone to support it. The silicone replicas were carefully removed from the copings and sectioned into four cross-sections with a straight scalpel blade, using a cross drawn on a piece of paper to guide the mesiodistal and buccolingual cuts. In each cross-section, one marginal point and two internal points—i.e., one axial and one occlusal point—were measured, resulting in 12 measurement points for each specimen. All measurements were conducted by the same operator using a stereomicroscope at ×80 magnification. To ensure accurate measurement, cross-sections were maintained in parallel orientation to the microscope lens, and measurements from digital photographs were done using an image-analysis program (AxioVision Program, Zeiss).

Statistical analyses were conducted using BioEstat 5.3 (Mamirauá Institute, Tefé, Brazil). Normality was evaluated with the Shapiro-Wilk test, after which the Mann-Whitney *U* test was used to identify differences in marginal and internal adaptation between the CT and OA groups ($\alpha = 0.05$). Additionally, five randomly selected samples from each group underwent digital evaluation to clarify potential interference and mismatches between the tooth and coping (Fig. 7). Tooth samples were scanned with a non-contact industrial scanner (ATOS Core 80, GOM, Braunschweig, Germany) [26], and a non-aqueous developer layer was applied to prevent reflections during scanning.

The internal surfaces of the copings were filled with a light-body silicone material (Xantopren, Kulzer) to replicate its volume and obtain an internal silicone replica of the coping (ISR). ISRs were scanned using the same non-contact industrial scanner with a non-aqueous developer layer, and the data obtained (STL file) were exported to an optical metrology software package (GOM Inspect, GOM). The meshes of the tooth and ISRs were paired by a best-fit algorithm and subjected to a deviation inspection comparison that used approximately 6,039 reference points [28].

For qualitative interpretation of the results obtained from the deviation inspection, a color chart was used for comparison with reference values of 50 μm on both the positive and negative scales. These reference values were based on the cementation spacer used during coping design. In this context, green on the chart indicates that the size of the ISR corresponds to that of the respective prepared tooth. Blue indicates that the ISR is smaller, and red indicates that the ISR exceeds the dimensions of its reference tooth.

Results

Table 1 shows the mean, standard deviation (SD), median, and interquartile range (IQR) for the measurements of specimens. The median marginal gap did not significantly differ between the CT group (72.99 μm; IQR: 57.16-95.14 μm) and OA group (68.35 μm; IQR: 58.37-86.25 μm) ($P = 0.8835$). However, the median axial gap significantly differed between the CT group (177.90 μm; IQR: 97.86-334.47 μm) and OA group (115.33 μm; IQR: 83.87-169.58 μm) ($P = 0.0027$), as did the occlusal gap: 408.80 μm (IQR: 268.05-606.44 μm) vs 261.24 μm (IQR: 155.77-345.38 μm), respectively ($P = 0.0002$).

Figure 8 illustrates the results of 3D digital evaluation utilizing optical metrology software. Reference values of 50 μm, derived from the cementation spacer used during coping design, were used on the positive and negative scales. Qualitative interpretation of the color chart revealed a consistent pattern of misadaptation. Because the design software did not include a spacer at the marginal band, the entire region should have appeared as green, indicating it was the same size as the prepared reference tooth. However, the marginal region of the specimens mostly appeared as blue, with some spots transitioning from green to red. The axial region retained the cementation spacer, identified as red. The occlusal region was expected to appear as red in all areas; however, some regions appeared as the blue reference instead.

The results were then analyzed in relation to the disparity between the

Table 1 Measurements of marginal, axial, and occlusal gaps of specimens

Group	N	Mean (μm)	SD (±)	Median (μm)	Q1 (25%)	Q2 (75%)	IQR	$\alpha = 0.05$
Marginal gap (CT)[a]	12	83.77	(±) 51.84	72.99	57.16	95.14	37.97	$P = 0.8835$
Marginal gap (OA)[a]	12	77.09	(±) 31.65	68.35	58.37	86.25	27.88	
Axial gap (CT)[a]	12	227.48	(±) 157.44	177.9	97.86	334.47	236.61	$P = 0.0027$
Axial gap (OA)[b]	12	138.64	(±) 77.60	115.33	83.87	169.58	85.7	
Occlusal gap (CT)[a]	12	482.25	(±)315.68	408.8	268.05	606.44	338.38	$P = 0.0002$
Occlusal gap (OA)[b]	12	268.28	(±)141.97	261.24	155.77	345.38	189.61	

Different superscript letters within each measurement region indicate statistically significant differences ($P < 0.05$).

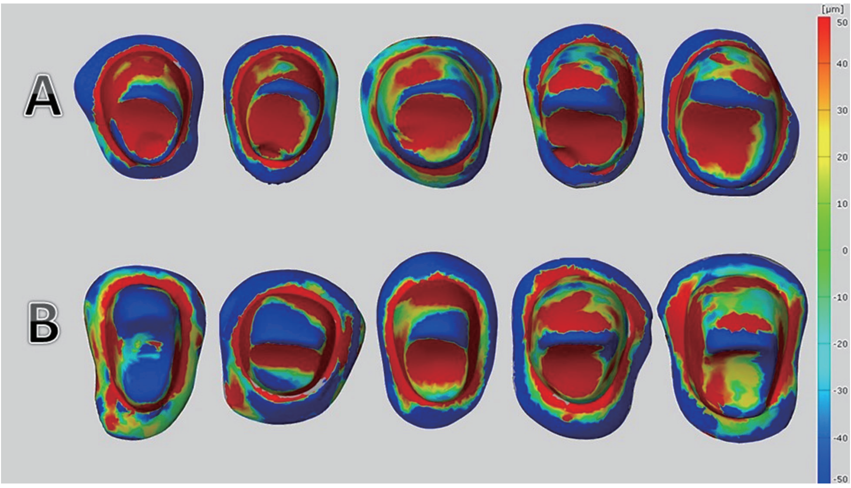

Fig. 8 Qualitative analysis by digital inspection: (A) color map of the CT group; (B) color map of the OA group; reference values, 50 μm

Table 2 Numerical references after scanning and analysis of the ISR

Mean (μm)	Distance SD	Number of points selected (total)
CT group ($n = 5$)		
73,142	98,970	4306 (6387)
42,904	85,853	3163 (4623)
24,502	71,934	5655 (8755)
47.339	103,884	4415 (6436)
57,341	122,818	5231 (6649)
OA group ($n = 5$)		
Mean (μm)	Distance SD	Number of points selected (total)
7,929	127,339	4311 (6427)
108,316	146,103	3408 (5409)
62,696	83,540	3510 (5197)
45,190	79,688	4531 (6239)
15,465	81,223	3160 (4270)

Results of digital analysis, number of points analyzed, average internal fit, and SD. The data could not be statistically analyzed.

internal volume of the coping and its prepared reference tooth. Table 2 shows the number of points analyzed and the mean (SD) internal fit, which could not be analyzed statistically [28].

Discussion

The success rate for endodontically treated teeth decreases when rehabilitation time is prolonged [7,15,16]. Eliminating the need for a second impression after cementation of the post-and-core expedites workflow, reduces cost, and lessens the risk of cross-contamination between clinicians and patients [17,18,29]. The present findings indicate that when the root canal and marginal design are already prepared, a single impression, and thus a single gypsum die, are sufficient with respect to marginal and internal adaptation for both procedures, thereby eliminating the need for a new impression when the post and core are cemented to the tooth. This approach is an important advance in addressing clinical challenges and enhancing patient care in prosthetic dentistry.

The mean marginal gap in the OA group was 77.09 μm, which is within the clinically acceptable range, defined in previous reports as 50-120 μm [23] and ≤200 μm [30]. The measurements of internal adaptation in the OA group (axial 138.64 μm and occlusal 268.28 μm) were also consistent with previously reported values [31,32]. The significant difference in internal adaptation between groups, i.e., the higher values in the CT group (axial 227.48 μm and occlusal 482.25 μm) might be attributable to the accumulation of distortions during the process, as the CT group required a second impression and, consequently, a new die cast and scanning.

Satisfactory marginal and internal adaptation is crucial for the success and longevity of indirect restorations, as it directly impacts the health of periodontal tissues [21,22,33], the integrity of the cement [19,20], and the mechanical stability of the restoration during function [34-36]. Radiographic examination and visual evaluation by an experienced operator were used to assess the acceptability of the post and core during seating of the restoration on the occlusal flat portion of the tooth prepared to support the core [27].

The primary aim of this study was not to assess adaptation of the post and core within the root canal. The indirect technique used to obtain the post and core, as described above, is well-established and widely taught in undergraduate dentistry courses.

Because of the narrower coping for single-rooted teeth, the scanner light could not adequately penetrate the entire internal area of the infrastructure, unlike, for example, the coping for molars, which is wider. To address the need for digital evaluation of the internal region, the present authors created a silicone replica of the internal volume of the coping. This replica comprises the volume of the dental preparation plus the thickness for the cementation line, as previously determined in the framework design on Exocad.

The data from the ISR and digital evaluation could not be analyzed statistically, for reasons explained by Dahl et al. [28], but the color chart in Fig. 8 displays characteristics that cannot be demonstrated by 2D techniques. Digital assessment revealed misfit, indicated by blue along the marginal band, in all specimens. The predominant color in this area should be green, indicating optimal contact between the inner wall of the coping and the marginal band of the preparation, thus confirming the absence of any spacer in this region, as designated in the CAD software. The observed deviation between the coping and tooth is likely due to resin contraction, although the marginal layer was least affected, and to accumulation of various errors during processing and post-processing of the resin patterns [25]. This finding suggests that a minimum spacer at the marginal band is necessary, even though marginal adaptation was clinically acceptable (<100 µm), to mitigate contraction during resin pattern polymerization and facilitate adaptation, which could be affected by processing and post-processing, thereby reducing the need for adjustments. Resin contraction during printing and post-processing might also account for misadaptation in the axial region, which was expected to be uniformly red but displayed areas transitioning from green to red.

Similarly, although the entire occlusal region was expected to be uniformly red, spots of blue and transitioning hues were observed. These findings, particularly for the occlusal surface, can be attributed to resin contraction [25] exacerbated by the presence of supports in the region and continuous exposure to printer light during printing [37]. Additionally, the more intricate design of the region could lead to distortions during printing that affect both the occlusal and axial areas [38].

The use of computer-aided design and computer-aided manufacturing (CAD-CAM) systems in the process facilitated delimitation, design, and manufacture of restorations. This approach reduces the likelihood of manual errors, conserves materials, and streamlines the work, thereby reducing the final price for rehabilitation and increasing patient satisfaction.

The present novel technique is not suitable when the finish line of the remaining root structure cannot be fully completed and refined. Furthermore, even if the marginal design is finalized, the technique remains unsuitable if the marginal limits cannot be entirely reproduced, as this is essential for proper adaptation of the future coping.

In conclusion, the present findings highlight the potential of this novel approach to enhance workflow efficiency and reduce costs while achieving satisfactory clinical outcomes. This method enables clinicians to use single-impression technique to fabricate both the metal post and core and metal coping. However, it is important to note that the present sample size was small and that the findings require validation in future studies. Future research should explore additional applications and refine this technique, thereby facilitating continued advances in prosthetic dentistry.

Abbreviations

2D: two-dimensional; 3D: three-dimensional; CAD-CAM: computer-aided design and computer-aided manufacturing; CT Group: conventional two-appointment method; DLP: digital light processing; IQR: interquartile range; ISR: internal silicone replica of the coping; OA Group: the novel, one-appointment method; SD: standard deviation; SRT: silicone replica technique; STL: stereolithography; UV: ultraviolet

Ethical Statements

This study was approved by the Ethics Committee of the Institute of Science and Technology of São José dos Campos, São Paulo State University (UNESP), under protocol number: CAAE: 10379919.8.0000.0077

Conflicts of Interest

The authors declare no conflicts of interest.

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Not applicable

Author Contributions

Luigi G. Bernardo Sichi: Acquisition of data; Analysis and interpretation of data; Statistics analysis and Manuscript preparation. Rodrigo M. Araújo: Substantive scientific and intellectual contributions to the study; Conception and design and Critical revision. All authors have read, reviewed, and approved the final version of the manuscript, fully agreeing with its content and ensuring its integrity and accuracy, while also assuming responsibility for all aspects of the work.

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Data Availability Statements

The data supporting the findings of this study are available from the corresponding author upon reasonable request.

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