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The influence of finishing line and luting material selection on the seating accuracy of CAD/CAM indirect composite restorations☆

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ABSTRACT

Objectives: This study aimed to assess the seating accuracy of resin composite CAD/CAM overlay restorations, employing various preparation designs and luting materials (pre-heated composite (HC) or resin cement (RC)).
Methods: A human molar's STL file was utilized to create 100 3D-printed resin tooth replicas, randomly distributed into 5 groups ($n = 20$) based on finishing line preparation designs: 1) Rounded shoulder above the dental equator - DE (SA); 2) Chamfer above the DE (CA); 3) Butt joint above the DE (BJ); 4) Rounded shoulder below the DE (SB); 5) Chamfer below the DE (CB). Digital impressions were acquired for all replicas, and restorations milled using Tetric CAD (Ivoclar Vivadent). The restorations were luted with HC (Tetric Prime, Ivoclar Vivadent) or RC (RelyX Universal, 3 M). Seating accuracy was evaluated through digital scans during try-in without any luting agent and post-cementation using a 3D analysis software (Geomagic wrap, 3D Systems). Data were statistically analyzed using Two-Way ANOVA ($p < 0.05$).
Results: The type of luting material (RC vs HC), preparation design, and their interactions significantly impacted 3D seating of the restorations ($p < 0.001$). HC exhibited higer volumetric increase than RC. BJ and CA designs consistently demonstrated superior seating accuracy, irrespective of the luting material used.
Conclusions: The utilization of pre-heated composite resin could negatively influence the seating of overlay restorations, probably due to its higher viscosity when compared to the resin cement. However, when HC is selected as luting agent, preparation designs lacking internal angles are recommended for enhancing the precision of overlays seating.

1. Introduction

Advancements in adhesive dentistry have facilitated the implementation of a minimally invasive approach, which underscores the intrinsic value of preserving healthy tooth tissue and minimizing the removal of structurally sound tooth components during dental procedures. Additionally, computer-assisted design/computer-assisted manufacturing (CAD/CAM) has gained popularity for the fabrication of bonded restorations, and it is assumed to be increasingly used in the next decades. The proper selection of the luting material is pivotal to obtain the long-term success in these kind of fixed dental prosthesis [1]. Resin cements (RC) have been traditionally preferred for the cementation of ceramic and resin composite indirect restorations, contributing to their esthetic and mechanical performances [2,3]. In alternative, pre-heated highly filler loaded composite resins (HC) have been proposed [4–7]. The rationale beyond the use of these materials relies on the inherent properties of resin composites. The higher filler loading, enhances their mechanical strength, concurrently mitigating polymerization shrinkage and associated stresses [2,5], while the pre-heating process is intended to reduce their viscosity [4–6].

Despite the aforementioned advantages of HC, concerns related to increased film thickness when compared to resin cements have been

☆ Clinical Significance: Findings suggest that HC might compromise seating accuracy of overlay restorations, particularly with preparation designs featuring wide internal angles and intricate geometry.

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raised [8,9]. The film thickness is an important characteristic influencing the long-term adaptation of an indirect restoration [10,11]. Indeed, inadequate marginal adaptation poses potential risks to both the abutment teeth and the supporting periodontium, leading to undesirable outcomes such as microleakage, degradation of the cement line, secondary caries, and periodontal diseases [12–14].

The type of preparation design for indirect partial restorations (IPRs) is another important factor to be considered for the selection of the correct luting system [15–17]. Although IPRs require carefully rounded preparation without any internal sharp angles, to facilitate optimal flow of cement materials [18,19], different finishing line designs have been proposed in the posterior teeth. The "butt joint" finishing line yields a predominantly planar configuration and an occlusal reduction that mirrors the evolutions of the cusps and the main sulcus of the tooth and has been indicated as the most conservative preparation, requiring minimal tissue removal [20,21]. The "inclined chamfer" or "inclined bevel" designs encompass preparations akin to the butt joint, distinguished by the inclusion of a 45° inclined chamfer or bevel at the margin. The inclined chamfer, characterized by a gradual restoration-to-tooth interface, has been reported to offer enhanced integration of the restoration. This attribute renders it particularly advisable for applications in aesthetically demanding regions [21,22]. The "rounded shoulder" finishing-line, typically featuring a rounded margin aims to offer an increase in material thickness at the margin of the restoration, concurrently providing an anti-rotational grasp to the restoration. Lastly, the "chamfer finishing-line", entails the utilization of a bur with a geometrically specified chamfer inner contour to create a chamfer margin [23,24].

The current body of literature fails to provide definitive insights into the influence of utilizing pre-heated resin composite on the seating accuracy of IPRs, as well as the interaction of different luting materials and different preparation designs. Consequently, the selection process for the cementation of these restorations, primarily relies on the subjective judgment of the operator, without due consideration for the properties of finishing line design and luting strategies.

Therefore, the objective of this in vitro study was to evaluate the effect of the luting strategies (dual-cure adhesive resin cement and pre-heated resin composite) and the preparation margin designs on the seating accuracy of resin composite CAD/CAM indirect restorations. Specifically, the null hypotheses tested were that the seating accuracy of resin composite CAD/CAM overlays is not influenced by 1) the type of luting system and 2) the type of preparation design.

2. Materials and methods

2.1. Sample size determination

A software package (G*Power Ver. 3.1.5, Germany) was used to determine the sample size required for the study. Power analysis was based on the effect difference observed in a previous study (f = 0.6158088) [5]. With a confidence level of 95 % (1 − α) and power of 90 % (1 − β), the required sample size for each group was determined to be 10.

2.2. Tooth replicas preparation

One non-carious, sound human lower first molar was used for the study. The tooth was obtained from an anonymous individual following informed consent under a protocol approved by the Ethical Committee of the University of Bologna (Italy; protocol N°: 71/2019/OSS/AUSLBO) and maintained in water solution at 4 °C until use. Tooth replicas were prepared as previously proposed [25]. Briefly, the molar was scanned by means of a Micro-CT scan (SkyScan 1172 Micro-CT; Bruker Optik, Ettlingen, Germany), with parameters set for high resolution (voltage = 100 kV, current = 100 µA, aluminum and copper [Al+Cu] filter, 14 µm pixel size, averaging = 5, rotation step = 0.6°, total scan duration = 1.15 h). To reconstruct the specimen and obtain 3D images (DICOM file), NRecon and Data Viewer software (Bruker Optik) were used. An STL file was extrapolated from the DICOM file. To facilitate the subsequent analyses and alignment of different STL files, a cube of 1.5 × 1.5 × 1 cm was placed on the base of the digital tooth using a 3D computer-aided design application software (Rhinoceros 3D, V. Rhino 7, Robert McNeel & Associates; Seattle, WA, USA). The STL file was then utilized as a model to print 5 tooth replicas with a 3D printer (PrograPrint PR5, Ivoclar Digital; Ivoclar Vivadent, Schaan, Liechtenstein).

The tooth replicas were then randomly assigned to 5 groups, and prepared according to the different finishing line (n = 1):

1. BJ: Butt joint preparation above the maximum contour line of the dental equator (4 mm from the cementum-enamel junction, CEJ);
2. CA: Circumferential hollow chamfer above the maximum contour line of the dental equator (4 mm from CEJ);
3. SA: Circumferential rounded shoulder preparation above the maximum contour line of the dental equator (4 mm from CEJ);
4. CB: Circumferential chamfer below the maximum contour line of the dental equator (1.5 mm from CEJ).
5. SB: Circumferential rounded shoulder preparation below the maximum contour line of the dental equator (1.5 mm from CEJ);

To precisely control the apical-coronal margin position before preparation, the planned margin line was marked with a pencil. The height of the pencil line (4 mm or 1.5 mm from the CEJ) was established for each specimen with a periodontal probe (CP-15). Standardized preparations (1.5 mm occlusal reduction, 1 mm reduction at the preparation axial walls, rounded edges, and 6° taper) for partial restorations with different finishing lines were performed on the replicas by a single experienced clinician (E.M.) with the use of magnifying glasses 4.5x [24]. The correct thickness of the preparation was continuously verified using a silicon index (Elite HD+; Zhermack, Badia Polesine, RO, Italy), a periodontal probe (CP-15, Hu-Friedy Italy SRL, Milan, Italy) and diamond burs with known dimensions (Neodiamond; Microcopy Dental, Kennesaw, GA, USA) mounted on a red ring contra-angle handpiece. The burs utilized for the different finishing margin lines are reported in Table 1. A new set of burs was used per each specimen and discharged after completion of the preparation.

After the preparation, the 5 tooth replicas were covered with a thin layer of high-resolution scanning powder (High-Resolution Scanning Spray; 3 M, St.Paul, MN, USA) and scanned with a laboratory laser scanner (inEos X5; Dentsply Sirona, York, Pennsylvania, USA) (Fig. 1a).

From each STL file, 20 teeth per group were produced with the 3D printer and used as tooth replicas for the cementation procedures (Fig. 1b).

The STL files of an intact tooth and of the prepared teeth were imported in a laboratory management software (3shape Dental System 2021, Copenhagen, Denmark).

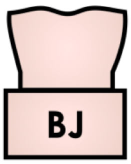
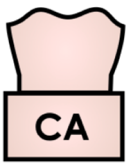
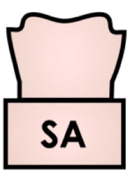
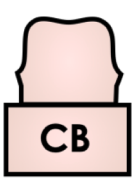
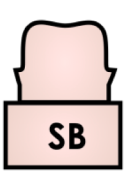
2.3. Design and manufacturing of the restorations

A master for the biogeneric copy of the restoration was generated from the coronal portion of the intact tooth STL file. This biogeneric copy was utilized as reference to recreate for each of the five differently prepared STL files, a CAD/CAM resin composite overlay.

The overlay design was modified so that in the central portion of the occlusal table, at the same location of each restoration, a 1 mm deep and 1 mm wide hemispherical occlusal concavity was created to precisely perform the subsequent restoration positioning and cementation procedures (Fig. 2a).

The composite restorations (Tetric CAD, Ivoclar Vivadent) were created using a milling machine (Sirona InLab MC XL, Dentsply Sirona) (Fig. 2b).

Table 1
Parameters and armamentarium used for the different preparation designs above or below the dental equator (DE).

Preparation designs	Graphic representation	Parameters	Burs employed ISO	References
Butt Joint		Margin placed 4 mm occlusal from CEJ Occlusal reduction: 1.5 mm 90° finishing line	806 314 142 534 014 806 314 142 534 018 806 314 142 534 014 806 314 142 514 014	[49]
Chamfer above DE		Margin placed 4 mm occlusal from CEJ Occlusal reduction: 1.5 mm 30° finishing line	806 314 142 534 014 806 314 277 534 018 806 314 277 514 018 806 314 257 534 016 806 314 257 514 016	[22]
Shoulder above DE		Margin placed 4 mm occlusal from CEJ Occlusal reduction: 1.5 mm 1 mm finishing line reduction 90° finishing line	806 314 142 534 014 806 314 173 534 018 806 314 173 514 018 806 314 257 534 016 806 314 257 514 016	[21]
Chamfer below DE		Margin place 1.5 mm occlusal from CEJ Occlusal reduction: 1.5 mm 1 mm finishing line reduction 60° finishing line	806 314 142 534 014 806 314 198 534 021 806 314 198 514 021 806 314 257 534 016 806 314 257 514 016	[49]
Shoulder below DE		Margin placed 1.5 mm occlusal from CEJ Occlusal reduction: 1.5 mm 1 finishing line reduction 90° finishing line	806 314 142 534 014 806 314 173 534 018 806 314 173 514 018 806 314 257 534 016 806 314 257 514 016	[49]

2.4. Luting procedures

The inner surface of the composite resin overlays was treated according to manufacturer's recommendations (sandblasting with 50 µm aluminum oxide at 1–1.5 bar pressure; cleaning of the restoration in an ultrasonic bath with 70 % ethanol for 4 min).

The following subgroups were further considered based on the luting material ($n = 10$):

1) Resin cement group (RC): a universal adhesive (Scotchbond Universal Plus, 3 M) was applied on the bonding surface of the tooth replicas and on the inner surface of the overlays for 20 s, gently dispersed with air for 5 s and not polymerized (Fig. 3a and b). Then, a universal resin cement luting system (RelyX Universal, 3 M) was loaded into the restoration before the seating procedure on the specimens (Fig. 3c).
2) Pre-heated resin composite group (HC): an adhesive resin (Optibond FL, bottle 2, Kerr, Orange, CA, USA) was applied on the bonding surface of tooth replicas, gently dispersed with air and not polymerized (Fig. 4a). The bonding surface of the restoration was treated as follows: a layer of silane (Silane Primer, Kerr) was applied and let dry for 5 min at room temperature (Fig. 4b) followed by adhesive application (Optibond FL) as previously described (Fig. 4c). Lastly, a composite resin (Tetric Prime Cavifil A2, Ivoclar Vivadent) was heated for 5 min at 68 °C utilizing a composite heater (Caps Warmer; VOCO, Cuxhaven, Germany), and then loaded into the restoration before the seating procedure on the specimens (Fig. 4d).

The luting procedures and materials employed are reported in Table 2.

2.5. Seating accuracy analysis

During cementation, all specimens were placed on a flat stainless-steel base and the outline of their cubic base marked with a pencil to guide and repeat their precise positioning. The restorations were seated on the corresponding tooth replica and subjected to a constant 40 N load, axially applied thorough a parallelometer (A3502 ISO, Dentalfarm; Turin, Italy) with a 1 mm spherical stainless-steel tip positioned to the central hemisphere in the occlusal surface of the restorations (Figs. 3d and 4e) [26,27]. In the RC group, after verifying the correct seating of the restorations, excess material was tack-cured for 2 s on each surface using an LED unit (Elipar DeepCure-S LED Curing Light, 3 M ESPE) and subsequently removed with a periodontal scaler [28]. Then, the light curing was concluded with the same LED unit for 20 s on each surface. For the HC group, all excess material was meticulously removed with a periodontal scaler until no composite could be further removed before polymerization. Subsequently, the final light curing was conducted with the same LED unit as in the RC group for 20 s on each surface. Two digital scans were acquired for each specimen with a laboratory laser scanner (InEos X5, Dentsply Sirona), one at baseline (T0), with the overlay restoration in place without the interposition of the luting material, and the second one 24 h after the resin cement application and polymerization (T1).

For each specimen, the T0 and T1 STL files were superimposed and a specific software (Geomagic Qualify 12, Geomagic; North Carolina, USA) was used to evaluate differences in the seating accuracy taking into consideration the volumetric occlusal dimension increase and the average distance. To calculate the 3D changes at the different timelines, the T0 and T1 scans were first overlapped utilizing the cubic bases as reference and, then, T0 was subtracted from T1, using a boolean operation. The resulting volume was calculated, representing the occlusal dimension increase at the end of the cementation procedures (Fig. 5a and b).

The average distance calculated by the software after the overlapping, corresponds to a comparison of the two scans (T1 and T0),

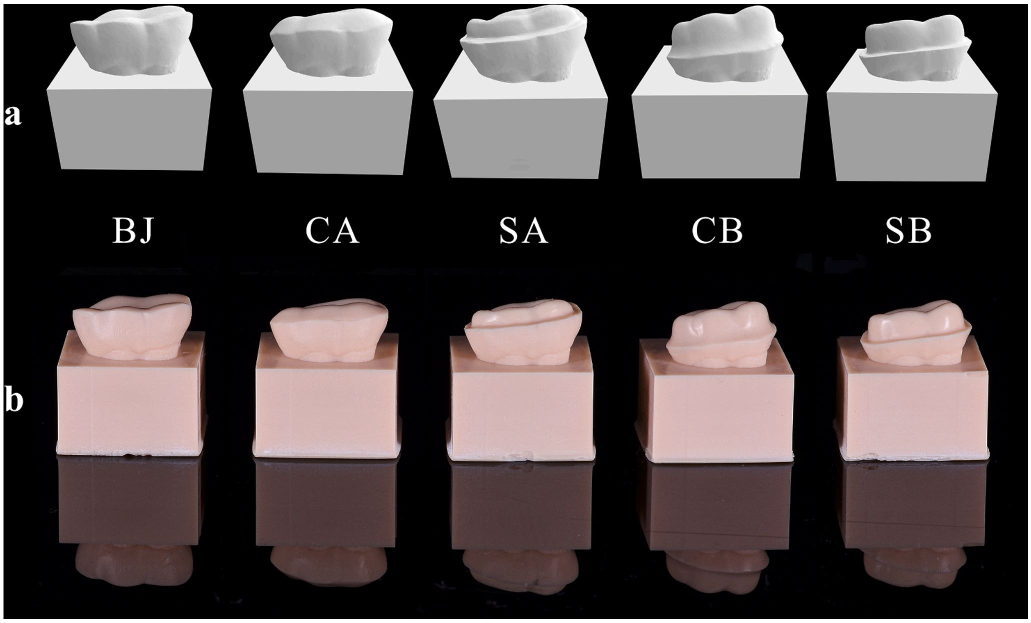


Fig. 1. a) Vestibular view of the STL file utilized to 3D print the tooth replicas with standardized preparations for indirect restorations.
b) Vestibular view of the high-definition 3D printed tooth replicas with standardized preparations for indirect restorations utilized as substrate for the cementation of indirect restorations. BJ: butt joint preparation above the maximum contour line of the dental equator; CA: chamfer preparation above the maximum contour line of the dental equator; SA: shoulder preparation above the maximum contour line of the dental equator; CB: chamfer preparation below the maximum contour line of the dental equator; SB: shoulder preparation below the maximum contour line of the dental equator.

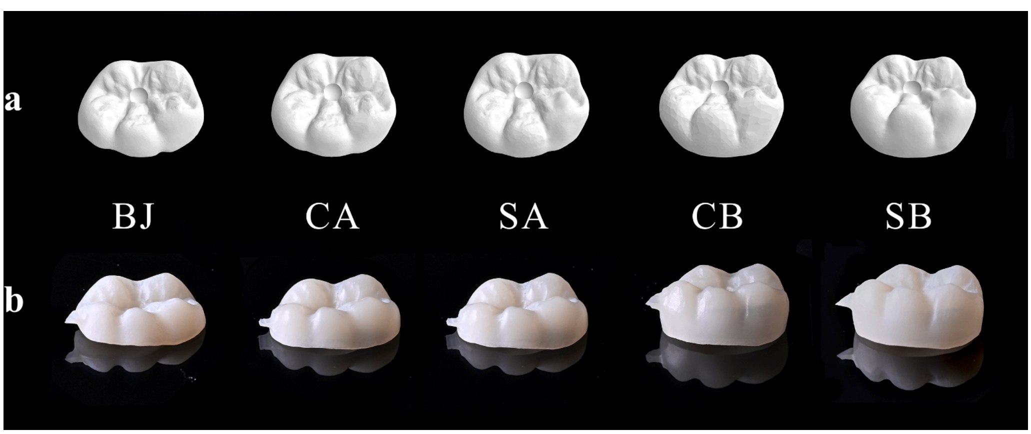


Fig. 2. a) STL files representing the design project for the overlays featuring a hemisphere positioned within the central fossa; b) Milled composite overlays following the various preparation designs;.

where the linear measurements starting from all the points in the scan T0 and ending in the corresponding points in the scan T1 represent the average distance measurements of the seating of the restoration before and after the cementation process (Fig. 6a and b).

The data for the occlusal dimension increase and average distance were normally and equally distributed (Shapiro-Wilk test and Brown-Forsythe test, respectively) ($p > 0.05$). Consequently, the statistical analysis was conducted with the two-way ANOVA and the Tukey post-hoc pairwise comparison to examine the influence of different finishing lines and luting materials on occlusal dimension increase and average distance. For all statistical analyses, the level of significance was pre-set at $p < 0.05$. All statistical analyses were performed using a specific software (Sigmaplot 14.0; Systat Software GmbH, Düsseldorf, Germany).

3. Results

The means and standard deviations of the linear and volumetric measurement for the preparation designs and luting materials are reported in Tables 3 and 4.

The type of luting material (RC vs HC), preparation design, and their interactions significantly influenced the 3D seating of the restorations ($p < 0.001$). HC resulted in a higher volumetric increase, irrespective of the preparation design utilized ($p < 0.001$). BJ and CA designs yielded a statistically significant higher volumetric seating accuracy when compared to the other preparation designs ($p < 0.05$).

The luting material significantly influenced the average distance irrespective of the preparation design utilized with RC performing better than HC ($p < 0.001$). Significant differences were found among the investigated preparation designs ($p = 0.023$) but not for their interaction with the luting material ($p = 0.155$). Specifically, BJ preparation determined a smaller average distance when compared with CA ($p =$

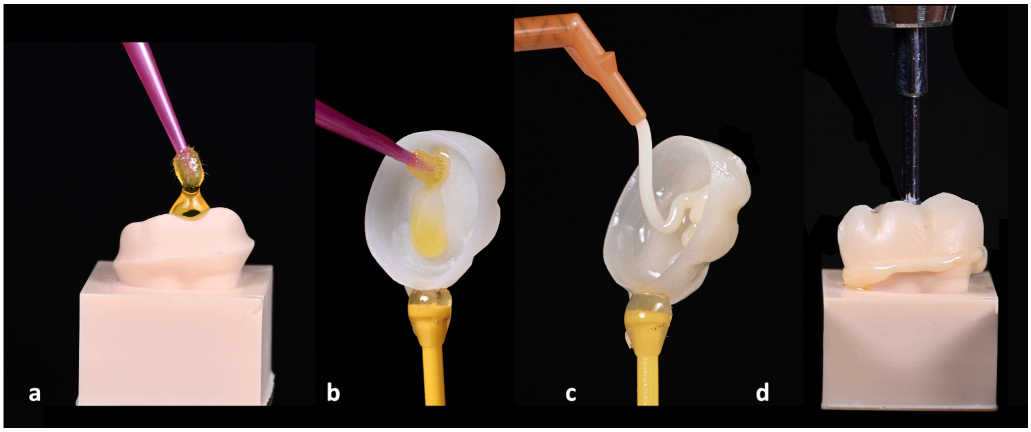


Fig. 3. Step-by-step procedure when the dual-cure universal resin cement was used in combination its universal adhesive system: a) application of the bonding agent (Scotchbond Universal Plus, 3 M) over the tooth replicas and b) on the inner surface of the overlay restoration; c) injection of the resin cement into the restoration (RelyX Universal, 3 M); d) seating of the overlays with a spherical stainless-steel tip.

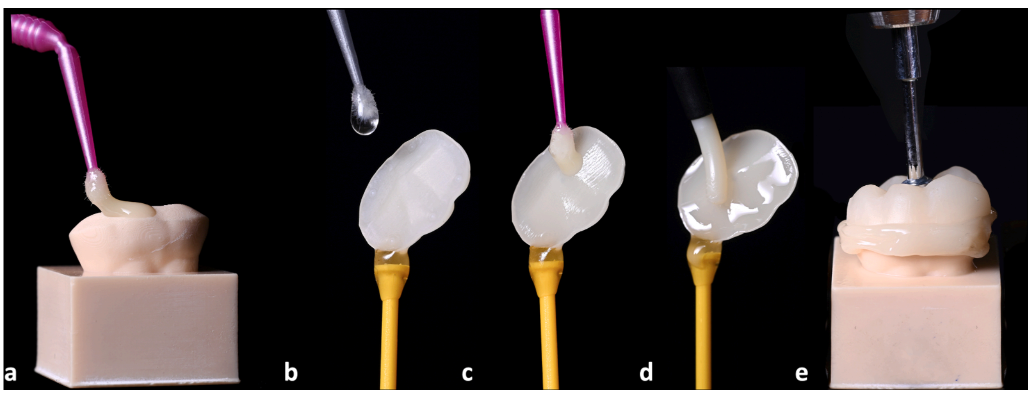


Fig. 4. Step-by-step procedure when the pre-heated composite resin was used: a) application of the bonding agent (Optibond FL, bottle 2, Kerr) over the tooth replicas; b) Silane application (Silane Primer, Kerr) on the inner surface of the overlay restoration; c) application of the bonding agent (Optibond FL) to the overlay restoration; d) pre-heated restorative composite resin (Tetric Prime Cavifil, Ivoclar Vivadent) dispensed into the restoration; e) seating of the overlays with a spherical stainless-steel tip.

Table 2
Details of the materials used in the study as provide by the manufacturers. The dual-cure universal resin cement (RelyX Universal) was used in association to its universal bonding system (Scotchbond Universal Plus), while the preheated resin composite (Tetric Prime Cavifil) was used after application of the adhesive resin (Bottle 2 of Optibond FL). The silane primer was used as restoration pretreatments before cementation. GMA: Glycidyl methacrylate; UDMA: urethane dimethacrylate; D3MA: 1,10-decanediol dimethacrylate; bis-EMA: bisphenol A diglycidyl methacrylate, BPA: bisphenol-A, HEMA: hydroxyethil methacrylate.

Material	Composition	Flexural strength (MPa)	Film thickness (μm)	Mean particle size (μm)	Filler content (% wt)
Dual-cure universal resin cement, RelyX Universal (3 M ESPE, Neuss, Germany)	Methacrylate monomers containing (or not) phosphoric acid groups; silanated fillers; Amorphous silica; initiator components, Ethanol; Water; stabilizers; pigments;	100	21	9.5	72 %
Preheated at 68 °C restorative composite resin, Tetric Prime Cavifil (Ivoclar Vivadent, Schaan, Liechtenstein)	Inorganic fillers; Dimethacrylates monomer matrix (GMA, UDMA, Bis-EMA, D3MA) copolymers; additives; initiators, stabilizers; pigments.	119	n/a	40 nm and 3 μm	77 %
Universal adhesive system, Scotchbond Universal Plus (3 M ESPE, Neuss, Germany)	Dimethacrylate resins contain a BPA derivative-free; HEMA; Filler; Phosphate Monomer; Mixture silane; Ethanol/water; Initiators; Dual cure accelerator;	n/a	10	n/a	n/a
Total-etch adhesive system, Optibond FL (adhesive Bottle 2)(Kerr, Orange, USA)	Adhesive: 2-hydroxyethil methacrylate; 3-trimethoxysily-propylmethacrylate; alkali fluorosilicate (n/a)	n/a	49	0,6	48 %
Coupling agent, Silane Primer (Kerr, Orange, USA)	Ethanol; metacrilates; prehydrolyzed silane.	n/a	n/a	n/a	n/a

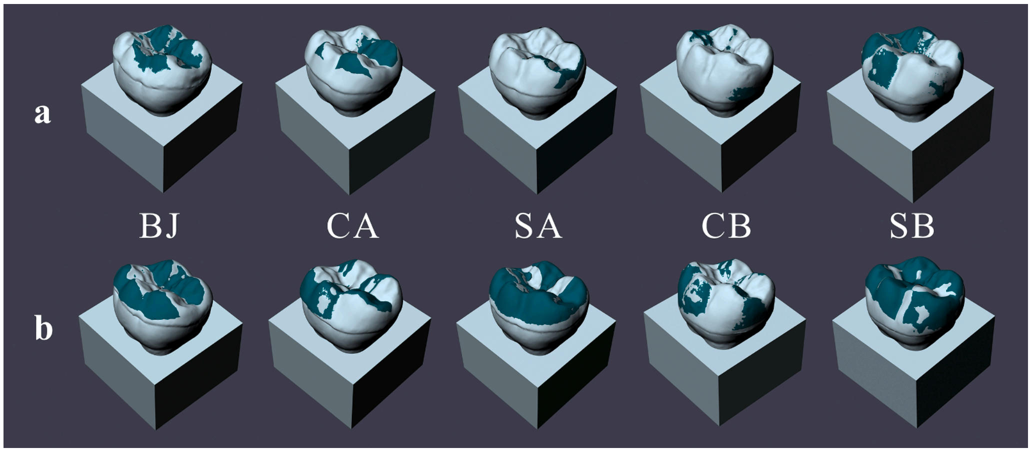


Fig. 5. Overlapped T0 and T1 scans for the different preparation designs. The dark green regions denote the resulting volume derived from the subtraction of the two scans representing the augmentation in occlusal dimensions subsequent to the luting procedures.

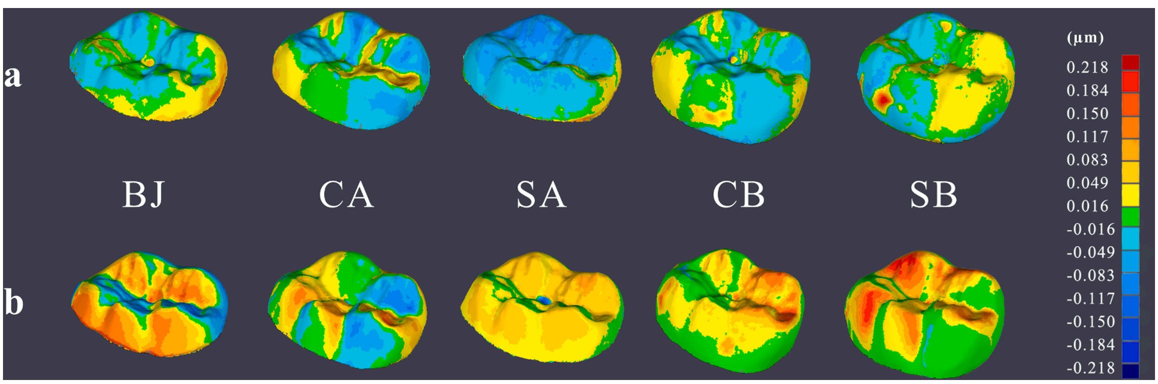


Fig. 6. Three-dimensional analysis for the average distance of overlapped T0 and T1 scans for the diverse preparation designs. Colored regions indicate the μm-scale spatial differential between the two scans.

Table 3
Mean average distance increase (μm) and standard deviation after cementation with resin cement or pre-heated resin composite.

Preparation design	Average Distance (μm)	
	Resin Cement	Pre-heated resin composite
Butt Joint	28.5 ± 6.1^{A,a}	61.4 ± 16.6^{A,b}
Chamfer above DE	51.3 ± 16.9^{A,a}	68.2 ± 11.5^{A,b}
Shoulder above DE	37.5 ± 13.8^{A,a}	72.8 ± 14.2^{A,b}
Chamfer below DE	30.1 ± 7.3^{A,a}	106.2 ± 31.7^{A,b}
Shoulder below DE	73.8 ± 13.4^{A,a}	97.4 ± 20.6^{A,b}

Different uppercase letters indicate statistical differences between finishing lines ($p = 0.05$).
Different lowercase letters indicate statistical differences between luting materials ($p = 0.05$).

Table 4
Mean volumetric increase (μm^3) and standard deviation after cementation with resin cement or pre-heated resin composite.

Preparation design	Volume (μm^3)	
	Resin Cement	Pre-heated resin composite
Butt Joint	2.14 ± 0.4^{A,a}	6.53 ± 1,8^{B,b}
Chamfer above DE	3.88 ± 2.3^{A,a}	7.49 ± 2.4^{B,b}
Shoulder above DE	3.02 ± 1.7^{A,a}	12.55 ± 2.8^{A,b}
Chamfer below DE	2.86 ± 1.3^{A,a}	12.55 ± 2.8^{A,b}
Shoulder Belo DE	2.87 ± 0.9^{A,a}	14.63 ± 3.7^{A,b}

Different uppercase letters indicate statistical differences between finishing lines ($p = 0.05$).
Different lowercase letters indicate statistical differences between luting materials ($p = 0.05$).

0,030) and SA ($p = 0,049$).

4. Discussion

The present findings indicate a statistically significant reduction in the overlay's adaptation in the pre-heated composite resin group, as observed in both 3D and linear analyses, regardless of the preparation design selected. Consequently, the first null hypothesis stating that "the seating accuracy of resin composite CAD/CAM overlays is not influenced by the type of luting system" was rejected. Significant differences were observed among the investigated preparation designs in the adaptation of the overlay restorations after luting. Consequently, the second null hypothesis which asserted that "the seating accuracy of resin composite CAD/CAM overlays is not influenced by the type of preparation design" must also be rejected.

As the success of indirect partial restorations is contingent upon a successful adhesive cementation, attempts have been directed towards optimizing the cementation process through the introduction of different materials and techniques, including the employment of pre-heated composite resins. The rationale behind the use of pre-heated composite resin relies in the possibility of exploiting the good mechanical properties of such material [29,30] along with increased shade options, diminished polymerization shrinkage, cost-effectiveness and improved fluidity due to the heating process [31]. However, composite resins exhibit greater film thickness than resin cements, potentially impeding the proper seating of indirect restorations, particularly in preparation designs characterized by steep axial walls and wide internal angles [5,8].

In this study, when HC was employed as the luting material across the different groups, overlay restorations displayed an increase in the average distance from the tooth ranging from 106 μm to 61 μm (Table 3). These findings align with those reported in literature [32–34], where the films created by pre-heated resins composite were 3 times thicker than those produced by dual-cure resin cements when using the same adhesive system and applied load [35]. Nonetheless, these materials are engineered to withstand occlusal and abrasive forces while maintaining their integrity over extended periods within the oral environment [36–38]. Then, a nominal increase of ≈100 μm at the luting space level may not pose issues in terms of survival and clinical function. However, such increase often necessitates occlusal adjustments on the restoration surfaces [8,9].

The maximum acceptable distance between the restoration and the tooth surface at the margins remains a topic of ongoing discussion and has yet to be conclusively determined. This study scrutinized alterations in the planned overlay positions (pre-cementation) and their post-luting placement, with subsequent calculation of the resulting volume changes. Clinically, this volumetric augmentation may manifest as static and/or dynamic occlusal interferences, thus requiring occlusal adjustment of the restorations. Notably, this would translate into clinical dissatisfactions, such as prolonged chairside time, patient's discomfort, weakening of the mechanical properties of the restorative materials (through microcracks formation and surface alterations) [39,40]. Subsequent further refinement of the surface through polishing, and optionally, re-glazing are indeed mandatory to enhance the mechanical integrity and wear performances of manually adjusted restorations [41,42].

Regarding the second factor examined in this study, significant differences were observed among the various preparation designs. However, although significant disparities were identified when comparing different finishing lines in the group cemented with HC, no differences were found when RC was utilized (Table 4). In particular, the highest volumetric increment was observed in the preparations performed below the dental equator (CB and SB) luted with HC.

During the cementation of bonded restorations, the axial walls of the preparation approach the axial walls of the internal surface of the restoration. The escape path for the cement is limited and the hydrostatic pressure within the restoration increases until it matches the seating pressures [43]. Accordingly, the longer axial walls of the CB and SB groups might have determined an increase in the friction between the opposing internal surfaces of the tooth and the restorations, hindering the overflow of the resin cement, especially with a more viscous material, such as the HC. Following this principle, BJ and CA preparation designs, that do not incorporate steep axial walls, have been the designs that demonstrated the best seating accuracy among the preparation designs, irrespective from the luting material utilized. In particular, the BJ determined the lowest increment in the volumetric and average linear measurement both for the RC and HC groups. However, although BJ has been found to be the most reliable preparation to achieve a precise cementation, it may not be as suitable for restorations in the aesthetic area as the CA. It has been reported how from an aesthetic point of view, the presence of a flat finishing margin does not allow good translucency and camouflage of the restoration at the interface with the dental substrate [21]. In light of these considerations, in terms of seating accuracy of partial restorations, it would be desirable, whenever possible, to execute preparation above the dental equator, avoiding internal angles as in the rounded shoulder preparation, especially when utilizing more viscous materials such as HC. This concept is also supported by the evidence that these kinds of designs require less invasive tooth preparation, orienting toward a more conservative approach during the rehabilitation [25]. When confronting the two preparations below the dental equator (CB and SB), no differences in terms of seating accuracy were found regardless of the cementation technique (Table 3 and 4).

Studies evaluating the effect of finishing line designs on the marginal and internal adaptations of complete coverage restorations have produced diverse and sometimes conflicting results [44–47]. In the systematic review of Yu et al. [16], ceramic crowns with chamfers exhibited significantly better internal adaptation than those with rounded shoulders. The relatively better seating (smaller internal gap) of restorations with chamfer preparation appeared to correlate with their poor marginal sealing (greater marginal gap) [16]. A smaller internal space may lead to premature contact between the internal surface of the restoration and the preparation and hinder the cement evacuation, possibly widening the marginal gap [48]. These results are in contrast with those emerged from our study. However, it should be considered that the effect of finishing line designs on marginal and internal adaptations of partial coverage restorations could be different because the cement escape might be better with a partial coverage restoration than in full crown restorations as previously investigated. To the best of author's knowledge, no studies have been performed assessing the seating accuracy of partial restorations in relation to their preparation designs.

Novelty of the present study is the realization of the high-definition 3D-printed replicas starting from real teeth through the use of scans obtained by Micro-CT. This, unlike similar studies in which resin teeth of the Typodont type were used [5,32], allowed for a more realistic representation of the tooth anatomy, and to analyse at the microscopic level the different structures and components within the tooth element examined. In this study standardized preparations for partial restorations with different finish line designs were performed on the tooth replicas, and this prepared samples were then transformed into STL files. From each STL file of the five prepared specimens, the specimens were then printed. This allowed the 20 partial restorations per group to be fabricated with the same cavity configuration, thus decreasing the variation within each group of finish line preparations during the cementation procedures. Moreover, the 3D analysis allowed to assess the occlusal increment after the cementation not just as vertical increment, but as a volume, with the chance of a better understanding of the three-dimensional effects of the luting material or finishing line choice.

In the current investigation, only a single sound lower first molar was employed as model to reproduce all the 3D-printed replicas. This represents a significant limitation to the research since it hinders the possibility to extrapolate the data obtained to other teeth, such as upper molars or premolars. The decision to select solely one sound tooth was intended to reduce as much as feasible the individual anatomical variability. Performing all the preparations on the same shaped tooth minimized the heterogeneity among groups, allowing to perform the analysis with different preparation designs while retaining micrometric precision at the finish-line margins and over the internal angles and it helped the alignment and comparisons among all the groups examined.

Even though in a minimally invasive and esthetically driven preparation designs, different finishing line designs may be used in different areas of the tooth, in the present study the same preparation was circumferentially performed in each tooth model. This choice, that somehow could be considered a limitation, was instead intentionally made to standardize the study protocol as the main focus of the study was to better understand whether a particular preparation has a discernible impact on the restoration seating compared to another.

The presented results suggest to refrain from employing pre-heated restorative composite resin materials as luting agent for overlays in terms of seating accuracy. However, it should be pointed out that in this study only one composite resin was employed. Alternative materials might present different viscosity and film thickness, also reacting differently to the pre-heating process [8]. Further studies are needed to evaluate the cementation behaviour of different materials with alternative luting techniques.

5. Conclusions

Within the limitations of this study, it can be concluded that the use of pre-heated composite resin could negatively influence the seating of overlay restorations, probably due to its higher viscosity when compared to the resin cement. When, however, the pre-heated composite resin is selected as luting agent, preparation designs lacking internal angles, such as butt joint or chamfer finishing lines, are recommended for enhancing the precision of overlays seating. Further research on diverse luting materials is warranted for comprehensive understanding of their performance with different finishing lines.

CRediT authorship contribution statement

Edoardo Mancuso: Writing – original draft, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Tina Gasperini:** Writing – review & editing, Software, Methodology, Data curation. **Tatjana Maravic:** Writing – review & editing, Visualization, Validation, Supervision, Formal analysis. **Claudia Mazzitelli:** Writing – review & editing, Visualization, Validation, Supervision, Data curation. **Uros Josic:** Writing – review & editing, Investigation, Data curation. **Annamaria Forte:** Writing – review & editing, Visualization, Methodology, Investigation. **João Pitta:** . **Annalisa Mazzoni:** Writing – review & editing, Validation, Supervision, Resources, Project administration. **Vincent Fehmer:** Writing – review & editing, Supervision, Funding acquisition. **Lorenzo Breschi:** Writing – review & editing, Supervision, Resources, Project administration, Funding acquisition. **Irena Sailer:** Writing – review & editing, Validation, Resources, Project administration, Investigation, Funding acquisition.

Declaration of competing interest

The authors declare no conflict of interest.

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