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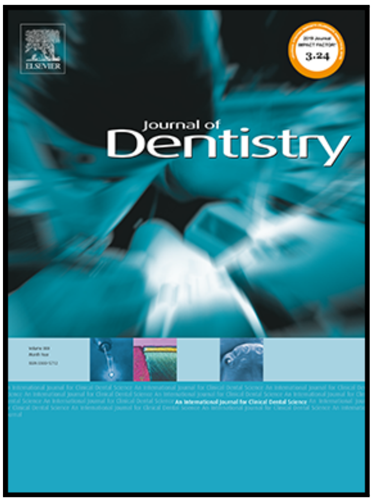

Fabrication trueness and margin quality of additively manufactured resin-based definitive laminate veneers with different restoration thicknesses

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Original article

Full Title: Fabrication trueness and margin quality of additively manufactured resin-based definitive laminate veneers with different restoration thicknesses

Short title: Effect of thickness on printed laminate veneers

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ABSTRACT

Objectives: To evaluate how restoration thickness (0.5 mm and 0.7 mm) affects the fabrication trueness of additively manufactured definitive resin-based laminate veneers, and to analyze the effect of restoration thickness and margin location on margin quality.

Methods: Two maxillary central incisors were prepared either for a 0.5 mm- or 0.7 mm-thick laminate veneer. After acquiring the partial-arch scans of each preparation, laminate veneers were designed and stored as reference data. By using these reference data, a total of 30 resin-based laminate veneers were additively manufactured (n=15 per thickness). All veneers were digitized and stored as test data. The reference and test data were superimposed to calculate the root mean square values at overall, external, intaglio, and marginal surfaces. The margin quality at labial, incisal, mesial, and distal surfaces was evaluated. Fabrication trueness at each surface was analyzed with independent t-tests, while 2-way analysis of variance was used to analyze the effect of thickness and margin location on margin quality (α=.05).

Results: Regardless of the evaluated surface, 0.7 mm-thick veneers had lower deviations (*P*<.001). Only the margin location (*P*<.001) affected the margin quality as labial margins had the lowest quality (*P*<.001).

Conclusion: Restoration thickness affected the fabrication trueness of resin-based laminate veneers as 0.7 mm-thick veneers had significantly higher trueness. However, restoration thickness did not affect the margin quality and labial margins had the lowest quality.

Clinical Significance: Laminate veneers fabricated by using tested urethane-based acrylic resin may require less adjustment when fabricated in 0.7 mm thickness.

However, marginal integrity issues may be encountered at the labial surface.

1. INTRODUCTION

Since the 1980s, laminate veneers have been one of the most popular and conservative treatment options for anterior teeth due to their ability to replicate natural appearance, superior esthetics, and high success rates [1]. In addition, the development of new restorative materials has enabled the fabrication of esthetically pleasing, minimally invasive ultrathin laminate veneers (0.3 mm–0.5 mm) that require minimal or no tooth preparation [2-4]. However, the difficulty of achieving adequate margin quality, tedious clinical positioning and intraoral procedures, the need for additional finishing and polishing to achieve a smooth transition without overhangs, and being more prone to fracture than thicker veneers are the disadvantages of ultrathin laminate veneers [5]. Therefore, material thickness and tooth preparation can affect the long-term prognosis of laminate veneers and their final esthetics [6-8], and the clinical question of whether thinner or thicker laminate veneers can be fabricated with adequate fabrication accuracy and margin quality is pertinent.

Material type and manufacturing method also plays a crucial role in the durability and esthetic appearance of laminate veneers [8-10], which are often heat-pressed or subtractively manufactured [11-14]. Given that the vibration of milling instruments may fracture thin laminate veneers and the fabrication trueness and fit depends on milling instrument's diameter [11-14], heat pressing is generally preferred over subtractive manufacturing for thin laminate veneers [12-14]. However, heat pressing is a technique-sensitive process that is more prone to human error [6, 11]. Considering these disadvantages, additive manufacturing may be a suitable alternative to these methods as it provides faster fabrication, causes less material waste, and enables the fabrication of thin restorations and complex structures [5, 15]. In addition, advancements in additive manufacturing technologies have facilitated laminate veneer fabrication in definitive resin or lithium disilicate glass-ceramic [11, 16]. Nevertheless, using resins to fabricate definitive laminate veneers may be more practical as additive manufacturing of lithium disilicate glass ceramic can be costly given that a proprietary 3-dimensional (3D) printer is needed and the postprocessing stage is more complicated than that of resins manufactured to be used for definitive restorations [16-18]. Therefore, additive manufacturing of definitive laminate veneers by using resins may be a cost-effective and straightforward alternative to other techniques.

High fabrication trueness can lead to optimal fit, prevent the need for internal and external adjustments, and ensure long-term clinical success [19, 20]. Considering the layer-by-layer fabrication principle of additive manufacturing [16-18], material thickness may affect the fabrication trueness and the margin quality of the printed object [21]. Previous studies on restorations fabricated by using additively manufactured definitive resins have mainly focused on crowns and fixed partial dentures [17, 18, 22-30], and the authors are aware of 4 studies that evaluated additively manufactured laminate veneers [11, 31-34]. However, only two of those studies focused on additively manufactured laminate veneers in definitive resins [33, 34]. Additively manufactured laminate veneers should be evaluated for their different properties before clinical application, and investigating their fabrication trueness in different clinical situations that involve different restoration thicknesses may be beneficial to make interpretations on their fit and possible complications that could be encountered.

Therefore, the purpose of this study was to evaluate how the restoration thickness (0.5 mm and 0.7 mm) affects the fabrication trueness and margin quality of additively manufactured definitive resin-based laminate veneers. In addition, the effect of margin location on margin quality of these veneers was investigated. The null hypotheses were that i) the restoration thickness would not affect the fabrication trueness and ii) the restoration thickness and margin location would not affect the margin quality of additively manufactured definitive resin-based laminate veneers.

2. MATERIAL AND METHODS

Two identical maxillary central incisor typodont teeth (AG-3; Frasaco GmbH, Tettnang, Germany) were prepared either for a 0.5 mm-thick or 0.7 mm-thick laminate veneer. A silicone index (Optosil Comfort Putty; Heraeus Kulzer, Hanau, Germany) was prepared for both teeth to verify preparation depth. Both teeth were prepared with a 0.3 mm-thick supragingival chamfer finish line, which was placed 0.5 mm above the gingiva and did not extend beyond the interproximal surfaces (JOTA efficient veneer prep kit 1443; JOTA AG, Rüthi, Switzerland) [35, 36]. The incisal edge was reduced for 1.5 mm and had a bevel. Preparation depth was verified by using the silicon indexes and a periodontal probe (CP 15 UNC; HU-Friedy, Rotterdam, the Netherlands). After the preparation, surfaces were polished by using a brown polisher (LS9871M; JOTA AG, Rüthi, Switzerland). An intraoral scanner (Trios 3; 3Shape A/S, Copenhagen, Denmark) was used to perform a partial-arch scan that involved the area from the right second premolar to the left second premolar for each preparation design. The palate was not scanned and the sequence of the scans was palatal, occlusal, and buccal [37]. Both scans were performed in a humidity- and temperature-controlled room, which was daylight-lit, by a single experienced operator (D.Y.). These scans were then exported as standard tessellation language (STL) files to design laminate veneers by using a dental design software program (DentalCAD 3.0 Galway; exocad GmbH, Darmstadt, Germany). Both laminate veneers were designed with a 25-µm cement gap and 0.4-mm minimal restoration thickness. Restoration thicknesses were verified by using the “cutting section tool” of the software program (Fig 1), and the designs were then exported as reference-laminate veneer STLs (RLV-STLs).

For each thickness, 15 laminate veneers were additively manufactured by using a urethane acrylate-based definitive resin (Tera Harz TC-80DP; Graphy, Seoul, Korea) (Fig. 2), considering the priori power analysis (for %95 CI (1-α), power= 95% (1-β), and effect size [f] =0.623) [17]. RLV-STLs were imported into a nesting software program (Composer; Asiga, Sydney, Australia) and positioned perpendicularly on the build platform. After automatically generating the supports, this orientation was duplicated 15 times for each thickness. A digital light processing (DLP) 3-dimensional (3D) printer (MAX UV; Asiga, Sydney, Australia) was used to fabricate the laminate veneers with a constant layer thickness of 50 µm. After printing, laminate veneers were left to drip excess resin for 10 min, and then ultrasonically cleaned for 45 s in 96% ethanol (Ethanol absolut; Dr. Grogg Chemie AG, Stetten, Switzerland) followed by cleaning with a 96% ethanol-soaked cloth. After air drying, laminate veneers were polymerized with a xenon polymerization device (Otoflash G171, NK-Optik GmbH, Baierbrunn, Germany) under nitrogen oxide gas atmosphere by applying a total of 4000 lighting exposures (2×2000 exposures). The support structures were removed under magnification loupes (EyeMag Pro; Carl Zeiss, Oberkochen, Germany) and no additional adjustments were made. The same experienced operator digitized each laminate veneer by using another intraoral scanner (CEREC Primescan SW 5.2; Dentsply Sirona, Bensheim, Germany) in the same humidity- and temperature-controlled room within 24 hours after fabrication, considering time-dependent dimensional changes. The labial surface of the laminate veneers was scanned initially and each laminate veneer was held with an adhesive tip applicator (Micro Stix; Microbrush International, Grafton, WI, USA) attached to the distoincisal edge during the scans. The applicator was attached to the mesioincisal edge after the entire laminate veneer was scanned, the image of the adhesive tip at the distoincisal edge was virtually removed, and that region was scanned. All scans were performed over a black background to facilitate the scans considering the translucency of the laminate veneers. The digitization of laminate veneers was randomized by using the randomization function of a software program (Excel; Microsoft Corp, Seattle, WA, USA). The intraoral scanner was calibrated in every 5 veneers and the operator took a 5-min rest in every 5 veneers. After all scans were completed, they were exported as test scan STLs (TLV-STLs).

An experienced operator (G.C) performed the trueness analyses by using a metrology-grade 3D analysis software program (Geomagic Control X; 3D Systems, Rock Hill, SC, USA). RLV-STLs were imported individually, and virtually segmented into regions (overall, external, intaglio, and marginal surfaces) [38] to analyze 3D deviations of these surfaces in addition to overall surface deviation (Fig. 3). After segmentation, each file was saved as templates for standardized analyses and the TLV-STLs were superimposed over their respective template by using initial and iterative closest point-based best-fit alignment to avoid operator-related errors. After superimposition, the “3D Compare Tool" of the software program was used and color maps (+100 µm/-100 µm maximum/minimum deviation values and +10 µm/-10 µm tolerance range) were generated to automatically calculate the root mean square (RMS) values at each surface (overall, external, intaglio, and marginal surfaces) [33].

A stereomicroscope (SMZ445/460 Stereoscopic Zoom Microscope; Nikon Corp, Tokyo, Japan) was used to qualitatively evaluate the labial, incisal, mesial, and distal surface margin qualities. The stereomicroscope images of all laminate veneers were taken under ×60 magnification and scored by using a previously described 3-point scale [33, 39]. According to this scale, “3” referred to a smooth edge with no defect (high quality), “2” referred to a slightly rough edge-like wave (medium quality), and “1” referred to a rough edge-resembling layer with some defects (low quality) (Fig. 4). The average margin quality of all surfaces was calculated for each laminate veneer.

Descriptive statistics on the measured data were calculated and the distribution was evaluated by the Kolmogorov-Smirnov test, which was a normal distribution. The effect of thickness on the RMS values measured at each surface was analyzed with independent t-tests, while 2-way analysis of variance and post-hoc Scheffé tests were used to evaluate the effect of thickness and margin location on margin quality. All analyses were performed by using a statistical analysis software (SPSS v23; IBM Corp) with a significance level of α=.05.

3. RESULTS

The deviations measured at the overall, external, intaglio, and marginal surfaces of 0.7 mm-thick veneers were significantly lower than those of 0.5 mm-thick veneers ($P<.001$). The difference in the RMS value between two groups was the largest at the marginal surface and the smallest at the external surface (Table 1). The mean RMS value was the highest at the marginal surface of 0.5 mm-thick veneers, while it was the highest at the external surface of 0.7 mm-thick veneers. The smallest RMS value of 0.5 mm-thick veneers was at the external surface, while that of 0.7 mm-thick veneers was at the intaglio surface (Table 1).

The color maps revealed that the orange and red areas, which indicate overcontoured areas, were more prominent in 0.5 mm-thick laminate veneers (Fig. 5). Even though blue areas, which are considered as undercontoured areas, were more prominent at the middle third of the intaglio surface of 0.5 mm-thick laminate veneers, overcontoured area was evident at its incisal and the gingival thirds. In addition, red-colored area was dominant at the labial margin of 0.5 mm-thick laminate veneers. On the contrary, the 0.7 mm-thick laminate veneers prominently showed yellow (slightly overcontoured) to light blue (slightly undercontoured) areas.

Two-way ANOVA showed that only the evaluated surface had a significant effect on the quality of margins ($P<.001$). Labial surface had a mean margin quality of 2.2, which was the lowest quality among evaluated surfaces ($P<.001$). However, the mean margin quality of other surfaces was 2.8 (mesial and distal) and 2.9 (lingual), and the differences among other surfaces were nonsignificant (*P*≥.563) (Table 2).

4. DISCUSSION

The present study analyzed how fabrication trueness and margin quality of additively manufactured definitive resin-based laminate veneers were affected by the restoration thickness, while the effect of margin location on margin quality was also assessed. The first null hypothesis was rejected as 0.7 mm-thick laminate veneers had significantly higher fabrication trueness (lower deviation) than 0.5 mm-thick laminate veneers, regardless of the evaluated surfaces. The second null hypothesis was also rejected as even though restoration thickness did not affect the margin quality of tested laminate veneers, labial margins had the lowest quality. The differences between the RMS values of 0.5 mm-thick and 0.7 mm-thick veneers ranged from 33.1 µm to 62.3 µm among tested surfaces. Considering that RLV-STL had a standardized 25-µm cement gap and 0.4-mm minimum thickness, these deviations might affect the internal fit to the prepared surfaces. As shown in the color maps, it can be speculated that the overcontoured area may lead to some misfit and require adjustments. The distortion of tested laminate veneers during polymerization may be associated with the distinct difference in the color maps. In addition, even though there was no significant difference between tested laminate veneers when external surface deviations were considered, the mean difference was 19.5 µm and the color maps indicate that 0.5 mm-thick laminate veneers may lead to esthetic complications due to overcontouring at the middle third, and would require adjustments.

A recent study on the fabrication trueness (external, intaglio, and marginal) and margin quality (cervical, incisal, mesial, and distal) of 1 mm-thick laminate veneers has also tested the additively manufactured resin used in this study while making comparisons among additively and subtractively manufactured laminate veneers in different materials [33]. The authors [33] have concluded that additively manufactured laminate veneers mostly had higher trueness than subtractively manufactured laminate veneers. The mean deviation values of the resin tested in the present study ranged between 51 µm and 77 µm in that study, and margin quality results and color maps were parallel to those of the present study. In another study on the fabrication trueness and margin quality of additively manufactured laminate veneers, it was concluded that subgingival margins led to lower trueness than equigingival and supragingival margins, and the intraoral scanner used for digitization mainly affected fabrication trueness of laminate veneers with subgingival margins and the cervical margin quality [34]. Other previous studies on additively manufactured laminate veneers have focused on their fit rather than their fabrication trueness or margin quality [11, 31, 32]. Two of those studies have reported acceptable marginal fit, which was similar to that of subtractively manufactured laminate veneers, when laminate veneers were fabricated in lithium disilicate and zirconia [11, 32]. However, Sampaio et al. [31] concluded that additively manufactured laminate veneers in interim restorative material had higher cement thickness than those that were subtractively manufactured. This may indicate the effect of material type on the fabrication of additively manufactured laminate veneers. Previous studies on the fabrication trueness of restorations fabricated by using additively manufactured definitive resins have reported mean deviations ranging from 9.93 µm to 116 µm [17, 26, 28-30]. Even though the resin tested in the present study was not involved in any of those previous studies [17, 26, 28-30], the deviations measured in the present study are within the range of those studies.

In this study, the margin quality of laminate veneers was not affected by the restoration thickness; the labial margin had the lowest quality, regardless of the veneer thickness. This may be related to the nature of additive manufacturing as unlike subtractive manufacturing, this method does not involve burs and bur-related manufacturing limitations do not apply here. Rues et al. [32] have also emphasized this aspect as they associated this difference between manufacturing methods to the higher marginal fit of additively manufactured veneers at the incisal edge compared with that of subtractively manufactured veneers. However, it is rather interesting that labial margins had the lowest quality, particularly considering that they were positioned supragingivally and greater thickness of the labial margin compared with those located at the mesial and distal may have minimized the potential effect of scanning inaccuracy. Therefore, significantly lower margin quality at the labial surface may be related to the fabrication process and the possible abovementioned distortion during the polymerization process as 0.7 mm-thick laminate veneer also had a similar color trend at the intaglio surface color map to that of the 0.5 mm-thick laminate veneer, but with smaller magnitude. In addition, overcontoured areas were prominent at the labial margin, whereas a range of colors from dark blue to light blue was more evident at the other margins. Another factor that may be associated with the low margin quality of labial margins may be the 50 µm-thick layer thickness, and layer thicknesses smaller than 50 µm may increase the margin quality, particularly at thin areas. It should also be mentioned that the qualitative margin evaluation performed in the present study that was adopted from previous studies [33, 39] is operator-dependent.

Previous studies on the fabrication trueness of additively manufactured restorations in definitive resins have also involved an intraoral scanner to digitize restorations and a metrology-grade 3D analysis software program to perform trueness analysis by comparing the scan data with the CAD data [17, 26, 28]. However, a laboratory scanner was also used in 2 recent studies while evaluating the fabrication trueness of additively manufactured definitive resin crowns [29, 30]. Nevertheless, it should be emphasized that only intaglio surface was assessed in those studies [29, 30] and using a high accuracy [40, 41] intraoral scanner enabled digitization of laminate veneers in one complete motion, which eliminated stitching of separate external and intaglio surface scans and possible amplification of measured deviations that could be encountered while using a laboratory scanner. The 3D analysis software program used in the present study was reported to have high reproducibility [41] and has also been indicated by the International Organization of Standardization standard 12836 [43] and therefore, represents the standard for such analyses. CAD data was deliberately chosen as the reference in the present study as the purpose of the manufacturing process is to fabricate the design as unchanged as possible, the CAD data is the ideal comparison for trueness analyses [38]. Even though previous studies on additively manufactured prostheses have also used the same 3-point scale [33, 39], there is no uniform rating scale for the evaluation of margin quality. Therefore, this scale should be adapted in future research for comparisons among different studies and to validate its applicability.

A limitation of the present study was that the preparations were performed on typodont teeth, which have different surface texture and optical properties than a natural tooth. Both preparations had supragingival finish lines with standardized 1.5-mm incisal edge reduction and different clinical situations that involve subgingival or equigingival finish lines and preparation designs may affect measured deviations and margin quality. In addition, a single intraoral scanner was used to digitize the preparations and laminate veneers, and different scanners may lead to different results. The laminate veneers were fabricated by using a single definitive resin and one 3D printer. In addition, other printing parameters that may affect the fabrication trueness such as layer thickness [38, 39] and printing orientation [29, 30] were not evaluated. Another limitation was that only 0.5 mm- and 0.7 mm-thick laminate veneers were investigated. Even though the fabrication trueness and margin quality of laminate veneers have clinical relevancy, the present study did not involve their fit on abutment teeth or other properties that are also critical for long-term stability. Therefore, future studies should focus on the fit and mechanical and optical properties of additively manufactured definitive resin-based laminate veneers in different thicknesses, particularly after mechanical and thermal aging, to broaden the knowledge on their limitations and applicability.

5. CONCLUSIONS

Within the limitations of this in vitro study, following conclusions were drawn:

1. The restoration thickness can significantly affect the fabrication trueness of resin-based additively manufactured definitive laminate veneers; 0.7 mm-thick veneers had higher trueness.
2. The margin quality of resin-based laminate veneers was not affected by the restoration thickness and the lowest quality was reported on the labial margin.

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TABLES

Table 1. Descriptive statistics (mean ±standard deviation) of deviation values (µm) of each thickness condition at different evaluated surfaces.

	Thickness	
Evaluated surface	0.5 mm	0.7 mm
Overall	69.9 ±17.4^{A}	36.8 ±3.1^{B}
External	59.5 ±12.7^{A}	40.0 ±4.2^{B}
Intaglio	69.1 ±12.7^{A}	28.1 ±3.7^{B}
Marginal	98.2 ±33.7^{A}	35.9 ±5.2^{B}

Different superscript uppercase letters in same row indicate significant differences among groups (P<.05)

Table 2. Descriptive statistics (mean ±standard deviation) of margin quality of each thickness-location pair

	Thickness		
	0.5 mm	0.7 mm	Total
Labial	2.1 ±0.3	2.4 ±0.5	2.2 ±0.4^{A}
Lingual	2.8 ±0.4	3.0 ±0	2.9 ±0.3^{B}
Mesial	2.8 ±0.4	2.7 ±0.5	2.8 ±0.4^{B}
Distal	2.7 ±0.5	2.8 ±0.4	2.8 ±0.4^{B}

Different superscript uppercase letters indicate significate differences in columns. Total values are derived from the pooled data of each surface evaluated ($P<.05$)

FIGURES

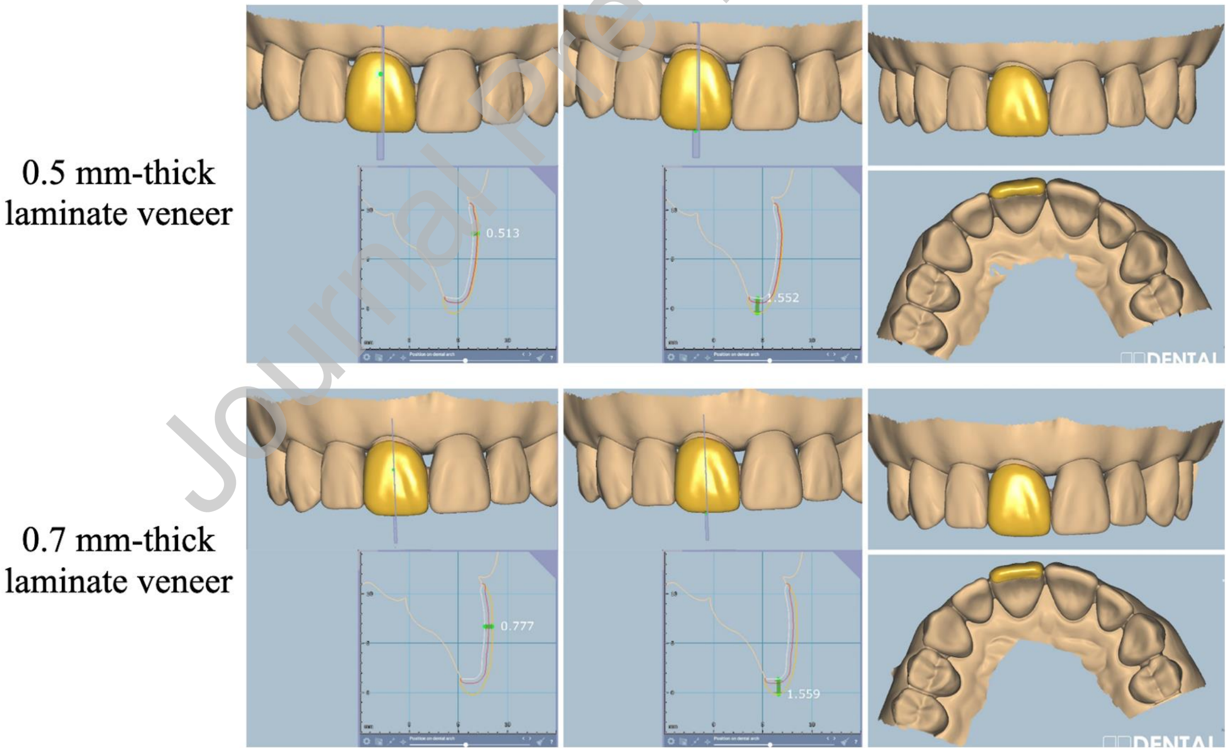


Figure 1. Laminate veneer designs for 0.5 mm- and 0.7 mm-thick laminate veneers

Figure 2. Definitive resin-based laminate veneers after fabrication

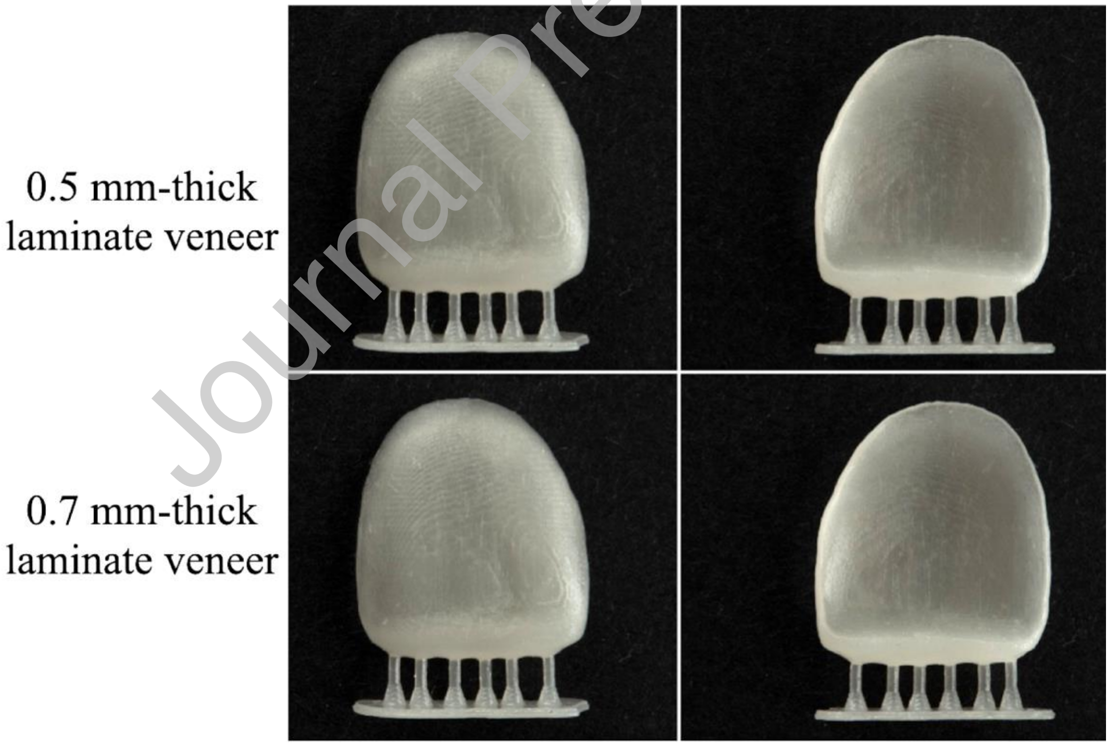


Figure 3. Virtually segmented external, intaglio, and marginal surfaces of reference standard tessellation language file.

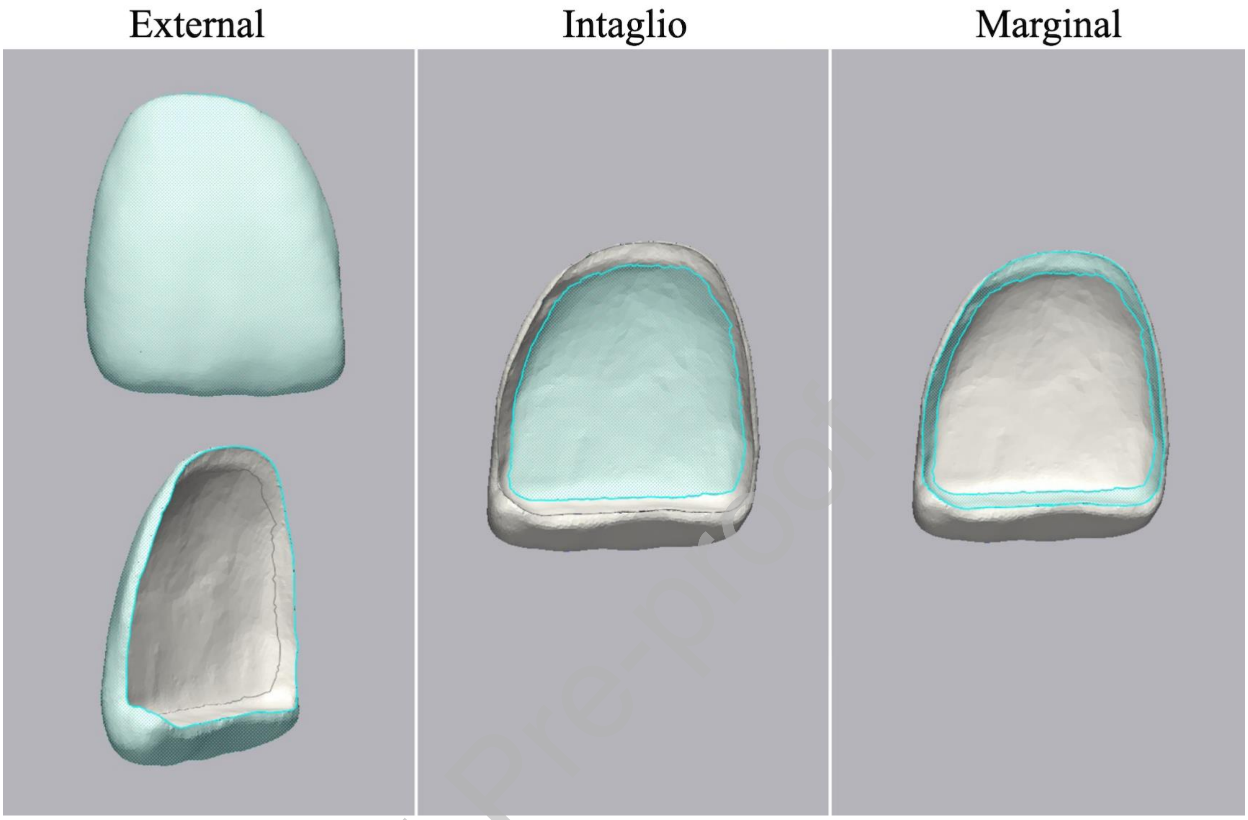


Figure 4. Representative stereomicroscope images used to evaluate margin quality of tested laminate veneers. Three-point scale used ranged from 3 (high marginal quality) to 1 (low marginal quality) and images show labial margin quality.

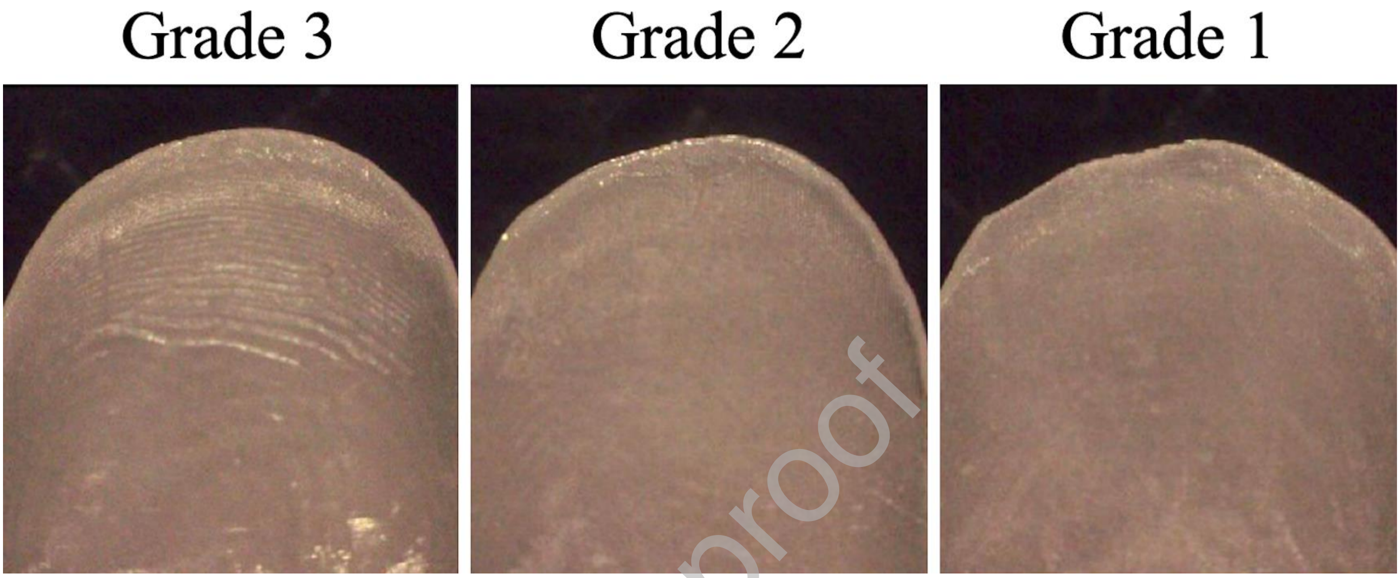
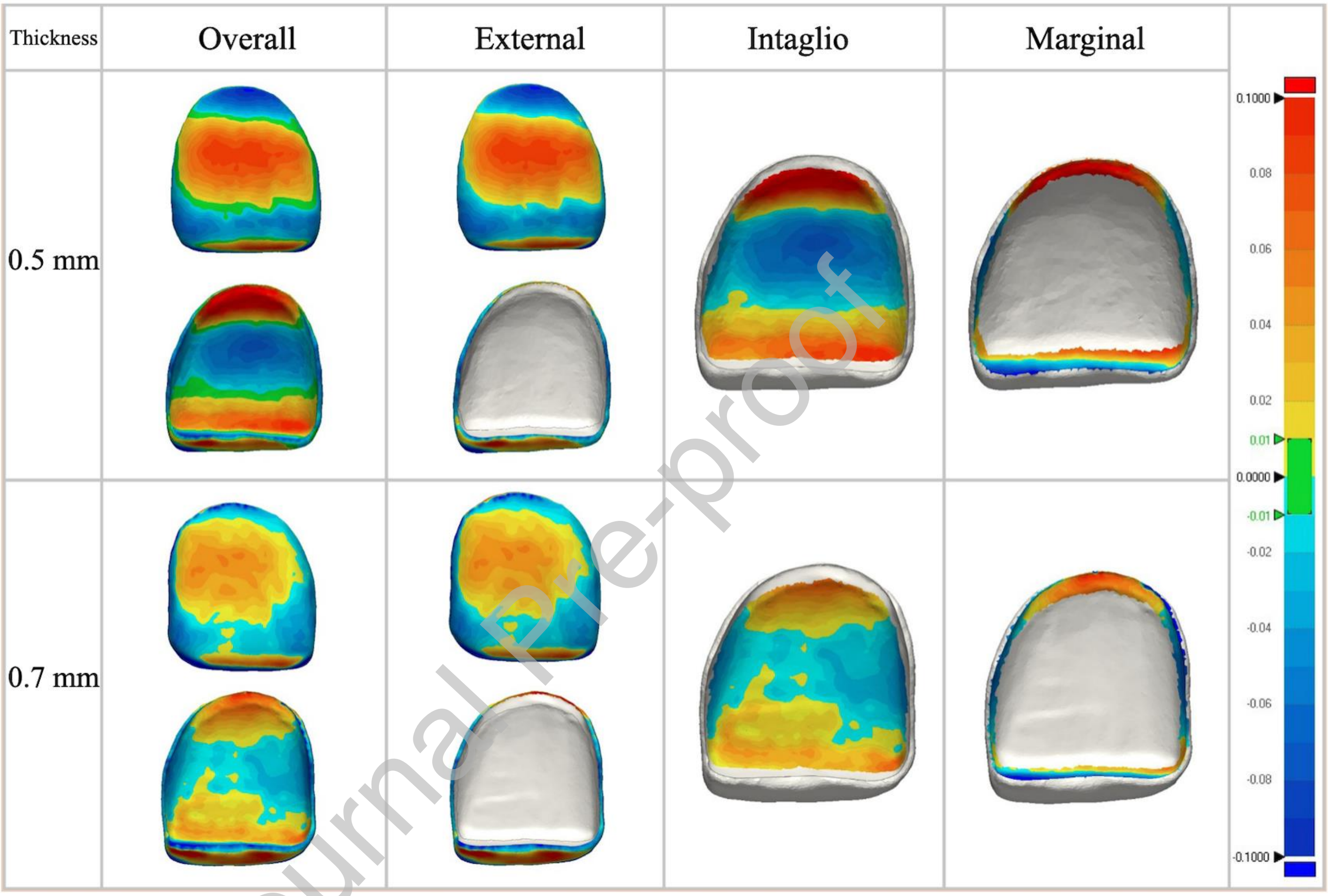


Figure 5. Representative color maps of each thickness-surface pair. Overcontoured areas are indicated in red color, while undercontoured areas are indicated in blue color green. Deviations within tolerance range are represented in green color.



The authors of the manuscript contributed in the following ways to the submitted manuscript:

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Declaration of interests

☒ The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

☐The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: