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RESEARCH AND EDUCATION

Influence of intraoral scanner and finish line location on the fabrication trueness and margin quality of additively manufactured laminate veneers fabricated with a completely digital workflow

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ABSTRACT

Statement of problem. Knowledge of the fabrication trueness and margin quality of additively manufactured (AM) laminate veneers (LVs) when different intraoral scanners (IOSs) and finish line locations are used is limited.

Purpose. The purpose of this in vitro study was to evaluate the fabrication trueness and margin quality of AM LVs with different finish line locations digitized by using different IOSs.

Material and methods. An LV preparation with a subgingival (sub), equigingival (equi), or supragingival (supra) finish line was performed on 3 identical maxillary right central incisor typodont teeth. Each preparation was digitized by using 2 IOSs, (CEREC Primescan [PS] and TRIOS 3 [TS]), and a reference LV for each finish line-IOS pair (n=6) was designed. A total of 90 LVs were fabricated by using these files and urethane acrylate-based definitive resin (Tera Harz TC-80DP) (n=15). Each LV was then digitized by using PS to evaluate fabrication trueness (overall, external, intaglio, and marginal surfaces). Each LV was also qualitatively evaluated under a stereomicroscope (×60), and the cervical and incisal margin quality was graded. Fabrication trueness and cervical margin quality were evaluated by using 2-way analysis of variance, while Kruskal-Wallis and Mann Whitney-U tests were used to evaluate incisal margin quality (α=.05).

Results. The interaction between the IOS type and the finish line location affected measured deviations at each surface (*P*≤.020). PS-sub and TS-supra had higher overall trueness than their counterparts. and the subgingival finish line resulted in the lowest trueness (*P*≤.005). PS and the subgingival finish line led to the lowest trueness of the external surface (*P*≤.001). TS-sub had the lowest intaglio surface trueness among the TS subgroups, and PS-sub had higher trueness than TS-sub (*P*<.001). PS-sub and PS-supra had higher marginal surface trueness than their TS counterparts (*P*<.001). TS resulted in higher cervical margin quality (*P*=.001).

Conclusions. Regardless of the IOS tested, subgingival finish lines resulted in the lowest trueness. The effect of IOS on the measured deviations varied according to the surface evaluated and finish line location. The cervical margin quality of AM LVs was higher when TS was used. (J Prosthet Dent xxxx;xxx:xxx-xxx)

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Clinical Implications

Laminate veneers fabricated by using the tested AM definitive resin may have higher fabrication trueness and require less adjustment if a preparation with equigingival or supragingival finish lines is digitized by using the tested confocal microscopy-based intraoral scanner TS.

Laminate veneers (LVs) have become a widely preferred conservative treatment option,[1,2] and a wide range of materials have been used to fabricate LVs.[3,4] The survival rate of indirect ceramic LVs was reported to be 90% after 10 years of service.[5] However, composite resin LVs are less invasive for the rehabilitation of discolorations and fractures and the correction of esthetics.[6] In addition, a 91.3% survival rate was reported for indirect composite resin veneers after 7 years.[7] Recently, additively manufactured (AM) resins indicated for definitive prostheses, including LVs, have been introduced.[8] AM definitive resin may be a cost-effective option, eliminating the disadvantages of direct and indirect composite resin veneers such as surface quality variations and maintenance requirements.[9] Previous studies have focused on different properties of AM definitive resins, including mechanical strength, surface properties, and color.[10–13] Considering that one of the aspects determining the clinical success of a prosthesis is its dimensional accuracy, which is correlated with optimal fit,[14] the fabrication trueness of AM definitive resin-based LVs should be known before their clinical use.

High fabrication trueness leads to improved marginal and internal fit and thereby reduces the risk of mechanical and biological complications.[15–17] In addition, higher fabrication trueness is essential to reduce the internal and external adjustments that may affect the mechanical strength, interproximal and occlusal contacts, cement gap, and fabrication time.[8,14] The marginal discrepancy of a LV has been reported to be affected by the manufacturing method and type of resin cement used for luting, while the position of the gap measurement has been reported to influence the absolute marginal discrepancy.[15,18] Marginal discrepancies have been reported to be greater on the incisal surface than on the cervical when composite resin or porcelain LV (cervical margin: 105 μm and incisal margin: 182 μm)[18] or pressed or milled porcelain LV are compared (cervical margin: 28 to 84 μm and incisal margin: 126 to 210 μm).[15] Therefore, fabrication trueness and margin quality assessments from different LV surfaces have clinical importance.

The finish line location of a fixed prosthesis may vary depending on the treatment plan.[19] The ability of an intraoral scanner (IOS) to identify the location of the finish line accurately may directly affect the marginal fit of a prosthesis.[20] The finish line location, complexity of the preparation design, and digitization technology and mesh quality of the IOS have been reported to affect the scanning accuracy and finish line determination of different IOSs.[19–24] In addition, preparation margins show greater deviations than preparation surfaces in single-unit prostheses when different IOSs are used.[25] A subgingival finish line might lead to inadequate scan accuracy, as the light beam reaching the finish line may be compromised because of the presence of blood, saliva, and collapse of the marginal gingiva.[19,20,26–28] Although the fabrication trueness of AM definitive resin-based crowns has been investigated,[8] studies on the fabrication trueness of AM definitive resin-based LVs are lacking. Therefore, the present study aimed to evaluate the influence of IOS type and finish line location (subgingival, equigingival, and supragingival) on the fabrication trueness and margin quality of AM definitive resin-based LVs. The null hypotheses were that IOS type and finish line location would not affect the fabrication trueness and margin quality (cervical and incisal) of AM definitive resin-based LVs.

MATERIAL AND METHODS

Figure 1 describes the workflow of the present study. Three identical maxillary right central incisor teeth were prepared for a LV on a dentate typodont (AG-3; Frasaco GmbH) with different finish line locations (subgingival, equigingival, and supragingival). To control the depth of the preparation, a heavy body silicone (Optosil Comfort Putty; Kulzer GmbH) index was prepared. Regardless of the finish line, initial orientation grooves were prepared with a diamond rotary instrument (Diatech InlayCrown Preparation Kit; Coltène AG) in a handpiece (Bien-Air CA 1:5 handpiece; BienAir Dental) for standardized depth, which was followed by the preparation of the entire labial surface and the finish line using round-end tapered diamond rotary instruments (JOTA efficient veneer prep kit 1443; JOTA AG). A shoulder incisal overlap design with a 1.5-mm incisal reduction[9,29] without palatal chamfer was prepared for all teeth, along with a 0.7-mm labial reduction at the deepest point of preparation with a 0.3-mm-thick labial chamfer. Location of the finish line was determined based on its level according to the free gingival margin, as the subgingival finish line (sub) was located approximately 0.5 mm apically, the equigingival finish line (equi) was at the same level, and the supragingival finish line (supra) was located approximately 0.5 mm incisally.[19] Preparation depth was confirmed by using a periodontal probe (CP 15 UNC; HU-Friedy), and all preparations were finished with a brown polisher (LS9871M; JOTA AG).

For each finish line, a partial-arch scan (from the right second premolar to the left second premolar) was performed by using 2 different IOSs: an IOS with confocal

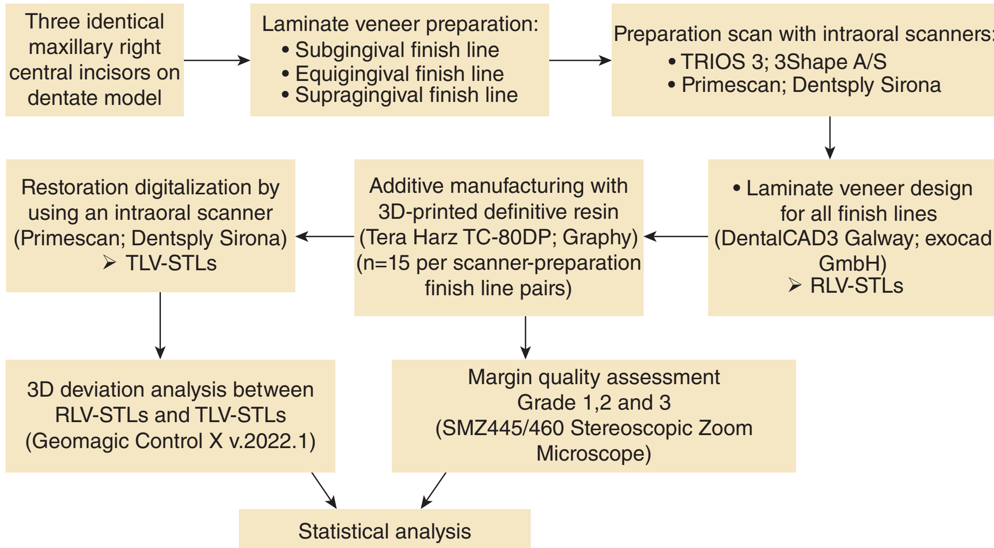

Figure 1. Study overview.

microscopy and ultrafast optical scanning technology (TRIOS 3; 3Shape A/S) (TS) and an IOS with smart pixel sensor technology (CEREC Primescan SW 5.2; Dentsply Sirona) (PS).[30] The palate was not scanned. All scanning followed the IOS manufacturers' recommendation, and the IOSs were calibrated before starting the scan of each model. A single operator (J.C.) performed each scan in the same temperature- and humidity-controlled room under ambient lighting. After confirming that the scans were free of error, they were converted to standard tessellation language (STL) files. A total of 6 maxillary model STL files (PS-Sub, PS-Equi, PS-Supra, TS-Sub, TS-Equi, and TS-Supra) were generated. These files were imported into a dental design software program (DentalCAD 3.0 Galway; exocad GmbH) to design reference LVs (Fig. 2). A reference LV with a 25-μm cement gap starting from 1 mm above the finish line with 0.4-mm minimal thickness was designed for each IOS-finish line pair and stored as reference LV STL file (RLV-STL).

Each RLV-STL was imported into a nesting software program (Composer; Asiga), and the incisal edge of the design was oriented perpendicular to the build platform. Supports were automatically generated at the external surfaces, and any support at the intaglio surface was

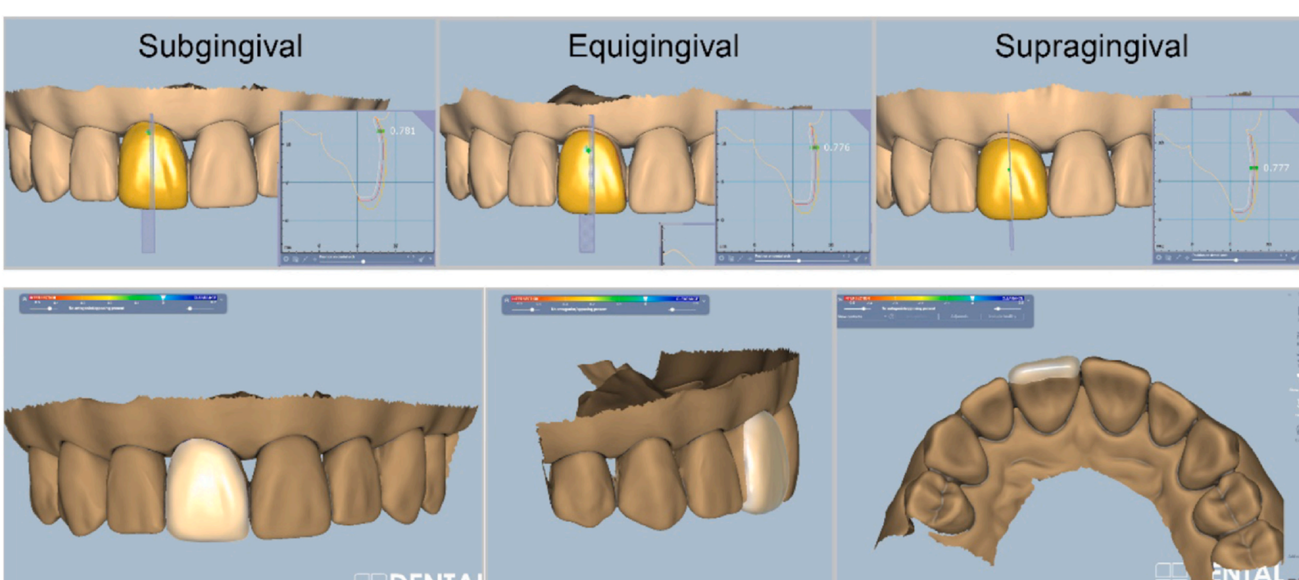

Figure 2. Laminate veneer design with each finish line.

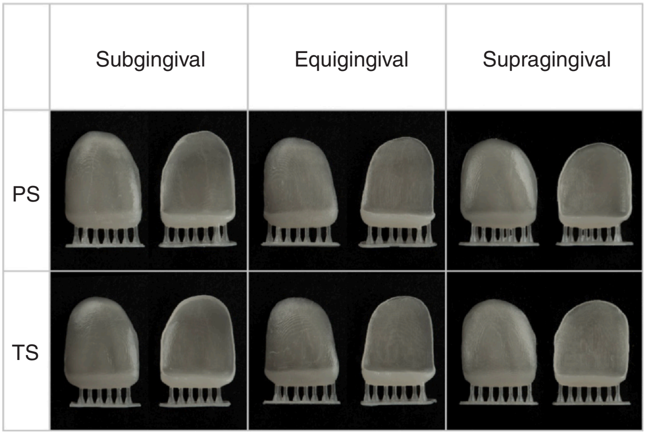

Figure 3. Representative image of additively manufactured laminate veneers for each intraoral scanner-finish line pair. PS, Primescan; TS, TRIOS 3.

removed manually. A total of 90 LVs were additively manufactured with a 50-µm layer thickness from a urethane acrylate-based resin for definitive use (Tera Harz TC-80DP A1 shade; Graphy Inc) and a digital light processing (DLP)-based printer (MAX UV; Asiga) (Fig. 3) (n=15). The specimens were positioned in the center of the build platform and positioning repeated 15 times per IOS-finish line pair. After printing, the support structures were removed, and LVs were ultrasonically cleaned with 96% ethanol (Ethanol absolut; Dr. Grogg Chemie AG) for 45 seconds, which was followed by cleaning with a 96% ethanol-soaked cloth. LVs were thoroughly dried and polymerized using a xenon lamp-polymerization unit (Otoflash G171, NK Optik GmbH) under nitrogen oxide gas atmosphere (2×2000 exposures with 5 minutes between sets of exposures).

After manufacturing, all LVs were steam-jet cleaned, air dried, and inspected for surface flaws. Remaining supports were removed with the aid of loupes (EyeMag Pro; Carl Zeiss) at ×3.5 magnification and a cut-off-wheel (Keystone Cut-off Wheels; Keystone Industries). No further adjustments were made to the external or intaglio surfaces. To minimize time-dependent dimensional changes, LVs were digitized within 24 hours of fabrication. A software program (Excel; Microsoft Corp) was used to randomize the scans of LVs with different thicknesses. An experienced operator (D.Y.) scanned each LV with PS in the same temperature- and humidity-controlled room to generate test LV STLs (TLV-STLs). LV scans started from their labial surface, and each LV was held with an adhesive tip applicator (Micro Stix; Microbrush International) attached to the disto-incisal edge. After the entire LV had been scanned, the applicator was attached to the mesio-incisal edge, the image of the adhesive tip at the distoincisal edge was virtually removed, and that region was scanned. PS was calibrated after every 5 LVs, and the operator took 5-minute breaks to avoid fatigue-related deviations.

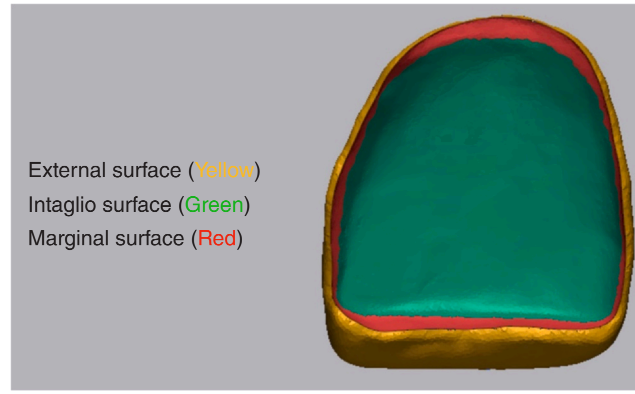

Figure 4. Virtually segmented external, intaglio, and marginal surfaces on RLV-STL file. RLV-STL; Reference laminate veneer standard tessellation language.

A 3-dimensional (3D) metrology-grade analysis software program (Geomagic Control X; 3D Systems), which is specified by the International Organization for Standardization 12836 standard,[31] was used to evaluate the fabrication trueness of the LVs. The RLV-STL of each IOS-finish line pair was initially imported into the software program and virtually segmented into 3 surfaces (external, intaglio, and marginal) by using the "Region Tool" (Fig. 4). These files were saved as templates to evaluate the 3D deviations of each LV. TLV-STLs were then superimposed over their respective RLV-STL template by using the best-fit alignment and iterative closest point algorithm. Color maps with maximum and minimum deviation values set at −100 and +100 µm and the tolerance range set at −10 and +10 µm[32] were generated (Fig. 5). Root mean square (RMS) values were automatically calculated at 4 surfaces (overall, external, intaglio, and marginal) by using the "3D comparison-Use selected data only" tool for previously segmented sections. Lower RMS values were interpreted as higher congruence between the RLV-STL and the TLC-STL and consequently higher fabrication trueness.[33]

Qualitative evaluation of the cervical and incisal margins of each LV was performed under ×60 magnification with a stereomicroscope (SMZ445/460 Stereoscopic Zoom Microscope; Nikon Corp) by a single blinded operator (M.B.D.) who had experience with the 3-point scale used in this study. For each specimen, a numerical grading system on a 3-point scale was used based on a previous study[33] in which a rough edge-resembling layer with some defects was graded as "1" (low quality), a slightly rough edge-like wave was graded as "2" (medium quality), and a smooth edge with no defect was scored as "3" (high quality) (Fig. 6).

Kolmogorov-Smirnov tests were used to evaluate the distribution of RMS data for each surface analyzed and the margin quality rating for each surface. Normal

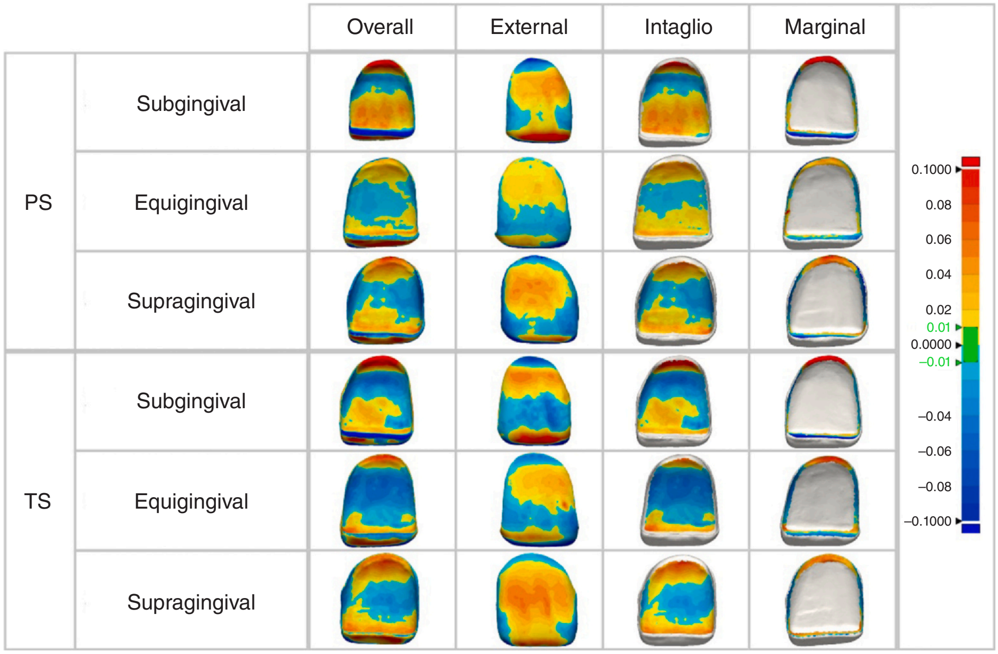

Figure 5. Representative color maps of overall, external, intaglio, and marginal surfaces. *Red* represents overcontoured areas, *blue* undercontoured areas (Nominal values: +100 μm and −100 μm), and *green* acceptable areas within tolerance range (+10 μm and −10 μm). PS, Primescan; TS, TRIOS 3.

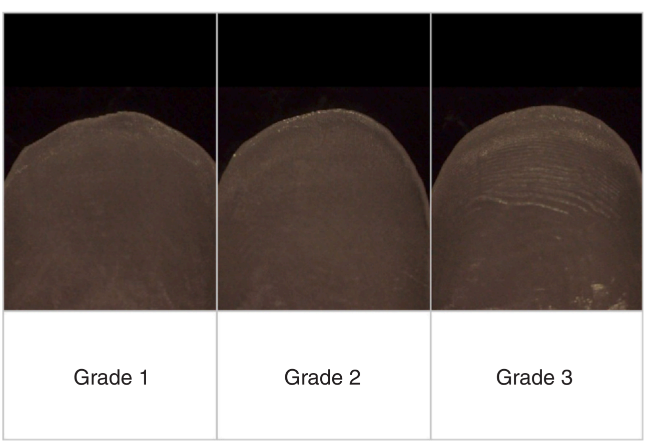

Figure 6. Representative stereomicroscope images showing margin quality of laminate veneers according to a three-point scale from 1 (low marginal quality) to three (high marginal quality).[29] Original magnification ×60.

distribution of the data could be assumed for all the measured values and graded points except those with incisal margin quality. Thus, the Kruskal-Wallis and Mann Whitney-U tests were used to evaluate the data of incisal margin quality, while 2-way analysis of variance (ANOVA) followed by either Scheffé (RMS values) or Tukey (data of cervical margin quality) tests with IOS and finish line location as main factors were used to analyze the remaining data. All statistical analyses were performed by using an analysis software program (IBM SPSS Statistics, v23; IBM Corp) (α=.05).

RESULTS

The results of the 2-way ANOVA are given in Table 1. Significant interactions were found between the finish line location and IOS type on the RMS measurements on all tested surfaces (P≤.020). The finish line location affected RMS values on every tested surface (P<.001), while the IOS type only affected external and intaglio surfaces (P<.001).

PS-sub had lower overall deviations than TS-sub (P=.002), and TS-supra had lower deviations than PS-supra (P=.005). However, the difference between PS-equi and TS-equi was statistically similar (P=.486). Regardless of the IOS type, a subgingival finish line led to the highest overall deviations (P<.001) (Table 2). PS and TS produced similar external surface deviations for each finish line (P≥.057). The subgingival finish line and PS led to higher deviations when pooled data were considered (P≤.001) (Table 3). The TS-sub had higher intaglio surface deviations than the TS-equi or TS-supra (P<.001), while LVs fabricated by using PS scans had similar deviations (P>.05). The PS-sub had lower intaglio surface deviations than the TS-sub (P<.001), whereas

Table 1. *P* values derived from 2-way analysis of variance analysis on each surface

	Surface			
	Overall	**External**	**Intaglio**	**Marginal**
Intraoral scanner	.170	<.001	<.001	.650
Finish line location	<.001	<.001	<.001	<.001
Intraoral scanner × Finish line location	<.001	.020	<.001	<.001

Table 2. Mean ±standard deviation overall RMS (µm) values of each intraoral scanner-finish line pair

	TS	PS	Total
Subgingival	78.6 ±6.5^{D}	69.1 ±9.3^{C}	74.2 ±9.2^{b}
Equigingival	41.2 ±3.9^{AB}	46 ±5.6^{B}	43.6 ±5.4^{a}
Supragingival	36.8 ±3.1^{A}	46.8 ±7.2^{B}	41.8 ±7.5^{a}
Total	53.0 ±19.9^{a}	53.8 ±13.0^{a}	

Different superscript uppercase letters indicate significant differences among intraoral scanner-finish line pairs. Different superscript lowercase letters indicate significant differences among different finish lines. Total values derived from pooled data of each finish line (*P*<.05).

Table 3. Mean ±standard deviation external surface RMS (µm) values of each intraoral scanner-finish line pair

	TS	PS	Total
Subgingival	62.8 ±6.4^{C}	61.8 ±8.1^{C}	62.3 ±7.2^{b}
Equigingival	43.4 ±5.3^{AB}	50.5 ±7.2^{B}	47 ±7.2^{a}
Supragingival	40 ±4.2^{A}	47.7 ±7.6^{AB}	43.8 ±7.2^{a}
Total	49.1 ±11.6^{a}	53.2 ±9.7^{b}	

Different superscript uppercase letters indicate significant differences among intraoral scanner- finish line. Different superscript lowercase letters indicate significant differences among different finish lines and between different intraoral scanners. Total values derived from pooled data of each intraoral scanner and each finish line (*P*<.05).

Table 4. Mean ±standard deviation intaglio surface root mean square (µm) values of each intraoral scanner-finish line pair

	TS	PS	Total
Subgingival	48 ±11.1^{B}	35.8 ±6^{A}	42.3 ±10.9^{b}
Equigingival	35.8 ±3.9^{A}	31.8 ±7.7^{A}	33.8 ±6.3^{a}
Supragingival	28.1 ±3.7^{A}	31.5 ±5.1^{A}	29.8 ±4.7^{a}
Total	37.6 ±11^{b}	33 ±6.5^{a}	

Different superscript uppercase letters indicate significant differences among intraoral scanner- finish line pairs. Different superscript lowercase letters indicate significant differences among different finish lines and between different intraoral scanners. Total values derived from pooled data of each IOS and each finish line (*P*<.05).

Table 5. Mean ±standard deviation marginal surface root mean square (µm) values of each intraoral scanner-finish line pair

	TS	PS	Total
Subgingival	133.9 ±11.7^{D}	104.2 ±19.3^{C}	120 ±21.6^{b}
Equigingival	43 ±7.6^{AB}	48.5 ±11.8^{AB}	45.8 ±10.2^{a}
Supragingival	35.9 ±5.2^{A}	56.6 ±15.1^{B}	46.2 ±15.3^{a}
Total	72.8 ±46.6^{a}	69.4 ±29.0^{a}	

Different superscript uppercase letters indicate significant differences among intraoral scanner- finish line pairs. Different superscript lowercase letters indicate significant differences among different finish lines. Total values derived from pooled data of each finish line (*P*<.05).

the differences in other finish lines were statistically similar (*P*≥.772). The subgingival finish line and TS led to higher deviations when pooled data were considered (*P*≤.003) (Table 4). The subgingival finish line resulted in the highest marginal surface deviations (*P*<.001), while the differences between equigingival and supragingival finish lines were statistically similar (*P*≥.672). The PS-sub and PS-supra had lower deviations than their TS counterparts (*P*<.001) (Table 5).

Table 6. Mean ±standard deviation graded point scale values of cervical margin quality for each intraoral scanner-finish line pair

	TS	PS
Subgingival	2.3 ±0.5	2.1 ±0.4
Equigingival	2.6 ±0.5	2.2 ±0.4
Supragingival	2.4 ±0.5	2.0 ±0
Total	2.4 ±0.5^{B}	2.1 ±0.3^{A}

Different superscript uppercase letters indicate significant differences between intraoral scanners. Total values derived from pooled data of each intraoral scanner (*P*<.05). PS, Primescan; TS, TRIOS 3.

Table 7. Descriptive statistics of graded point scale values of incisal margin quality for each intraoral scanner-finish line pair

	TS		PS	
	Mean ±Standard Deviation	Median (Min-Max)	Mean ±Standard Deviation	Median (Min-Max)
Subgingival	2.9 ±0.4	3 (2–3)	3.0 ±0	3 (3–3)
Equigingival	2.9 ±0.3	3 (2–3)	3.0 ±0	3 (3–3)
Supragingival	3.0 ±0	3 (3–3)	2.8 ±0.4	3 (2–3)

Descriptive statistics of the graded point scales of cervical and incisal margin quality are given in Tables 6 and 7. For the cervical margin quality, no significant interaction between the finish line and the IOS was detected (*P*=.356). TS led to higher margin quality (*P*=.001). The differences among the groups were statistically similar when the quality of the incisal margin data was considered (*P*≥.589) (Fig. 7).

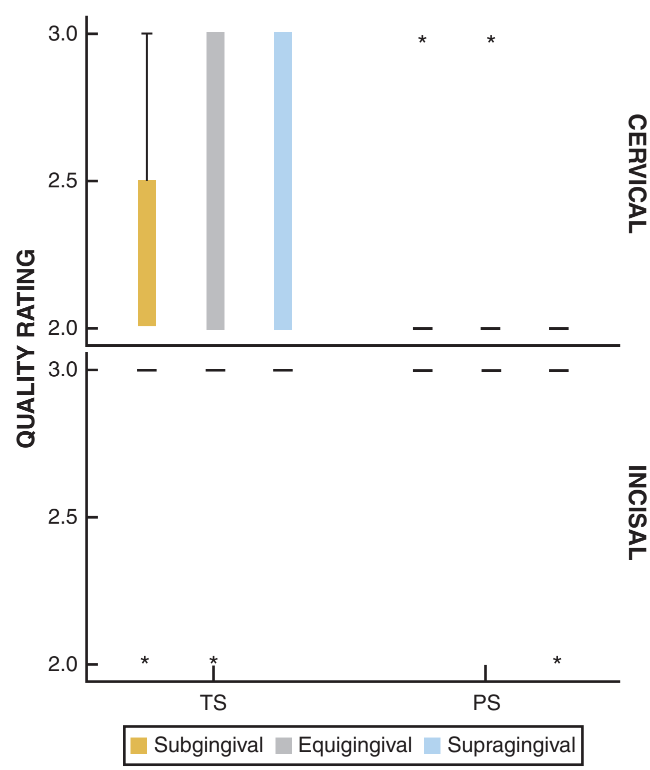

Figure 7. Box-plot of margin quality of intraoral scanner-finish line pairs, evaluated with three-point scale from one (low marginal quality) to three (high marginal quality). PS, Primescan; TS, TRIOS 3.

DISCUSSION

Regardless of the IOS type and the surface evaluated, a subgingival finish line resulted in the lowest fabrication trueness for AM LVs. TS led to higher overall (supragingival finish line) and external (pooled data) and marginal (supragingival finish line) surface trueness, while PS led to higher overall (subgingival finish line), intaglio (subgingival finish line and pooled data), and marginal (subgingival finish line) surface trueness. In addition, cervical margin quality was affected by the IOS type. Therefore, the null hypotheses that IOS type and finish line location would not affect the fabrication trueness and margin quality (cervical and incisal) of AM definitive resin-based LVs were rejected.

LVs fabricated with TS scans showed trueness that was either similar to or higher than those fabricated with PS scans when a supragingival finish line was used, and PS led to mostly higher trueness when a subgingival finish line was used. In addition, the cervical margin quality of LVs fabricated by using TS scans was higher than those fabricated by using PS scans. The highest finish line detection capability for TS when compared with 6 other IOSs that did not involve PS was also reported in a previous study.[20] However, the greatest mean difference between the deviation values of LVs fabricated with the tested IOSs was 29.7 μm (marginal surface deviations when the subgingival finish line was used). This difference was even smaller for the equigingival or supragingival finish lines (greatest mean difference 10 μm). Considering these differences are relatively small and the cement gap in LV designs was set as 25 μm, the difference between LVs fabricated by using the scans of the tested IOSs may be clinically negligible, particularly if a subgingival finish line is not used.

Except for the intaglio surface trueness of LVs fabricated with PS scans, the subgingival finish line resulted in the lowest trueness for the tested AM LVs, which could be associated with decreased accuracy of the IOS scans at the subgingival region because of restricted accessibility or alignment errors.[22] Similar findings to that of the present study have been reported previously,[19] and the authors related the subgingival finish line with poor scan accuracy and recommended gingival displacement to improve accuracy. The scan performance of an IOS is directly affected by an unrestricted viewing angle and a proper angle of incidence of the light source. The improved fit of prostheses was also reported when preparations with easy-to-detect designs that do not have deep and subgingival finish lines were digitized by using IOSs.[22,23] As shown in the present study, the prosthesis with the supragingival finish line could be more accurate than the others because the direct line-of-sight for the IOS could ensure the accuracy of the scan.[22,23]

A recent study[26] on the intaglio surface trueness of AM resin crowns also concluded that the subgingival finish line led to inaccurate marginal fit, which was attributed to the poor reproducibility of the marginal region. The authors also concluded that the fabrication of an AM resin crown using IOS data may not be recommended in the case of the subgingival finish line, consistent with the findings of the present study. A subgingival finish line was reported to have no significant effect on the fit of metal-ceramic copings fabricated by using the IOS scans[28]; yet, a direct comparison might be misleading given the differences in the tested materials and the fact that that study was based on 2-dimensional measurements performed by using the silicone replica technique.

Mean deviations on each surface of the tested AM LVs were below 90 μm, except for those at the marginal surface when the finish line was subgingivally prepared (133.9 μm for TS and 104.2 μm for PS). These results were consistent with the color maps, as a relatively high deviation at the cervical region was visible for LVs with subgingival finish lines (Fig. 5). Regardless of the finish line location, colors that represent overcontour (yellow, orange, and red) were visible at the finish lines of all LVs. However, red, which indicated the most overcontoured areas when maximum and minimum deviation values set in the present study were considered, was the predominant color at the margins of subgingival LVs. Therefore, LVs with subgingival finish lines may require more adjustment to ensure proper fit than LVs with other finish line locations. The authors are unaware of a standardized minimum intaglio surface deviation value when additive or subtractive manufacturing methods were used. However, previous studies on the marginal discrepancy of ceramic or resin LVs have reported values greater than 100 μm[15,18]; thus, LVs may be adequately fabricated with the tested AM definitive resin and IOSs, particularly when an equigingival or supragingival finish line was used.

Limitations of the present study included the absence of a priori power analysis. However, post hoc power analyses were performed for both main factors and the interaction between them, and the sample size was deemed adequate for 80% power with a minimum effect size of 0.69 and α=.05. In addition, the post hoc power was 95% with an effect size of 0.39 and α=.05 when the quality rating of cervical margins was considered. The present study aimed to evaluate the fabrication trueness and margin quality of AM LVs fabricated with a complete digital workflow. Nevertheless, the absence of a control group that involved stone casts obtained with conventional polyvinyl siloxane impressions and digitized by using a laboratory scanner is a limitation. Typodont teeth were used for master LV preparations, and, considering the differences in surface texture and optical properties of a natural and a typodont tooth, these results may differ in actual clinical situations. No gingival displacement was used, and this may have affected the results, particularly for those LVs with subgingival finish lines, as the stiffness of the typodont gingiva might have amplified the deviations of the subgingival finish line scans. Another limitation was that only 1 definitive resin, 1 3D printer, and 2 IOSs were used; thus, the results of the present study should be generalized with caution. In addition, all LVs were printed with a standardized layer thickness and printing orientation, which has been reported to affect the fabrication trueness of AM dental appliances.[33,34] An IOS with high accuracy[35] was chosen as it enabled digitization in a single complete motion, eliminating stitching of separate external and intaglio surface scans, which would have been required if a laboratory scanner or an industrial scanner had been used, and the possible amplification of measured deviations. Nevertheless, different scanners may lead to different results. Another limitation was that the present study did not investigate how the tested IOSs and finish line locations affected the marginal discrepancies and the fit of the fabricated LVs. The present study assessed the initial fabrication trueness of AM LVs depending on IOS type and finish line location; how these LVs maintain their long-term stability should also be evaluated. Finally, other clinically relevant parameters such as optical properties and the surface texture of AM LVs should be investigated.

CONCLUSIONS

Based on the findings of this in vitro study, the following conclusions were drawn:

1. The tested intraoral scanners mostly led to similar deviations of tested additively manufactured resin-based definitive laminate veneers.
2. Subgingival finish line resulted in the lowest trueness at each surface evaluated, whereas the differences between equigingival and supragingival finish lines were statistically similar. In situations with subgingival finish line, the intraoral scanner with smart pixel sensor technology may be preferred for lower overall, intaglio, and marginal surface deviations.
3. The cervical margin quality of additively manufactured laminate veneers was affected by the intraoral scanner type and the confocal microscopy-based intraoral scanner led to higher quality.

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