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Huanhuan Liu
Sun Yat-sen University
Runli Li
Sun Yat-sen University
YangYun Li
Sun Yat-sen University
Yan Wang
wangyan9@mail.sysu.edu.cn

Sun Yat-sen University

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Effect of scanner type and preparation design on the accuracy of digital impressions for maxillary anterior veneers

Huanhuan Liu[a,1], Runli Li [a,1], YangYun Li [a], Yan Wang [a]

[a] Hospital of Stomatology, Guanghua School of Stomatology, Guangdong Provincial Key Laboratory of Stomatology, Sun Yat-sen University, Guangzhou, Guangdong, PR China.

Corresponding author

Yan Wang, DDS, PhD, Hospital of Stomatology, Guanghua School of Stomatology, Guangdong Provincial Key Laboratory of Stomatology, Sun Yat-sen University, 56 Lingyuan West Road, Guangzhou, Guangdong 510055, PR CHINA

E-mail: wangyan9@mail.sysu.edu.cn

Huanhuan Liu and Runli Li contributed equally to this work.

Abstract

Background: The increasing adoption of intraoral scanning in restorative dentistry has made scan accuracy a critical determinant of clinical outcomes for laminate veneers. Although scan accuracy may be influenced by both the scanner used and the preparation design, evidence regarding these effects remains limited. To investigate the influence of both intraoral scanner (IOS) type and preparation design on the accuracy of digital impressions of maxillary anterior veneers.

Methods: Three maxillary typodonts were prepared with three different laminate veneer designs: window (W), bevel (B), and incisal overlap (IO). A total of 90 complete-arch intraoral scans were obtained using three IOSs (3Shape TRIOS 3, CEREC Omnicam, and Medit i500), with ten scans per subgroup. All scans were exported as standard tessellation language (STL) files. Accuracy was assessed using 3D analysis software program (Geomagic Control X). All STL files were individually registered to the reference scan via a best-fit algorithm, after which 3D deviations were determined and expressed as root mean square (RMS) values. Two-way analysis of variance (ANOVA) followed by post hoc comparison tests was performed to analyze the trueness and precision data ($\alpha = 0.05$).

Results: Two-way ANOVA results revealed that both preparation design and scanner type significantly affected trueness and precision ($P < 0.001$), whereas no significant interaction was observed between these two factors. For trueness, the 3Shape TRIOS 3 exhibited significantly better trueness than the CEREC Omnicam and Medit i500, and the IO design showed significantly better trueness than the W and B designs, with

the B design yielding the highest RMS values. For precision, the 3Shape TRIOS 3 again showed significantly better precision than the other two scanners, while the IO design exhibited the highest precision and the W design the lowest.

Conclusions: Both the laminate veneer preparation design and the intraoral scanner type significantly influenced the accuracy of intraoral scans for maxillary anterior veneers. The IO design exhibited greater trueness than the W and B designs. The 3Shape TRIOS 3 showed significantly greater precision than the CEREC Omnicam and Medit i500. Therefore, both preparation design and scanner selection should be considered when optimizing the accuracy of digital impressions for laminate veneers.

Keywords: Digital scan, laminate veneer, preparation design, intraoral scanner, scanning accuracy

Background

In recent decades, digital technology has become increasingly central to the workflow of prosthetic dentistry. Specifically, technologies such as intraoral optical scanning (IOS), computer-aided design, and computer-aided manufacturing (CAD/CAM) have facilitated the application of indirect restorations.[1] Different IOSs have become essential tools in clinical dentistry and dental laboratories, offering advantages in patient comfort and digital transferability, simplifying the workflow between dental practitioners and technicians, eliminating fabrication errors encountered with conventional methods in delivering various types of indirect

restorations.[2] Owing to the continued development of new scanners and software upgrades, the most important prerequisite of an intraoral scanner is accuracy. However, the accuracy of digital scanning in general is affected by the IOS system, scanning area, scanning pattern, operator experience, and preparation design.[3-5] Among these factors, the influence of preparation design on the accuracy of IOSs have not been fully investigated.

Laminate veneers have become increasingly popular because of their minimally invasive preparation design, superior esthetic qualities, and excellent long-term clinical performance. The three most common veneer preparation designs are the incisal overlap (IO), window (W), and bevel (B).[6] The incisal overlap technique involves extending the preparation onto the palatal surface of the tooth, which establishes a clear insertion path for the restoration. The window design is typically used for teeth with sound incisal edges, as it preserves anterior guidance. In the bevel design, the preparation is placed directly at the incisal edge, enabling elongation of that edge when the clinical crown height is insufficient. The laminate veneer preparation design can influence various clinical steps, including tooth preparation complexity, digital scanning ease, adhesive cementation, and marginal integrity.[7] Optimal accuracy is critically important, especially in the case of esthetic laminate veneers, for which marginal adaptation exerts a direct effect on clinical success and the longevity of the restoration.[8] Furthermore, the quality of digital scans for veneers may vary depending on the scanning system used.[9] However, the effect of veneer preparation design on the accuracy of digital scans with different IOSs used has not

yet been reported. Given these variables, further investigation is needed to clarify how to obtain accurate intraoral scan data for laminate veneers when different preparation designs are involved.

An intraoral scan is constructed by stitching together numerous partially overlapping three-dimensional images into one comprehensive 3D representation. Variations in laminate veneer preparation designs can affect the scanning process and the efficiency of intraoral scanners in capturing preparation details, particularly for multiple consecutive veneer preparations.[10] According to ISO standard 5725-1, accuracy assessment for digital scans consists of trueness and precision.[11] Trueness describes how closely a scanned object matches the actual reference object, while precision reflects the degree of agreement among repeated measurements of the test object. Previous studies have reported that scan pattern and scanning speed influence the accuracy and reliability of intraoral scans.[12,13] However, it remains unclear how different intraoral scanners perform under various clinical conditions, or which scanner system is optimal for a given preparation design. Accordingly, the present in vitro study aimed to determine the influence of preparation design and scanner type on the scanning accuracy of multiple anterior veneers. The null hypothesis stated that neither preparation design nor scanner type would significantly affect scanning accuracy.

Materials and methods

The design of all veneer preparations was conducted using a CAD software program

(DentalCAD; exocad GmbH, Dresden, Germany). Subsequently, standard tessellation language (STL) files of the master models were imported into the software. Three different preparation designs, including window, bevel, and incisal overlap, were digitally created on the maxillary anterior teeth ranging from the right canine to the left canine (Figure 1). The completed digital veneer models were then saved as STL files and fabricated using a stereolithography 3D printer (UltraCraft Reflex 2 Pro; HeyGears, Guangzhou, China) and resin material. The typodonts were scanned with a high-precision laboratory scanner (DS-MIX; Shining 3D, Hangzhou, China) to obtain three reference scans, which were exported as reference STL files.

To replicate a clinical scenario, the reference model was fixed onto the typodont of a dental simulator mannequin (NISSIM Type 1; Nissin, Kyoto, Japan), which was then mounted on the headrest of a dental chair. IOSs from three manufacturers, 3Shape TRIOS 3, CEREC Omnicam, and Medit i500, were utilized in this study, as summarized in Table 1. All digital impressions were obtained by one experienced operator (L.R.L.) with 3–4 years of prior scanning experience: 4 years with the 3Shape TRIOS 3, 4 years with the CEREC Omnicam, and 3 years with the Medit i500. The operator followed the same scanning pattern for all devices. Throughout the scanning procedure, illumination and interincisal mouth opening were kept consistent, with the maximum mandibular opening set to 50 mm. Ten scans were performed for each subgroup, a total of 90 test data sets and 3 reference data sets were saved as STL files for 3D comparative analysis (Figure 2).

A 3D software analysis program (Geomagic Control X 2022.1; 3D Systems,

Rock Hill, USA) was used to evaluate scan accuracy. The region of interest was limited to the anterior teeth prepared for laminate veneers. A total of 90 STL files (3 preparation designs × 3 IOS systems × 10 scans) were analyzed to determine trueness, defined as the closeness between the test files and the reference scan. The two models were initially superimposed via n-point alignment and subsequently refined using best-fit registration based on the iterative closest point algorithm, which incorporated all surface points. Thereafter, a 3D surface comparison was performed, and the root mean square (RMS) value was computed to quantify the 3D deviations within the region of interest. Color maps were also generated to qualitatively illustrate the 3D differences after alignment (Figure 3). To assess precision, the STL files obtained from ten consecutive scans within each subgroup were paired to form 45 combinations, and RMS values were calculated using the best-fit algorithm. Higher RMS values reflect increased deviation between the two STL files, whereas low RMS values indicate a high three-dimensional congruency between the superimposed models.

Statistical analysis was performed using a statistical software program (IBM SPSS Statistics for Windows, v24.0; IBM Corp). Descriptive statistics, including mean and standard deviation, were calculated for the RMS values to quantify trueness and precision. The Shapiro–Wilk test was performed to assess the normality of data distribution. Two-way analysis of variance (ANOVA) followed by post hoc comparison tests was applied to analyze precision and trueness data. Differences were considered statistically significant at $P<0.05$.

Results

Regarding trueness, two-way ANOVA and post hoc comparison tests revealed that both scan system ($p < 0.001$) and preparation design ($p < 0.001$) had significant main effects on trueness, whereas the interaction between the two factors was not statistically significant ($p = 0.707$) (Table 2). Within each preparation design, CEREC Omnicam and i500 showed no significant RMS discrepancies, whereas TRIOS 3 consistently demonstrated significantly lower RMS values, indicating superior trueness. Across all three scanners, the preparation design of B presented the highest RMS values, followed by W, while IO yielded the lowest RMS values, with all pairwise differences reaching statistical significance (Table 3). These findings indicate that the IO preparation design facilitated the highest trueness regardless of the scanner used, whereas the B design consistently produced the greatest systematic deviation.

Regarding precision, two-way ANOVA and post hoc comparison tests revealed significant differences among different scan systems and preparation designs ($p < 0.05$). Both scan system ($p < 0.001$) and preparation design ($p < 0.001$) exhibited significant main effects, however, their interaction was not statistically significant ($p = 0.415$) (Table 4). Within each preparation design, no significant differences were found between CEREC Omnicam and i500, whereas TRIOS 3 showed significantly lower mean RMS values across all groups, reflecting its superior repeatability. For all three scanners, the W preparation design produced the highest RMS values, the B

design was intermediate, and the IO design yielded the lowest RMS values, suggesting that IO was the most favorable preparation design for achieving high precision (Table 5). Notably, the RMS values for precision were consistently lower than those for trueness across all experimental groups, indicating that random measurement errors were smaller than the systematic deviations from the reference scan. Notably, no significant interaction was observed between scanner type and preparation design for either trueness or precision, indicating that the ranking of scanners remained consistent across the different veneer designs.

Discussion

The present study investigated the effects of different veneer preparation designs (window, bevel, and incisal overlap) and scanner type on the accuracy of three IOSs when scanning multiple consecutive anterior teeth restored with laminate veneers. Accuracy was assessed in terms of trueness and precision. To avoid arbitrary preparation by a practitioner, the teeth were digitally designed using a CAD software program and subsequently printed.[14] Laboratory scanners served as the reference standard for evaluating scanner accuracy and precision. Scanning time was averaged across all scans to standardize conditions and minimize any potential influence of time on trueness and precision.[15] All scans were acquired by one clinician who had received standardized training on the three IOS systems to exclude the potential influence of operator experience on scan accuracy.[16] The results support the rejection of the null hypothesis, as both tested variables significantly affected the accuracy of

intraoral scanning.

The present study employed trueness and precision as the two principal parameters for the assessment of digital scan accuracy. Trueness, assessed through intergroup comparisons of different scan patterns and preparation designs, quantifies the deviation between the scanned object and its actual dimensions. Precision refers to the agreement among repeated scans, reflecting the reproducibility of each scan without reference to a master scan. Precision analysis, derived from intragroup comparisons, indicates the predictability of each scanning system and preparation design.[17] Several methodologies, encompassing distance metric values, deviation percentages, RMS errors, and linear and angular deviations along the X, Y, and Z axes, have been reported for evaluating digital scan accuracy subsequent to the superimposition of reference and test files.[18,19] In this study, the RMS method was adopted to identify intergroup discrepancies, as it is considered more reliable owing to the inclusion of both positive and negative values for each data point. In quantitative evaluations, when positive and negative values are evenly distributed, their sum approaches zero.

Laminate veneers have become a reliable alternative to conventional all-ceramic crowns owing to their minimally invasive preparation, favorable long-term survival rates, and satisfactory esthetics.[20] However, few studies have evaluated the accuracy of digital scans specifically for laminate veneers. To date, no investigation has examined the scan accuracy of multiple consecutive anterior laminate veneers while considering both preparation designs and scanner types as variables. In the present

study, two-way ANOVA revealed that both preparation design and scanner type had a significant effect on trueness and precision ($P < 0.001$). Among the three preparation designs compared, the IO design scanned with the 3Shape TRIOS 3 yielded the best trueness and precision values (47.45 ± 2.65 μm and 22.58 ± 4.71 μm, respectively). Preparation design has been identified as a factor influencing intraoral scan accuracy, yet conflicting findings exist in the literature. Some investigators have concluded that increased preparation complexity and surface area reduce scanning accuracy, while others have reported no such effect.[21] The present findings support the notion that preparation design affects IOS accuracy, as significant differences in RMS values were observed among the three designs. Notably, the IO design consistently produced the lowest RMS values for both trueness and precision across all three scanners, whereas the B design generally yielded the highest values. Nevertheless, direct comparisons with previous studies remain challenging owing to differences in preparation designs, scan patterns, and clinical scenarios, including single-tooth preparations, IOS technologies, and measurement methodologies.

Significant differences were also observed among the three scanner types. No significant differences in trueness or precision were found between the Medit i500 and CEREC Omnicam, whereas the 3Shape TRIOS 3 exhibited significantly superior trueness and precision. This finding agrees, to some extent, with the ranking of intraoral scanner accuracy reported by Dutton et al.[22] The attainment of optimal accuracy in digital scanning is closely related to the underlying imaging technology.[23] The 3Shape TRIOS 3 functions based on the principle of parallel confocal

microscopy, in which only in-focus light reflected from the tooth surface passes through a pinhole to the optical detector. The tooth surface is subsequently reconstructed from a series of images acquired at various focal depths and from multiple orientations around the object. This technology enhances depth perception and reduces distortion, thereby improving the capture of structural details.[24,25] By contrast, both the CEREC Omnicam and Medit i500 utilize active triangulation technology, which localizes a point on an object by forming a triangle based on the positions and angles of two viewing points.[26,27] These scanners project light directly onto the object and analyze the reflected light for positional calculation. Accordingly, the higher trueness observed with scanners employing parallel confocal microscopy compared with those using active triangulation can be attributed to these technological differences.

Beyond the aforementioned variables, the accuracy of intraoral digital scans may be influenced by several additional determinants, including the software version, scanning protocol, environmental illumination, and operator proficiency.[28-30] Studies have shown that while experienced dental professionals complete intraoral scans more quickly, greater speed does not necessarily yield higher accuracy.[31] Vág et al. reported that software updates can significantly affect scan accuracy, though not always positively.[32]

The present study is subject to several limitations inherent to its in vitro design, in which a typodont model was utilized that does not completely reproduce the optical characteristics of natural dentition. Although a dental simulator mannequin was used

to mimic some intraoral variables, clinical factors such as blood, saliva, and patient interaction were not reproduced. These factors may affect IOS accuracy, suggesting that clinical conditions could be more challenging than those tested here.[33] Further studies incorporating different IOSs and intraoral environments are needed to establish guidelines for appropriate clinical use across various scenarios. Additionally, the IOS devices used in this study have since been superseded by newer models. Newly introduced scanners, including the TRIOS 5 and Medit i700, incorporate refined scanning algorithms capable of minimizing stitching errors during data reconstruction.[34] Consequently, the findings of the present investigation should be interpreted with caution, and further comprehensive studies are warranted.

Conclusions

Within the constraints of this in vitro investigation, the following conclusions were drawn: Regarding preparation design, the IO design appeared to be advantageous in terms of both trueness and precision, whereas the B design demonstrated the lowest trueness, irrespective of the IOS type. In terms of IOS, accuracy increased in the following order: CEREC Omnicam, Medit i500, and 3Shape TRIOS 3. Both preparation design and ISO type affected the accuracy of intraoral digital impressions for multiple consecutive laminate veneers. Accordingly, to mitigate the impact of preparation configuration, the adoption of complementary measures, such as clearly defined preparation margins and adequate scanning duration, is advocated to enhance scanning accuracy in clinical scenarios involving multiple consecutive laminate

veneers.

Abbreviations

IOS	Intraoral scanner
W	Window
B	Bevel
IO	Incisal overlap
STL	Standard tessellation language
RMS	Root mean square
CAD/CAM	Computer-aided design, and computer-aided manufacturing

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Author contributions

The present manuscript was written through the contributions of all authors. All authors made substantial contributions to the present study. LHH designed the study, prepared the typodonts, and drafted the manuscript. LRL performed the intraoral scanning and the 3D deviation analysis. LYY performed the statistical analysis. WY critically revised the manuscript. All authors read and approved the final manuscript.

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Availability of data and materials

The STL files and 3D surface models obtained in this study with the IOS, as well as the reference files obtained with the laboratory scanner, belong to the Guanghua School of Stomatology, Sun Yat-sen University, and are therefore available only upon reasonable request after approval by the university. The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate

Not applicable. None of the human data were used in this study.

Consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

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TABLES

Table 1. Scanner type and software version.

Scanner type	Manufacturer	Scanner technology	Software
CEREC Omnicam	Dentsply Sirona	Active triangulation	CEREC version 4.6.1Medit
Medit i500	Medit Corp	Active triangulation	Link version 1.2.0.3
3Shape TRIOS 3	3Shape A/S	Parallel confocal microscopy	Design Studio version 19.3.1—Software build 1.6.9.1

Table 2. Two-way ANOVA results for trueness.

Source of variation	Sun of squares	*df*	Mean square	*F*	Sig.
Scanner type	3698.56	2	1849.28	49.50	<0.001
Preparation design	15033.21	2	7516.61	201.20	<0.001
Scanner type × Preparation design	80.61	4	20.15	0.54	0.707
Error	3026.01	81	37.36		
Corrected total	21838.39	89			

Table 3. Trueness of RMS considering different preparation designs and Scanner types.

Trueness, RMS, mean ± SD (μm)			
Preparation design	Scanner		
	CEREC Omnicam	Medit i500	3Shape TRIOS 3
W	84.67 ± 8.15^{Ba}	82.41 ± 8.43^{Ba}	71.72 ± 3.23^{Bb}
B	92.35 ± 7.40^{Aa}	91.33 ± 5.73^{Aa}	76.34 ± 3.40^{Ab}
IO	60.18 ± 2.45^{Ca}	61.61 ± 8.73^{Ca}	47.45 ± 2.65^{Cb}

Table 4. Two-way ANOVA results for precision.

Source of variation	Sun of squares	*df*	Mean square	*F*	Sig.
Scanner type	1826.45	2	913.22	46.34	<0.001
Preparation design	3164.84	2	1582.42	80.30	<0.001
Scanner type × Preparation design	77.69	4	19.42	0.99	0.415
Error	7803.32	396	19.71		
Corrected total	12872.31	404			

Table 5. Precision of RMS considering different preparation designs and Scanner types.

Precision, RMS, mean ± SD (μm)			
Preparation design	Scanner		
	CEREC Omnicam	Medit i500	3Shape TRIOS 3
W	33.99 ± 4.33^{Aa}	33.59 ± 5.71^{Aa}	28.06 ± 3.34^{Ab}
B	28.57 ± 5.67^{Ba}	27.76 ± 4.44^{Ba}	24.57 ± 3.16^{Bb}
IO	27.09 ± 4.33^{Ca}	26.21 ± 3.50^{Ca}	22.58 ± 4.71^{Cb}

FIGURES

FIGURE 1 Maxillary models showing three different preparation designs. (a) Window preparation design (W); (b) Bevel preparation design (B); and (c) Incisal overlap preparation design (IO).

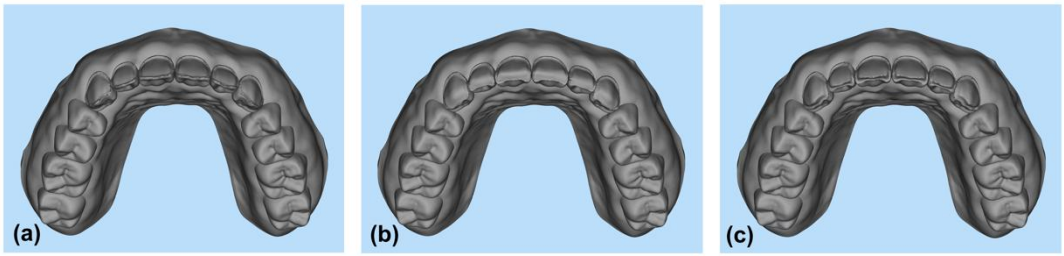


FIGURE 2 Workflow of study design. STL, standard tessellation language.

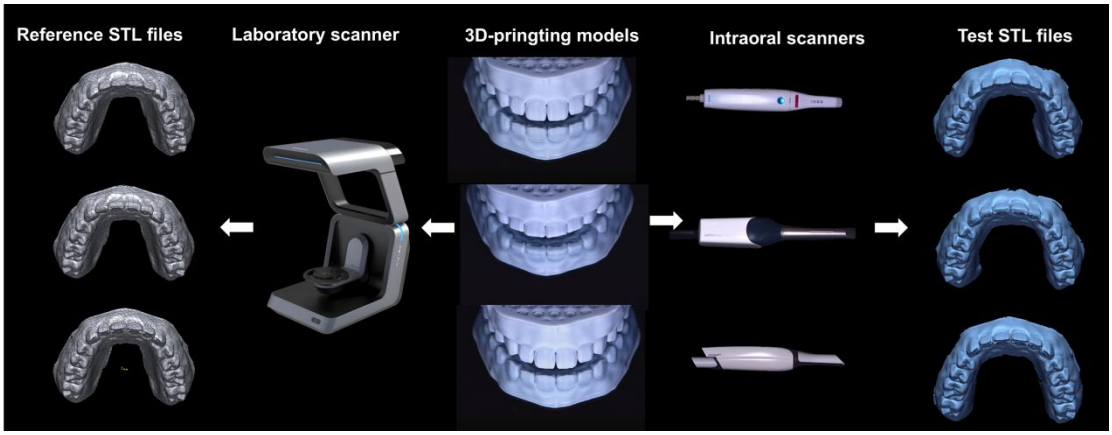
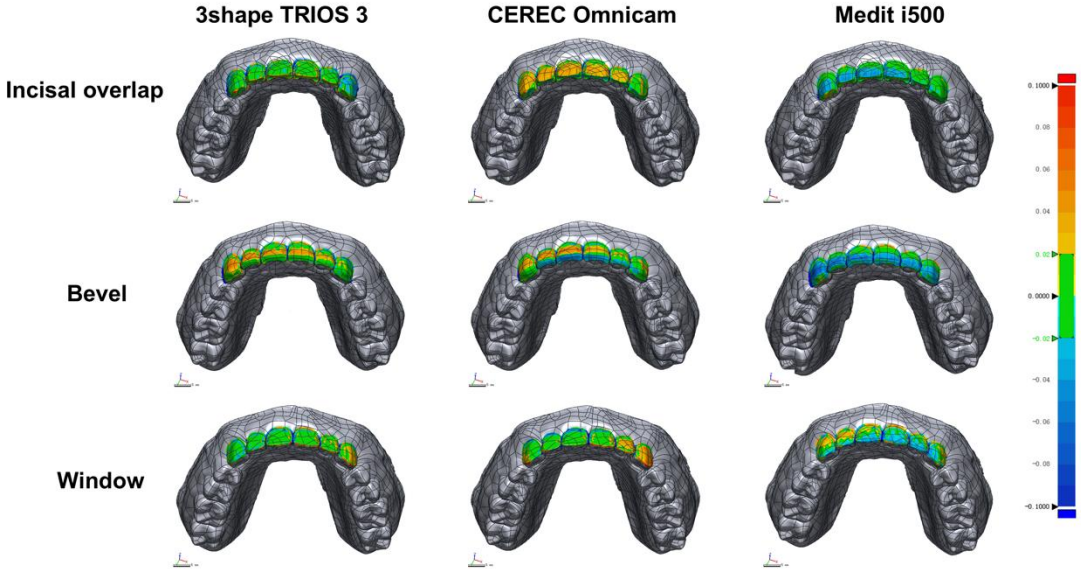


FIGURE 3 Deviation between digital impressions acquired by each intraoral scanner and reference scanner. Colors indicate deviations from -0.1 mm (blue) to +0.1 mm (red), representing contraction and expansion.


3shape TRIOS 3
CEREC Omnicam
Medit i500
Incisal overlap
Bevel
Window
0.1000
0.08
0.06
0.04
0.02
0.0000
-0.02
-0.04
-0.06
-0.08
-0.1000