Original Article

Evaluating the influence of different light conditions on scanning trueness

Yu-Lun Cheng, DDS
Division of Prosthodontics, Department of Dentistry, Kaohsiung Medical University Hospital, Kaohsiung Medical University, Kaohsiung, 80708, Taiwan.

Jen-Hao Chen, DDS, MS, PhD,
Je-Kang Du, DDS, MS, PhD,
Chun-Cheng Hung, DDS, MS, PhD,
Jen- Chyan Wang, DDS, MS,
Ting-Hsun Lan, DDS, MS, PhD*
Division of Prosthodontics, Department of Dentistry, Kaohsiung Medical University Hospital, Kaohsiung Medical University, Kaohsiung, 80708, Taiwan.
School of Dentistry, College of Dental Medicine, Kaohsiung Medical University, Kaohsiung,
80708, Taiwan.
Running title: IOS Trueness of different light conditions

Corresponding author:
Dr. Ting-Hsun Lan
School of Dentistry, College of Dental Medicine, Kaohsiung Medical University, 100 Shin-Chuan 1st Road, Sanmin District, Kaohsiung 80708, Taiwan
Phone : +886-7-3121101 ext. 7003
Fax: +886-7-3157024
Email: tinghsun.lan@gmail.com

DO: 10.6926/JPI.202303_12(1).0002

Abstract

Aims: *This in vitro study aimed to compare the trueness of maxilla and mandible full-arch optical scans using one scan path with five different light conditions.*

Materials and methods: *Standard maxilla and mandible models were set in a dental chair using a holder to simulate position and posture. The reference models' Standard Tessellation Language files were formatted using a desktop scanner, and the operative model's files were obtained using an intra-oral scanner (Trios 3 Pod) and superimposed using Exocad DentalCAD software. The same scan path was designed to scan ten times per jaw with five light conditions (room daylight [Original], unit [UL], white [WL], green [GL], orange [OL]), creating 100 scan files that were then compared with the reference files. The maximum deviation of each tooth was recorded, and statistical analysis used one-way analyses of variance followed by Tukey's post hoc test.*

Results: *The trueness of the optical impression for the full arch using one path differed between the maxilla and mandible and depended on the different light conditions ($P < 0.05$). In the same path, peak deviation was found at the turning points for the left central incisor, left first premolar, left second molar, and right second molar in the maxilla, and for the right first premolar, right second molar, and left second molar in the mandible. The Original condition showed the lowest deviation (0.121 ± 0.095 mm) in the maxilla and GL in the mandible (0.072 ± 0.035 mm). The five light conditions did not differ significantly in the maxilla ($P = 0.267$). However, the UL condition differed significantly from the other four light conditions in the mandible ($P = 0.001$).*

Conclusions: *UL is not recommended during the intraoral scan. However, the trueness might be less affected by the different light conditions from the headlamp of the loupes during an optical intra-oral scan.*

Key words: Light conditions, trueness, full-arch scan, intra-oral scanner

Introduction

In the digital dentistry era, dentists increasingly use the intra-oral scanner (IOS) in clinical treatment to replace the traditional impression.[1,2] From image capture, software design, and biomaterial selection to manufacturing type, digital dentistry is changing the treatment process.[3,4] However, artificial intelligence,[5] augmented/virtual reality,[6] navigation,[7] or the addition of other biomechanical considerations[8,9] is impacting the dental treatment concept.

The pioneering IOS device used in clinical dentistry was the CEREC system in 1987.[10] Many IOS devices have been launched in dentistry and are gaining popularity in dental offices in the past decade.[11] The accuracy studies for most IOSs have been compared and validated in meeting clinical needs, and the accuracy of some IOSs even exceeds traditional silicone impression materials.[12,13] Conversely, the accuracy of IOSs has been shown to deviate significantly depending on the model, scanning field, scanning strategy, and environmental disturbances. Kim et al.[14,15] showed significant deviations between different IOSs ranging from 17.80 to 200.24 μm. In addition, Medina-Sotomayor[16] stated that full-arch scanning still had limitations and discrepancies, although using IOS devices for single crown work is increasingly popular.

While recording the digital data of the full dental arch is very useful for full mouth rehabilitation, correcting and verifying its limitations and errors is necessary. Richert et al.[17] reviewed articles and highlighted that saliva, blood, rebound after gingivae, patient's mouth-opening durability, and cheek and tongue movement would affect oral scan quality. Arakida et al.[18] demonstrated that ambient light of 3900 K and 500 lux is suitable for taking optical impressions.

Dentists use a magnifying glass, known as loupes, in clinical applications to help them see small details more clearly.[19] This allows them to perform procedures such as filling cavities, placing crowns, and performing root canals with greater precision and accuracy, improving the overall outcome of the treatment for the patient. A headlamp provides additional lighting, which can help the dentist see small details more clearly. This additional lighting can be beneficial when the natural lighting in the room could be more optimal or when the dentist works in an area that is difficult to access with traditional overhead lighting.[20] Additionally, a headlamp allows the dentist to position the light source directly where needed, which can be more efficient than attempting to position the patient or chair to get the best lighting.

Loupes with headlamps often have different light color options because different colors of light can affect visibility and color perception differently. A cool white light could provide a bright, clear view of the teeth and gums, and a warm white light could provide a more realistic scenery of the teeth and gums and help reduce glare and reflections.[21] Some loupes with headlamps also have a red light, which can be beneficial for specific procedures such as endodontics since it helps to reduce the glare on metal surfaces and the visibility of blood, making it easier for the dentist to see the inside of the tooth.[22] Since green light is less intense than white light, it can be less harsh on the eyes and may cause less eye fatigue for the dentist. In addition, green light is a neutral color, so it does not affect the color perception of the teeth and gums; it can be helpful for the color matching of restorative materials and natural teeth.[23] Moreover, some headlamps also come with UV light options[24] that can be used to detect the fluorescence of the dental materials and teeth, helping the dentist identify the decay's specific location.

Wesemann et al.[25] used the dental model in a box with different ambient light sets, showing that the ambient light would influence the accuracy and scanning time of IOSs. Ochoa-López et al.[26] showed that ambient light influenced the accuracy and scanning time of IOSs, and the effect was different for all devices. Revilla-León et al.[27,28] used the lower model, showing similar results with aforementioned study and revealing that Trios 3 provided better accuracy and mesh quality. In a clinical study, Revilla-León. et al. [29] showed that light conditions significantly influenced the scanning accuracy of the IOS. The higher the extension of the digital scan performed, the lower the accuracy values obtained.

To evaluate the influence of ambient light in oral scans of the maxilla and mandible, this *in vitro* study aimed to measure the impact of various ambient scanning light conditions on the accuracy of intra-oral scanning. The null hypotheses were: (i) that no significant differences would be found in either the maxilla or mandible for the digital scan trueness of the same IOSs and (ii) that no significant differences would be found under the five different ambient scanning light conditions in one jaw.

Methods and Materials

1. Pre-scan preparation

A dental simulator model (Nissin Dental Products, Inc., Kyoto, Japan) put in a Nissin Simple Manikin II (Nissin Dental Products, Inc.) was set on a dental chair to simulate the clinical condition. The model was initially scanned with a desktop scanner (E4; 3Shape, Copenhagen, Denmark) to obtain initial STL files. The Trios 3 Pod Scanner (version 19.2.4; manufactured 2017-12; 3Shape) is an IOS system commonly used clinically; it was calibrated according to the manufacturer's guidelines. An experienced right-handed dentist performed all scans, keeping an arch scan under 1500 sheets of image.

2. Scan strategies

The original model was scanned using a desktop model scanner (3Shape E4 scanner) and an IOS (3Shape Trios 3). The model was set on the unit to simulate a real patient position and scanned ten times under five different light conditions by this IOS. The scan strategy followed the manufacturer's guidelines (Figure 1). For the maxilla, the occlusal surface begins, starting at the left second molar, continuing to the right second molar, returning through the palatal surface, and finally sweeping the buccal surfaces. The mandibular path begins at the occlusal side of the second molar in quarter III, progresses longitudinally along the dental arch, ends at the right second molar, continues lingually through the arch, and finally completes the buccal arch. Then, an experienced dentist performed each condition ten times, with 100 scans recorded.

The same dentist performed all test scans in the same room under similar temperatures (22°C), relative humidities (60%), and five different light conditions with the same distance and angles. The different light sources were set at room daylight (Original); unit light (UL); white light (WL), green light (GL), and orange light (OL) from the loupe headlight (Figure 2).

(1) For the Original group, the chair's light was turned off, and only the ceiling light was used, with no windows or natural light. The illuminance of the room was 1003 lux as measured using the same light meter.

(2) For the UL group, in a room with a dental chair (A-dec 500; A-dec, Newberg, OR, USA), the chair's LED light had an intensity of 15000 lux and 5000 K and was oriented 45° at 66 cm from the dental model.

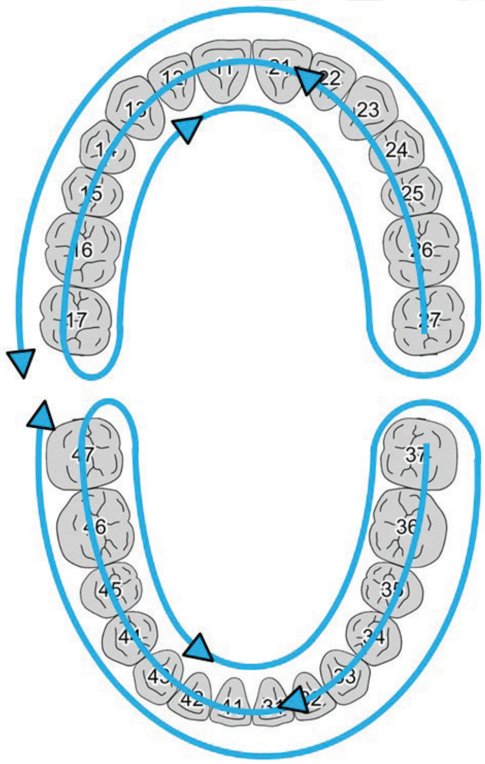

Figure 1. The scan path follows the manufacturer's guidelines.

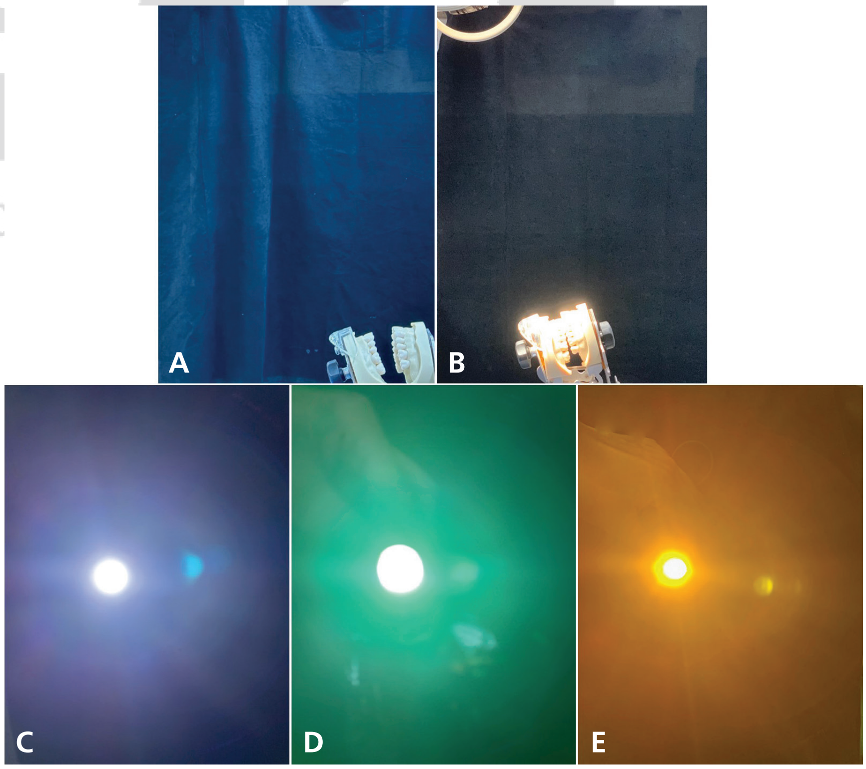

Figure 2. SThe different light source was set at (A) room daylight (Original), (B) unit light (UL), (C)white light (WL), (D) green light (GL), and (E) orange light (OL).

(3) For the WL group, not subgroup of the loupe headlight group, the loupe's LED light had an intensity of 50000 lux and 5600 K (Snap On Optics, Phoenix, AZ, USA).

(4) For the GL group, not subgroup of the loupe headlight group, the loupe's LED light had an intensity of 50000 lux and 4100K (Snap On Optics).

(5) For the OL group, not subgroup of the loupe headlight group, the loupe's LED light had an intensity of 50000 lux and 2500K (Snap On Optics).

Trueness was defined by comparing a test dataset with a reference dataset and determining the scanner's true accuracy. The difference between the model's measured point and the superimposed model's furthest corresponding point could be calculated using the "Best Fit Match" and "Cutting View" tools in a CAD software program (Exocad DentalCAD; Exocad GmbH, Santa Clara, CA, USA). One model recorded fourteen teeth with maximum deviations, and 1400 data points were recorded for two jaws. Figure 3 shows deviations between the scanning and reference models with different light sources.

3. Statistical analysis

Seven hundred data points were recorded for each jaw for the trueness comparisons. Descriptive statistics were used to present the data in each group. Groups were compared using one-way variance analysis with Turkey's post hoc test using IBM SPSS Statistics for Windows (version 20; IBM Corp, Armonk, NY, USA). A $P < 0.05$ was considered statistically significant for all tests.

Results

The mean absolute deviation among the five light conditions was 0.132 ± 0.110 mm in the maxilla and 0.081 ± 0.054 mm in the mandible. The statistical results indicated a significant interaction between the upper and lower jaws ($P < 0.05$).

For trueness, the maximum mean deviations are shown in Table 1. Figure 4 shows the maximum deviation of different tooth positions among five light conditions in the maxilla. The mean deviation was largest in the UL group (0.146 ± 0.108 mm) and smallest in the Original group (0.121 ± 0.095 mm). However, the trueness of each tooth position in the oral scan did not differ significantly between the various light conditions and the original light source.

Figure 5 shows the maximum deviation of different tooth positions among the five light conditions in the mandible. The mean deviation was largest in the UL group (0.096 ± 0.071 mm) and smallest in the GL group (0.072 ± 0.035mm). In addition, the trueness of the oral

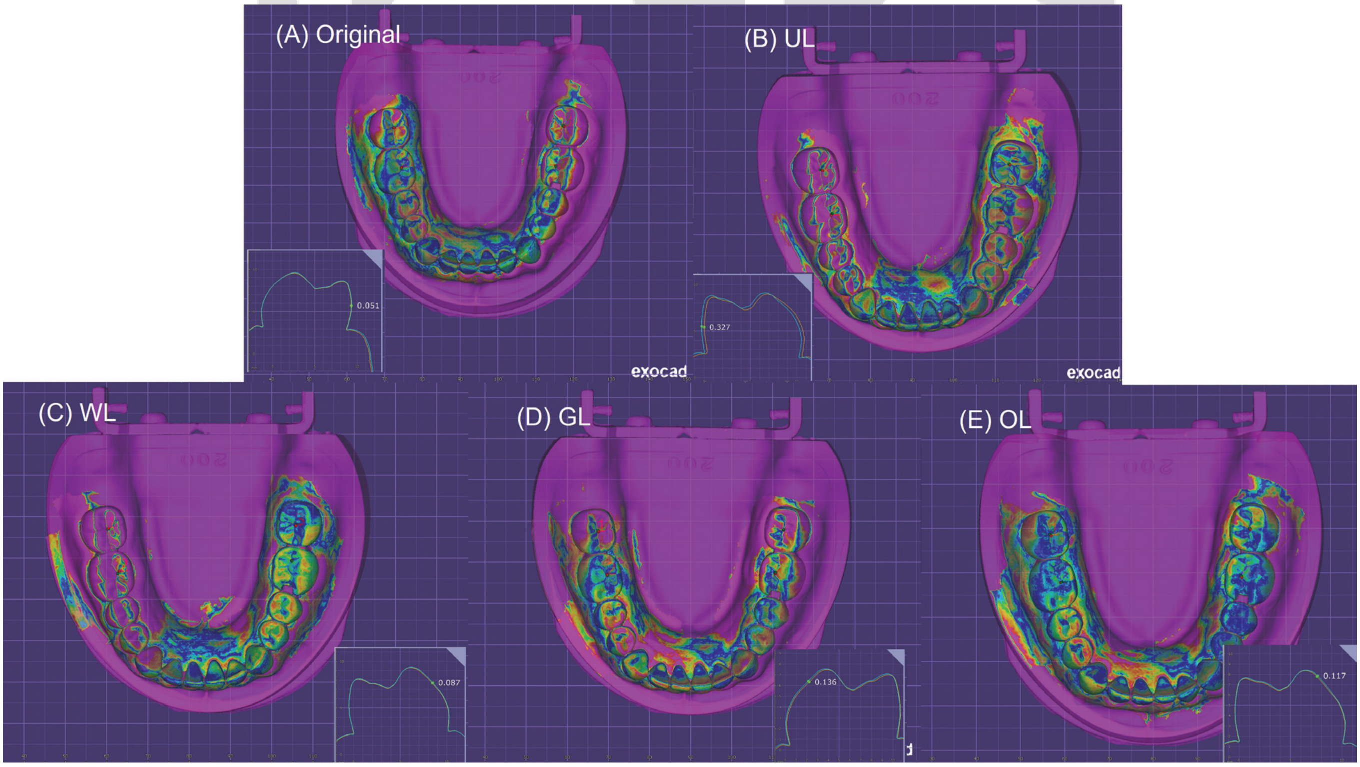

Figure 3. Color code showing deviations for (A) original, (B) UL, (C) WL, (D) GL, and (E) OL scans with the reference model.

Table 1. Maximum mean absolute maxilla and mandible deviation (unit: mm).

	Maxilla			Mandible		
	Mean ± SD	95%CI	*P*-value	Mean ± SD	95%CI	*P*-value
Original	0.121 ± 0.095	(0.105, 0.136)	0.267	0.076 ± 0.060[a]	(0.069, 0.083)	0.001
UL	0.146 ± 0.108	(0.128, 0.164)		0.096 ± 0.071[b]	(0.087, 0.104)	
WL	0.127 ± 0.098	(0.111, 0.143)		0.080 ± 0.065[a]	(0.072, 0.087)	
GL	0.140 ± 0.141	(0.117, 0.164)		0.072 ± 0.035[a]	(0.068, 0.035)	
OL	0.126 ± 0.102	(0.108, 0.143)		0.079 ± 0.058[a]	(0.072, 0.086)	

Different superscript letters in a column indicate a significant difference among groups ($P < 0.05$; one-way ANOVA [*K* independent sample] with Tukey's post hoc test).

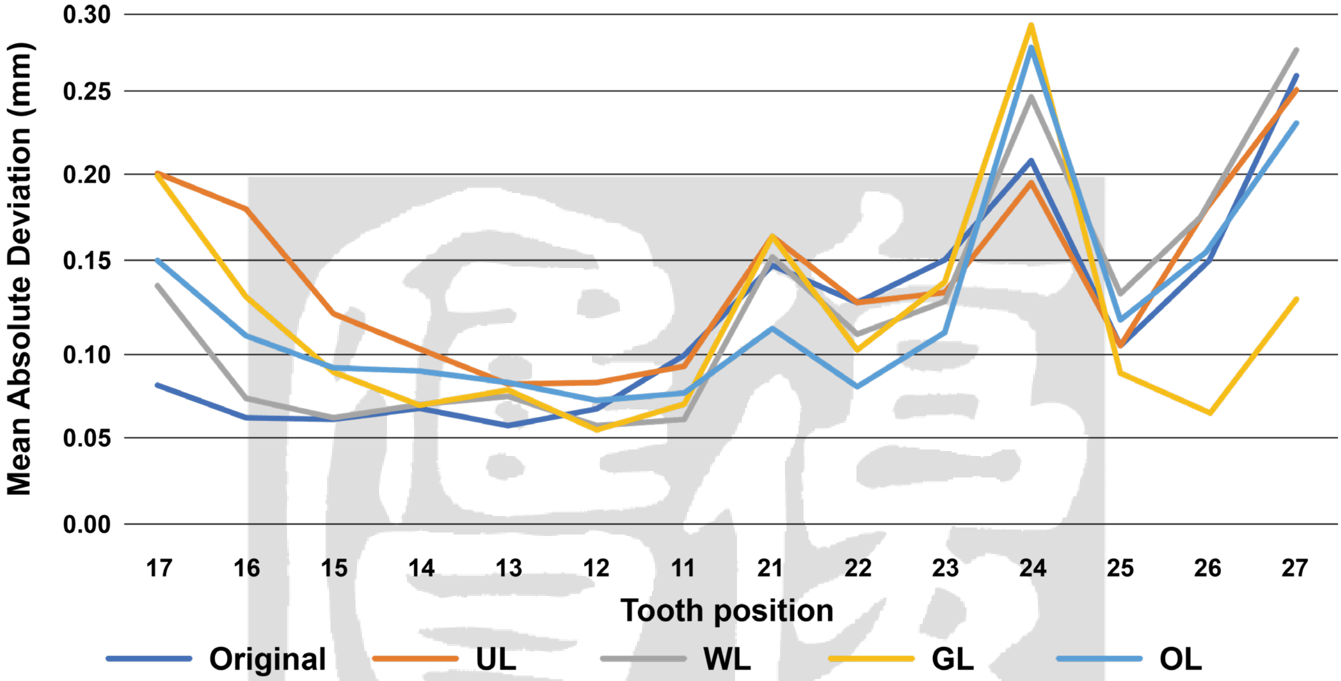

Figure 4. Mean deviations at different tooth positions among five light conditions in the maxilla.

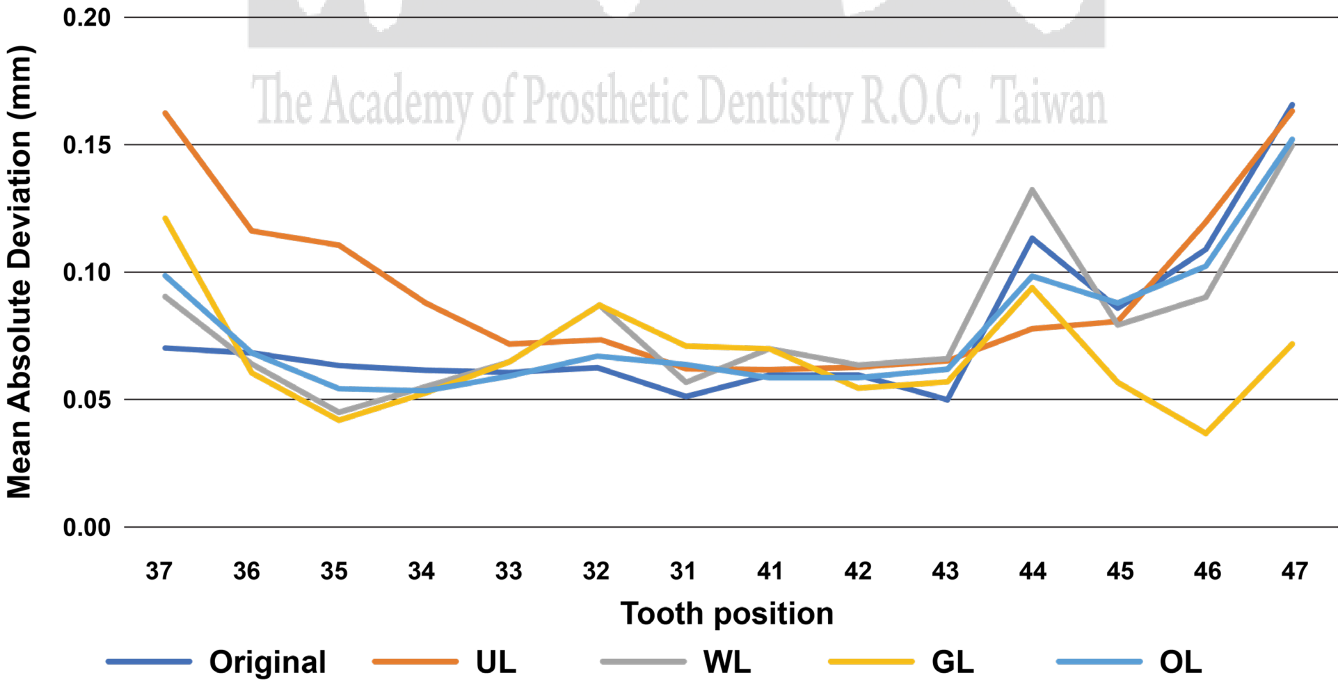

Figure 5. Mean deviations at different tooth positions among five light conditions in the mandible.

scan was significantly influenced by the different light conditions, especially the UL ($P = 0.001$).

Discussion

This in vitro study evaluated the impact of various ambient scanning light conditions on the accuracy of an IOS, finding that UL affected the trueness of the IOS of the mandible. The null hypothesis was rejected. The original light source provided similar data to Feng et al.[30] This study showed a similar value in the deviation of trueness to the findings of Kim et al.[14,15] Constructing the 3D model from the IOS would cause larger deviations in the curved areas of the dental arch, such as premolars, canines, and the distal surface of the molars, which require more angles to be flipped during capture. These deviations could be attributed to the inevitable shaking and movement when holding the IOS or the limitations of the Trios 3 system. In the maxilla, the larger deviations in the linear movement at the left first premolar than the right first premolar might be attributed to changes in the lens focus during the move when converting a straight line into a curved surface, which would necessarily create a defocused image. Feng et al.[30] showed that the maxilla would be affected significantly more than the mandible, consistent with the findings of this study.

Revilla-León et al.[27,28] used the lower model to compare trueness in different ambient lights, finding that Trios 3 provided better accuracy and mesh quality. This study's results are similar but show distinct upper and lower jaw patterns. Wesemann et al.[25] used the dental model in a box with different ambient light sets, showing that ambient light would influence the accuracy and scanning time of IOSs. This study demonstrated that ambient light would significantly affect the lower jaw when setting the model on a dental chair to simulate clinical posture. A clinical study by Revilla-León et al.[29] showed that light conditions significantly influenced the scanning accuracy of the IOS, and the higher the extension of the digital scan performed, the lower the accuracy values obtained. This study provides full arch results that demonstrate the trueness of IOS over the upper and lower jaw. The trueness would be affected by the clinical setting. In the maxilla, turning points and longer scan time would jeopardize the trueness; however, different ambient light conditions did not significantly affect the trueness ($P = 0.267$). In contrast, the lower jaw was relatively stable in different tooth positions; however, dental unit light significantly affected the trueness under different ambient light conditions.

Chang et al.[31] indicated that marginal fit is essential for the longevity of restoration, but the threshold value remains controversial. A mean marginal gap of 50–100 μm has been generally defined as clinically acceptable,[32,33] and 120 μm has been considered the maximum tolerable marginal opening.[34] In this study, the statistical data of deviation in the mandible varied under different light sources; however, the mean values did not differ appreciably (UL = 0.096 mm vs. Original = 0.076 mm), and they were all close to the upper limit of the clinically acceptable range. Even with improvements in the IOS, while the accuracy is gradually approaching the clinically acceptable range for the marginal gap, there remains room for improvement. Therefore, in addition to the continuous improvement of the IOS, it remains necessary to avoid environmental interference, such as light sources (especially UL), during clinical operations.

In clinical practice, the treatment chair and the loupe will illuminate the teeth from different directions and distances. In this study, the irradiation angle and distance were fixed for its consistency. While there will be some clinical differences, under the current setting, it was found that the loupe had no influence on the oral scan, and the UL of the treatment chair produced differences on the jaw. Since Feng et al.[30] highlighted that accuracy was better for the mandible than the maxilla, it is inferred that the light (especially UL) will interfere with the stability of the oral scan. Conversely, since the difference in the upper jaw was significant, even the effect after adding light became more prominent; however, the difference between each after this increase was not statistically significant.

Since a dental model was set on a dental chair in a Nissin holder to simulate the posture, the absence of environmental influences such as saliva, blood, and soft tissue changes is a limitation in this study. Moreover, the reason for UL light affects the result remains unclear and may be related to multiple factors. Therefore, future studies should evaluate the influence of factors such as light wavelength, illumination brightness, illumination distance, and different equipment. In addition, they should compare different IOS and hybrid environmental settings.

Conclusion

Within the limitations of this study, the accuracy of optical impressions for the full arch using one path with five light conditions differed between the maxilla and mandible ($P < 0.05$). In maxilla optical impressions obtained using an IOS, the effect of various light conditions on the oral scan did not differ from the original light source regarding the trueness of each tooth position. The influence of various light conditions differed significantly under the influence of the trueness of the oral scan, particularly for the UL ($P = 0.001$).

Acknowledgments

This study is grateful for the partial support of the Taiwan Ministry of Science and Technology (MOST 111-2314-B-037-043-MY3 and KMUH111-1R71).

Conflicts of Interest

The authors declare no conflicts of interest related to this article.

References

1. Blatz MB, Conejo J. The current state of chairside digital dentistry and materials. Dent Clin North Am 2019;63:175–97.
2. Chang IC, Hung CC, Du JK, Liu CT, Lai PL, Lan TH. Accuracy of intraoral scanning methods for maxillary Kennedy class I arch. J Dent Sci 2023;18:747–53.
3. Sulaiman TA. Materials in digital dentistry-a review. J Esthet Restor Dent 2020;32:171–81.
4. Rekow ED. Digital dentistry: The new state of the art - Is it disruptive or destructive? Dent Mater 2020;36:9–24.
5. Mahdi SS, Battineni G, Khawaja M, Allana R, Siddiqui MK, Agha D. How does artificial intelligence impact digital healthcare initiatives? A review of AI applications in dental healthcare. Int J Inform Manage Data Insights 2023;3:100144.
6. Fahim S, Maqsood A, Das G, et al. Augmented reality and virtual reality in dentistry: highlights from the current research. Appl Sci 2022;12:3719.
7. Hong G, Hung CC, Mayanagi G, et al. Questionnaire survey on the satisfaction of SimEx dental education system. J Dent Sci 2023;18:840–7.
8. Cheng KC, Liu PH, Chen HS, Lan TH. Stress distribution of four-unit implant-supported fixed partial prosthesis with different numbers and positions of fixtures in maxilla anterior region-3D FEA. J Med Biol Eng 2022;42:526–33.
9. Lan TH, Fok ASL, Hung CC, Du JK, Liu CT, Chen JH. Stress analysis and risk of failure during clenching in ceramic assembly models: 3-dimensional finite element analysis. J Dent Sci 2023;18:791–800.
10. Hwang HHM, Chou CW, Chen YJ, Yao CCJ. An overview of digital intraoral scanners: past, present and future-from an orthodontic perspective. Taiwanese J Orthod 2020;30:148–62.
11. Marques S, Ribeiro P, Falcão C, et al. Digital impressions in implant dentistry: a literature review. Int J Environ Res Public Health 2021;18:1020.
12. Krahenbuhl JT, Cho SH, Irelan J, Bansal NK. Accuracy and precision of occlusal contacts of stereolithographic casts mounted by digital interocclusal registrations. J Prosthet Dent 2016;116:231–6.
13. Solaberrieta E, Garmendia A, Brizuela A, Otegi JR, Pradies G, Szentpétery A. Intraoral digital impressions for virtual occlusal records: section quantity and dimensions. Biomed Res Int 2016;2016:7173824.
14. Kim RJY, Benic GI, Park JM. Trueness of ten intraoral scanners in determining the positions of simulated implant scan bodies. Sci Rep 2021;11:2606.
15. Kim RJY, Park JM, Shim JS. Accuracy of 9 intraoral scanners for complete-arch image acquisition: a qualitative and quantitative evaluation. J Prosthet Dent 2018;120:895-903.e1.
16. Medina-Sotomayor P, Pascual-Moscardó A, Camps I. Accuracy of four digital scanners according to scanning strategy in complete-arch impressions. PLoS One 2018;13:e0202916.
17. Richert R, Goujat A, Venet L, et al. Intraoral scanner technologies: a review to make a successful impression. J Healthc Eng 2017;2017:8427595.
18. Arakida T, Kanazawa M, Iwaki M, Suzuki T, Minakuchi S. Evaluating the influence of ambient light on scanning trueness, precision, and time of intra oral scanner. J Prosthodont Res 2018;62:324–9.
19. Aldosari MA. Dental magnification loupes: an update of the evidence. J Contemp Dent Pract 2021;22:310–5.

20. Wajngarten D, Botta AC, Garcia PPNS. Magnification loupes in dentistry: a qualitative study of dental students' perspectives. Eur J Dent Educ 2021;25:305–9.
21. Suero Molina E, Hellwig SJ, Walke A, Jeibmann A, Stepp H, Stummer W. Development and validation of a triple-LED surgical loupe device for fluorescence-guided resections with 5-ALA. J Neurosurg 2021;31:1–9.
22. Rocha MG, Ottenga ME, Zoidis P, Pontes S, Reis AF, Oliveira D. Effect of dental headlights spectrum on the polymerization and working time of light-cured resin composites. J Clin Exp Dent 2022;14:e492–e498.
23. Stamatacos C, Harrison JL. The possible ocular hazards of LED dental illumination applications. J Mich Dent Assoc 2014;96:34–9.
24. Giantini-Larsen AM, Parker WE, Cho SS, et al. The evolution of 5-aminolevulinic acid fluorescence visualization: time for a headlamp/loupe combination. World Neurosurg 2022;159:136–43.
25. Wesemann C, Kienbaum H, Thun M, Spies BC, Beuer F, Bumann A. Does ambient light affect the accuracy and scanning time of intraoral scans? J Prosthet Dent 2021;125:924–31.
26. Ochoa-López G, Cascos R, Antonaya-Martín JL, Revilla-León M, Gómez-Polo M. Influence of ambient light conditions on the accuracy and scanning time of seven intraoral scanners in complete-arch implant scans. J Dent 2022;121:104138.
27. Revilla-León M, Jiang P, Sadeghpour M, et al. Intraoral digital scans-Part 1: influence of ambient scanning light conditions on the accuracy (trueness and precision) of different intraoral scanners. J Prosthet Dent 2020;124:372–8.
28. Revilla-León M, Jiang P, Sadeghpour M, et al. Intraoral digital scans: Part 2-influence of ambient scanning light conditions on the mesh quality of different intraoral scanners. J Prosthet Dent 2020;124:575–80.
29. Revilla-León M, Subramanian SG, Özcan M, Krishnamurthy VR. Clinical study of the influence of ambient light scanning conditions on the accuracy (trueness and precision) of an intraoral scanner. J Prosthodont 2020;29:107–13.
30. Feng CW, Hung CC, Wang JC, Lan TH. Accuracy of different head movements of intraoral scanner in full arch of both maxilla and mandible. Appl Sci 2021;11:8140.
31. Lan TH, Chen YF, Wang YY, Chou MMC. Evaluation of the feasibility of nacapo4-blended zirconia as a new CAD/CAM material for dental restoration. Materials 2021;14:3819.
32. May KB, Russel MM, Razzoog ME, Lang BR. Precision of fit: the procera allceram crown. J Prosthet Dent 1998;80:394–404.
33. Coli P, Karlsson S. Fit of a new pressure-sintered zirconium dioxide coping. Int J Prosthodont 2004;17:59–64.
34. McLean JW, von Fraunhofer JA. The estimation of cement film thickness by an in vivo technique. Br Dent J 1971;131:107–11.