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INFLUENCE OF LIGHT SOURCE ON ACCURACY OF INTRAORAL SCANNER
COLOR DETERMINATION

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DEDICATION

To my wife, Amanda

DISCLAIMER

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ABSTRACT

INFLUENCE OF LIGHT SOURCE ON ACCUARCY OF INTRAORAL SCANNER

COLOR DETERMINATION

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Purpose: This is an *in-vitro* study to assess influence of various lighting conditions on the ability of an intraoral scanner (TRIOS 3; 3Shape) to accurately identify tooth shades.

Materials and Methods: Color measurements were obtained using two Vita Classical and two Vita 3D Master shade guides with shade tabs placed into a gingival matrix.

Scanner shade measurements were obtained under three different light conditions; no light, overhead room light, and natural day light. Eighty-four shade tabs were scanned under each lighting condition. Accuracy was determined by the total number of shade tabs correctly identified for each guide. Consistency between each shade guide and light condition was performed using cross-classified chi-square (Fisher's exact) analysis. Pair-wise comparisons were used to determine differences in accuracy under the various lighting conditions ($\alpha = 0.05$). **Results:** No significant difference in scanner consistency was observed between shade guides under the various light conditions ($p > 0.05$). Pair-wise comparison revealed significant differences in scanner accuracy with the Vita Classical shade guide at daylight compared to no light and room light ($p < 0.05$).

Varying light conditions had no effect on accuracy when using the Vita 3D Master guide ($p > 0.05$). **Conclusions:** Light intensity influences the accuracy of the IOS to identify tooth shades. When using the Vita Classical shade guide, lower light conditions are recommended

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LIST OF ABBREVIATIONS

CAD/CAM	Computer aided design/computer aided manufacturing
IOS	Intraoral scanner
VC	Vita classical
3DM	Vita 3D master

CHAPTER 1: Introduction

Color matching appropriate tooth shade to achieve optimum esthetics is still one of the greatest challenges faced by dental professionals. In order to meet patient's esthetic demands, practitioners must strive to deliver restorations that match natural tooth color and translucency.¹ Traditionally, this is accomplished through visual methods using commercially available shade guides.² A recent study revealed that 100% of the private dental practitioners surveyed still use commercially available guides for shade selection in their offices.³

Although visual methods are most commonly used, color perception is inherently subjective and can be influenced by intrinsic as well as extrinsic factors. Age, gender, eye fatigue, experience, and environmental conditions can all affect a dentist's ability to repeatedly select an appropriate shade.⁴ To overcome the shortcomings of conventional shade matching and produce more objective and reliable results, electronic shade matching instruments (e.g., spectrophotometers and colorimeters) have been recommended. These instruments have been shown to improve accuracy and repeatability in color selection for direct and indirect restorations, lab communication, and shade reproduction.⁵⁻⁷

With the advancement of computer-aided design and computer-aided manufacturing (CAD-CAM) technology, digital dentistry is now available chairside in many civilian and military dental offices with advantages which include reduced working time, lowered costs, and more predictable outcomes.⁸ As a result, intraoral scanners (IOSs) are now routinely used to make digital impressions of dental arches. Many intraoral scanners also have a tooth shade determination module for shade taking at the

time of digital impression.⁹⁻¹² For this study, TRIOS 3 intraoral digital scanner (3Shape, Inc., New Providence, NJ) was used with a shade-taking functionality.^{14, 15}

Previous studies showed that intraoral scanners and other electronic shade matching devices are not affected by daylight or ambient contrasts^{6, 11-12}; however, a recent study by Arakida *et al.*, showed the amount of ambient light present in a dental operatory can affect the trueness of intraoral scanners used for digital impressions.¹³ Although it is generally believed that digital scanning and computer software systems are comparable to conventional, visual methods for color determination, the effects of ambient lighting on the shade matching accuracy of an intraoral scanner have not been comprehensively studied. The purpose of this *in-vitro* study is to assess the influence of various conditions on the ability of the TRIOS scanner to accurately identify tooth shade. The null hypothesis postulates that no difference in matching accuracy will be observed regardless of lighting conditions.

CHAPTER 2: Materials and methods

This study was reviewed by Water Reed National Military Medical Center Institutional Review Board and determined to be not human subjects research. The study was approved by Naval Medical Leader and Professional Development Command. This *in-vitro* study was designed to simulate clinically relevant conditions. An experimental shade model was fabricated by placing shade tabs from the Vita Classical (VC) and Vita 3D Master (3DM) shade guides into a gingiva silicone matrix (**Fig 1**).

To test whether IOS (TRIOS 3; 3Shape, Inc.) is more accurate identifying tooth shades under a certain lighting condition, digital scans were made under three different light illuminances: namely no light (0 Lux), operatory room light (500 Lux), and natural daylight (1250 Lux). The amount of ambient light present during scanning was registered using a hand held illuminance meter (MT-912; URCERI, Shenzhen, China).

For dental operatory room light scans (500 Lux), only overhead ceiling light was used. Dental operatory window blinds were closed and the dental chair light was turned off. Overhead room lighting consisted of linear fluorescent bulbs with a color temperature rating of 4100 K (F32T8-SPX41; GE, Fairfield, CT). For the natural daylight scans (1250 Lux), overhead ceiling lights were turned off and operatory window blinds were open during noonday sun conditions. For no light conditions (0 Lux), scans were made with ceiling lights off in a room without windows (**Table 1**).

Prior to scanning under each light condition, the IOS was color- and 3D-calibrated following the manufacturer's instructions. As recommended by the manufacturer, 5 mm space was created between tooth surface and scanner tip by having the scanner wane fixed on the docking station as the gingival matrix with shade tabs was

placed on a dental survey table (**Fig 2**). During scanning, only the survey table was moved to maintain spatial consistency.

Following each shade tab scan, the IOS shade selection software was used to record the resulting shade. Shade was selected from the middle third of the tab. Shade measurement was considered to be accurate if the IOS returned a shade recommendation identical to the shade tab measured. Accuracy was calculated as a percentage of the total number of measurements made for each tab (n =16 for VC and n = 26 for 3DM) that was an exact match (**Table 2**) All entire experiment parameters were conducted by a single calibrated investigator.

To verify that the “lot-to-lot” variation in manufacturing of shade guides is acceptable for this study, scans were repeated using a second set of Vita Classic and second 3D Master guide under each light condition (identified as VC1, VC2, 3DM1, 3DM2) resulting in a total of 84 scans. Consistency between shade guides was compared using cross-classified chi-square (Fisher’s exact) analysis. The methodology was reviewed by an independent statistician.

CHAPTER 3: Results

The overall accuracy for scans under all lighting conditions is listed in Table 2. The IOS had the highest accuracy when using the Vita Classical shade guide under 0 Lux lighting condition. Cross-classified chi-square (Fisher's exact) analysis to determine if variability exists between shade guides showed no significant difference ($p < 0.05$) between shade guides (VC1 vs VC2 and 3DM1 vs 3DM2) under the three lighting conditions tested (**Table 3**). Pairwise comparison of the various lighting conditions revealed significant difference ($p < 0.05$) for the Vita Classical guide when comparing the no light (0 Lux) to daylight (1250 Lux), and room light (500 Lux) to daylight (1250 Lux) conditions. No statistical difference was noted between no light (0 Lux) and room light (500 Lux) conditions for the Vita Classical shade guide. Pairwise comparison revealed no significant difference ($p < 0.05$) for the 3D Master shade guide under all tested light conditions (**Table 4**).

CHAPTER 4: Discussion

Significant differences in shade matching accuracy were found for Vita Classical shade guide when comparing the three ambient light conditions. However, no significant difference was found when using the Vita 3D Master shade guides. Therefore, the null hypothesis was partially rejected. The findings of this study that higher illuminance conditions can affect IOS shade matching confirm previous studies showing high illuminance ambient light conditions can affect IOS scanning time.¹³ The finding that darker room conditions improve shade matching with IOS contradict shade matching recommendations for traditional visual assessment. For this experiment, the overhead ceiling lighting consisted of fluorescent lights with a color correlated temperature of 4100K, which is below the recommended ideal color temperature of 5500K when shade matching through traditional visual means.¹⁷ Despite this less than ideal lighting condition, the greater accuracy of shade match was found at room light (500 lux) compared to natural day light (1250 lux). This further supports the finding the higher illuminance can negatively affect TRIOS shade match ability.

This study showed that ambient light conditions did not significantly affect the IOS ability to correctly identify Vita 3DM shade tabs. This could be related to the broader range of shade coverage provided by the Vita 3DM (26 vs 16 tabs). The findings of this study validate with previous research showing the 3DM shade guide to be more reliable than the VC.¹⁰ Brandt *et al.* showed that dentists and dental technicians had an accuracy rate of 35.5% and 33.6% respectfully when asked to visually shade match using Vita 3DM.¹¹ Our study showed the accuracy of TRIOS with 3DM ranged from 34.6 to

42.3% depending on light condition, suggesting it may be a good alternative to the traditional visual shade matching method.

The present study has a number of limitations. This was an *in-vitro* study that did not account for anatomical factors that would be encountered in the clinical environment. Natural teeth have different structural layers with a polychromatic nature and varying degrees of translucency, resulting in optical properties that differ from resin shade tabs. Furthermore, scans were obtained by a single provider and were conducted in a controlled manner using a dental survey table. The study did not include any variation in provider experience or scanning technique that would be found with *in-vivo* studies. Further studies are necessary to fully understand the impact of various light conditions on the shade selection capability of intraoral scanners using human subjects with a range of tooth colors.

CHAPTER 5: Conclusions

Based on the findings of this *in-vitro* study, ambient light affects the accuracy of the IOS (TRIOS 3; 3Shape, Inc.) to identify tooth shades. When using the Vita Classic shade guide, lower light conditions are recommended.

REFERENCES

1. Chu SJ, Mielezsko AJ. Three steps to predictable shade matching of anterior teeth. *The American Journal of Esthetic Dentistry*. Spring 2013 Volume 3, Issue 1 : 66-71
2. Paul S, Peter A, Pietrobon N, Hammerle CH. Visual and spectrophotometric shade analysis of human teeth. *J Dent Res* 2002; 81(8): 578-582
3. Wee AG, Meyer A, Wu W, Wichman C. Lighting conditions used during visual shade matching in a private dental office. *J Prosthet Dent* 2016;115:469-474.
4. Ozat PB, Tuncel I, Eroglu E. Repeatability and reliability of human eye in visual shade selection. *J Oral Rehabil* 2013; 40:958-964
5. Gomez-Polo C, Gomez-Polo M, Celemin-Vinuella A, Martinez Vazquez De Parga JA. Differences between the human eye and the spectrophotometer in the shade matching of tooth colour. *J Dent* 2014; 42: 742-745.
6. Lagouvardos PE, Fougia AG, Diamantopoulou SA, Polyzois GL. Repeatability and interdevice reliability of two portable color selection devices in matching and measuring tooth color. *J Prosthet Dent* 2009;101:40-45.
7. Chu SJ, Trushkowsy RD, Paravina RD. Dental color matching instruments and systems. Review of clinical and research aspects. *J Dent* 2010; 38 (suppl 2): e2-e16
8. Gallardo YR, Bohner L, Tortamano P, Pigozzo MN, Lagana DC, Sesma N. Patient outcomes and procedure working time for digital versus conventional impressions: A systematic review. *J Prosthet Dent* 2018; 119(2); 214-219.
9. Kim RJ, Park JM, Shim JS. Accuracy of 9 intraoral scanners for complete-arch image acquisition: A qualitative and quantitative evaluation. *J Prosthet Dent*. 2018; 120(6): 895-903
10. Rutkunas V, Dirse J, Bilius V. Accuracy of an intraoral digital scanner in tooth color determination. *J Prosthet Dent*. 2020; 123(2): 322-329
11. Brandt J, Nelson S, Lauer H-C, von Hehn U, Brandt S. In vivo study for tooth colour determination-visual versus digital. *Clin Oral Investig* 2017; 21:2863-71.
12. Gotfredsen K, Gram M, Brahem BE, Hosseini M, Petkov M, Sitorovic M. Effectiveness of shade measurements using a scanning and computer software system: A pilot study. *Int J Dent Oral Health* 2015;1:2-5
13. 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 Prothodont Res*. 2018;62(3):324-329
14. Renne W, Ludlow M, Fryml J, et al. Evaluation of the accuracy of 7 digital scanners: An in vitro analysis based on 3-dimensional comparisons. *J Prothet Dent*. 2017;118(1):36-42
15. Al-Hassiny HA-A. Review of the intraoral scanners at IDS 2019. Cologne: Institute of digital dentistry; 2019.
16. Kim-Pusateri S, Brewer JD, Davis El, Wee AG. Reliability and accuracy of four dental shade-matching devices. *J Prosthet Dent*. 2009;101(3):193-199
17. Rosenstiel, S., Fujimoto, J. and Land, M., 2006. *Contemporary fixed prosthodontics*. 4th ed. St. Louis, Mo.: Elsevier, pp.712-715.

Table 1. Description of various lighting conditions

Light Illuminance	Dental Chair Light	Ceiling Light	Windows
0 Lux	No	No	No
500 Lux	No	Yes	No
1250 Lux	No	No	Yes

Table 2. Accuracy of IOS under each lighting condition for the various shade guides

Shade Guide	No Light (0 Lux)	Room Light (500 Lux)	Daylight (1250 Lux)
VC1	53.6%	62.5%	18.8%
VC2	81.3%	68.8%	50%
3DM1	42.3%	34.6%	38.5%
3DM2	34.6%	36.9%	42.3%

Table 3. Consistency between shade guides under different lighting conditions

Lighting	p-value	Significance at 0.05
No light (0 Lux)		
VC1 vs VC2	0.252	Not significant
3DM1 vs 3DM2	0.776	Not significant
Room light (500 Lux)		
VC1 vs VC2	0.999	Not significant
3DM1 vs 3DM2	0.764	Not significant
Daylight (1250 Lux)		
VC1 vs VC2	0.135	Not significant
3DM1 vs 3DM2	0.999	Not significant

Table 4. Pairwise comparison of different lighting conditions on accuracy of IOS

Vita Classical Guide	p-value	Significance at 0.05
Lux 0 vs Lux 500	0.999	Not significant
Lux 0 vs Lux 1250	0.012	Significant
Lux 500 vs Lux 1250	0.024	Significant
3D Master Shade Guide	p-value	Significance at 0.05
Lux 0 vs Lux 500	0.537	Not significant
Lux 0 vs Lux 1250	0.999	Not significant
Lux 500 vs Lux 1250	0.413	Not significant



Figure 1. Experimental gingival matrix. Shade tabs from both VC and 3DM guides were placed in matrix to simulate clinically relevant conditions. Scans were obtained from middle third of shade tabs



Figure 2. Experimental device set up. The scanner wand was fixed and positioned 5 mm from shade tab surface to scanner tip. To maintain constant distance during scans, gingival matrix positioned on dental survey table. Only survey table moved during scanning



Figure 3. Digital scan screenshot of gingival matrix. STL image made using TRIOS IOS of experimental gingival matrix with shade tabs. Pictured here with VC shade tabs.

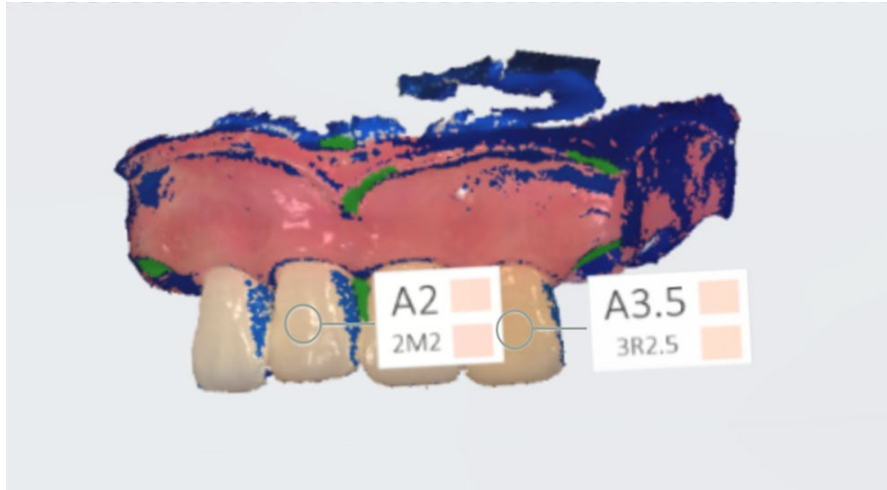


Figure 4. Shade proposal by TRIOS IOS. Shade proposals were obtained from middle third of shade tab. Shade registered as both VC and 3DM shades