Original Article

Improving Accuracy of Edentulous Areas Digital Impression Using Artificial Markers: The Future of Edentulous Patient in Aging Societies

Le Zhang[1], Widchaya Kanchanavasita[2]*, Montri Ratanajanchai[3], Somchai Urapepon[4], Kallaya Suputtamongkol[5]

[1]MD, Dental Biomaterials Science (International Program), Faculty of Dentistry, Mahidol University, Bangkok, Thailand. 10400. MD, Department of Prosthodontics, School and Hospital of Stomatology, Kunming Medical University, Kunming, China. 650000. Email: dr_zhangle@163.com
[2]PhD, Department of Prosthodontics, Faculty of Dentistry, Mahidol University, Bangkok, Thailand. 10400. Email: widchaya.kan@mahidol.ac.th
[3]PhD, Department of Prosthodontics, Faculty of Dentistry, Mahidol University, Bangkok, Thailand, 10400. Email: montri.rat@mahidol.ac.th
[4]PhD, Department of Prosthodontics, Faculty of Dentistry, Mahidol University, Bangkok, Thailand. 10400. Email: somchai.ura@mahidol.ac.th
[5]PhD, Department of Prosthodontics, Faculty of Dentistry, Mahidol University, Bangkok, Thailand. 10400. Email: kallaya.sup@mahidol.ac.th

Abstract

Objective: To investigate the accuracy of digital impressions obtained from two IOS (intraoral scanners) in capturing an upper edentulous arch using varying number of artificial markers, and explore the potential implications for edentulism rehabilitation in aging societies. **Methods:** An edentulous maxilla model, scanned by a desktop scanner (3Shape D900L), served as a reference. The model was fitted with varying numbers of markers (0, 3, 6, 9, 15, 21) and scanned thirteen times with each intraoral scanner. Scanned models were aligned with the reference using Geomagic software, and accuracy was assessed via root mean square (RMS) values for trueness and precision. Data analysis involved one-way ANOVA and a post hoc Tukey test (α=0.05). **Results:** Increasing the number of markers generally improved the scanners' trueness and precision. The 3Shape TRIOS3 and Medit i500 showed significant trueness enhancement with at least nine markers (42.7±8.7µm and 89.9±20.6µm, respectively) compared to no markers (66.7±27.8µm and 128.7±56.7µm). Precision also improved notably for Medit i500 with nine or more markers (76.3±23.0µm) versus none (124.0 ± 60.1µm). **Conclusion:** The 3D printed markers improved the accuracy of both 3Shape TRIOS3 and Medit i500 scanners. An optimal range of 9 to 15 markers is recommended for these scanners. This research contributes to the advancement of edentulous digital impression, which has a positive impact on the rehabilitation of edentulism in the aging society.

Keywords: Accuracy, Intraoral Scanners, IOS, Digital Impression, Edentulous, Artificial Markers.

Introduction

Global Trends in Population Aging and Edentulism

Population aging is a global trend, as indicated by the United Nations World Population Aging Report, which found that the global population aged 60 and above was 9.01 billion in 2015, a 48% increase compared to 6.07 billion in 2000.[1] In many countries, with the decline in birth rates and the increase in life expectancy, the proportion of elderly individuals is expected to further rise in the future. The cumulative nature of two major debilitating dental diseases, dental caries and periodontitis, suggests that aging is invariably associated with tooth loss.[2] With the complete loss of teeth, edentulism is associated with aesthetic concerns, impaired masticatory function, compromised communication abilities, and consequently, diminished quality of life.[3] Although significant advancements have been made in dental treatment and preventive healthcare over the past few decades, edentulism remains a challenging issue.[4]

Overall, although the proportion of edentulism in developed countries has significantly decreased compared to 30 years ago, with Sweden declining from 47% in 1975 to 3% in 1996, and the United Kingdom declining from 37% in 1968 to 5% in 2018.[5,6] However, in developing countries,

Access this article online

Quick Response Code:

Website: www.jnsbm.org

DOI: https://doi.org/10.4103/jnsbm.JNSBM_15_2_8

Address for Correspondence: Department of Prosthodontics, Faculty of Dentistry, Mahidol University, Bangkok, Thailand, 10400
Email: widchaya.kan@mahidol.ac.th

Submitted: 08th April, 2024 **Received:** 09th April, 2024
Accepted: 24th May, 2024 **Published:** 12th July, 2024

How to cite this article: Zhang L, Kanchanavasita W, Ratanajanchai M, Urapepon S, Suputtamongkol K. Improving Accuracy of Edentulous Areas Digital Impression Using Artificial Markers: The Future of Edentulous Patient in Aging Societies. J Nat Sc Biol Med 2024;15:236-243

the proportion of edentulism remains considerable. In China, findings from the third national epidemiological survey conducted in 2005 indicated a prevalence of 7% among individuals aged 65-74 years. A sampling survey conducted in Brazil in 2009 revealed a prevalence of 63% for edentulism, while a study in India in 2009 reported a prevalence of 60%.[7-9] Considering the large population bases in developing countries, the absolute number of edentulous patients is even more staggering than the proportions suggest. The study predicts that within the next 50 years, the necessity of complete denture treatment will not disappear, and the fluctuating global economic conditions may instead lead to a growing need.[10]

According to surveys, although the proportion of edentulous individuals has decreased compared to 20 years ago, there remains a significant socio-economic gradient within the population, with a much higher prevalence of edentulism observed in lower socio-economic groups.[11] Coinciding with the survey findings, participants residing outside major urban centers and those with the lowest socio-economic status are less likely to replace their complete dentures if they have been in use for less than 10 years, displaying a reluctance to undergo denture replacement.[12] From this, it can be inferred that economic burden is a barrier for some low-income patients in choosing complete denture restoration. Reducing the production cycle and cost of complete dentures is also one of the challenges in treating edentulism in future aging societies.

Lowering the production cost of complete dentures involves reducing material wastage and prices, as well as minimizing treatment cycles and the labor costs of dentists and technicians. Therefore, if the current cycle of 3-4 follow-up visits for a set of complete dentures can be condensed into a single visit for delivery, labor costs would significantly decrease, and the price of complete dentures could correspondingly decrease. Ultimately, this would benefit edentulous patients from various economic backgrounds and social strata.

Advancements and Challenges in Digital Impressions for Edentulous Arch

In clinical practice, there are two methods for restoring edentulism: traditional complete dentures and implant-supported dentures. Traditional complete denture therapy has been the primary treatment modality for edentulism for decades. With the proliferation of implant-supported dentures, some literature suggests that they offer greater comfort and improved chewing efficiency compared to traditional complete dentures.[13] However, for the majority of patients, economic factors, as well as chronic illnesses and contraindications, prevent them from undergoing implant surgery, leading them to opt for traditional complete dentures.[14]

Consequently, as societies age, the integration of digitization into denture treatment becomes increasingly pertinent in the future. Digital impressions and AI-trained data offer avenues for enhancing accuracy and efficiency in creating 3D models of edentulous arches. This technological advancement enables streamlined processes, from capturing jaw relationships to fabricating full dentures using CAD-CAM milled device,[15] thereby improving accessibility and affordability for patients of diverse socioeconomic backgrounds. Furthermore, the preservation of 3D model data facilitates the rapid fabrication of new dentures during follow-up visits, eliminating the need for repetitive traditional restoration processes.

The first step in complete denture restoration is impression. With the advancement of technology, digital impressions obtained by intraoral scanners are associated with numerous advantages compared to traditional impression methods, e.g., mitigate patient discomfort and reduce costs; enhance time efficiency and streamline clinical procedures by eliminating plaster models, improved communication with dental technicians and patients.[16,17] Furthermore, most patients express a preference for digital impressions over traditional impression techniques involving dental elastomers.[18,19]

However, with increasing age, patients' mobility and willingness to seek treatment gradually decrease. For elderly patients, the current process for complete dentures involves multiple steps, including preliminary impressions, recording jaw relations, final impressions, try-in, and final delivery, constituting a lengthy procedure. Condensing the number of visits for complete denture fabrication to just one would greatly enhance patients' treatment experiences and willingness to seek care. Therefore, the future trend is expected to shift towards fully digital workflows for complete denture fabrication.

In general, the treatment procedures of complete dentures mainly rely on traditional impression and workflow, or traditional impression combined with partial digital workflow. Currently, there are still many problems to be solved in the process of full digital impression, one of the challenge which is the accuracy of digital edentulous impression.[20] Accuracy describes an object how accurate and precise in terms of trueness and precision. Trueness is a measure of how close a scanned model to the original model. The higher the trueness, the closer the scanned model is to the true model. Precision describes the repeatability of the scanning process, with higher precision indicating greater stability and repeatability of multiple scans. There are several studies reported that the larger edentulous area will increase the difficulties for intraoral scanners to acquire accuracy digital impression.[21] Since the imaging principle of almost all intraoral scanners is based on stitching multiple images together to form a complete 3D model, the lack of easily recognizable anatomical structures in large edentulous areas can increase the difficulty of image stitching and reduce accuracy. Additionally, the larger the area scanned by an intraoral scanner, the greater the number of images captured, and the accumulation of minor discrepancies during image stitching can lead to larger errors. Numerous studies have demonstrated that the accuracy of intraoral scanners for scanning a single tooth is comparable to that of traditional impressions, but the accuracy of scanning multiple teeth and full arches is less stable than that of traditional impressions. In the case of edentulous areas, particularly in the upper jaw, it is necessary to scan the entire alveolar ridge and the entire palatal area. This large scanning area inevitably results in more image stitching, leading to greater overall deformation.[22]

An accuracy of the models obtained by intraoral scanning is guaranteed in many published articles.[23-26] However, the digital impression is still controversial for removable prosthodontic works. One major issue is an inaccuracy of IOS towards large edentulous area that appear pink-colored gingival tissue only and less prominence or variation in its structure.[27]

Some efforts have been made to enhance the accuracy of digital impressions on edentulous arches through the using of artificial markers. The artificial markers would assist the IOS to capture large area that contains only oral mucosa. Varieties of markers designs have been applied including painting mucosa by pressure indicating paste,[28] placing a few pieces of small-size resin markers,[29] establishing alumina markers with 4mm x 3mm in size,[30] and placing large polymeric frameworks on edentulous arches.[31] Nevertheless, the conceptual design of the markers is still skeptical and has not been optimized. Too long distance between markers would not improve accuracy of the digital impression. Whereas, too much number of markers would create defects that hinder details of the digital model.

Developing a Marker System for Digital Impressions

In the present study, the markers system is developed to assist the digital impression. Principle idea is generated by concept of digital impression for full arch implant restoration using scan-bodies. From previous studies, the accuracy of IOS demonstrated an increase with a reduction in the distance between the scan-bodies.[32] Such evidence could be hypothesized by relative distance between markers compared to size of the scanner tip. Achieving a distance between scan-bodies shorter than the size of the scanner tip results in improved accuracy.[33] Herein, two different types of IOS (confocal and triangulation) are chosen to take impression digitally on fully edentulous model. Effect of various number of markers on accuracy of the digital impression will be investigated. The null hypotheses were that there will be no significant difference in the trueness and precision of the maxilla edentulous model scanned with different numbers of markers.

Materials and Methods

A maxilla edentulous model was created using a hard resin base and a soft silicone cover and scanned using a desktop scanner D900L (3-Shape, Copenhagen, Denmark). The model was scanned by the 3shape D900L lab scanner ten times, and the data were cross-compared with each other. The scanning of the model (STL files) which has the lowest RMS value were selected as the reference model.(R_m)

The 3Shape TRIOS 3 (Version 18.1.2, 3-Shape, Copenhagen, Denmark) and Medit i500 (Version 1.1.1, Medit, Seoul, Korea) IOS will be utilized in this study. The selection of these two intraoral scanners in this study is based on the fact that they represent two distinct image processing principles. Other commonly used intraoral scanner brands in clinical practice include Cerec Omnicam, iTero system, Lava C.O.S system, etc. Through preliminary testing, it was determined that scanners using triangulation principles, such as Cerec Omnicam, and those using confocal principles, such as iTero, were incapable of capturing models of edentulous area. The Lava C.O.S system employs a unique technology known as active wavefront sampling, which is not commonly adopted by other brands in the market, making it less representative, and therefore, it was not included in the selection.[34] On the other hand, 3Shape TRIOS3 and Medit i500 are frequently mentioned in the literature related to similar studies.[35-37] Hence, for this experiment, these two scanners, known for their widespread usage, optimal overall performance, and representation of two highly distinctive scanning principles, were chosen as the experimental intraoral scanner.

The aim of identifying the optimal number of landmarks is to optimize their efficiency in clinical practice. Having fewer landmarks on the model leads to reduced material consumption and less time spent on placement and bonding. Moreover, using fewer landmarks can result in capturing more actual detail of the tissue, as a smaller number of landmarks means less surface coverage. Therefore, finding the optimal number of landmarks is crucial to maximize their effectiveness in the clinic while minimizing resource utilization. The models were divided into six groups in total, with the "no markers" group(N=0) designated as the control group, while the other five groups had increasing numbers of markers added, ranging from 3, 6, 9, 15, to 21. (As shown in Figure 1)

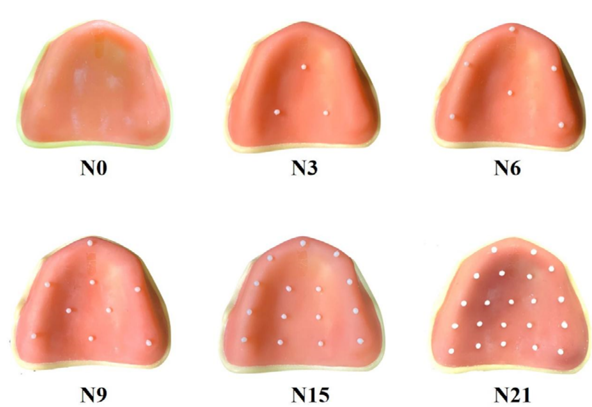

Figure 1: Scheme Represents the Positions of the Artificial Markers on the Maxillary Edentulous Models. N0 to N21 Indicates the Digital Edentulous Impression Using 0 to 21 Pieces of Artificial Markers, Respectively.

Prior to scanning, the devices will undergo an auto-calibration process. The ambient lighting will be controlled to maintain a consistent 1000 lux illumination level within the room. A single operator, with over 6 years of experience in intraoral scanning, scanned the edentulous model without markers 13 times by both 3Shape TRIOS3 and Medit i500 as the control group respectively. The operator captured another 13 times for each group which has 3D-printed 2mm roundish resin markers attaching on the model by each IOS as the testing group.

To minimize the potential effects of fatigue and overheating, the scans were spaced out with a rest period of 15 minutes for both the computer and operator. The scanning began from the left posterior area and proceeded with a zig-zag movement towards the anterior area. It then turned buccally around the periphery area, and the scan was completed on the buccal side with an anticlockwise direction of scan.

The use of markers would cause defects or artifacts on the digital impression models. Such defects must be removed and reconstructed prior to the superimposition step. These removal and reconstruction processes were performed under the 3D software (Geomagic Wrap v2021.0.0; Geomagic control X v2019.0.1; 3D Systems) to minimize errors and inaccuracies from the artifact correction. Moreover, the outer border of all models were also deleted in this step to obtain the edentulous area only. In brief, the software-corrected 3D models will be imported into Geomagic Control X for superimposition using the following commands: Set Reference model- Set test model-Best fit Alignment-and 3D compare. The alignment of the reference model and the test model will be based on optimized alignment (best-fit alignment).

To evaluate the accuracy of the digital impressions, the software-corrected models obtained by the IOS will be superimposed with the reference models from the desktop scanner. Evaluation of the accuracy of IOS has been based on a combination of trueness and precision according to the International Organization for Standardization (ISO) 5725-1.[38] In the present study, the accuracy also will be discussed in two terms including 1) trueness and 2) precision.

Trueness describes the deviation of the tested 3D model from the original geometry, and it will be referred by the root-mean-square (RMS) values between the models from the intra-oral scanners (test models) and the Desktop scanner (reference models). Because the RMS values indicated the absolute distance between all point clouds of two models, the RMS values that close to zero would indicate good trueness.[39-41] Precision refers to the ability of an intraoral scanner to reproduce a particular measurement consistently, and it reflects the deviations between the scans within a test group. The precision of digital impressions obtained from different scanners and landmark systems will be analyzed by comparing the root mean square (RMS) of cross-comparison for each group.[29]

All RMS values of the models were analyzed using IBM SPSS Statistics v25.0 (IBM Corp. Released 2017. IBM SPSS Statistics for Windows, Version 25.0. Armonk, NY:IBM Corp.).The trueness and precision of the digital impression with different numbers of markers were subjected to One-way ANOVA tests. Post-hoc multiple comparisons among the groups were conducted using homogeneous subsets of Tukey B.

Result

The results of 3Shape TRIOS3 are shown in Table.1 Figure.2 Figure.3 For trueness, no significant differences were observed between N3, N6, and the control group. A significant difference in comparison to the control group was found when at least 9 pieces of the markers were used. For the precision, all groups showed significant differences in comparison to the control group.

Table 1: Trueness and Precision in RMS Value (μm) of Digital Impression Using 3Shape Trios3 with Different Numbers of Markers. The Data was Shown as Mean and Standard Deviation.

Group#	3Shape TRIOS3	
	Trueness	Precision
N0	66.7 ± 27.8a	92.1 ± 15.8a
N3	49.3 ± 18.1ab	31.1 ± 20.7c
N6	56.4 ± 25.1ab	38.8 ± 23.7c
N9	42.7 ± 8.7b	21.8 ± 6.7c
N15	42.1 ± 8.2b	25.1 ± 7.1c
N21	45.3 ± 13.7b	71.9 ± 15.4b

The group abbreviation “Ny” indicated the marker design using y number of markers. Values with superscript letters a, b, and c are significantly different across columns (P<0.05).

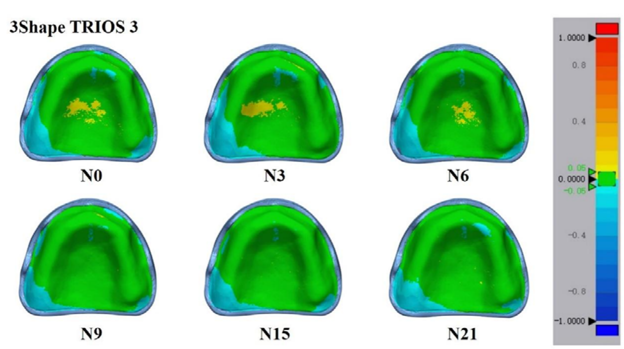

Figure 2: Colorimetric Map of the Deviation between the Scanned Model from 3Shape TRIOS3 and the Reference Model from the Lab Scanner. N0 to N21 Indicates the Digital Edentulous Impression Using 0 to 21 Pieces of Artificial Markers, Respectively.

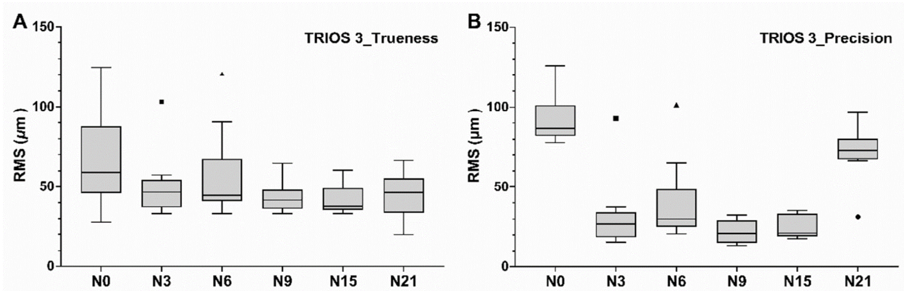

Figure 3: Trueness (A) and Precision (B) of Digital Edentulous Impression Using 3Shape TRIOS3 with Different Numbers of the Artificial Markers (0 to 21 pieces). The Data in RMS (µm) are Illustrated as Box and Whisker Plot that Includes Median, Interquartile Range, and Outliers.

The results of Medit i500 are shown in Table 2 Figure 4 Figure 5. It can be observed that the RMS values of both trueness and precision decreased with increasing the number of markers. For both trueness and precision, no significant differences were observed between N3, N6, and the control group. A significant difference in comparison to the control group was found when at least 9 pieces of the markers were used.

Table 2: Trueness and Precision in RMS Value (µm) of Digital Impression Using Medit i500 with Different Numbers of Markers. The Data was Shown as Mean and Standard Deviation.

Group#	Medit i500	
	Trueness	Precision
N0	128.7 ± 56.7^{a}	124.0 ± 60.1^{a}
N3	102.2 ± 31.7^{ab}	114.5 ± 31.2^{ab}
N6	96.2 ± 35.6^{ab}	103.5 ± 41.6^{abc}
N9	89.9 ± 20.6^{b}	76.3 ± 23.0^{bcd}
N15	88.8 ± 29.2^{b}	82.9 ± 31.2^{bcd}
N21	69.8 ± 12.8^{b}	58.2 ± 15.3^{d}

The group abbreviation "Nx" indicated the marker design using x number of markers. Values with superscript letters a, b, c and d are significantly different across columns (P<0.05).

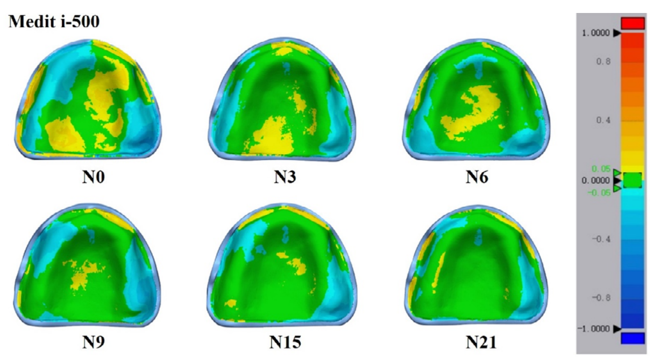

Figure 4: Colorimetric Map of the Deviation between the Scanned Model from 3Shape TRIOS3 and the Reference Model from the Lab Scanner. N0 to N21 Indicates the Digital Edentulous Impression Using 0 to 21 Pieces of Artificial Markers, Respectively.

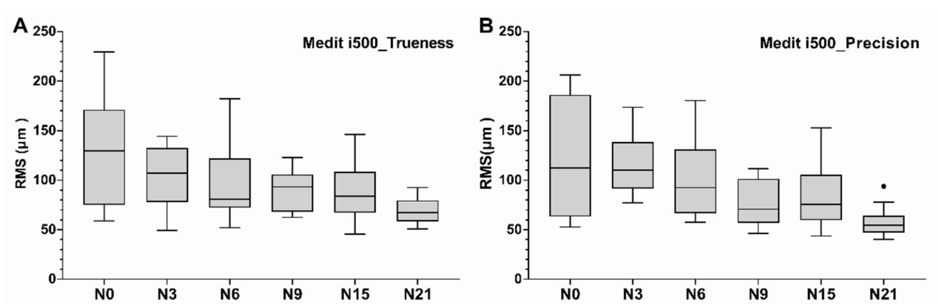

Figure 5: Trueness (A) and Precision (B) of Digital Edentulous Impression Using Medit i500 with Different Numbers of the Artificial Markers (0 to 21 pieces). The Data in RMS (µm) are Illustrated as Box and Whisker Plot that Includes Median, Interquartile Range, and Outliers.

Discussion

This study compared the different number of markers in maxilla edentulous model of two different IOS. There was significant difference between control and test group. Based on the findings, the null hypothesis of this study was rejected. Theoretically, semi-transparent characteristics of oral mucosa can cause some interference and difficulty in intraoral scanning.[42] In the present research, the edentulous model is covered with a biomimetic mucosal layer that is made by silicone. This silicone surface exhibits a refractive index that is relatively closer to that of oral mucosa.[33] Therefore, the model in this study could simulate intraoral conditions to some extent.

In evaluating the comparative efficacy of two IOS, the 3Shape TRIOS3 and the Medit i500, a significant disparity in accuracy was observed in digital impressions of edentulous arches. The 3Shape TRIOS3 demonstrated superior outcomes in terms of trueness and precision (approximately 67µm and 92µm, respectively) compared to the Medit i500, which exhibited trueness and precision of around 129µm and 124µm. One possible explanation is difference in an image processing principle. The 3Shape TRIOS3 operates on a confocal principle, which does not measure the distance between the scanning head and the object directly. Instead, it uses the focus of the laser to selectively capture light information from the specific planes of the object. Consequently, this confocal-type scanner exhibits reduced sensitivity to the surface characteristics of the scanned object.[43] In contrast, the Medit i500, based on the active triangulation principle, is highly dependent on the optical properties of the scanned surface.[43,44] Factors such as color, translucency, or opalescence of the material can significantly influence the accuracy of digital impressions obtained using this technology.[36] The semi-transparent nature of the edentulous model poses a challenge for the Medit i500, leading to reduced accuracy. However, the introduction of markers enhances the scanner's accuracy by creating diffuse Lambertian surfaces, reminiscent of the established protocol in active triangulation scanners that involves the use of titanium oxide powder to improve surface scan recognition.[37]

From entire experiments, success rate of scanning edentulous models using the Medit i500 scanner itself was only about 60%. Some errors in recognition and image were frequently occurred that required deleting and starting over. Interestingly, the scanning success rate was remarkably enhanced to over 90% by utilizing the markers. The markers not only improved the success rate but also reduce scanning duration (speed). For 3shape TRIOS3 scanner, the scanning success rate without the markers was approximately 80%. While, approximately 95% of the models being scanned successfully was obtained by using the markers. A higher success rate implies a reduction in the operational time within the patient's mouth during clinical procedures, enhancing the patient's treatment experience.

Increasing the number of the markers caused the improvement in trueness and precision for both IOS. In comparison to the control with no markers, both trueness and precision of Medit i500 significantly increased when at least 9 pieces of markers were used. The similar pattern was found for trueness of 3Shape TRIOS3 that required at least 9 markers to reduce the deviation. The acceptable value of prosthesis misfit is 100 µm (trueness) which reported by the literature,[39,45] and precision is not mentioned by any of the studies in this case. Based on the findings from the current study, it is evident that in the absence of markers, the trueness of 3Shape TRIOS3 and Medit i500 is 66µm and 128µm respectively. However, upon increasing the number of markers to 9, the trueness values decrease to below 50 µm for 3Shape TRIOS3 and 90µm for Medit i500. Notably, studies involving dental impressions have previously reported trueness values of approximately 20µm for conventional impressions and around 50µm for IOS,[46] and investigations into scanning across entire edentulous regions have indicated trueness values ranging from 44µm to 590µm for IOS.[20] Regarding to these studies, the improvement in trueness through the markers in this study is substantial and significant.

One possible reason to support this evidence is the relationship between the markers-markers distance and the scanning head size. According to literature reports, IOS with larger scanning heads exhibit better accuracy compared to those with smaller scanning heads.[33] In this study, the scanner head size of 3Shape TRIOS3 was 16x18 mm^2, while that of Medit i500 was 15x17 mm^2. As the number of markers increases, the spaces between the markers decrease. If the distance between markers are shorter than scanning head size, more than one markers would be simultaneously captured by the intraoral scanner. This could facilitate more accurate image positioning and stitching process. As the number of markers increases to 9, the spaces between markers on the palatal area are 15 mm, approximately. Consequently, two markers on such area could simultaneously appear within the field of view of both IOS. As a result, the success rate of 3D model stitching has been enhanced, errors accumulation has been reduced, thereby increasing the overall accuracy of the two intraoral scanners.

Conclusion

Within the limitations of the present in-vitro study, the following conclusions can be concluded:

1. Within this study, the different number of markers had an impact on the accuracy in terms of trueness and precision of 3Shape TRIOS3 and Medit i500 IOS. With the number of markers increased, the accuracy RMS getting better. The optimal number is ranging from number 9-15 for both 3Shape TRIOS3 and Medit i500 IOS. The introduction of artificial markers significantly improved the trueness and precision of digital impressions obtained by both IOS, offering a promising solution to enhance digital impression accuracy in clinical practice.
2. The future one-visit deliver of digital complete dentures requires research into algorithm simulation for functional impression, digital recording of jaw relationships, and extensive clinical data to meet the requirements for AI training.
3. This study has limitations, including the lack of real conditions such as patient movement and saliva reflections in the in vitro experiments, and the potential bias

introduced by manually removing markers from 3D models. Future research should involve in vivo testing and employ software algorithms for automated marker removal to reduce bias.

Acknowledgements

The research project is mainly supported by IDCMR program, Faculty of dentistry, Mahidol University, Bangkok, Thailand. The authors thank Chao Xiaoming for his help in the laboratory procedures.

Funding

The research project is partially supported by Clinical Research Center for Oral Diseases of Yunnan Province, China (Grant Number: 2022LX002).

Conflit of Interest

The authors declare no conflict of interest.

Reference

1. Beard JR, Officer AM, Cassels AK. The World Report on Ageing and Health. Gerontologist. 2016; 56(Suppl 2): S163-6. doi: https://doi.org/10.1093/geront/gnw037.
2. McKenna G, Tsakos G, Burke F, Brocklehurst P. Managing an Ageing Population: Challenging Oral Epidemiology. Prim Dent J. 2020; 9(3): 14-17. doi: https://doi.org/10.1177/2050168420943063.
3. McGarry TJ, Nimmo A, Skiba JF, Ahlstrom RH, Smith CR, Koumjian JH. Classification system for complete edentulism. The American College of Prosthodontics. J Prosthodont. 1999; 8(1): 27-39. doi: https://doi.org/10.1111/j.1532-849x.1999.tb00005.x.
4. Al-Rafee MA. The epidemiology of edentulism and the associated factors: A literature Review. J Family Med Prim Care. 2020; 9(4): 1841-43. doi: https://doi.org/10.4103/jfmpc.jfmpc_1181_19.
5. Osterberg T, Carlsson GE, Sundh V. Trends and prognoses of dental status in the Swedish population: analysis based on interviews in 1975 to 1997 by Statistics Sweden. Acta Odontol Scand. 2000; 58(4): 177-82. doi: https://doi.org/10.1080/000163500429181.
6. Steele JG, Treasure E, Pitts NB, Morris J, Bradnock G. Total tooth loss in the United Kingdom in 1998 and implications for the future. Br Dent J. 2000; 189(11): 598-603. doi: https://doi.org/10.1038/sj.bdj.4800840.
7. Shigli K, Hebbal M, Angadi GS. Prosthetic Status and Treatment Needs among Patients Attending the Prosthodontic Department in a Dental Institute in India. Eur J Prosthodont Restor Dent. 2009; 17(2): 85-9. Available from: https://www.ejprd.org/view.php?article_id=475&journal_id=69.
8. Qi XQ. Report of the third national oral health survey in China. Beijing: People's Medical Publishing House; 2008.
9. Moreira Rda S, Nico LS, Tomita NE. Oral health conditions among the elderly in Southeastern São Paulo State. J Appl Oral Sci. 2009; 17(3): 170-8. doi: https://doi.org/10.1590/s1678-77572009000300008.
10. Felton DA. Edentulism and comorbid factors. J Prosthodont. 2009; 18(2): 88-96. doi: https://doi.org/10.1111/j.1532-849x.2009.00437.x.
11. Whelton H. Oral health of Irish adults 2000-2002: final report - April 2007 / H. Whelton ... [et al.]. 2007. -3962. Available from: http://hdl.handle.net/10147/45326.
12. Taylor M, Masood M, Mnatzaganian G. Complete denture replacement: a 20-year retrospective study of adults receiving publicly funded dental care. J Prosthodont Res. 2022; 66(3): 452-58. doi: https://doi.org/10.2186/jpr.jpr_d_20_00323.
13. Turkyilmaz I, Company AM, McGlumphy EA. Should edentulous patients be constrained to removable complete dentures? The use of dental implants to improve the quality of life for edentulous patients. Gerodontology. 2010; 27(1): 3-10. doi: https://doi.org/10.1111/j.1741-2358.2009.00294.x.
14. Owen PC. Appropriatech: prosthodontics for the many, not just for the few. Int J Prosthodont. 2004; 17(3): 261-2. Available from: https://pubmed.ncbi.nlm.nih.gov/15237869.
15. Srinivasan M, Kalberer N, Naharro M, Marchand L, Lee H, Müller F. CAD-CAM milled dentures: The Geneva protocols for digital dentures. J Prosthet Dent. 2020; 123(1): 27-37. doi: https://doi.org/10.1016/j.prosdent.2018.12.008.
16. Miyazaki T, Hotta Y, Kunii J, Kuriyama S, Tamaki Y. A review of dental CAD/CAM: current status and future perspectives from 20 years of experience. Dent Mater J. 2009; 28(1): 44-56. doi: https://doi.org/10.4012/dmj.28.44.
17. Wimmer T, Gallus K, Eichberger M, Stawarczyk B. Complete denture fabrication supported by CAD/CAM. J Prosthet Dent. 2016; 115(5): 541-6. doi: https://doi.org/10.1016/j.prosdent.2015.10.016.
18. Ahmed KE. We're Going Digital: The Current State of CAD/CAM Dentistry in Prosthodontics. Prim Dent J. 2018; 7(2): 30-5. doi: https://doi.org/10.1177/205016841800700205.
19. Yuzbasioglu E, Kurt H, Turunc R, Bilir H. Comparison of digital and conventional impression techniques: evaluation of patients' perception, treatment comfort, effectiveness and clinical outcomes. BMC Oral Health. 2014; 14: 10. doi: https://doi.org/10.1186/1472-6831-14-10.
20. Patzelt SB, Vonau S, Stampf S, Att W. Assessing the feasibility and accuracy of digitizing edentulous jaws. J Am Dent Assoc. 2013; 144(8): 914-20. doi: https://doi.org/10.14219/jada.archive.2013.0209.
21. Braian M, Wennerberg A. Trueness and precision of 5 intraoral scanners for scanning edentulous and dentate complete-arch mandibular casts: A comparative in vitro study. J Prosthet Dent. 2019; 122(2): 129-36.e2. doi: https://doi.org/10.1016/j.prosdent.2018.10.007.
22. Thanasrisuebwong P, Kulchotirat T, Anunmana C. Effects of inter-implant distance on the accuracy of intraoral scanner: An in vitro study. J Adv Prosthodont. 2021; 13(2): 107-16. doi: https://doi.org/10.4047/jap.2021.13.2.107.

23. Lee SJ, Kim SW, Lee JJ, Cheong CW. Comparison of Intraoral and Extraoral Digital Scanners: Evaluation of Surface Topography and Precision. Dent J (Basel). 2020; 8(2): 52. doi: https://doi.org/10.3390/dj8020052.
24. Güth JF, Keul C, Stimmelmayr M, Beuer F, Edelhoff D. Accuracy of digital models obtained by direct and indirect data capturing. Clin Oral Investig. 2013; 17(4): 1201-8. doi: https://doi.org/10.1007/s00784-012-0795-0.
25. Tsirogiannis P, Reissmann DR, Heydecke G. Evaluation of the marginal fit of single-unit, complete-coverage ceramic restorations fabricated after digital and conventional impressions: A systematic review and meta-analysis. J Prosthet Dent. 2016; 116(3): 328-35.e2. doi: https://doi.org/10.1016/j.prosdent.2016.01.028.
26. Suese K. Progress in digital dentistry: The practical use of intraoral scanners. Dent Mater J. 2020; 39(1): 52-56. doi: https://doi.org/10.4012/dmj.2019-224.
27. D'Arienzo LF, D'Arienzo A, Borracchini A. Comparison of the suitability of intra-oral scanning with conventional impression of edentulous maxilla in vivo. A preliminary study. Journal of Osseointegration. 2018; 10(4): 115-20. doi: https://doi.org/10.23805/JO.2018.10.04.02.
28. Lee JH. Improved digital impressions of edentulous areas. J Prosthet Dent. 2017; 117(3): 448-49. doi: https://doi.org/10.1016/j.prosdent.2016.08.019.
29. Tao C, Zhao YJ, Sun YC, Heng MD, Xie QF, Pan SX. Accuracy of Intraoral Scanning of Edentulous Jaws with and without Resin Markers. Chin J Dent Res. 2020; 23(4): 265-71. doi: https://doi.org/10.3290/j.cjdr.b867887.
30. Kim JE, Amelya A, Shin Y, Shim JS. Accuracy of intraoral digital impressions using an artificial landmark. J Prosthet Dent. 2017; 117(6): 755-61. doi: https://doi.org/10.1016/j.prosdent.2016.09.016.
31. Li J, Moon HS, Kim JH, Yoon HI, Oh KC. Accuracy of impression-making methods in edentulous arches: An in vitro study encompassing conventional and digital methods. J Prosthet Dent. 2022; 128(3): 479-86. doi: https://doi.org/10.1016/j.prosdent.2020.09.038.
32. Flügge TV, Att W, Metzger MC, Nelson K. Precision of Dental Implant Digitization Using Intraoral Scanners. Int J Prosthodont. 2016; 29(3): 277-83. doi: https://doi.org/10.11607/ijp.4417.
33. Hayama H, Fueki K, Wadachi J, Wakabayashi N. Trueness and precision of digital impressions obtained using an intraoral scanner with different head size in the partially edentulous mandible. J Prosthodont Res. 2018; 62(3): 347-52. doi: https://doi.org/10.1016/j.jpor.2018.01.003.
34. Coemert S, Veith L, Strauss G, Schmitz PM, Lueth TC. Anatomical Characterization of Frontal Sinus and Development of Representative Models. Annu Int Conf IEEE Eng Med Biol Soc. 2019; 2019: 6113-17. doi: https://doi.org/10.1109/embc.2019.8856327.
35. Camardella LT, Breuning H, de Vasconcellos Vilella O. Accuracy and reproducibility of measurements on plaster models and digital models created using an intraoral scanner. J Orofac Orthop. 2017; 78(3): 211-20. doi: https://doi.org/10.1007/s00056-016-0070-0.
36. Abduo J, Elseyoufi M. Accuracy of Intraoral Scanners: A Systematic Review of Influencing Factors. Eur J Prosthodont Restor Dent. 2018; 26(3): 101-21. doi: https://doi.org/10.1922/ejprd_01752abduo21.
37. Camardella LT, Alencar DS, Breuning H, de Vasconcellos Vilella O. Effect of polyvinylsiloxane material and impression handling on the accuracy of digital models. Am J Orthod Dentofacial Orthop. 2016; 149(5): 634-44. doi: https://doi.org/10.1016/j.ajodo.2015.10.027.
38. ISO. Accuracy (trueness and precision) of measurement methods and results — Part 1: General principles and definitions (ISO 5725-1:1994). International Organization for Standardization; 1994. Available from: https://www.iso.org/standard/11833.html.
39. Fukazawa S, Odaira C, Kondo H. Investigation of accuracy and reproducibility of abutment position by intraoral scanners. J Prosthodont Res. 2017; 61(4): 450-59. doi: https://doi.org/10.1016/j.jpor.2017.01.005.
40. Alzahrani SJ, El-Hammali H, Morgano SM, Elkassaby H. Evaluation of the accuracy of 2 digital intraoral scanners: A 3D analysis study. J Prosthet Dent. 2021; 126(6): 787-92. doi: https://doi.org/10.1016/j.prosdent.2020.10.004.
41. Ender A, Attin T, Mehl A. In vivo precision of conventional and digital methods of obtaining complete-arch dental impressions. J Prosthet Dent. 2016; 115(3): 313-20. doi: https://doi.org/10.1016/j.prosdent.2015.09.011.
42. Wolff LB, Nayar SK, Oren M. Improved Diffuse Reflection Models for Computer Vision. Int J Comput Vis. 1998; 30(1): 55-71. doi: https://doi.org/10.1023/A:1008017513536.
43. Dutton E, Ludlow M, Mennito A, et al. The effect different substrates have on the trueness and precision of eight different intraoral scanners. J Esthet Restor Dent. 2020; 32(2): 204-18. doi: https://doi.org/10.1111/jerd.12528.
44. Aubreton O, Bajard A, Verney B, Truchetet F. Infrared system for 3D scanning of metallic surfaces. Mach Vis Appl. 2013; 24(7): 1513-24. doi: https://doi.org/10.1007/s00138-013-0487-z.
45. Ender A, Mehl A. In-vitro evaluation of the accuracy of conventional and digital methods of obtaining full-arch dental impressions. Quintessence Int. 2015; 46(1): 9-17. doi: https://doi.org/10.3290/j.qi.a32244.
46. Ender A, Mehl A. Accuracy of complete-arch dental impressions: a new method of measuring trueness and precision. J Prosthet Dent. 2013; 109(2): 121-8. doi: https://doi.org/10.1016/s0022-3913(13)60028-1.