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Palatal vault configuration and its influence on intraoral scan time and accuracy in completely edentulous arches: a prospective clinical study

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PURPOSE. The aim of this prospective clinical study was to compare the influence of palatal vault forms on accuracy and speed of intraoral (IO) scans in completely edentulous cases. **MATERIALS AND METHODS.** Based on the palatal vault form, participants were divided into three equal groups (n = 10 each); Class I: moderate; Class II: deep; Class III: flat palatal vault. A reference model was created for each patient using polyvinylsiloxane impression material. The poured models were digitized using an extraoral scanner. The resultant data were imported as a solid CAD file into 3D analysis software (GOM Inspect 2018; Gom GmbH, Braunschweig, Germany) and aligned using the software's coordinate system to determine its X, Y, and Z axes. Five digital impressions (DIs) of maxilla were captured for each patient using an intraoral scanner (TRIOS; 3Shape A/S, Copenhagen, Denmark) and the resultant Standard Tessellation Language (STL) scan files served as test models. Trueness was evaluated by calculating arithmetic mean deviation (AMD) of the vault area between reference and test files while precision was evaluated by calculating AMD between captured scans to measure repeatability of scan acquisition. The scan time taken for each participant was also recorded. **RESULTS.** There was no significant difference in trueness and precision among the groups (P = .806 and .950, respectively). Average scan time for Class I and III palatal vaults was 1 min 13 seconds and 1 min 37 seconds, respectively, while class II deep palatal vaults showed the highest scan time of 5 mins. **CONCLUSION.** Palatal vault form in edentulous cases has an influence on scan time. However, it does not have a substantial impact on the accuracy of the acquired scans. [J Adv Prosthodont 2024;16:201-11]

KEYWORDS
Flat palatal vault; Deep palatal vault; Moderate palatal vault; Scan accuracy; Scan time

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INTRODUCTION

Digital impressions obtained through intraoral (IO) scanners have revolutionized the treatment alternatives by which partially and completely edentulous patients are rehabilitated. Digital intraoral scans offer numerous advantages over conventional impression techniques. This technology minimizes the patients' discomfort and reduces the overall working time.[1]

Simultaneously, the technology improves the communication between clinicians and fabrication labs and enables permanent data archiving for ease of prosthesis repair or reconstruction.[2] However, the accuracy of IO scans for completely edentulous arches remains an area with limited scientific evidence.[3] The accuracy and efficiency of these digital impressions are critical factors that can significantly impact the final prosthesis fit and patients' satisfaction.

Recently, introduced IO scanners enabled highly accurate full arch impressions with shorter scan time.[4] However, the accuracy of scanning completely edentulous arches, without the presence of teeth that aid in the stitching process, requires further investigation. Previous studies,[5-10] including the research conducted by Patzelt *et al*.,[11] highlighted the challenges associated with obtaining accurate IO scans of completely edentulous arches, specifically in the palatal region. The absence of anatomical landmarks hampers the stitching process and negatively affects the overall accuracy of the scanned images. Another influential factor on accuracy of IO scans of completely edentulous arches is the anatomy of area being scanned; of particular interest is the configuration of the palatal vault. According to The Glossary of Prosthodontic Terms, the palatal vault is defined as "the deepest and most superior part of the palate or the curvature of the palate".[12] Completely edentulous patients may present moderate, flat or deep palatal vaults. These variations in palatal vault form may pose challenges during intraoral scanning process, potentially affecting the scan time and accuracy of the digital impressions.[13]

A recent *in vitro* study by Osman and Alharbi[13] evaluated the accuracy and scan speed of IO scans in completely edentulous arches with different palatal vault configurations. Three virtual models representing Class I moderate, Class II deep, and Class III shallow palatal vaults were 3D-printed and scanned using an intraoral scanner. Scan time, trueness, and precision were assessed. The results revealed significantly increased scan time and challenges during the scan process of the Class II deep palatal vault group. The deep vault necessitated the modification of the scan strategy that was adopted at the offset of the study with no significant differences in accuracy among the groups. However, clinical data on the topic are scarce.

Thus, the scope of the current study was to clinically address the question of whether different palatal vault configurations would influence or not the speed and accuracy of IO scans in completely edentulous cases. The null hypothesis assumed that there would be no difference in the evaluated parameters when considering flat, deep and moderate palatal vault forms. Providing an answer to previously posed question will enable valuable insights into the field of digital denture fabrication, optimizing treatment planning and outcomes for completely edentulous patients.

MATERIALS AND METHODS

To determine the number of participants to be included in the study, sample size calculation was performed based on the results of a previous *in vitro* study by Patzelt *et al*.[11] The results of this study revealed that a true difference of 100 µm with a standard deviation value of 200 µm in the mean of assessed outcomes with a probability (power) of 0.80 would allow the rejection of the null hypothesis. Type I probability error associated with this test was set at 0.05. Accordingly, 30 subjects were included in the study.

The current study was carried out in the Department of Prosthodontics, Faculty of Dentistry, Modern Sciences & Arts University (MSA), Egypt. The study has been registered in the ClinicalTrials.gov PRS under the identification number (NCT06146153). Participants who met the inclusion criteria comprehended the purpose of study and expressed their willingness to participate, signed an informed consent and were enrolled in the study. Inclusion criteria were as follows: 1. Completely edentulous maxillary arch opposing an edentulous or a partially edentulous mandibular arch; 2. Participants with (ASA-1/ASA-2) systemic health; 3. Participants within age range between 40 and 75 years; 4. Participants who comprehended study objectives and presented willingness to cooperate throughout the whole duration of the study. Exclusion criteria included: 1. Presence of any developmental defects, postoperative scarring or infectious lesions in the palatal area which represents region of interest for acquiring study measurements and outcomes; 2. Participants with remaining teeth that may impact the accuracy of acquired scans; 3. Participants with any temporomandibular joint disorder that can negatively impact mouth opening during scan process; 4. Cases where measurements of palatal vault configuration revealed a palatal vault form that was a border line between two classes. The Ethics Committee of MSA University approved the study with the reference number (REC-D-432-4). The research was conducted in accordance with the ethical principles outlined in the Declaration of Helsinki for medical research involving human subjects.

Based on the depth of the palatal vault, participants were divided into three groups - Class I: (moderate palatal vault) (Fig. 1A); Class II: (deep palatal vault) (Fig. 1B); Class III: (flat palatal vault) (Fig. 1C). Palatal vault form was classified based on the cross-sectional view of the palatal vault at its deepest point. Class I (medium) is characterized by a slightly concave round curvature and a palatal slope that forms an angle of 30 to 45 degrees with the horizontal plane, extending from the crest of the ridge at the first molar region to the deepest point at the midline of the palate. Class II (high/steep) exhibits a steeper palatal slope compared to the medium palate, with an angle greater than 45 degrees formed by the aforementioned landmarks. Class III (shallow/flat) is characterized by a shallow and flatter palatal slope compared to the medium palate, with an angle less than 30 degrees formed by the same landmarks. In Class III, the palatal slope is typically shorter, and the mid-palate surface is flat.[14] After inclusion of participants in the study, a preliminary impression was made for each participant. The resultant models were then scanned and the generated STL files were exported to measurement software (Exocad, DentalCAD 3.2 Elefsina) to determine palatal vault configuration and the participants were allocated to either of the three groups (Fig. 2). All the measurements were performed by a single experienced operator. In the cases where the measurements revealed a palatal vault configuration that was a border line between two classes, such a case was excluded from the study. This approach helped address any inter-examiner variability and ensured a reliable and standardized classification process.

On the study cast of each patient, a custom tray was constructed and was used for making the final impressions. A reference model was created for each patient using polyvinylsiloxane impression material (Aquasil ULTRA XLV-Dentsply Sirona, York, USA). The poured models were digitized using an extraoral scanner (Trios 3; 3Shape, Copenhagen, Denmark). Resultant data were imported as a solid CAD file into

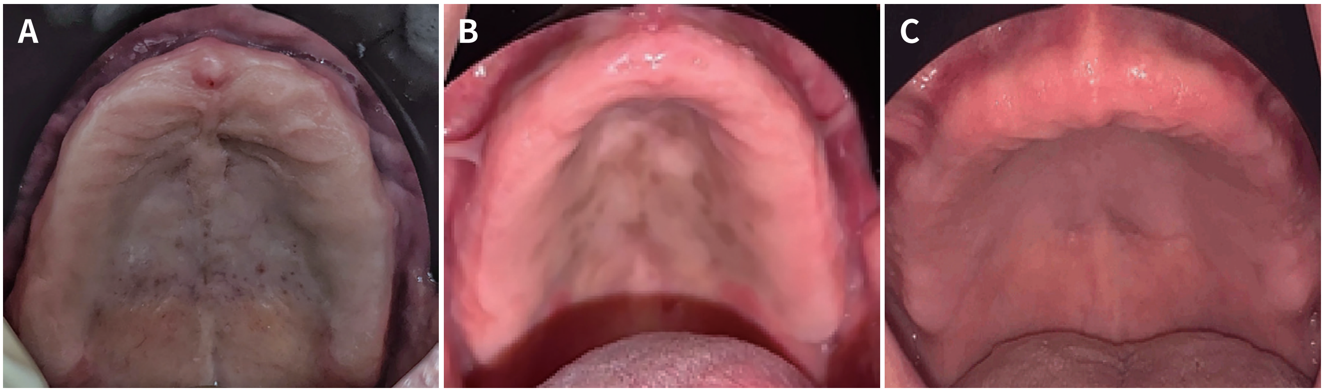

Fig. 1. Clinical photo showing different palatal vault forms. (A) Moderate palatal vault, (B) Deep palatal vault, (C) Shallow/flat palatal vault.

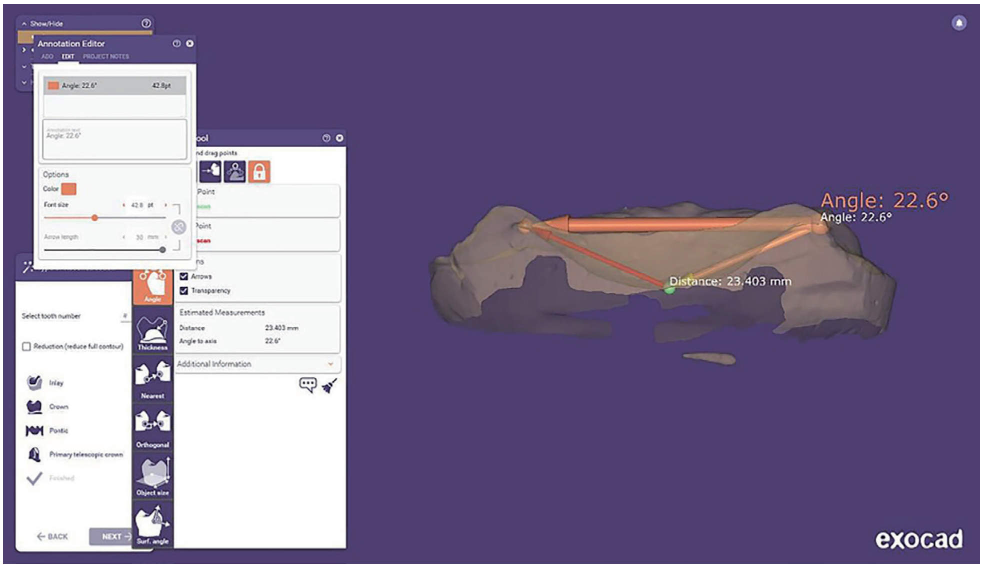

Fig. 2. Palatal vault measurements by Exocad software.

3D analysis software (GOM Inspect 2018; Gom GmbH, Braunschweig, Germany) and aligned using the software's coordinate system to determine its X, Y, and Z axes.

To obtain the test files, 5 digital impressions of maxilla were captured for each patient using an intraoral scanner (TRIOS; 3Shape A/S, Copenhagen, Denmark). Prior to the scanning process, thorough cleaning of the edentulous ridge and elimination of saliva were performed.

For Class I (medium/U-shaped) and Class III (flat) palatal vault configurations, scans were performed according to the manufacturer's recommended scanning protocol. The scan process was initiated along the crest of the ridge on one side following a straight path till the canine-incisor area. Then, a zigzag path was followed to scan the crest of the alveolar ridge and the anterior slope of the palate. The scan path then continued straight along the crest of the ridge on contralateral side of the scan starting point. The scanner head was then tilted to scan the buccal side following a linear path until the buccal scan was completed. Following the completion of the buccal scan, the palatal slope of the tuberosity and the posterior palatal slope were then scanned till reaching the initially scanned anterior palatal slope. The same scan process was repeated on the contralateral side of the arch until the digital image of entire palatal area has been completely captured.

For Class II deep palatal vault cases, a modified scan technique was followed to avoid scanning errors.[13] The crest of the alveolar ridge and palatal slopes were scanned following a zigzag path. The scanner head was then rotated to complete the scan of the buccal side in a linear path. Following the buccal scan, the scan of the mid-palatal vault was performed progressing posteriorly in a zigzag pattern till the capture of the entire palatal region area.

During the scan process, small deviations were corrected by a trimming tool in the scanner software to delete irrelevant areas and rescan missing areas. Acquired images with larger deviations that could not be managed by the rescan process were discarded and new scans were reinitiated for digital acquisition of new images. Only complete and smooth digital images of high quality were considered. The scan time of each digital impression was recorded. This process was repeated four more times to generate 5 digital impressions for each participant (n = 5 per patient). Digital impressions (DIs) were acquired by a single, experienced operator and the resultant data were exported to model analysis software (Ortho Analyzer; 3Shape, Copenhagen, Denmark) and converted into Standard Tessellation Language (STL) file format to serve as test models.

The scan time taken to complete the IO scans for each participant from the time the scan started till the end of scan acquisition was recorded using a highly accurate digital stop watch. The scan time was recorded in minutes, seconds and fraction of a second.

According to International Organization for Standardization standards (ISO 5725-1), the accuracy of digital impressions obtained with intraoral scanners (IOS) was evaluated using two main parameters: trueness and precision.[15]

Trueness is defined as the degree of agreement between the scan files of digital impressions and the reference scans. To assess trueness, the surface deviation between the reference and test files was evaluated both quantitatively and qualitatively. Quantitatively, trueness was evaluated by calculating the arithmetic mean deviation of the palatal vault area. Reference scans were imported as a CAD solid into 3D analysis software (GOM Inspect 2018; Gom GmbH, Braunschweig, Germany) and aligned using the software's coordinate system to determine its X, Y, and Z axes (Fig. 3A). The STL files obtained from the IOS process were then incorporated into the CAD body as a mesh component. Subsequently, the reference and test files were precisely aligned using the software's coordinate system. To further improve the surface match between reference and test files, best-fit alignment feature was employed (Fig. 3B).

Seven points (Fig. 3C) were selected: two points at the hamular notches on both sides, two points at the area of the first molar, two points at the canine area, and one point at the middle of the incisive papilla, to isolate palatal vault area which is the area of concern in trueness and precision evaluation.

Qualitatively, the pattern of deviation was evaluated using colored heat maps to detect areas of positive and negative deviation of test scans relative to reference scans. (Fig. 4) The maximum and minimum range of color bar for all colored maps was set at 1 mm and a tolerance level of ± 0.1 mm was applied.

Precision, on the other hand, describes the repeatability of results of different samples within the same group. Within each group, STL files of the five captured IOS impressions for each participant were compared relative to each other in which the first scan was used as a reference file and compared to the second, third, fourth and fifth impression. Similarly, the second scan was used as a reference and then compared to the first, third, fourth and fifth files. The process was repeated with five IOS impressions, and then the arithmetic mean was calculated to evaluate the precision within each group (Fig. 5).

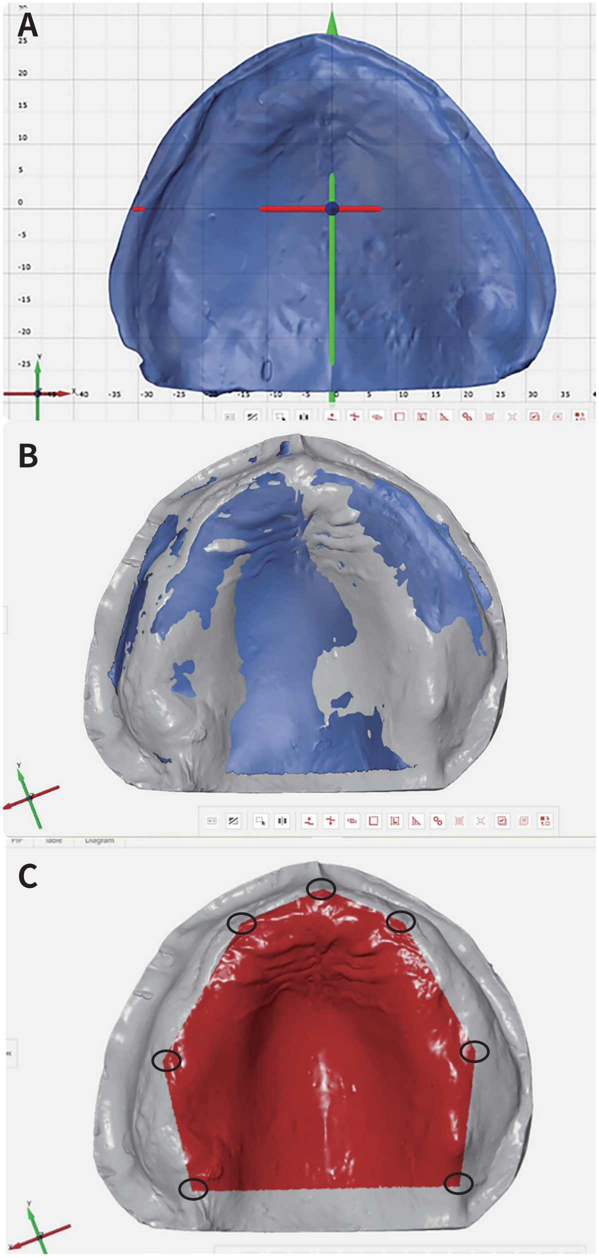

Fig. 3. (A) Reference scan of plaster model aligned using the software's coordinate system, (B) Alignment of reference and test STL files using best fit algorithm, (C) The seven points need to be emphasized. They are marked in black in the figure.

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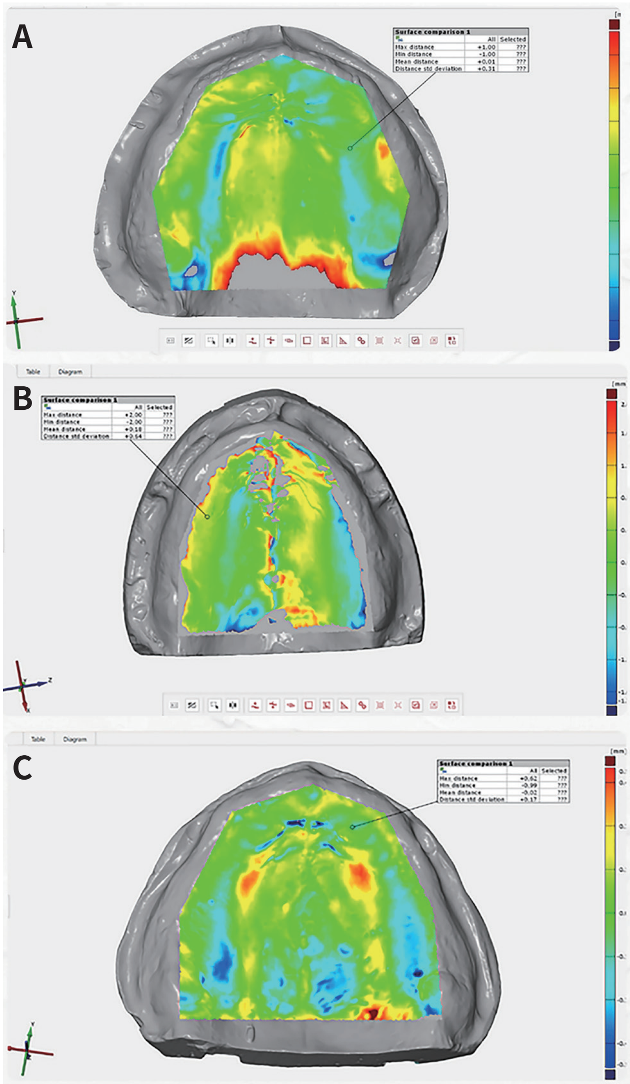

Fig. 4. Trueness color map of all test groups. (A) Class I, (B) Class II, (C) Class III.

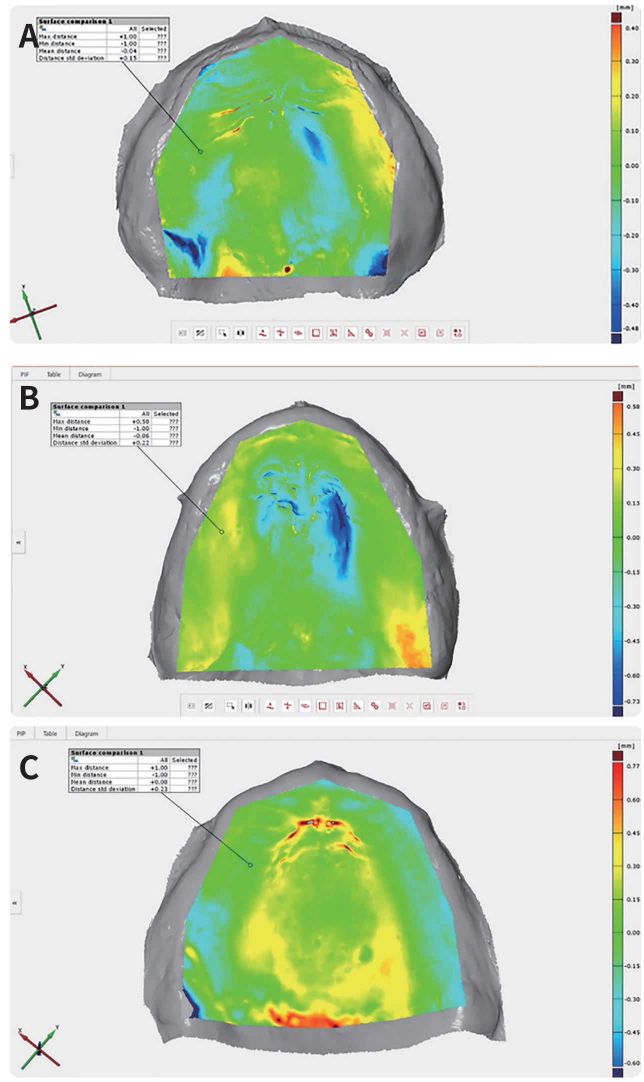

Fig. 5. Precision color maps of all test groups. (A) Class I, (B) Class II, (C) Class III.

Trueness and precision deviation values were statistically described in terms of mean ± standard deviation (SD), median, minimum and maximum deviation values. Numerical data were tested for the normal distribution using Shapiro-Wilk test. Comparison between the study groups was done using Kruskal Wallis test with post-hoc multiple 2-group comparisons. Two-sided *P*-values less than 0.05 was considered statistically significant. IBM SPSS (Statistical Package for the Social Science; IBM Corp., Armonk, NY, USA) release 22 for Microsoft Windows was used for all statistical analyses.

RESULTS

Thirty participants, 18 men and 12 women, with a mean ± SD age of 65.3 ± 10.4 years took part in the study. 17 participants were completely edentulous in both the maxillary and mandibular arches and 13 were edentulous in the maxillary arch and partially edentulous in the mandibular arch.

The average scan time for Class I and III palatal vaults was 1 min 13 seconds and 1 min 37 seconds, respectively, while Class II deep palatal vaults showed the highest scan time of 5 mins. There was a statistically significant difference in scan time among the groups with ($P < .001$) (Table 1) (Fig. 6).

Quantitative analysis of trueness revealed no significant difference in the mean value of palatal deviation within the three groups: Class I (0.0930 ± 0.006), Class II (0.0930 ± 0.00949), and Class III (0.0890 ± 0.01197) with P-value of 0.806 as shown in Table 1 and Fig. 7. Similarly, there was no significant difference in the mean deviation values of precision among the three groups: Class I (0.0830 ± 0.01), Class II (0.0840 ± 0.01), and Class III (0.0820 ± 0.007) with P-value of 0.95 (Fig. 8).

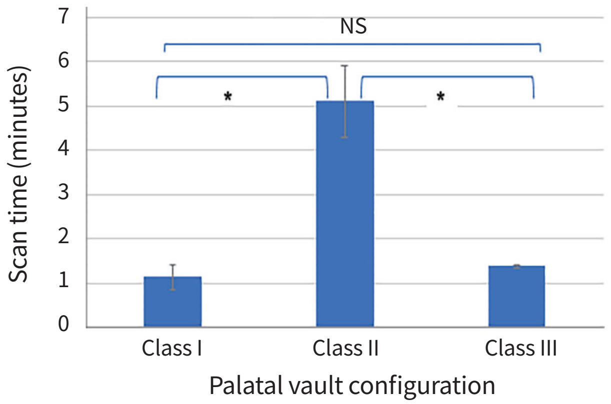

Fig. 6. A bar chart showing mean scan time in minutes in three study groups.
NS: Not significant, $P > .05$.
*: Significant, $P < .05$

Table 1. Descriptive statistics showing trueness, precision and scan time of 3 groups

Group		Trueness (mm)	Precision (mm)	Scan time (min)
Class I normal	Mean	0.0930	0.0830	1.1370
	N	10	10	10
	Std. Deviation	0.00675	0.01494	0.26990
	Median	0.0900	0.0800	1.1350
	Minimum	0.08	0.06	0.75
	Maximum	0.10	0.11	1.54
Class II deep	Mean	0.0930	0.0820	5.0980
	N	10	10	10
	Std. Deviation	0.00949	0.00789	0.79586
	Median	0.0900	0.0800	4.9200
	Minimum	0.08	0.07	4.18
	Maximum	0.11	0.09	6.71
Class III shallow	Mean	0.0890	0.0840	1.3780
	N	10	10	10
	Std. Deviation	0.01197	0.01075	0.04131
	Median	0.0900	0.0800	1.3650
	Minimum	0.07	0.07	1.32
	Maximum	0.10	0.10	1.44
Total	Mean	0.0917	0.0830	2.5377
	N	30	30	30
	Std. Deviation	0.00950	0.0830	1.90273
	Median	0.0900	0.0800	1.4150
	Minimum	0.07	0.06	0.75
	Maximum	0.11	0.11	6.71
P-value		0.806	0.950	$P < .001$*

* Statistical significance exists.

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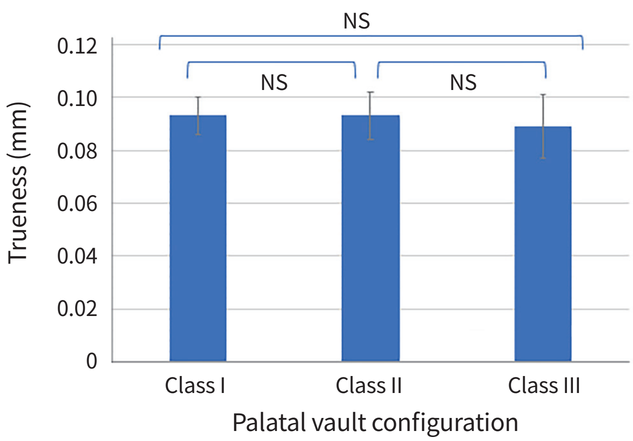

Fig. 7. A bar chart showing mean trueness in three study groups.
NS: Not significant, $P > .05$.

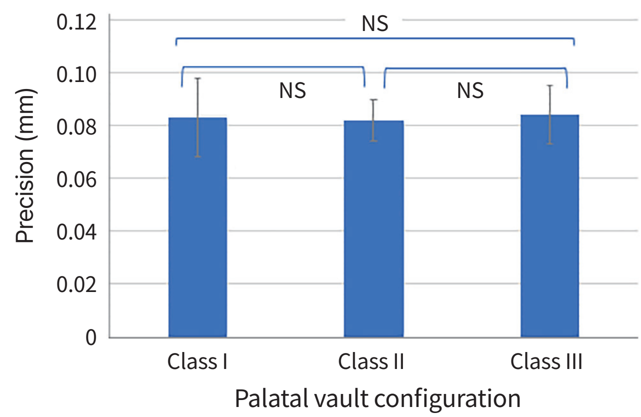

Fig. 8. A bar chart showing mean precision in three study groups.
NS: Not significant, $P > .05$.

Qualitative color maps of trueness revealed a wide distribution of green, yellow and orange colors in mid-palatal and palatal slope regions. Sporadic distribution of negative deviation as denoted by dark blue color was also observed in 3 groups mainly in posterior and tuberosity areas. Positive deviation denoted by yellow and orange color was mainly concentrated in mid-palatal region in Class I (Fig. 4A) and Class II (Fig. 4B) opposite to Class III (Fig. 4C) where positive deviation was observed on palatal slopes on both sides of mid-palatal region.

Precision heat maps revealed most prominent irregular deviation pattern in Class III cases as evident by wide spread distribution of yellow, red and orange colors in the palatal region that did not follow a specific pattern (Fig. 5).

DISCUSSION

The present *in vivo* study aimed to investigate the influence of different palatal vault configurations on the accuracy in terms of trueness and precision and on the scan speed of intraoral (IO) scans in completely edentulous arches. Recording the scan time for each acquisition provides valuable information about the efficiency and workflow of the intraoral scanning process. The findings of this study contradict the null hypothesis that there is no significant difference in all the evaluated parameters among the three tested groups. Scan time was significantly increased in cases of deep palatal vault compared to the other two groups with no significant difference in accuracy among the three groups.

A rigorous methodology was implemented in this study, which demonstrated a systematic approach to capture 3D datasets. Scan paths adopted in this study during the scanning process of the three groups were based on a previous *in vitro* study that evaluated the influence of different palatal vault configurations on the scan accuracy and scan speed.[13] The aforementioned study advocated the use of the manufacturer's recommended scan path in moderate and flat palatal vaults and introduced new path in case of deep vault that facilitated the stitching of images in deep palatal region and enabled the avoidance of scan errors encountered with recommended path. Further, the authors of the previously described study conducted a reliability test that revealed high agreement between the two scan strategies with no significant influence on scan accuracy. Thus, based on their findings, and considering that the same scanner type was used, it was deemed appropriate to adopt the two scan strategies that were employed in the current study.

Thorough cleaning of the edentulous ridge and elimination of saliva was also performed. By digitizing the reference model, it was ensured that the virtual models generated from the scanned data would be accurate and free from the shadowing effects that would have been present if the elastomeric impressions were scanned directly. This approach contributes to the robustness and reliability of the study's findings. The involvement of a single, well-trained operator in performing all the scans was essential and ensured that the operator's experience was not a factor that influenced the reported outcomes.[16,17]

The increased scan time recorded in Class II cases can be attributed to the modified scan path that was adopted. With modified path, multiple image acquisitions from different directions resulted in significantly longer scan time compared to the other two groups. Osman & Alharbi[13] demonstrated that with confocal technology utilized with TRIOS 3 scanner, scan has to be completed at two different levels; one level to capture the crest of ridge and palatal slope while the other level is to capture the region of deep palatal vault. Confocal imaging technology is characterized by optical sectioning phenomena which entails the acquisition of focused images at a single selected depth. To overcome the limitation of technology while scanning Class II cases, multiple scans following a zig-zag pattern from different directions thus had to be acquired, which resulted in prolonged scan time.

In accordance with study by Osman & Alharbi,[13] no significant difference was found in trueness and precision among the three groups. However, direct comparison of our findings with their results was not possible. Accuracy measurement in our study was restricted to palatal vault area opposed to accuracy evaluation throughout the whole scanned edentulous ridge in their study. Restriction of accuracy measurement to palatal vault area was performed to ensure that the readings recorded were mainly related to region of interest and under investigation while avoiding commonly reported scan deviations in vestibular area or the so-called peripheral seal zone. *In vivo* studies[5,9] that evaluated the possibility of acquiring digital impressions of completely edentulous cases revealed that the highest deviation values were recorded in the areas that exhibit tissue mobility such as soft palate and the vestibular flanges limiting areas. Lack of significant difference in accuracy measurements among the groups suggests that selection of proper scan strategy could be of more importance than morphological shape of area being scanned.

Positive deviation displayed in yellow color observed in trueness color maps of test scans in relation to reference scans in 3 groups can be attributed to the flexibility of the palatal mucosa. Contrary to conventional impression, intraoral digital scans do not contact or exert any pressure on oral tissues resulting in mucostatic impression technique and thus the observed positive deviation. The concentration of positive deviation along mid-palatal suture area particularly in Class II cases can be related to vault anatomy featuring narrow and high palatal slopes combined with the scanner head size. Orientation of the scanner head parallel to mid palatal region during scan process was not feasible. The aforementioned anatomy further complicated the situation owing to the shadowing effect. The light projected from scanner head was reflected away from sheltered hidden areas at a more superficial level resulting in observed positive deviations.

In accordance with the findings of Hack *et al.*,[5] visual examination of trueness color maps revealed that most of uncaptured data was located on soft palate at the posterior seal area as the scanner software algorithm automatically deleted the images of mobile, non-steady objects during the scan process. This deficiency in capturing the seal area will be clinically reflected in the form of reduced prosthesis retention if it is to be fabricated relying solely on final digital impression. In deep palatal vault group, the non-homogeneous red and blue colors in the rugae area and the middle part of the posterior palatal seal may suggest compromised fit of complete dentures constructed on the basis of final digital scans. Thus, the authors recommend that for optimal results, a combined digital and conventional workflow should be combined to overcome the limitations associated with fully digital workflow. Future studies should focus on improving the software algorithm for acquiring digital impressions of movable regions.

The irregular deviation pattern that was observed in precision color map of Class III group can be attributed to the flat anatomical shape of palatal vault, which complicated the superimposition of test and reference file scans during the matching process.

A limitation of this study is the comparison of test scans to reference scans created by scanning poured

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models obtained from conventionally taken impressions rather than being compared to actual edentulous ridges. Nevertheless, this kind of comparison could only be performed in an *in vitro* study design which would not ideally mimic all patient-related factors such as but not limited to oral tissues mobility, presence of saliva, and scan acquisition in a confined area. The influence of different scanners with different operating technologies should also be evaluated. Though only one type of scanner was used, the results of this study could be applied to any intraoral scanner operating using the confocal imaging technology.

CONCLUSION

The depth of the palatal vault has an effect on scanning time with deeper vaults requiring modification of the manufacturer's recommended scan path, resulting in longer scan time. However, the accuracy of IO scans remained consistent across different palatal vault configurations. Understanding the underlying technology of each scanner can aid in the selection of best clinical protocol that matches anatomical requirements of each case and can enhance the efficiency of intraoral scanning process in prosthodontic application.

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