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TRUENESS AND PRECISION OF STEREOPHOTOGRAMMETRY SCANNING METHOD FOR PREPARED TEETH (AN INVITRO STUDY)

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ABSTRACT

Objectives: To assess the accuracy in terms of trueness and precision of two-dimensional image-based scanning stereophotogrammetry method compared to extraoral scanner.

Methods: in this study an **a**natomically prepared maxillary central incisor was scanned using an extraoral scanner as reference control. For Stereophotogrammetry scanning a setup was customised, its construction is based on digital single reflex camera (DSLR) for capturing photos. For standardization the camera is accompanied with a computer-controlled wireless communication Arduino based device to produce photos that fulfil the requirements of this technique ensuring repeatable and overlapping photography. Produced photos were processed using a dedicated stereophotogrammetry software to create three dimensional models exported as standard tessellar language files (STL). To compare accuracy an extraoral desktop scanner was used as control. Scanning was repeated 5 times for both methods. Accuracy was assessed in terms of trueness, and precision was assessed by overlapping the produced STL files using surface matching software.

Results: Stereophotogrammetry scanning displayed mean trueness of (39±1 microns), and mean precision (2.8±1.3 microns). The desktop extraoral scanner displayed mean trueness mean (23±3 microns) and mean precision of (17.5±7 microns).

Conclusions: Stereophotogrammetry scanning method showed reliable scanning accuracy of prepared teeth and can be used as an affordable alternative scanning method with comparable results to commercially available laboratory desktop extraoral scanners.

KEYWORDS: Photogrammetry, trueness, precision, scanning, extraoral scanner.

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INTRODUCTION

Digital scanning is the first step for acquiring a virtual model that can be further used for fabrication of CAD/CAM restorations [1]. The accuracy of this step determines the overall success for the digitally fabricated dental restorations [2]. obtaining virtual impressions of prepared teeth entails scanning either using an extraoral desktop scanner or an intraoral scanner [3]. Accuracy of scanners is defined in terms of trueness and precision. Trueness can be defined as closeness between the expectation of a test result or a measurement result and a true value with high degree of accuracy [4,5]. Precision was defined as the closeness of the measurements obtained upon repeating measurements under specified conditions[4,5]. Multiple technologies were introduced for digital scanning of dental structures including structured light scanning, triangulation, conofocal and active wavefront sampling (AWS)[6,7,8].

Stereophotogrammetry started as image-based rendering (IBR) scanning method depending on algorithmic analysis of two-dimensional images to estimate three dimensional coordinates of an object [9]. This method is considered a passive scanning method, where ambient light is only used to illuminate the object [4]. Stereophotogrammetry was introduced as an affordable and simple method for acquisition and creation of virtual dental models [10,11]. A gap of knowledge still exists regarding the validity and reliability of this method regarding its accuracy in scanning of dental models or preparations. The objective of this study was to asses the accuracy in terms of trueness and precision of stereophotogrammetry two-dimensional image-based scanning method for prepared teeth compared to extraoral scanner.

A null hypothesis for this study is that there will be no difference in accuracy between photogrammetry and extraoral desktop scanner on scanning prepared teeth.

MATERIALS AND METHODS

Sample size calculation

Power analysis used trueness and precision as the primary outcome. Based upon the results of a pilot study conducted on three samples, the mean (Standard deviation) values were 0.07 (0.08) and -0.03 (0.1) with scanner and photogram, respectively. The effect size (dz) was 1.091. Using alpha (α) level of (5%), β level of 0.8 (Power = 80%); the minimum estimated sample size was 5 impressions per each group for either scanning methods. Sample size calculation was performed using G*Power version 3.1.9.2.

Master die preparation. an acrylic typodont maxillary central incisor was selected and manually reduced to receive an all-ceramic restoration; a deep chamfer finish line and anatomical preparation was carried out to simulate the clinical conditions (Figure 1). Following this the die was sprayed with scanning spray (Ipdent, Germany).

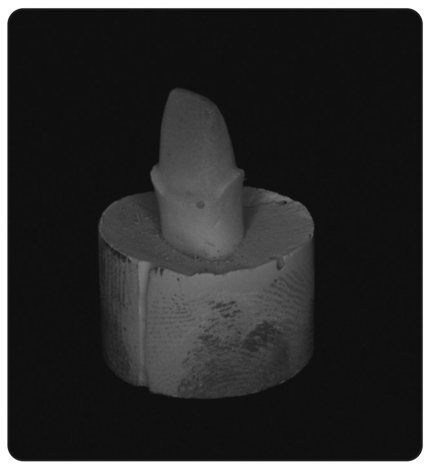

Fig. (1) Anatomically prepared master die sprayed with scanning spray

Reference model creation for trueness. To assess trueness a reference model or file had to be created for the prepared master die; using the extraoral scanner (inEos X5, Dentsply Sirona) was scanned, the created model was exported as standard tessellation language file (STL).

Extraoral scanning. Five impressions were recorded using extraoral laboratory dental scanner Up300+ (up3d, Shenzhen, China) that operates with blue structured light technology.

Photogrammetry scanning. To standardize image acquisition and angles of the dies for photogrammetry, the camera setup was established first; the Digital single reflex camera (DSLR) camera (Nikon D3200, Nikon, Japan) was fixed on a tripod, the dies placed on the platform of a customized Audrino controlled (Audrino, Uno, USA) mobile turnable, the platform built on two motor axes system composed of an acrylic circular part with diameter of 10 cm fixed on a stepper motor to precisely position and control the rotation step angle between different image positions (Figure 2).

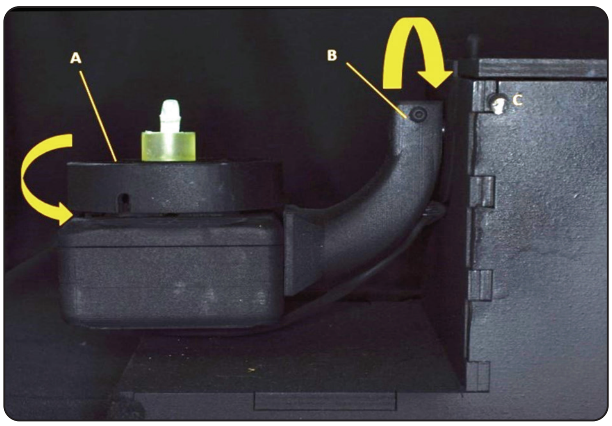

Fig. (1) Anatomically prepared master die sprayed with scanning spray

Camera settings: stabilized on a tripod and set at a distance of 20 cm from the object to avoid image blurring during shooting Adequate even lighting was ensured using a ring flash (Godox, Shenzen, China) to avoid shadowing of the image and ensure proper light distribution. A product photography box (General, Egypt) with a dark background macro photography employed using a 40 mm macro lens (Nikkor, Nikkon, Japan) were used, shutter speed 1/160 sec, f stop 22 and iso 100.

Motor configuration: micro stepping feature selected for smooth operation and vibration reduction during image capturing. Another stepper motor was fixed with an acrylic arm to the side of the circular part, allowing for tilting of the circular part to capture images from a different angle. The master die was placed in the centre of the rotating part of the platform, and the step rotation angle was set to be 10 degrees ensuring maximum overlap between the images for optimum photogrammetric construction. Images were captured from three angle: Horizontal, 30 and 60 degrees respectively (Figure 3 A & B).

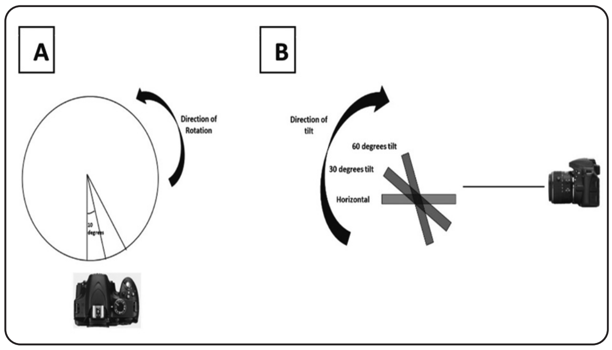

Fig. (3) A: Rotation Step Angle by 10 degrees, B: Tilting angle Horizontal, 30 & 60 degrees.

An infrared remote transmitter was used to send trigger signal to the camera for capture an image after each movement of the platform. A graphical user interface (GUI) (Figure 4) based on Python programming language was used to control the device motors stepping angle and tilting angle as well as the speed of rotation.

Photogrammetric construction: A dedicated photogrammetry software (Zephyr 3d, 3d flow, Italy) was used to reconstruct the three-dimensional model to create a Standard Tessellation Language (STL) file. The software works in different steps. After uploading of images, the software). Thects common points between them to construct a sparse point cloud (Figure 5A) to identify the relation between common points of the overlapping images, followed by densification of these points to make a dense point cloud (Figure 5B) and finally creating a mesh for the three-dimensional model with detailed surface texture (Figure 5C & D).The process of digital model creation using photogrammetry IBR method was repeated five times for the master die.

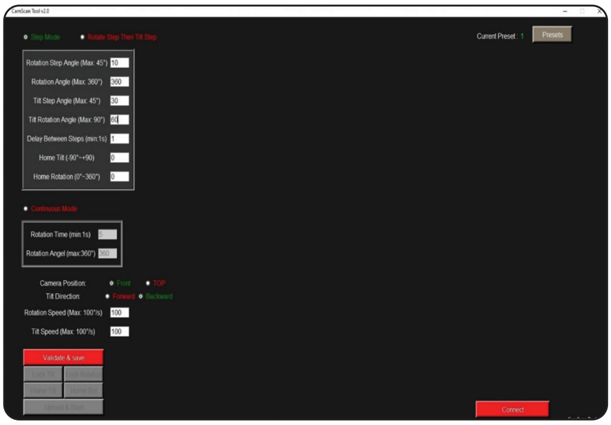

Fig. (4) Graphical user interface (GUI) used for controlling the turnable device.

Assessment of trueness and precision

For trueness measurement CAD reference models obtained from reference scanner, and all (STL) files obtained from both studied scanning methods were loaded into a 3D reverse engineering software (Geomagic QualifyTM 2012, Geomagic, Morrisville, USA). All unnecessary information were removed using the “cut with planes” option available inside the software, colour difference maps and reports were obtained by superimposing the digital data sets of the scans onto the reference model, then 3D deviation analysis was performed uisng the best-fit algorithm method. For each superimposition, the root mean square (RMS) of the amount of deviation at each measurement point was recorded according to equation

RMS = 1 √ n · vtXn i=1 (X1,i – X2,i) 2 . [12]

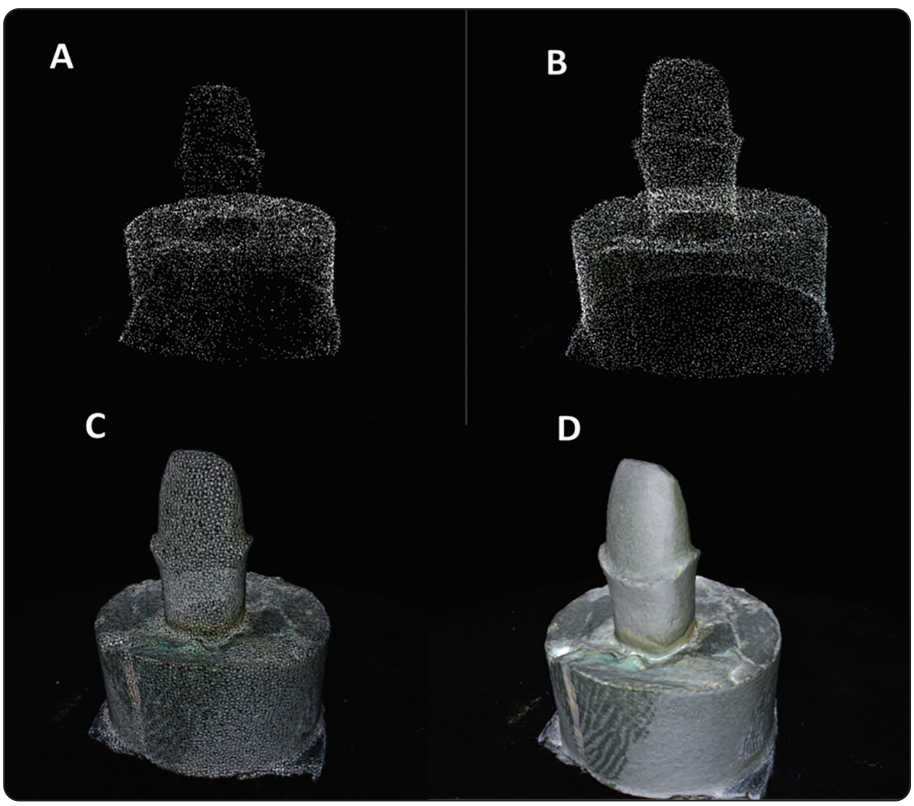

Fig. (5) Reconstruction of three-dimensional model. A: Sparse point cloud, B: Dense point cloud, C: Mesh construction & D: Textured mesh.

where X1,i is the measurement point of i of the CAD reference model (CRM), X2,i is the measurement point of i of the CAD test model (CTM), and n is the number of all points measured in each analysis. Meanwhile for the assessment of precision the repetitions of impressions were superimposed on each other for the (Figure 6).

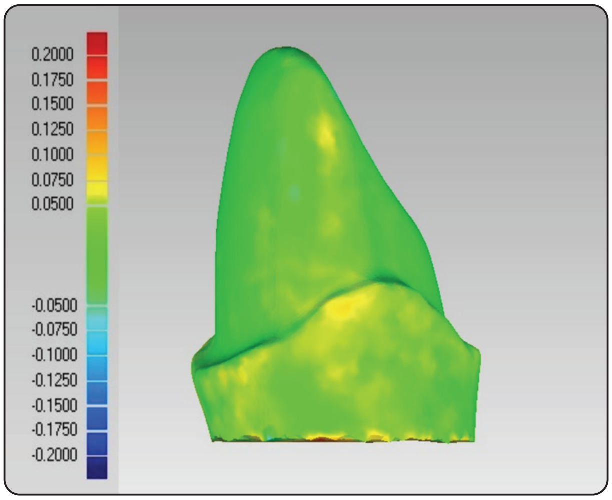

Fig. (6) Superimposition of STL files for assessment of trueness and precision.

Statistical Analysis

Numerical data were explored for normality by checking the distribution of data and using tests of normality (Kolmogorov-Smirnov and Shapiro-Wilk tests). All data showed normal (parametric) distribution. Data were presented as mean and standard deviation (SD) values. Student's t-test was used to compare between the two groups. The significance level was set at $P \leq 0.05$. Statistical analysis was performed with IBM SPSS Statistics for Windows, Version 23.0. Armonk, NY: IBM Corp.

RESULTS

Photogrammetry showed a statistically significant higher mean of deviation from the reference scan model (39±1 microns), when compared to that of extraoral scanner (23±3 microns) (*P*-value <0.001, Effect size = 4.93).

For precision assessment of deviation from overlapping repetitions of digital impressions, photogrammetry has shown statistically lower significant mean of deviation (2.8±1.3 microns), when compared to that of extraoral scanner (17.5±7 microns) (*P*-value <0.001, Effect size=2.883). (Figure 7 and Table 1).

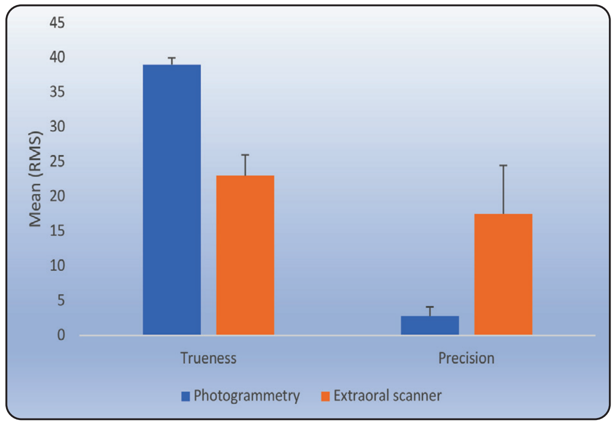

Fig. (7) Bar chart showing deviation results for trueness and precision in microns

TABLE (1) Descriptive statistics and results of Student's t-test for comparison trueness and precision (RMS) in the two groups

	PG		UP3D		*P*-value	*Effect size (d)*
	Mean	SD	Mean	SD		
Trueness	0.039	0.001	0.023	0.003	<0.001*	4.93
Precision	0.0028	0.0013	0.0175	0.007	<0.001*	2.883

: Significant at P ≤ 0.05

DISCUSSION

The aim of an impression is to obtain a highly accurate replica of the dental structures[13], reproduction of accurate details of prepared teeth helps to produce highly accurate restorations that have long term success [14].

As multiple digital impression technologies were introduced for obtaining digital 3d virtual model for prepared teeth, photogrammetry was still a challenging option because of the need of special sophisticated equipment for image acquisition and sequence them [15]. Advances in image capturing technologies using highly accurate equipment and production of dedicated softwares for photogrammetry helped in the production of an accurate, reliable and economic method that can be used in dental field [16,17]. This study included more standardization for the technique of photogrammetry by fabricating a custom-made device that helped to produce repeatable movements and photographs that allows the production of more accurate three-dimensional dental models. These photos are required to have 60 to 80% overlap between images. Using DSLR camera produces high image quality, this facilitates image rendering process in photogrammetric software [11]. Ring light with diffuser was used to provide even light distribution and to avoid shadowing as much as possible, as shadowing can cause loss of the entire shadowed area [18, 19]. Spraying master die with scanning spray was required to eliminate refraction and scattering of ambient light used while photographing the object, which may result in a deficient determination of the depth of the scanned object [20]. Another benefit of using scanning spray is to create random texture surface that helps in image correlation especially for the case of uniform objects with no landmarks that help photogrammetric software [21].

Photogrammetry displayed statistically significant higher deviation from reference model trueness when compared to extraoral scanner, on the contrary precision showed statistically lower mean of deviation when compared to other extraoral scanners, these results were consistent with previous studies which emphasized the capability of photogrammetry to produce models with high accuracy and within the clinically acceptable range which was below 100 microns [22,23,24].

A limitation of this study was that an isolated prepared master die for anterior acrylic tooth was used for assessment of trueness and precision not simulating the oral condition.

CONCLUSION

Within the limitation of this study Stereophotogrammetry scanning method displayed reliable accuracy for scanning prepared teeth and can be used as an alternative affordable technique for dental applications with results comparable to commercially available extraoral scanners.

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Conflict of Interest

The authors have no proprietary, financial, or other personal interest of any nature or kind in any product, service, and/or company that is presented in this article.

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