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Accuracy of Guided Implant Surgery in the Partially Edentulous Jaw Using Digital impression versus Desktop Scanner and CBCT cast scan: Randomized Clinical Trial

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Abstract

AIM: The aim of the study is to compare the accuracy of surgical guided implant produced by intraoral scanner, desktop scanner, and CBCT cast scan.

SUBJECTS AND METHODS: A total of 63 dental implants were placed using 14 surgical guides. A total of 15 subjects, eight males and seven females (eight bilateral cases and seven unliteral cases), with mean age of 45 years (38–55 years) were included in the study. Patients were randomly divided into three groups (n = 21 each): Group 1: Surgical guide manufactured using intraoral digital impression. Group 2: Surgical guide manufactured using model cast scanning by CBCT while Group 3: Surgical guide manufactured using model cast scanning by desktop scanner the linear and angular deviations of inserted planned implants were measured.

RESULTS: In the intraoral scan group, the mean angular deviation, platform 3D deviation, apical 3D deviation, and vertical deviation were 2.5°, 0.7 mm, 1.1 mm, and 0.6 mm, respectively. While in desktop scanner group, the mean angular deviation, platform 3D deviation, apical 3D deviation, and vertical deviation were 2.6°, 0.1 mm, 1.1 mm, and 1.1 mm, respectively. In the CBCT scan group, the mean angular deviation, 3D platform deviation, 3D apical deviation, and vertical deviation were 3.5°, 1.3 mm, 1.6 mm, and 1.7 mm, respectively. There is no statistically significance difference between intraoral scanner, CBCT cast scan, and desktop scanning on implant deviation that was observed.

CONCLUSION: There was no statistically significance difference between intraoral scanner, CBCT cast scan, and desktop scanning on implant deviation that was observed although IOS shows better accuracy and least mean angular deviation.

Introduction

Digital workflows in dentistry are increasingly popular and state-of-the-art in dentistry. Cone beam computed tomography (CBCT) allows dentists to diagnose, build treatment options, and plan restorations by three dimensionally (3D) brining hard tissues to life that were otherwise available to dentist by only using panoramic and periapical radiographs. In addition, a variety of optical scanning methods are commercially available and allow for interdisciplinary communication and collaboration, as well as providing patient education tools [1].

One of the goals of digital dentistry is to avoid as many as handling property errors as possible by eliminating partially, if not fully the use of dental materials. CBCT, 3D printed surgical guides, optical, and intraoral scanning software are all innovative tools that can provide such accurate, predictable, and safe placement of the implant [1].

A surgical guide assists in guiding the position and inclination of the dental implant in the correct position. It allows accurate implant placement into planned positions, facilitating flapless minimally invasive surgery resulting in less postoperative morbidity and reduces the complication of implant, such as prosthetic failure, peri-implant failure, and unesthetic due to malposition of the implant fixture [2], [3].

However, any of these advantages is depending on a high accuracy of transferring the virtual planning into reality. There are many sources of inaccuracies for guided implant surgery. Some are basic and common irrespective of the used system (such as artifacts occurring during image acquisition); others are specific and related to the respective software and technique transferring the virtual planning into reality [4].

Traditional impression technology has been widely used for many years due to advancements in impression materials. With the rise of digital concepts in dentistry, digital impression technology has grown in popularity [5].

There are currently two common methods for obtaining digital impressions. One is to use a desktop scanner to scan a plaster cast to obtain a digital model, and the other uses an IOS to directly scan the patient's natural dentition to obtain a digital model [5], [6], [7].

Compared with obtaining digital impressions using desktop scanners that still require the use of traditional impression technique to obtain physical casts or impressions, the method for obtaining digital impressions using IOSs has many apparent advantages such as reduced anxiety and nausea response better, comfort, and better communication with patient as feeling more involved in their treatment, this emotional involvement may have a positive impact on the overall treatment, greater time efficiency, simplified operating procedures, and it eliminates the need for materials and impression trays which are unwelcome to the patients. Patients have a tendency to prefer optical impressions reported in the literature [5], [6], [7].

According to a systematic review by Gallardo *et al*., it reported that the advantage of digital approach over the conventional one not necessarily faster than the conventional approach (a full arch scan may take 3–5 min, similar to that required for conventional impressions), but rather the fact that a scan does not require the additional steps of pouring and obtaining a physical plaster model. You can email virtual 3D models (proprietary or STL files) directly to the patient [5], [6], [7].

Furthermore, if there is an inaccuracy in the intraoral scan or if the clinician is not satisfied with some of the details of the recorded optical impression, it is easily corrected by deleting only the error and rescanning the site without having to repeat the entire procedure, this aspect is time saving. A conventional impression would need to be remade [5].

The accuracy of computer-guided surgery can be sensitive to cumulative errors. It is a sum of technical errors during the examination, planning, surgical guide accuracy which dependent on implant site location, whether the patient being completely or partially edentulous, the type of tissue support for the guide and the amount of surgical restriction offered by it and surgical procedure. Clinical factors, such as patients' intraoral condition, can also affect the implant deviation. Therefore, clinicians should be aware of and understand each factor that can potentially influence the implant placement accuracy in the workflow sequence for computer-guided surgery [8], [9].

The aim of this study is to compare the accuracy of surgical-guided implant produced by intraoral scanner, desktop scanner, and CBCT cast scan.

Methods

Trial design

A randomized and clinical trial where allocation and randomization of the eligible patients was with ratio 1:1.

Sample size calculation

This power analysis used lateral deviation at implant apex as the primary outcome. The effect sizes d = (0.73) was calculated based upon the results of Lin CC al (2020). Using alpha (α) level of (5%), Beta (β) level of (20%), that is, power = 80%; the minimum estimated sample size was a total of 63 implants (21 implants per group). Sample size calculation was performed using G*Power Version 3.1.9.2. [10].

Participants

Eligibility criteria:

- Patient seeking implant.
- Partially edentulous patient.
- Patients with Bucco-lingual bone thickness more than 6 mm allowing flapless implant placement.
- Both sexes were involved.

Exclusion criteria:

- Completely edentulous patient.
- Patients needing graft or sinus lifting with implant placement.
- Patients with thin ridges.
- Patients with systemic disease that may affect bone quality and Osseo integration as uncontrolled diabetes mellitus.
- Patients with poor oral hygiene and active periodontal diseases.
- Patient with limited mouth opening.
- Patient receiving chemotherapy or radiotherapy.

Randomization

- Patients were randomly divided to three groups.
- The whole sample size were divided into equal three groups.
- All patients who give consent for participation.

Implantation

- Main supervisor generated the allocation sequence.
- Implantologist enrolled participants.
- Co-supervisor assigned participants to interventions.

Masking/blinding

- Each patient has given a code by the researcher and the observers who was blind to which group this case belong.
- Evaluators and statistician were blinded.

Patient history and clinical examination

A detailed history taking and clinical examination of 15 subjects, eight males and seven females (eight bilateral cases and seven unilateral cases), with mean age of 45 years (38–55 years) were performed, thorough extra and intraoral examinations were performed for every patient.

Cone-beam computed tomography and impression taking

All patients scanned by CBCT (Planmeca Promax 3D Mid - Asentajankatu, Helsinki, Finland) to obtain bone data within the edentulous area into which the implants were placed. The images were exported as digital imaging and communication in medicine (DICOM) after acquisition. In Group I, full arch digital impression was taken by intraoral scanner (Medit i700 Seol, South Korea) to produce the digital cast for patient in the form of surface tessellation language (STL) file. In Group II, Conventional impression was taken from the patient then poured to obtain a plaster cast. This plaster cast was scanned by CBCT to produce a digital cast in the form of STL file. While in Group III, conventional impression was taken, then poured to obtain a plaster cast that was digitized by a desktop scanner (Medit T, Seol, South Korea) to obtain a digital cast in the form of STL file.

Implant planning and guide fabrication

- In the virtual implant planning step, the implants position and angulation were virtually designed. The width (diameter) and length of each implant were measured at the proposed sites. The type and size were chosen from the implant library supplied by the software depending on the implant system used (Figure 1).

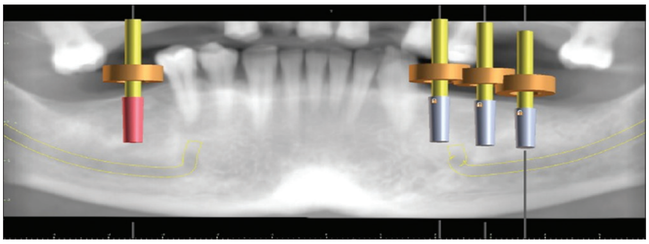

Figure 1: Virtually planned implants and tracing of canal

- For multiple implants, a parallelism tool was used (Figure 2). The system also offers the option to set a safety limit around and between implants, the system warns if these limits were violated.
- DICOM file from CBCT scan of each patient was imported to implant planning software blue sky bio (Langenhagener, Mdi Europa GmbH) and superimposed with the STL file (Figure 3). Guide printing involves the use of a 3D printer that hardens the photosensitive resin in the layers beneath the action of the laser (laser printer T310) to generate the guide (Figure 4).

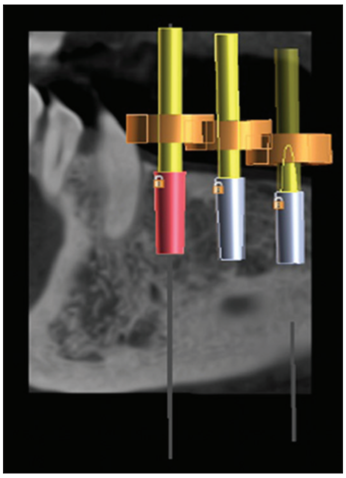

Figure 2: Parallization tool for multiple implants

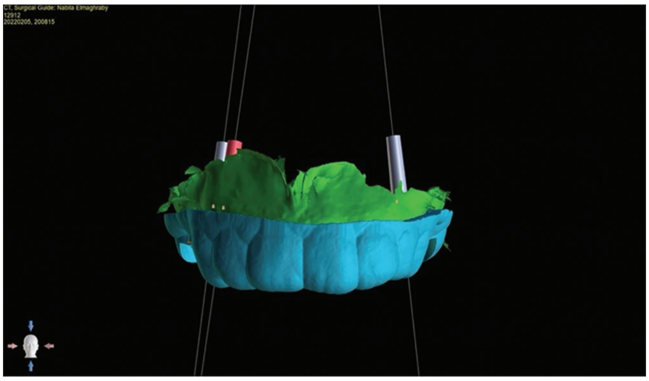

Figure 3: Superimposition of CBCT with STL to fabricate the guide

After the surgical guide was printed, the metal sleeves specific to the implant system were incorporated.

Figure 4: 3D printed upper guide

- The 3D printed guide was autoclaved at a pressure of + 1 bar and a temperature of 121°C for 15 min as the accuracy of the guide not affected when sterilized under such conditions. It was then examined in the patient’s mouth to ensure that the guide was adjusted and stable during surgery [8].

Surgical procedure

- The implant placement was performed under local anesthesia. After checking the anesthesia, the surgical guide was inserted inside patient's mouth.

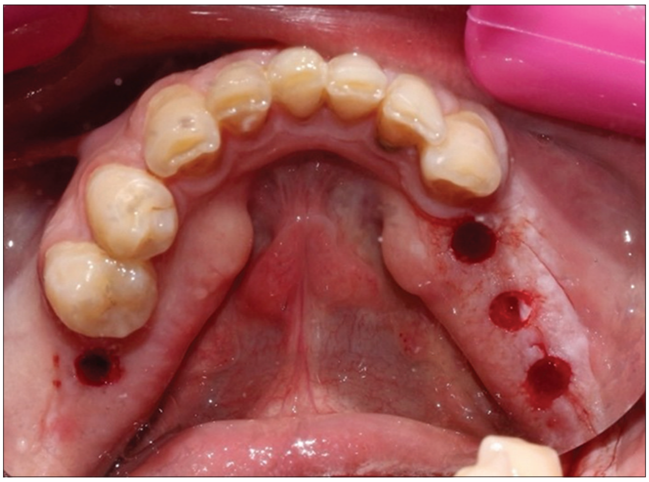

Figure 5: Flapless-guided surgery (tissue punch)

- A fully-guided protocol with flap and a flapless technique was performed according to each case [11]. In case of flapless surgery (seven subjects), a tissue punch was used with the same diameter of the selected implant (Figure 5). While in flap surgery (eight subjects), a supracrestal incision without a vertical releasing incision was performed before reflecting amucoperiosteal flap (Figure 6).

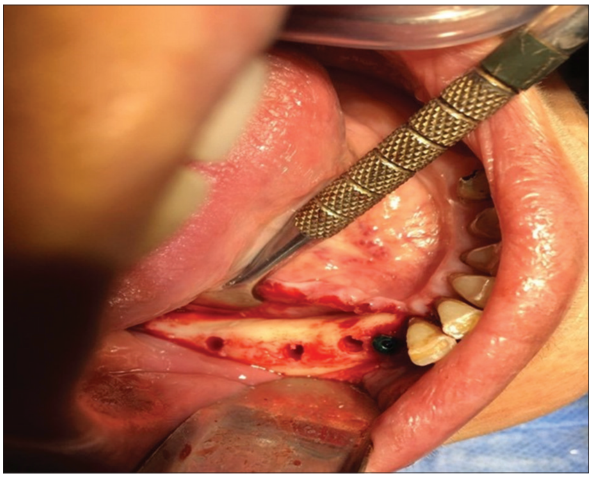

Figure 6: Flap-guided surgery (supracrestal incision)

- The osteotomies were prepared according to the manufacturer's instructions of fully guided protocols, in the fully guided protocol, drilling was performed using the fully-guided implant kit until the final drill drilling protocol was then followed for each osteotomy site according to the drill sequence. The drilling depth was controlled by a drill stopper after proper depth preparation the implant inserted [2].
- The primary implant stability was evaluated at the time of implant placement using the surgeon's perception and insertion torque measurements [12].

Methods of evaluation

- Patients were recalled after implant insertion for another CBCT scan. The same pre-operative CBCT machine and parameters were used.
- The DICOM data were exported to the Blue-Sky plan software for segmentation; removal of soft tissue. Superimposition of pre- and postoperative scans was made. The virtually planned and actual implant positions were compared.

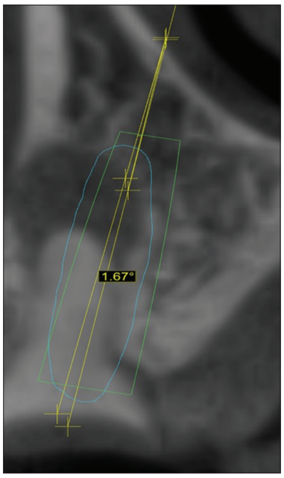

Figure 7: Buccolingual angular deviation

- The deviation in the most coronal part (platform) and the apex of the implant were calculated in millimeters, and the overall angle deviation was measured in degrees. The measurements used to perform the statistical analysis [12], [13]. Moreover, they are described as follows:
- Angular deviation (Figures 7 and 8).

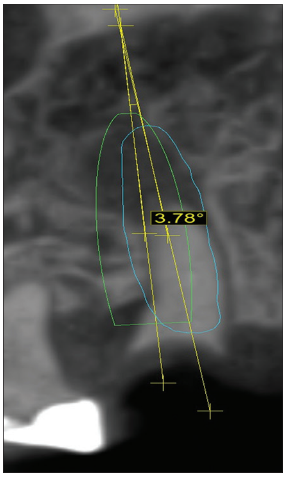

Figure 8: Mesiodistal angular deviation

- Deviation at implant shoulder – mesiodistal (MD).
- Deviation at implant shoulder – buccolingual (BL).

- Deviation at implant apex – mesiodistal.
- Deviation at implant apex – buccolingual.
- Vertical deviation (Figure 9).

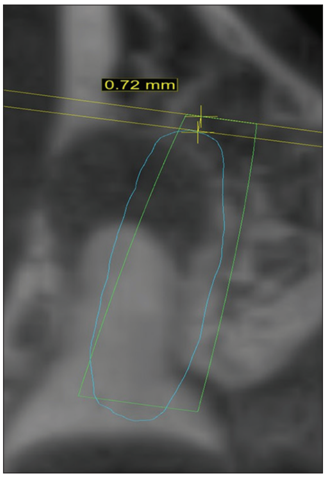

Figure 9: Vertical deviation

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 non-normal (nonparametric) distribution. Data were presented as median, range, mean, and standard deviation (SD) values. Kruskal–Wallis test was used to compare between the three groups. Dunn's test was used for pair-wise comparisons when Kruskal–Wallis test is significant. Wilcoxon signed rank test was used for comparisons within each group. Mann–Whitney U test was used to compare between tooth-supported and mucosa-supported 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

Angular deviation

Comparison between groups

Pre-operatively; there was a statistically significant difference between the three groups ($p < 0.001$, Effect size = 0.725). Pair-wise comparisons between groups revealed that CBCT showed the statistically significantly highest deviation. Desktop scanner showed statistically significantly lower deviation. IOS scan showed the statistically significantly lowest angular deviation.

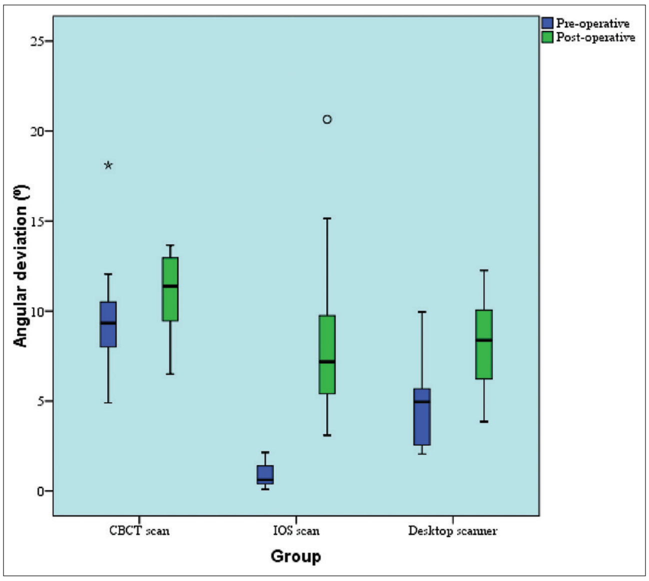

Figure 10: Box plot representing median and range values angular deviation in the three groups (Circle and star represent outliers)

Postoperatively; there was a statistically significant difference between the three groups ($p = 0.019$, Effect size = 0.108). Pair-wise comparisons between groups revealed that CBCT showed the statistically significantly highest deviation. There was no statistically significant difference between desktop scanner and IOS scan; both showed the statistically significantly lowest angular deviations (Table 1 and Figure 10).

Horizontal deviation

At the coronal level; there was no statistically significant difference between the three groups ($p = 0.054$, Effect size = 0.140).

At the apical level; there was a statistically significant difference between the three groups

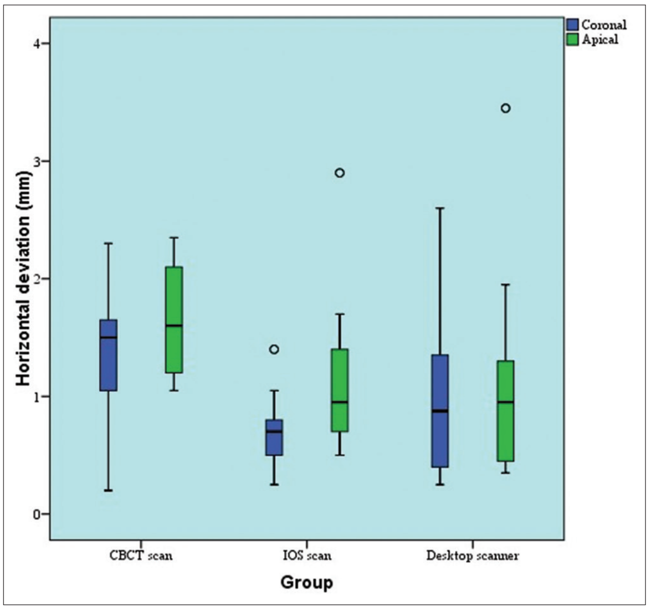

Figure 11: Box plot representing median and range values horizontal deviation in the three groups (Circles represent outliers)

Table 1: Descriptive statistics and results of Kruskal-Wallis test for comparison between angular deviation (º) in the three groups

Time	CBCT scan (n = 21)		IOS scan (n = 21)		Desktop scanner (n = 21)		p-value	Effect size (Eta squared)
	Median (Range)	Mean (SD)	Median (Range)	Mean (SD)	Median (Range)	Mean (SD)		
Pre-operative	9.3 (4.9-18.1)^{A}	4.5 (3.5)	0.6 (0.1-2.2)^{C}	0.9 (0.6)	5 (2.1-10)^{B}	4.6 (2.1)	<0.001*	0.725
Post-operative	11.4 (6.5-13.7)^{A}	3.5 (2.4)	7.2 (3.1-20.7)^{B}	2.5 (4.2)	8.4 (3.9-12.3)^{B}	2.6 (2.4)	0.019*	0.108

*Significant at p ≤ 0.05, Different superscripts in the same row indicate statistically significant difference between groups.

(p = 0.025, Effect size = 0.066). Pair-wise comparisons between the groups revealed that CBCT scan showed the statistically significantly highest median deviation. There was no statistically significant difference between IOS scan and desktop scanner; both showed the statistically significantly lowest median deviations (Table 2 and Figure 11).

Vertical deviation

There was a statistically significant difference between the three groups (p = 0.029, Effect size = 0.254). Pair-wise comparisons between groups revealed that there was no statistically significant difference between CBCT scan and desktop scanner; both showed statistically significantly higher vertical deviation than IOS scan (Table 3 and Figure 12).

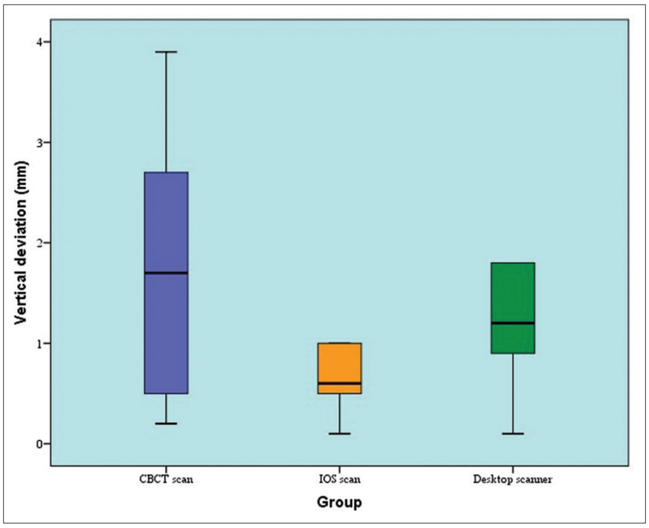

Figure 12: Box plot representing median and range values vertical deviation in the three groups

Discussion

Many factors can affect accuracy and reproducibility of 3D printed surgical guides, including errors in CTdata acquisition, data processing, software planning, surgical guides manufacturing, physical properties of the material used, guide systems software and printers, longer drill length, limited mouth opening, posterior position of implants, variability in IOS accuracy, interpolation of the software used for planning, shrinkage of STL guide, mal-positioning of the guide intraorally, and incorrect operative techniques. Intraoperatively, administration of local anesthesia in the mucosa can cause edema which can induce minor changes in adaptation between the SLA surgical guide [1], [9].

An accuracy defect can be sensitive to cumulative errors that lead to a deviation of the implant positioning. The inaccuracies or deviations in implant placement were reflected by the sum of technical errors during the examination, planning, surgical guide manufacturing, and surgical procedure. Therefore, clinicians should be aware of and understand each factor that can potentially influence the implant placement accuracy in the current workflow sequence for computer-guided surgery and study them individually, to improve accuracy and reproducibility [14], [15].

For planning of implant insertion and guide fabrication, a pre-operative CBCT was taken, in agreement with the previous studies [9], [16].

In this study, in the intraoral scan group, the mean angular deviation, platform 3D deviation, apical 3D deviation, and vertical deviation were 2.5°, 0.7 mm, 1.1 mm, and 0.6 mm, respectively. While in the extraoral scan groups, in desktop scanner group, the mean angular deviation, platform 3D deviation, apical 3D deviation, and vertical deviation were 2.6°, 0.1 mm, 1.1 mm, and 1.1 mm, respectively. In the CBCT scan group, the mean angular deviation, 3D platform deviation, 3D apical deviation, and vertical deviation were 3.5°, 1.3 mm, 1.6 mm, and 1.7 mm, respectively.

A meta-analysis of accuracy revealed an average error of about 1 mm at the entry point and about 1.3 mm at the apex. Furthermore, results by Kiatkroekkrai *et al.*, concluded that, in the intraoral scan group, the average angle deviation, platform 3D deviation, and apical 3D deviation were 2.41 ± 1.47°, 0.87 ± 0.49 mm, and 1.10 ± 0.53 mm, respectively. In the extraoral scan group, the average angular deviation, platform 3D deviation, and apical 3D deviation was 3.23 ± 2.09°, 1.01 ± 0.56 mm, and 1.38 ± 0.68 mm,

Table 2: Descriptive statistics and results of Kruskal-Wallis test for comparison between horizontal deviation (mm) in the three groups

Level	CBCT scan (n = 21)		IOS scan (n = 21)		Desktop scanner (n = 21)		p-value	Effect size (Eta squared)
	Median (Range)	Mean (SD)	Median (Range)	Mean (SD)	Median (Range)	Mean (SD)		
Coronal	1.5 (0.2–2.3)	1.34 (0.73)	0.7 (0.25–1.4)	0.71 (0.34)	0.88 (0.25–2.6)	0.99 (0.69)	0.054	0.140
Apical	1.6 (1.05–2.35)^{A}	1.66 (0.53)	0.95 (0.5–2.9)^{B}	1.17 (0.73)	0.95 (0.35–3.45)^{B}	1.15 (0.92)	0.025*	0.066

Significant at p ≤ 0.05, Different superscripts in the same row indicate statistically significant difference between groups.

Table 3: Descriptive statistics and results of Kruskal-Wallis test for comparison between vertical deviation (mm) in the three groups

CBCT scan (n = 21)		IOS scan (n = 21)		Desktop scanner (n = 21)		p-value	Effect size (Eta squared)
Median (Range)	Mean (SD)	Median (Range)	Mean (SD)	Median (Range)	Mean (SD)		
1.7 (0.2-3.9)^{A}	1.74 (1.23)	0.6 (0.1-1)^{B}	0.68 (0.29)	1.2 (0.1-1.8)^{A}	1.16 (0.67)	0.029*	0.254

*Significant at p ≤ 0.05, different superscripts in the same row indicate statistically significant difference between groups.

respectively. In this study, they only compare between intraoral group and the laboratory. Scanner group, the increased mean of angular deviation in this present study in comparison with this study may be due to different IOS and laboratory, scanner type, and single edentulous sites, while the sample size was the same as this present study [12], [17].

In this study, CBCT cast scan is slightly less accurate than optical scanner cast scan, but is considered to lie within a clinically acceptable margin of error and should therefore not affect the clinical applications of this digital process. Becker *et al*. stated that, even if the scanner's precision is lower than that of the reference desktop scanner, it is still clinically acceptable. Emara *et al*., who found the tested CBCT scanner, showed high precision and validity. To avoid additional acquisition costs for clinicians, those who already have a CBCT device with a digitization protocol do not need to purchase an optical scanner to digitize the models [18].

On the contrary Lin *et al*., concluded that surgical guides fabricated from CBCT-scanned casts have been shown to be less accurate than those fabricated from optically scanned casts [10].

This an *in vivo* study as *in vitro* study might be an underestimate of error and overestimate of accuracy due to the lack of limitations, leading to confounding factors, such as limited mouth opening, saliva, bleeding, mucosal resilience, and bone density. Clinical factors, such as patients' intraoral condition, can also affect the implant deviation [9].

In this present study, the deviations that were investigated are generated from the cumulative sum of all errors throughout the "computer-aided implant placement" cascade; they include CBCT imaging (acquisition and reliability); software planning (conversion, segmentation, volume rendering, and manual removal of artifacts); guide manufacturing (simulation software or method before production, precision of the Stereolithographic machine, production and quality control, rigidity, and physical properties of the material used, placement method); and proper guide positioning in the mouth.

Conclusion

Within the limitations of this study:

There was no statistically significance difference between intraoral scanner, CBCT cast scan and desktop scanning on implant deviation was observed. Although IOS shows better accuracy and least mean angular deviation.

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