Received: 1 December 2020 | Revised: 26 February 2021 | Accepted: 22 March 2021

DOI: 10.1111/cid.12998

ORIGINAL ARTICLE

WILEY

Accuracy of static computer-assisted implant placement in long span edentulous area by novice implant clinicians: A cross-sectional in vitro study comparing fully-guided, pilot-guided, and freehand implant placement protocols

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Funding information
ITI Research Grant, Grant/Award Number: 1335_2018; Kernot Early Career Researcher Award

Abstract

Background: To ensure accurate implant placement, surgical guides are used to control the steps of implant placement surgery.

Purpose: Evaluation of the accuracy of implant placement in long span edentulous area by novice implant clinicians according to fully-guided (FG), pilot-guided (PG), and freehand (FH) placement protocols.

Materials and methods: Maxillary surgical models with four missing teeth from the right first canine to the first molar were produced by 3-dimensional printing. Fourteen clinicians new to implant dentistry participated in the study, and each one of them inserted one canine and one molar implant for every implant placement protocol. All implant placement steps were completed in phantom heads to simulate the clinical situation. To evaluate the accuracy, the implant vertical, horizontal platform, horizontal apex, angle, and interimplant distance deviations from the planned positions were calculated.

Results: With the exception of vertical deviation, the FG placement was clearly more accurate than the PG and FH placements for all the variables for canine and molar implants. The PG placement was significantly more accurate than the FH placement for the horizontal platform and apex deviations, and interimplant distance deviation. The FG placement did not show a significant impact of the location of the implant, or the horizontal deviations of the platform or the apex. The PG and FH placements showed increased deviation at the canine implant than the molar implant, and at the apex of the implants than the platform of the implants.

Conclusions: Within the limitations of this in vitro study, novice clinicians achieved a significantly more accurate implant position with FG placement, followed by PG and FH placements respectively. Therefore, a form of guided surgery is beneficial for novice clinicians.

KEYWORDS
3-dimensional printing, computer-guided surgery, deviation, surgical guides

1 | INTRODUCTION

It is widely accepted that implants must be placed in an ideal position necessary for functional, aesthetic, and healthy implant restoration and peri-implant tissues.[1,2] Poorly placed implants may violate vital anatomic structure, are associated with increased marginal bone loss,[1-3] are more difficult to restore,[4] and influence the restoration emergence and appearance.[1-3,5] Therefore, any clinician practicing implant dentistry should follow an accurate approach for ideal implant placement. As the field of implant dentistry is rapidly growing, many clinicians aim to increase their scope of practice by including implant treatment. One of the challenges encountered by clinicians new to implant dentistry is determining and controlling implant placement. The steep learning curve associated with implant dentistry may influence implant placement and can be responsible for a greater failure rate of implants placed by novice clinicians.[6-10] As a result, continuing professional development courses and postgraduate training programs are required to ensure adequate training for clinicians new to implant dentistry.

Surgical guides were frequently used to control all the steps of implant placement surgery, including drilling location and angulation, and final implant location. Subsequently, they are necessary tools in the hands of novice clinicians. With the development of 3-dimensional imaging, scanning and digital design technologies, static computer-assisted implant placement (sCAIP) was proposed to control implant placement surgery.[11-13] sCAIP involves using a digitally-designed surgical guide to precisely control osteotomy preparation and subsequent implant placement. This approach has been shown to increase the accuracy of implant placement,[8,14,15] reduce the necessity of invasive adjunctive procedures and bone augmentation, and reduce the patient discomfort.[16-19] Currently, there are two variations for sCAIP: fully-guided (FG) and pilot-guided (PG) placements.[5,7] The FG placement controls all the drilling, tapping, and implant placement by the surgical guide. Guided surgery requires dedicated licensed software and special surgical tools, which may increase the cost of sCAIP by about 10–30% of the implant treatment.[14,20,21] Alternatively, the PG placement is an abbreviated form of sCAIP that only guides the pilot drill. Frequently, it uses an open source software and does not require a special surgical kit. As a result, the PG placement is generally more economical than the FG placement.

While there are preliminary data indicating superior accuracy of the FG placement over PG placement,[5,22] the clinical relevance of this difference is yet to be determined. In addition, there is limited information on how beneficial the FG placement is in the hands of novice clinicians, and there is a pressing need to generate recommendations on the use of sCAIP by clinicians new to implant dentistry. This is important with increased edentulous area span, which creates extra challenges on clinicians with minimal surgical experience. Therefore, this study aimed to investigate the accuracy of implant placement by novice implant clinicians in a long span edentulous area by FG, PG and FH placement protocols. The hypothesis is there is no difference in the accuracy of implant placement by the different surgical protocols in the hands of novice clinicians in the field of implant dentistry.

What is known

- Static computer-assisted implant placement (sCAIP), in the form of fully-guided (FG) and pilot-guided (PG) placements, has been shown to be more accurate than freehand (FH) implant placement.

What this study adds

- The present study showed that a form of sCAIP, FG, or PG, allowed for more accurate implant placement in long span edentulous area by novice implant clinicians.
- FG implant placement was most accurate method of implant placement, and was not affected by the location of the placed implant.

2 | MATERIALS AND METHODS

This cross-sectional in vitro study evaluated the accuracy of implant placement in long span edentulous area via FG, PG and FH placement protocols by novice implant clinicians. The accuracy of placed implants was evaluated by measuring the implant vertical, horizontal platform, horizontal apex, angle, and interimplant distance deviations from the planned implant positions. The study was conducted in the preclinical training laboratory of Melbourne Dental School, Melbourne University, in June 2019. Ethics clearance was granted by the University of Melbourne Human Research Ethics Committee (1851406.1). This study followed the STROBE Statement Guidelines for cross-sectional studies, and the CRIS Guidelines for in vitro studies. The number of participants was determined by power calculation using G*Power software (version 3.1.9.2; University of Dusseldorf, Dusseldorf, Germany). According to the reported difference between the different placement protocols from the earlier studies,[5,7-9,11,12,15] and by applying 80% statistical power and 5% significance level, at least 11 participants were needed.

2.1 | Participants

Fourteen specializing clinicians with a minimum of 3 years of general practice experience were invited to participate in the study. The participating clinicians were new to the field of implant dentistry and were enrolled in formal postgraduate training involving implant dentistry at Melbourne Dental School, Melbourne University. Prior to participating in the study, the clinicians covered the basics of restorative and surgical aspects of implant dentistry, such as the principles of implant planning and placement.

2.2 | Surgical models and surgical guides fabrication

A maxillary standard training model (Nissin Dental Products Inc., Kyoto, Japan) was used to design the surgical models for implant placement. Initially, the training model with a complete set of intact teeth was scanned by a laboratory scanner (Identica T300, Medit Identica, DT Technologies, Davenport, IA) to generate a virtual model with intact teeth morphology for implant planning. The right canine, first premolar, second premolar and first molar were removed from the training model along with their tissue formers. The ridge of the model was smoothed to simulate a healed bone ridge with crest width of 6.5 mm at the canine region and 8.0 mm at the molar region. The modified model was scanned to generate a virtual model with the missing teeth. Subsequently, this virtual model was used to produce a total of three surgical models for each clinician by a 3-dimensional printer (ProJet, 3510 DP Pro, 3D Systems, Rock Hill, SC) (Figure 1(A)). To increase the clinical relevance of the experiment, the surgical models were attached to training phantom heads with an opposing intact mandibular arch.

All the planned implants were bone level Straumann implants of 4.1 mm diameter and 10 mm length. No guides were produced for the FH placement. For the FG protocol, the virtual model with the missing teeth was merged with the virtual intact model by a commercial software (coDiagnostiX, Dental Wings, Montreal, Canada). This was followed by placing virtual implants in the canine and the first molar sites in the most ideal position as determined by the teeth morphology of the intact model. Subsequently, a virtual whole arch surgical guide was designed and produced by a commercial five-axis milling unit (DWX-51D, Roland, Sydney, Australia) to produce a total of 14 surgical guides (Figure 1(B)). Two metal sleeves of 5 mm diameter (Straumann AG, Basel, Switzerland) were attached in each guide at the sites of implant placement. For the PG placement, an open source software (Blue Sky Bio, Grayslake, IL) that can design surgical guides for pilot drilling was used. Similar steps were followed to the FG placement, with the exception that the software designed surgical guide with holes to accept only pilot drilling sleeves at the location of the implants. A total of 14 PG surgical guides were produced by a 3-dimensional printer (ProJet, 3510 DP Pro, 3D Systems). Two pilot drilling sleeves of 2.2 mm internal diameter were inserted within the holes of the guides (Figure 1(C)). After the virtual implant planning of the FG and PG placements, the STL file of the virtual model with the planned implants was generated. This model with the virtual implants served as a master model to measure the deviations of all the placed implants by every placement protocol.

For the FG placement, all the steps and sequence of tools were provided by the commercial software and were followed for each implant placement. This involved pilot drilling, sequential drilling, tapping, and implant placement. The PG placement only allowed for pilot drilling through the guide. The rest of the steps were completed freehand. All the participants were requested to insert the implants according to the FH placement first, followed by the PG and FG placements. This ensured the clinicians did not practice placing the implants with a guide prior to the FH implant placement.

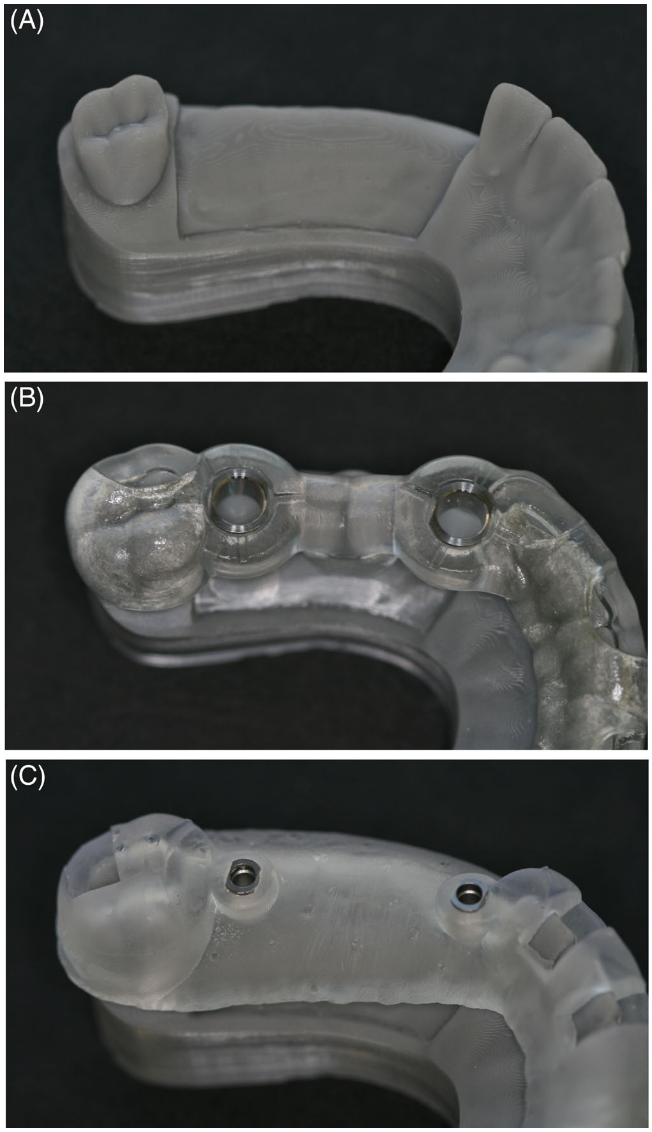

FIGURE 1 Occlusal view of the surgical model used for implant placements. (A) For the freehand (FH) placement no surgical guide was used. (B) A surgical guide of the fully-guided (FG) placement with the wide metal Straumann sleeve. The wide sleeve accepts different cylinders that control all the drills and the implant. (C) A surgical guide of the pilot-guided (PG) placement that has narrow metal sleeves. The narrow sleeve only accepts the pilot drill

2.3 | Accuracy evaluation

For accuracy evaluation, laboratory scan bodies (ZFX Scan body, ZFX Dental, Zimmer Biomet, Warsaw, IN) were attached to the inserted implants in each surgical model. The models with the attached scan bodies were scanned by the laboratory surface scanner to produce a virtual surgical model with the placed implants. The implants were

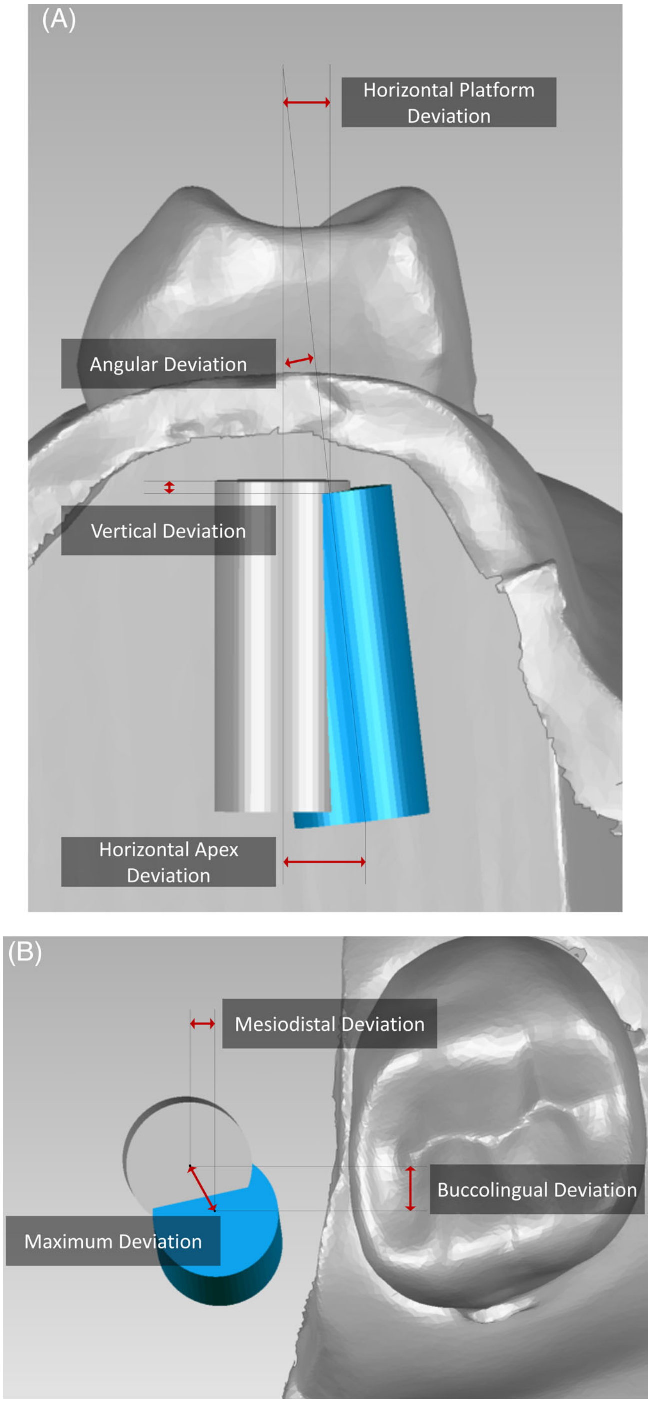

FIGURE 2 Virtual images of superimposed implants illustrating the measured variables. (A) Measurement of vertical, horizontal platform, horizontal apex, and angle deviations. (B) Measurement of maximum, mesiodistal, and buccolingual horizontal deviations

converted to a cylindrical parametric shape to facilitate the measurements and eliminate the effect of implant threads. Two forms of accuracy evaluation were implemented. At first, the position of the placed implant was compared against the position of the planned implant at the virtual master model. This was completed by superimposing the virtual surgical model against the virtual master model by a 3-dimensional rendering software (Geomagic Studio, Raindrop, Geomagic Inc., Research Triangle Park, NC). Since the teeth were stable landmarks of all the models, they were used for the superimposition. The superimposition consisted of point-to-point registration of widely distributed common points followed by automated registration to obtain the best fit between the two virtual models. Eventually, each placed implant was spatially related to the planned implant, which allowed for the measurement of the deviation. The deviation of implant position was measured by calculating the vertical deviation, horizontal platform deviation, horizontal apex deviation, and implant angle deviation (Figure 2). The vertical deviation was measured by calculating the discrepancy along the long axis of the planned implant at the center of the platform (Figure 2(A)). In addition to the magnitude of the deviation, the direction of the deviation was determined. The horizontal deviations were measured at the platform and the apex of the planned implant. Maximum, buccolingual, and mesiodistal deviations of the horizontal and angle deviations were determined (Figure 2 (B)). The angle deviation was computed by measuring the maximum angle between the long axes of two implants. The second form of accuracy evaluation involved measuring the interimplant distance at the platform and apex levels at the surgical model and comparing it to the interimplant distance of the master model. Subsequently, the interimplant distance deviation was calculated for every placement protocol.

2.4 | Statistics

For each variable, the mean and standard deviation (SD) were measured. For statistical evaluation, the magnitude of the variables was used for the evaluation. After confirming the normality of the data, the one-way analysis of variance test was applied to determine the statistical difference among the groups. In the case of the presence of a significance difference, the Tukey post hoc test was applied. In addition, for each variable, the difference between the canine and molar implants was determined. All the statistical tests were conducted via the SPSS software package (SPSS for Windows, version 23, SPSS Inc., Chicago, IL). The level of significance was set at 0.05. The horizontal mesiodistal and buccolingual platform and apex deviations of each implant of every placement protocol were plotted in 3-dimensional scatter diagrams.

3 | RESULTS

For all the comparisons, the FG implants showed greater similarity to the virtual master model implants than PG and FH implants (Table 1). Likewise, the deviations of the interimplant distances were less between FG implants than PG and FH implants (Table 2). The FH implants appeared to have the greatest deviations and variations in most of the variables.

For the maximum horizontal platform deviation (Figure 3), the FG and PG implants were similar regardless of the implant location, and both were significantly more accurate than FH implants ($p < 0.001$).

TABLE 1 Summary of implant horizontal, vertical and angle magnitude deviations

	Maximum horizontal implant platform deviation						
	Canine implant			Molar implant			p-Values between canine and molar implants
	FG	PG	FH	FG	PG	FH	
Mean (mm)	0.46	0.53	2.13	0.39	0.34	1.58	FG = 0.43
SD (mm)	0.23	0.26	0.71	0.24	0.24	0.69	PG = 0.05
Maximum (mm)	0.89	0.98	3.51	0.75	0.83	3.09	FH = 0.05
Minimum (mm)	0.11	0.21	1.11	0.01	0.02	0.55	
p-Values	All groups <0.001			All groups <0.001			
	FG vs PG = 0.91			FG vs PG = 0.96			
	FG vs FH < 0.001			FG vs FH < 0.001			
	PG vs FH < 0.001			PG vs FH < 0.001			
	Maximum horizontal implant apex deviation						
	Canine implant			**Molar implant**			***p*-Values between canine and molar implants**
	FG	**PG**	**FH**	**FG**	**PG**	**FH**	
Mean (mm)	0.62	1.49	3.29	0.71	0.76	1.88	FG = 0.57
SD (mm)	0.42	0.54	1.34	0.41	0.52	0.72	PG < 0.001
Maximum (mm)	1.46	2.27	6.58	1.53	2.16	3.37	FH < 0.001
Minimum (mm)	0.12	0.16	0.88	0.21	0.22	0.70	
p-Values	All groups <0.001			All groups <0.001			
	FG vs PG = 0.03			FG vs PG = 0.97			
	FG vs FH < 0.001			FG vs FH < 0.001			
	PG vs FH < 0.001			PG vs FH < 0.001			
	Vertical implant deviation						
	Canine implant			**Molar implant**			***p*-Values between canine and molar implants**
	FG	**PG**	**FH**	**FG**	**PG**	**FH**	
Mean (mm)	0.31	0.61	0.62	0.37	0.51	0.39	FG = 0.58
SD (mm)	0.26	0.35	0.39	0.30	0.47	0.20	PG = 0.54
Maximum (mm)	0.84	1.18	1.5	1.08	1.77	0.69	FH = 0.06
Minimum (mm)	0.03	0.11	0.06	0.03	0.05	0.07	
p-Values	All groups = 0.03			All groups = 0.52			
	FG vs PG = 0.03						
	FG vs FH = 0.02						
	PG vs FH = 0.92						
	Maximum implant angle deviation						
	Canine implant			**Molar implant**			***p*-Values between canine and molar implants**
	FG	**PG**	**FH**	**FG**	**PG**	**FH**	
Mean (°)	1.25	6.76	6.65	1.59	4.00	3.68	FG = 0.38
SD (°)	0.84	2.49	3.58	1.13	2.62	2.43	PG = 0.01
Maximum (°)	2.66	9.65	15.18	4.2	9.07	8.72	FH = 0.02
Minimum (°)	0.3	1.6	2.69	0.17	0.76	0.67	
p-Values	All groups <0.001			All groups = 0.01			
	FG vs PG < 0.001			FG vs PG = 0.02			
	FG vs FH < 0.001			FG vs FH = 0.04			
	PG vs FH = 0.99			PG vs FH = 0.92			

Abbreviations: FG, fully-guided; FH, freehand; PG, pilot-guided.

TABLE 2 Interimplant distance deviation between the platforms and apices of the implants

	Platforms deviation			Apices deviation			*p*-Values between interimplant distances at the platforms and the apices
	FG	PG	FH	FG	PG	FH	
Mean (mm)	0.21	0.40	1.50	0.37	1.27	2.33	FG = 0.09
SD (mm)	0.19	0.24	1.41	0.26	0.50	1.63	PG < 0.001
Maximum (mm)	0.69	0.83	4.39	0.89	2.33	5.84	FH = 0.16
Minimum (mm)	0.00	0.03	0.09	0.01	0.68	0.35	
p-Values	All groups <0.001			All groups <0.001			
	FG vs PG = 0.83			FG vs PG = 0.02			
	FG vs FH < 0.001			FG vs FH < 0.001			
	PG vs FH < 0.001			PG vs FH = 0.02			

Abbreviations: FG, fully-guided; FH, freehand; PG, pilot-guided.

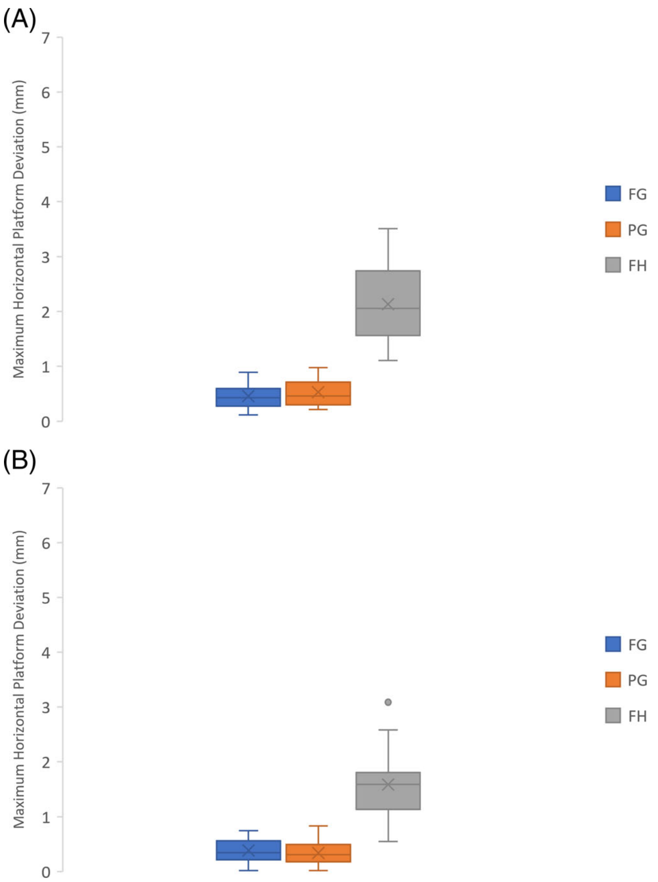

FIGURE 3 Box-and-whisker plot diagrams illustrating the distribution of maximum horizontal platform deviations of each placement protocol. (A) Canine implants. (B) Molar implants

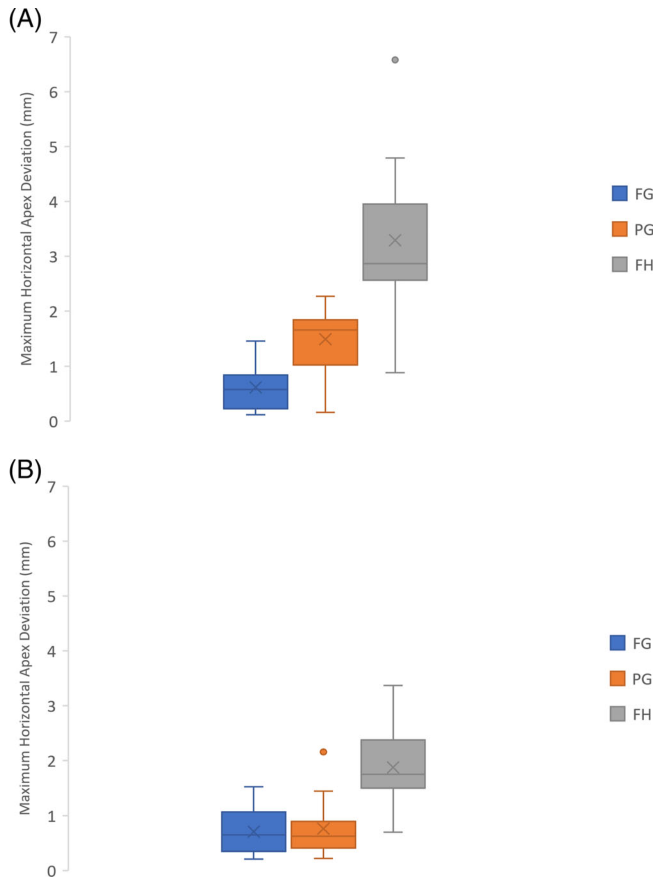

FIGURE 4 Box-and-whisker plot diagrams illustrating the distribution of maximum horizontal apex deviations of each placement protocol. (A) Canine implants. (B) Molar implants

The canine and molar implants' maximum horizontal platform deviations were similar for FG (p = 0.43), PG (p = 0.05), and FH (p = 0.05) placements. For the maximum horizontal apex deviation (Figure 4), all the placement protocols were different for the canine implants, where the FG placement was most superior (0.45 mm, 95% CI: 0.34–0.58 mm), followed by PG (0.53 mm, 95% CI: 0.39–0.67 mm) and FH (2.13 mm, 95% CI: 1.76–2.50 mm) placements (p < 0.001). The FG (0.39 mm, 95% CI: 0.26–0.52 mm) and PG (0.34 mm, 95% CI: 0.21–0.47 mm) implants' maximum horizontal apex deviations were similar for the molar implants (p = 0.97) and both were significantly superior to FH implants (1.58 mm, 95% CI: 1.22–1.94 mm) (p < 0.001). The FG implants had similar horizontal apex deviation for the canine

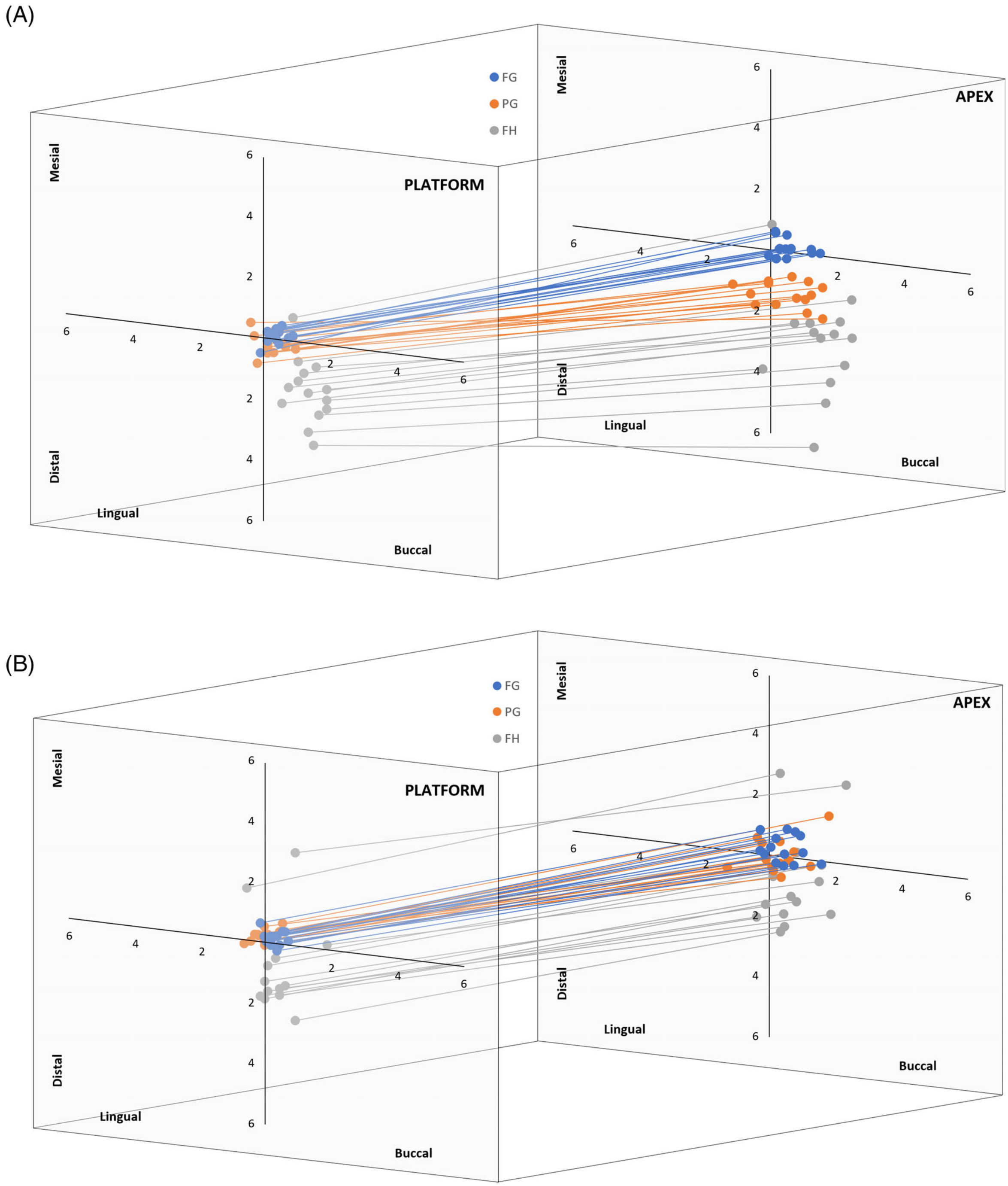

FIGURE 5 3-Dimensional scatter diagrams outlining the mesiodistal and buccolingual deviations of the platform and apex of each implant. (A) Canine implants. (B) Molar implants

(0.62 mm, 95% CI: 0.40–0.84 mm) and molar (0.71 mm, 95% CI: 0.50–0.92 mm) implants (p = 0.57). However, the PG and FH implants showed significantly greater horizontal apex deviations for canine implants (PG: 1.49 mm, 95% CI: 1.21–1.77 mm; FH: 3.29 mm, 95% CI: 2.59–3.99 mm) than molar implants (PG: 0.79 mm, 95% CI: 0.49–1.03 mm; FH: 1.88 mm, 95% CI: 1.50–2.26 mm) ($p < 0.001$).

Figure 5(A) showed that the FG and PG horizontal platforms of canine implants were centered around the middle of the graph, while the FH implants clearly had more deviations and were skewed toward the distobuccal aspect from the planned implant. At the apical region, the FG implants remained at the center of the graph with minimal skewing toward the buccal aspect, while the PG implants deviated toward the distobuccal aspect. On the other hand, the FH implants had accentuated deviations and were skewed toward the distobuccal aspect. For the molar implants (Figure 5(B)), there are indications that the FG and PG implant platforms were generally close to the middle of the graph, while the FH implant platforms were distributed along the mesiodistal direction with more skewing toward the buccal aspect.

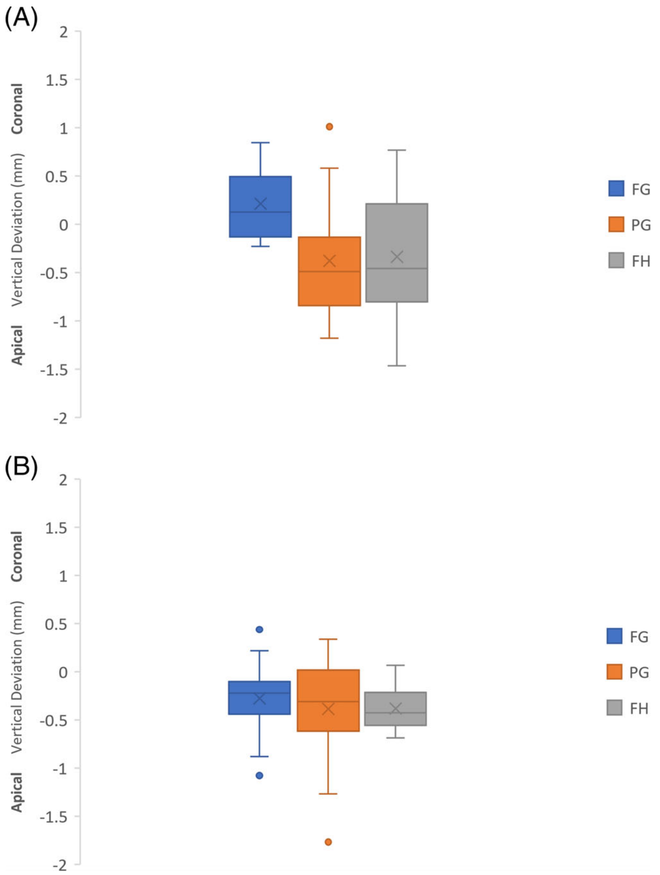

FIGURE 6 Box-and-whisker plot diagrams illustrating the distribution of vertical deviation of each placement protocol. (A) Canine implants. (B) Molar implants

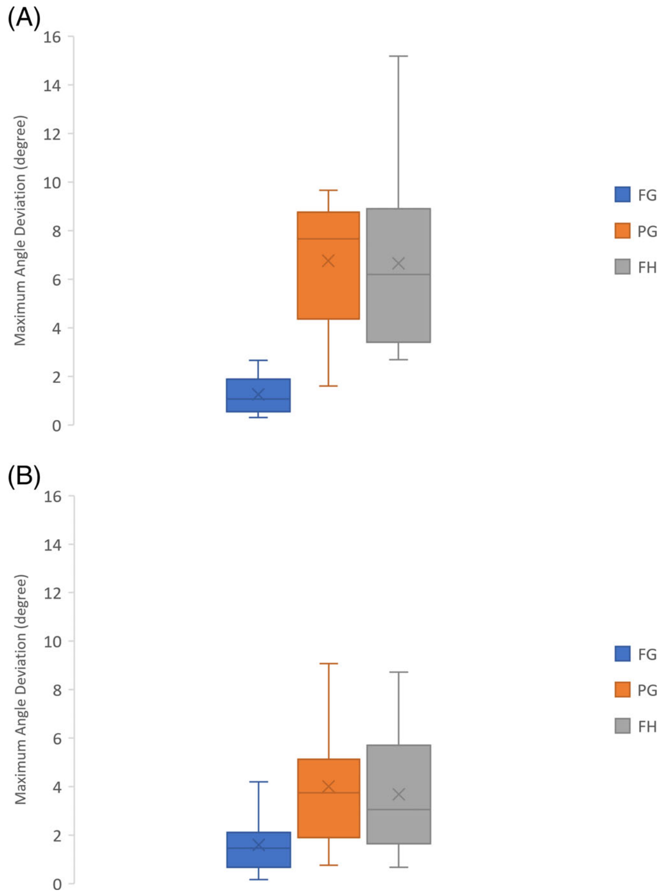

FIGURE 7 Box-and-whisker plot diagrams illustrating the distribution of maximum angle deviation of each placement protocol. (A) Canine implants. (B) Molar implants

At the apex, greater variations were observed for the FG and PG implants, but still centered at the middle of the graphs. The FG implants showed minor deviation, mainly in the mesiobuccal aspect, while the PG implants showed wider distribution than FG implants. The FH implants suffered from more deviation in the buccolingual and the mesiodistal directions.

Comparing the canine and molar implant horizontal deviations, the FG implants seemed to be minimally affected by altering the implant location and showed similar accuracy pattern for the platform and apex of the implants. On the other hand, the PG implant apices suffered from greater deviation in the canine region than the molar region. The FH placement generally showed greater deviations for the canine implants than molar implants at the platforms and apices.

For the canine implants, the vertical deviation of the FG (0.31 mm, 95% CI: 0.17–0.45 mm) implants was significantly less than the PG (0.61 mm, 95% CI: 0.43–0.79 mm) and FH (0.62 mm, 95% CI: 0.42–0.82 mm) implants (p = 0.03). The PG and FH implants exhibited similar vertical deviations (p = 0.92). The vertical deviation of FG implants was closer to 0 and skewed to a position that is occlusal to the planned implant (Figure 6). The PG and FH implants had greater variation in the vertical position and were generally deeper than the FG implants. For the molar implants, the vertical deviations of FG implants (0.37 mm, 95% CI: 0.21–0.53 mm) were similar to FH implants (0.39 mm, 95% CI: 0.29–0.49 mm), and both had less variation than PG implants (0.51 mm, 95% CI: 0.26–0.76 mm). However, the difference among them was insignificant (p = 0.52). The molar implants of all the placement protocols were generally deeper than the planned implants. The difference between the canine and molar implants of each placement protocol was insignificant.

Significantly less maximum angle deviation was observed for the FG implants for the canine (p < 0.001) and molar (p = 0.01) implants (canine: 1.25°, 95% CI: 0.81–1.69°; molar: 1.59°, 95% CI: 0.99–2.18°) than PG (canine: 6.76°, 95% CI: 5.46–8.06°; molar: 4.00°, 95% CI: 2.63–5.37°) and FH (canine: 6.65°, 95% CI: 4.77–8.53°; molar: 3.68°, 95% CI: 2.41–4.96°) implants, which were generally similar (Figure 7). The FG implants showed no difference between the angle deviations of the canine and molar implants (p = 0.38), while the molar implant angle deviations were significantly less than the canine implant angle deviations for PG (p = 0.01) and FH (p = 0.02).

The interimplant distance deviations were the least for FG implants, followed by PG and FH implants (Figure 8). This was observed between the platforms and the apices. At the platform levels, the FG (0.21 mm, 95% CI: 0.11–0.31 mm) and PG (0.40 mm, 95% CI: 0.27–0.53 mm) implants were similar (p = 0.83), and were

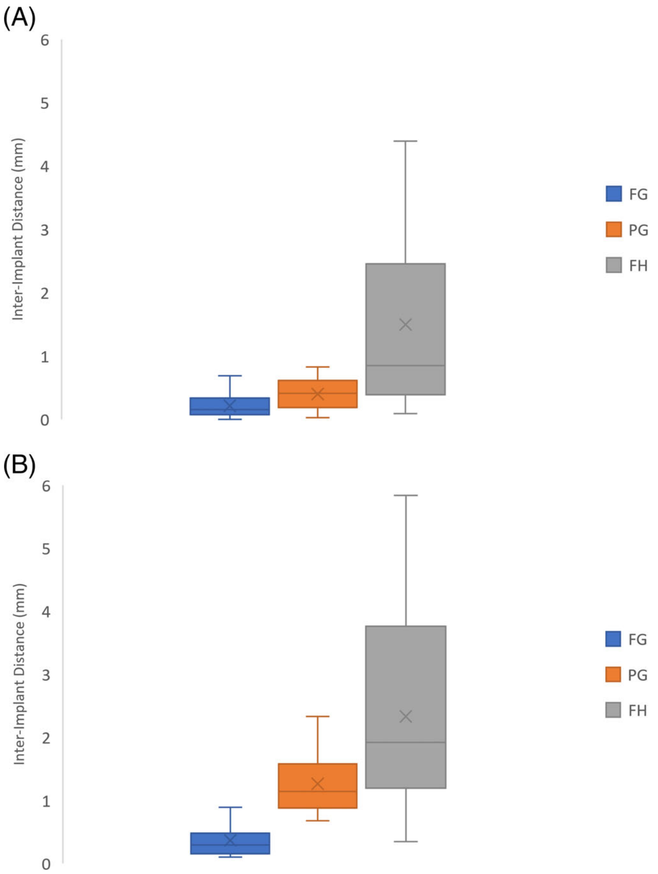

FIGURE 8 Box-and-whisker plot diagrams illustrating the distribution of the interimplant distance deviations of each placement protocol. (A) Interimplant distance between the platforms. (B) Interimplant distance between the apices

significantly more accurate than FH (1.50 mm, 95% CI: 0.76–2.24 mm) ($p < 0.001$). At the apices, the FG implants (0.37 mm, 95% CI: 0.23–0.51 mm) were significantly more accurate than PG (1.27 mm, 95% CI: 1.01–1.53 mm) ($p = 0.02$) and FH (2.33 mm, 95% CI: 1.48–3.18 mm) implants ($p < 0.001$). In addition, the PG implants were significantly more accurate than FH implants ($p = 0.02$). The implants of all the placement protocols showed more deterioration between the apices than between the platforms, however, the significant difference was observed only for the PG implants ($p < 0.001$).

4 | DISCUSSION

In the present study, the virtual implants of the master model were used to evaluate the horizontal, vertical and angle deviations of the placed implants within the surgical models. The interimplant distance outlined the relation between the placed implants, and was compared to the interimplant distance of the planned implants, regardless of the fit of guide. Despite the deviations of all placement protocols, the study confirms the advantage of the FG placement over PG and FH placements for every evaluated parameter in the hands of novice implant clinicians. The study corroborates the outcomes of earlier studies that indicated superiority of FG placement over other implant placement protocols.[5,9,12,23-26] In the present study, the accuracy of FG placement over the PG and FH placements is evident from (1) less magnitude of deviations and variations, (2) similarity in accuracies of the apex and platform of the implants, (3) similarity in accuracies of canine and molar implants, and (4) minimal interimplant distance deviations. The superior outcome of the FG placement can be attributed to controlling all the steps of the surgery and the implant placement by precision sleeves and drills.[5,9,12,13,23-26] Therefore, the hypothesis that there is no difference in the accuracy of the different placement protocols by novice clinicians was rejected, and there is a clear benefit of a form of guided surgery, with FG placement being considerably more accurate than PG placement.

The observed accuracy of FG placement in the present study is similar to what has been reported by other studies by experienced clinicians.[5,9,12,23-26] This reinforces that FG placement allows novice clinicians to insert implants to a similar level of accuracy to experienced clinicians. While experienced clinicians were more precise in placing implants without surgical guides than novice clinicians,[8] placing implants via FG placement was found by numerous laboratory studies to eliminate the differences between experienced and novice clinicians for single implants[7,15] and multiple adjacent implants.[8] A similar outcome was observed by a clinical study on novice clinicians[9] that compared FG and FH placements and revealed the mean deviation in implant placement was significantly less for FG than FH placements. In addition, the FG placement was shown to frequently be more superior than PG implant placements, especially in the hands of novice clinicians.[9] A study conducted on final year dental students revealed that the FG implant placement was more accurate than the PG placement.[7] Further, Marei et al found PG placement accuracy differed based on experience, where experienced clinicians had more accurate outcomes than novice clinicians. They attributed their findings to the inability of clinicians to fully control all the steps of surgery.[10] Interestingly, in the present study, the canine implants showed noticeable angle and horizontal deviation when placed by FH and PG placements. The inferior outcome of the PG and FH implants in the canine region can be due to the location in the corner in the arch and the lack of adjacent teeth with similar long axis orientation to the canine implant. All of this makes it difficult to control and orient the drill by novice clinicians. Such potential deviation is alarming to the novice clinicians and outlines the difficulties of eyeballing the drilling procedure. Eventually, this can lead to serious apical deviations that can influence the biological and aesthetic outcomes. In a clinical study, Younes et al, reported that 19.2% of the FH implants were restored with cement-retained restorations and 4.2% of PG implants were restored with cement-retained restorations,[5] as opposed to 100% of FG implants restored with screw-retained restorations, which illustrates the clinical impact of the deviation from each of placement protocol. In the present study, this is further accentuated by the long span edentulous area, which has been shown to increase the deviations of the placed implants in comparison to placing implants in single tooth sites bound by neighboring teeth.[27] Therefore, while the FG placement is associated with increased costs and more planning time, it is worthy to be considered by novice clinicians.[20,21,25] Further, FG placement should be used as a tool to help clinicians that are gaining experience when the location of the implant is more difficult.

The deviation of FG placement in the present study is comparable to the range reported by numerous studies that reported platform deviation of 0.4–1.2 mm, apex deviation of 0.7–1.5 mm, vertical deviation of 0.1–0.2 mm, and angle deviation of 1.4–4.2°.[5,9,23-26] The inevitable FG placement deviation has been attributed to the numerous steps and the accumulated deviations involved in FG planning and implant placement.[11,13,15] Steps such as CBCT scanning, 3-dimensional image reconstruction,[28] guide fabrication method, fit of the guide on the teeth, the nature of supporting tissues,[12,26] tolerance of drilling components, bone quality,[26] and the implant placement procedure.[12] Clinically, the FG placement deviation is further increased by patient movement, limited visibility, limited access, and the presence of saliva and blood.[11,29] As a result, a safety zone of 1–2 mm horizontally and vertically, and up to 5° angle deviation are necessary to incorporate whenever an FG implant placement is considered.[11,12,29,30] Also, it is recommended to frequently evaluate the osteotomy at different stages of FG implant placement.[12,25,31]

The considerably greater deviation with FH placement in the present study is in accordance with several studies,[5,30,32] and can be related to the lack of adjacent teeth that can dictate the drilling, and the lack of any guide that can provide indication on where to place the implant. Once the presentation becomes more complex, and more implants are involved, the FH implant placement will further be challenged.[22,27] While the PG placement may mark the drilling entry for the osteotomy, the rest of the drilling is completed freehand, and is prone to manual handling deviation. The deviation is accentuated toward the apex of the osteotomy, which is likely due to the excursion of the drilling instrument tip,[5,10,24,33] or even the deviation during placing the implant in the osteotomy without the guide.[34,35] This may explain the findings of this study and numerous studies that PG placement is associated by double the deviation of FG placement.[5,22]

On the other hand, the PG placement is advantageous in being more accurate than the FH placement in relation to the horizontal platform (by four times), and the horizontal apex (by two times). This supports the merits of PG placement in the hands of novice. Despite that the PG placement does not control all drilling steps, it is a viable tool for novice clinicians, as it ensures greater security during the surgery. Specifically, it allows for relatively accurate implant entry and platform placement to a similar level to the FG placement. Consequently, it was shown by a clinical study to reduce the deviation from the planned restoration compared with the FH placement.[5] The use of PG placement in clinical practice has multiple merits, such as being more economical, involving readily available software, and producing guides by hardware accessible in the clinic.[10] With all these factors taken into consideration, it can be argued that FG and PG placements yield acceptable outcomes, and the necessity of FG placements increase when the bone is limited, or the planned implant is close to neighboring teeth. Despite the superiority of the FG placement over the PG placement, this difference may not be of clinical significance where the surgical site is ideal. Especially that several studies indicated that the method of placement will not necessary affect implant survival or marginal bone loss.[14]

The outcome of this study should be taken with caution, as it is a laboratory study and differs from the clinical set-up. This involves the simulation of natural bone, and actual patient mouth opening, movement, restricted interarch clearance, and the presence of blood and saliva. After comparing laboratory and clinical studies on the accuracy of implant placement, Bover-Ramos et al reported that clinical and cadaver studies showed greater deviations of FG placement than laboratory studies.[11] These deviations had led to the recommendation of maintaining a safety zone, frequent intraoperative evaluation of the osteotomy,[25] and the necessity of sound surgical experience and training prior to using the FG placement. This will allow the clinician to manage the complications if they occur during the procedure.[12-14] In addition, since the study evaluated the accuracy of implant placement by novice clinicians in partially edentulous arch with relatively wide ridge, different presentations require further evaluation and safety zone recommendation. Another limitation of the study is the use of different software and guide manufacturing process for FG and PG protocols. Although this allowed the comparison of a commercial workflow to a simpler open source workflow, it may add to the deviations of the placed implants. The complexity of the FG placement protocol should be taken into consideration when introducing FG placement to novice clinicians. It has been reported that FG placement can be influenced by guide misfit, fracture, and reduced implant primary stability.[12,31] Therefore, more evidences are desirable to relate the advantages of FG placement to measured patient-related and clinician-related benefits that outweigh the extra cost and time involved for FG planning.

5 | CONCLUSIONS

Within the limitations of this in vitro study, it can be concluded that in the hands of novice clinicians within the field of implant dentistry, the guided implant placements were significantly more accurate than FH placement. In addition, the FG placement was significantly more accurate than the PG placement. Whenever a more exacting implant position is required, the FG placement should be considered by the novice clinicians. Since all types of implant placements showed a level of deviation, a safety zone should be always considered.

ACKNOWLEDGMENTS

Both authors acknowledge the technical support of Mr Attila Gergely and the team of Digital Dental Network in designing and manufacturing the guides and the training models. They would also like to thank the team of Straumann Australia for their generous support in providing the surgical kits and training implants. This study has been funded by the ITI Research Grant (1335_2018) and the Kernot Early Career Researcher Award.

CONFLICT OF INTEREST

Both authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

Jaafar Abduo: Concept/design, funding sourcing, data collection, data analysis/interpretation, drafting article, statistics, approval of article. **Douglas Lau**: Design, data interpretation, critical revision and editing of article, approval of article.

DATA AVAILABILITY STATEMENT

The data sets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

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How to cite this article: Abduo J, Lau D. Accuracy of static computer-assisted implant placement in long span edentulous area by novice implant clinicians: A cross-sectional in vitro study comparing fully-guided, pilot-guided, and freehand implant placement protocols. *Clin Implant Dent Relat Res*. 2021;1–12. https://doi.org/10.1111/cid.12998