Accuracy of Static Computer-Assisted Implant Placement in Posterior Edentulous Areas with Different Levels of Tooth-Support by Novice Clinicians

Keywords

3D
Deviation
Single Implant
Surgical Guides
Computer-Guided Surgery

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Received: 22.11.2022
Accepted: 21.03.2023

doi: 10.1922/EJPRD_2494Abduo10

ABSTRACT

Correct implant placement is necessary for satisfactory implant restoration. Therefore, the use of surgical guide is recommended. This study evaluated the accuracy of implant placement in posterior edentulous areas with different levels of tooth-support by novice clinicians according to fully-guided (FG), pilot-guided (PG), and freehand (FH) placement protocols. A mandibular model with missing first molars was designed. On one side, the model had a bound edentulous area (BEA), and on the other side, a free end edentulous area (FEA). Fourteen clinicians new to implant dentistry participated in the study, and each clinician inserted an implant in the BEA and FEA sites for every placement protocol. Angle, vertical and maximum horizontal platform and apex deviations were measured. The FG placement was more accurate than the PG and FH placements. This was significant for BEA angle deviation, BEA and FEA maximum horizontal platform deviations, and BEA maximum horizontal apex deviation. The PG placement was significantly more accurate than the FH placement for BEA and FEA maximum horizontal platform deviations. FG shows significantly greater angle, maximum horizontal platform and maximum horizontal apex deviations at FEA than BEA. This can be attributed to reduced guide support and the possibility of guide displacement during surgery.

INTRODUCTION

Correct implant placement is essential for the biological, mechanical and aesthetic success of implant prosthesis.[1,2] Malpositioned implants may prevent successful implant restoration or even lead to damage to vital structures and adjacent teeth.[1-6] In addition, poorly placed implants are prone to more biological complications such as soft tissue inflammation, peri-implant bone loss and peri-implantitis.[2] Placing implants in an ideal position is a challenging and stressful surgical procedure for clinicians new to implant dentistry, and earlier reports indicated that implants placed by novice clinicians may suffer from greater deviation than implants placed by experienced implant clinicians.[7-11] Establishing surgical implant experience is associated with a steep learning curve, and is thought to cause a greater failure rate of implants placed by novice clinicians.[7-10,12] As a result, it is recommended for novice clinicians to use surgical guides to control implant placement.[7,9,10]

Different forms of implant placement guiding procedures were proposed to ensure predictable implant placement. This can be in the form of laboratory made surgical guides, digitally fabricated static computer-assisted implant surgery (sCAIS) guides or dynamic implant placement. sCAIS is commonly discussed and widely applied due to accessibility of 3D implant planning software, widespread application of scanning technologies, the routine use of CBCT and availability of digital fabrication tools such as 3D printing and milling. sCAIS is based on combining a 3D image of the dental arch with the CBCT data and plan for an ideal implant placement based on the intended prostheses. According to the planned implant(s), a surgical guide is virtually designed and produced by either milling or 3D printing. Several reports confirmed the advantages of sCAIS such as less invasive surgery, a reduced need for grafting, a better aesthetic outcome, and a greater similarity to restorative plan.[1,3,6,7,13-15]

There are 2 popular forms of sCAIS, pilot guided (PG) and fully guided (FG).[1,9] The PG involves guiding the pilot drill only, while the rest of the steps are completed freehand (FH) without the surgical guide. This is advantageous as it does not require alteration of the surgical protocol, uses the same surgical kit, and allows visualizing the rest of the drilling steps. On the other hand, the FG controls all the drilling steps, tapping and the complete implant placement.[3,6,13] However, FG requires a modified surgical protocol and a dedicated surgical kit to ensure the drills and implants are usable with the guide. This involves a surgical kit that is compatible with the surgical guide, longer tools that can drill bone through the guide, and a longer implant mount for implant placement through the guide. As a result, FG is associated with a more complex procedure at an increased cost.[14,16,17] Nevertheless, there is consensus in the clinical and laboratory studies that FG is more accurate than PG in placing the implant closer to the planned implant location.[1,3,5,18,19] In addition, there is encouraging evidence to support that FG placement shortens the duration of implant site preparation.[20] As a result, FG can be attractive to clinicians new to implant dentistry and can be used as a way to reduce the stress associated with implant placement. However, considering the complexity and increased cost of FG over PG implant placement and the different possible clinical scenarios, the following questions are raised: (1) does the accuracy of FG over PG justify the application of a more complex and costly implant placement procedure? And (2) is there an implication of different clinical scenarios on the accuracy and pattern of errors of FG and PG placements? The present study implements a common clinical presentation of a missing mandibular molar tooth, where accurate implant placement is necessary due to closeness to the inferior alveolar nerve and the presence of mandibular concavity. Two common presentations were planned for a single implant in the first mandibular molar region, bounded edentulous area (BEA), and free end edentulous area (FEA). The different presentations provided different support for the surgical guide. Therefore, the aim of this study was to evaluate the accuracy of implant placement by novice implant clinicians in BEA and FEA sites by FG, PG and FH placement protocols. The hypotheses were there is no difference in the accuracy of implant placement by the different surgical protocols in the hands of novice implant clinicians, and there is no difference between BEA and FEA locations within each surgical protocol.

MATERIALS AND METHODS

A total of 14 clinicians enrolled in formal postgraduate training involving implant dentistry at the Melbourne Dental School, Melbourne University, were invited to participate in the study. The participants had at least 3 years of general practice experience, and they were new to the field of implant dentistry. A power calculation with G*Power software (version 3.1.9.2; University of Dusseldorf, Dusseldorf, Germany) was used to confirm the number of participants. With the anticipated difference among the different implant placement protocols as determined by the earlier studies,[3,7] and by applying 80% statistical power and 5% significance level, at least 11 participants were needed for the study. Before the study, the clinicians covered the theoretical principles of implant planning and placement. Ethics clearance was obtained by the Human Research Ethics Committee of the University of Melbourne (1851406.1).

A mandibular training model (Nissin Dental Products Inc., Kyoto, Japan) was modified with the removal of all the molars on the right side and the 1st molar on the left side. The sockets of the removed teeth were sealed with wax and the associated soft tissue formers were removed to simulate exposed bone morphology. The exposed ridges of the models were further trimmed to simulate healed bone ridge with 8 mm crest width. The modified model was scanned by a laboratory scanner (Identica T300, Medit Identica, DT Technologies, Davenport, IA, United States) to generate a virtual surgical model. The virtual model was used to produce three resin surgical models for each clinician by a 3D printer (ProJet, 3510 DP Pro, 3D Systems, Rock Hill, SC, United States) to ensure similarity of all the models (*Figure 1A*). To simulate a clinical set-up, the surgical models were fixed to training phantom heads with an opposing fully dentate maxillary model.

Implant planning for the right and left mandibular first molars was executed by commercial software (coDiagnostiX, Dental Wings, Montreal, Canada). To ensure the implants were planned according to the restorative outcome, a fully dentate mandibular virtual model was superimposed on the virtual surgical model. The planned implants were Straumann bone level implants of 4.1 mm diameter and 10 mm length. The implant positions were determined by the research supervisor. The STL file of the virtual model with the planned implants was extracted to serve as a master model to measure the deviations of the placed implants. The FG protocol planning designed whole arch surgical guides that accepts metal sleeves of 5 mm diameter at the site of each implant (*Figure 1B*). The surgical guide was supported solely by the teeth in the arch. The PG protocol planning followed the same design principles of the FG protocol planning, with the exception of the allocation of pilot drilling sleeves of 2.2 mm internal diameter (*Figure 1C*). The virtual

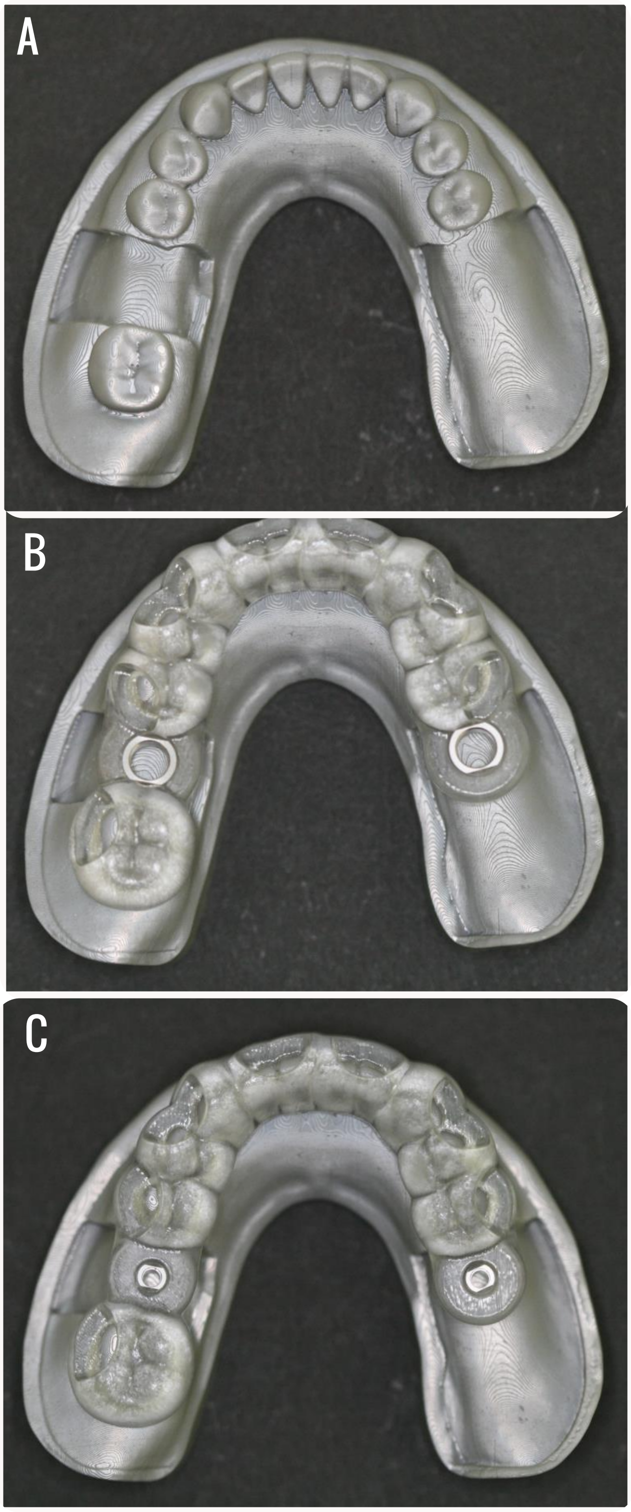

Figure 1: Occlusal view of the surgical model used for implant placements. For the FH (A) no surgical guide was used. A surgical guide of the FG placement with the wide metal Straumann sleeves that accepts different components that control all the drills and the implant (B). A surgical guide of the PG placement that has narrow metal sleeves that only accepts the pilot drill (C). The remaining design features of the FG and PG guides were similar.

surgical guides were imported into the 3D printer to produce a total of 14 surgical guides for FG and PG. Subsequently, the metal sleeves (Straumann AG, Basel, Switzerland) were placed on the corresponding surgical guides. The FH protocol did not involve the fabrication of any surgical guide.

The participating clinicians inserted the implants according to FH placement, followed by PG and FG placements. This sequence was followed to avoid clinicians practicing implant placement within the model prior to the FH placement. The clinicians had access to surgical planning images to assist in orienting the implant drills. Flap elevation was not simulated in the present study. The steps of FG placement and the sequence of tools were provided by coDiagnostix software and were followed for each implant placement. This included pilot drilling, sequential drilling, tapping, and implant placement through the guide. The PG placement only allowed for pilot drilling through the guide, while the rest of the steps were completed freehand. In addition, the vertical positioning of the PG placement was determined by measuring the insertion of each implant drill within the crest of the model. Half the clinicians started at the BEA site, and the other half started at the FEA site, before moving to the other side.

Laboratory scan bodies (ZFX Scan body, ZFX Dental, Zimmer Biomet, Warsaw, IN, United States) were fitted on the inserted implants in each surgical model. With the aid of the laboratory scanner, the models with the attached scan bodies were scanned to generate virtual surgical modes. Prior to scanning, the laboratory scanner was calibrated according to manufacturer instructions. Virtual keys of scan body and implant were superimposed on the scan bodies of the virtual surgical model to establish the location of the placed implants. Parametric shaped cylindrical implants were used to facilitate the measurements and eliminate the effect of implant threads. The virtual master model with the planned implants was superimposed against each surgical model with the placed implants to determine the differences between the implants. The teeth of the models were used as landmarks for the initial superimposition, which was followed by automated best fit alignment of the models by a 3-dimensional rendering software (Geomagic Control X, Raindrop, Geomagic Inc., Research Triangle Park, NC, United States). To ensure consistency, similar set of teeth were used for every superimposition step (facial cusp tips of canines and 2nd premolars). Subsequently, the placed implants were compared against the planned implants by measuring implant angle deviation, vertical deviation, horizontal platform deviation, and horizontal apex deviation. The angle deviation was determined by measuring the maximum angle between the long axes of two implants. The vertical deviation was the discrepancy along the long axis of the planned implant at the center of the platform. Horizontal platform and apex deviations were the horizontal differences between the centre point of the platform and the apex of the implants respectively. For each variable, the magnitude and direction deviation were determined.

The mean and standard deviation (SD) were measured for each variable. After confirming the normality of the data, the one-way analysis of variance test was applied followed by the Tukey *post hoc* test. Further, for each variable, the difference between BEA and FEA was determined. The statistical tests were conducted via the SPSS software package (SPSS for Windows, version 23, SPSS Inc., Chicago, IL, United States), with a

0.05 level of significance. The horizontal mesiodistal and buccolingual platform and apex deviations of each implant of BEA and FEA sites were plotted in 3-dimensional scatter diagrams.

RESULTS

For all the analyses, the FG implants showed the greatest similarity to the planned implants, followed by PG and FH implants. In addition, the BEA location was associated with greater similarity to planned implants than FEA for most of the comparisons *(Table 1*).

The FG implants had a more superior angle accuracy than PG and FH implants. At the BEA, FG was more superior than PG and FH ($p < 0.001$), while the PG and FH were similar ($p = 0.78$) *(Figure 2A*). At the FEA, all of the placement protocols were generally similar ($p = 0.07$) *(Figure 2B*). Comparing the 2 locations revealed that the FG at the FEA exhibited a significantly inferior outcome and more than double the errors than at the BEA location ($p < 0.01$), while the PG and FH did not show significant differences between the 2 locations ($p > 0.05$).

The vertical deviations at the BEA location showed similarity between FG and PG implants, and were closer to 0 than for the FH implants ($p = 0.63$). For the FEA location, the FG implants were noticeably deeper than the PG and FH implants ($p = 0.69$), while the rest of the implant protocols were above the planning *(Figure 3A*). The PG and FH were generally similar at the FEA location *(Figure 3B*). There has been no significant difference in the magnitude of vertical errors among the different protocols and between the 2 locations ($p > 0.05$).

For the maximum horizontal platform deviation, the FG and PG implants were similar at the platform level ($p > 0.05$), and both were more accurate than FH implants ($p < 0.05$) *(Figure 4A*). A similar pattern was observed for the FEA and BEA locations. Every implant placement protocol had inferior accuracy for the FEA than BEA locations ($p < 0.05$). The FEA tended to cause approximately twice the deviation than BEA at every location *(Figure 4B*).

At the apex, FG implants were more accurate than PG and FH for the BEA location ($p < 0.01$) *(Figure 4C*). However, the difference was significant only between FG and FH ($p < 0.01$). There was no difference between PG and FH ($p = 0.49$). All implant placement protocols were similar at the FEA ($p = 0.10$) *(Figure 4D*). At the apex, there was no difference between the FEA and BEA locations for the PG and FH implants ($p > 0.05$). However, the FG implants showed more than twice the deviation at FEA than BEA ($p < 0.01$).

The 3D graph of the BEA site revealed that the platform and apex of FG implants were centred to the middle of the graph *(Figure 5A*). With the exception of 1 implant that showed the apex skewing mesially, the implants were centred to the middle of the graph, with a slightly wider distribution at the apex. The FG implants were generally parallel, with the exception of the single skewed implant. The PG implants showed a similar distribution to the FG at the platform, however, at the apex a noticeably wider distribution buccolingually and distally was observed. FH had a wider distribution at the platform, and a considerably wider distribution at the apex with noticeable skewing distally and buccolingually.

At the FEA location, the FG showed a platform location at the middle of the graph. However, at the apex it showed a significantly greater distribution buccolingually with noticeable deviation mesially *(Figure 5B*). Still the FG implants maintained a relative parallelism between the planned and the inserted implants. The PG implants showed greater mesiodistal distribution than FG at the platform, which is further accentuated at the apex. The FH was clearly associated with greater error and distribution at the platform (predominantly mesiodistally) that further increased at the apex.

DISCUSSION

The present study illustrated that despite that all implant placement protocols were associated with deviation, they exhibited variable patterns of deviation and were affected differently by the presentation of the edentulous area. The study is in line with earlier investigations that showed the FG was most superior followed by PG then FH respectively.[1,3-5,8,19,21-23] Therefore, the hypothesis that there is no difference in the accuracy of implant placement by the different surgical protocols in the hands of novice implant clinicians was rejected. On the other hand, the FG implants appeared to be prone to more errors at FEA than BEA in comparison to PG and FH implants. Therefore, the hypothesis that there is no difference between BEA and FEA locations within each surgical protocol was rejected.

The recorded deviation magnitudes of FG implants corroborate the findings of earlier laboratory and clinical studies by experienced clinicians.[1,3-5,8,19,21] where the horizontal platform deviation ranged from 0.4 mm to 1.2 mm, the horizontal apex deviation ranged from 0.7 mm to 1.5 mm, the vertical deviation ranged from 0.7 mm to 1.5 mm, and angle deviation ranged from 1.4° to 4.2°.[1,3-5,19,21-23] As this study involved only inexperienced operators, it indicated that FG placement allows novice clinicians to insert implants to a similar level of implant deviation from planned implants to experienced clinicians as shown from previous studies. On the contrary, earlier studies indicated that experienced clinicians were able to insert implants to a more accurate location by FH[7] and PG[8-11] placements than inexperienced clinicians. However, the effect of different levels of implant experience of clinicians on the accuracy of placed implants was mitigated by the use of the FG guide.[7-9,15,24] This was clearly demonstrated by Park *et al* who found on resin laboratory models that use of FG guide reduced implant deviation differences among clinicians regardless of their level of experience.[7] The superior accuracy of FG implants over FH and PG implants can be attributed to controlling all the drilling steps and actual implant placement via the surgical guide.[1,3-5,19,21-23] While the PG controlled the pilot drilling, errors were found to

Table 1. Summary of implant horizontal, vertical and angle deviations.

Maximum implant angle deviation

	BEA			FEA			p values between BEA and FEA
	FG	PG	FH	FG	PG	FH	
Mean (°)	1.17	5.93	6.64	2.72	5.03	5.01	FG = 0.004 PG = 0.48 FH = 0.23
SD (°)	0.99	2.50	4.04	1.51	3.96	2.95	
Maximum (°)	3.31	12.50	14.00	4.92	13.20	11.40	
Minimum (°)	0.25	3.00	0.82	0.57	1.00	1.50	
p values	All groups < 0.001 FG vs PG < 0.001 FG vs FH < 0.001 PG vs FH = 0.78			All groups = 0.07			

Magnitude of vertical implant deviation

	BEA			FEA			p values between BEA and FEA
	FG	PG	FH	FG	PG	FH	
Mean (mm)	0.35	0.33	0.41	0.50	0.53	0.60	FG = 0.18 PG = 0.05 FH = 0.11
SD (mm)	0.25	0.22	0.23	0.31	0.30	0.36	
Maximum (mm)	0.91	0.76	0.79	1.15	1.05	1.44	
Minimum (mm)	0.01	0.04	0.09	0.07	0.16	0.18	
p values	All groups = 0.63			All groups = 0.69			

Maximum horizontal implant platform deviation

	BEA			FEA			p values between BEA and FEA
	FG	PG	FH	FG	PG	FH	
Mean (mm)	0.28	0.34	0.76	0.60	0.65	1.34	FG = 0.001 PG = 0.01 FH = 0.02
SD (mm)	0.18	0.15	0.48	0.27	0.37	0.71	
Maximum (mm)	0.66	0.59	1.85	0.98	1.41	2.96	
Minimum (mm)	0.14	0.20	0.25	0.31	0.10	0.58	
p values	All groups < 0.001 FG vs PG = 0.89 FG vs FH = 0.001 PG vs FH = 0.002			All groups < 0.001 FG vs PG = 0.98 FG vs FH = 0.00 PG vs FH = 0.001			

Maximum horizontal implant apex deviation

	BEA			FEA			p values between BEA and FEA
	FG	PG	FH	FG	PG	FH	
Mean (mm)	0.55	1.10	1.38	1.15	1.02	1.58	FG = 0.001 PG = 0.72 FH = 0.56
SD (mm)	0.38	0.57	0.89	0.46	0.66	0.90	
Maximum (mm)	1.55	2.33	3.73	1.81	2.3	3.43	
Minimum (mm)	0.14	0.20	0.25	0.31	0.10	0.58	
p values	All groups = 0.005 FG vs PG = 0.07 FG vs FH = 0.004 PG vs FH = 0.49			All groups = 0.10			

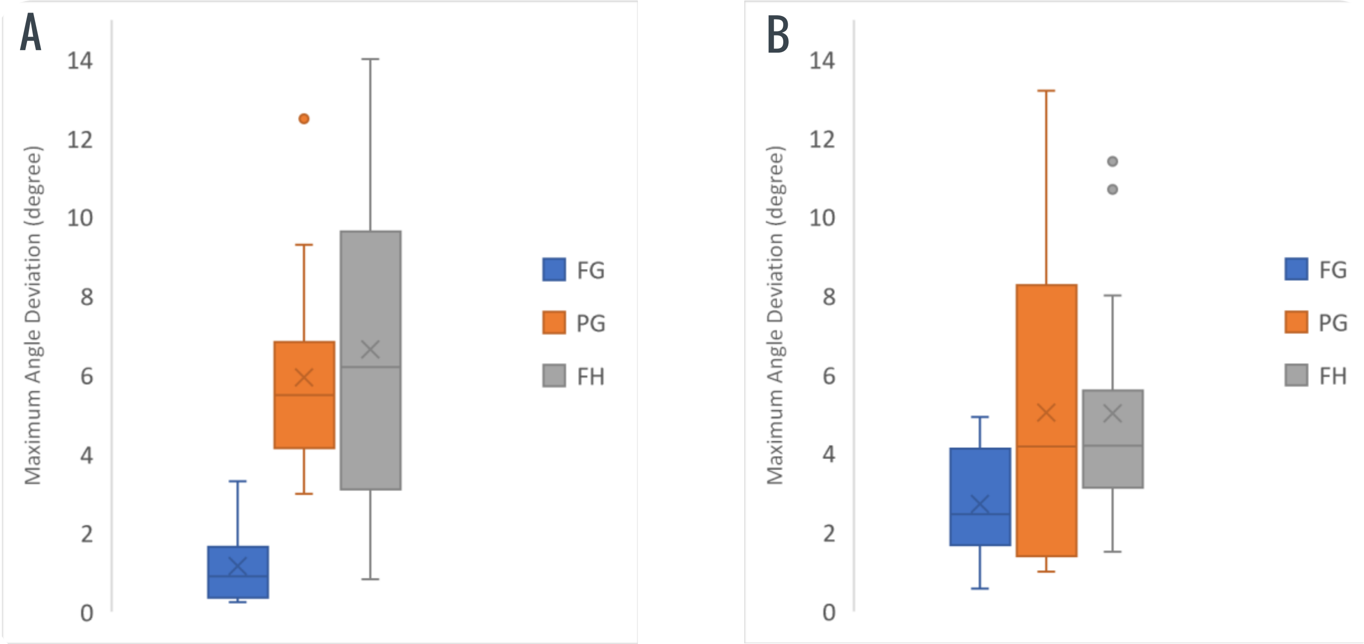

Figure 2: Box-and-whisker plot diagrams illustrating the distribution of angle deviation of different placement protocols for BEA (A), and FEA (B).

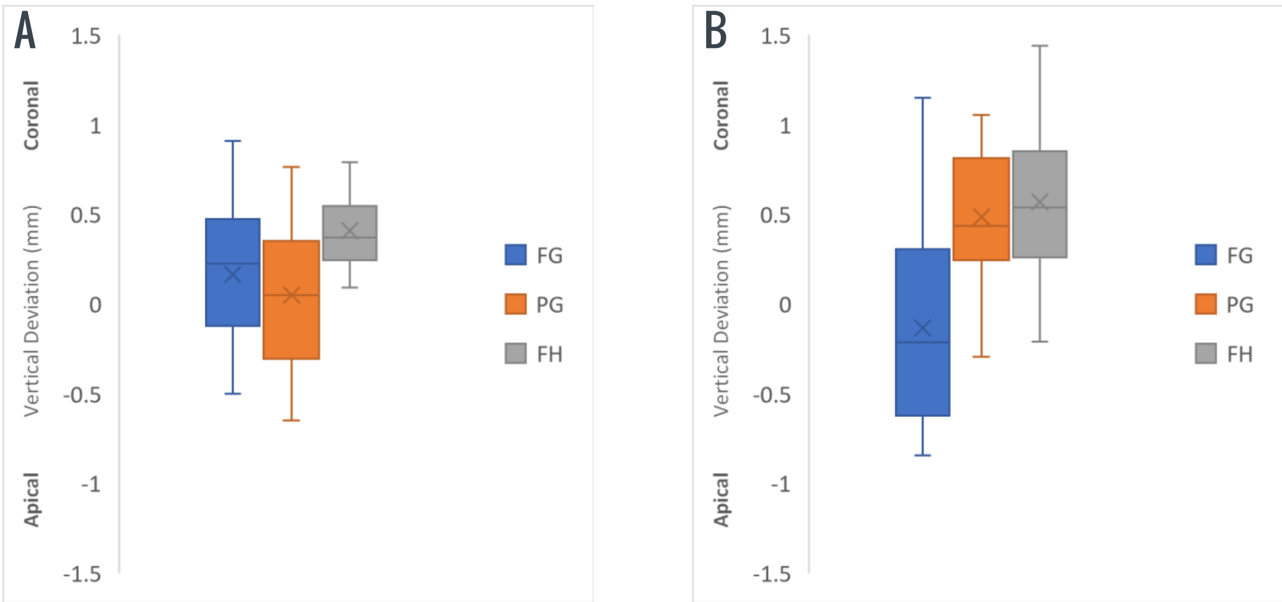

Figure 3: Box-and-whisker plot diagrams illustrating the distribution of vertical deviation of different placement protocols for BEA (A), and FEA (B).

occur with the subsequent drilling and implant placement that were completed without the use of a guide. In addition, implant deviation can still occur as it is inserted.[8-11] While the actual accuracy difference between FG and PG implants of the present study appears minimal, clinical studies reported clinical implications of this difference.[1,22] For example, Younis *et al* reported the FG implants were more likely to be restored with screw retention as opposed to PG implants.[1] Moreover, after comparing the white and pink aesthetics of FG and PG implants, Lou *et al* found greater reliability of FG in achieve a more aesthetic outcome than PG after 1 year follow up.[22] On the other hand, the present study also corroborates the conclusion of earlier studies that FG is still prone to deviations.[1,3-5,19,21-23] This has been attributed to the fit of the guide, CBCT-related and scanning-related errors, tolerance of components, and depth of drilling.[3,6,25] The errors from each step may be minimal, however, due to the accumulated nature of errors, the placed implant may suffer from measurable deviation. As a result, a safety horizontal and vertical zone of 1–2 mm is recommended whenever an FG implant is employed.[3,6,25]

The superiority of FG is more evident at the BEA than FEA. This could be attributed to greater guide stability and tooth support at both ends of the edentulous area at the BEA. At the FEA, while the FG showed some superiority over other placement protocols, the accuracy of FG greatly deteriorated for

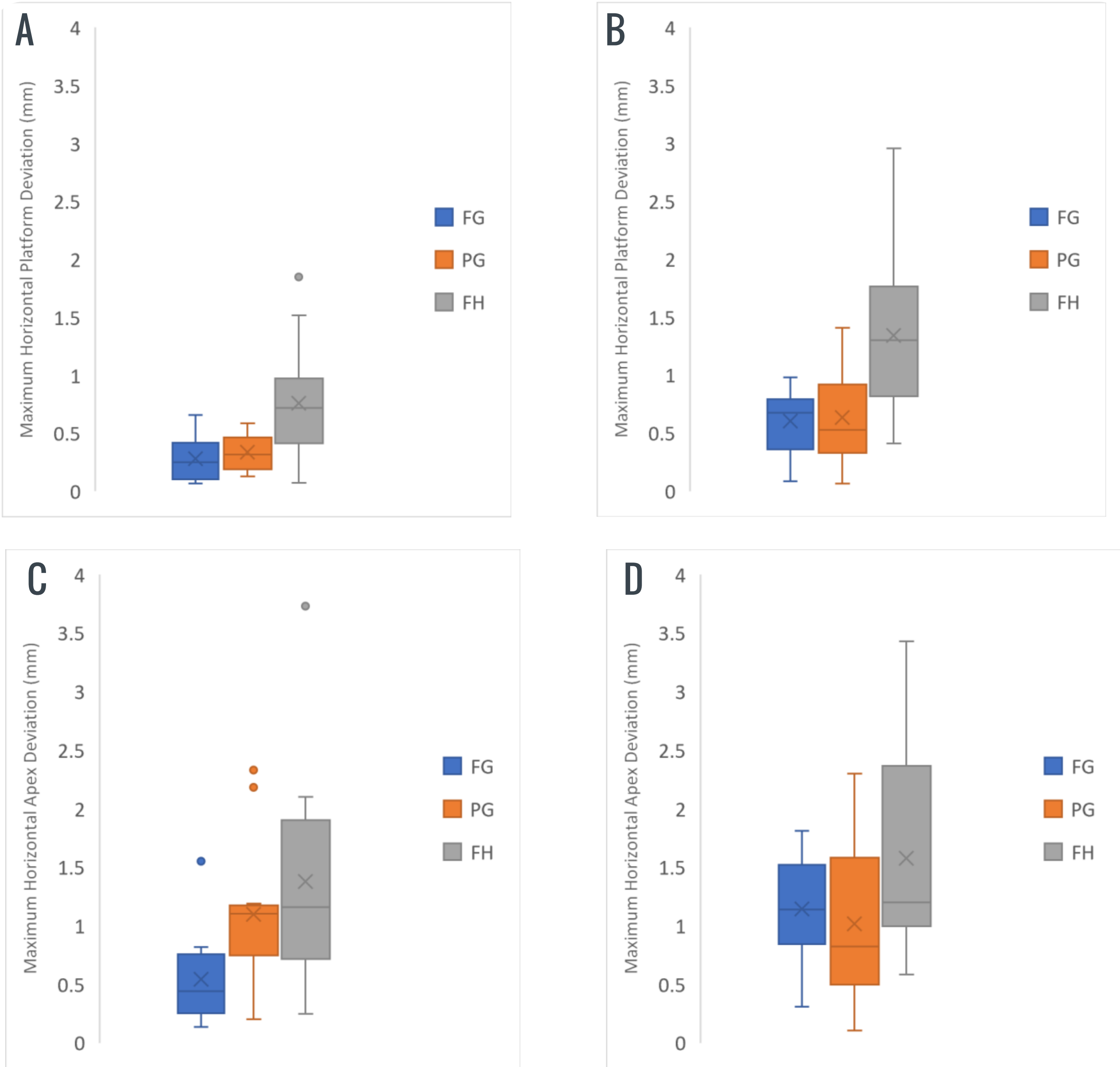

Figure 4: Box-and-whisker plot diagrams illustrating the distribution of maximum horizontal deviation of different placement protocols at the platform and the apex. BEA platform deviation (A), FEA platform deviation (B), BEA apex deviation (C), and FEA apex deviation (D).

the horizontal platform, horizontal apex and angular deviations. The susceptibility of FG to greater deviation at FEA was demonstrated by several earlier studies that evaluated FG implant placement at FEA scenarios.[5,18,24,26-30] Contrary to BEA, at the FEA, the FG guide may suffer from reduced guide stability, and guide deformation and displacement during drilling and implant placement. The present study revealed a predominant pattern of FG implant deviation where the platform and apex were deviated mesially, with more prominent deviation for the apex, and the tendency of implants at FEA to be deeper than BEA. This pattern of error is consistent with the possibility of the operator leaning and exerting pressure at the handheld sleeve of the guide, leading to guide distortion and displacement towards the edentulous area similar to a class I level movement.[24,30,31] As the guides used in the present study were rigid and supported by 11 teeth across the arch, they are likely to withstand distortion, and the displacement of guides is the most likely cause of implant deviation. This is further exacerbated by the posterior implant location and hand holding the guiding sleeve during drilling and implant placement. In posterior regions, the displacement can be more severe due to limited access and visibility, and more challenging drilling. The systematic nature of this error is further illustrated with the parallel orientation of the deviated FG implants at FEA. In support of this study, several investigations found that at FEA, the more distal the positioning of the implant from the nearest tooth, the greater the deviation,[24,26,27,29] which is an accentuated effect of the lack of distal support at the FEA. Therefore, despite the general closeness of FG implants to the planned implants, clinicians should be aware of the

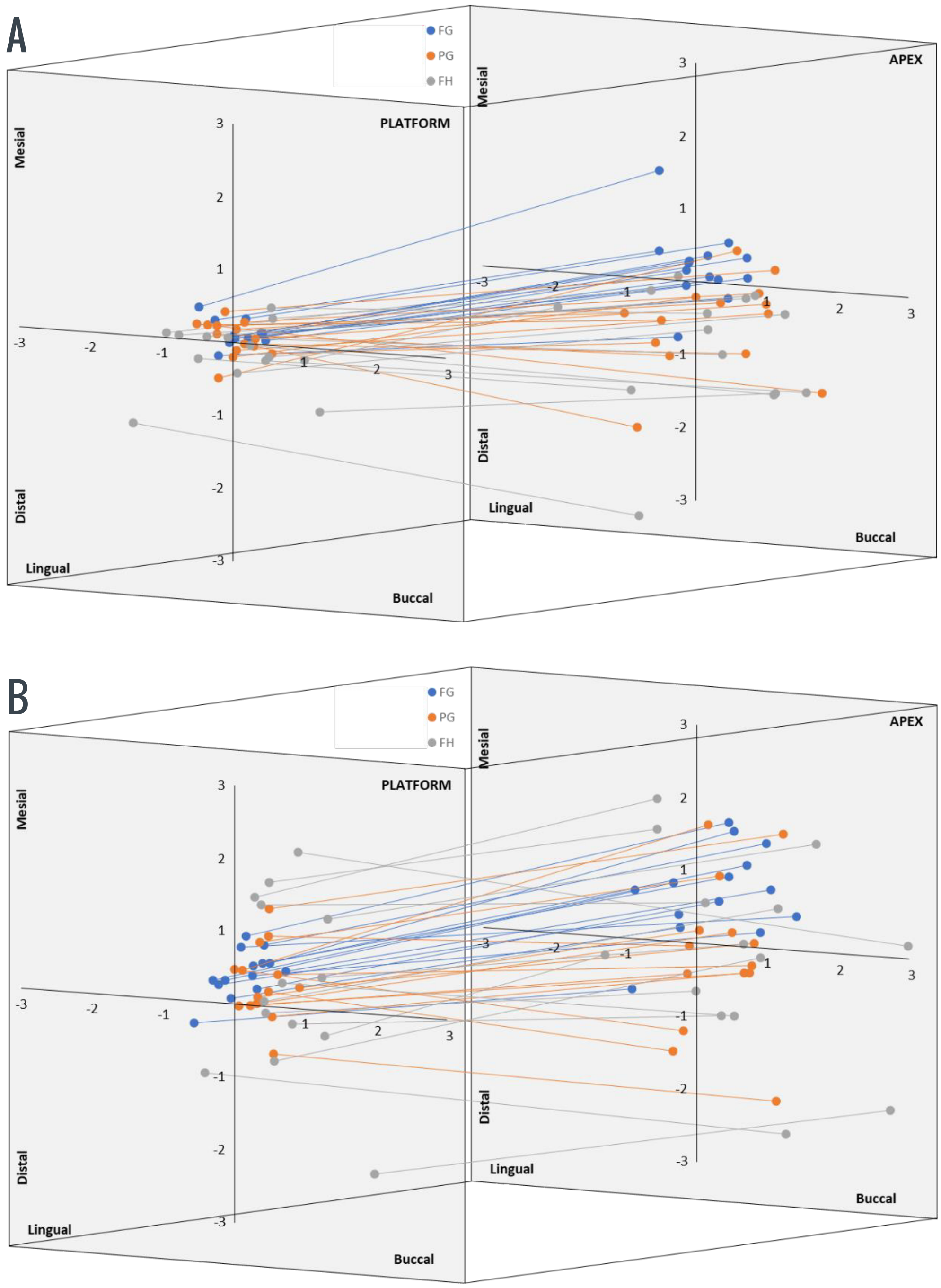

Figure 5: 3-Dimensional scatter diagrams outlining the mesiodistal and buccolingual deviations of the platform and apex of each implant for BEA (A), and FEA (B).

greater deviations with FG at FEA situations. Specifically, the guide is prone to distortion and displacement during drilling, and the sole reliance on the guide to control implant placement should be avoided. In addition, this deviation should be considered during planning, and the clinician may consider compensating for it by increasing the safety zone between the planned implant and the nearby vital structures. Further, additional forms of support for the surgical guide at FEA should be considered as they were shown to reduce guide distortion and displacement. This involves extending the guide for mucosal support,[26,27] bone support[29] or anchor implant support.[24] In line with earlier recommendations, intermittent evaluation of the osteotomy is necessary to avoid significant deviation of FG implants.[3,6,21,32]

The present study illustrates the merits of PG placement. Despite the PG accuracy appearing inferior to FG, it allowed the clinicians to place implants in a relatively close position to the planned implants. This was evident from the statistically similar horizontal accuracy with FG placement for the 2 edentulous presentations. Interestingly, PG appears minimally affected by the presentation of the edentulous area, with the exception of the maximum horizontal platform deviation, where it was inferior for FEA. The minimal implication of FEA on PG placement could be due to reduced reliance on the guide, and the completion of the remaining drilling steps and implant placement freehand, which eliminated the effect of guide displacement and allowed the operator to control and correct the drilling orientation in relation to adjacent teeth.[24] In addition, drilling and implant placement through the PG guide is generally simple and similar to the FH drilling procedure, and less affected by posterior placement and limited access. As a result, it was found to be appealing to clinicians new to implant dentistry.[33] As the simulated ridge is wide and of ideal dimensions, preparing the subsequent stages freehand is of minimal challenge to the operator. Still, the control of the pilot drilling is of significant benefit, as it allowed for significantly more accurate implant placement for PG than FH.[8-11]

While the differences among the techniques for the different presentations appear clinically minimal, they should be taken with caution. The results of the present study indicate that all the protocol errors were within what is considered to be acceptable clinically for restorable implants. However, laboratory studies on the accuracy of implant placement are limited due to the lack of simulation of clinical variables, absence of blood and saliva, ideal ridge anatomy, inevitable dissimilarity to natural bone properties, and wide mouth opening. It has been shown by earlier studies that cadaver and clinical studies show greater deviations than laboratory studies.[6,34] In addition, the present study evaluated the accuracy of FG implant placement by a single workflow (software and implant system), which may differ with other FG workflows,[11,35] and different variables, such as sleeve length, implant length, drilling depth, distance from the ridge, and the ergonomics of guides and sleeves.[28,36,37] Nevertheless, the study outcome emphasizes the importance of sufficient guide stability in the form of rigid support at both ends of the implant site.[29] It is recommended for clinicians to avoid exerting excessive pressure on the guide during drilling, and to ensure the guide is firmly seated on the teeth with no displacement during drilling. Simplifying the FG implant placement protocol by reducing the reliance on the handling of the guide sleeves may further reduce the implant deviation.

CONCLUSIONS

Within the limitations of the present study, it can be concluded that a form of guided implant placement increased the accuracy of placed implants by novice clinicians. A significantly greater accuracy was observed for FG followed by PG and FH respectively. However, FG accuracy suffered from greater deterioration at the FEA than at the BEA, which can be attributed to a reduced guide support and the possibility of guide displacement during surgery.

ACKNOWLEDGEMENTS

The authors would like to acknowledge the technical support of Mr. Attila Gergely and the input of the team of Digital Dental Network in designing the guides. The implants, surgical kits, and guide sleeves were provided by Straumann Australia. This study has been funded by ITI Research Grant (1335_2018).

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