THESIS APPROVAL PAGE FOR MASTER OF SCIENCE IN ORAL BIOLOGY

"Comparison of accuracy for three types of implant surgical guides"

Name of Candidate: CPT Patricia M. Walworth
Master of Science Degree
11 June 2019

All work has been completed to the satisfaction of the research committee.

MANUSCRIPT APPROVED:

[redacted]

CYNTHIA M. AITA-HOLMES, COL, DC
DIRECTOR, US ARMY ADVANCED EDUCATION IN PROSTHODONTICS,
ARMY POST-GRADUATE DENTAL SCHOOL

MANUSCRIPT APPROVED:

____

PETER GUEVARA, COL, DMD
DEAN, ARMY POST-GRADUATE DENTAL SCHOOL

The author hereby certifies that the use of any copyrighted material in the thesis manuscript entitled:

"**Comparison of accuracy for three types of implant surgical guides.**"

Is appropriately acknowledged and, beyond brief excerpts, is with the permission of the copyright owner.

[redacted]

Patricia M. Walworth
US Army Advanced Education in Prosthodontics
Uniformed Services University
Date: **06/11/2019**

Distribution Statement

Comparison of accuracy for three types of implant surgical guides.

Patricia M. Walworth, DMD,[a] Cynthia M. Aita-Holmes, DMD, FACP,[b,c] Peter Liacouras, PhD,[d,e]

[a]Resident, U.S. Army Advanced Education Program in Prosthodontics and Army Postgraduate Dental School, Uniformed Services University, Fort Gordon, GA.

[b]Program Director, U.S. Army Advanced Education Program in Prosthodontics, Fort Gordon, GA.

[c]Associate Professor, Army Postgraduate Dental School, Uniformed Services University, Fort Gordon, GA.

[d]Assistant Professor, Radiology and Radiological Services & Naval Postgraduate Dental School, Uniformed Services University of the Health Sciences, Bethesda, MD.

[e]Director of Services, 3D Medical Applications Center, Department of Radiology, Walter Reed National Military Medical Center, Bethesda, MD.

Disclaimer:

The views expressed in this manuscript are those of the authors and do not necessarily reflect the official policy of the Department of Defense, Department of the Army, U.S. Army Medical Department, or the U.S. Government.

Funding: The research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors

Declaration of Interests: None

Corresponding Author:

Dr Patricia M. Walworth

320 East Hospital Road

Fort Gordon, GA 30905

Email: patricia.m.walworth.mil@mail.mil

ABSTRACT

Statement of Problem. Accurate placement of implants in bone is critical for preservation of anatomical structures, restorability, and survival of the implant. While literature on the success and survival of implants is plenteous, there has been little investigation into the effect of different types of implant surgical guides on the accuracy of implant placement.

Purpose. To investigate the effect of conventional, partially guided, and fully guided implant surgical guides on the angulation of placed implants.

Material and Methods. An implant was digitally planned, and its 3D placement was utilized to fabricate three groups of surgical guides. The groups were divided based on the amount of guiding provided and were termed one drill protocol (fully-guided), partially-guided and conventional approach. Four periodontists used the guides to place trilobe internal connection implants into 3D printed models. The angulation difference between planned and actual implant position was calculated. A 1-way ANOVA was used to examine the effect of surgical guide type and provider on the accuracy of implant placement.

Results. The angulation differences between planned and actual implant placements ranged from 2.448 to 13.017 degrees. Mean angulation difference for the fully-guided approach was 5.7663 $\pm$ 1.0050 degrees, partially-guided was 6.7984$\pm$ 2.4565 degrees, and conventional guided was 7.4754 $\pm$ 2.8486 degrees. One-way ANOVA of surgical guide groups indicated a statistically significant difference in the accuracy of the guides, with the one-drill protocol or fully guided approach being most accurate. A one-way ANOVA also indicated a statistically significant difference in accuracy based on the provider placing the implant.

Conclusions. The use of a fully-guided approach for the placement of implants leads to significantly higher accuracy when compared to partially-guided or conventionally fabricated

surgical guides. Angular deviations existed between three dimensionally planned and actual implant positions following placement. The differences decreased as the degree of guidance provided by the surgical guide increased, giving the one-drill protocol (a fully-guide approach) significantly higher accuracy than partially-guided or conventionally fabrication surgical guides. These discrepancies in implant position should be taken into consideration when planning implants and determining surgical protocol. Further investigation is needed to determine the amount of deviation that would be considered clinically acceptable.

CLINICAL IMPLICATIONS

Increasing the degree of guidance provided by a surgical guide gives providers significantly higher accuracy in implant placement. The amount of deviation from the planning implant position is also dependent on the provider placing the implant, however, this deviation may be independent of the type of surgical guide used.

INTRODUCTION

In 2005, the World Health Organization estimated that between 6-70% of the adult population internationally was completely edentulous, depending in part on geographic location. In the United States alone, nearly 180 million people are missing at least one tooth.[1] Although the incidence of tooth loss in the United States is declining (by almost 6% from 1988-2000), population size has increased, indicating that prosthodontic rehabilitation for patients with missing teeth will still be a major issue in dental treatment for the foreseeable future.[2]

There are several treatment options for replacing missing teeth. No treatment is always an option for a patient who does not desire to "fill gaps" in their dentition and who can still function on a reduced dental arch. For patients with partial edentulism, treatment will depend on the position of the missing teeth. Long span edentulous spaces are not suitable for fixed dental prostheses (FDP) due to occlusal forces on the pontic units which could cause fracture or debonding of the prosthesis.[3] Although non-rigid connectors can help distribute forces and prevent failure of these prostheses, a more favorable treatment option in these cases could be a removable partial denture or an implant supported prosthesis, both of which have their own advantages and disadvantages. For complete edentulism, complete dentures are an affordable option for many patients. However, patient satisfaction with complete removable dental prostheses (CRDP) has been shown to be as low as 57-76% for esthetics, mastication and function.[4] Mandibular dentures frequently present with poor retention and stability, and some patients cannot tolerate the palatal coverage seen with maxillary complete dentures.

With advancements in the design, manufacturing, and surgical placement of endosseous implants over the last twenty years, implant supported fixed dental prostheses are now a common treatment option for partially or fully edentulous patients. The success rate for dental implants has been shown to be high, with a 2014 systematic review of 2211 patients, 7711 implants, and an average follow-up period of 15.4 years revealed a combined success rate of 94.6%.[5] Other studies have shown similar results, demonstrating success rates of over 97% after eight years of follow-up.[6] The high rate of implant success could be due to increased time spent planning for implant placement and restoration. Part of this planning process includes design and fabrication of a surgical guide based on the method chosen to place the implant.

The conventional method of guide fabrication involves direct fabrication of the guide on a stone model based on approximation to vital structures and adjacent teeth. A more recently developed method is computer-aided implant planning with software programs that aid in implant placement by projecting a three dimensional prototype of the implant into the patient's jaw based on cone beam computer tomography (CBCT) data. A surgical guide can then be fabricated to exactly fit this 3D model that will include not only adaptation to the patient's dental arch, but also the angulation, depth and position of the implant within the bone. Many studies have shown that the use of three dimensional imaging in implant planning has great value over two dimensional imaging.[7,8] Several studies have examined the accuracy of implants placed utilizing such an approach since the early 2000s. A 2003 study by Sarment compared traditional lab fabricated guides to stereolithic guides fabricated from CBCT. Five surgeons placed ten implants in epoxy mandibles, five in the right side using the lab fabricated guides and five in the left with stereolithic guides. Angulation and linear differences between planned and placed implants were compared, and the stereolithic guides produced implants placed closer to the planned position for both measurements.[9] It is known that computer-aided surgical guides increase the accuracy of implant placement, but there is still the question of how strictly guided the surgery needs to be to obtain the most accuracy.

One way to measure accuracy of implant placement is to place an implant in a model using a guide fabricated from a CBCT and to measure the differences between planned implant placement and actual placement. In 2012, a study by Turbush, et al, was done to examine just that. Computer designed surgical guides were 3D printed and used to place implants in a stereolithic mandibular model depending on support (tooth, bone or mucosa). Presurgical and postsurgical CBCT images of the model were then merged with the planned implant placement from the software and the linear and angular deviation of the central axis was calculated. The mean angular deviation was 2.2±1.2 degrees, although the difference between the groups was not statistically significant. The linear deviation of the implants was 1.18 ± 0.42 mm at the neck and 1.44 ± 0.67 at the apex. All values were deviation from the planned implant position, and it was found that bone and tooth supported guides produced more accurately placed implants than mucosa supported guides.[10] This study examined accuracy of surgical guides based on support: bone, mucosa, or tooth borne guides. A 2015 study by Rungcharssaeng explored experience of providers related to implant accuracy. Ten experienced providers and 10 inexperienced providers used fully guided computer aided surgical guides to place one implant in mandibular models which were then scanned in a CBCT machine and merged with the planned position to observe any angular deviation. It was found that there was no statistically significant difference in the angular deviation from the planned position between the two groups of providers, which led to the conclusion that fully guided surgeries are very accurate for all levels of experience.[11] However, no published studies could be located that examined the differences in accuracy of different types of surgical guides based on the degree of guidance. The aim of this study was to determine the accuracy of three types of surgical guides: a one drill protocol guide (fully guided approach), a partially guided approach, and a conventional approach.

MATERIAL AND METHODS

Cone beam computed tomography (J. Morita MFG Corp, Kyoto, Japan) was used to obtain a DICOM image of a typodont model (Nissan Dental Products, Kyoto, Japan) with teeth #27 and 29 extracted. The image was imported into an implant planning software (Blue Sky Plan 4.0, Blue Sky Bio, Libertyville, IL) where it was converted to a stereolithography (STL) file format. The crown of tooth #28 was digitally removed and a 4.3 x 10 mm trilobe regular platform implant (ITT4310, Blue Sky Bio, Libertyville, IL) was planned over the root form utilizing the 3D planning software. This 3D position will be referred to as "planned implant placement" for the remainder of the study. Forty eight models of the STL were then 3D printed in Veroglaze MED 620 material (Stratasys, Eden Prairie, MN).

From the 3D plan of the implant position, two types of surgical guides were designed. The first was a one drill protocol guide for a fully guided implant placement (termed group FG). The one drill protocol (Blue Sky Bio) involves using osteotomy drills that are designed with topography to limit the number of drills needed to prepare the site. Guide tubes are fabricated that pair with specific direct cut drills to allow the use of only one osteotomy drill prior to free-hand implant placement. The second group was a guide for partially guided implant placement (termed group PG) with a 2 mm twist drill being used in the guide tube followed by subsequent osteotomy drills used free-hand. To ensure stability, the guides were designed to extend into the extraction sockets of teeth #27 and 29 and over the occlusal or incisal surfaces of the surrounding teeth. All guides were 3D printed using Biocompatible Clear LED 610 material (Stratasys).

A second model was designed with a 2 mm diameter post extending 15 mm coronal to the center of the planned implant platform. This model was 3D printed in Veroglaze MED 620 and was used to fabricate the third type of surgical guide simulating a conventional approach (termed group CG). Clear Triad sheets (Dentsply Sirona, York, PA) were formed around a 2 mm twist guide tube (SGT25, Zimmer Biomet, Palm Beach Gardens, FL) placed on the post. The Triad was extended into the extraction sockets to provide guide stability. A TruByte Triad 2000 oven (Dentsply Sirona) was used to cure the material. Sixteen guides for each protocol were fabricated, along with 48 printed models. Sample size was determined by power analysis. The guides and models were matched and divided into three groups according to implant placement protocol: conventional guide protocol, partially guided protocol, and fully guided protocol. For all protocols, insertion torque and drill speed were as per recommendation by Nobel Biocare for the placement of trilobe internal connection implants. Four board certified periodontists with experience ranging from seven to 20 years were given four kits from each group, along with all necessary equipment and detailed, type-written instructions for each implant placement protocol. Each periodontist placed twelve implants in total.

After implant placement, an intraoral scan body (Dess, Roseville, CA) was placed on each implant. The models were scanned in an optical scanner (Zirkonzahn, Gais, Italy), transferred to digital software (Modellier, Zirkonzahn), and an implant was digitally placed in each model based on the geometry of the scan body. The implant position in the model was exported in the STL file format, which will be referred to as the “actual implant placement” for the remainder of the study. The STL file was imported into the implant planning software (Blue Sky Plan, Blue Sky Bio) where the actual implant placement file was correlated to the planned implant placement used to fabricate the surgical guides. An STL file of the scan body imposed over the planned implant abutment was exported, and a vector line was placed down the long axis of both planned and placed implants (Magics, Materialise, Plymouth, MI). The greatest angulation difference between the two vector lines was calculated in a spread sheet (Excel, Microsoft, Redmond, WA). Statistical analyses between groups and providers were made using a one way analysis of variance (ANOVA) test (SPSS, SPSS, Inc. Chicago, Ill) with $\alpha = 0.05$.

RESULTS

A total of 48 implants were placed in stereolithographic models, 16 from each of the three guide groups, 12 from each of four providers. A computer program (Magics, Materialise) was used to find two points, thus creating a central axis or vector line for both the planned and placed implants. The largest angulation difference in 3D based on the vector lines was calculated in a spread sheet (Excel, Microsoft) for each implant following the dot product formula presented in a 2012 study by Turbush.[10] As shown in Table 1, the angulation values ranged from 2.448 to 13.017 degrees, and were divided according to surgical guide group. The measurements for group FG were relatively uniform, while the data ranges for group PG and group CG were large compared to the range for group FG. The values were combined according to guide type and mentor. The mean angulation and standard deviation for each mentor per guide type group is presented in Table 2. For group FG, the mean angulation difference for the 16 implants was 5.7663 $\pm$ 1.0051 degrees. The 16 implants in group PG averaged 6.7984 $\pm$ 2.4565 degrees deviation, and group CG averaged 7.4754 $\pm$ 2.8486 degrees.

The one-way ANOVA ($\alpha = .05$) of guide type groups (Table 3) revealed a statistically significant main effect [$F(2,36) = 7.639$, $p = .002$]. This indicates that there is a statistically significant difference between the guide groups with group FG being most accurate, and group PG being more accurate than group CG. The same was true for the one-way ANOVA ($\alpha = .05$) of providers (Table 4) which revealed a statistically significant main effect [$F(3,36) = 22.429$, $p < .001$]. This indicates that there is a statistically significant difference between providers with provider 1 being most accurate, provider 4 being more accurate than providers 2 and 3, and provider 3 being more accurate than provider 2. The mean angulation difference for each provider per group was plotted graphically along with standard error bars as shown in Figure 1, and the mean angular deviation for each surgical guide group was plotted graphically along with standard error bars as shown in Figure 2.

DISCUSSION

Implants were placed according to three protocols by four periodontists and accuracy was measured based on angulation differences between planned and actual implant position. The statistical analysis indicated that guide type and provider both have a statistically significant effect on the accuracy of implant placement.

While prior studies have compared guide support and accuracy of placed implants, data is lacking as to how guided a surgery must be in order to produce accurately placed implants. It is well documented that utilizing 3D imaging to assist in planning for dental implants aids in accuracy, however there are many different types of surgical guides that can be fabricated from that plan. These range from free hand placement using the imaging as a visual aid only, to fully guided placement with subsequent keys for each drill as well as the implant. The one-drill protocol used in this study still allows for potential error to be added as the implant is not placed through the guide. Despite the possibility of error, the method was the most accurate by an average of 1.034 degrees in angulation. This is expected as the guides for group PG and CG only assisted in positioning of the 2 mm twist drill. All subsequent drills were approximated based on coronal tooth structure and remembrance of the angulation within the guide for the first drill.

The surgical guides for group CG resulted in implants placed with the largest range of angulation deviations (6.712 degrees), and the greatest mean difference between planned and actual implant position (7.4754 $\pm$ 2.8486 degrees). Horwitz et al[13] commented on this in a study which utilized CT planning for implants, but laboratory fabricated guides for placement. Reproducibility errors were cited as a cause for deviations that SLA printed guides based on the planning could decrease. The guides fabricated for group CG in this study were laboratory made and although the error was reduced by providing a post based on the 3D planning of the implant, the play between the guide tube and post allowed for irregularities between the guides and resultant error in implant placement. Both group FG and group PG had protocols that used SLA printed guides, and resulted in implants placed with less angular deviation from planned.

Accuracy of implant placement based on experience has been explored in previous studies. Rungcharassaeng, et al[11] found that when utilizing a fully guided approach, increasing experience of the provider did not correlate to increased accuracy of placement. The study concluded that the method for fully guided implant placement is suitable for all providers to aid in accurate implant positioning. Casetta, et al[12] found similar results stating that experience did not lead to more accurate coronal or angular positioning of placed implants, but experienced providers did have significantly more accurate bodily positioning than inexperienced providers. Experience was defined as 500 implants placed using computer-guided technology. The results of the present study are consistent with this finding, as the range of angular deviation for the one drill protocol, our fully guided approach, was the smallest (1.603 degrees compared to 5.109 degrees for group PG and 6.712 degrees for group CG) and most consistent between providers of the three guide groups. All of the providers in the present study were board certified periodontists, and their years in practice ranged seven to 20. While previous studies have shown that the accuracy of placed implants using computer guided approaches is not affected by experience, a partially guided or conventional approach may be affected as they have an increased free-hand component. However, experience did not seem to have an effect on accuracy regardless of the amount of guiding in the present study as provider 2 was the most experienced and had the greatest range of deviations between planned and placed implant position (9.47 degrees). The remaining three providers had angular deviations within 3.2439 – 4.1064 degrees for their 12 implant placements.

It is well known that the use of radiographic imaging, especially three dimensional radiographs and implant planning software, aid in avoidance of anatomical structures and decrease the occurrence of neural injuries, 75% of which result in permanent injury.[14] While some actual implant positions were closer to planned implant positions than others in the present study, none of the protocols resulted in implants placed with angular deviation less than 1 degree from the planned position. As such, the question of how much angular deviation from planned position would be tolerable is still unanswered. Implant prosthetics such as multi-unit abutments and angulated screw channel tibases are on the market which can correct 25 – 30 degrees of misangulation. Angulated stock abutments (15 degrees) would also aid in bringing the implant to a more favorable restorative position. All of the implants placed in this study were off angulated less than 14 degrees with the majority being under 8 degrees making them prosthetically well within restorable limits. One variable not examined in this study which may add relevance to clinical significance is linear deviation from planned position, and resultant distance to adjacent anatomical structures.

CONCLUSION

Within the limitations of this bench top study, utilization of the one-drill protocol in a fully guided implant placement approach produced more accurately placed implants when compared to planned implant position than partially guided and conventional guide approaches. The accuracy of the implant placement is also dependent on the provider performing the procedure. This difference in accuracy may be independent of the type of surgical guide provided for implant placement. Further research is necessary to determine linear deviation and its effect on adjacent anatomical structures.

REFERENCES

1. Petersen PE, Bourgeois D, Ogawa H, Estupinan-Day S, Ndiaye C. The global burden of oral diseases and risks to oral health. Bull World Health Organ 2005;83:661-69.

2. Douglass CW, Shih A, Ostry L. Will there be a need for complete dentures in the United States in 2020? J Prosthet Dent 2002;87:5-8.

3. Rosenstiel, SF, Land MF, Fujimoto J. Contemporary Fixed Prosthodontics. 5th ed. St. Louis: Elsevier; 2016. p. 58-60.

4. Bilhan H, Erdogan O, Ergin S, Celik M, Ates G, Geckili O. Complication rates and patient satisfaction with removable dentures. J Adv Prosthodont 2012;4:109-15.

5. Moraschini V, Poubel LA, Ferreira VF, Barboza E. Evaluation of survival and success rates of dental implants reported in longitudinal studies with a follow-up period of at least 10 years: a systematic review. Int J Oral Maxillofac Surg 2015;44:377-88.

6. Busenlechner D, Furhauser R, Haas R, Watzek G, Mailath G, Pommer B. Long-term implant success at the Academy for Oral Implantology: 8-year follow-up and risk factor analysis. J Periodontal Implant Sci 2014;44:102 – 108.

7. Reddy MS, Mayfield-Donahoo T, Vanderven FJ, Jeffcoat MK. A comparison of the diagnostic advantages of panoramic radiography and computed tomography scanning for placement of root form dental implants. Clin Oral Implants Res 1994;5:229-38.

8. Cher ME, Richardson AC. The accuracy of dental radiographic techniques used for evaluation of implant fixture placement. Int J Periodontics Restorative Dent 1995;15:268-83.

9. Sarment DP, Sukovic P, Clinthorne N. Accuracy of Implant Placement with a Stereolithographic Surgical Guide. Int J Oral Maxillofac Implants 2003;18:571-77.

10. Turbush SK, Turkyilmaz I. Accuracy of three different types of stereolithographic surgical guide in implant placement: An in vitro study. J Prosthet Dent, 2012; 108: 181-88.

11. Rungcharassaeng K, Caruso JM, Kan JYK, Schutyser F, Boumans T. Accuracy of computer-guided surgery: A comparison of operator experience. J Prosthet Dent 2015;114:407-13.

12. Cassetta M, Bellardini M. How much does experience in guided implant surgery play a role in accuracy? A randomized controlled pilot study. Int J Oral Maxillofac Surg 2017;46:922-30.

13. Horwitz J, Zuabi O, Machtei EE. Accuracy of a computerized tomography – guided template – assisted implant system: an in vitro study. Clin Oral Implants Res 2009;20:1156 – 62.

14. Bornstein MM, Horner K, Reinhilde J. Use of cone beam computer tomography in implant dentistry: current concepts, indications and limitations for clinical practice and research. Periodontol 2000 2017;73:51-72.

TABLES

Table 1. Angulation differences between planned and actual implant position (degrees)

Group 1: Fully Guided	Group 2: Partially Guided	Group 3: Conventional Guided
5.4662	4.3728	3.5235
5.7554	3.5362	3.6753
5.2961	2.7220	5.1746
5.1881	2.4475	5.2600
3.5474	10.8377	13.0174
5.1344	9.1527	11.0388
6.3711	7.7278	10.9472
5.5636	5.7964	9.4799
6.5736	9.2434	8.9406
6.2799	7.8853	5.3735
6.6203	6.8545	8.8498
7.5527	8.9406	8.8242
7.3573	6.8416	4.8596
5.6075	7.7557	8.4719
4.7196	8.3069	6.0988
5.2280	6.4330	6.0715

Table 2. Mean angulation differences between planned and actual implant position based on guide type and provider

Guide Type	**Provider**	**Mean (Degrees)**	**Number of Samples**
FG	1	5.4264 ± 0.2474	4
	2	5.1539 ± 1.1872	4
	3	6.7566 ± 0.5517	4
	4	5.7281 ± 1.1454	4
PG	1	3.2696 ± 0.8687	4
	2	8.3787 ± 2.1399	4
	3	8.2109 ± 1.0662	4
	4	7.3343 ± 0.8522	4
CG	1	4.4084 ± 0.9368	4
	2	11.1208 ± 1.4522	4
	3	7.9970 ± 1.7497	4
	4	6.3755 ± 1.5124	4

Values are given as mean ± standard deviation

Table 3. One-way analysis of variance within the surgical guide groups

Source of Variation	Sum of Squares	d*f*	Mean Square	F	P - Value
Between Groups	23.706	2	11.853	7.639	0.002
Within Groups	55.857	36	1.552		
Total	79.563	38			

Table 4. One-way analysis of variance within providers

Source of Variation	**Sum of Squares**	**d*f***	**Mean Square**	**F**	**P - Value**
Between Groups	104.401	3	34.800	22.429	<0.001
Within Groups	55.857	36	1.552		
Total	160.258	39			

FIGURES

Fig. 1. Mean angulation difference for the three surgical guide groups by provider with standard error bars

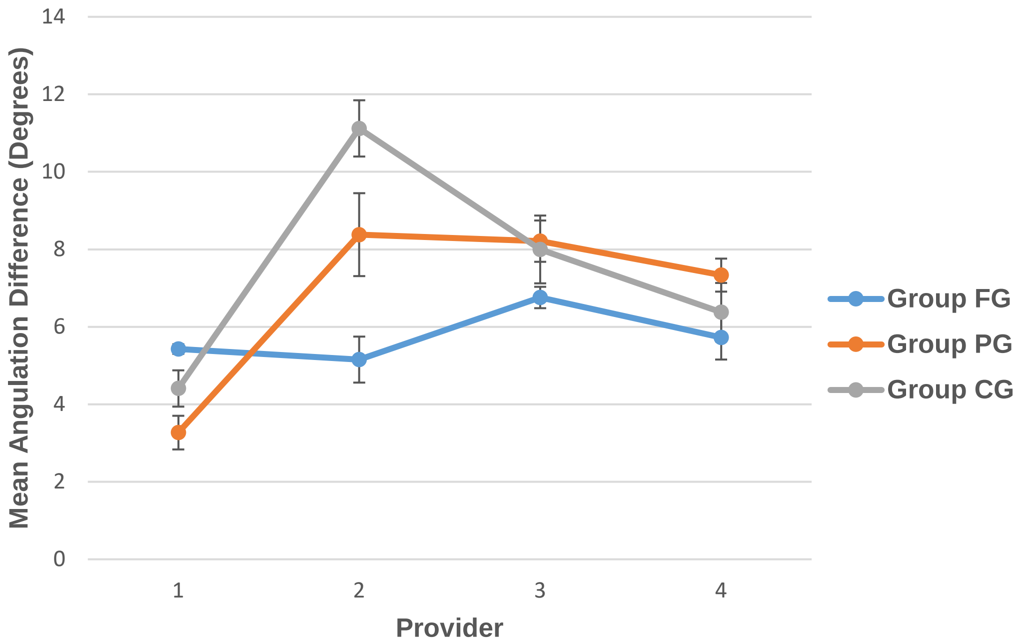

Fig. 2. Mean angular deviation for three types of surgical guide with standard error bars