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EFFECT OF DIFFERENT FORCES MAGNITUDE APPLIED DURING IMPLANT-GUIDED SURGERY ON IMPLANT DEVIATION: INVITRO STUDY

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ABSTRACT

INTRODUCTION: Surgical guides are used to allow implant placement in a prosthetic-driven manner. Forces applied to the guides during surgery were argued to cause implant displacement from the planned position. That may cause failure of the implant or injury to important structures. Moreover, the magnitude of force could have a great influence on implant deviation.

AIM OF THE STUDY: Evaluate the effect of different forces magnitude in implant angular and depth deviation.

Material and methods: Ten epoxy resin models were used. For each model, a surgical guide with two sleeves was designed and printed. Surgical guides were fitted to the models, then they were attached to a testing platform to allow the application of forces. For each sleeve, eight forces were applied from two directions. For each direction, four forces were applied (0.1N,1N,2.5N, and 5N). After force application, surgical guides were scanned. Superimposition was made to detect the suspected implant position after force application. Vertical and angular implant deviation was measured from the planned implant position.

RESULTS: Vertical and angular deviations increased significantly with increasing force magnitude. Vertical deviation for 0.1N, 1N, 2.5N, and 5N forces was (0.30± 0.22mm, 0.5±.043mm, 0.65±0.58mm,0.81±0.69mm, P<0.001 respectively). Complete deportation of guides from models was reported four times with 5N force. Angular deviation for 0.1N, 1N, 2.5N, and 5N forces was (1.04±0.82o, 1.88±0.93o, 2.84±1.90o ,2.47±2.13o, P<0.001 respectively).

CONCLUSION: Forces applied during guided implant surgery are an important source of implant deviation causing reduced surgical guide accuracy. Therefore, stabilization of the surgical guide is highly recommended.

KEYWORDS: CBCT, Surgical guide, Implant, Force.

RUNNING TITLE: Forces applied in guided implant surgery.

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INTRODUCTION

Tooth loss negatively impacts social interaction, eating, speaking, and facial appearance. Given its high prevalence and reported association with depression besides poor self-health, edentulism is considered a significant public health issue around the world(1).

Dental implants have revolutionized modern dentistry, offering a reliable and effective solution for the replacement of missing teeth(2). The success rate and durability of dental implants have increased because of substantial development in materials, procedures, and research over time(2, 3).

The guided implant surgery process is distinct from the free-hand implant surgery (4). In guided implant surgery, a Digital Imaging and Communications in Medicine (DICOM) file is generated from cone beam computed tomography (CBCT), and it is imported to the implant planning software along with Standard Tessellation Language (STL) files of the patient's oral structures. After prosthetic-dependent treatment planning has been completed, the digital data is gathered to generate a surgical guide, and the guide is then printed(5).

To precisely control the depth, angulation, buccal-lingual, and mesial-distal positions of the implant, the guide has cylindrical sleeves at the implant site. The sleeve diameter is planned based on the implant corresponding surgical guided kit. This kit's drills are different from the traditional implant drills in that they have a stopper on each drill that should probably fit the sleeve in the designed guide(5).

The difference between the location of the "planned" and "inserted" implants can be defined as the accuracy of the surgical guide(6). Most frequently, a second, postoperative CBCT is used to confirm the accuracy through superimposition of preoperative and postoperative CBCT. Four levels of deviation are usually used to assess accuracy: deviation at the apex, deviation at the entry point, deviation of the long axis (angulation), and deviation in depth(7).

Implant surgical guides can vary in accuracy depending on several factors(6). A major factor in the generation of the surgical guide is the quality of CBCT and scans(8). The effectiveness of the surgical guide may also be impacted by patient-specific variables such as bone density(5, 9-11). Furthermore, a few variables might affect the drilling process, which in turn affects guide stability and accuracy, including the choice of drill, drill speed, and surgical technique. Previous research considered the improper fitting of guides as the main source of reduced accuracy(12, 13). However, recently Kobe et al. (14) argued that the forces applied during surgery cause instability of the surgical guide, which reduces the guide's accuracy (14).

Different forms of forces are reported to be applied in surgical guides such as placement forces, drilling forces, cutting forces, torque forces, and shearing forces. Drilling forces are forces applied during the preparation of implant osteotomy. They include lateral forces and axial forces. The magnitude of forces is related to different factors. These factors include the speed of drilling, bone density, and the type of drill(15, 16).

Deviation in implant position due to the instability of the surgical guide was reported to cause serious complications(17) such as inferior alveolar canal injury. Furthermore, there is a lack of studies detecting the effect of forces in surgical guides. Besides, there is debate in the literature concerning the main cause of surgical guide inaccuracy and the importance of detecting any small deviation in implant positions. Therefore, the primary objective of this study is to thoroughly assess and understand the influence of forces applied during guided surgery on both the implant depth and angular deviation. By closely examining the effects of these varying forces, this study aims to enhance our understanding of the cause of the resulting implant placement deviation in guided surgery. This investigation is crucial for developing more precise and effective techniques in implant dentistry. The null hypothesis is that there isn't any alteration in implant deviation measurements with different forces.

MATERIAL AND METHODS

Study design:

The current in-vitro study was performed after the approval of the Ethics Committee of the Faculty of Dentistry, Alexandria University (IRB: 00010556-IORG0008839).

Sample size:

The sample size was calculated based on Kobe et al.(14) study that evaluated the stability of the retentive surgical guide (RSG) and a conventional surgical guide (CSG). The minimum required sample size was found to be 10 models, assuming a power of 80% (=0.20) to detect a standardized effect size in implant depth deviation (primary outcome) of 0.405, and a level of significance 5% (α error acceptable =0.05) (18). The sample size was calculated using GPower software version 3.1.9.2 (19).

Methods:

Ten different mandibular epoxy models with soft tissue-like material were used. All the models were class II Kennedy's classification (Fig.1). The models were scanned using a Cerec InEos X5 extraoral scanner (Sirona, Germany). CBCT was taken for models using the same machine with the same exposure parameters (Icat2, Kavo, Germany). The STL files with DICOM data were imported into open-access implant planning software (BlueSky-Plan 4; BlueSky Bio) (Fig.2). First, virtual teeth were created to resemble the final prostheses. Then, two standards sized Neodent implants measuring 4 by 10 mm were planned in each model. In accordance with the guided kit's manufacturer's instructions, matching sleeves were created (sleeve diameter 5.1mm, height 4mm and offset 9mm). The Bluesky Bio program was used to create the surgical guide. The entire arch was covered by the surgical guide (Fig.2). Surgical guides were printed by an SLA printer (Form 3, USA) using white resin. The manufacturer's instructions were followed for all printing settings, including the creation of automatic supports with the setting of the layer thickness at 0.1 mm and print resolution at 100 microns. All surgical guides were printed with a horizontal orientation. The post-curing protocol of surgical guides followed the manufacturers' recommendations. It involved post-curing with 1.25 mW/cm³ of 405 nm LED light for 60 minutes at 60°C. Surgical guides were used immediately to prevent any dimensional changes.

Surgical guides were fitted to the models. The models were attached to the platform to allow force application. The drill handle was inserted into the surgical guide sleeve. Forces were applied by force gauge through a drill handle with a fixed distance from the sleeve to the point of force application(5mm) (14). For each model, eight forces were applied (4 from the buccal direction and 4 from the oral direction). Following Kobe et al. (14) method, the following force magnitudes were applied 0.1N,1N,2.5N, and 5N. Scanning of surgical guide and model was performed during the application of

forces using an intraoral scanner (Omnicom Sirona, Germany) (Fig.3). A total of 80 scans were taken.
Scanned data were superimposed with a planned surgical guide and implant to generate the anticipated implant position following force application (Fig.4). After adding virtual implants (160 implants), the scanned data were superimposed on the original plan by point registration. A minimum of four points were positioned in teeth to optimize registration. For the detection of implant deviation from the planned position , three measurements were taken. First, Implants were transferred to cylinder form to standardize measurements. The depth deviation of the implant was measured in coronal and apical directions and an average was calculated(20). Angular deviation was measured between the long axis of the planned implant and the proposed implant position following force application(20)(Fig.5).
Version 23.0 of IBM SPSS was used to analyze the data. parametric analysis was employed for all the variables. The means and standard deviations of each variable were calculated. The four force groups were compared. Repeated pairwise comparisons using the Bonferroni adjusted significance level were carried out if the results were significant. A p-value of 0.05 was used to determine significance.
Figure 1: Epoxy models with soft tissue.

Figure 2: Model CBCT and scan used for Planning of surgical guide using Bluesky software.

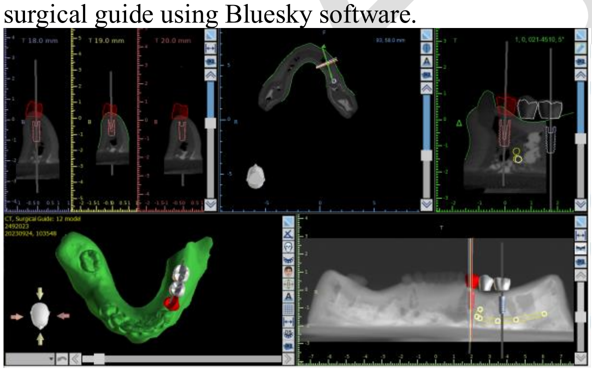

Figure 3: showing intraoral scan of surgical guide following 0.1N force applied from the buccal direction.

Figure 4: Intraoral scan after adding a virtual implant.

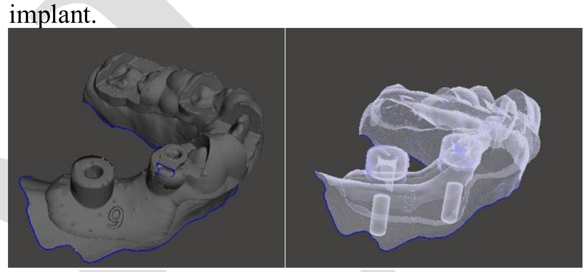

Figure 5: Implant depth deviation measurement and angular deviation between planned and virtual implant.

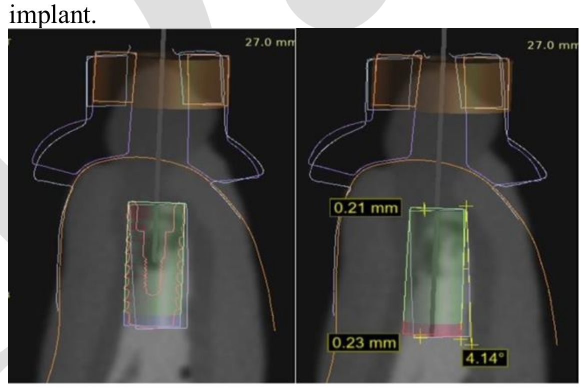

Table 1: Difference in implant vertical deviation (mm) among different forces.

Vertical deviation	Force			
	0.1N	1N	2.5N	5N
- n	**40**	**40**	**40**	36
- Min – Max	**0.00 – 0.84**	**0.00 – 2.18**	**0.13 – 3.11**	0.15 – 3.30
- Mean ± Std. Deviation	**0.30 ± 0.22**	**0.50 ± 0.43**	**0.65± 0.58**	0.81 ± 0.69
- SEM	**0.04**	**0.07**	**0.09**	0.12
- 95% CI for mean	**0.23-0.37**	**0.36 – 0.63**	**0.49 – 0.83**	0.57 – 1.04
Test of significance ***p-value***	$F_{(df=3)}$=6.95 *P*<0.001*			
	Post-hoc pair-wise comparison Bonferroni method			
	0.1N	1N	2.5N	5N
0.1N		Diff=0.19 *p*=0.56	Diff=0.35 *p*=0.015*	Diff=0.50 *P<0.001**
1N			Diff=0.16 *p*=1.00	Diff=0.31 *p*=0.05*
2.5N				Diff=0.15 *p*=1.00
5N				

n: Number of specimens
Min-Max: Minimum – Maximum
CI: Confidence interval
SEM: Standard error of the mean
df=degree of freedom
F: F of ANalysis Of VAriance (ANOVA)
*: Statistically not significant *(p<0.*05)
NS: Statistically not significant *(p*≥0.05)

Table 2: Difference in implant angular deviation (°) among different forces**.**

Vertical deviation	Force			
	0.1N	**1N**	**2.5N**	**5N**
- n	40	40	40	36
- Min – Max	0.00 – 2.70	0.00 – 3.64	0.00 – 9.38	0.92 – 9.49
- Mean ± Std. Deviation	1.04 ± 0.82	1.88± 0.93	2.85 ± 1.90	3.45 ± 2.13
- SEM	0.13	0.15	0.30	0.35
- 95% CI for mean	0.78 - 1.30	1.58 – 2.18	2.23 – 3.45	2.75 – 4.19
Test of significance *p* value	$F_{(df=3)}$=18.48 *P*<0.001*			
	Post-hoc pair-wise comparison Bonferroni method			
	0.1N	**1N**	**2.5N**	**5N**
0.1N		Diff=0.84 *p*=0.94	Diff=1.80 *P<0.001**	Diff=2.43 *P<0.001**
1N			Diff=0.96 *p*=0.035*	Diff=1.59 *P<0.001**
2.5N				Diff=0.63 *p*=0.47
5N				

n: Number of specimens
Min-Max: Minimum – Maximum
CI: Confidence interval
SEM: Standard error of the mean
df=degree of freedom
F: F of ANalysis Of VAriance (ANOVA)
*: Statistically not significant *(p<0.*05)
NS: Statistically not significant *(p*≥0.05)

RESULTS

Implant vertical deviation increased significantly with increased forces as shown in Table 1. With vertical deviation within 5N forces is more than twice the deviation in 0.1N forces (0.81 ± 0.69mm, 0.30 ± 0.22 mm, P<0.001, respectively).

No significant difference was reported between the guides after application of 0.1N and 1N forces. Besides, no difference was also detected between the 2.5N and 5N groups.

Implant angular deviation is significantly affected by the forces applied as shown in Table 2. The higher angular deviation is detected with the force of 5N (3.45 ± 2.13°, p<0.001). No significant difference was reported between groups of 2.5N and 5N forces. However, significantly higher angular deviation was detected in 2.5N forces in comparison to 0.1N and 1N forces.

The mean vertical deviation of all the applied forces was 0.56 ± 0.53mm. Furthermore, the mean angular deviation in the study was 2.28 ± 1.78 °. Complete dislodgement of surgical guides was reported 4 times. All the dislodgement occurred with 5N forces.

DISCUSSION

Different forces are applied during guided implant surgery, especially during the preparation of implant osteotomy and implant placement. These forces were argued to cause surgical guide displacement(14). Since any small displacement in surgical guides leads to implant deviation from the planned position, therefore evaluating the effect of these forces is very critical.

In a recent systematic review, a higher implant deviation was observed in free-end saddle situations in comparison to tooth-supported guides(21). The primary contributing factor was thought to be the surgical guide's instability. Therefore, in the current study free-end saddle models were utilized with soft tissue to simulate the clinical situation. Furthermore, the surgical guides were used immediately after printing to eliminate any dimensional changes that could affect the guides' accuracy(13).

Kinoshita et al.(22) evaluated different forces to create an implant surgery simulator that would give students a sense of the dynamic drilling forces required to execute an osteotomy in the posterior mandibular bone. They reported that up until a depth of 4 mm, less than 4 N of drilling forces were needed. Based on that and following Kobe et al. (14) methodology, this study applied .1N, 1N, 2.5N, and 5N forces.

In a study conducted by Younes et al.(23) , it was found that the angular deviation resulting from fully guided implant placement in partially edentulous patients was measured at 2.30 ± 0.92°. This value closely corresponded to the mean angular deviation observed from the total forces applied in the study (2.28 ± 1.78 °). Additionally, Younes et al. (23) study reported an implant vertical deviation of 0.43 ± 0.09 mm, which was slightly lower than the measurements obtained in the current study (0.56 ± 0.53mm). Based on that, the forces applied in this study were highly comparable to the clinical situation.

Liu et al.(24) found that in free-end saddle models, the implant angular deviation was 1.98 ± 0.91°, and the vertical deviation was 0.35 ± 0.53mm. These values were lower than the total results across all forces and lower than the in vivo results reported by Younes et al. (23). However, these results are consistent with the measurements of implant deviation using lower forces in this study (0.1N and 1N). This could be due to the fact that lower forces were applied in vitro compared to the forces used in this study and those applied in clinical situations.

Kobe et al. (14) reported increased implant deviation with increasing forces similar to this study. Furthermore, complete dislodgement of surgical guides was reported in their study but with different rates. That could be due to the difference in the type of surgical guide in our study than Kobe et al. (14) . In Kobe et al. (14) study they evaluated bilateral tooth-supported surgical guides while this study evaluated unilateral tooth-supported guides.

The findings of this research oppose the conclusions of earlier studies, which had identified improper fitting of surgical guides as the primary factor contributing to implant deviation(12, 25, 26) . In this study, we observed a correlation between increased forces and greater implant deviation. Notably, the current study found statistically significant differences in implant deviation across various force levels, particularly between the lower and higher force ranges.

The use of hand fixation of the surgical guides was evaluated by Kauffmann et al. (27) in fully edentulous patients. Hand fixation of surgical guides was reported to improve guide accuracy. Therefore, based on our findings proper stabilization of the surgical guide is highly recommended with care to the forces applied during surgery.

Based on our findings the null hypothesis was rejected as there was a difference in implant deviation within different forces. Given the limitation of the current study which is the invitro nature of the study and the limited forces applied. Further studies are recommended to evaluate the effect of different forces' magnitude and nature on the accuracy of surgical guides.

CONCLUSION

With the limitations in the current study, this study declared that one of the significant causes of implant deviation that lowers surgical guide accuracy is forces used during guided implant surgery. Increased forces during surgery are correlated with larger implant deviation. Therefore, stabilizing the surgical guides is strongly advised.

Conflict of interest:

The authors declare that they have no conflict of interest.

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