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OSSEOINTEGRATION OF DENTAL IMPLANTS IN RIDGES WITH INSUFFICIENT BONES USING DIFFERENT MEMBRANES FOR GUIDED BONE REGENERATION

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Abstract

Background
For successful dental implant therapy, it is vital to have high accuracy in the implant position which is assessed by various methods. Static Computer-Assisted Implant Surgery is shown to have high accuracy and efficacy among various methods.

Aim
The present in-vitro study aimed to assess the effect of alveolar bone morphology on the accuracy of static computer-assisted implant surgery. The study also assessed the effect of guide hole design on final implant position accuracy.

Methods
The study included 9 standard maxillary models that were partially edentulous and had two different types of morphologies in the alveolar ridge. Before implant placement, all models underwent CBCT evaluation and a laboratory scan was done before placing the implant using static computer-assisted implant surgery. Scan after surgery was superimposed on the position of initial treatment planning to assess deviation between planing and postsurgical position of the dental implant.

Results
36 implants were divided into 2 groups. Mean deviations at crest were significantly higher at the angular deviation, apex, and crest of implants at fresh extraction sockets with 4.31 ± 1.85^{o}, 1.63±0.57mm, and 0.82±0.27mm respectively compared to healed alveolar ridges with 1.84±0.97◦, 0.67±0.34, and 0.34±0.15 mm with $p<0.001$. Implants placed with manufacturer's sleeves had significantly higher angular (3.44 ± 1.7^{o}, $p=0.01$) and apical deviations (1.25±0.65 mm, $p=0.01$) compared to sleeveless guide-hole design with 2.74 ± 1.91^{o} and 1.04±0.64mm respectively. Also, significantly higher deviations for angular, apex, and crest were seen in parallel bone level implants compared to deep-threaded tapered bone with $p=0.01$, 0.002, and 0.0004 respectively.

Conclusion
The study concludes that final implant position accuracy with static computer-assisted implant surgery is assessed by implant macro design, guide-hole design, and alveolar ridge morphology.

Keywords: CBCT, Dental implant, digital imaging, guide-hole design, static computer-assisted implant surgery.

INTRODUCTION

The treatment outcomes following dental implant placement to replace missing teeth are largely determined by the correct final position of the placed dental implant. The treatment plan for the ideal 3D position of the placed dental implants is based on both anatomical and prosthetic considerations. Despite f vigorous planning, it is challenging to achieve the preoperatively determined 3D implant position with the use of manual implant-placement procedures and protocols [1]. To overcome these concerns and to attain an ideal 3D implant position, computer-guided implant placement procedures have become common in dentistry with the technological advancements in computer-assisted manufacturing technologies and the digital knowledge associated. Among various adopted techniques and technologies concerning dental implant placement, sCAIS (static computer-assisted implant surgery) has proven to have high accuracy and efficacy in comparison to other used modalities [2].

Digital workflow governs the fabrication of a guide for static computer-assisted implant surgery with the DICOM (Digital Imaging and Communication in Medicine) and STL (standardized tessellation language) files. The use of digital workflow owns a role in introducing various errors that can lead to reduced accuracy and precision concerning the final position of placed dental implant [3]. These potential errors can be associated with errors related to drill, guide-hole design, free drilling distance, inaccurate support, and guide position, the process of surgical guide fabrication, matching and transfer of data in digital planning software, and image processing errors. Improving the scanning technologies and CBCT quality, improving the precision of 3D printing and the use of artificial intelligence in various software have helped in reducing the error sources associated with static computer-assisted implant surgery and manufacturing [4].

The errors related to fabrication and other variables that can affect the final implant position have not been comprehensively studied in the literature despite of the high accuracy associated with static CAIS [5]. Based on the prosthetic, surgical, systemic, and local factors, dental implants can be placed in Type I, II, III, or IV sockets signifying the fresh extraction socket, early healing of soft tissues in 4-8 weeks, partial bone healing in 3-4 months, and full bone healing in more than 4 months [6].

Deviations can be seen from preoperatively planned implant position along with changes in the surgical drill trajectories that can be attributed to different morphologies of the alveolar ridges. The other factor can be implanted placement feasibility with static computer-assisted implant surgery in sleeveless manufacturers' sleeves. Sleeveless guide-hole design needs less space and reduces manufacturing time, total cost, instrument cost, and tolerance of the instrument [7].

Also, sleeveless guide-hole design is highly technique sensitive and should be controlled with expertise by using precise 3D printers, adequate hole offset, and correct guide-hole dimensions to attain the 3D deviations that are either lower or comparable to implants with sleeves by manufacturers. The recent literature data based on various clinical and in-vitro studies has shown inter-system and inert-manufacturer differences in assessing the final implant position accuracy where a vital role was depicted for implant macro-design and surgical component tolerance [8].

The existing literature knowledge is limited for potential error sources concerning implant-specific characteristics, surgical protocols, and local anatomic characteristics. To widen the knowledge of the predictability and accuracy of static computer-assisted implant surgery procedures, and overcome various limiting factors, the present in-vitro study was aimed at assessing the effect of alveolar bone morphology on implant placement accuracy [9]. The present study also aimed to assess the effect of implant macro design and guide-hole design on final implant position accuracy.

MATERIALS AND METHODS

The present in-vitro study aimed to assess the effect of alveolar bone morphology on the accuracy of static computer-assisted implant surgery. The study also assessed the effect of implant macro design and guide-hole design on final implant position accuracy. For the present study, the models used were partially edentulous maxillary jaw models that had a close simulation of D2 natural bone density with no soft tissues. In each of the 9 study models, 6 teeth were missing in single units making 6 edentulous sites and depicting either the fresh extraction socket or healed alveolar ridge.

Before placing the dental implants, a laboratory scan was done for each model along with the assessment using CBCT (cone-beam computed tomography) scan using the same equipment and scanner for each model. The DICOM and STL files obtained were then transferred to the implant planning software. The ideal 3D position of the dental implant was determined with a single clinician expert in the field keeping in consideration the prosthetic parameters and anatomical characteristics following the digital wax-set up made. Each implant was then placed digitally to support a single crown that was screw-retained.

The study included two guide-hole systems and two different implant macro designs. The two different implant macro designs used were self-tapping bone-level and tapered implants having 2.25 mm thread pitch (A) and deep thread-depth and self-tapping bone-level and parallel-walled bone-level implants with 0.8 mm thread pitch and shallow thread depth (B). The two guide-hole designs used in the study were sleeveless sites with the incorporation of the manufacturer's sleeve dimensions into the sleeveless sites and standard manufacturer's sleeves made of polyether-ether ketone and stainless-steel sleeves.

The guide to teeth offset was 0.15 mm and the thickness of the guide material was set to 3.5mm. Various fenestrations were made to allow a view of the guide's fit on the model intraoperatively. All the guides were made using the same light-cure and transparent resin for stereolithography in a 3D printer by a single technician expert in the field and were kept in a dark room till use.

Implants were placed after placing the models on the fixed and stabilized medium. All the implants were placed by a single oral surgeon expert in the field utilizing the static computer-assisted implant surgery using a surgical motor and utilizing the recommendations of the manufacturer. After implant placement, following the recommendations of the manufacturer, scan bodies were inserted into the implants. The implants were tightened till the tactile resistance was felt and the scan bodies were visualized for seating.

This was followed by attaining the STL files postoperatively by scanning the model using the laboratory scanner. These STL files obtained postoperatively were transferred to the treatment assessment tool of the implant plan software. Angular and linear deviations were assessed for the final implant position and planned implant position using the software for implant apex and implant shoulder.

The data were assessed following statistics and using the ANOVA the alveolar bone morphology and the results for guide hole designs were assessed. The data for the study were expressed in tables and utilizing the mean and standard deviation. The p-value of <0.05 defined the statistical significance of the study. All statistical assessments were performed utilizing the SPSS software version 25.0 (IBM Corp., Armonk, NY, USA).

RESULTS

The present in-vitro study aimed to assess the effect of alveolar bone morphology on the accuracy of static computer-assisted implant surgery. The study also assessed the effect of implant macro design and guide-hole design on final implant position accuracy. The study assessed 9 models with 18 healed alveolar ridges following extraction and 18 fresh extraction sockets. In these clinical situations, 18 implants were placed using static computer-assisted implant surgery with either SL or MS guide-hole design in 36 sites each. The study used 9 different guides changing the position of the guide-hole design to make a sample that was equally distributed. The measurements of all the angular and linear deviations are summarized in Table 1.

The study results showed that a significantly lower deviation was seen in implants placed in models having fully healed alveolar ridges compared to the ridges simulating the fresh extraction sockets. The implants placed in models showing fully healed extraction sockets and alveolar ridges depicted the mean deviations of angular, apex, and crest deviation of 1.88±0.97o, 0.67±0.38, and 0.38±0.15 mm respectively, and were 4.35±1.85, 1.63±0.57, and 0.82±0.27 mm respectively in models simulating the fresh extraction socket as shown in Table 1. In all the scenarios, it was noted that both digital and clinical deviation trajectory in the fresh extraction sockets was towards the alveolus, whereas, in healed ridges, in all directions, deviation from initial planning was noted.

It was also seen that the implants placed in the sleeveless manner depicted significantly lower mean angular and apical deviations with 2.74±1.91 and 1.04±0.68 mm respectively compared to the implants placed in the manufacturer’s sleeve with 3.48±1.7 and 1.29±0.65 mm respectively (Table 1). Also, a high deviation was seen at the crestal level which was a statistically non-significant difference between the sleeveless manner and manufacturer's sleeve with respective values of 0.56±0.32 and 0.65±0.32 mm respectively.

The study results showed a significantly higher deviation with the implants of 0.8 mm thread pitch compared to implants having thread-pitch of 2.25 mm. The mean deviation at angle, apex, and crest for the implants of 0.8 mm thread pitch was 3.58±1.91, 1.34±0.69, 0.69±0.32 was seen, whereas, for implants of thread-pitch 2.25 mm, the angular, apical, and crestal deviation was 2.65±1.83, 0.99±0.61, and 0.47±0.32 mm respectively (Table 1).

S. No	Variable	Number (n)	Min	Median	Max	Mean ± S. D	p-value
Angular deviation	Manufacturer sleeve	18	0.6	3	7.3	3.48±1.7	<0.05
	Sleeveless	18	0.5	2	7.8	2.74±1.91	
Implant macro design	0.8mm thread pitch	18	1.2	3.33	7.8	3.58±1.91	<0.05
	2.25mm thread pitch	18	1.33	2	6.6	2.65±1.83	
Ridge morphology	Fresh socket	18	0.3	4.3	7.8	4.35±1.85	<0.05
	Healed ridge	18	0.1	1.4	5.6	1.88±0.97	
3D deviation apex (mm)	Manufacturer sleeve	18	0.22	1.15	2.63	1.29±0.65	<0.05
	Sleeveless	18	0.27	0.74	2.73	1.04±0.68	
Implant macro design	0.8mm thread pitch	18	0.36	1.25	2.73	1.34±0.69	<0.05
	2.25mm thread pitch	18	0.22	0.73	2.33	0.99±0.61	
Ridge morphology	Fresh socket	18	0.43	1.66	2.73	1.63±0.57	<0.05
	Healed ridge	18	0.22	0.54	2.16	0.67±0.38	
3D deviation crest (mm)	Manufacturer sleeve	18	0.17	0.56	1.33	0.65±0.32	<0.05
	Sleeveless	18	0.04	0.41	1.53	0.56±0.32	
Implant macro design	0.8mm thread pitch	18	0.16	0.4	1.53	0.69±0.32	<0.05
	2.25mm thread	18	0.04	0.33	1.14	0.47±0.32	

	pitch						
Ridge morphology	Fresh socket	18	0.22	0.81	1.53	0.82±0.27	>0.05
	Healed ridge	18	0.04	0.31	0.97	0.38±0.15	

Table 1: Assessment of apical, crestal, and angular 3D implant deviation to evaluate guide-hole design, implant macro design, and ridge morphology in study models

The study results showed that apical, crestal, and angular deviations were seen in assessing the alveolar ridge morphology with $p<0.0001$. Also, for the implant macro design, statistically significant results were seen for apical, crestal, and angular deviations with respective p-values of 0.002. 0.0004, and 0.01. For guide hole design, the respective p-values for 3D deviation apex, 3D deviation crest, and angular deviation were 0.01, 0.07, and 0.03 showing statistically significant results for angular deviation and 3D deviation apex. However, a near-significant result was seen for the crest. In combining these variables and on interaction-term analysis, the results were statistically non-significant with Implant macro design: Guide-hole design showing p-values of 0.73, 0.67, and 0.72 for apex, crest, and angular deviation respectively. These values respectively were 0.92, 0.94, and 0.81 for Alveolar ridge morphology: Guide-hole design and were 0.35, 0.36, and 0.24 respectively for Alveolar ridge morphology: Implant macrodesign as denoted in Table 2.

DISCUSSION

The present in-vitro study assessed the potential error sources that can be attributed to implant-specific characteristics, surgical protocols, and the various anatomical characteristics on the accuracy and efficacy of static computer-assisted implant surgeries. The study results showed that static computer-assisted implant surgeries have high accuracy concerning the final positioning of the dental implant in the healed alveolar sockets compared to the implants placed in the fresh extraction sockets where a facial drift is noted in the implant position in the sleeveless guide-hole design compared to the guide-hole design where the manufacturer's sleeve was taken into consideration and in thread-pitch of 2.25 mm compared to thread pitch of 0.8mm.

The accuracy of static computer-assisted implant surgeries was largely governed by the morphology of the alveolar ridge.

Significantly lower angular, apical, and crestal deviation was seen for the implants placed in completely healed alveolar ridges compared to the fresh extraction socket. These results were consistent with the previous studies of El Kholy K et al [10] in 2019 and Wang M et al [11] in 2022 where authors reported higher deviations in implants placed in fresh extraction sockets compared to completely healed alveolar ridges. In the fresh socket implants, the deviation was noted towards the alveolar socket which was less resistance zone. Wang et al [11] in 2022 suggested that drill deflection by the wall of the bony socket can shift the implant to a more facial aspect. This facial shift is vital to consider for static computer-assisted implant surgeries to avoid the facial malposition of the dental implant.

The study results culminated in the vital role of a comprehensive evaluation of the clinical orientation of implant position during the complete surgical procedure to assess potential 3D malposition and to rectify it during the surgical procedure itself if needed. However, it was not evaluated in the present study. However, it should be considered in cases with early implant placement where healing is only limited to the soft tissues following extraction as suggested by Hammerle CHF et al [12] in 2007. With the deviations in the present study, it is vital to have a minimum of 2 mm distance from the vital anatomic structures in the apical area in cases of immediate implant placement.

Concerning the guide-hole design, a significantly higher deviation at the apex was seen in the manufacturer's sleeve group compared to the sleeveless group. Also, a lesser and statistically non-significant deviation was seen in the crest for the sleeveless group. These results were in agreement with the systematic review by Tallarico M et al [13] in 2021 and studies of Adams CR et al [14] in 2022 and Oh KC et al [15] in 2021 and can be attributed to reduced tolerance in surgical guide components. Surgical guides with manufacturer's sleeve had three gaps namely key-drill, key, and guide, whereas, in sleeveless, two gaps were there including the key-drill and guide-key. Each gap adds to tolerance for surgical instruments, sleeves, and guides.

Hence, the sleeveless guide can modify the gap tolerance with different guide-hole offsets. The more precision in a fit of a key in a guide hole is seen with small guide hole offsets as concluded by Cassetta M et al [16] in 2015. Also, a high precision fit makes it difficult to dismount and mount the guide and key which further affect the surgical instrument handling.

All-resin sleeveless design help in precision for narrow gaps seen in the maxillary anterior region as the outer diameter of the manufacturer sleeve is not useful in sleeveless guide-hole design. Also, with a sleeveless design, a reduced cost is seen for fabrication. For correct results, the sleeveless offset was assessed after printer matrix calibration which is recommended for laboratory set-up as the accuracy of the manufacturing process is largely defined by factors including printing orientation, material, and 3D printer use as suggested by Unkovskiy A et al [17] in 2018 and Kebler A et al [18] in 2022. Accuracy values largely differ with various manufacturers of static computer-assisted implant surgeries systems as concluded by Leaderach V et al [19] in 2017 and Zadrozny L et al [20] in 2022 where different accuracy was reported with different manufacturers.

The study results were following the results of El Kholy K et al [10] in 2019 where implant macro design affected the deviation and authors reported that tapered and shallow-threaded implants depicted less apical and crestal deviation compared to parallel-walled implants.

Limitations

The present study, however, holds various clinical limitations including the implant macroscopic designs including different diameters and lengths, other guide-hole designs such as closed or open sleeves, the effect of edentulism, and extended edentulous space that was not assessed in the present study. These factors can also affect the accuracy of the final position of the dental implant, particularly in cases where socket morphology makes it vital to attain primary implant stability for successful treatment. Also, the in-vitro nature and limited sample size limit the study results and clinical significance seen in the results of the present study.

This warrants further clinical and in-vitro studies to assess whether the closed or open sleeve guide-hole design, implant macro design including thread-design, diameter, length, or implant body, surgery as flapless or flap-elevation, and the morphology of alveolar bone as partial bone healing, early soft-tissue healing, long-span partial edentulism, and fully edentulous ridge affect the precision and accuracy of implants placed with static computer-assisted implant surgery.

Conclusion

The present study helps in standardizing various variables that can influence the final clinical outcomes. The study in-vitro study, considering its limitations, concludes that final implant position accuracy with static computer-assisted implant surgery is assessed by implant macro design, guide-hole design, and alveolar ridge morphology. Higher facial shifts and 3D deviations were seen in the implants placed at the fresh extraction socket compared to implants placed at fully healed alveolar ridges. Better accuracy concerning the final implant position is seen in the sleeveless guide hole design compared to the manufacturer's sleeve. Also, high accuracy in final implant position in deep-threaded tapered implants compared to shallow-threaded parallel-walled implants.

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