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Variations in Implant Position Based Upon Planning Strategy

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by

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Abstract

Objective: To compare different techniques for the digital planning of dental implant placement using commercially available computed aided design software and assess the variability in planned implant position.

Materials and methods: Eight dentists individually planned fifteen dental implants using SimPlant software. For each implant, the examiner planned the implant under four different conditions relating to the amount of digital reference data used: (1) no waxed up tooth, (2) pre-op intra-oral scan, (3) pre-op intraoral scan with a virtual tooth created by the examiner, and (4) pre-op intra-oral scan with wax up tooth in occlusion provided by the prosthodontist. . Implant sites included single tooth-bound, adjacent to a single tooth, and “stand alone” as in a distal abutment for an implant bridge. The implant placements were then compared against each other using analysis software in SimPlant. The outcome variables were angular deviation, horizontal placement, and vertical placement.

Results: For all measured outcomes in angulation and horizontal distance, “stand alone” planned implants were significantly different from each other (p-value = < 0.05). For vertical distance outcomes, single tooth-bound edentulous site planned implants were significantly different from each other (p-value=0.0057).

Conclusion: The variability between digitally planned dental implants is indirectly proportional to the number and proximity of reference points to the surgical site. If there are many fixed reference points available in close proximity to the surgical site, the estimation is likely to be more accurate in angulation and axial position, but not depth (e.g., a one-tooth edentulous site with adjacent teeth on the mesial and distal surfaces). In situations where there are fewer references (sites with multiple missing teeth), the estimation is more challenging and is prone to variability, which appears to be on par with error created between guided and implant surgery.

Introduction

The advent and proliferation of digital dentistry and all its associated capabilities is changing dentistry in a myriad of ways. Dental implant placement has been no exception to this changing tide of the digital age of dentistry. In the past several years, new advancements such as the cone-beam computerized tomography (CBCT) imaging, intra-oral scanners, and 3D implant planning software have provided dental professionals potentially better ways to diagnose and treat implant cases. With the increased information that this data provides, clinicians can diagnose and treatment plan while regarding a patient's anatomic structures, bone quantity, and final prosthesis. The team can now start with the end result (prosthetic outcome) and the implant can be placed according to a restoratively driven treatment plan. This combination of technology has become the norm in quality patient care.

Since the introduction of the first dental radiographs, dentists have been comfortable diagnosing and treating patients with two-dimensional imaging. The obvious limitations in these technologies are restricted visualization of three-dimensional structures. In 1988, Columbia Scientific, Inc. introduced a three-dimensional dental software which converted computerized axial slices and reformatted them into cross-sectional images which allowed for diagnosis and evaluation.[1] In 1993, Columbia Scientific introduced their first version of Simplant which allowed dental implants to be superimposed on the cross-sectional images to allow for further diagnostic information. In 2002, Columbia Scientific introduced technology for drilling osteotomies through a surgical guide based on the information produced from the CBCT scan. Since then, several software companies have created proprietary implant planning software and associated surgical instrumentation to allow a guided surgical approach.

For each computed tomography brand, specific software exists to support such three-dimensional planning. The specific software transforms the cross-sectional imaging to a Digital Imaging and Communication in Medicine (DICOM) format which can then be used to plan implant cases. After reformatting these images, the software allows the positioning of implants in a virtual environment by intuitively placing the implant in an ideal position based on trans-sectional views of the alveolar bone and adjacent teeth.

Besides the 3-dimensional anatomy, the ideal tooth position is also taken into account to determine the final implant placement. Because there isn't always a tooth at the site of implant placement to determine the correct prosthetic orientation, information on where the ideal crown location can be prepared. This can be performed in several ways: The first option is to virtually create a crown and position it based on the anatomical structures captured by the CBCT scan. However, information on the surrounding soft tissue and ideal occlusion cannot be determined from the scan alone. Therefore, the second option is to obtain an intra-oral scan and design a crown with a more realistic view of the soft tissues and occlusion. Consequently, the software can superimpose the image of the intra-oral scan and diagnostic wax-up over the images of the cone-beam computerized tomography to determine an ideal prosthetic restoration compared to vital anatomy and the hard and soft tissues of the patient.

Once the virtual plan is optimized, the information is used to fabricate a guide to transfer the virtual implant position to the ideal position in the patient. Several options are available for such a transfer: free-hand surgery, a static guide, or a dynamic guide. A static guide is produced via sterolithography using computer-aided design/computer assisted manufacture technology in the office or by a dental laboratory. With dynamic navigated surgery, the surgeon is able to display the virtual plan to allow real-time transfer of the information. This navigation can be adjusted during the surgery for more ideal implant placement if deemed necessary by the surgeon. Fig.1 outlines the steps in the creation and application of a guided implant protocol.

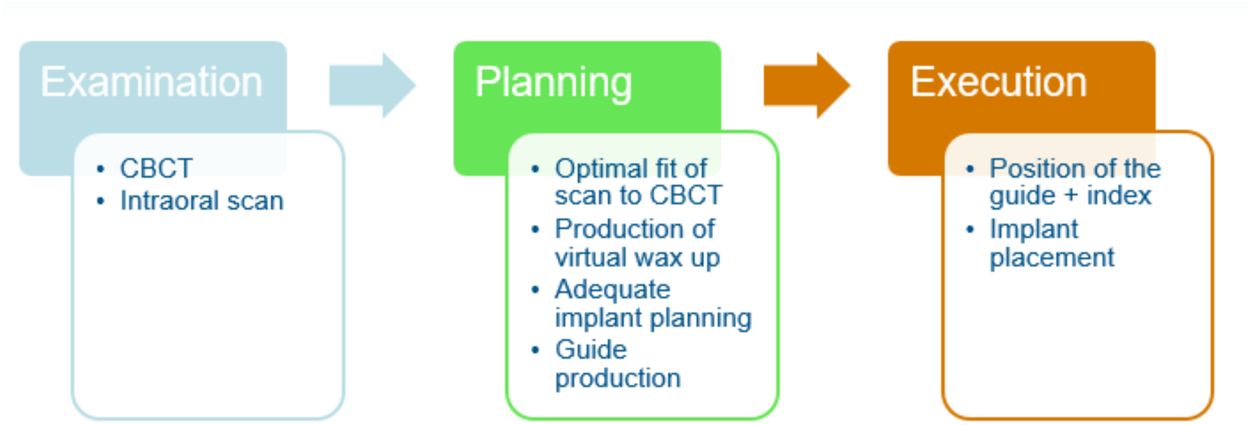

FIGURE 1 Workflow of the static and dynamic guided surgery systems.

Although this digital approach to treatment planning has its advantages to plan and optimize the implant position in a restoration-driven placement manner, many doubts have risen on its usefulness and accuracy compared to free-hand implant placement. Because digital dentistry depends on the cumulative and interactive steps presented above, small errors in obtaining data and treatment planning can lead to larger problems in the end result. In recent years, several studies have been performed to determine if guided surgery is superior to conventional procedures and what factors influence the accuracy of these different techniques such as guide production, guide support, level of guidance, and dynamic vs static guidance.

Ample studies have looked at the differences in guided versus free hand placement of implants. For example, Arisan studied a total of 353 implants in 54 patients using free hand and computer-aided methods.[2] They found significant errors in implant positioning probability in free hand implant placement (88%) versus mucosa-supported guides (6%). Moreover, Tan et al studied the accuracy of placing a single dental implant in the planned position using a guided surgery technique versus a free hand technique and compared the results with the planned position for each implant.[3] They found differences in angulation, shoulder apex, and depth displacements to be significantly closer to the planned implant in the fully guided protocol compared to the free hand protocol. Recent systematic reviews supported the conclusion of these results suggesting that fully guided implant placement yields higher accuracy than lower levels of guidance, especially when comparing free hand versus guided implant placement.[4,5]

The overwhelming results of the current literature suggest that any degree of guidance yields better results than free-hand surgery and that increasing the level of guidance increases accuracy. However, surgical guides do not perfectly translate the virtual implant position into reality. Deviations from the planned implant position still occur when stereolithographic guides are used for osteotomy procedures. In a study of 40 implants in six edentulous jaws, 85% of the implants were within 1mm of the intended position.[6] The mean coronal deviation has been shown to vary from 0.22 to 1.52mm. This is more accurate than the mean apical position, which varies from 0.24mm to 1.97mm. There can also be inaccuracies in the implant angle, varying from 1.5 degrees to 7.9 degrees.[3] Implant depths, both coronally and apically, have been found to be up to 0.38mm from the planned implant height.

Although digital planning and guided implant surgery has been shown to be superior to free-handed implant placement, there are some level of error in implant placement compared to the digitally planned implant. Clinically, errors can be minimized clinically by using shorter drills, reducing the diameter or the drill sleeves, and ensuring the guide is properly positioned. However, deviations may also reflect the sum of all errors occurring from imagining to the transformation of data into a guide, to the improper positioning of the latter during surgery.

External to the concept of error during implant placement, there is an unknown of how implant planning strategies also affect the final implant position. Although the difference in planning strategies would not be considered an "error" as the deviation reflects the practioner's intentional position and plan, it is logical that different digital planning techniques could lead to different planned implant positions. The extent to which having access to varying different levels of digital data affects implant planned position is unknown and may reflect levels of deviation equal to or greater than the differences seen comparing different surgical strategies. The implications of this may be clinically significant. Therefore, the objective of this study is to compare the primary techniques for digital planning of dental implant placement using commercially available computer aided design software and assess the variability in planned implant position. Those digital techniques are digital planning with: 1. CBCT only. 2. CBCT with intraoral scan superimposition. 3. CBCT, intraoral scan, and fitting of stock virtual tooth in the 3D view. 4. CBCT, intraoral scan, and full CAD/CAM digital diagnostic waxup.

<u>Null hypothesis:</u> There is no difference in digitally planned implant position when comparing plans using different planning strategies.

Materials and Methods:

The study protocol involved the data from seven patients that presented to the Medical University of South Carolina College of Dental Medicine needing at least one implant to restore adequate function. All patients' names were removed from the data and replaced with a randomized ID number before evaluation to ensure anonymous attribution of necessary information. The study was approved by the institutional review board.

Cone beam computed tomographs were acquired using the Planmeca Promax Mid. Patient specific CBCT capture settings were used to acquire the maxillary and mandibular alveolar arches. A bite tab was used to ensure a correct positioning of the patient and to avoid maxillary intercuspation during the radiographic phase. A digital scan of both the maxillary and mandibular arch were made using an in-laboratory intraoral scanner, TriOs (3Shape). Subsequently, a wax up in occlusion was completed on the oral using 3Shape software. Both the DICOM files from the CBCT as well as the STL files from the oral scan were imported in designated implant planning software (Simplant 17.0, Dentsply Sirona Implants, Hasselt, Belgium). After segmentation of the CBCT data and matching with the STL file, virtual 3D planning was performed for all implants. In all cases, Astra Tech EV implants with a standard diameter and length were used.

Eight dentists individually planned dental implants using the Simplant software. A total of 15 implants were planned by each examiner. Implant sites included single tooth-bound, adjacent to a single tooth, and "stand alone" as in a distal abutment for an implant bridge (Table 1). For each implant, the examiner was assigned the implant sites along with the implant size to plan under four different conditions relating to the amount of digital reference data used: (1) no waxed up tooth, (2) pre-op intra-oral scan, (3) pre-op intraoral scan with a virtual tooth created by the examiner, and (4) pre-op intra-oral scan with wax up tooth in occlusion provided by the prosthodontist. An example of an implant planning under the four different conditions is noted in Fig 2. The examiners planned each implant in order, to prevent the use of the additional information derived from the wax-up and virtual tooth being used prior.

TABLE 1 Demographic Distribution of Implant Sites

Variable	Value
Average implants per subject	1.9
Implant Position	
Maxilla	11
Central incisor	2
Lateral incisor	0
Canine	1
First premolar	4
Second premolar	0
First molar	4
Second molar	0
Mandible	4
Central incisor	1
Lateral incisor	0
Canine	0
First premolar	0
Second premolar	0
First molar	2
Second molar	1
Anterior	4
Posterior	11
Planned case	
Single implant	5
Implants part of a multiunit prosthesis	10
Condition	
Single unit, tooth bound implants (Group 1)	5
Adjacent to one tooth and one edentulous space (Group 2)	6
Stand alone, edentulous site (Group 3)	4

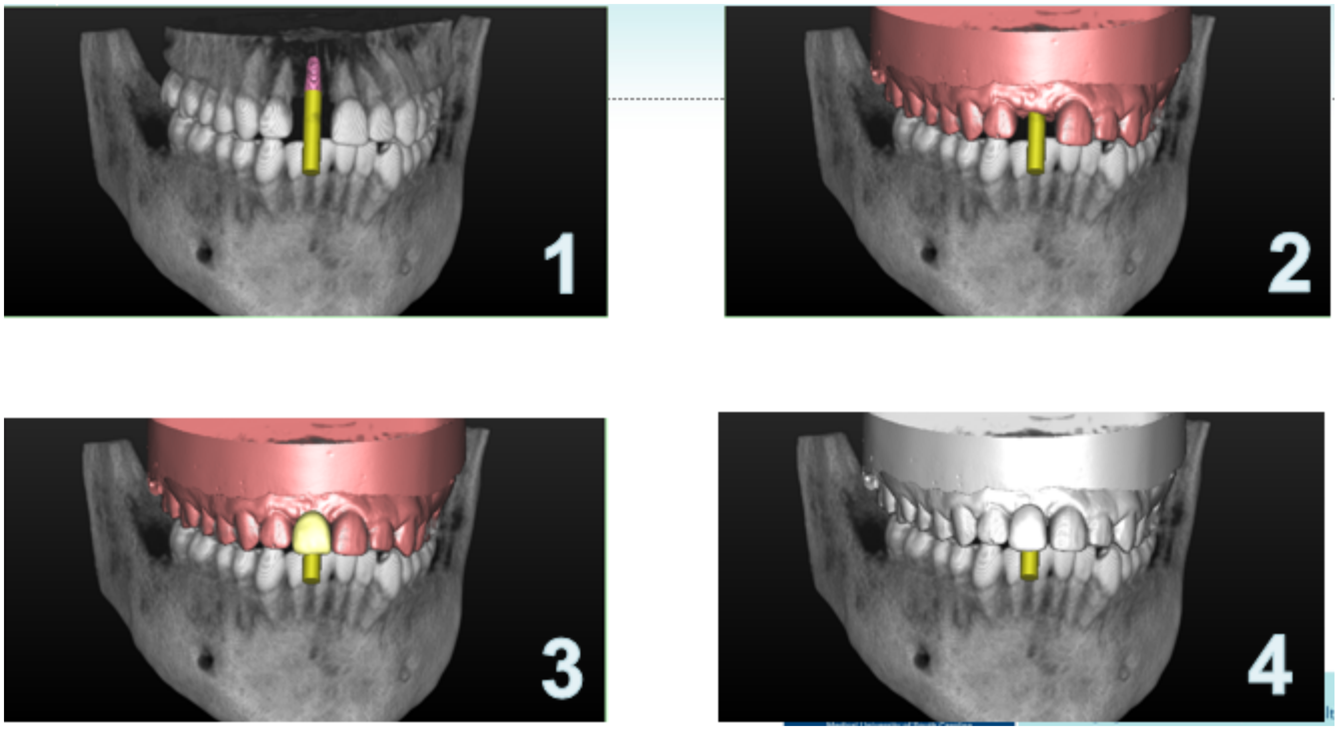

FIGURE 2 For each implant, the examiner was assigned the implant sites along with the implant size to plan under four different conditions relating to the amount of digital reference data used: (1) no waxed up tooth, (2) pre-op intra-oral scan, (3) pre-op intraoral scan with a virtual tooth created by the examiner, and (4) pre-op intra-oral scan with wax up tooth in occlusion provided by the prosthodontist.

Data Acquisition and Statistical Analysis

The difference between the virtually planned implant placements were measured in SimPlant to quantify the differences in implant planning between the various planning methods, calculating deviations in angulation (Fig. 3A), horizontal position (Fig. 3B) , and vertical position (Fig. 3C) between each condition. To make the angulation and axial position differences more clinically relevant, they are broken into mesial/distal and buccal/lingual deviations. The differences were calculated between conditions for each implant intraexaminer, then averaged together between all examiners. Therefore for a given implant, the deviations in position for that implant, for that examiner were calculated. For each implant position, the deviations were averaged between examiners. Deviations between all conditions were calculated: 1 v 2, 1 v 3, 1 v 4, 2 v 3, 2 v 4, 3 v 4. The deviations between groups were then compared to the other deviations: 1v2 vs. 1v3, 1v2 vs. 1v4, 1v2 vs. 2v3, etc. Then, the simulated cases were assigned to one of three groups for analysis. Group 1 was a single unit, tooth bound implant. Group 2 was an implant adjacent to one tooth or implant and one edentulous site. Group 3 was an implant part of a multiunit case planned in an edentulous site with no adjacent tooth or implant (Fig. 4).

For all outcomes, a repeated measures mixed model was run with condition in the model for each group (Group 1, 2, 3). If the main effect for condition was significant (less than 0.05) then we could look at the posthoc pairwise comparisons. A Tukey adjustment was used for those. All outcomes except Vertical Distance were transformed using a log-transformation for normality, but all values are presented on the original scale.

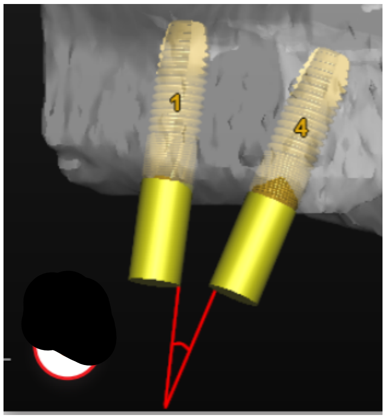

FIGURE 3A The angulation difference between planned implant.

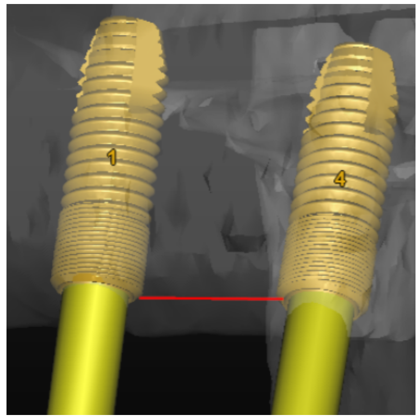

FIGURE 3B Horizontal distance between implants along the panoramic curve.

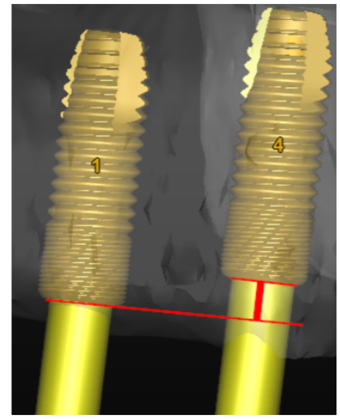

FIGURE 3C Vertical distance between planned implants.

FIGURE 4 The simulated were assigned to one of three groups for analysis.

Results

For all measured outcomes in angulation and horizontal distance, Group C planned implants were significantly different from each other (p-value = < 0.05). For vertical distance outcomes, Group 1 planned implants were significantly different from each other (p-value=0.0057) (Table 2).

TABLE 2 Resulting p values for differences in angulation and distance

	M/D Angulation	M/D Distance	Vertical Distance	B/L Angulation	B/L Distance
Single unit, tooth bound implants (Group 1)	0.08	0.40	0.006*	0.22	0.22
Adjacent to one tooth and one edentulous space (Group 2)	0.37	0.93	0.62	0.58	0.31
Stand alone, edentulous site (Group 3)	0.013*	<0.001*	0.42	0.002*	0.021*

When the main effect was significant, the conditions were analyzed for significant differences. In the mesial/distal angulation, 1v2 was significantly different than 1v4 (p-value= 0.0216) and 1v2 was significantly different than 2v4 (p-value=0.0088). In the mesial/distal distance, 1v2 was significantly different than 1v3 (p= <0.001) and 1v2 was significantly different than 2v3 (p=0.0018). In the buccal/lingual angulation comparisons, 1v2 vs 1v4 (p=0.028) and 1v2 and 2v4 (p=0.0023) were significantly different. In the buccal/lingual direction comparisons, 1v2 was significantly different than 1v3 (p=0.0089). In the vertical distance comparisons, 1v3 vs 3v4 was significantly different (p=0.0301) and 2v3 and 3v4 were significantly different (0.0315). All results are demonstrated in Table 3. The descriptive for each outcome are displayed in Figs. 5-9.

TABLE 3 Pairwise comparisons of the main effect for a significant condition. Significance is highlighted ($P < 0.05$)

Condition	Mesial Distal Angulation	Mesial Distal Distance	Vertical Distance	Buccal Lingual Angulation	Buccal Lingual Distance
1v2 versus 1v3	0.1776	<.0001	0.9378	0.2366	0.0089
1v2 versus 1v4	0.0216	0.4417	0.7460	0.0028	0.1846
1v2 versus 2v3	0.1543	0.0018	0.9418	0.0554	0.0941
1v2 versus 2v4	0.0088	0.1051	0.7370	0.0023	0.6110
1v2 versus 3v4	0.2979	0.0894	0.2806	0.1241	0.4656
1v3 versus 1v4	0.9643	0.0574	0.1981	0.6169	0.8750
1v3 versus 2v3	1.0000	0.9735	1.0000	0.9888	0.9642
1v3 versus 2v4	0.8816	0.3016	0.1920	0.5782	0.4245
1v3 versus 3v4	0.9998	0.3380	0.0301	0.9996	0.5682
1v4 versus 2v3	0.9752	0.3090	0.2042	0.9341	0.9997
1v4 versus 2v4	0.9998	0.9756	1.0000	1.0000	0.9745
1v4 versus 3v4	0.8875	0.9646	0.9750	0.8016	0.9947
2v3 versus 2v4	0.9064	0.7737	0.1981	0.9161	0.8993
2v3 versus 3v4	0.9995	0.8098	0.0315	0.9995	0.9614
2v4 versus 3v4	0.7474	1.0000	0.9772	0.7694	0.9999

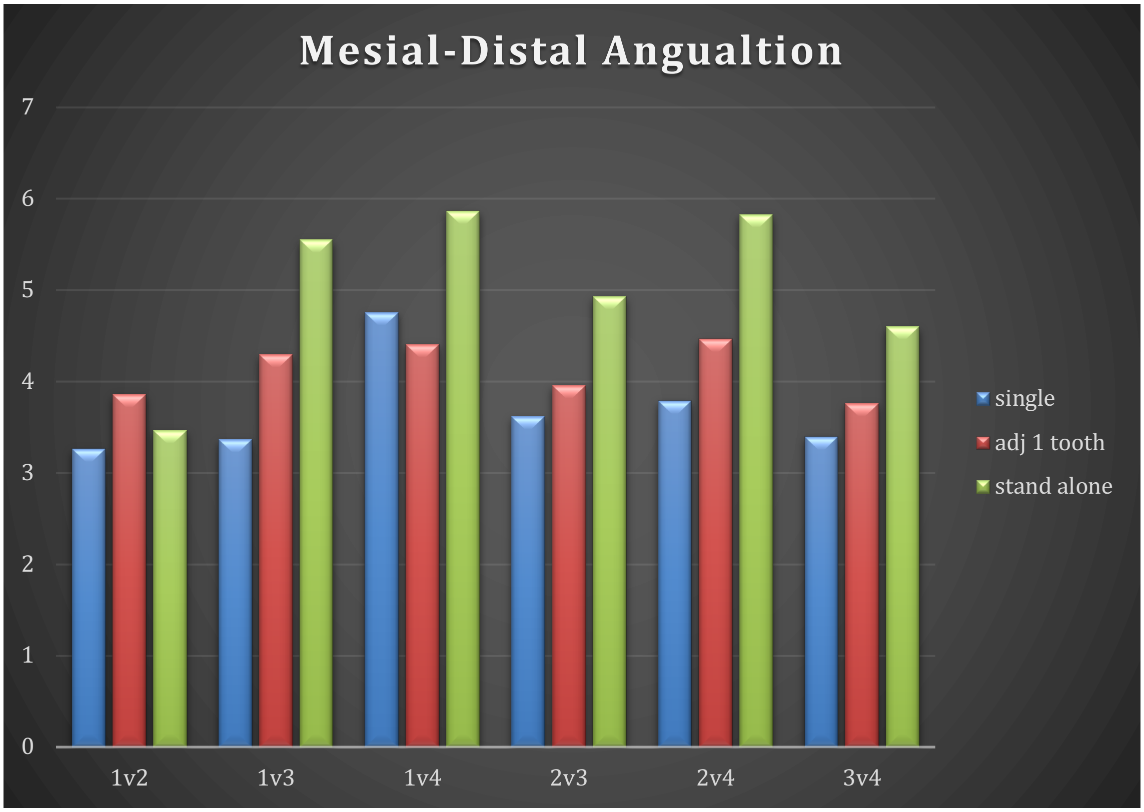

FIGURE 5 Bar graph comparison of the main effect of mesial-distal angulation on planned implants

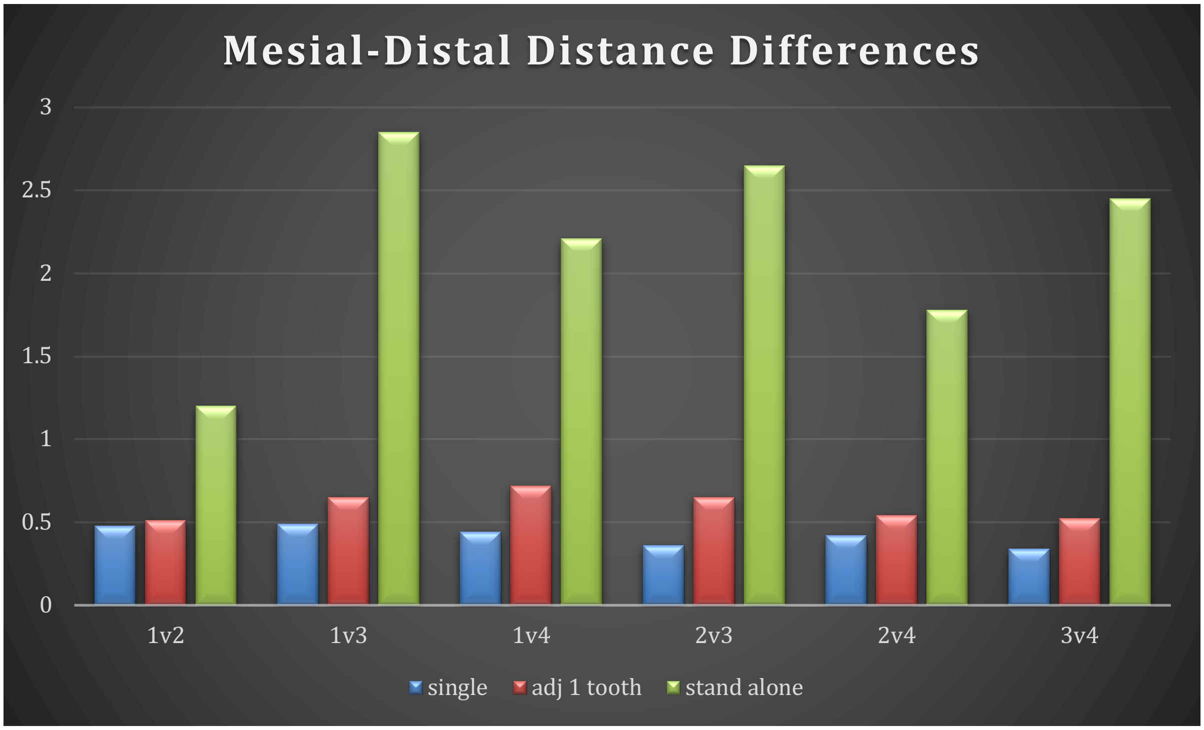

FIGURE 6 Bar graph comparison of the main effect of mesial-distal distance on planned implants

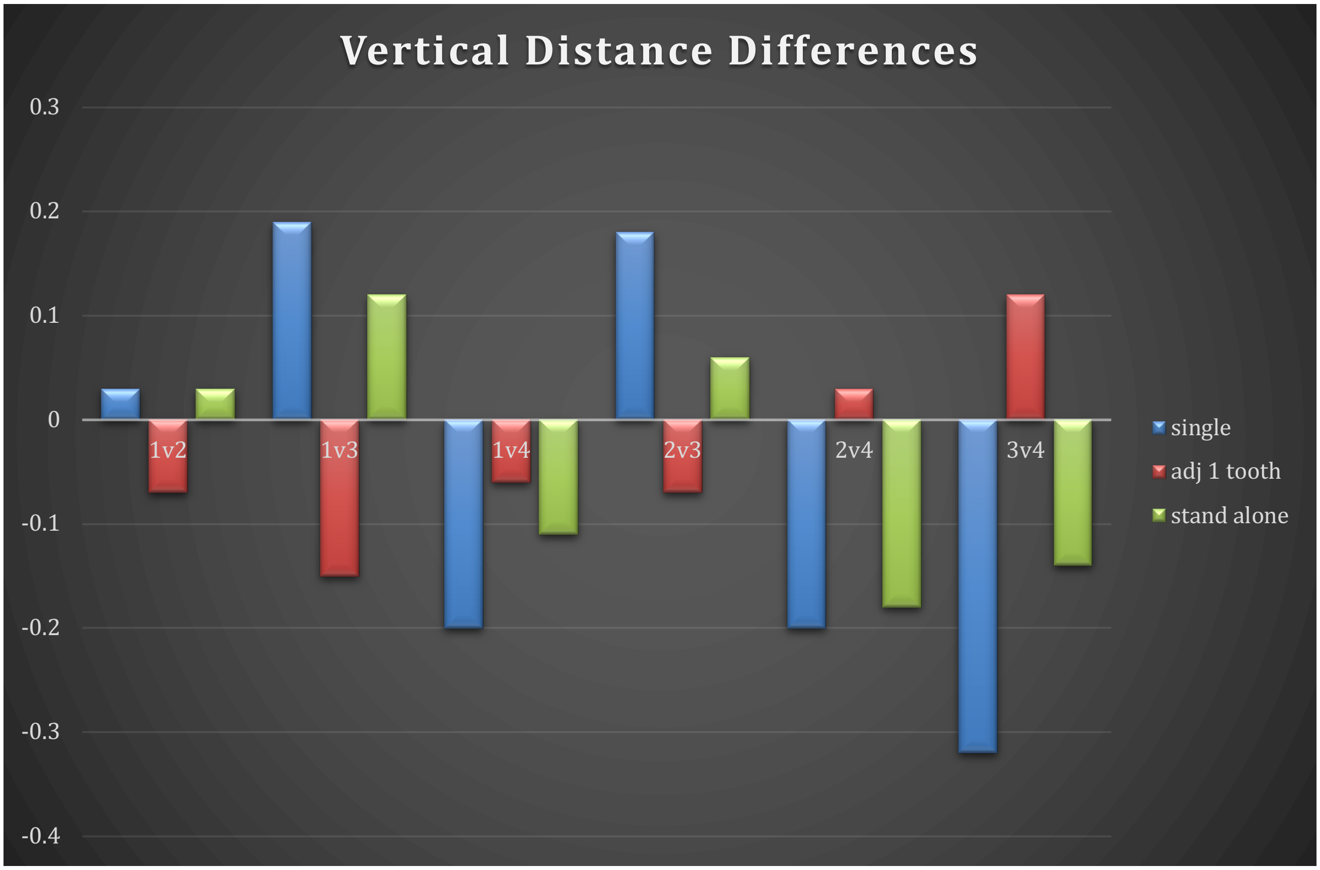

FIGURE 7 Bar graph comparison of the main effect of vertical distance on planned implants

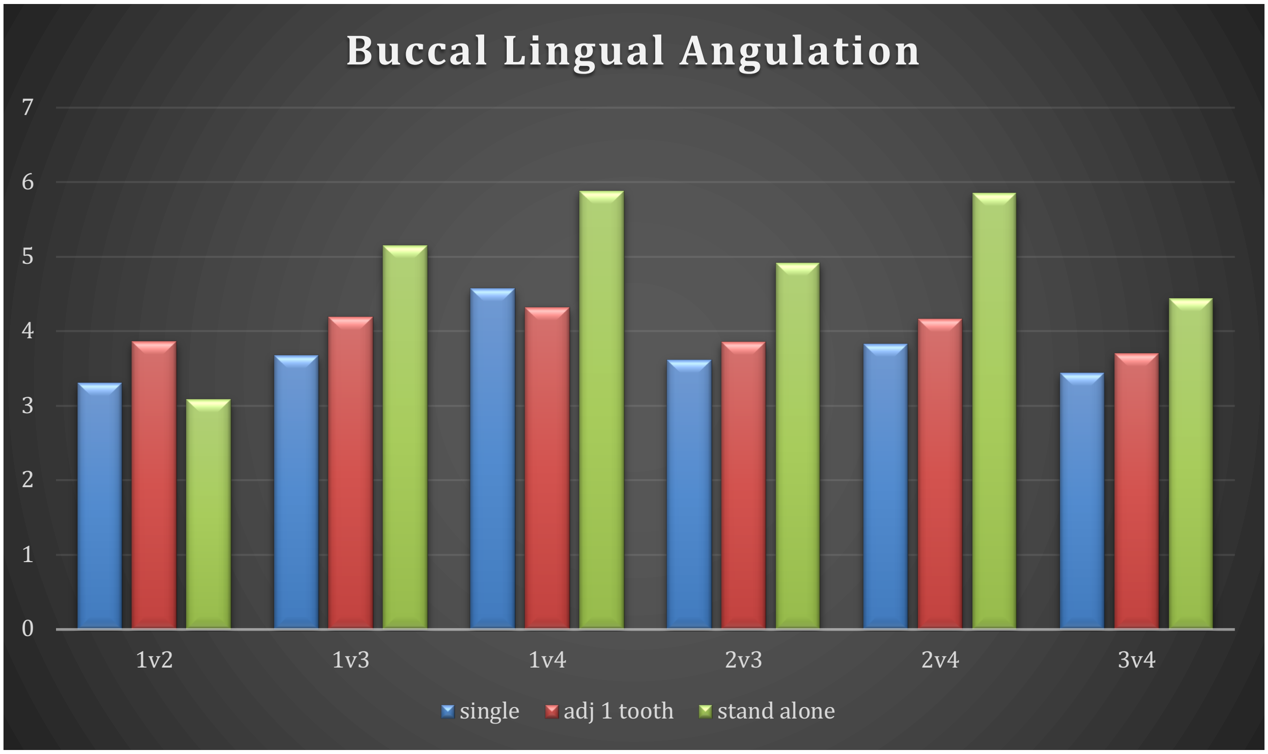

FIGURE 8 Bar graph comparison of the main effect of buccal-lingual angulation on planned implants

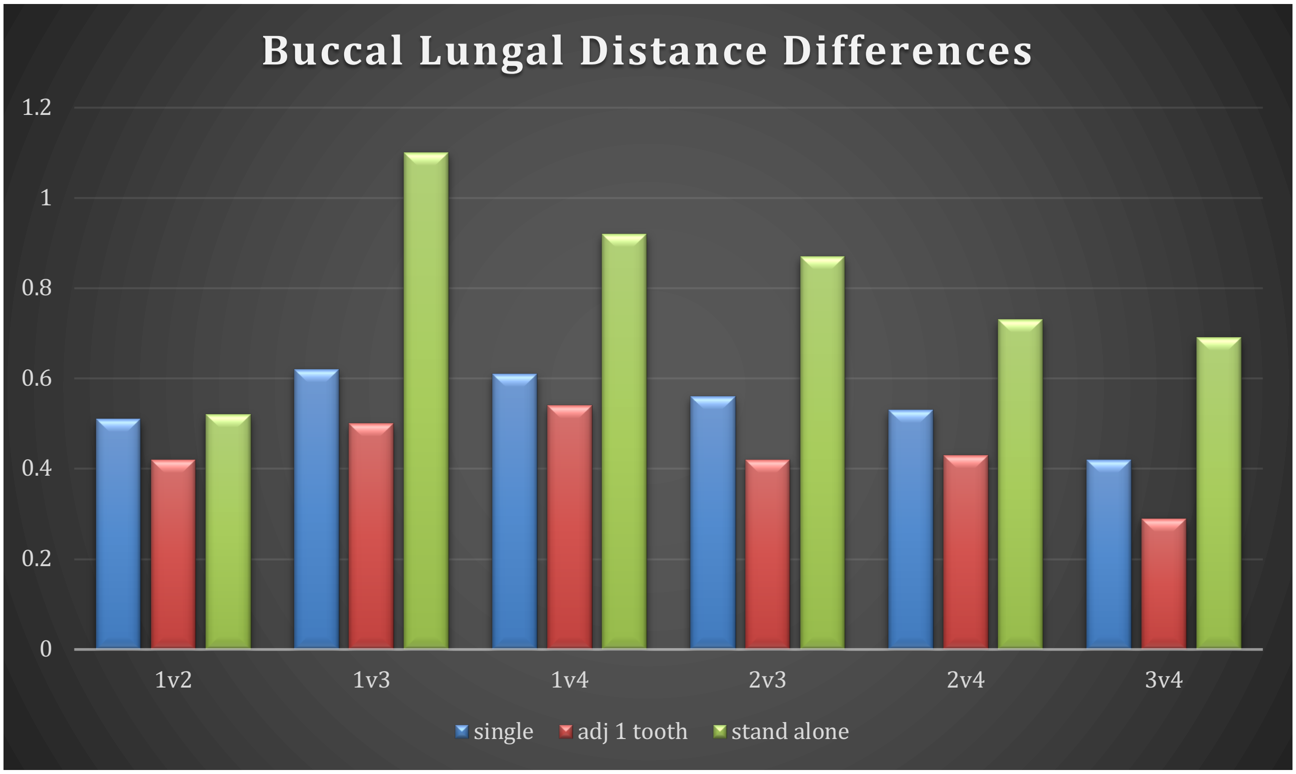

FIGURE 9 Bar graph comparison of the main effect of buccal-lingual distance on planned implants

Discussion

In the present study, different techniques for the digital planning of dental implants were evaluated and compared to one another to determine whether the strategy itself could possibly result in variations in implant position. The concept is that these differences are manifested surgically. Eight experienced clinicians planned a total of fifteen implants in eight patients. A commercially available computer aided design software was used to plan the implant cases, then used to assess the variation in angulation, horizontal distance, and vertical distance between all planned implants. We hypothesized that there would be a difference in all measured outcomes between various types of implant planning. Our working hypothesis can be accepted.

For all measured outcomes in angulation and horizontal distance, Group C (stand-alone bridge abutment implants) were significantly different from each other (p-value = <0.05). There was a much smaller difference in buccal-lingual angulation and bodily placement compared to mesial distal angulation and bodily placement. The range differences suggest the implant placement is limited by the bony architecture in the sagittal view and may not have as much variation as the implants placed without bony reference.

For all measured outcomes in the vertical distance comparisons, Group A planned implants were significantly different from one another (p-value= 0.0057). While the angle and bodily position of the single unit implants are not different, based on the different planning conditions there is a significant difference in platform depth. For example, one examiner planned two implants with a vertical difference of over 2mm.

Mistakes of positioning of the implant are one of the main errors in implant dentistry. The precise and prosthetically functional placement of the implant is of utmost importance if reliable sustainability is to be maintained. While fully guided implant surgery has been proven to result in less variation in implant deviations compared with free-hand implant placement, it is not enough to rely on transferring a preoperative virtual planning to the clinical situation if the preoperative planning is not clinically ideal.[7,8] Although each clinician may consider an "ideal" implant to be in a different position than another clinician, there is no doubt that an unexpected displacement of their "ideal" implant during planning with limited data could be a critical factor in the final implant placement. Therefore, a good outcome can only be obtained if the implant is planned in an ideal position compared to the prosthetic wax-up in relation to occlusion and vital anatomical structures.

There are a myriad of different ways to place implants guided, including robotic assistance, static guides, or dynamic guides that all claim to have accurate placement compared to the plan. However, many of these software systems that are available have different planning tools and most rely on a virtual tooth to create a virtual rendering of the prosthetic outcome and a vast majority of these do not allow you to do a fully guided wax up. In some situations, a virtual stock tooth may be adequate to plan the ideal implant. However, the results of this study have demonstrated that there is a significant difference in virtual treatment planning techniques and the clinician must take steps to avoid error in the planning stage. Specifically, clinicians should pay particular attention to angulation deviation and mesial/distal displacement of implant fixtures when planning wide-span edentulous multiunit sites and esthetic anterior implants.

A limitation to this study was that there was no defined "control" implant. Because there is no "ideal" implant placement, we were unable to use an independent variable to act as a baseline to compare our groups against. Although we were not able to determine which implant planning strategy was "the best", we can assume that planning with a full digital wax up is "ideal". When comparing data of planned implants using CBCT only, intraoral scan only, and stock tooth against the virtual wax-up in occlusion, we found there was a 7.71 degree difference, 6.62 degree difference, and a 5.74 degree difference, respectively. This shows the error of deviation only increases with decreased reference points and the planning method might only add to the error of overall guided implant placement accuracy.

Another limitation in our findings showed large differences in mean standard deviations. Alevizakos et. al. found that experienced clinicians place guided implants more accurately than inexperienced clinicians.[9] No study to date has researched whether the superiority of guided surgery planning is also present when performed by experienced clinicians. Future studies on our data could distinguish between intra-examiner variability to determine if surgical and/or digital experience has an effect on implant positioning during planning with different techniques.

Conclusion

The variability between digitally planned dental implants is indirectly proportional to the number and proximity of reference points to the surgical site. If there are many fixed reference points available in close proximity to the surgical site, the estimation is likely to be more accurate in angulation and axial position, but not depth (e.g., a one-tooth edentulous site with adjacent teeth on the mesial and distal surfaces). In situations where there are fewer references (sites with multiple missing teeth), the estimation is more challenging and is prone to variability, which appears to be on par with error created between guided and implant surgery.

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