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Comparative Evaluation Of The Influence Of Different Software And Effect Of Time On The Accuracy And Precision of Fully Guided Implant Placement– An In-Vitro Study

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Abstract—**This study aimed to evaluate and compare the accuracy and precision of surgical guides fabricated using different implant planning software and to assess the effect of time on their dimensional stability. Seven 3D-printed mandibular models were used for guided implant placement, and accuracy was analyzed via post-placement scan superimposition. Dimensional stability was assessed over 20 days using deviation analyses. Results showed BlueSky Bio guides had higher placement accuracy than 3Shape when Exoplan was used as control group. In the second parameter tested, time-related dimensional changes were statistically significant, indicating potential effects on the precision of guided implant surgery.**

Index Terms—**surgical guide; exoplan; Bluesky bio; 3shape; 3D printing.**

I. INTRODUCTION

Dental implants are a predictable and effective solution for rehabilitating edentulous patients, providing both functional and aesthetic benefits. Accurate three-dimensional (3D) implant positioning is crucial for long-term success and optimal prosthetic outcomes. Prosthetically driven planning minimizes biological and technical complications, while inaccurate placement can lead to bone loss, peri-implantitis, and poor aesthetics.

Computer-assisted implant placement (CAIP) and 3D-printed surgical guides enhance precision by improving control over implant angulation, depth, and position. Static CAIP (sCAIP) systems integrate CBCT and surface scan data through computer-aided design (CAD) software to produce accurate, prosthetically guided templates.

However, factors such as fabrication techniques, material stability, and guide adaptation influence accuracy. Dimensional changes over time may also affect guide fit and implant placement precision. Limited research exists comparing software accuracy or evaluating time-related guide stability.

This study therefore compares the accuracy of surgical guides fabricated using different implant planning software (BlueSky Bio, 3Shape, and Exoplan) and assesses the effect of time on their dimensional stability to enhance precision in guided implant surgery.

II. MATERIAL AND METHODOLOGY

Seven mandibular models with bilateral posterior edentulous spaces were 3D-printed using thermoplastic resin (Shining 3D ACCUFAB-D1S, China). Each model was scanned with an extraoral scanner and CBCT, and the datasets were merged into STL format for surgical guide fabrication. One control guide was designed using Exoplan (S1), while six test guides (three each) were designed using BlueSky Bio (S2) and 3Shape (S3) software. Implants (4.2 × 10 mm, MIS) were virtually planned and placed using standardized sequential drilling (2–4.2 mm). A single operator performed all procedures to minimize variability. Post-placement scans of the control and test models were superimposed to evaluate positional accuracy. Additionally, a separate anterior model (region 23) guide was fabricated using Exoplan to assess dimensional stability over time. Scans were taken at 5-, 10-, 15-, and 20-days post-fabrication, and STL comparisons were made with the original CAD file. Mean Absolute Deviation (MAD), axial, and linear deviations were measured to analyze time-dependent dimensional changes in the guides.

Model Fabrication

For the fabrication of 3D printed models, a CBCT scan (CS 9300, Carestream, Germany) of a patient with missing posterior teeth was selected. In addition, the patient's diagnostic casts were scanned to generate STL files. The CBCT data were converted into DICOM format.

Both the DICOM and STL files were merged using Exoplan software to produce a virtual 3D model for printing. A total of seven mandibular models, each featuring bilateral posterior edentulous areas (regions 46 and 36), were fabricated using thermoplastic resin via 3D printing.

Implant Planning

Virtual implant planning was conducted for both control and test groups using three different software platforms: Exoplan (control group), BlueSky Bio, and 3Shape. The STL and DICOM files were imported into each software and merged to allow for precise planning. To ensure standardization and minimize variability, a single implant size (4.2 × 10 mm, MIS implant) was chosen for placement in both edentulous sites. After virtual implant planning, STL files of the digitally planned models were generated for each software system.

Surgical Guide Fabrication

The merged DICOM and STL datasets were used within each software (Exoplan, BlueSky Bio, and 3Shape) to design surgical guides. These guides were fabricated using a 3D printer (Shining 3D L4D) and SG resin (Shining 3D).

A total of seven surgical guides were fabricated:

- 1 guide using Exoplan (for the control group)
- 3 guides each using BlueSky Bio and 3Shape (for the test groups)

Additionally, one surgical guide was fabricated for a model with a missing anterior tooth (region 23) using Exoplan software. This guide was used to assess dimensional distortion over time.

Implant Placement

All implants planned were straight, bone-level MIS implants (4.2 × 10 mm). The guides were placed and stabilized on the printed models, which were fixed into custom acrylic platforms using cold-cure acrylic resin (DPI RR) in the dough stage. Each model was stabilized prior to drilling.

A single experienced surgeon performed all implant placements using a standardized guided sequential drilling protocol (from 2 mm to 4.2 mm). A total of 12 implants were placed using the surgical guides from the test software, and 2 implants using the guide from the control group.

Accuracy Evaluation

To assess implant placement accuracy, laboratory scan bodies were attached to the implants placed in all models. These models were scanned using a Shining 3D laboratory scanner, generating STL files of the final implant positions. Accuracy was evaluated by superimposing the STL files of test models onto the reference (control) model, using Geomagic Control X software. Teeth served as stable landmarks to facilitate point-to-point and automated registration for optimal superimposition. Following superimposition, spatial deviations of the implants in the test group relative to the control group were assessed by measuring:

- Angular deviation: determined by creating vectors from the center of cylindrical scan bodies and calculating the angle between corresponding implant vectors.
- Vertical deviation: measured along the implant's long axis from the platform level.
- Horizontal deviation: measured in both the buccolingual (X-axis) and mesiodistal (Y-axis) directions.

Dimensional Stability Assessment

To evaluate the dimensional stability of the surgical guides over time, printed guides were scanned at 5, 10, 15, and 20-day intervals. STL files obtained at each time point were compared to the original CAD design. The following parameters were measured:

- Mean Absolute Deviation (MAD) of the intaglio (tissue-contacting) surface
- Axial and linear deviations of the guides over time

This analysis helped determine whether time-dependent distortion occurred, which could influence the longer

III. RESULTS

Table no. 1 Comparison of mean Angular deviation in Tooth site 36 & 46 b/w 2 implants using Mann Whitney Test

Tooth	Implants	N	Mean	SD	Mean Diff	p-value
Implant on 36	Blue sky	3	3.644	1.895	-0.918	0.83
	3 Shape	3	4.562	3.096		
Implant on 46	Blue sky	3	6.089	0.564	-2.309	0.04*
	3 Shape	3	8.398	1.522		

Table no. 2 Comparison of mean Vertical deviation in Tooth site 36 & 46 b/w 2 implants using Mann Whitney Test

Tooth	Implants	N	Mean	SD	Mean Diff	p-value
Implant on 36	Blue sky	3	1.156	0.653	0.499	0.51
	3 Shape	3	0.657	0.330		
Implant on 46	Blue sky	3	2.975	1.001	-0.521	0.51
	3 Shape	3	3.496	0.240		

Table no. 3 Comparison of mean Horizontal deviation on X-axis in Tooth site 36 & 46 b/w 2 implants using Mann Whitney Test

Tooth	Implants	N	Mean	SD	Mean Diff	p-value
Implant on 36	Blue sky	3	1.291	0.556	-0.029	0.83
	3 Shape	3	1.319	1.180		
Implant on 46	Blue sky	3	2.203	2.663	-0.248	0.83
	3 Shape	3	2.451	3.431		

Table no. 4 Comparison of mean Horizontal deviation on Y-axis in Tooth site 36 & 46 b/w 2 implants using Mann Whitney Test

Tooth	Implants	N	Mean	SD	Mean Diff	p-value
Implant on 36	Blue sky	3	0.894	0.257	-0.763	0.04*
	3 Shape	3	1.657	0.589		
Implant on 46	Blue sky	3	1.337	1.054	0.600	0.28
	3 Shape	3	0.737	0.739		

Table no. 5 Comparison of mean MAD - Intaglio surface contacting teeth b/w diff. time intervals using Repeated Measures of ANOVA Test

Time	N	Mean	SD	Min	Max	p-value
T0	3	0.0133	0.0015	0.012	0.015	0.01*
T1	3	0.0123	0.0021	0.010	0.014	

T2	3	0.0047	0.0025	0.002	0.007	
T3	3	0.0037	0.0015	0.002	0.005	
T4	3	0.0030	0.0010	0.002	0.004	

Table no. 6 Comparison of mean MAD - Intaglio surface contacting mucosa b/w diff. time intervals using Repeated Measures of ANOVA Test

Time	N	Mean	SD	Min	Max	p-value
T0	3	0.0437	0.0015	0.042	0.045	<0.001*
T1	3	0.0437	0.0021	0.042	0.046	
T2	3	0.0320	0.0010	0.031	0.033	
T3	3	0.0750	0.0010	0.074	0.076	
T4	3	0.0637	0.0015	0.062	0.065	

Table no. 7 Multiple comparison of mean difference in MAD - Intaglio surface contacting teeth b/w diff. time intervals using Bonferroni's post hoc Test

(I) Time	(J) Time	Mean Diff. (I-J)	95% CI for Diff.		p-value
			Lower	Upper	
T0	T1	0.0010	-0.0270	0.0290	1.00
	T2	0.0090	-0.0170	0.0350	0.43
	T3	0.0100	-0.0140	0.0330	0.29
	T4	0.0100	0.0010	0.0200	0.04*
T1	T2	0.0080	-0.0230	0.0380	0.73
	T3	0.0090	0.0040	0.0130	0.02*
	T4	0.0090	-0.0160	0.0340	0.34
T2	T3	0.0010	-0.0270	0.0290	1.00
	T4	0.0020	-0.0150	0.0190	1.00
T3	T4	0.0010	-0.0200	0.0210	1.00

Table no. 8 Comparison of mean Axis deviation (degrees) of sleeves' housings on sagittal plane b/w diff. time intervals using Repeated Measures of ANOVA Test

Time	N	Mean	SD	Min	Max	p-value
T0	3	0.0670	0.0010	0.066	0.068	<0.001*
T1	3	0.0550	0.0010	0.054	0.056	
T2	3	0.0640	0.0010	0.063	0.065	
T3	3	0.0430	0.0010	0.042	0.044	
T4	3	0.0210	0.0010	0.020	0.022	

Table no. 9 Multiple comparison of mean difference in MAD - Intaglio surface contacting mucosa b/w diff. time intervals using Bonferroni's post hoc Test

(I) Time	(J) Time	Mean Diff. (I-J)	95% CI for Diff.		p-value
			Lower	Upper	
T0	T1	0.0000	-0.0080	0.0080	1.00
	T2	0.0120	-0.0070	0.0300	0.13
	T3	-0.0310	-0.0360	-0.0270	0.001*
	T4	-0.0200	-0.0200	-0.0200	0.52
T1	T2	0.0120	-0.0090	0.0320	0.15
	T3	-0.0310	-0.0410	-0.0220	0.005*
	T4	-0.0200	-0.0280	-0.0120	0.008*
T2	T3	-0.0430	-0.0570	-0.0290	0.005*
	T4	-0.0320	-0.0500	-0.0130	0.02*
T3	T4	0.0110	0.0070	0.0160	0.009*

Table no. 10 Multiple comparison of mean difference in Axis deviation of sleeves' housings on sagittal plane b/w diff. time intervals using Bonferroni's post hoc Test

(I) Time	(J) Time	Mean Diff. (I-J)	95% CI for Diff.		p-value
			Lower	Upper	
T0	T1	0.0120	-0.0020	0.0260	0.07
	T2	0.0030	-0.0130	0.0190	1.00
	T3	0.0240	0.0160	0.0320	0.006*
	T4	0.0460	0.0320	0.0600	0.005*
T1	T2	-0.0090	-0.0170	-0.0010	0.04*
	T3	0.0120	0.0040	0.0200	0.02*
	T4	0.0340	0.0200	0.0480	0.009*
T2	T3	0.0210	0.0070	0.0350	0.02*
	T4	0.0430	0.0350	0.0510	0.002*
T3	T4	0.0220	0.0060	0.0380	0.03*

Table no. 11 Comparison of mean Axis deviation (degrees) of sleeves' housings on frontal plane (XZ plane) b/w diff. time intervals using Repeated Measures of ANOVA Test

Time	N	Mean	SD	Min	Max	p-value
T0	3	0.1743	0.0021	0.172	0.176	<0.001*
T1	3	0.1750	0.0010	0.174	0.176	
T2	3	0.0450	0.0010	0.044	0.046	
T3	3	0.1320	0.0010	0.131	0.133	

T4	3	0.4030	0.0010	0.402	0.404	

Table no. 12 Multiple comparison of mean difference in Axis deviation of sleeves' housings on frontal plane b/w diff. time intervals using Bonferroni's post hoc Test

(I) Time	(J) Time	Mean Diff. (I-J)	95% CI for Diff.		p-value
			Lower	Upper	
T0	T1	-0.0010	-0.0240	0.0230	1.00
	T2	0.1290	0.1060	0.1530	0.002*
	T3	0.0420	0.0250	0.0590	0.008*
	T4	-0.2290	-0.2460	-0.2120	<0.001*
T1	T2	0.1300	0.1300	0.1300	0.002*
	T3	0.0430	0.0350	0.0510	0.002*
	T4	-0.2280	-0.2360	-0.2200	<0.001*
T2	T3	-0.0870	-0.0950	-0.0790	<0.001*
	T4	-0.3580	-0.3660	-0.3500	<0.001*
T3	T4	-0.2710	-0.2710	-0.2710	<0.001*

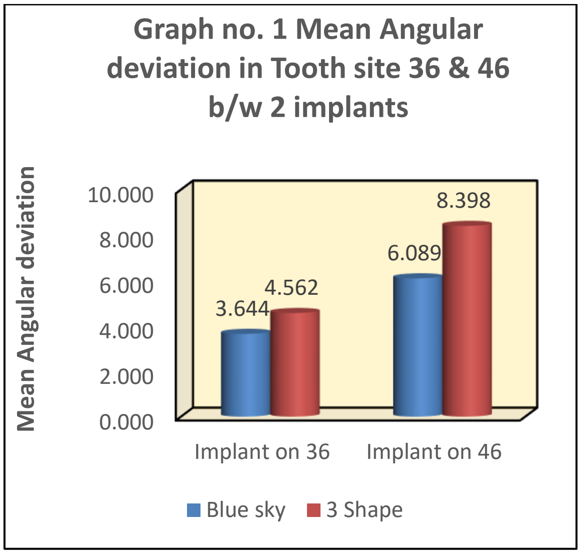
Table no. 13 Comparison of mean Centre points deviation at the entrance of sleeves' housings (in mm) b/w diff. time intervals using Repeated Measures of ANOVA Test

Time	N	Mean	SD	Min	Max	p-value
T0	3	0.1560	0.0010	0.155	0.157	<0.001*
T1	3	0.1450	0.0010	0.144	0.146	
T2	3	0.0320	0.0010	0.031	0.033	
T3	3	0.4040	0.0010	0.403	0.405	
T4	3	0.0630	0.0010	0.062	0.064	

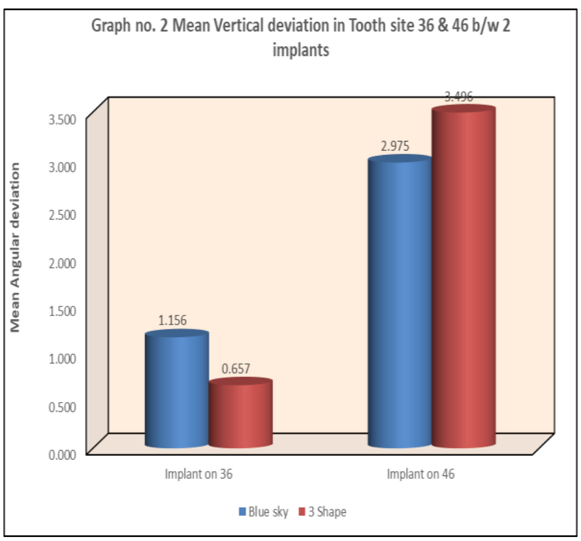
Table no. 14 Multiple comparison of mean difference in Centre points deviation at the entrance of sleeves' housings b/w diff. time intervals using Bonferroni's post hoc Test

(I) Time	(J) Time	Mean Diff. (I-J)	95% CI for Diff.		p-value
			Lower	Upper	
T0	T1	0.0110	-0.0030	0.0250	0.08*
	T2	0.1240	0.1080	0.1400	0.001*
	T3	-0.2480	-0.2620	-0.2340	<0.001*
	T4	0.0930	0.0850	0.1010	<0.001*
T1	T2	0.1130	0.1050	0.1210	<0.001*
	T3	-0.2590	-0.2730	-0.2450	<0.001*
	T4	0.0820	0.0660	0.0980	0.002*

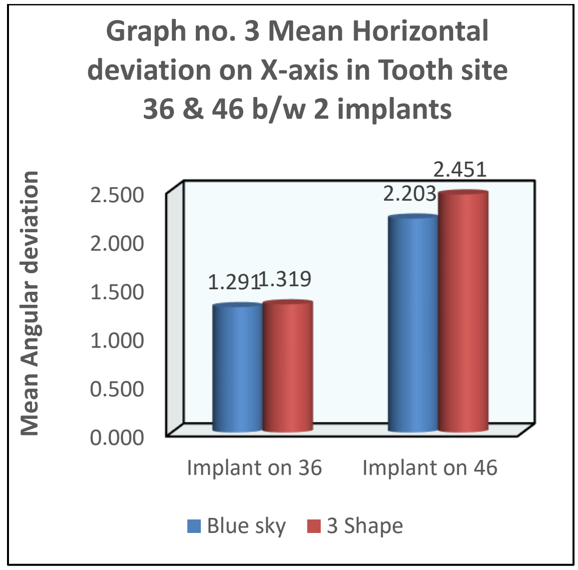
T2	T3	-0.3720	-0.3800	-0.3640	<0.001*
	T4	-0.0310	-0.0450	-0.0170	0.01*
T3	T4	0.3410	0.3330	0.3490	<0.001*



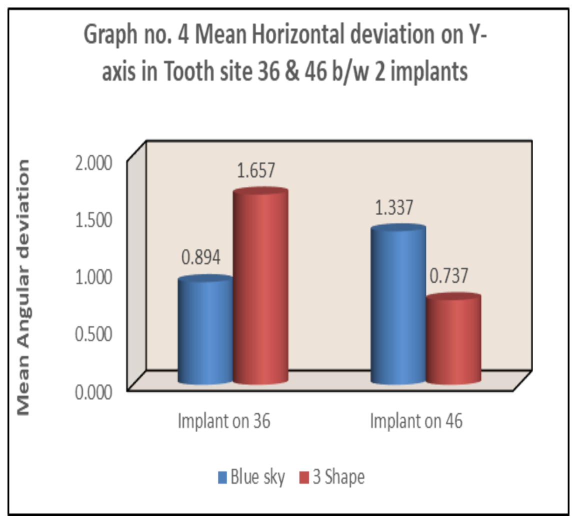
Graph no. 1 Mean Angular deviation in Tooth site 36 & 46 b/w 2 implants



Graph no. 2 Mean Vertical deviation in Tooth site 36 & 46 b/w 2 implants



Graph no. 3 Mean Horizontal deviation on X-axis in Tooth site 36 & 46 b/w 2 implants



Graph no. 4 Mean Horizontal deviation on Y-axis in Tooth site 36 & 46 b/w 2 implants

IV. DISCUSSION

Surgically guided implant placement ensures precise and predictable positioning of dental implants, enhancing both function and aesthetics. Using CBCT data, custom CAD/CAM or 3D-printed guides translate virtual plans into accurate clinical outcomes, minimizing operator error compared to freehand methods.

Software such as 3Shape, BlueSkyBio, and Exoplan differ in precision, usability, and cost—BlueSkyBio being more user-friendly, while Exoplan offers advanced customization and AI-assisted planning. Guided implant surgery improves 3D accuracy, reduces invasiveness, and enhances prosthetic outcomes, though at a higher cost.

This study compared different software for fabricating surgical guides and evaluated the effect of time on their dimensional stability to achieve precise, aesthetic, and prosthetic implant placement. Using Geomagic Control X, STL files of test groups were superimposed over control files to measure deviations. Implant accuracy was assessed by evaluating vertical, horizontal (buccolingual and mesiodistal), and angular deviations. Vertical deviation represented discrepancies along the implant's long axis, horizontal deviation along X and Y axes, and angular deviation was measured between vectors of planned and placed implants. Results from both test groups were compared and tabulated against the control. 3Shape showed higher angular deviation than BlueSky, significantly at site 46 (8.398° ± 1.522 vs. 6.089° ± 0.564; $p = 0.04$). Though differences at site 36 were not significant ($p = 0.83$), 3Shape generally exhibited greater angular error, while BlueSky's lower deviation suggests better guide design and data integration. Vertical differences were not significant ($p = 0.51$). BlueSky showed higher deviation at site 36, and 3Shape at site 46, indicating posterior anatomical challenges may affect guide stability and implant depth No significant X-axis difference was noted ($p = 0.83$). However, 3Shape had greater Y-axis deviation at site 36 (1.657 mm ± 0.589 vs. 0.894 mm ± 0.257; $p = 0.04$), showing lower mesiodistal accuracy.

Overall: Deviations were greater at posterior sites (46) across both systems. BlueSky demonstrated higher overall accuracy, especially in angular and Y-axis parameters, indicating superior guide precision and software performance.

Guide Accuracy and Deviation Analysis: This study evaluated surgical guide accuracy based on deviations in the intaglio surface and metal sleeve housing.

Intaglio surface MAD significantly decreased from T0 (0.0133) to T4 (0.0030; $p = 0.01$), indicating improved dimensional stability over time. Axis deviation showed an overall significant reduction ($p < 0.001$) from T0 (0.0670) to T4 (0.0210), reflecting enhanced angular precision. Values initially decreased (T0–T2) but peaked at T4 (0.4030), suggesting variable lateral stability during fabrication. Center deviation fluctuated, peaking at T3 (0.4040) and dropping at T4 (0.0630), indicating sensitivity to procedural and environmental factors.

Interpretation: Dimensional fluctuations occurred across stages, emphasizing strict quality control to preserve surgical accuracy.

V. STRENGTHS AND LIMITATIONS

The strengths of this study include a standardized reference model, controlled in vitro setup, and reproducible workflow. Limitations involve absence of clinical conditions, small sample size, potential software bias, and unspecified operator influence.

VI. CONCLUSION

Within the study's limitations, BlueSky surgical guides showed superior angular and mesio-distal (Y-axis) accuracy compared to 3Shape, while vertical and bucco-lingual deviations were comparable. Though differences were minor and within clinically acceptable limits, BlueSky demonstrated better precision, particularly in posterior sites. All software systems remained safe and reliable within the 2 mm safety margin. Additionally, small but significant dimensional changes occurred over time, underscoring the need to consider material stability when guides are stored before use to maintain optimal accuracy in static computer-guided implant surgery.

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