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Implant Deviation analysis using a Novel Milling Technique in comparison with the 3-D Printed Computer Guided Surgical Stents

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Abstract

Aim: The objective of this study was to compare the pre-planned implant deviation with the actually placed implant deviation, employing two different approaches for fabricating Computer Guided Surgical Stents: a Novel Milling technique and the 3D Printing technique.

Materials and Methods: In this investigation, a total of fourteen Computer Guided Surgical Stents were fabricated. Among these, seven were produced using an innovative Milling technique which involved the conversion of radiographic stents into Computer Aided Surgical Stents (MCASS) by directly milling the implant vector holes into the radiographic stent using a CAD/CAM milling machine. The remaining seven stents were created using 3D printing rapid prototyping technology (3DCASS). The assessment of Linear and Angular deviations for each set of stents was carried out both prior to and after the surgical phase.

Results: An Independent t-test was employed to compare implant deviations in the MCASS and 3DCASS groups before and after the surgical procedure was performed. The findings indicated that across all measurements prior to and after the procedure, the 3DCASS group consistently displayed statistically significant higher values in comparison to the MCASS group ($P < 0.05$).

Conclusion: The MCASS technique outlined in this article has the potential to enhance accuracy and reduce the accumulation of errors by eliminating complex and unnecessary procedural steps. Additionally, this technique streamlines the process of fabricating computer-guided surgical stents.

Keywords: Milling, computer guided stents, 3D printing, CAD/CAM, deviation, flapless stents, static stents.

List of Abbreviations

MCASS: Milled Computer Aided Surgical Stent

3DCASS: 3D Printed Computer Aided Surgical Stent

CAD/CAM: Computer Aided Design/ Computer Aided Manufacturing

CBCT: Cone Beam Computerized Tomography

PP: Pre-planned Implant

AP: Actually Placed Implant

AG: Apical Global deviation

CG: Coronal Global deviation

AV: Apical Vertical deviation

CV: Coronal Vertical deviation

AML: Apical Medio-Lateral deviation

CML: Coronal Medio-Lateral deviation

AAP: Apical Antero-posterior deviation

CAP: Coronal Antero-Posterior deviation

Introduction

Prosthodontically guided implant dentistry offers the most effective approach for treating patients with dental implants [1]. The recognition of the need for implants that go beyond mere osseointegration has led to the emergence of the "Prosthetic-driven implant placement" concept. This approach suggests implant positioning that fulfills both functional and aesthetic criteria [2]. An optimal implant site is one that possesses sufficient bone volume and aligns with ideal prosthetic considerations [3].

To achieve precise three-dimensional (3-D) implant positioning within the alveolar bone in relation to planned prosthetic restorations, meticulous pre-treatment planning is essential [4]. A 3-D model or digital representation of the alveolar bone and relevant oral anatomy can be generated through methods like CT (computed tomography) or CBCT (cone beam computed tomography). Furthermore, the introduction of surface scanning technology, using intra-oral or extra-oraal approaches, generates an additional 3-D model representing the patient's oral condition. This model can be overlaid onto the radiographic dataset, resulting in a realistic 3-D virtual patient. This virtual patient can be visualized using implant planning software, providing insight into soft and hard dental tissues, proposed prosthetic treatment plans, and bone volume information [5].

Nevertheless, the incorporation of this technique has raised pivotal inquiries: Is the technique accurate, safe, efficient, and suitable for routine clinical implementation? [5] The accuracy of the entire procedure can be gauged by assessing the "discrepancy between the actual implant position and the planned position". This discrepancy typically arises from a cumulative effect of errors that occur throughout the computer-assisted process such as inaccuracies during image acquisition and data processing averaging under 0.5 mm., inherent inaccuracies during stereolithography surgical template production ranging from 0.1 to 0.2 mm, deviations stemming from template placement and potential template movement during the drilling process, and mechanical discrepancies attributed to the bur-cylinder gap [6]

Given the proximity of implants to critical structures such as nerves and blood vessels, precision is paramount. In fact, instances of serious and even fatal complications have been attributed to inaccuracies in implant placement [7]. In a clinical study conducted by Pattersson et al. [8], significant disparities between the virtually planned positions of implants and their final clinical placements were reported. Likewise, Valente et al. [6] conducted a retrospective study using stereolithographic templates which revealed average lateral deviations of 1.4 mm and 1.6 mm at the coronal and apical ends of the implants and depth deviation of 1.1 mm and a mean angular deviation of 7.9 degrees.

The available documentation regarding the accuracy of computer-assisted/template-guided oral implant surgery is limited, and the analysis of existing literature yields a range of outcomes [9]. Generally, proof-of-concept studies conducted in vitro or ex vivo [10,11] have showcased superior accuracy, with average discrepancies slightly below 1 mm both in the coronal and apical directions. However, these studies might overestimate accuracy and underestimate errors. In vivo studies, on the other hand, tend to report greater deviations between planned and actual implant positions. For instance, Vrielinck et al. [12] demonstrated mean deviations of 1.5 mm at the implant base and 3 mm at the apex. In a study involving 21 implants, Di Giacomo et al. [13] identified average coronal, apical, and angular discrepancies of 1.4 mm, 3 mm, and 7.2 degrees, respectively. Torres et al. [14] highlighted the precision of Computer-aided static navigation for orthodontic mini-implant placement.

The pressing need to address these inherent deviations in the literature, attributed to the cumulative errors introduced during various stages of computer-guided surgical stent fabrication, served as the primary motivation for the initiation of this clinical study.

Materials and Methods

This study comprised the creation of a total of fourteen Computer Guided Surgical Stents. Among these, seven stents were produced using a Novel Milling technique which involved the conversion of radiographic stents into Milled Computer Aided Surgical Stents (MCASS) by milling the implant vector holes into the stent using a CAD/CAM machine. The remaining seven splints were manufactured using the conventional 3D printing rapid prototyping technology (3DCASS).

Sample Size Calculation:

The sample size determination was guided by a prior study (15). Adhering to the recommendations outlined in that study, a minimum acceptable sample size of 7 patients per group was established, resulting in a total of 84 implants to be included and analyzed in this current study. This was under the assumption that the response within each subject group followed a normal distribution with a standard deviation of 0.87. The desired statistical power was set at 80%, with a type I error probability of 0.05. The calculation was performed using PS Power 3.1.6.

Patient Selection and Prosthetic Preparation

In this study, Fourteen male patients were selected from the outpatient clinic of the Prosthodontics Department at the Faculty of Oral and Dental Medicine in Cairo. These patients exhibited Completely Edentulous Maxillae and displayed a normal maxillo-mandibular relationship (Class I Angle classification), were free from para-functional habits and any systemic medical conditions.

Patients who satisfied the criteria proceeded to sign the consent form, adhering to the ethical principles outlined in the Helsinki Declaration (https://www.wma.net). This signified their endorsement of participation in the study and their willingness to undergo surgical procedures for implant placement. Furthermore, ethical clearance was acquired from the Ethical Approval Committee within the Faculty of Dentistry at Cairo University.

Using sealed envelopes, the patients, who were blinded from the primary investigator, were allocated randomly into two groups: the MCASS Group, which received Milled Computer Aided Surgical Stents, and the 3DCASS Group, which received the 3D printed Computer Aided Surgical Stents. The laboratory technician participating in this study was responsible for anonymizing the subjects' names, randomizing their allocation to respective groups, and assigning codes to them. These codes were then placed within sealed envelopes to maintain confidentiality.

The initial phase involved the creation of well-fitting conventional complete dentures for all the fourteen patients. Subsequently, duplications of the maxillary dentures were made. For the denture base, clear heat-cured acrylic resin (Pattern Resin; GC America Inc., Alsip, IL, USA) was utilized. As for the teeth, a mixture of sifted barium sulphate and clear heat-cured acrylic resin in a 1:3 ratio was used. Following meticulous finishing and polishing of the radiographic template, 2mm channels were drilled through the stent at the central axes of the lateral incisor, first premolar, and first molar regions. These channels were then filled with self-cured clear acrylic resin.

3DCASS (3D printed Computer Aided Surgical Stent) Workflow

The patients' maxillae underwent radiographic examination using a Cone Beam Computed Tomographic (CBCT) scanning machine (SCANORA® 3Dx; Soredex, Helsinki, Finland). During the imaging process, patients were directed to wear their stents and to secure them in place by biting on an occlusal index tailored for each individual, which created a separation between the mandibular teeth and the stent. The DICOM files resulting from the CT scan were imported into the Mimics software (Mimics Software version 14.1; Materialise HQ, Leuven, Belgium) which was employed for the design of computer-guided surgical stents.

The radiolucent channels previously incorporated into the radiographic stent at the centers of the prosthetic teeth were used to identify the desired implant sites. For each patient, six virtual implants were planned in the lateral incisor/canine region, the first premolar region, and the first molar region, taking into account the available bone height and width using Virtual STL files of the implants imported into the MIMICS software.

Using the Mimics software, the radiographic stent was superimposed with the optically scanned radiographic stent which was then combined with the supra bony section of the implant model using the "Boolean operation" tool. The outcome of this process was a set of STL files constituting the final 3D virtual stent which were then sent for 3D printing (Invision Si2; Valencia, CA, USA). Metallic sleeves were inserted into the designated holes of the produced stent. Subsequently, the stent was evaluated in the patient's mouth to ensure stability and proper fit. Upon completion of the 3D printing, the computer-guided stent was evaluated intra-orally to assess its stability and fit.

MCASS (Milled technique Computer Aided Surgical Stent) Workflow

The construction of the MCASS involved the creation and utilization of three primary tools: 1.The Orienter, 2.The Orienter Mount and 3.The Fixation Plane Metal Disc. The following workflow was executed:

I. Orienter preparation and attachment to the radiographic Template

The first step involved securing the Orienter to the facial surface of the radiographic (Fig. 1A, 1B). The Orienter played a pivotal role, serving as the central reference point as it enabled the CAM software and milling machine to recognize the spatial orientation of the pre-planned implant vectors, determining the (x-y-z) point of entry for each intended implant site. This was accomplished by generating twelve rectangular-shaped engravings that were subsequently filled with composite resin, serving as radiographic markers. Furthermore, the Orienter functioned to secure and stabilize the MCASS (Milled Computer-Aided Surgical Stent) onto the milling machine disc throughout the milling process.

II. Orienter positioning on the Orienter Mount and CBCT Image Acquisition

The extruding extra-oral male segment of the Orienter was subsequently fastened onto the orienter mount, which featured a corresponding female component. The Orienter mount was securely attached to the bite block slot of the CBCT machine. This step was carried out while the patient was wearing the radiographic stents/Orienter complex securely fastened to the Orienter mount (Fig. 1C, 1D), and during this phase, CBCT (SCANORA® 3Dx; Soredex, Helsinki, Finland) image acquisition was performed (Fig. 1D).

The calibration of the Orienter mount was meticulously undertaken using a precise digital laser water balance, positioning it precisely at the zero-zero-zero x-y-z coordinates. It was crucial for the midline groove engraved onto the projecting male section of the Orienter to be precisely aligned with the red midline laser beam emitted by the CBCT machine. The primary rationale behind implementing this Orienter mount was to seamlessly position both the Orienter and the patient at a uniform zero-zero-zero x-y-z coordinates.

This functionality effectively obviates the necessity for conducting any registration or superimposition procedures, as the orientation of the Orienter is already known and established.

Figure 1:

A: Duplicated maxillary dentures/Radiographic template affixed to The Orienter.

B: Self-cured clear acrylic resin utilized to securely fasten the radiographic stent and the Orienter.

C: Patient wearing the radiographic stent/Orienter complex.

D: Patient wearing the radiographic stent/Orienter complex positioned on the Orienter mount during image acquisition.

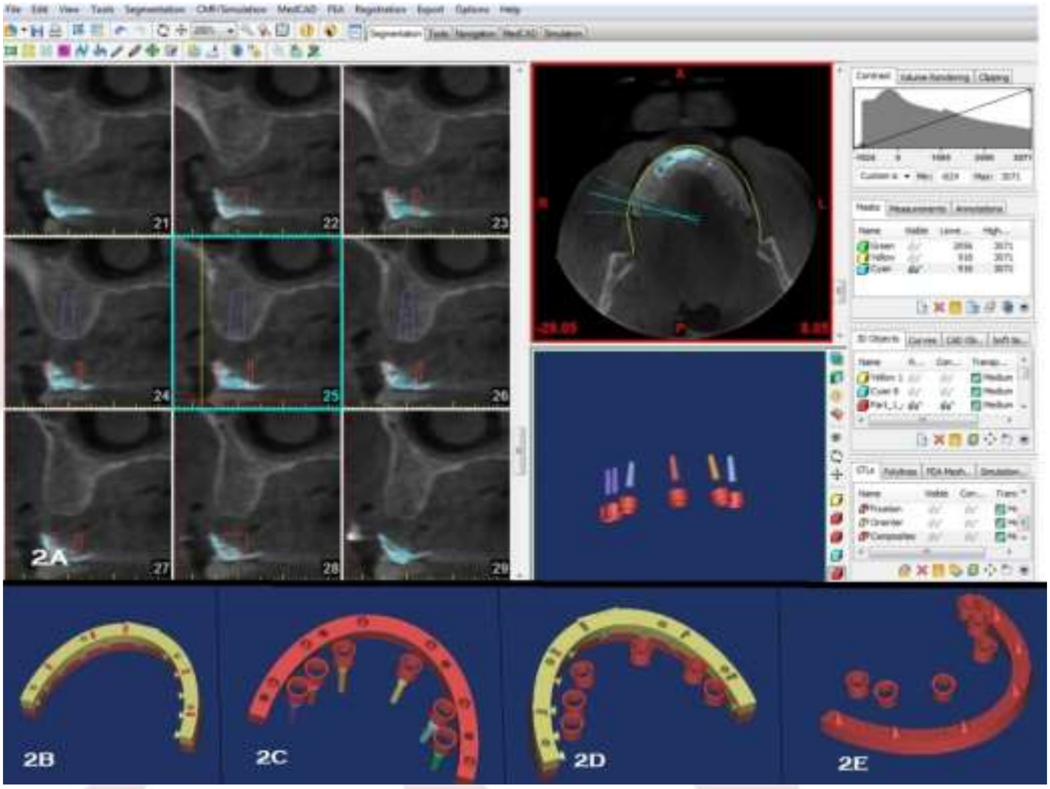

Figure 2:

A: Virtual implant planning is conducted at the desired implant sites.

B: Radiographic markers within the Orienters are superimposed.

C: Through the Boolean operation tool, the supra bony (sleeve) sections of the virtual implants are initially separated from the implant bodies and then joined together.

D: The combined sleeves are then united with the fixation plane/orienter complex.

E: The STL object is exported from the Mimics software.

III. Virtual Orienter Registration with the Actual/real Orienter

The design and creation of the Orienter and Fixation plane were initially executed using Rhinoceros (Rhinoceros®, Robert McNeel & Associates, Seattle, WA, USA). The STL files containing the Virtual Orienter/Fixation plane complexes were imported into each of the seven radiographic template projects, which were loaded onto the Mimics software (Fig. 2). The Orienter and Fixation plane were intentionally designed and positioned at the zero-zero-zero x-y-z coordinates. Consequently, upon importing them into any Mimics project, the procedure merely involved manually dragging them over the radio-opaque rectangular composite markers. Alternatively, they could be automatically superimposed using the STL registration tool available within the Mimics software (Fig. 2B).

IV. Virtual Implant planning and Exporting STL file extension

Virtual implant planning was executed a executed for the seven patients utilizing the Mimics software at the specified implant sites, which were identified through the radiolucent channels (Fig. 2A) For each patient, six implants were planned in the lateral incisor/canine region, the first premolar region, and the first molar region, taking into account the available bone height and width.

By employing the Boolean operation tool, the supra-bony (sleeve) sections of the virtual implants were merged together (Fig. 2A, 2C). Subsequently, these merged components were combined with the virtual fixation plane (Fig. 2C, 2D). The underlying rationale for this approach was to attain the implant vectors represented by the supra-bony (sleeve) parts, with respect to the fixation plane.

The Fixation plane was designed in such a manner that it maintained a consistent spatial relationship within the CAD/CAM machine disc. The outcome of this process was an amalgamated object, which was then exported as an STL file extension from the Mimics program (Fig. 2D, 2E).

V. Fixation of the Orienter on The Fixation Plane within CAD/CAM Milling machine

At this stage of the process, the Radiographic template is referred to as the MCASS. The external segment of the Orienter was then removed. Subsequently, the Orienter/MCASS complex was firmly attached to the fixation plane utilizing four bolts and nuts and the CAD/CAM machine (Fig. 3A). These fasteners passed through four corresponding holes created in both the Orienter and the fixation plane metal disc (Fig. 3A, 3B).

VI. CAM Software and Milling Procedure within the radiographic template

The STL object resulting from the union of the supra-bony sleeves with the fixation plane was then imported into the Computer-Aided Manufacturing (CAM) software of the CAD/CAM milling machine. The Fixation plane was designed in a manner ensuring a consistent spatial relationship with the CAD/CAM machine disc. This design allowed the CAM software to accurately identify the vectors (supra-bony sleeves) for each implant.

The CAM software initiated a sequence of tasks to be executed by the milling machine. To streamline the process, manual intervention was employed to cancel all but the essential operations, leaving only the vector holes of the supra-bony sleeves (Fig. 3C). Following this, the task assigned to the milling machine involved drilling the vector holes into the MCASS. The CAD/CAM machine (Roland DWX50, Roland DG Corporation, Hamamatsu-shi, Shizuoka-ken Japan) took approximately 3-5 minutes for drilling each vector hole (Fig. 3B). Subsequently, metal sleeves were affixed to the drilled holes (Fig.4A).

Implant Installation for Both Groups:

Prior to commencing the surgical procedure, the peri-oral region of the patient was cleansed with Betadine antiseptic solution (povidone-iodine, 10%) (Avrio Health L.P., New York, NY, USA). The surgical instruments were autoclaved, ensuring sterilization, while the computer-guided stents were disinfected using a suitable disinfectant.

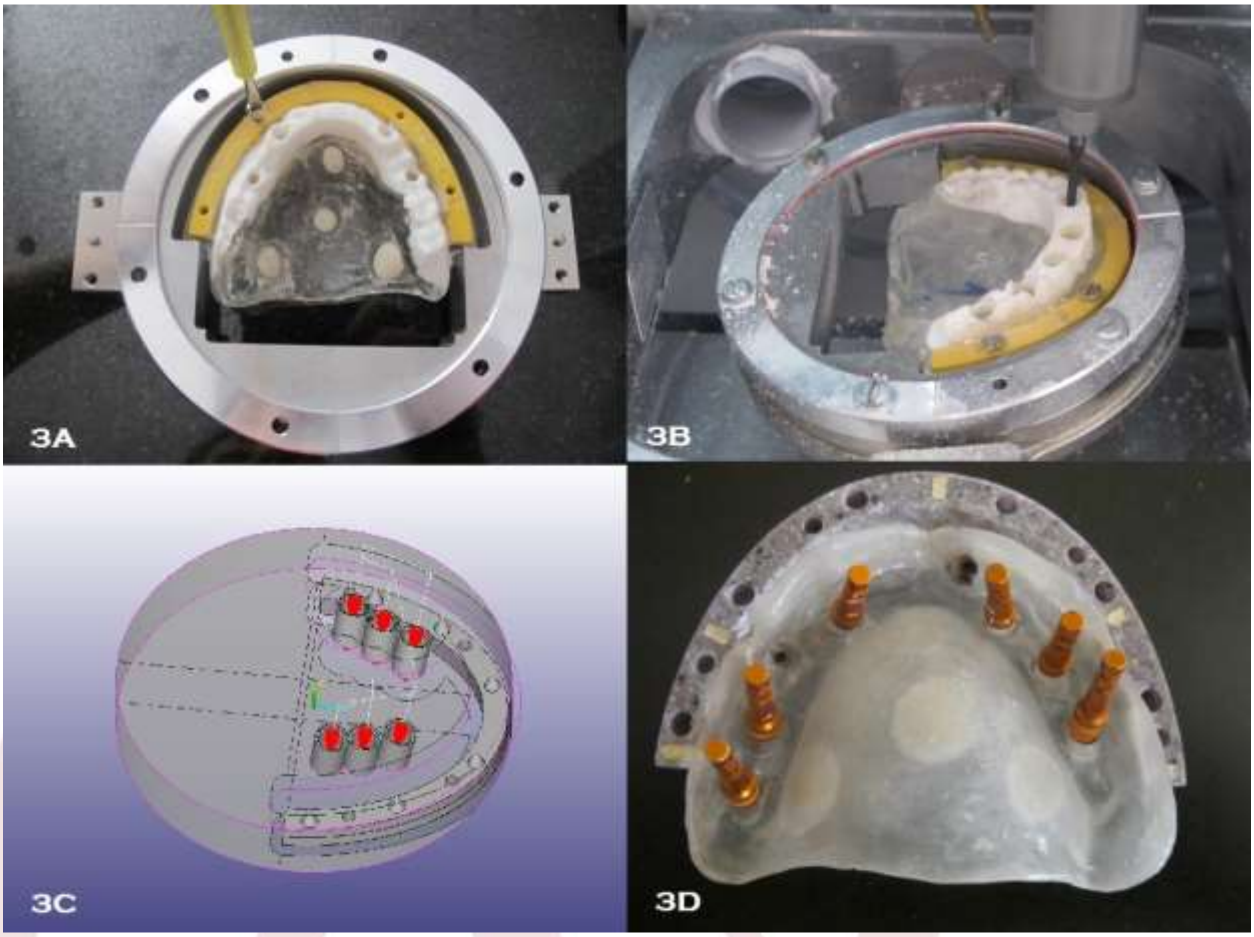

Figure 3:

A: The Orienter/MCASS complex securely affixed to the fixation plane disc, which is attached to the CAD/CAM Machine disc receptacle.

B: Milling of the vector holes for the preplanned implants directly onto the MCASS.

C: Importing the STL file into the CAM software to identify the vector sleeve holes of the planned implants.

D: Implant mimics attached to the MCASS for the evaluation of pre-surgical phase implant deviations.

During the surgery, infiltration anaesthesia (Ubestesin; 3M ESPE, Seefeld, Germany) was administered at each implant site. The stent was firmly secured in place utilizing three fixation screws (Biomet M Fix; Warsaw, IN, USA) (Fig.4A). The osteotomies were then meticulously created using the conventional drilling sequence employing a specially designed "drill guide", ensuring copious sterile saline irrigation between and during the drilling procedure (Fig.4B, 4C). Subsequently, the implants (ScrewIndirect implants; Implant Direct

Sybron International, Thousand Oaks, CA, USA) were unpacked and manually inserted through the stent until encountering initial resistance (Fig.4D). The height of all implants in this study was standardized: 13 mm for the four anterior implants and 10 mm for the two posterior implants. Subsequent tightening was accomplished using a ratchet, employing a depth-controlling implant driver. To assess the primary stability of each implant, the Implant Stability Quotient ISQ of each implant was required to be between 55- 65 ISC using the Osstell device (Osstell AB, Göteborg, Sweden).

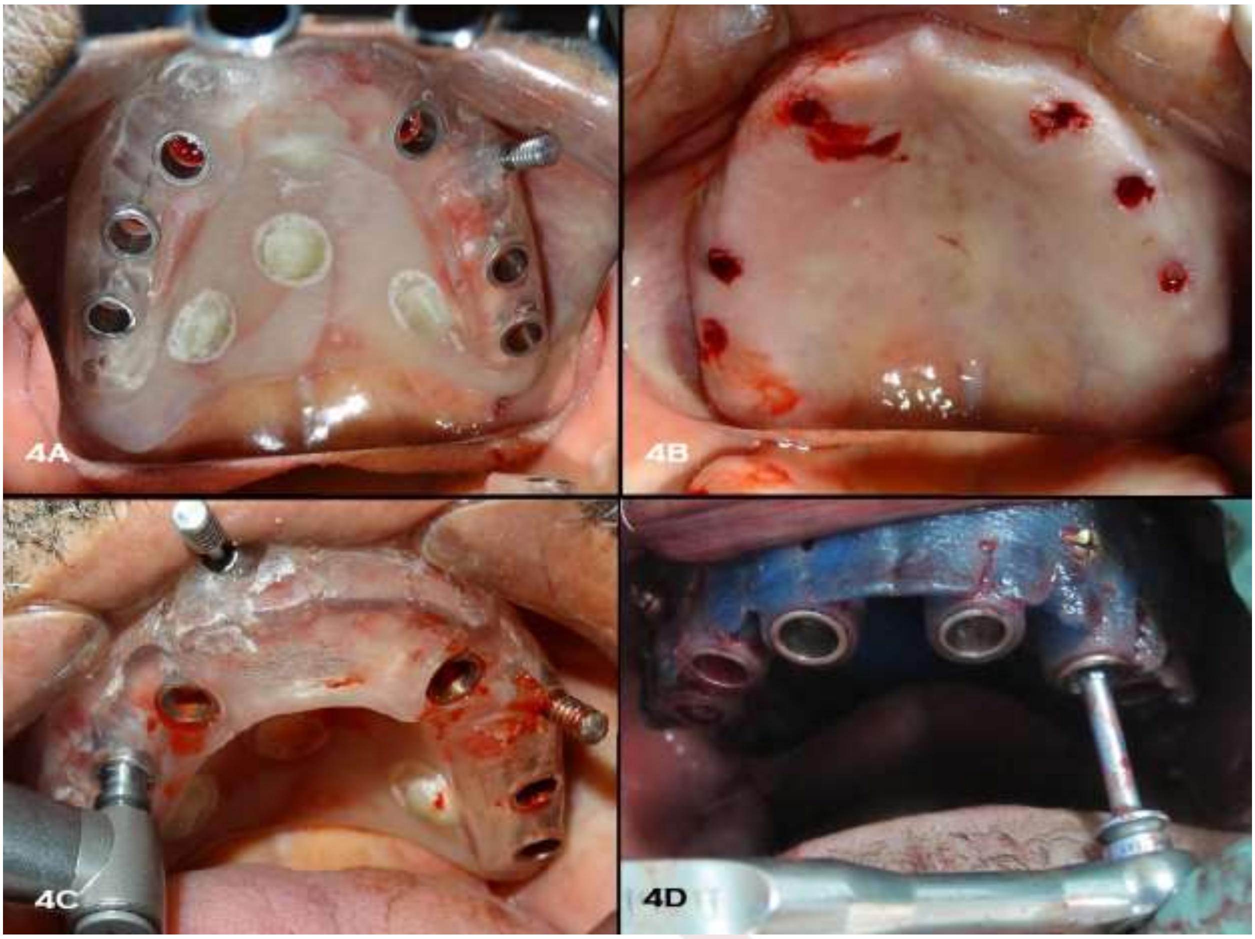

Figure 4:

A. MCASS positioned within the patient's oral cavity

B. Surgical Phase

C. Osteotomy Preparation

D. Implants placed in the 3DCASS group

Implant Deviation Analysis

Accuracy analysis in this study was conducted by quantifying the amount of deviation between the pre-planned PP implant positions and the actual AP implants' placements. This assessment was carried out both before and after the surgical placement, aiming to identify any potential errors introduced during the surgical phase.

Pre-Surgical Phase Analysis

To analyze the deviation between the Preplanned (PP) implant positions and the Actually Placed (AP) implants prior to the surgical phase, model implants were meticulously positioned and accurately fitted into the metal sleeves (Fig.3D). This simulation accurately replicated the positions where the implants would be placed, prior to the actual surgical procedure. Following this, both the MCASS and 3DCASS underwent radiography using a CBCT scanning machine, generating a new simulated post-operative project.

By employing composite radio-opaque markers, the PP project Orienters were superimposed onto the new post-operative project. This alignment was achieved through the utilization of STL registration tools within the Mimics software. Subsequently, the STL objects representing the PP and AP implants were exported to the Rhinoceros software for an in-depth analysis and interpretation (Fig. 5B).

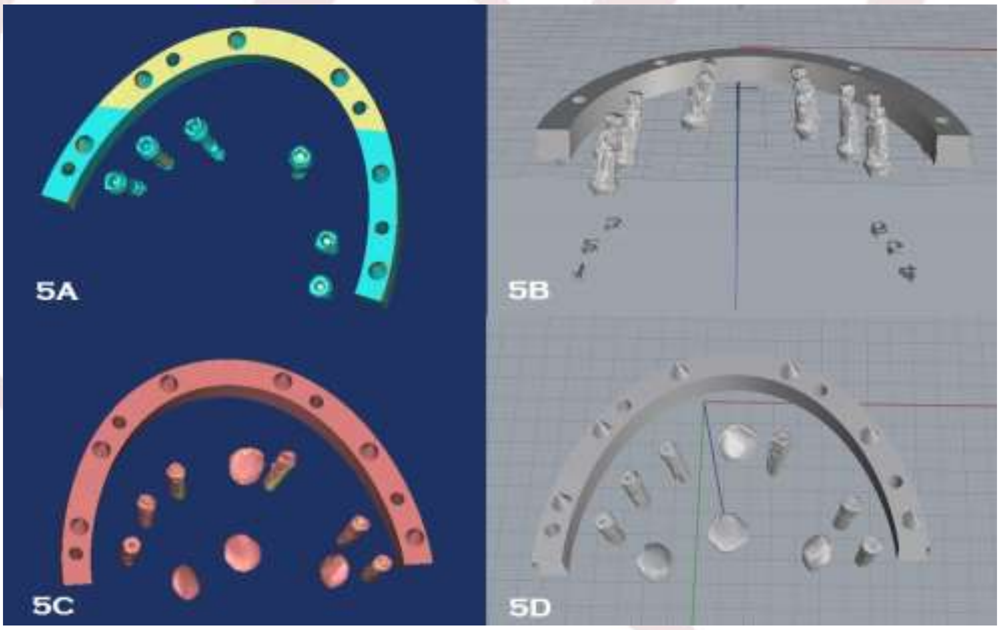

Figure 5:

A: Superimposing the STL files of the PP implants with the AP implants using the Orienter/fixation plane setup through the Mimics software for pre-surgical analysis.

B: Analyzing linear and angular deviations using the Rhinoceros software for pre-surgical analysis.

C: Superimposing the STL files of the PP implants with the AP implants using the Orienter/fixation plane

setup through the Mimics software for post-surgical analysis.

D: Assessing linear and angular deviations using the Rhinoceros software for post-surgical analysis.

Post-Surgical Phase Anaylsis:

To assess the Deviation between the Preplanned (PP) Implant positions and the Actually Placed (AP) Implants after the surgical phase, patients underwent CBCT scans while wearing their MCASS and 3DCASS, which were already equipped with composite radiographic markers on the palatal aspect of the surgical stents. Employing these radio-opaque markers, the PP project orienters were superimposed onto the new post-operative project using the Mimics software STL registration tools (Fig. 5C). Subsequently, the STL objects representing the PP and AP implants were exported to the Rhinoceros software for in-depth analysis and interpretation, as shown in (Fig. 5D)

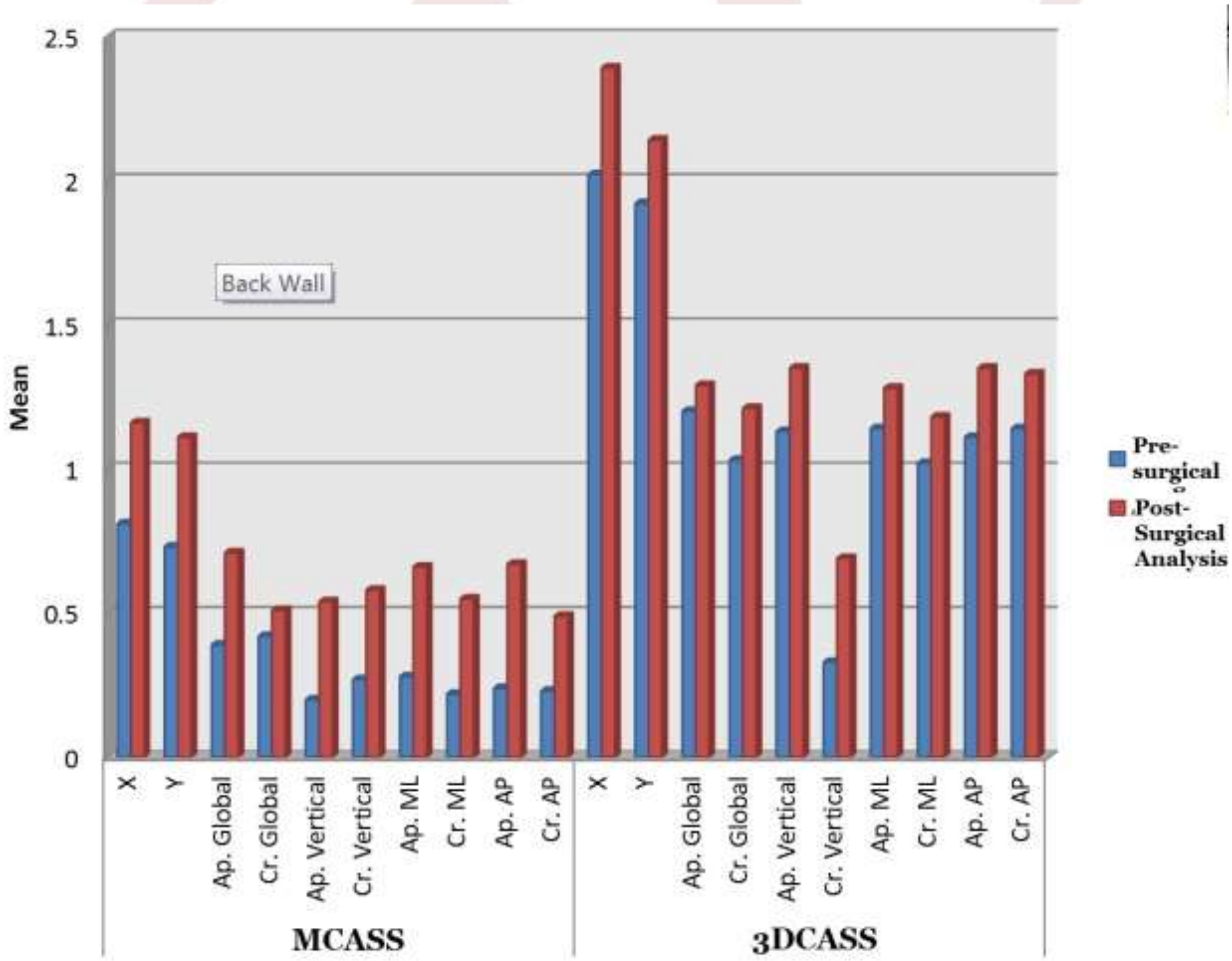

Figure 6: A bar chart illustrating a comparison of mean implant angular deviations (along the X-axis and Y-axis) and linear deviations (Apical Global - AG, Coronal Global - CG, Apical Vertical - AV, Coronal Vertical - CV, Apical Medio-Lateral - AML, Coronal Medio-Lateral - CML, Apical Antero-posterior - AAP, and Coronal Antero-Posterior - CAP deviations) between the pre and post-surgical phases of the 3DCASS and the MCASS groups.

Statistical analysis

A comprehensive assessment of different deviation types was conducted for each stent group, both prior to and after the surgical phase. These deviations included angular deviations along the X and Y axes, as well as linear deviations such as Apical Global (AG), Coronal Global (CG), Apical Vertical (AV), Coronal Vertical (CV), Apical Medio-Lateral (AML), Coronal Medio-Lateral (CML), Apical Antero-Posterior (AAP), and Coronal Antero-Posterior (CAP) deviations.

Statistical analysis was performed with SPSS version 20 (IBM, Cary, NC, USA), GraphPad Prism® version 8.0.2 (Dotmatics Insightful Science, Boston, MA, USA) and Microsoft Excel 2016 (Redmond, WA, USA). All data were analyzed for normality by using Shapiro Wilk and Kolmogorov Normality test. This information was organized into two tables (Table 1 and 2) and two graphs (Figure 1 and 2) for clear presentation.

Results

This study aimed to evaluate the extent of both linear and angular deviations between the actually placed AP implants and the virtually pre-planned PP implants. Two techniques for fabricating Computer Guided Surgical Stents were employed: a Novel Milling technique and the 3-D Printed Rapid Prototyping technique.

Various categories of deviations were meticulously documented for each stent group before and after the surgical phase. The Linear deviations were analyzed using the Rhinoceros computer software and included Apical Global (AG), Coronal Global (CG), Apical Vertical (AV), Coronal Vertical (CV), Apical Medio-Lateral (AML), Coronal Medio-Lateral (CML), Apical Antero-posterior (AAP), and Coronal Antero-Posterior (CAP) deviations. Additionally, the Angular Deviations of the AP from the PP implants were assessed along the X and Y axes. The recorded values were presented in terms of mean and standard deviation (SD) values and subsequent statistical analysis was conducted.

In the present study, the findings revealed that the mean angular deviation along the x and y axes before the surgical phase was 0.81±0.14° and 0.73±0.17° in the MCASS group, compared to 2.02±0.17° and 1.92±0.19° in the 3DCASS group, respectively. Subsequent to the surgical phase, the outcomes indicated that the mean angular deviation along the x and y axes was 1.16±0.09° and 1.11±0.18° in the MCASS group, while it was 2.39±0.06° and 2.14±0.14° in the 3DCASS group, respectively (Table 1, Fig. 6).

Moreover, the results also demonstrated that the mean linear AG and CG (angular and coronal) deviations before the surgical phase were 0.39±0.16mm and 0.42±0.12mm in the MCASS group, as opposed to 1.2 ±0.04 mm and 1.03±0.04 mm in the 3DCASS group, respectively. Similarly, the results further indicated that the mean linear AG and CG deviations after the surgical phase were 0.71±0.07 mm and 0.51±0.13 mm in the MCASS group, while they were 11.29±0.04 mm and 1.21±0.06 mm in the 3DCASS group, respectively (Table 2, Fig. 7).

A comparison between implant deviations prior to and after the surgical procedure was executed using the Paired t-test, yielding the finding that the values before the procedure were significantly lower than those after the procedure ($P < 0.05$), a pattern observed across all measurements for both groups (Table 1, Fig. 6).

Additionally, a comparison between implant deviations within the MCASS and 3DCASS groups before and after the surgical procedure was conducted using the Independent t-test. The results revealed that in all measurements before and after the procedure, the 3DCASS group exhibited significantly higher values compared to the MCASS group ($P < 0.05$). The only exceptions were the measurements for Cr. Vertical, where the difference was not statistically significant with P-values of 0.11 before and 0.14 after (Table 2, Fig. 7).

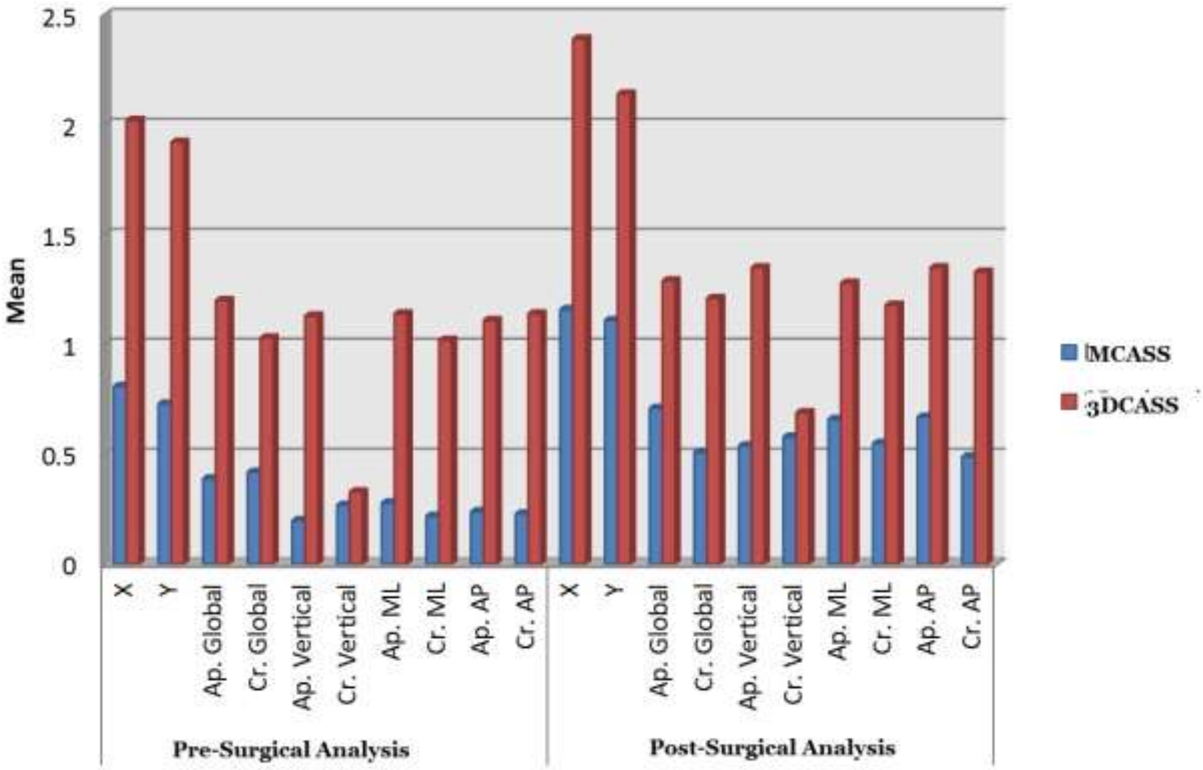

Figure 7: A bar chart showing a comparison between the 3DCASS and the MCASS groups.

Group	Measurements	Before		After		Paired Differences					
						MD	SD	SEM	95% CI		P value
		M	SD	M	SD				Lower	Upper	
	MILLED GROUP										
Angular (degree)	X	0.81	0.14	1.16	0.09	0.35	0.14	0.06	-0.53	-0.18	.005
	Y	0.73	0.17	1.11	0.18	0.38	0.23	0.10	-0.66	-0.10	.019
Linear (mm)	AG	0.39	0.16	0.71	0.07	0.32	0.09	0.04	-0.44	-0.21	.001
	CG	0.42	0.12	0.51	0.13	0.09	0.07	0.03	-0.18	0.00	.048
	AV	0.20	0.07	0.54	0.21	0.34	0.16	0.07	-0.55	-0.14	.009
	CV	0.27	0.07	0.58	0.18	0.30	0.16	0.07	-0.51	-0.10	.014
	AML	0.28	0.13	0.66	0.06	0.38	0.09	0.04	-0.49	-0.27	.001
	CML	0.22	0.12	0.55	0	0.33	0.12	0.05	-0.48	-0.19	.003
	AAP	0.24	0.11	0.67	0.04	0.43	0.13	0.06	-0.59	-0.27	.002

	CAP	0.23	0.06	0.49	0.12	0.26	0.09	0.04	-0.37	-0.14	.003
	3D PRINTED GROUP										
Angular (degree)	X	2.02	0.17	2.39	0.06	0.37	0.16	0.07	-0.56	-0.17	.006
	Y	1.92	0.19	2.14	0.14	0.21	0.07	0.03	-0.30	-0.13	.002
Linear (mm)	AG	1.2	0.04	1.29	0.04	0.10	0.01	0.00	-0.11	-0.09	.000
	CG	1.03	0.04	1.21	0.06	0.18	0.08	0.04	-0.28	-0.08	.008
	AV	1.13	0.11	1.35	0.04	0.22	0.10	0.05	-0.34	-0.09	.009
	CV	0.33	0.06	0.69	0.05	0.36	0.03	0.01	-0.40	-0.33	.000
	AML	1.14	0.06	1.28	0.01	0.14	0.06	0.03	-0.22	-0.07	.006
	CML	1.02	0.05	1.18	0.04	0.16	0.09	0.04	-0.27	-0.04	.021
	AAP	1.11	0.11	1.35	0.01	0.24	0.11	0.05	-0.37	-0.10	.008
	CAP	1.14	0.09	1.33	0.03	0.20	0.10	0.04	-0.32	-0.08	.010

*Significant difference as P<0.05

M: mean, SD: standard deviation, MD: mean difference, SEM: standard error of mean, CI: confidence interval

Table (1): Mean and standard deviation of the pre and post-surgical phases and acomparison between them using Paired t test of the MCASS and the 3DCASS groups

		Milled		**3D printed**		**P value**
		M	SD	M	SD	
	BEFORE					
Angular (degree)	X	0.81	0.14	2.02	0.17	<0.0001*
	Y	0.73	0.17	1.92	0.19	<0.0001*
Linear (mm)	AG	0.39	0.16	1.20	0.04	<0.0001*
	CG	0.42	0.12	1.03	0.04	<0.0001*
	AV	0.20	0.07	1.13	0.11	<0.0001*
	CV	0.27	0.07	0.33	0.06	0.11
	AML	0.28	0.13	1.14	0.06	<0.0001*
	CML	0.22	0.12	1.02	0.05	<0.0001*
	AAP	0.24	0.11	1.11	0.11	<0.0001*

	CAP	0.23	0.06	1.14	0.09	<0.0001*
	AFTER					
Angular (degree)	X	1.16	0.09	2.39	0.06	<0.0001*
	Y	1.11	0.18	2.14	0.14	<0.0001*
Linear (mm)	AG	0.71	0.07	1.29	0.04	<0.0001*
	CG	0.51	0.13	1.21	0.06	<0.0001*
	AV	0.54	0.21	1.35	0.04	<0.0001*
	CV	0.58	0.18	0.69	0.05	0.14
	AML	0.66	0.06	1.28	0.01	<0.0001*
	CML	0.55	0.00	1.18	0.04	<0.0001*
	AAP	0.67	0.04	1.35	0.01	<0.0001*
	CAP	0.49	0.12	1.33	0.03	<0.0001*

*Significant difference as $P<0.05$

M: mean, SD: standard deviation

Table (2): The mean and standard deviation of the MCASS and 3DCASS groups shown, and a comparison between them was conducted using an Independent t-test for both the pre and post-surgical phases

Discussion

Utilizing flapless static computer-guided stents offers ease, speed, contributes to enhanced implant placement accuracy, and effectively reduces surgical side effects. This was in agreement with Tattan et al. [16] conducted quantitative analyses, showing static Computer Aided Implant Placement to have notably lower mean angular 4.41°, mean coronal 0.65 mm, and mean apical 1.13 mm deviations than Free Hand Implant Placement.

In fact, for novices and beginners, using a surgical guide for initial implant placement led to reduced deviations compared to freehand surgery, with similar accuracy observed as specialists, along with greater efficiency [17, 18].

Nonetheless, the integration of computer guided surgical stents has raised substantial inquiries: Is the technique accurate enough, secure, and efficient, making it suitable for routine clinical implementation? [6] Literature review revealed a plethora of studies focused on assessing implant deviations from pre-planned to actual placements. These investigations predominantly employed static 3D printed stereolithographic templates. The findings from these studies have been gathered and summarized within this discussion. For example, Vrielinck et al. [12] reported different results with mean deviations of 1.5 mm and 3 mm at the implant base and apex, respectively, and a mean angular deviation of 10.5 degrees. Similarly, Di Giacomo et al. [13] detected mean coronal, apical, and angular deviations of 1.4 mm, 3 mm, and 7.2 degrees, respectively.

A Meta-analysis by Van Assche et al. (19) revealed a mean entry point error of 0.99 mm (ranging from 0 to 6.5 mm) and an apex error of 1.24 mm (ranging from 0 to 6.9 mm), with a mean angular deviation of 3.81° (ranging from 0 to 24.9°). Another meta-analysis, carried out by Tahmseb et al. (20) showed a mean entry point error of 1.12 mm (maximum 4.5 mm) and a mean apex error of 1.39 mm (maximum 7.1 mm). This aligns with findings from a systematic review by D'Haese et al. (21), who reported that ex-vivo studies revealed an average apical deviation between 0.6 and 1.2 mm, while in-vivo studies demonstrated apical deviations ranging from 0.95 to 4.5 mm. Furthermore, the same review indicated complications in 42% of cases when stereolithographic guided surgery was combined with immediate loading.

Another study, published by Turbush and Turkyilmaz (22), indicated that the mean linear deviation along the long axis of 150 implants placed with Stereolithographic SLA guides was 1.18 ± 0.42 mm at the implant neck and 1.44 ± 0.67 mm at the implant apex and a mean angular deviation of the long axis of 2.2° ± 1.2°. Conversely, in a study conducted by Beretta et al. (23), a comparison of 14 implants demonstrated lower mean linear deviation values; 0.56 ± 0.23 mm at the implant head and 0.64 ± 0.29 mm at the implant apex, with a mean angular deviation of the long axis being 2.42° ± 1.02°. Cassetta et al. (24) disclosed that the mean deviations between planned and actual implant positions at the coronal and apical ends were 1.47 mm and 1.83 mm, respectively and average angular deviation of 5.09 degrees.

Alternatively, Dynamic Computer Aided Implant placement systems achieved an average angular deviation of under 4°, but a 2-mm safety margin is recommended due to deviations exceeding 1 mm as reported by Jorba-García et al. [25]. However, these results are comparable but not superior to the static guided stents Dynamic Guided Stents emerged as reported by Marques-Guasch et al. [26]. This was also agreed upon by the systematic review performed by Schnutenhaus et al. [27] which indicates that dynamic computer-assisted navigation's clinical accuracy parallels static navigation, although heterogeneity among dynamic navigation systems must be acknowledged. Despite this, clinical data remains limited, necessitating further exploration into dynamic navigation's practicality [27] leaving the dynamic guided stents a more complicated, expensive and yield results that are only marginally comparable to those achieved with static 3D printed stents.

The collective findings of these previous studies indicate that implant deviations from planned to placed (PP to AP) using SLA computer-guided stents can at times be notably high, potentially posing risks to surrounding vital structures. Moreover, there is a possibility of significant prosthetic errors if immediate functional loading is carried out using prostheses generated from computer-guided preoperative plans. The majority of the reviews and studies discussed earlier strongly advocate for the necessity of maintaining a safety margin of at least 2 mm. This precaution is strongly advised to prevent potential complications associated with impingement of anatomical structures. These findings align with the implant deviation values observed in the the 3DCASS group reported in the current study.

The motivation behind the MCASS production stemmed from the desire to address the persistent issue of unavoidable deviations and the intention to simplify the intricate processes involved. The following outline the primary merits of this approach:

1) Environmental Impact: The CAD/CAM milling machine required approximately 3 to 5 minutes for drilling each vector hole hence, contributing to the environmental preservation by conserving energy, promoting a more sustainable planet .

2) Cost Efficiency: This technique operates with zero material usage which significantly reduced costs by eliminating the need for expensive machinery and materials like Stereolithography (SLA), Selective Laser Sintering (SLS), and Fused Deposition Modeling (FDM) for fabricating the surgical stent.

3) Streamlined Registration: Introducing a novel, uncomplicated registration technique that simplifies the registration process significantly.

4) Leveraging Fit: Harnessing the attained precision in fit, adaptation, retention, and stability of the radiographic template substantially mitigated errors originating from misfits in 3D printed Stereolithographic templates.

5) Precision Utilization: Leveraging the accuracy of CAD/CAM milling technology to achieve high precision with minimal machine time and no material usage, resulting in optimal cost-effectiveness.

In summary, the MCASS technique, despite its remarkable potential in implantology, faces limitations that require careful consideration. To fully leverage its capabilities on a global scale, it necessitates sponsorship from implant companies to integrate MCASS registration tools into their software. Furthermore, the separate purchase of Orientor and Orientor Fixation planes adds a layer of complexity, but also represents a gateway to new possibilities in the field. These challenges are not mere roadblocks; they serve as a catalyst for potential collaborations with global industry leaders, paving the way for a future rich in innovation and groundbreaking developments.

Conclusion

Within the constraints of the MCASS technique, it holds the potential to enhance precision and minimize error accumulation by streamlining complex and unnecessary procedural steps. The CAD/CAM milling took approximately 3 to 5 minutes for drilling each vector hole, resulting in substantial time and energy savings, along with the elimination of the need for additional materials, contributing to a more eco-friendly approach. An additional notable advantage is the utilization of the accurate fit, adaptation, retention, and stability already achieved in the radiographic template.

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