Comparison of Dental Implant Placement Accuracy Using a Static Surgical Guide, a Virtual Guide and a Manual Placement Method - *An In-Vitro* Study

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Abstract

Introduction: The use of a surgical guide during pre-operative planning significantly increases the efficiency and safety of dental implantation. However, the current widespread use of static navigation has led to a decrease in accuracy. Dynamic navigation, on the other hand, can be an alternative. This study compared the accuracy of dental implant placement on jaw models using static navigation, a virtual guide and the manual placement method. **Materials and Methods:** Nine patients with favourable conditions were selected, and three-dimensional full-body jaw models were set up. Group I had 21 implants placed using static navigation, Group II had 21 implants placed using dynamic navigation and Group III had 21 implants placed using the 'free hand' method. Placement accuracy was calculated by the deviation between the planned implant position and the actual position obtained from post-operative cone-beam computed tomography and model scanning. **Results:** The deviation from the planned implant position was 0.4° in Group I and 0.5° in Group II. The 'free hand' method yielded the worst result, with a statistically significant difference between Groups I and II. However, implantation using dynamic navigation showed a lower variance of deviation, with the majority of implants having a deviation ≤0.5 mm (86% compared to 67% in the static navigation group). **Discussion:** The accuracy of implant positioning using a virtual guide with dynamic imaging was comparable to static navigation and surpassed the accuracy obtained using the 'free hand' technique. This study highlights the potential of dynamic navigation control in dental implantology and warrants further clinical research to improve this system.

Keywords: Accuracy, augmented reality, computer-aided surgery, dental implant

Introduction

A dental implant placement involves the use of computer technology to ensure optimal positioning and accurate reproduction during surgery.[1,2] A surgical guide is essential to minimise invasiveness, reduce time and avoid intraoperative complications.[3,4] Pre-operative planning of an implant position promotes tissue stability and long-term treatment results. The static navigation system for dental implants is currently active, using a computer-aided design–computer-aided manufacturing (CAD-CAM) technology-based surgical guide to direct drills for bed preparation and implant placement.[1,3,5,6]

Dynamic navigation, on the other hand, allows for real-time control of an implant bed preparation during surgery.[7-12] The study aimed to compare the accuracy of dental implant placement on jaw models using static navigation, virtual guide with dynamic visualisation and manual placement method.

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Materials and Methods.

The Research Ethics Committee (REC) reference number 261.

I. Pre-operative preparation
   1. Cone-beam computed tomography (CBCT) and intraoral scan data from nine patients
   2. Printout of 27 three-dimensional (3D) jaw models
   3. Computer-based planning for dental implantation

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    4. Preparation of 3D files for intraoperative use.
II. Surgical intervention
    1. Placement of dental implants according to a 'full protocol' guide using the original navigation kit
    2. Dental implant placement according to a virtual guide with dynamic visualisation
    3. Dental implant placement using the 'free hand' method.
III. Post-operative assessment of implant placement accuracy
    1. Scanning of jaw models with implant-fixed scan markers
    2. CBCT of jaw models with placed implants
    3. Statistical analysis.

Pre-operative preparation

Cone-beam computed tomography and intraoral scan data from patients

Before the initiation of this *in-vitro* comparative study, nine CBCT files and corresponding intraoral scans of patients with favourable conditions for dental implantation were selected from the database of the Research Institute of Dentistry and Maxillofacial Surgery, FSBEI HE I.P.Pavlov SPBSMU MOH, Russia.

The inclusion criteria were as follows:

- Availability of intraoral scan data (Standard Tessellation Language [STL] file)
- Availability of CBCT data (Digital Imaging and Communications in Medicine [DICOM] file)
- Bone tissue Types D II to D III
- Bounded edentulous space or free-end edentulous space (four teeth in one segment or less are missing)
- A type of edentulous space allows the use of a surgical guide under the 'full protocol'
- Dental implant placement does not require any additional bone-plastic interventions
- The guide is firmly fixed on the model and no additional fixation pins are required.

We printed 27 3D jaw models (9 equal models in each of the three groups: 12 for maxilla [4 models in each of the three groups], 15 for submaxilla [5 models in each of the three groups]), from files obtained by intraoral scanning of patients-STL, with their subsequent adaptation for printing using a 3D printer ASIGA MAX ultraviolet (UV) manufactured in Australia. Harzlabs Dental Peach, made in Moscow, Russia, was used for printing full-body models.

In Group I (9 models), surgeries were performed using a surgical guide by static navigation method. In Group II (9 models), dental implants were placed using dynamic navigation. In Group III (9 models), implants were placed using the free hand technique by a dental surgeon with more than 10 years of experience.

Group I – Dental implantation planning was performed using Exoplan 3.0 software (Exocad GmbH, Darmstadt, Germany). The STL files of the jaws were combined with the CBCT reconstruction in DICOM format. The implants were positioned in compliance with the established safety zones: the cortical bone layer thickness of at least 1.5 mm was preserved both on the lingual and vestibular sides. The depth of the implant position is 2 mm from the apex of the alveolar ridge. The safety zone from the implant apex to the anatomical structure is 1.5 mm. The dental implant position obtained on computer-aided planning was taken as a reference and considered a control group. Surgical guides (9 pieces) were planned and printed for the complete protocol of dental implant placement.

Group II – The implant positions were exported after computer planning using the Virtual Planning Export option in STL format.

A surgical navigation system was designed as a set consisting of a computer, an optical tracking system with four OptiTrack Flex 13 cameras, a model recorder, an angled handpiece tracker (W and H, Bürmoos, Austria) and drills of various types, as well as processing software for positioning system data, recording and visualisation of the navigation process. A registration device of the model consists of three reflective marks installed on a 3D-printed plate with a slot intended for the printed jaw model fixation. The angle handpiece tracking device is designed as a frame with four reflective marks. The frame is also made using 3D printing from a 3D scan of the handpiece. Linking the planning data to the model is performed using the appropriate model coordinates and then comparing with the coordinates of the reflective marks, taking into account the displacement based on the geometry of the tracking device. The program visualises 3D images of the drill path relative to the model based on the conversion matrix from the pre-operative CBCT registration and planning data. Before operation, the device is calibrated by inserting the end of the drill bit into a pre-determined slot on the registration device plate. The drill position and orientation are detected in real-time with a frequency of 90 Hz and a delay of no more than 20 millisecond (ms). The drill can be easily removed from the handpiece after insertion and another drill of greater thickness can be inserted.

Group I – Surgical guides (9 pieces) were planned and printed for the complete protocol of dental implant placement. The guides were printed in the digital dental laboratory. Harzlabs Dental Yellow Clear material was used to print the guides on the ASIGA MAX UV 3D printer, manufactured in Australia. Harzlabs Dental Peach, made in Moscow, Russia, was used for printing the models.

Group II – To perform dynamic navigation, planning elements and STL files of jaws were pre-converted into the OBJ format. The conversion was necessary for the correct import into the Unity development environment (Unity Technologies, USA). The materials were assigned to the models after the import - blue transparent for the dental model, green transparent for the optimal drilling axis, yellow for the drilling starting point and red for the optimal implant position.

Group III – An analysis of the patient's CBCT data and the results of computer planning of dental implantation were performed. An algorithm for implant placement by the free hand method was planned.

Surgical intervention

A single surgeon experienced in static and dynamic navigation systems performed surgical intervention in the three groups. Sixty-three dental implants were placed in 27 jaw models. Straumann training implants of 3.3/10 and 4.1/10 mm were placed. The models were stabilised on a special fixation device before the intervention. The implants in the three groups were placed in strict compliance with the manufacturer's surgical protocol.

In Group I (9 models), a surgical guide was preliminarily applied and stabilised on the model. A step-by-step preparation with drills from the Straumann navigation kit was then performed according to the surgical protocol. Straumann dental implants [21 implants, Figure 1] were placed. In Group II (9 models), the navigation process was organised in the following way: optical navigation transmitted the coordinates of model and handpiece tracking device. Then, the virtual models of the required jaw and a handpiece with a certain drill were substituted for these coordinates in the Unity environment, resulting in a reconstruction of what happens in reality represented in the virtual environment. At the same time, the drilling axis of the tool was visualised on the computer as a red line. The navigation was performed by matching the beginning of this axis (the end of the drill) with the yellow-marked point of drilling initiation. Later, the axis of this tool was aligned with the planned drilling axis and drilling was performed after reaching the optimal position. Straumann dental implants (21 implants) were placed using a Straumann surgical kit [Figure 2]. In Group III (9 models), a 'free hand' method was used to perform implant osteotomy, taking into account the general requirements for implant placement. Straumann dental implants (21 implants) were placed using a Straumann surgical kit [Figure 3].

Post-operative assessment of implant placement accuracy

After the surgical intervention, the original Straumann scan markers were linked to the dental implants and the models were scanned using a Medit I 500 intraoral scanner [Figure 4].

Then, the marks (10–12 pieces) were applied to the models with a liquid composite to create contrasting X-ray points. The modified models were fixed in a computed tomography (CT) scanner and radiological examination was performed on a CT scanner. Scanning conditions: Field of view (FOV) 8 cm × 8 cm, voxel size 200 µm, 270° rotation, exposure time 12 s, tube voltage 90 kV and tube current 8.0 mA.

The present study is a pilot one, so the main variable of the result describing the difference between the planned and performed implant positions was the implant body displacement from the planned position in the pre-operative computer simulation. The variables were calculated using exoplan 3.0 after registration of post-operative and pre-operative CBCT and model scan data in the system.

Statistical analysis

Considering the non-normal distribution values of the transplant position deviation angle from the planned position

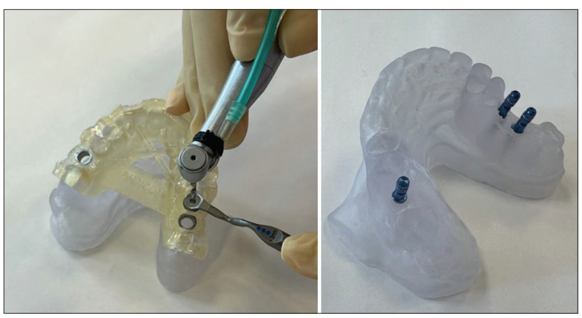

Figure 1: Placement of Straumann dental implants using the surgical guide with the original navigation kit

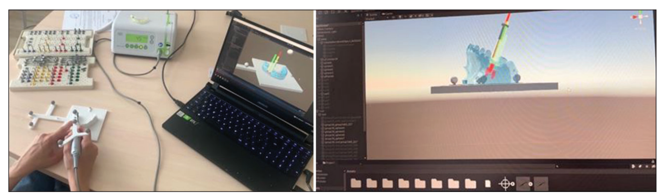

Figure 2: Straumann dental implants placement under dynamic navigation control

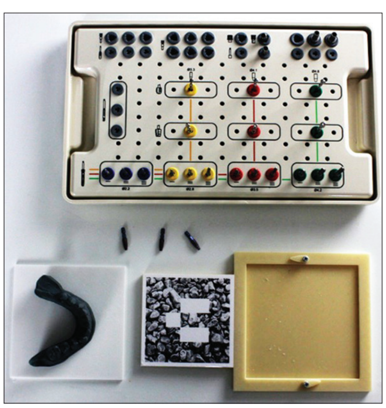

Figure 3: Placement of Straumann dental implants in models fixed in a special holder using the original surgical kit

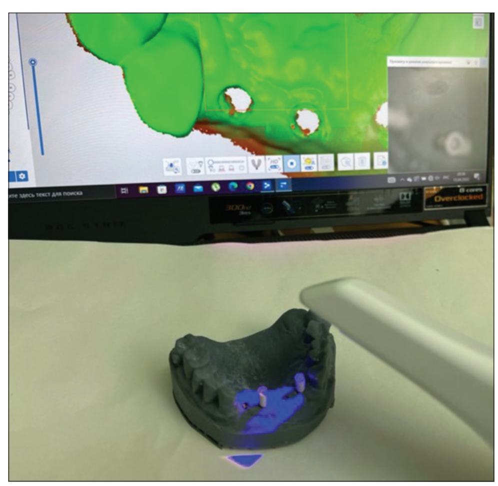

Figure 4: Scanning of models with dental implants placed and scan markers fixed on them using an intraoral scanner

in the studied groups, the median and interquartile range in the form of 'Me (Q_1; Q_3)' were used to describe the variable. Mann–Whitney *U*-test was used to check the statistical significance of differences between the study groups. Differences at $P < 0.05$ were considered statistically significant. Dispersion of the studied attribute was also used to measure variability. The percentage of implants with a target deviation level is reported as a percentage with a 95% confidence interval calculated according to the Wilson method.

Results

When comparing all System-3 dental implants in the three groups under study, the axial deviation angle from the planned position was found to be the greatest after 'free hand' placement, being 1.3° (0.9; 0.2). The differences were statistically significant compared to both Group I ($P = 0.001$) and Group II ($P = 0.001$). The deviation from the planned implant position during placement using static and dynamic navigation was not significantly different, being 0.4° (0.2; 0.7) in Group I, and 0.5° (0.4; 0.5) in Group II ($P = 0.37$). However, implantation with dynamic navigation is characterised by a lower variance of deviation (0.03 mm^2, compared to 0.25 mm^2 in the case of static navigation). As a consequence, the proportion of implants with a ≤0.5 mm deviation from the planned position in Group II was 86% (95% proportion of implants 65%–95%), while in Group I, it was only 67% (95% proportion of implants 45%–83%) [Table 1 and Figure 5].

Table 1: The value of dental implant's body displacement in the study groups

Model number	Tooth number	Jaw layout	Implant axis deviation (body displacement)		
			Group I (static navigation)	Group II (virtual guide with dynamic navigation)	Group III (free hand method)
1	45	Submaxilla	0.5°	0.5°	1.4°
2	46	Submaxilla	0.7°	0.4°	1.8°
3	45	Submaxilla	0.7°	0.9°	0.9°
4	47	Submaxilla	0.4°	0.5°	1.2°
5	46	Submaxilla	0.9°	0.9°	2.3°
6	47	Submaxilla	0.4°	0.5°	3.2°
7	12	Maxilla	0.3°	0.4°	1.3°
8	11	Maxilla	0.2°	0.3°	1.3°
9	21	Maxilla	0.3°	0.5°	2.0°
10	22	Maxilla	0.7°	0.5°	2.7°
11	22	Maxilla	0.3°	0.4°	2.1°
12	47	Submaxilla	2.5°	0.8°	0.9°
13	37	Submaxilla	0.7°	0.5°	1.6°
14	36	Submaxilla	0.6°	0.5°	2.0°
15	24	Maxilla	0.4°	0.5°	1.2°
16	26	Maxilla	0.2°	0.3°	0.9°
17	16	Maxilla	0.2°	0.3°	0.6°
18	26	Maxilla	0.4°	0.5°	0.6°
19	27	Maxilla	0.2°	0.3°	0.4°
20	14	Maxilla	0.2°	0.3°	0.9°
21	15	Maxilla	0.2°	0.4°	1.3°

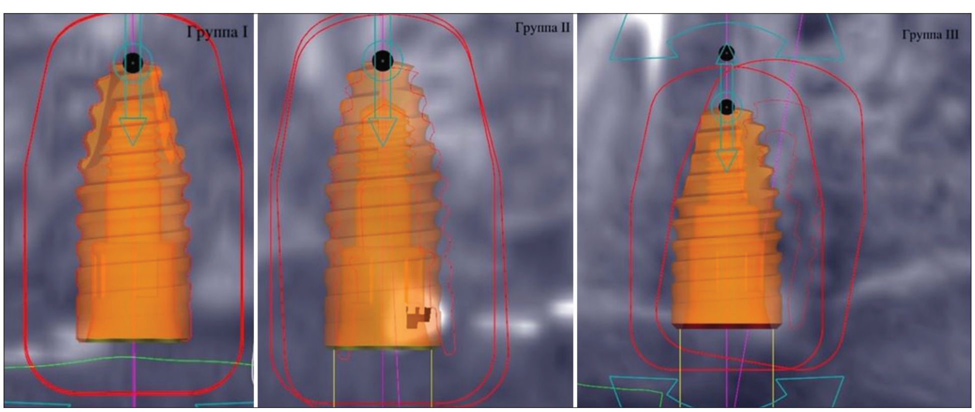

Figure 5: A one-case example of the results showing the comparison of the implant position with the planned position in the three study groups

Discussion

A virtual guide with dynamic imaging is a relatively new method of navigation. For this reason, it is crucial to assess the accuracy of implant positioning achieved with this type of navigation compared to more traditional navigation methods before starting clinical studies.

The advantage of dynamic navigation over static navigation is that there is no need to produce a guide, it is just possible to instantly load a surgical plan into the system. Consequently, the following limitations that can arise when using a conventional surgical template are eliminated: insufficient drill cooling and the need for additional space to place a drill and a guide in the lateral areas of the mouth or when the mouth is difficult to open.

A limitation of the present study was the fact that the augmented reality-based system only had to track the drill when stabilising the models during surgery. When dynamic navigation is used in the clinical setting, it is necessary to additionally track the patient's movements. However, it is to be noted that dynamic navigation will yield to static navigation when working with challenging sites of the jaws requiring additional drill movement path stabilisation.[13] A limited FOV and the need to keep the markers and the operating area in the surgeon's sight at the same time are other disadvantages of this technology. If it is impossible to keep these images, there is a delay and, as a consequence, inaccuracy of image superposition. It is also worth noting that the present study was conducted with only one system of implants, and their number was relatively small.

At the same time, due to the use of post-operative CBCT and additional data of implanted models optical scanning, we were able to achieve high accuracy in the assessment of an implant positioning and its comparison with the pre-operative plan.

It should be noted as well that currently the possibility to implement artificial intelligence (AI) is a promising trend. AI technology can simplify the virtual template design process replacing the conventional software.[14]

Conclusions

Pre-clinical studies have shown that the accuracy of implant positioning using a virtual guide with dynamic imaging is comparable to the accuracy provided by static navigation and to a great extent surpasses the results of the 'free hand' technique. The augmented reality navigation system that has been developed can supplement the operating field with a 'virtual scene' featuring additional sources of information and give the dentist a 'sense of depth'. Dynamic navigation-controlled dental implantation certainly shows potential for the future of dental implantology, but the results of the *in vitro* study cannot be fully transferred to real practice due to the more complex conditions of the procedure, which requires further clinical research.

Declaration of patient consent

The authors certify that they have obtained all appropriate patient consent forms. In the form, the patient(s) has/have given his/her/their consent for his/her/their images and other clinical information to be reported in the journal. The patients understand that their names and initials will not be published and due efforts will be made to conceal their identity, but anonymity cannot be guaranteed.

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Nil.

Conflicts of interest

There are no conflicts of interest.

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