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Influence of clinical expertise and practical experience on transfer accuracy in guided dental implant placement - an in vitro study

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Abstract

Purpose To investigate whether inexperienced users applying a static navigation system can perform in-vitro a fully guided implant placement protocol and achieve similar results in terms of accuracy compared to experienced clinicians.

Methods Based on 36 identical resin models, a computer-assisted implant planning was performed and a surgical guide was produced accordingly. Three study groups were composed with 12 operators, each: control group with experienced surgeons (DOC), test group 1 with dental technicians (TEC) and test group 2 with non-specialists (OFC). Using a fully guided drilling protocol, two implants were placed into each of the 36 models. Subsequently, the differences between the virtually planned and final implant positions were determined and the transfer accuracy was evaluated.

Results For the control group DOC, the mean value of axial deviation was 1.90 ± 1.15 degrees, for 3-dimensional deviation at the implant base 0.52 ± 0.33 mm, for 3-dimensional deviation at the implant tip 0.76 ± 0.39 mm and for vertical deviation at the implant tip -0.11 ± 0.51 mm. For corresponding parameters, the mean values of test group TEC were 1.99 ± 0.87 degrees, 0.42 ± 0.21 mm, 0.68 ± 0.30 mm and -0.03 ± 0.33 mm and for test group OFC 2.29 ± 1.17 degrees, 0.63 ± 0.35 mm, 0.89 ± 0.43 mm and -0.24 ± 0.57 mm, respectively. The results did not reveal any statistically significant differences between the control and the 2 test groups ($p > 0.05$).

Conclusion The results of the present in-vitro study demonstrated that inexperienced users applying a static navigation system can perform a fully guided implant placement protocol and achieve similar results in terms of accuracy compared to experienced clinicians in this specific in vitro setup.

Keywords Accuracy · Experience · Guided surgery · Dental implant · Static navigation

Background

The use of static navigation systems in implant dentistry to transfer a virtually planned implant position to the clinical site is established and has been studied very well [1–3]. Predictable treatment results and the reduction of intraoperative complications even with complex cases are considered advantages of this concept [4, 5]. The so-called transfer accuracy (TA) is a decisive set of parameters to evaluate the reliability of guided implant placement systems, determining the difference between the virtually planned and the clinically placed implant position. The TA demonstrates how accurately the virtually planned implant position was transferred to the clinical surgical site. The availability of static navigation systems poses the question if users with little or even no experience in implant dentistry can achieve good clinical results, i.e., high accuracy with the help of drilling guides. Only few scientific studies investigated this

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relation and their results are controversial. For example, clinical and in vitro studies reported that less experienced users benefit from the use of drill templates and significantly improve accuracy values [6, 7]. In contrast, clinical studies found that the degree of experience is not a significant factor influencing the accuracy [8–10]. It was also reported that inexperienced users achieved inferior results in terms of TA [11].

This shows that no clear conclusion can be drawn and further investigation is needed. Thus, the aim of this in-vitro study was to assess the influence of the operator's clinical expertise and practical experience on TA in guided dental implantation.

Methods

The experiments were conducted using maxillary polyurethane models of the type Maxilla S1, (GOS® GmbH, Northeim, Germany). After a quality control, a reference model was determined and used for the creation of a 3-dimensional X-ray image using cone beam computer tomography (CBCT). The parameters of the CBCT scanner Veraview X800 (J. MORITA® MFG. CORP., Kyoto, Japan) were set as follows: Voltage 79.0 kV; Amps 1.9 mA; exposure time 9.4 s; original angle 0.0°; FOV 88.125×88.125×80.500 mm; voxel size 0.125 mm, slice

thickness 1.000 mm, slice interval 1.000 mm. Subsequently, the obtained data set was exported as Digital Imaging and Communications in Medicine (DICOM) file format with maximum resolution. The reference model was then scanned with a desktop scanner (Straumann® Desktop Scanner 7-Series, Dental Wings® GmbH, Chemnitz, Germany) and the resulting surface scan was exported as a Standard Tessellation Language (STL) file. Both data sets were superimposed using a planning software (coDiagnostiX®, Dental Wings® GmbH, Chemnitz, Germany) and virtual implant planning was performed. One implant was planned as a single-tooth gap in region 15 and another implant as a free-end situation in region 26. Following that, the drill template was designed and manufactured by an experienced user using the Objet 260 3D printer (Stratasys® Ltd., Rehovot, Israel). The material OBJET MED610 Biocompatible, Clear, (Stratasys® GmbH, Rheinmünster, Germany) validated for this process was used. Original Straumann® T-sleeves, Ø 5 mm, height 5 mm made of steel (Straumann Group, Basel, CH) were used as drill sleeves.

Thirty-six test persons were included in the study, forming three equal groups of operators (Table 1).

All groups consisted of 50% female and 50% male operators. The control group (DOC) consisted of eight oral surgeons and four oral and maxillofacial surgeons. Both professional titles represent a high level of specialized expertise and practical clinical experience in the field

Table 1 Demographic data of participating subjects

Group		DOC	TEC	OFC
Age	<i>mean age</i>	46	40	45
	<i><40</i>	3	2	4
	<i>>40</i>	9	10	8
Gender	<i>male</i>	6	6	6
	<i>female</i>	6	6	6
Handedness	<i>right-handed</i>	11	11	10
	<i>left-handed</i>	1	1	2
Profession	<i>Oral and Maxillofacial Surgeon</i>	4		
	<i>Oral Surgeon</i>	8		
	<i>Master Dental Technician</i>		7	
	<i>Dental Technician</i>		5	
	<i>Business Economist</i>			5
	<i>Economist</i>			3
	<i>Marketing Manager</i>			1
	<i>Industrial Clerk</i>			1
	<i>Engineer</i>			1
	<i>Event Manager</i>			1

of implant dentistry and surgery, respectively. Test group 1 (TEC) consisted of five dental technicians and seven master dental technicians. Dental technicians have limited theoretical knowledge but no clinical or practical experience with static navigation systems. The test group 2 (OFC) consisted of twelve office workers. The operators of this group were non-clinicians and have neither dental nor dental technical training. Conducting the experimental implant placement was the first contact with implant dentistry resp. guided surgery for them.

Implementation of the experimental implant placement

All operators performed the experimental implant placement separately under the same conditions and were individually instructed by the investigator. After a technical briefing on the use of the surgical motor and the contra-angle handpiece, the experiment was carried out. A training video (Straumann® Guided Surgery – Leading Your Way In Your Treatment, Straumann Group, Basel, CH) provided by the manufacturer of the implant system showing the clinical application of the guided-implant systems was shown to the operators. In this way, the individual steps of the experimental implant placement were successively demonstrated. Afterwards, the operators autonomously practically performed the demonstrated steps and were supervised by the investigator. The investigator documented the drilling procedures and implant placements of each operator. However, he did not influence this procedure by any kinds of comments or practical interactions.

A total of 72 dummy implants with a tapered design, with a diameter of 4.1 mm and a length of 10 mm (Straumann® BLT implants, Roxolid® SLActive, Straumann Group, Basel, CH) were used for the experimental implant placement. Each operator placed the implants into a separate jaw model, but all operators used the same drill template.

A surgical motor with contra-angle handpiece was used for preparation, profile drilling and tapping. Implants were inserted manually using the surgical hand ratchet from the surgical cassette provided. The drilling protocol was performed according to the specifications of the manufacturer’s instructions. The surgical instruments used were the Straumann® Guided Surgery Basic Cassette (Straumann Group, Basel, CH) for guided implant placement. The drills and the profile drill of this system have a physical depth stop. The drills were replaced after 10 times of use according to the manufacturer’s recommendation. For the experimental implant placement, the operators used the Straumann® Surgical Motor Pro with the contra-angle handpiece Ti-Max X-SG20L (NSK® NAKANISHI INC., Tochigi, Japan). For implant placement, the surgical motor settings for the drills with diameters of 2.2 mm, 2.8 mm, and 3.5 mm were set to 800 rpm. The profile drill with a diameter of 4.1 mm was set to 300 rpm, while the BLT Tap with a diameter of 4.1 mm was set to a lower speed of 15 rpm.

For the accuracy analysis, RC Mono Scanbodies (Straumann Group, Basel, CH) were mounted on the implants and scanned with the previously used desktop scanner. The 36 surface scans were exported as STL files and compared with the reference data set of the originally created planning case with the planning software. For this purpose the manufacturer of the planning software provides a non-commercially available plug-in tool named Treatment Evaluation. In accordance to the methodology of previously conducted studies [5, 12, 13] four clinically relevant deviation parameters measured between the planned and the final implant position were determined: the three-dimensional offset of the implant base (Db) and the implant tip (Dt) was defined as the distance between the coronal / apical centers of the planned and finally placed implants. The angular deviation (Ad) was calculated as the angle between the longitudinal axes of the planned and the finally placed implant. The vertical deviation at the implant tip (Vd) was calculated as the

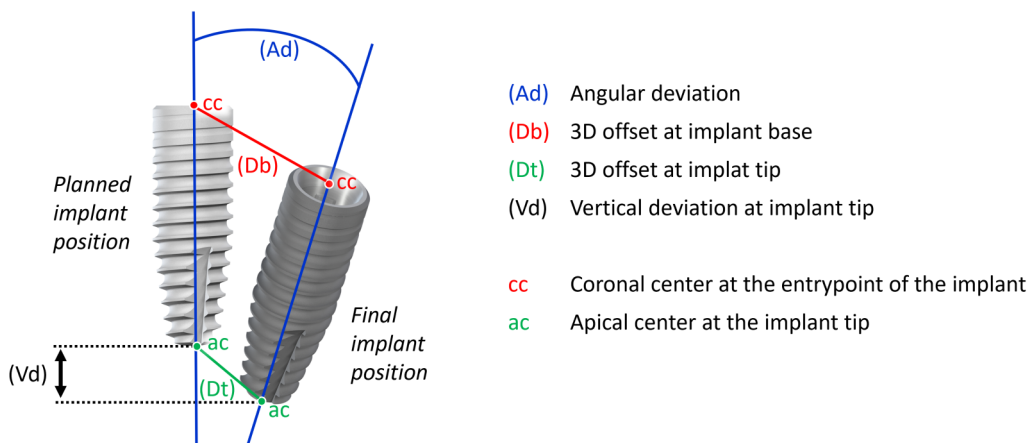


Fig. 1 – Evaluated deviation measurements

distance between the apical center of the planned implant and the apical center of the finally placed implant (Fig. 1).

The complete data acquisition, scanning of the models and the implant position evaluation were performed by the investigator using a blinded design.

The values for the angular deviation were calculated by the evaluation software in °(degrees) with one decimal place, the 3D offset and vertical deviation in millimeters with two decimal places. Data were visualized using group-specific boxplots and dotplots. The boxplots visualize five summary measures: the median, the 25th and 75th percentiles (Q1 and Q3), and the upper and lower adjacent values, which are the most extreme values within $Q3 + 1.5(Q3 - Q1)$ and $Q1 - 1.5(Q3 - Q1)$, respectively. The dots represent single values and the red lines mark mean values. Pairwise comparisons between groups were conducted using the Mann-Whitney U test. Furthermore, to assess for each group whether the difference between regions was equal to 0, Wilcoxon signed rank tests were performed. Due to the exploratory character of the study, P-values are to be interpreted only descriptively, thus no formal adjustment for multiple testing was performed. P-values smaller than 0.05 were considered to be statistically significant. Statistical analyses were conducted using Stata/SE 16.0 (StataCorp LLC, Texas, USA).

Results

Deviation between groups

All 36 operators were able to complete the experimental implantations with two implants each and all 72 implant

positions were submitted to the statistical analysis. For the group comparison regarding the mean TA, the values of the inter-dental gap situation at region 15 and the free-end situation at region 26 were combined and the operator groups were then compared with regard to the respective deviation parameters.

The mean value of angular deviation (Ad) at control group DOC was 1.9° (min. 0.2° / max. 4.0°) at test group TEC 2.0° (min. 0.5° / max. 4.1°), and for the test group OFC at 2.3° (min. 0.4° / max. 5.0°) (Fig. 2).

In the group comparison, no statistically significant differences were found between the control group DOC and the test groups TEC ($p=0.642$) and OFC ($p=0.348$). The comparison between the two test groups also showed no statistically significant difference ($p=0.257$).

The mean values of the 3-dimensional deviation at implant base (Db) at control group DOC was 0.52 mm (min. 0.14 mm / max. 1.74 mm), at test group TEC 0.42 mm (min. 0.11 mm / max. 1.10 mm), at test group OFC 0.63 mm (min. 0.14 mm / max. 1.68 mm) (Fig. 3).

The measured mean value of the 3-dimensional deviation at the implant tip (Dt) at control group DOC was 0.76 mm (min. 0.23 mm / max. 1.80 mm), at test group TEC 0.68 mm (min. 0.16 mm / max. 1.29 mm) and at test group OFC 0.89 mm (min. 0.12 mm / max. 1.74) (Fig. 4).

Considering the group comparison, no statistically significant differences were found between the control group DOC and the test groups TEC ($p=0.709$) and OFC ($p=0.381$). The comparison between the two test groups also showed no statistically significant difference in terms of this TA parameter ($p=0.070$).

The measured mean value of the vertical deviation at the implant tip (Vd) at the control group DOC was -0.11 mm

Fig. 2 - Boxplots demonstrate analysis of the values in terms of axial deviation (Ad) by groups ($N=72$ implants)

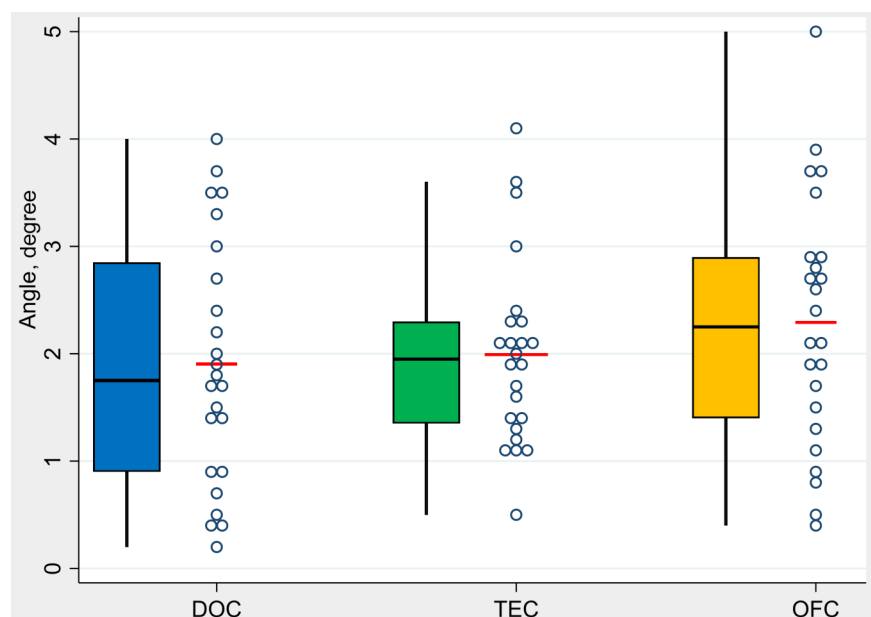


Fig. 3 - Boxplots demonstrate analysis of the values in terms of 3-dimensional deviation at implant base (Db) by groups ($N=72$ implants)

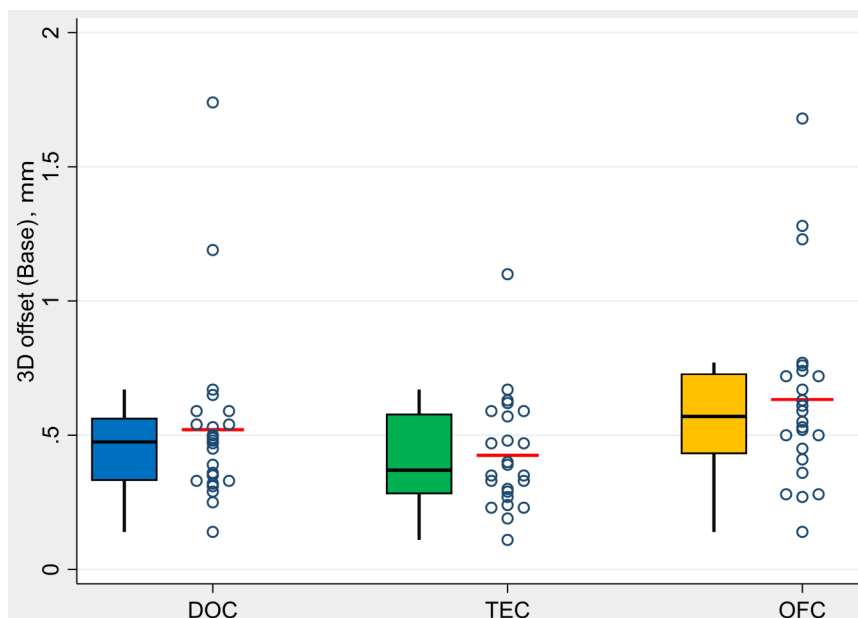
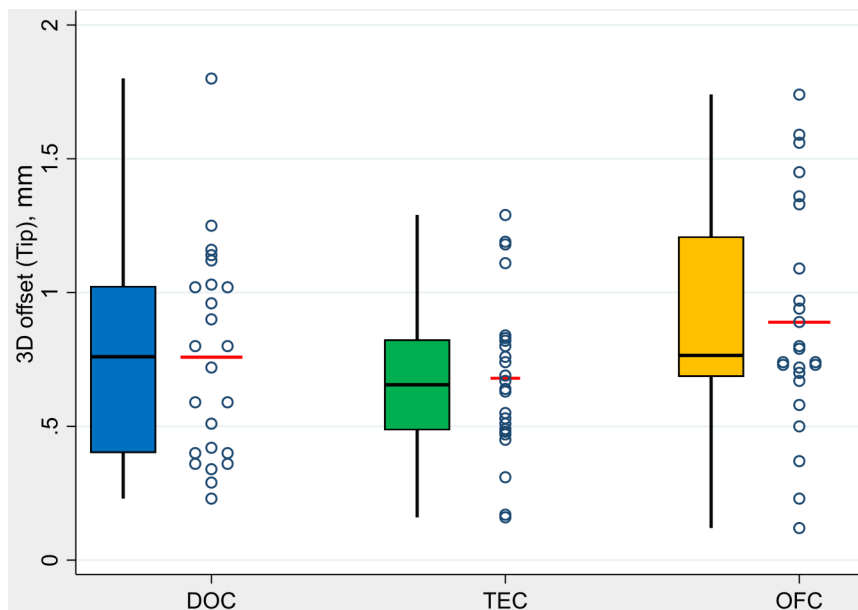


Fig. 4 - Boxplots demonstrate analysis of the values in terms of 3-dimensional deviation at implant tip (Dt) by groups ($N=72$ implants)



(-1.71 mm / max. 0.57 mm), at test group TEC -0.03 mm (min. -1.08 / max. 0.61 mm), at test group OFC -0.24 mm (min. -1.66 mm / max. 0.61 mm) (Fig. 5).

Negative values mean a deviation in the coronal direction and positive values mean a deviation in the apical direction. When comparing groups, no statistically significant differences were found between the control group DOC and the test groups TEC ($p=0.490$) and OFC ($p=0.365$). The comparison between the two test groups also showed no statistically significant difference in TA ($p=0.149$) (Table 2).

Deviation between inter-dental gap situation and free end situation

Different values of TA were found between the inter-dental gap and the free end situation. When comparing the mean values of TA regarding the angular deviation it was noticeable that for all three groups of operators the deviations in the free-end situation were larger than in the inter-dental gap situation. These differences turned out to be statistically significant in all three groups (DOC $p=0.046$, TEC $p=0.029$, OFC $p=0.006$).

Comparing the 3D offset at implant base, the groups DOC and OFC achieved smaller deviations in the free-end

Fig. 5 - Boxplots demonstrate analysis of the values in terms of apical (vertical) deviation (Vd) by groups (N=72 implants)

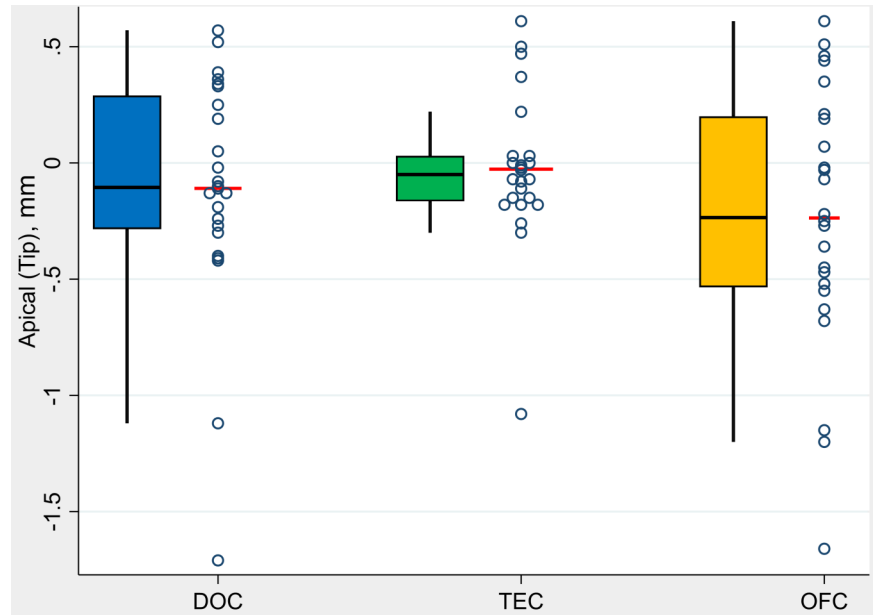


Table 2 Deviation values in terms of accuracy and comparison between groups

Group	Mean	SD	Minimum	Maximum
<i>Angular deviation (°)</i>				
DOC	1.90	1.15	0.20	4.00
TEC	1.99	0.87	0.50	4.10
OFC	2.29	1.17	0.40	5.00
Total	2.06	1.07	0.20	5.00
<i>3D-offset at base (mm)</i>				
DOC	0.52	0.33	0.14	1.74
TEC	0.42	0.21	0.11	1.10
OFC	0.63	0.35	0.14	1.68
Total	0.53	0.31	0.11	1.74
<i>3D-offset at tip (mm)</i>				
DOC	0.76	0.39	0.23	1.80
TEC	0.68	0.30	0.16	1.29
OFC	0.89	0.43	0.12	1.74
Total	0.78	0.38	0.12	1.80
<i>vertical deviation at tip (mm)</i>				
DOC	-0.11	0.51	-1.71	0.57
TEC	-0.03	0.33	-1.08	0.61
OFC	-0.24	0.57	-1.66	0.61
Total	-0.12	0.48	-1.71	0.61

situation than in the inter-dental gap, whereas TEC achieved larger deviations. However, no statistically significant difference was found for any group ($p > 0.05$).

Comparing the 3D offset at implant tip, it became evident that all three groups of operators achieved greater deviations in the mean values in the free-end situation than in the inter-dental gap situation. The difference in mean values between regions 15 and 26 was found to be statistically significant at TEC ($p = 0.012$).

Regarding the comparison of the vertical deviation at the implant tip between the inter-dental gap and the free-end situation, a shift of the mean values from the negative range in region 15 to the positive range in region 26 was observed in all three groups of operators. The differences between region 15 and region 26 reached statistical significance within the groups DOC ($p = 0.008$) and OFC ($p = 0.004$) (Table 3).

Discussion

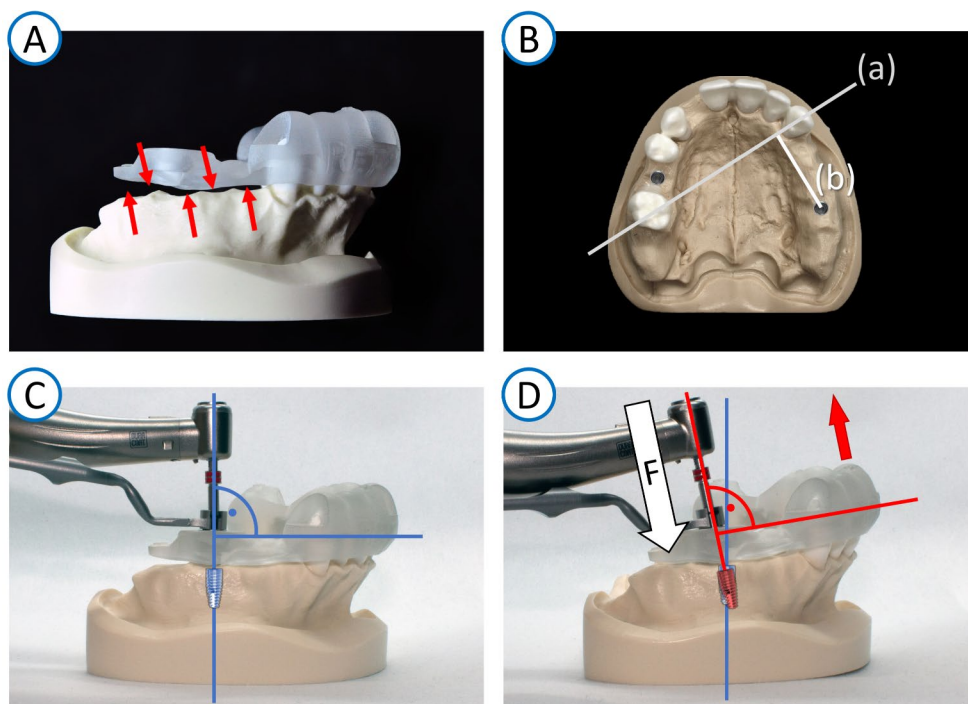
To the authors' current knowledge, no comparable studies have been conducted on this topic using operators without any relation to dentistry as a test group. In the present study, TA of experimental implantations was compared between experienced clinicians and non-specialist groups. In various

current studies, operators related to dentistry are often included, such as dental students or inexperienced surgeons [7, 8, 10, 11, 14]. Product-related user tests with inexperienced or even non-specialist users are often part of a standardized development and validation process, concerning the usability of a product or system. During the initial planning phase of the study, comparing the results between male and female operators was considered since previously published studies have suggested that female surgeons achieved better results [15, 16] or may have superior fine motor skills [17], which could be reflected in the results of transfer accuracy. For this reason, all groups were created with an equal number of male and female subjects. In order to only focus on the influence on clinical experience and expertise on transfer accuracy, the participants were chosen according to a balanced gender ratio. The aim of the present study is to analyze the influence of the user's competence level on TA of guided implant surgery. An investigation with this focus can only be performed as in vitro study design by reproducing a planned patient case and excluding all other influencing factors to the TA e.g. anatomic characteristics of the patient [18]. To avoid bias due to mechanical influences like the use of different drill guide geometries or various guided surgery systems described in further studies [19, 20], the experimental setup also required all operators to perform the implantation with the same drill guide, because the use

Table 3 Distribution of deviation at inter-dental gap situation and free end situation

Group	inter-dental gap, region 15				free-end situation, region		
	Mean	SD	Minimum	Maximum	Mean	SD	Minimum
<i>Angular Deviation (°)</i>							
DOC	1.40	0.77	0.40	3.00	2.41	1.27	0.20
TEC	1.68	0.70	1.10	3.50	2.31	0.93	0.50
OFC	1.68	0.98	0.40	3.70	2.91	1.04	1.10
Total	1.58	0.81	0.40	3.70	2.54	1.09	0.20
<i>3D-offset at base (mm)</i>							
DOC	0.56	0.46	0.14	1.74	0.49	0.10	0.32
TEC	0.34	0.08	0.23	0.48	0.51	0.27	0.11
OFC	0.66	0.31	0.27	1.28	0.61	0.39	0.14
Total	0.52	0.34	0.14	1.74	0.54	0.28	0.11
<i>3D-offset at tip (mm)</i>							
DOC	0.69	0.48	0.23	1.80	0.82	0.29	0.34
TEC	0.54	0.18	0.16	0.80	0.82	0.33	0.17
OFC	0.79	0.37	0.23	1.59	0.99	0.47	0.12
Total	0.67	0.37	0.16	1.80	0.88	0.37	0.12
<i>Vertical deviation at tip (mm)</i>							
DOC	-0.38	0.52	-1.71	0.05	0.16	0.34	-0.41
TEC	-0.08	0.07	-0.18	0.00	0.03	0.47	-1.08
OFC	-0.51	0.39	-1.20	0.07	0.03	0.62	-1.66
Total	-0.32	0.41	-1.71	0.07	0.07	0.48	-1.66

Fig. 6 - **A**: The template does not rest basally in the distal area of the free-end situation. **B**: Representation of the rotation axis (a) and lever with force (b). **C**: The template in correct position leads to a correct implant position (blue implant). **D**: Force 'F' exerted on the template results in tilting effect. As a result, the template is no longer seated in the correct position, which leads to a deviated implant position (red implant)



of different guides could lead to different implant positions [21]. The coDiagnostiX® planning software was used for planning and designing the drill template. This is an established system that has been used in everyday clinical practice for several years and has been investigated in numerous studies [10, 22–25].

In order to compare the final implant position with the originally planned reference positions, different measurement methods are described in the literature. Currently the most common method to determine the TA is to perform postoperative CTs, which are processed in planning software. The method used in this study to measure the TA with scan bodies, is described in recent studies [6, 19, 26], which also avoids unnecessary radiation exposure and provides a more precise measurement to achieve and compare the implant position [13]. There are several factors that can cause errors in transfer accuracy, such as differences in imaging quality of CBCT and surface scans [27, 28], also issues with the superimposing process and errors of reproducibility when overlaying the different imaging data sets [29–31]. Additionally, the reproducibility of results between the planned and actual placed implant position can be influenced by different production techniques and material selection of the 3D-printed surgical guides [7, 21, 32].

The results of the present study revealed that no statistical significance of the TA could be determined for the deviation parameters when comparing the control group DOC with the two test groups TEC and OFC. Only the 3D offset at implant base revealed a statistical significance ($p=0.009$) between the test groups TEC and OFC. The results of the

present in vitro study also showed that experience has no influence with regard to the TA. Comparing with similar in vitro studies it comes to light that the TA measured in this present study is comparable in terms of magnitude and shows within several parameters even higher accuracy [8, 10, 11, 14, 26, 33, 34].

The fact that even the operators without any expertise and experience in dental implant placement achieved acceptable results regarding TA can be explained by the use of technical guidance through demonstrating a training video. In this case the use of such an animated video tutorial, which demonstrates the complex process steps of the static navigation system, seems to be a proven training tool even for people outside the field or inexperienced operators. At this point, further investigation is recommended, especially on the part of the responsible manufacturers and providers of static navigation systems. Providing the instruction as an animated video tutorial could guide the experienced but also inexperienced surgeon before and during intra-operative use and could provide additional safety.

Observed complications

Axial deviations can be caused by different reasons. Firstly, it was observed that the surgical template could tilt and rotate during use, which can lead to a deviating angle and thus negatively influence the TA. This phenomenon was observed in all of the three groups during the operator trials performed. On the other hand, the phenomenon of fit tolerances between the sleeves and drill handles discussed

by Cassetta et al. (2015) can significantly influence the TA [35]. Significantly larger angular deviations of the implant axis were found for the inserted implants in the free-end situation compared to the inter-dental gap situation. The difference was statistically significant in all three groups of operators ($p < 0.05$). This significantly different TA can be explained by the intrinsic mobility and especially caused by the extension of the drill template. Whereas the drill template could be supported mesially and distally by teeth in the inter-dental gap situation in region 15, the drill template tended to descend distally in the unilateral free-end situation in region 26. This confirms the results of Toyoshima et al. (2015) and Naziri et al. (2016) that extensive unsupported drill templates in free-end situations may tilt apically and thus have an influence on the TA [36, 37] (Fig. 6).

The mechanism of tilting can be counteracted by actively holding the template in the correct position during use, e.g. by applying finger pressure to the tooth-supported area. However, this method requires a certain level of expertise and practical experience on the part of the user. Due to the experience level it was assumed that the group DOC would achieve a higher TA on these parameters than the test groups. However, this assumption could not be confirmed by the results.

Conclusion

The present in vitro results showed no statistically significant differences between the control group DOC and the test groups TEC and OFC regarding transfer accuracy at all four deviation parameters investigated ($p > 0.05$).

In the present in vitro study, clinical expertise and practical experience had no significant effect on transfer accuracy.

However, it is important to emphasize that the present results were obtained in a highly controlled in vitro experimental set up investigating only single procedures of a specific guided surgery workflow and therefore the clinical relevance needs to be critically discussed.

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Author contributions FSR contributed to study conception, methodology design, operators selection and supervision, collection of the data, interpretation of the data, writing the original draft, and approving the final version of the manuscript. CB contributed to the study conception, interpretation of the data, reviewing the final version of the manuscript. HW contributed to the statistical analysis. SR contributed to the study conception, interpretation of the data, reviewing and approving the final version of the manuscript. All authors read and approved the final manuscript.

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Data availability The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate This study was approved by the University of Greifswald Ethics Committee (Reg.Nr.:BB152/20). The study complied with the Declaration of Helsinki. All participants were aware of the nature of the study and provided their consent prior to the commencement of the study.

Consent for publication Not applicable.

Competing interests The authors declare no competing interests.

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