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Original Article

Tooth-Implant digital guide improves implantation accuracy in patients with periodontitis

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Abstract: Objective: To investigate the accuracy of Tooth-Implant digital guide-assisted implantation, explore the influence of periodontitis on the accuracy of the digital guide, and evaluate the effect of the residual abutment looseness after periodontitis treatment on the implant accuracy of the digital guide. Methods: In this retrospective clinical study, 45 patients who received dental implantation at the Department of Periodontology, Beijing Stomatological Hospital affiliated with Capital Medical University, were selected and grouped. Group A consisted of non-periodontitis patients (n=15) who underwent Tooth-Implant digital guide-assisted implantation surgery. Group B was composed of periodontitis patients (n=15) who received Tooth-Implant digital guide-assisted implantation surgery. Group C included periodontitis patients (n=15) with freehand implantation. Three dental landmarks were identified to compare the planned implant position generated by the Tooth-Implant digital guide before implantation and the actual implant position in the same patient. Differences in implant depth, angle, shoulder and apex were analyzed before and after the implantation. Results: There were statistical differences in implant depth, angle, shoulder, and apex between group B and group C. While statistical significance was found only in the implant angle and depth between group A and group B, not in the implant shoulder or apex. In periodontitis patients treated by Tooth-Implant digital guide-assisted implantation, significant differences were identified in implant depth and shoulder between non-abutment looseness and abutment looseness subgroups, but not in implant angle and apex. Under the digital guide-assisted implantation, no significant differences were found in implant depth, angle, shoulder and apex at different jaw positions, but at different tooth positions, significant differences were identified in implant angle and apex, not in implant depth and shoulder. The accuracy of Tooth-Implant digital guide-assisted implantation was consistent with previous data. Conclusions: The Tooth-Implant digital guide-assisted implantation has reliable implant accuracy that outperforms freehand implantation. Periodontitis is a factor affecting the accuracy of digital guide in dental implant placement, and this could be due to the looseness of residual abutments after systematic periodontal treatment. Different jaw positions have no impact on the accuracy of digital guide-assisted implantation, but different tooth positions have an impact on the accuracy of implant placement using a digital guide.

Keywords: Tooth-Implant digital guide, accuracy, periodontitis, implantation, looseness

Introduction

Periodontitis, a chronic infectious disease caused by dental plaques, and is the primary cause of tooth loss in adult Chinese patients [1]. Traditional restoration techniques for dentition defects and dentition loss have been unable to keep up with the demands of patients. In contrast, dental implants are becoming increasingly accepted due to their comfort, high chewing efficiency and the fact that they do not need to be removed and worn [2]. The accuracy of implant placement in the jaw needs to satisfy both mechanical and biological requirements and, in the case of anterior teeth, aesthetic requirements [3, 4]. The application of computer technology in dental implants is also developing rapidly, playing a guiding role in the development of oral implantology [5].

Computer-guided implantation can improve the accuracy and predictability of the implant surgery and greatly shorten the operation time. Therefore, the study of digital technology can play an important role in promoting the development of oral implants, with vital clinical implications [6]. However, in the field of oral implantology, digital guide is still in a developmental stage, which requires a large number of clinical investigation [7-9]. In addition, there are some issues that need to be addressed. For example, it remains to be clarified whether the looseness of the remaining abutments in periodontitis patients affects the fabrication of digital guides. Besides, the impact of abutment looseness on the accuracy of implant guides in clinical settings needs further investigation.

The Tooth-Implant digital surgical guide used in this clinical trial is the first of its kind to be used in China, with registered qualifications and validated clinical accuracy. But there is no literature or clinical trials about its accuracy in patients with periodontitis. Correspondingly, this study aims to investigate the accuracy of the Tooth-Implant digital guide on implantation in periodontitis patients, as well as the potential impact of abutment looseness on implant accuracy, thus providing a better understanding of the use of digital guides in dental implantation for patients with periodontitis.

Materials and methods

Subjects

This retrospective study has been reviewed by the Ethics Committee of Beijing Stomatological Hospital affiliated to Capital Medical University, with an approval number of CMUSH-IRB-KJ-PJ-2021-01. From January 2018 to January 2021, 45 patients who underwent oral implantation at the Periodontology Department of Beijing Stomatological Hospital affiliated to Capital Medical University were selected and grouped. Group A was composed of non-periodontitis patients who underwent Tooth-Implant digital guide-assisted implantation surgery. Group B included periodontitis patients who received Tooth-Implant digital guide-assisted surgery. Group C consisted of periodontitis patients who underwent freehand implantation.

Patient inclusion criteria: patients who were 18-65 years old; patients with complete medical records and Cone-Beam Computed Tomography (CBCT) imaging data; non-periodontitis patients and periodontitis patients in the periodontal maintenance phase after periodontal scaling for 8 weeks and systemic periodontal treatment, respectively; patients who used 10-mm-long Straumann implants (Straumann Company, Switzerland); patients with no contraindications to dental implants. Exclusion criteria: patients with intraoperative accidents during implantation; patients with intraoperative maxillary sinus lift; patients in the periodontitis freehand group who had no preoperative CBCT and plaster models.

Methods

Subjects in groups A and B received Tooth-Implant digital guide-assisted implantation, and their implant placement was planned by providing patient information to the guide processing plant. Patient data were saved in a subject number folder on a dedicated hard disk. For group C, plaster models and preoperative CBCT data were provided. Then, the a technician carried out the simulation design (**Figures 1**, **2**) for subjects in group C using the Tooth-Implant digital guide design software and obtained patients' guide design data. The preoperative CBCT data of subjects in group C were imported into the Tooth-Implant digital guide software in Digital Imaging and Communications in Medicine (DICOM) format, and the plaster model was scanned by a 3Shape scanner (Denmark) after setting the maxillary and mandibular thresholds, marking the nerves and important tissue structures, and selecting the ideal position to simulate the implant design. The two were utilized to determine the final implant placement, including implant type, direction, depth and angle, using a repair-oriented software information processing technique, and the data were exported and saved in Standard Template Library format.

Determination of the ideal position: The location, depth and axial direction of the dental implant were determined with restoration as the guide. The spacing between the implant and the abutment was 1.5 mm, and that between implants was 2 mm. The distance from the buccal bone plate was >1.5 mm, and the anterior buccal bone plate was at least 2 mm in thickness, otherwise, bone increment was required. The implant and the mandibular nerve canal were spaced at least 2 mm apart.

Data collection

The CBCT data were collected immediately after implantation and imported into the preoperative Tooth-Implant digital guide software in

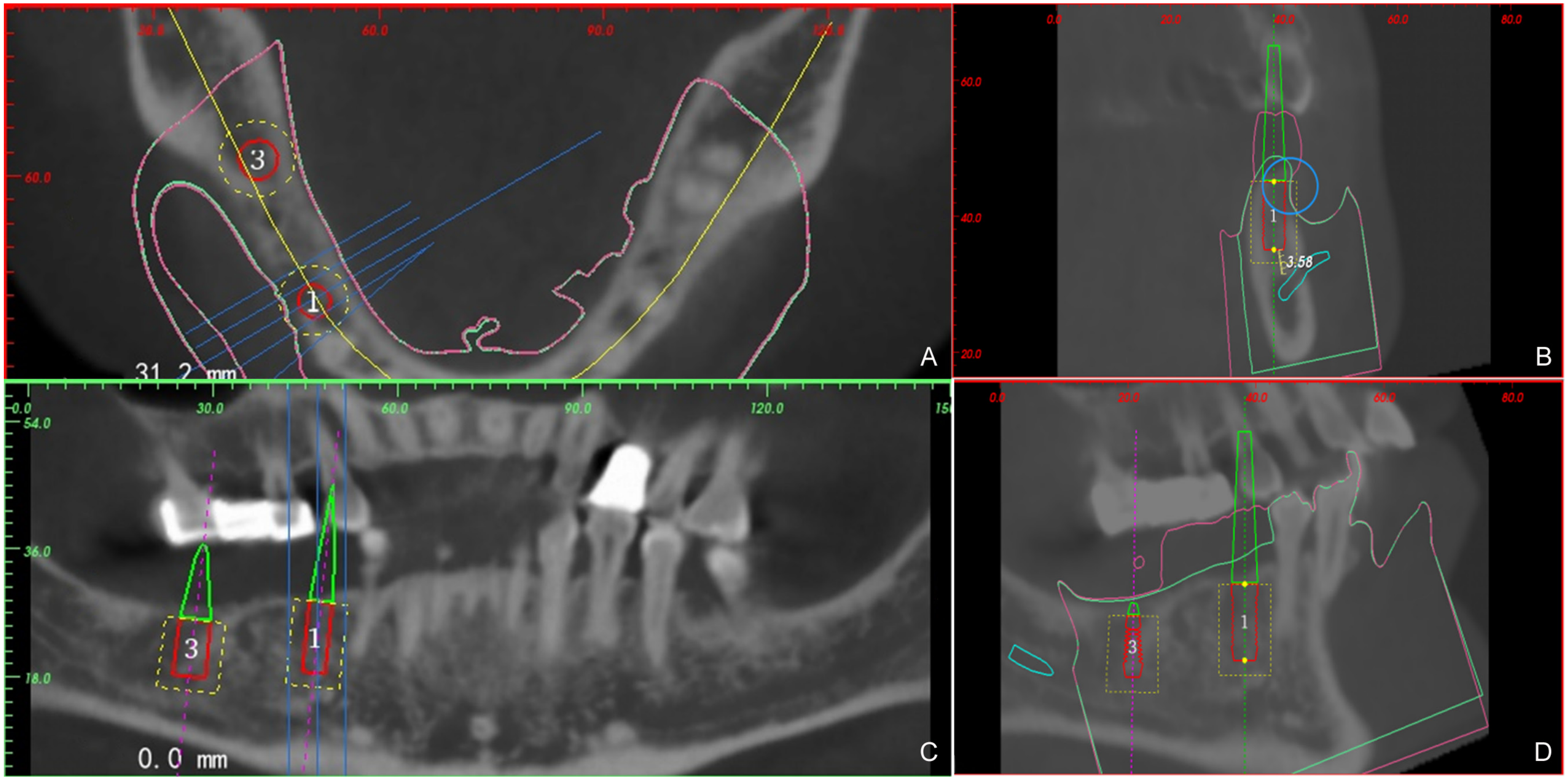

Figure 1. Preoperative design drawing. A: Horizontal view of preoperative design; B: Sagittal view of preoperative design; C: Coronal view of preoperative design; D: Repair-oriented determination of the final axial position.

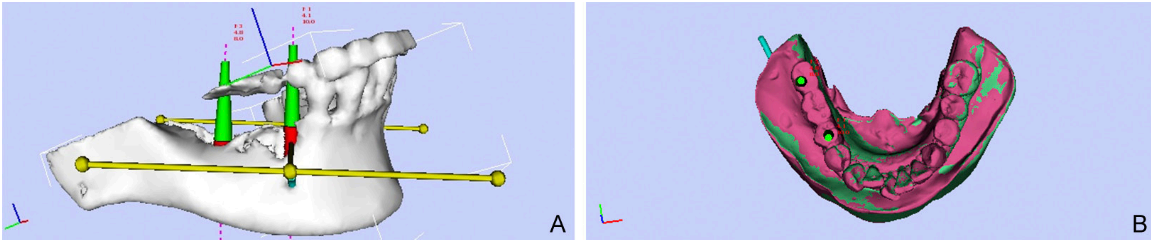

Figure 2. Effect simulation diagram. A: 3D imaging of effect simulation; B: Simulation of the actual repair effect.

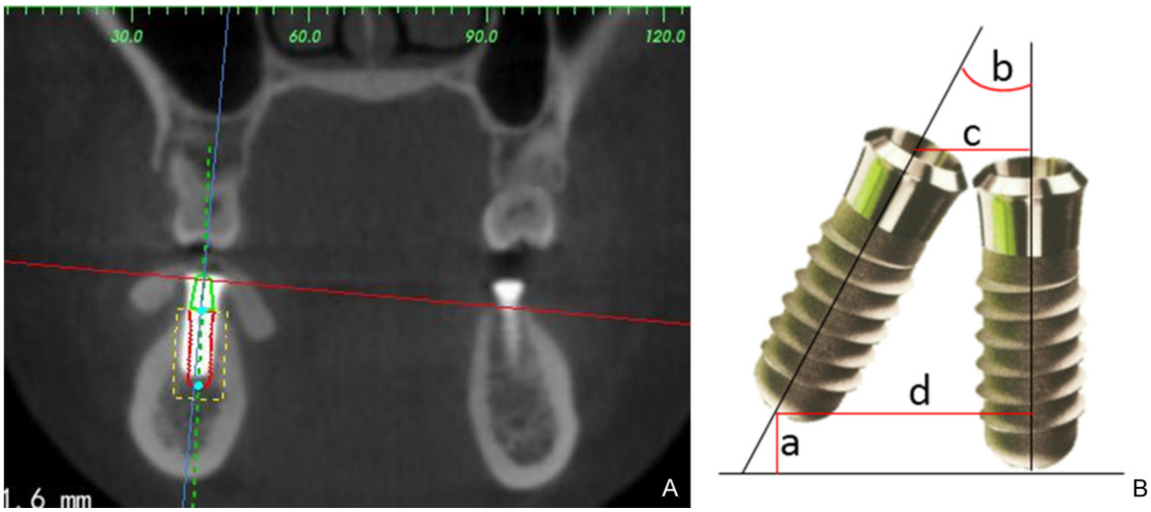

Figure 3. Measurement of implant deviation before and after implantation. A: Comparison of planned implant position designed by Tooth-Implant digital guide before implantation with the actual postoperative implant CBCT image of the same patient. B: Based on the ideal implant position designed by the Tooth-Implant digital guide software, a vertical line was drawn from the actual implant position to the ideal position to measure the differences in implant depth, angle, shoulder, and apex before and after implantation. a: The difference in depth before and after dental implantation; b: The difference in angle before and after dental implantation; c: The difference in shoulder before and after dental implantation; d: The difference in the apex before and after dental implantation.

DICOM format. Three dental landmarks (incisal end of incisor and buccal tip of maxillary first molar on both sides) were established to compare the planned position of implants designed by the Tooth-Implant digital guide before implantation with actual postoperative CBCT images of implants in the same patient. The measurements are shown in **Figure 3**. Based on the ideal position designed by the Tooth-Implant digital guide software, the actual implant position was drawn perpendicular to the ideal position. Differences in implant depth, angle, shoulder, and apex before and after implantation were measured, and the clinical data were obtained. Measurements were performed again one week later, and the values from both runs were averaged in the analysis of the clinical cases in groups A, B, and C.

Statistical analysis

The statistical software SPSS19.0 was used for statistical analysis. Count data, represented by n (%), was analyzed by the chi-square test. Measurement data were interpreted as mean ± standard deviation, and independent samples t test and one-way analysis of variance, were conducted to identify the differences between two groups and among multiple groups, respectively. $P<0.05$ was the significance threshold.

Results

All implants exhibited good initial stability and a torque of 25N after implantation. There were no intraoperative accidents or maxillary sinus lift, and the recovery was good upon postopera-

Table 1. Basic information of patients in the three groups

	Group A	Group B	Group C	*P* value
Age	43.67±7.29	47.00±9.43	49.07±7.14	0.190
Sex				0.713
Male	7 (46.67)	7 (46.67)	6 (40.00)	
Female	8 (53.33)	8 (53.33)	9 (60.00)	
Implant site				0.066
Anterior teeth	9 (60.00)	7 (46.67)	4 (26.67)	
Posterior teeth	6 (40.00)	8 (53.33)	11 (73.33)	
Jaw position				0.709
Maxillary teeth	10 (66.67)	8 (53.33)	9 (60.00)	
Mandibular teeth	5 (33.33)	7 (46.67)	6 (40.00)	
Loosened tooth	-	10 (66.67)	6 (40.00)	0.143

Table 2. Comparison of implant accuracy between group B and group C

	Implant quantity	Depth (mm) ($\bar{x}$±s)	Angle (°) ($\bar{x}$±s)	Shoulder (mm) ($\bar{x}$±s)	Apex (mm) ($\bar{x}$±s)
Group B	15	0.57±0.20	3.43±0.95	0.53±0.25	0.55±0.24
Group C	15	0.80±0.23	13.05±3.97	0.94±0.24	1.01±0.24
P		0.008	<0.001	<0.001	<0.001

Table 3. Comparison of implant accuracy between group A and group B

	Number of implants	Depth (mm) ($\bar{x}$±s)	Angle (°) ($\bar{x}$±s)	Shoulder (mm) ($\bar{x}$±s)	Apex (mm) ($\bar{x}$±s)
Group A	15	0.35±0.16	2.33±1.15	0.38±0.21	0.42±0.18
Group B	15	0.57±0.20	3.43±0.95	0.53±0.25	0.55±0.24
P value		0.003	0.009	0.088	0.111

tive suture removal. Patients' age ranged from 29 to 65 years. The non-periodontitis patients in group A showed a mean age of (43.67±7.29) years and a male-to-female ratio of 7:8. Among them, there were 9 implants in anterior teeth, 6 in posterior teeth, 10 in maxillary teeth, and 5 in mandibular teeth, without looseness of the remaining abutments. As for periodontitis patients in the group B (7 males and 8 females with a mean age of 47.00±9.43 years), there were 7 implants in anterior teeth, 8 in posterior teeth, 8 in maxillary teeth, 7 in mandibular teeth, and 10 loose abutments. Among the periodontitis patients in group C with freehand implantation, there were 6 males and 9 females aged (49.07±7.14) years on average, and there were 4 implants in anterior teeth, 11 in posterior teeth, 9 in maxillary teeth, 6 in mandibular teeth, and 6 loose abutments. See **Table 1** for the basic information of the three groups.

Comparison of implant accuracy between group B and group C

There were statistical differences between groups B and C in depth, angle, shoulder, and apex of the implants (P<0.01). See **Table 2**.

Comparison of implant accuracy between group A and group B

The implant depth and angle were statistically different between group A and group B (P<0.05), but no statistical difference was found in implant shoulder and apex (P>0.05). See **Table 3**.

Comparison of implant accuracy between non-abutment looseness and abutment looseness subgroups in group B

The implant depth and shoulder were statistically different between abutment looseness and non-abutment looseness subgroups in group B (P<0.05), but no statistical differences were identified in implant angle and apex (P>0.05), as shown in **Table 4**.

Comparison of accuracy of computer-guided implantation in different jaw or tooth positions

Analysis of the 30 implants in groups A and B showed no statistical differences in depth, angle, shoulder and apex between maxillary and mandibular implants (P>0.05). However, between anterior and posterior implants, statistical differences were identified in angle and apex (P<0.05), but not in depth and shoulder (P>0.05). See **Tables 5** and **6**.

Discussion

For patients with periodontitis, implants can help obtain bone integration and long-term stability [10, 11]. However, poor implant positioning can increase the risk of peri-implant diseas-

Table 4. Comparison of implant accuracy between abutment looseness and non-abutment looseness subgroups in group B

Group B	Number of implants	Depth (mm) ($\bar{x}$±s)	Angle (°) ($\bar{x}$±s)	Shoulder (mm) ($\bar{x}$±s)	Apex (mm) ($\bar{x}$±s)
Abutment looseness	10	0.63±0.20	3.67±1.02	0.65±0.22	0.59±0.27
Non-abutment looseness	5	0.44±0.10	2.96±0.56	0.30±0.06	0.48±0.15
P		0.021	0.084	0.007	0.30

Table 5. Comparison of implant accuracy between maxillary and mandibular implants assisted by the Tooth-Implant digital guide

	Number of implants	Depth (mm) ($\bar{x}$±s)	Angle (°) ($\bar{x}$±s)	Shoulder (mm) ($\bar{x}$±s)	Apex (mm) ($\bar{x}$±s)
Maxillary position	18	0.41±0.17	2.67±1.11	0.39±0.22	0.52±0.28
Mandibular position	12	0.53±0.23	3.2±1.19	0.55±0.24	0.46±0.16
P		0.116	0.242	0.089	0.588

Table 6. Comparison of implant accuracy of anterior and posterior implants assisted by Tooth-Implant digital guide

	Number of implants	Depth (mm) ($\bar{x}$±s)	Angle (°) ($\bar{x}$±s)	Shoulder (mm) ($\bar{x}$±s)	Apex (mm) ($\bar{x}$±s)
Anterior tooth position	16	0.44±0.21	2.49±1.22	0.45±0.24	0.38±0.16
Posterior tooth position	14	0.49±0.20	3.34±0.94	0.46±0.24	0.61±0.22
P		0.535	0.050	0.877	0.003

es [12], making the accuracy of implant positioning particularly important. The Tooth-Implant digital guide we used is the earliest of its kind with registered qualification in China, with confirmed high accuracy by clinical trials [13]. This guide integrates the data captured by CBCT and the information on oral soft and hard tissues obtained by a three-dimensional laser scanner, and analyzes the data through specific digital guide software to simulate implant design [14, 15]. Under the guidance of anatomy and repair, the implant site, angle, and depth are simulated while considering mechanics, aesthetics and biology aspects to generate digital data. The implant surgery guide is manufactured by 3D printing or computer cutting technology to assist dentists to accurately place the implant in the ideal position during clinical implantation [16]. Clinically, digital guides offer the advantages of intuition, safety, high efficiency, minimal invasiveness, and accuracy [17]. Therefore, studying their impact on implantation accuracy is of great clinical significance. Pettersson et al. [18] measured 139 implants and found that the average error of the shoulder, root and angle was 0.80 mm, 1.09 mm, and 2.26°, respectively, indicating that the use of digital guides to assist implantation can improve the accuracy of implant placement. In this study, the Tooth-Implant digital guide was used to assist the implantation in patients. By analyzing the data obtained in groups B and C, it was found that there were significant differences in implant depth, angle, shoulder, and apex, suggesting that the digital guide could effectively enhance implant accuracy in periodontitis patients. This is also consistent with the studies mentioned above. Baldi et al. [19] carried out a comparative observation on the clinical effects of digital guide-assisted implantation versus freehand implantation for anterior single tooth loss. Through longitudinal studies of the soft tissue health around the implant at 6 months, one year, two years and three years, it was found that digital guide-assisted implantation achieved more stable clinical outcomes. Therefore, using digital guides to assist implantation to improve the accuracy of the surgery can help avoid the increased risk of peri-implant diseases caused by poor implant positioning, which is consistent with the views of Lee et al. [20].

The 30 implants in groups A and B under the assistance of the Tooth-Implant digital guide were combined into one group to analyze the accuracy, and we found 0.26~0.66 mm in depth, 1.71~4.59° in angle, 0.22~0.70 mm in shoulder, and 0.27~0.71 mm in apex. Van Assche et al. [21] conducted a meta-analysis of 19 articles (1,688 implants and 10 different imported digital guide systems) and found that the overall mean deviation of the angle, shoulder, apex and depth was 3.81°, 1.09 mm, 1.28 mm, and 0.46 mm, respectively. Other scholars found through meta-analysis that the difference between the actual implantation position and the planned implantation position was less than 1 mm, and the angle difference was less than 5° [22]. This is in line with the data range obtained in this experiment, which suggested a comparable high accuracy of Tooth-Implant digital guide with imported digital guides. In this study, there were significant differences between anterior and posterior implants in angle and apex, while not in depth and shoulder, indicating that different tooth positions may affect the accuracy of digital guide-assisted implantation, which is similar to the finding of Vasak C et al. [23]. However, there were no significant difference between implants at different jaw positions in depth, angle, shoulder, and apex. Pettersson et al. [18] studied the accuracy of 139 implants from 25 patients and found that jaw position was an influencing factor for the accuracy of digital guides, but they did not qualitatively analyze the length of the implants and the support mode of guides. Vercruyssen et al. [24] found that the deviation of mandibular implants assisted by digital guide was higher than that of maxillary implants. The different results of this research may be related to the small sample size, the impact of abutment loosening and use of guides in patients with periodontitis.

Furthermore, periodontitis was identified as a factor affecting the accuracy of digital guides when they are used to assist implant surgery. The influence of periodontitis on the accuracy of the guide may be related to the characteristics of alveolar bone at the implant site and the looseness of the abutment covered by the guide. Further analysis of the influence of abutment loosening on the accuracy of the Tooth-Implant digital guide in periodontitis patients showed statistical differences between non-abutment looseness and abutment looseness subgroups in implant depth and shoulder, but not in angle and apex. It is suggested that abutment looseness after periodontal treatment can affect the accuracy of the digital guide. Abutment looseness can affect the accuracy of implant placement, while differences in bone properties can influence the preparation of the implant site. This is specifically manifested in cases where the bone has irregular shape or uneven density, which the drill can slip into and result in deviation of the actual implant position, thus affecting the clinical accuracy of digital guides. Relevant literature has confirmed that during the clinical operation of digital guide-assisted implantation, the accuracy of the guide could be affected by the deviation of the guide due to the position and angle of the drilling hole, the precision of the casing, the residual bone mass at the implantation site, the slippage of the drill bit, etc. [25, 26].

Given that only 45 implants were analyzed for in this study, the clinical sample size should be increased in the future to further analyze the influence of abutment looseness on the accuracy of the Tooth-Implant digital guide. In addition, extensive clinical trials are needed to investigate the impact of different levels of residual abutment mobility on impression preparation, guide fabrication, and accuracy of digital guide.

Conclusion

Tooth-Implant digital guide can improve the implant accuracy for periodontitis patients and is comparable to imported digital guides. In addition, periodontitis, abutment looseness, and different tooth positions can all affect the accuracy of the digital guide.

Disclosure of conflict of interest

None.

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