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Application of 3D Printing Technology in Oral Implant Dentistry and Its Impact on Bite Force and Masticatory Efficiency

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Abstract: *Objective*: To analyze the impact of 3D printing technology application on bite force and masticatory efficiency in patients following oral implant dentistry treatment. *Methods*: A total of 84 patients with single-tooth defects, selected from 100 patients who sought treatment from May 2023 to March 2025 and met the study criteria, were included in this study. The patients were divided into groups using a random number table method. The control group (42 cases) received conventional oral implant treatment, while the observation group (42 cases) underwent oral implant treatment guided by 3D printing technology. Both groups were followed up continuously for 6 months postoperatively. Masticatory efficiency, bite force, implantation accuracy indicators, and the incidence of treatment complications were compared between the two groups before treatment and 6 months after treatment. *Results*: There was no statistically significant difference in the incidence of complications following oral implantation between the two groups ($p > 0.05$). Compared to the control group, the observation group showed increased masticatory efficiency and bite force after oral implant treatment, with statistically significant differences in the deviation values of the implant crown, apical part in the sagittal plane, axial angle, and neck ($p < 0.05$). *Conclusion*: The application of 3D printing technology in oral implant treatment can effectively reduce implant placement deviations, enhance implantation accuracy, and effectively correct and maintain the oral occlusal force and masticatory function health of patients.

Keywords: Oral implant; 3D printing technology; Occlusal force; Masticatory efficiency

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1. Introduction

Oral implant treatment, as the primary restorative treatment for patients with dentition defects at this stage, involves implanting implants into the areas of dentition loss in the patient's mouth. After completing the second-stage crown restoration, it actively restores the patient's dentition health and offers clear fixed support and aesthetic advantages [1]. Traditional oral implant treatment operations rely on two-dimensional preoperative oral imaging for treatment assessment, providing guidance for oral implant treatment by analyzing characteristics such as the thickness of the alveolar bone and anatomical structures at the implantation site. However, due to limitations in imaging observation angles, inadequate precision in implant placement can lead to adverse outcomes such as infection and long-term implant loosening, affecting the correction of oral masticatory function and occlusal force in patients, thus presenting application limitations [2,3]. As a novel technology widely applied in orthopedic surgical treatment in recent years, 3D printing technology can utilize the three-dimensional imaging examination results of the bone structure at the surgical site before the operation to print a 3D model. Subsequently, by simulating therapeutic procedures, it provides more precise and effective operational guidance for the actual treatment of patients. Alternatively, this technology can be applied to oral implant therapy to optimize actual therapeutic outcomes [4]. Therefore, to analyze the impact of the application of 3D printing technology on the bite force and masticatory efficiency of patients after oral implant treatment, a study was specifically conducted, with details as follows.

2. Materials and methods

2.1. Clinical data

Eighty-four patients meeting the study criteria were selected from 100 patients with single-tooth defects who sought treatment from May 2023 to March 2025 as the research subjects for the therapeutic study. They were divided into a control group and an observation group using the random number table method, with 42 patients in each group. There were no statistically significant differences in age, location of tooth defects, or causes between the two groups ($p > 0.05$), as detailed in **Table 1**.

Table 1. Comparison of clinical data between the two groups

Clinical data		Control group (n = 42)	Observation group (n = 42)	Statistical value (χ^2/t)	*p*-value
Gender (n, %)	Male	24 (57.14)	22 (52.38)	0.192	0.661
	Female	18 (42.86)	20 (47.62)		
Age (years, Mean ± SD)		55.68 ± 6.32	55.71 ± 6.45	0.022	0.983
BMI (kg/m^2, Mean ± SD)		21.45 ± 0.62	21.49 ± 0.65	0.289	0.774
Missing tooth position (n, %)	Anterior	9 (21.43)	11 (26.19)	0.263	0.608
	Posterior				
Etiology of tooth loss (n, %)	Trauma	14 (33.33)	12 (28.57)	0.369	0.712
	Periodontal disease	23 (54.76)	25 (59.52)		
	Other	5 (11.90)	5 (11.90)		

2.1.1. Inclusion criteria

(1) Meeting the diagnostic criteria for single tooth dentition defect
(2) Sufficient bone mass at the fractured defect site, with an intermaxillary distance ≥ 10 mm
(3) Meeting the indications for oral implant treatment
(4) No abnormal oral occlusion

2.1.2. Exclusion criteria

(1) Adjacent teeth in the implant area with lesions or severe periodontal disease

(2) Presence of severe bone metabolic disorders
(3) Contraindications to oral implant treatment
(4) Pregnant or lactating women
(5) Incomplete clinical follow up information

2.2. Methods

2.2.1. Control group (Conventional oral implant treatment)

Preoperative oral CT scan examination was performed to analyze the occlusal health and anatomical relationships at the dentition defect site. Subsequently, a silicone rubber impression was taken, and a transparent resin film implant guide was fabricated using a vacuum press machine to locate the implant insertion points. After completing the above treatment preparations, the patient was scheduled to receive oral implant treatment. Prior to oral implantation, local infiltration anesthesia was administered to the periodontal tissues at the implant site. After anesthesia, disinfection and draping were performed. Following incision of the gingiva along the top of the alveolar ridge at the implant site, the subgingival tissues were separated to expose the alveolar bone. Subsequently, drilling and rinsing of the alveolar bone implant holes were completed, followed by implant placement. After fixation, the gingiva was sutured. Postoperatively, routine anti-infective and oral hygiene treatments were administered as needed, and secondary crown restoration treatment was completed as required.

2.2.2. Observation group (Oral implant treatment guided by 3D printing)

Before surgery, oral CT and 3D scanning examinations were performed as needed. Three-dimensional imaging data was utilized to reconstruct oral three-dimensional images, and a comprehensive analysis was conducted on the occlusal health and anatomical relationships following dentition defects. Individualized implant guides and surgical plans were designed, and the implantation of dental implants was simulated through virtual surgery to achieve the optimal implantation effect. After completing the above preparations, an implant guide was fabricated using a 3D printer. The implant was then placed using the guide, with the implantation procedure and postoperative treatment being the same as those in the control group.

2.3. Observation indicators

2.3.1. Masticatory efficiency

A peanut (2 g) masticatory test was conducted. The weight of peanut residue after 20 chews on each side of the teeth was measured to calculate the masticatory efficiency.

2.3.2. Bite force

A test piece was placed at the position of the mandibular first premolar. Subjects were instructed to bite evenly for 20 seconds, and the test was repeated 10 times consecutively. The mean value of the three strongest bite force test results was taken as the final test data.

2.3.3. Implantation accuracy indicator

Six months after dental implant placement, oral CT images were reviewed. After three-dimensional image reconstruction, the actual apical implantation positions, axial angles, and cervical deviations in the sagittal and coronal planes under the maximum axial section of the implant guide design and the implant were measured.

2.3.4. Incidence of treatment complications

The overall incidence of complications within six months after implant placement was recorded, including three categories: infection, tooth pain, and implant loosening.

2.4. Statistical methods

Data were analyzed using SPSS 24.0 software. Normally distributed continuous data were expressed as ($\bar{x} \pm s$) and compared using t-tests. Categorical data were expressed as n (%) and compared using appropriate statistical tests. A statistically significant difference was considered when $p < 0.05$.

3. Results

3.1. Comparison of chewing efficiency and bite force between the two groups

Before and after treatment before treatment, there was no statistically significant difference in chewing efficiency and bite force between the two groups ($p > 0.05$). After treatment, both chewing efficiency and bite force increased in patients, with the observation group showing higher values than the control group, and the differences were statistically significant ($p < 0.05$). See **Table 2**.

Table 2. Comparison of chewing efficiency and bite force between the two groups before and after treatment ($\bar{x} \pm s$)

Group	Masticatory efficiency (%)		Bite force (kg)	
	Before treatment	After treatment	Before treatment	After treatment
Control group (n = 42)	55.65 ± 5.58	75.36 ± 6.85*	39.24 ± 5.32	52.36 ± 6.31*
Observation group (n = 42)	55.74 ± 5.49	82.95 ± 7.81*	39.32 ± 5.25	58.25 ± 6.74*
t-value	0.075	4.735	0.069	4.134
p-value	0.941	< 0.001	0.945	< 0.001

Note: Compared with the same group before treatment, *$p < 0.05$.

3.2. Comparison of implantation accuracy indicators between the two groups

In the observation group, the deviation values of the implant crown, apical part in the sagittal plane, axial angle, and neck after oral implantation were all lower than those in the control group, with statistically significant differences ($p < 0.05$). See **Table 3**.

Table 3. Comparison of implantation accuracy indicators between the two groups ($\bar{x} \pm s$)

Group	Coronal plane			Sagittal plane		
	Apex (mm)	Axial angle (°)	Neck (mm)	Apex (mm)	Axial angle (°)	Neck (mm)
Control group (n = 42)	0.93 ± 0.15	3.28 ± 0.35	0.75 ± 0.13	0.82 ± 0.12	2.58 ± 0.41	0.48 ± 0.08
Observation group (n = 42)	0.55 ± 0.07	1.65 ± 0.11	0.40 ± 0.05	0.42 ± 0.05	1.45 ± 0.22	0.28 ± 0.03
t-value	14.878	28.793	16.285	19.941	15.739	15.170
p-value	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001

3.3. Comparison of incidence rates of treatment complications between the two groups

There was no statistically significant difference in the incidence rates of treatment complications between the two groups ($p > 0.05$). See **Table 4**.

Table 4. Comparison of incidence rates of treatment complications between the two groups (n, %)

Group	Infection	Tooth pain	Implant loosening	Total incidence
Control group (n = 42)	2 (4.76)	1 (2.38)	1 (2.38)	4 (9.52)
Observation group (n = 42)	1 (2.38)	0	0	1 (2.38)
χ^2-value				1.914
p-value				0.167

4. Discussion

Dentition defects, as a common type of oral disease, are primarily induced by local tooth loss due to trauma or periodontal diseases. They can affect the oral functional health of patients due to the loss of one or multiple teeth, manifesting mainly as abnormalities in biting force and chewing function, and also impacting the aesthetics of the dentition. Oral rehabilitation treatment can restore the dentition health of patients and correct related oral functional issues [5]. Oral implant therapy, as a dental prosthetic treatment technique with a relatively high clinical application rate in recent years, can actively correct the health of a patient's dentition after implant placement and crown restoration, with definite therapeutic effects. However, during the clinical application of this treatment technique, it has been found that due to the operational requirements of implant placement, it is necessary to comprehensively evaluate the bone health of the patient's implantation site and the occlusal relationship, while completing the precise placement of the implant to avoid the risk of short- and long-term complications caused by damage to adjacent teeth and periodontal tissues due to deviations in the implantation angle and position, ensuring the effectiveness and safety of the patient's treatment. Therefore, it is necessary to reasonably select oral implant guidance techniques [6,7].

As an auxiliary technology widely applied in fields such as orthopedic repair and oral orthodontics at the current stage, 3D printing technology can provide personalized guidance plans for disease treatment by printing three-dimensional models of relevant bone structures based on three-dimensional imaging examination results of patients before treatment and conducting simulated treatment operations based on these models. This enhances the precision of actual treatment operations. Moreover, recent studies have indicated that the clinical application of 3D printing technology can actively improve the accuracy of oral implant placement and optimize the correction effects on oral function after treatment [8]. Against the above backdrop, this study, conducted under the guidance of 3D printing technology in oral implant treatment, revealed that, compared to the control group, the observation group exhibited increased masticatory efficiency and bite force after oral implant treatment. Moreover, statistically significant differences ($p < 0.05$) were observed in the deviation values of implant crown, apical part in the sagittal plane, axial angle, and neck. Analysis indicates that the application of 3D printing technology enables the reasonable design of implant guides through the simulation of implant placement operations after printing a three-dimensional model of the patient's oral cavity. This effectively enhances the fit between the guide and the oral mucosa, providing a foundation for precise operations in implant treatment. The materials used in 3D printing are adhesive materials with high strength and resistance to deformation, which actively reduce deviations in drill bit direction guidance caused by guide deformation in practical applications.

Additionally, the guide's stop ring structure limits drilling depth, enhancing the accuracy of implant hole preparation and implant placement operations. The hollow design of the guide ensures the effective entry of irrigation cooling water into the holes, reducing the risk of thermal injury to the bone tissue at the implant site and surrounding periodontal tissues [9,10]. Furthermore, compared to traditional implant guides, the production of 3D-printed implant guides involves fewer human factors, effectively avoiding the risk of positional deviations during implant placement operations.

5. Conclusion

In summary, the application of 3D printing technology in oral implant treatment can effectively reduce implant placement deviations, enhance implantation accuracy, and simultaneously correct and maintain the patient's oral bite force and masticatory function health.

Disclosure statement

The authors declare no conflict of interest.

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