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Original Article

Efficacy of digital guide-assisted implant restoration in anterior teeth aesthetics and its impact on labial bone mass

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Abstract: Objective: To analyze the efficacy of digital guide-assisted implant restoration technique in enhancing the anterior teeth aesthetics and its impact on labial bone mass. Methods: We retrospectively analyzed clinical data from 90 patients who underwent maxillary anterior teeth implant restoration at The First People's Hospital of Fuyang, Hangzhou, from January 2021 to September 2023. The patients were divided into two groups: a conventional group (n=45, 45 implants, standard implant restoration) and a digital group (n=45, 45 implants, digital guide-assisted implant). We compared implant positional deviations, changes in dental plaque index (PLI), aesthetic effect scores, labial bone mass differences, and the occurrence of adverse reactions post-treatment between the two groups. Results: The digital group exhibited significantly less deviation in root position in the buccolingual and vertical directions, less neck deviation in the buccolingual and vertical directions, and less apical deviation than the conventional group (P=0.021, P=0.005, P=0.016, P=0.008, P=0.026, respectively). Three months postoperatively, the digital group demonstrated a significantly lower mean PLI (P<0.001), higher white and pink aesthetic scores (P=0.021, P=0.005), and increased alveolar ridge height and coronal and middle labial bone mass (P=0.006, P=0.015, P=0.008). Additionally, this group experienced lower incidence of adverse reactions (4.44% vs. 17.78%) compared with the conventional group (P=0.044). Conclusion: The digital guide-assisted implant restoration significantly enhances implant accuracy, reduces bone resorption, improves aesthetic outcomes, and ensures higher safety.

Keywords: Digital guide, assisted implant, restoration technique, anterior teeth aesthetics, labial bone mass, safety

Introduction

As global living standards improve, there has been a continuous increase in the emphasis on oral aesthetics, with a growing number of patients seeking to improve their oral condition through implant overdentures [1]. The World Health Organization (WHO) has listed oral health as one of the ten essential criteria for human health, with tooth loss as an indicator of poor oral health [2]. Recent epidemiologic survey in China has shown that tooth loss among young and middle-aged individuals caused by dental caries, periodontal disease, and trauma affects as much as 32.3% of the population [3]. In response, dental implantology has rapidly developed, becoming the preferred method for addressing dentition defects. The success of implant restoration, particularly in the anterior aesthetic zone, heavily depends on the preservation of bone contours, optimal implant positioning, and the maintenance of natural and harmonious aesthetics of the surrounding soft tissues [4, 5].

Traditional implant restoration techniques, which largely rely on the clinician's experience, often suffer from issues of replicability, operability, and accuracy. This can lead to discrepancies between patient expectations and clinical outcomes, potentially causing conflicts [6, 7]. Therefore, there is a pressing clinical need for

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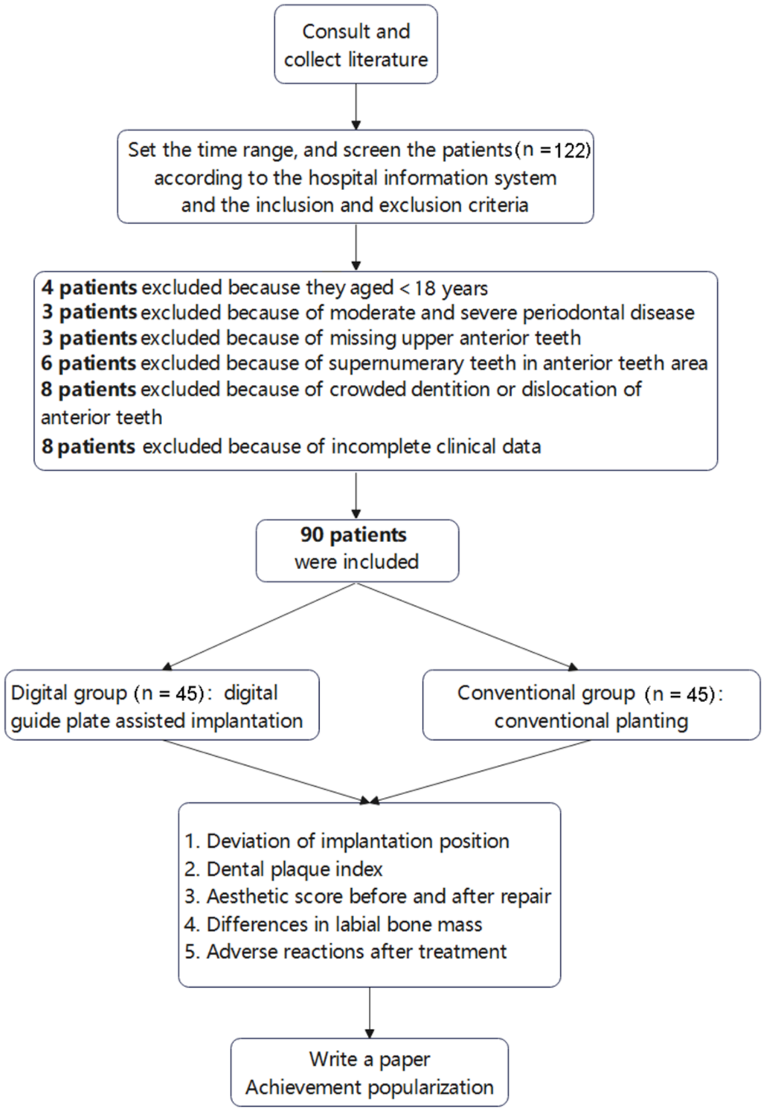

Figure 1. Flow chart.

more precise restoration methods that enhance the aesthetic appeal of the anterior teeth area. Advances in computer technology now allow for the use of digital guides to create detailed periodontal anatomical models, facilitating accurate implant positioning. Despite these advancements, research into the effects of digital guide-assisted implant techniques on the aesthetic restoration of anterior teeth remains limited [8]. The purpose of this study was to investigate the effectiveness of the digital guide-assisted implant technique in improving the aesthetic outcomes of anterior teeth restorations and to assess its impact on labial bone mass, addressing a significant gap in current dental research.

Materials and methods

Case selection

This retrospective study was conducted from January 2021 to September 2023 at The First People's Hospital of Fuyang, Hangzhou. A total of 122 patients undergoing anterior teeth implant restoration were initially identified through the hospital information system. After rigorous screening based on specific inclusion and exclusion criteria, 90 eligible patients were included.

Inclusion criteria: (1) age ≥18 years; (2) absence of moderate to severe periodontal disease; (3) no anterior tooth loss; (4) complete general data (sex, age, body weight) and research-specific data (including preoperative and 3-month postoperative plaque index (PLI), white aesthetic score, and pink aesthetic score).

Exclusion criteria: (1) presence of supernumerary teeth in the anterior area; (2) crowded dentition or anterior tooth misalignment; (3) congenital missing teeth; (4) history of orthodontic treatment; (5) history of alveolar process fracture; (6) concurrent malignant tumors; (7) use of medications in the past 3 months that may induce gingival tissue hyperplasia; (8) concurrent uncontrolled systemic diseases; (9) current use of medications that may alter bone density; (10) systemic diseases associated with bone alterations; (11) incomplete clinical data; (12) pregnancy or lactation.

The included patients were categorized into a conventional group (n=45, 45 implants, receiving standard implant restoration) and a digital group (n=45, 45 implants, receiving digital guide-assisted implant). This study was approved by the Ethics Committee of The First People's Hospital of Fuyang Hangzhou.

Table 1. Comparison of general clinical data between the two groups of patients ($\bar{x} \pm s$)/n

Group	Number of cases	Sex (male/female)	Average age (years)	Average body weight (kg)	Implant length (mm)	Implant width (mm)
Digital group	45	20/25	31.07±5.19	70.43±5.50	11.86±2.28	4.57±1.42
Conventional group	45	19/26	29.14±5.89	68.85±6.74	11.20±2.62	5.09±1.20
t/χ^2	-	0.156	0.339	0.477	1.677	0.237
P	-	0.862	0.735	0.635	0.097	0.813

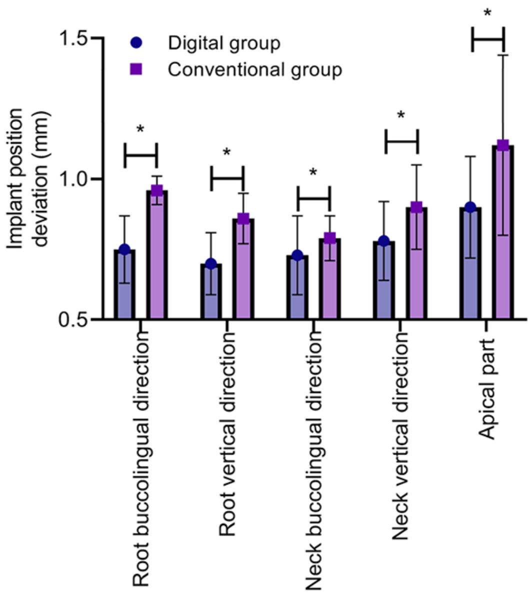

Figure 2. Comparison of implant position deviation between the two groups. * represents a statistically significant difference between the two groups.

Data collection

Data were systematically collected from the hospital's information system and recorded independently by two individuals in tabular format. Accuracy was ensured through a cross-verification process involving position exchange.

Intervention methods

All patients underwent comprehensive preoperative examinations to assess the required specifics of dental restoration.

In the conventional group, treatment was guided by physician experience and preoperative cone-beam computed tomography. Standard implantation procedures were followed, including pilot hole creation, and guided bone tissue regeneration.

In the digital group, patients underwent a digital guide-assisted implant [9]. The specific measures are as follows. (1) Silicone rubber impressions and cone-beam computed tomography were used to create three-dimensional (3D) models of the maxilla and anterior teeth. Guidemia implant design software, a customized implantology, was then used to design and 3D print custom implant guides, which were tested for fit and comfort. (2) Adjustments were made as needed before proceeding with surgery under local anesthesia. (3) Implant restoration surgery was conducted on the patient. Prior to the procedure, local anesthesia was routinely applied to the patient. Techniques such as flap elevation, alveolar crest trimming, and precise guide placement were employed to ensure optimal implant placement. (4) Under the guidance of the digital guide, subsequent creation of the pilot hole and implant implantation surgery were conducted. During the preoperative assessments and throughout the surgical process, Bio-Oss bone powder or Bio-Gide membrane was flexibly utilized as necessary. (5) After the implantation, the tension of the incision was reduced, and subsequent suture was performed. The specific measures were shown in the flow chart in **Figure 1**.

Observation indicators

Main outcomes: (1) Implant deviation: Implant imaging indicators were evaluated preoperatively and at 3 months postoperatively. Measurements included postoperative implant root deviation in the buccolingual and vertical directions, neck deviation in the buccolingual and vertical directions, and apical deviation. To minimize measurement error, each parameter was measured in three dimensions: buccolingual, vertical, and apical. (2) Labial bone mass: The labial bone mass (alveolar ridge height, coronal labial bone mass, and middle labial bone mass) of patients was assessed immediately after operation and 3 months postoperatively. The

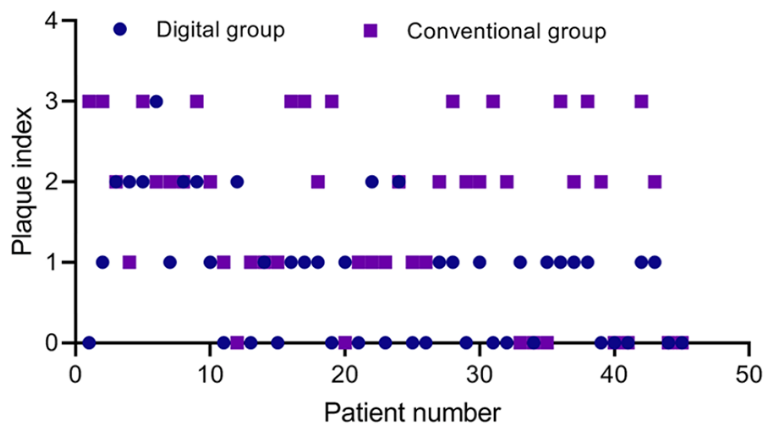

Figure 3. Comparison of PLI between the two groups. PLI: plaque index.

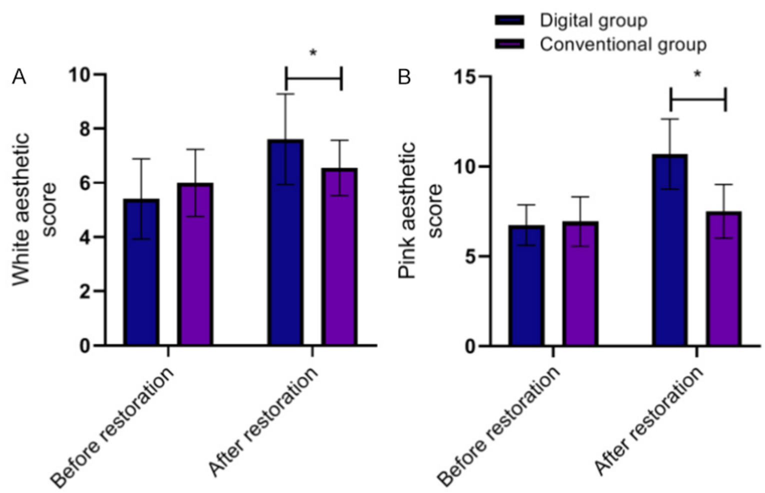

Figure 4. Comparison of aesthetic scores before and after restoration between the two groups. A: White aesthetic scores; B: Pink aesthetic scores. * represents a statistically significant difference between the two groups.

alveolar ridge height was measured from the top of the ridge to the implant-abutment connection, while coronal and middle labial bone masses were measured at 1 mm from the implant-abutment connection and at the central length of the implant, respectively. (3) Adverse reactions: At a subsequent visit at 3 months postoperatively, adverse reactions (such as implant loosening, rejection responses, gingival swelling, and implant loss) were recorded.

Secondary outcomes: (1) PLI: The PLI [10] was measured in patients at 3 months postoperatively. A probe was used to gently scratch the patient's tooth surface, with a score of 0 indicating no plaque, a score of 1 indicating the presence of plaque on the side of the probe but invisible to the naked eye, a score of 2 indicating a moderate amount of plaque visible at the gingival margin or adjacent surfaces, and a score of 3 indicating the presence of large amount of soft deposit in the gingival sulcus or margin and adjacent surfaces. (2) Aesthetic outcomes: Aesthetic scores [11] were evaluated pre-restoration and at 3 months postoperatively using scores up to 10 for white aesthetics and 14 for pink aesthetics, with higher scores indicating minimal deviation from adjacent teeth. (3) Multivariate regression analysis was conducted to analyze the impact of different implantation methods on outcomes.

Statistical methods

Data consolidation was performed using EXCEL 2021, while statistical analysis was conducted using the Statistical Package for the Social Sciences (SPSS) version 19.0. Measurement data, such as mean age and PLI, which conformed to a normal distribution, were analyzed using independent sample t-tests for inter-group comparisons and paired samples t-tests for preoperative versus postoperative comparisons within the same group. Categorical data, such as sex and incidence of adverse reactions, were expressed as rates and analyzed using chi-square tests. Multivariate logistic regression analysis was employed to analyze risk factors. Statistical significance level was set at P<0.05.

Results

Comparison of general clinical data between the two groups

General clinical data of patients in both groups, including sex, average age, average body weight, proposed implant length, and proposed implant width, were collected and compared.

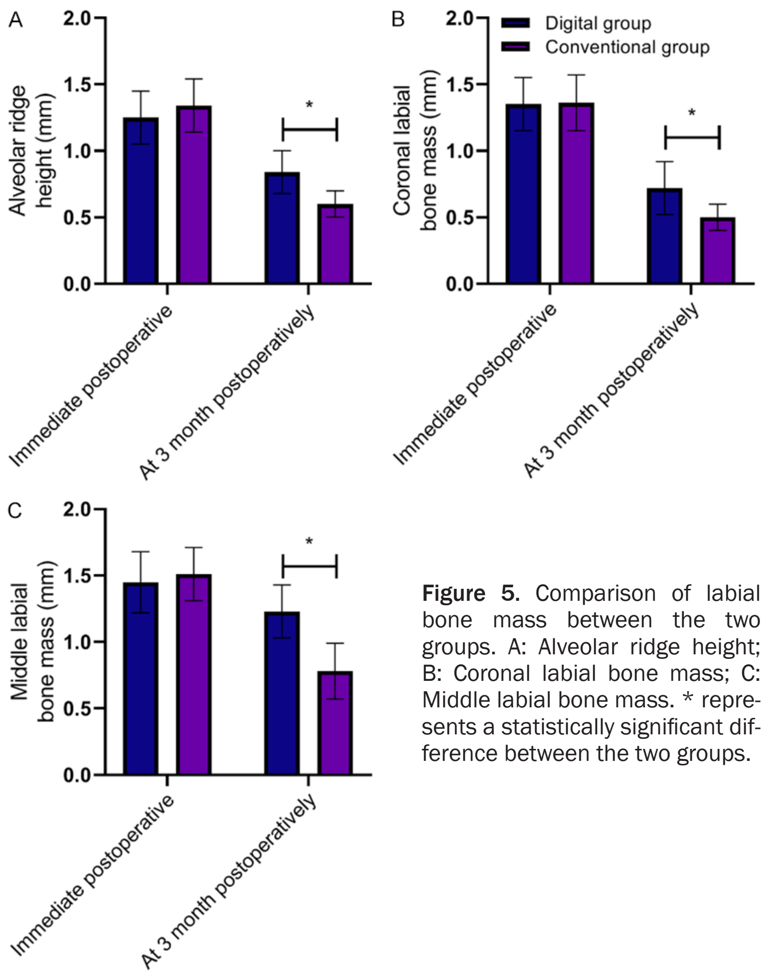

Figure 5. Comparison of labial bone mass between the two groups. A: Alveolar ridge height; B: Coronal labial bone mass; C: Middle labial bone mass. * represents a statistically significant difference between the two groups.

The comparisons revealed no statistically significant differences between the two groups in terms of the above-mentioned data (P>0.05), indicating good comparability, as shown in **Table 1**.

Comparison of implant position deviation between the two groups

The root deviation in the buccolingual and vertical directions, neck deviation in the buccolingual and vertical directions, and apical deviation of the patients were collected, and the levels of the above indicators in the digital group were found to be significantly lower than those in the conventional group (P=0.021, P=0.005, P=0.016, P=0.008, P=0.026), as shown in **Figure 2**.

Comparison of PLIs between the two groups

The average PLI in the digital group at 3 months postoperatively was (0.84±0.81), which was significantly lower than (1.68±1.07) in the conventional group (t=12.032, P<0.001), as shown in **Figure 3**.

Comparison of aesthetic scores before and after restoration between the two groups

There were no statistically significant differences in the white and pink aesthetic scores between the two groups before restoration (P>0.05). At 3 months after restoration, there were statistically significant elevations in the white and pink aesthetic scores of the enrolled patients compared with before restoration (P=0.011, P=0.026). Patients in the digital group had higher white and pink aesthetic scores than those in the conventional group at 3 months postoperatively (P=0.021, P=0.015), as shown in **Figure 4**.

Comparison of labial bone mass between the two groups

Comparisons of alveolar ridge height, coronal labial bone mass, and middle labial bone mass right after the operation exhibited no significant differences between the two groups (P>0.05). At 3 months postoperatively, the alveolar ridge height, coronal labial bone mass, and middle labial bone mass of the digital group were significantly higher than those in the conventional group (P=0.006, P=0.015, P=0.008), as indicated in **Figure 5**.

Incidence of adverse reactions

In the digital group, there was 1 case of implant loosening and 1 case of gingival swelling, with a total incidence of adverse reactions of 4.44% (2/45), while in the conventional group, there were 3 cases of implant loosening, 2 cases of rejection responses, 2 cases of gingival swelling, and 1 case of implant loss, with a total incidence of 17.78% (8/45), exhibiting a statistically significant difference between the two groups (P=0.044), as shown in **Table 2** and **Figure 6**.

Table 2. Incidence of adverse reactions after treatment in both groups of patients

Group	Number of cases	Implant loosening	Rejection responses	Gingival swelling	Implant loss	Total incidence
Digital group	45	1 (2.22)	0 (0.00)	1 (2.22)	0 (0.00)	2 (4.44)
Convention al group	45	3 (6.67)	2 (4.44)	2 (4.44)	1 (2.22)	8 (17.78)
χ^2	-	1.236	2.015	1.056	1.008	4.050
P	-	0.098	0.016	0.105	0.101	0.044

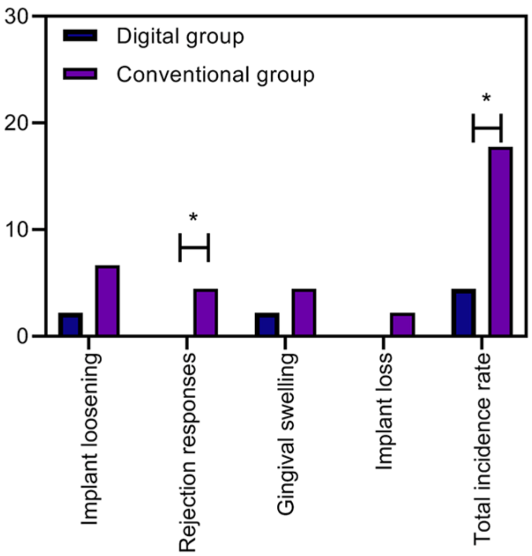

Figure 6. Adverse reactions after treatment in both groups of patients. * represents a statistically significant difference between the two groups.

Multivariate regression analysis of implant outcomes

The occurrence of adverse reactions (implant loss) served as the dependent variable, while patient age and implantation method were the independent variables. The analysis indicated that conventional implant method was an independent risk factor for adverse implant outcome (P=0.03), as shown in **Table 3**.

Discussion

The continuous progress in socio-economic and scientific-technological domains has improved people's living standards, leading to an increased emphasis on oral health and aesthetics, and the standards for oral health have progressively expanded to teeth hygiene, absence of cavities, being painless, and normal gum color [12, 13]. Tooth loss is one of the specific manifestations of poor oral health. However, epidemiological investigations in China suggest a more pronounced incidence of tooth loss among middle-aged individuals, which compromises their quality of life [14]. The aesthetic area refers to the area of the exposed teeth, restoration structures, and surrounding tissues when an individual smiles. The tooth loss in the aesthetic area can impact one's appearance during social interactions [15]. The proactive restoration is of great significance for improving the look of tooth loss of the aesthetic area and restoring soft tissue morphology. However, conventional dental restorations have been confirmed to exhibit complications such as poor soft tissue and restoration morphology, peri-implant marginal bone absorption, and concavities in the missing tooth arch. One of the crucial causes identified is the lack of understanding of the anatomical structures in the implant area, leading to deviations during the implant process. Therefore, how to accurately design the implant protocol to minimize the deficiency of labial bone mass after implantation has become a research focal point [16, 17].

In this retrospective analysis, the clinical efficacy of digital guide-assisted implants on the aesthetic restoration of anterior teeth was explored, and our results showed that compared with the conventional technique, digital guidance significantly reduced root deviation in the buccolingual and vertical directions, neck deviation in the buccolingual and vertical directions, and apical deviation. This is similar to the findings of another comparative study on patients undergoing implant restoration [18], which demonstrated the affirmative efficacy of digital guide-assisted implants in enhancing implant adaptability, indicating its potential in reducing deviations during implantation. In this study, the conventional restoration method was based on the practitioner's experience and two-dimensional imaging results, which leads to the lack of quantitative indicators to guide the procedure. Simultaneously, the limited field

Table 3. Multivariate regression analysis of implant outcomes

Risk factors	B	SE	Wald	P	OR	95% CI
Age	1.015	0.068	0.795	0.353	1.228	0.701-2.056
Conventional implant	1.365	0.698	4.301	0.030	4.236	1.051-16.356

of vision for the operator during surgery greatly impacts the accuracy of the implant position. Furthermore, the differences in anatomical structure of jawbone and tooth loss locations among patients further restrict the precision of subjective judgment [19]. The digital guide technique utilizes a computer to model patients' actual condition, precisely obtaining information about the defective area, which enables the operator to thoroughly observe the patient's condition from various angles such as coronal, sagittal, and axial before the surgery. Consequently, a personalized implant protocol can be developed, specifying the depth, position, and direction of implantation, which contribute to enhancing the accuracy rate of the surgical protocol, thereby effectively reducing postoperative positional deviations [20, 21].

This study also revealed that digital guidance is conducive to reducing postoperative dental PLIs and enhancing patients' aesthetic scores. This is also related to the fact that a digital guide facilitates precise restoration. This is, however, different from the research conducted by other scholars. A study involving 40 patients with dental implants [22] revealed that those who underwent digital guidance exhibited higher postoperative PLI compared to those undergoing conventional procedures, contrary to the findings of this study. This may be attributed to differences in the sources of the study patients, dietary structures, and post-discharge personal care measures. In comparison to conventional restoration, digital guidance can formulate personalized restoration protocols based on specific conditions, enabling the implant to be more compatible with the original anatomical shape. In theory, a more precise implantation should reduce the probability of food residue near the implant, thereby reducing the formation of dental plaque [23].

Regarding the labial bone mass, the use of digital guidance held affirmative value in alleviating bone absorption of the alveolar ridge height and preserving coronal labial bone mass and middle labial bone mass. During the restoration process, bone absorption and remodeling phenomena may occur in the wound healing process, leading to the decrease of the alveolar ridge in vertical direction of the prosthesis. Simultaneously, some patients may also experience concomitant absorption on the outer side of the bone wall [24]. Research also has indicated that bone absorption tends to increase over time, making the assessment of the labial bone mass a crucial indicator for evaluating the effectiveness of restoration [25]. The digital guide-assisted implant can reduce labial bone absorption in implants due to its precision. This is attributed to the close fit of the implant to the palatal side, thereby preserving a relatively greater amount of labial bone mass. Consequently, this reduces the absorption in the alveolar ridge, prevents the recession of soft tissue, and maintains labial bone mass [26].

In conclusion, digital guide-assisted implant restoration is conducive to the accuracy of implantation, thus reducing the postoperative dental plaque, inhibiting bone resorption, improving aesthetics, and ensuring higher safety compared to conventional methods. However, this study also has certain limitations, such as its retrospective nature, limited number of included cases, short follow-up period, and single patient source. Subsequent efforts will be made to address these shortcomings through further multicenter prospective analyses.

Disclosure of conflict of interest

None.

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