Assessing the Role of Guides in Enhancing Dental Implant Placement Precision and Patient Outcomes

Running title: Fully guided dental implant placement and primary stability

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Abstract:

Background: The precision of dental implant placement is vital for long-term implant success. The surgical guide is designed using advanced 3D imaging techniques allows for a highly accurate simulation of the ideal implant position, angulation, and depth based on the patient's unique anatomy. The aim of the study is to compare implant stability and postoperative pain between guided and freehand surgical implant placement.

Methods: randomized controlled clinical study included 30 patients with a total of 30 implants were placed and analyzed. All patients were randomly allocated into two groups: Test Group (Guided Surgery Group) and Control Group (Freehand Surgery Group). For all the patient in the study primary stability was assessed immediately after implant placement and secondary stability was assessed three months postoperatively. Postoperative pain was measured using the (VAS), immediately after surgery and one week later.

Keywords: dental implant, 3D- implant surgical guide, C-Tech® implants, DICOM file.

Introduction

The accuracy of dental implant placement is crucial for the procedure's success, as deviations from the planned positions can lead to complications such as improper osseointegration, damage to adjacent structures, and aesthetic or functional issues[1-4] . Additionally, improper placement increases the risk of peri-implantitis, implant failure, nerve damage, and poor prosthetic outcomes[5,6]. Minimizing these deviations requires a combination of advanced technology, meticulous planning, and precise execution. Traditional freehand implant placement, while commonly used, heavily relies on the clinician's skill and experience, often leading to variability in positioning accuracy[7]. In contrast, 3D-printed surgical guides, developed through preoperative digital planning, have significantly enhanced implant placement precision [8]. The proposed 3D-printed guide aims to improve accuracy by minimizing deviations from the planned positions, ensuring that implants are placed precisely as intended. This precision is vital for long-term implant success and stability[9]. The guide is designed using advanced 3D imaging techniques, such as CBCT scans, in conjunction with digital implant planning software. This approach allows for a highly accurate simulation of the ideal implant position, angulation, and depth based on the patient's unique anatomy[4,10]. Success in dental implantology is no longer solely defined by implant survival but also by the stability of the implant-prosthetic complex, long-term mechanical integrity, and overall tissue health [11]. Modern criteria for success emphasize a holistic evaluation, including functional performance and patient satisfaction[12-15]. Implant stability, a key factor in long-term success, is divided into primary stability (mechanical stability achieved immediately after placement) and secondary stability (biological stability obtained through osseointegration)[16,17]. Advancements in guided surgery, dynamic navigation, and robotic-assisted implant placement have further enhanced accuracy, reducing complications and improving patient outcomes[18,19]. Artificial intelligence is increasingly being used in many research and development of many types of studies, in this research, the data collection, analysis and manuscript preparation was conducted entirely without the use of any assistance of any form of AI tools or technologies [20]. The research objective is to assess and compare the clinical outcomes of guided surgical implants placement versus conventional freehand implant placement, focusing on primary implant stability, secondary implant stability and postoperative pain. In alignment with this objective, the aim of this study is to compare the clinical outcomes: as implant primary and secondary stability and postoperative pain between guided surgical implant placement and conventional freehand surgical implant placement.

Hypothesis of the study

This study hypothesized that guided implant surgery will result in superior implant stability outcome and reduced postoperative pain compared to the freehand technique.

Materials and Methods

Study Design: (Fig.1)

This study was designed as a randomized controlled clinical study approved by the local ethical committee [Approval letter No. UOM.Dent/25/1029]. The work has been reported in line with Consolidated Standards of Reporting Trials (CONSORT) Guidelines [12]. Written informed consent was obtained from the patient for publication of the results and accompanying images. The study included 30 patients requiring dental implants, with a total of 30 implants placed and analyzed. Each patient received one implant. All patients were randomly assigned using a computer-generated randomization to two groups: Test Group (Guided Surgery Group): Implants were placed using 3D-printed surgical guides. Control Group (Freehand Surgery Group): Implants were placed freehand without guide assistance.

The inclusion criteria for the study were:

1. Patients ≥18 years of age.
2. Presenting with maxillary tooth loss,
3. Tooth extraction at least 3 months before (delayed placement);
4. Adequate amount of bone volume to place the implant without bone augmentation (2 mm bone circumferentially around the implant).

The exclusion criteria for the study were: Patients were excluded from the study for the following reasons:

1. General contraindications to implant surgery;
2. Patients with history of chemo or radiotherapy;
3. Poor oral hygiene;
4. Pregnant or lactating women;

5. Uncontrolled diabetic patients.

All implant placements were performed exclusively in the maxillary region (upper jaw) to ensure a controlled comparison within the same anatomical area. The implants used in this study were C-Tech® implants (C-Tech Implant, Italy) with the following dimensions: Diameter: 3.8 mm Length: 11 mm (Fig.2). Cone-Beam Computed Tomography (CBCT): To assess bone quality, quantity, and anatomical structures (e.g., nerves, sinuses). Digital Intraoral Scans Heron Scanner (USA) to obtain detailed gingival contours, occlusion, and existing teeth. The scan data was exported as an STL file for digital planning. Easy Check Implant Stability Measuring System (Fig. 3) is used for implant stability measurement, the tapping rod was gently placed in slight contact with the healing abutment, avoiding any axial or lateral pressure, and aligned within 0°–30° relative to the abutment's occlusal surface. If the angle exceeded 30°, the device issued an alert and prevented measurement, ensuring consistent alignment.

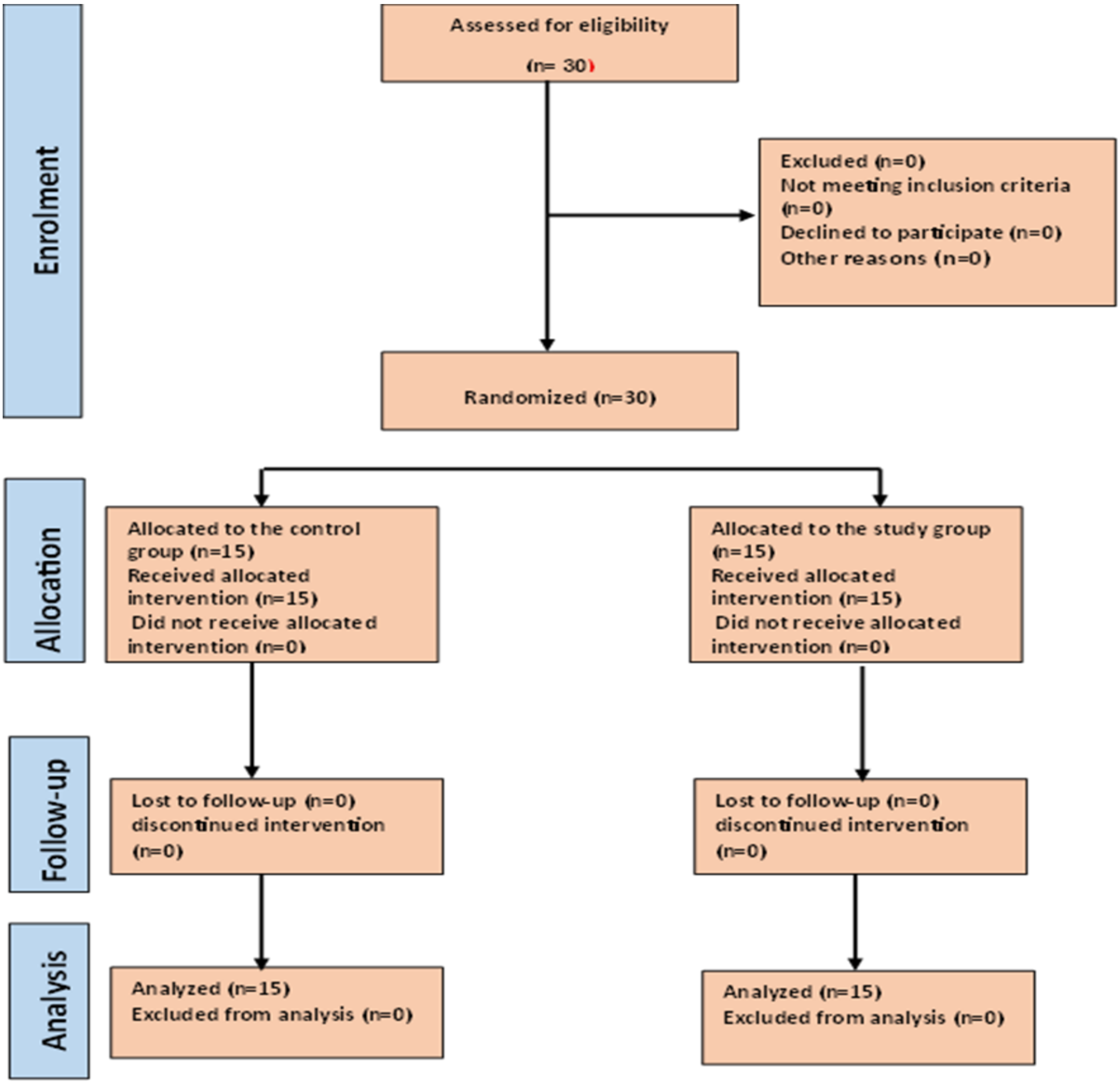

Figure 1. Flow diagram of participant selection

Figure 2. C-tech dental implant

Figure 3. Easy Check Implant Stability Measuring System

Surgical Guide Design and Fabrication

The STL file from the intraoral scan was merged with CBCT data (DICOM file) using RealGUIDE® software (3DIEMME, Italy). Implant positions were virtually planned based on anatomical and prosthetic considerations. Surgical guides were printed using a SHINING 3D AccuFab-Printer with high-resolution biocompatible resin (layer thickness: 50–100 µm), (Fig.4). Printed guides were washed in isopropyl alcohol (IPA) to remove residual resin and cured under UV light for maximum hardness. Chemical sterilization was performed before clinical use.

Figure 4. Surgical Guide

Surgical Procedures

Freehand Implant Placement (Control Group)

A thorough clinical examination was conducted, including evaluation of oral health and medical history. - CBCT scans and digital impressions were used to plan implant size and position. Local anesthesia was administered, and a small incision was made in the gingiva to expose the bone. A pilot drill was used to create the initial osteotomy, followed by sequential drilling to expand the site. Continuous saline irrigation was used to prevent bone overheating. The implant was inserted manually or using a torque driver until it reached the desired depth. The soft tissue flap was repositioned and sutured.

Guided Implant Placement (Test Group)

The sterilized surgical guide was positioned and secured in the patient's mouth, (Fig. 4). A tissue punch was used through the guide sleeve to minimize soft tissue disruption. A pilot drill was used to establish osteotomy, followed by sequential drilling to prepare the site for the 3.8 mm diameter, 11 mm length implant (Fig.5). Continuous saline irrigation was maintained throughout drilling. The C-Tech implant was inserted through the guide sleeve using a guided implant carrier until platform-level positioning was achieved (Fig.6).

Figure 5. C-tech surgical guide kit

Figure 6. Surgical Guide Adaptation

Study Variables

The predictor variable in this study was the method of implant placement, either guided surgery or freehand surgery. Outcome variables included implant stability and postoperative pain and discomfort. Implant stability was evaluated using the Dentium Easy Check. Implant Stability Measuring System, with primary stability assessed immediately after implant placement and secondary stability assessed three months postoperatively to determine the degree of osseointegration. The Scale Implant Stability Quotient (ISQ) range between 1 to 100. The Interpretation of scores as follow:

ISQ >70: High stability
ISQ 60–69: Moderate stability
ISQ <60: Low stability

Postoperative pain was measured using the Visual Analog Scale (VAS), ranging from 0 (no pain) to 10 (worst possible pain), immediately after surgery and one week later. All patients received standardized postoperative care instructions, including guidance on pain and swelling management, activity restrictions, and prescriptions for antibiotics and anti-inflammatory medications as needed.

Discussion

This study evaluates the primary and secondary implant stability and postoperative pain using surgical guide versus those with free hand implant placement. Primary implant stability (mechanical) is crucial for successful osseointegration and long term successful clinical outcomes, therefore securing the primary stability is positively associated with a secondary implant stability [21]. One of the reliable methods for measuring the primary implant stability is the use of radio frequency analysis device (RFA) [22], this device displaying the implant stability quotient (ISQ) values, which identify the firmness at the implant–tissue interface. It has been stated that ISQ values >70: High stability, ISQ 60–69: Moderate stability, ISQ <60: Low stability [23]. In the present study, the statistical analysis of the data revealed a significant difference in primary and secondary stability between guided surgery and free hand implant placement, where higher ISQ values of primary and secondary implant stabilities were recorded in surgical guide group. It has been reported that the most common problem of fully guided implant surgery is the lack of primary stability [24-26] in contrast to the data obtained from this study. The higher values of implant stability recorded in surgical guide patients in the present study may be attributed to the precession of implant placement and minimal degree of implant deviation between planned and placed implant position which was reported in other studies compared between guided and free hand implant placement [27,28].

In this context, the enhanced primary stability observed with guided implant placement could be attributed to improved angulation, depth control, and bone density during planning. As a result, micromovements are minimized, promoting more favorable conditions for bone remodeling and secondary stability, which is biologically driven. This in line with result of Nagar et al, in which they found the guided implant surgery demonstrated superior outcomes in terms of implant stability, reduced marginal bone loss, and higher patient satisfaction compared to conventional submerged and one-stage techniques [29].

Furthermore, the digital planning and surgical guide fabrication steps allow clinicians to visualize and anticipate anatomical challenges, thereby reducing surgical trauma and preserving bone integrity. These advantages may also contribute to a shorter healing period, better soft tissue management, and potentially higher patient satisfaction due to reduced postoperative complications [30].

Moreover, the increase in secondary stability observed may be attributed to the improved bone-to-implant contact, resulting from precise osteotomy preparation and accurate implant placement. These factors are essential for reducing micromovement and promoting successful long-term osseointegration, which ultimately affects implant survival rates [31].

Regarding the postoperative pain and discomfort, in the present study, the analysis of the data showed a statistically significant reduction in immediate postoperative pain for the patients in surgical guide group (mean VAS=2.1) compared to those treated by free hand surgery (mean VAS=5.9). The findings in this study are in agreement with other previous studies demonstrated that the patient treated with flapless guided surgery have the advantage of decreasing pain and discomfort in the immediate postoperative period [32,33]. In addition, it has been reported that the flapless surgical procedures significantly reduce the rate of complications such as bleeding, wound dehiscence, and pain when compared with conventional flap surgery [34-36], these data support the finding in the present study concerning postoperative pain and discomfort after implant placement [37].

The clinical relevance of this study is to improve the future success rate and decrease the complication associated with dental implants. However, while the results are promising, it is important to consider certain limitations. Guided surgery requires access to specialized equipment and software, which may not be readily available in all clinical settings. Additionally, errors in the digital planning phase or inaccuracies in the guide fabrication can still lead to deviations in implant placement.

Future studies with larger sample sizes and long-term follow-up are recommended to further validate these findings and determine whether the observed benefits translate into significantly higher survival rates over time compared to conventional surgical techniques.

Provenance and peer review

Not commissioned, externally peer-reviewed.

- Conflicts of Interest: No

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