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The Impact of 3D Printing Technology on the Accuracy and Efficiency of Dental Implant Placement: A Randomized Controlled Trial in Semarang, Indonesia

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A B S T R A C T

Introduction: Accurate and efficient dental implant placement is crucial for successful treatment outcomes. Traditional implant placement techniques rely on 2D imaging and freehand surgery, which can be associated with inaccuracies and prolonged surgical time. This study aimed to evaluate the impact of 3D printing technology, specifically the use of patient-specific surgical guides, on the accuracy and efficiency of dental implant placement in Semarang, Indonesia. **Methods:** This randomized controlled trial included 60 patients requiring a single dental implant in the posterior mandible. Participants were randomly assigned to either the control group (conventional freehand implant placement) or the experimental group (3D printed surgical guide-assisted implant placement). Primary outcome measures were implant placement accuracy (deviation from planned implant position) and surgical time. Secondary outcomes included postoperative pain, swelling, and patient satisfaction. **Results:** The use of 3D printed surgical guides significantly improved implant placement accuracy in all three dimensions (mesiodistal, buccolingual, and apicocoronal) compared to the freehand technique ($p<0.001$). Surgical time was also significantly reduced in the experimental group ($p=0.02$). There were no significant differences between the groups in terms of postoperative pain, swelling, or patient satisfaction. **Conclusion:** 3D printing technology significantly enhances the accuracy and efficiency of dental implant placement. The use of patient-specific surgical guides resulted in more precise implant positioning and reduced surgical time, contributing to improved treatment outcomes.

1. Introduction

Dental implantology has emerged as a transformative domain within dentistry, offering predictable and efficacious solutions for the rehabilitation of patients afflicted with tooth loss. The placement of dental implants constitutes a cornerstone of this field, serving as a foundational step toward the restoration of oral functionality and aesthetics. The success of dental implant treatment hinges on a multitude of factors, including meticulous patient selection, judicious implant design selection, and the utilization of precise surgical techniques. Among these factors, the accuracy of implant placement assumes paramount importance, as it directly influences the long-term stability, functional efficacy, and aesthetic appeal of the implant-supported restoration. The accuracy of implant placement is inextricably linked to the avoidance of complications and the attainment of favorable treatment outcomes. Precise implant positioning ensures that the implant is strategically placed within the alveolar bone, maximizing its contact with the surrounding bone tissue. This intimate contact between the implant and bone is essential for achieving osseointegration, the biological process by which the implant becomes firmly anchored to the jawbone. Successful osseointegration is the linchpin of dental implant stability, providing a durable foundation for the long-term support of the prosthetic restoration. Inaccurate implant placement, conversely, can precipitate a cascade of complications that compromise the success of implant treatment. Deviation from the planned implant position can result in encroachment upon vital anatomical structures, such as nerves and blood vessels, potentially leading to sensory disturbances, bleeding, or even more severe sequelae. Moreover, inadequate implant positioning can compromise the aesthetic outcome of the restoration, particularly in the anterior region of the mouth where even minor deviations can be readily discernible. Additionally, inaccurate implant placement can lead to biomechanical complications, such as overloading of the implant or uneven force distribution, potentially increasing the risk of implant failure.[1-4]

Traditionally, dental implant placement has been performed using conventional freehand techniques, guided by two-dimensional radiographic imaging modalities such as panoramic radiographs and periapical films. While these techniques have served the dental profession for many years, they possess inherent limitations that can compromise the accuracy and predictability of implant placement. Two-dimensional radiographic images provide a limited representation of the complex three-dimensional anatomy of the jaws, potentially obscuring critical anatomical structures and hindering accurate assessment of bone quality and quantity. Freehand implant placement, relying solely on the surgeon's clinical judgment and manual dexterity, is susceptible to variations in operator skill and experience, potentially introducing inconsistencies in implant positioning. The advent of three-dimensional (3D) printing technology has ushered in a paradigm shift in dental implantology, offering unprecedented capabilities for enhancing the accuracy and efficiency of implant placement procedures. Cone beam computed tomography (CBCT), a 3D imaging modality, has revolutionized the way dentists visualize and assess the maxillofacial region. CBCT provides detailed volumetric information, enabling accurate measurement of bone dimensions, identification of vital anatomical structures, and assessment of bone quality. This comprehensive 3D dataset empowers clinicians to meticulously plan implant placement, taking into account all relevant anatomical and biomechanical considerations. The integration of CBCT data with computer-aided design and manufacturing (CAD/CAM) technology has enabled the fabrication of patient-specific surgical guides, also known as surgical templates or stents. These guides are custom-made devices designed to precisely guide the drilling and placement of dental implants according to the pre-surgical plan. Surgical guides provide a physical framework for the surgical procedure, ensuring accurate implant angulation, depth, and mesiodistal positioning. By eliminating the reliance on freehand implant placement, surgical guides minimize the risk of human error and enhance the predictability of treatment outcomes.[5-7]

Numerous studies have corroborated the benefits of 3D printing technology and surgical guides in dental implant placement. Research has consistently demonstrated that the use of surgical guides improves the accuracy of implant placement, reduces surgical time, and minimizes the incidence of complications. The precision afforded by surgical guides ensures that the implant is placed in the optimal position, maximizing its functional and aesthetic potential. Moreover, the streamlined surgical workflow facilitated by surgical guides reduces operative time, potentially enhancing patient comfort and satisfaction. While the advantages of 3D printing technology in implant dentistry are well-documented, the majority of research has been conducted in developed countries with advanced healthcare infrastructure. There remains a paucity of evidence regarding the impact of this technology in developing countries, where access to advanced dental technology may be limited.[8-10] This study aims to address this gap in knowledge by evaluating the impact of 3D printing technology on the accuracy and efficiency of dental implant placement in Semarang, Indonesia, a rapidly developing city with a burgeoning demand for dental implant treatment.

2. Methods

This randomized controlled trial (RCT) was meticulously designed to evaluate the impact of 3D printing technology on the accuracy and efficiency of dental implant placement in the posterior mandible. The study was conducted at the Department of Oral and Maxillofacial Surgery at a Private Hospital in Semarang, Indonesia, a rapidly developing city with a growing demand for advanced dental care. Ethical approval for the study was obtained from the CMHC's ethics committee (Indonesia), ensuring adherence to the highest standards of research integrity and patient safety. All participants were fully informed about the study's purpose, procedures, and potential risks and benefits, and they provided written informed consent before enrollment.

The study population comprised 60 patients who presented to the Department of Oral and Maxillofacial Surgery at the Private Hospital in Semarang, Indonesia, with a clinical indication for a single dental implant in the posterior mandible. The posterior mandible was chosen as the implant site due to its anatomical complexities, including the proximity of vital structures such as the inferior alveolar nerve and the maxillary sinus, which necessitate precise implant placement to avoid complications.

To ensure the homogeneity of the study population and minimize the influence of confounding factors, strict inclusion criteria were applied. Participants were eligible for the study if they met the following criteria; Age between 20 and 60 years: This age range was selected to ensure that the participants had reached skeletal maturity and had adequate bone quality for implant placement while excluding older individuals who may have significant bone resorption or underlying medical conditions that could compromise implant success; Good general health (ASA I or II): Participants were required to be in good general health, classified as American Society of Anesthesiologists (ASA) physical status I or II, to minimize the risk of complications during or after surgery; Adequate bone volume and density in the proposed implant site: Adequate bone volume and density at the intended implant site were essential to ensure primary stability of the implant, a critical factor for successful osseointegration; Absence of any contraindications to dental implant surgery: Participants were excluded if they had any contraindications to dental implant surgery, such as uncontrolled systemic diseases, active oral infections, or a history of head and neck radiation therapy. In addition to the inclusion criteria, specific exclusion criteria were applied to further refine the study population and minimize potential confounding factors. Participants were excluded if they met any of the following criteria; History of radiotherapy to the head and neck region: Radiation therapy can adversely affect bone quality and vascularity, potentially compromising implant osseointegration and increasing the risk of complications; Uncontrolled periodontal disease: Periodontal disease, if not adequately controlled, can increase the risk of peri-implantitis, an inflammatory condition affecting the tissues surrounding the implant, which can lead to implant failure; Pregnancy or lactation: Pregnant or lactating women were excluded from the study due to the potential risks of radiation exposure from CBCT scans and the use of medications during the surgical procedure; Smokers (more than 10 cigarettes per day): Smoking has been identified as a significant risk factor for implant failure due to its adverse effects on wound healing and osseointegration; Patients with bruxism or other parafunctional habits: Bruxism, or teeth grinding, can place excessive forces on dental implants, potentially increasing the risk of mechanical complications and implant failure.

To minimize the risk of selection bias and ensure the comparability of the control and experimental groups, participants were randomly assigned to either group using a computer-generated randomization sequence. This process ensured that each participant had an equal chance of being assigned to either group, minimizing the potential for confounding factors to influence the study outcomes. Blinding of the surgeon performing the implant placement procedures was not feasible due to the nature of the intervention. The surgeon had to be aware of the group assignment to perform either the conventional freehand technique or the 3D printed surgical guide-assisted technique. However, the outcome assessor, an independent prosthodontist who evaluated the implant placement accuracy using postoperative CBCT scans, was blinded to the treatment group assignment. This blinding of the outcome assessor minimized the risk of assessment bias and ensured the objectivity of the implant placement accuracy measurements.

All surgical procedures were performed by the same experienced oral and maxillofacial surgeon, ensuring consistency in surgical technique and minimizing the potential for operator variability to influence the study outcomes. The surgeon had extensive experience in both conventional freehand implant placement and 3D printed surgical guide-assisted implant placement, ensuring proficiency in both techniques.

In the control group, implant placement was performed using conventional freehand techniques, guided by 2D radiographic imaging, including panoramic radiographs and periapical films, as well as clinical examination. The implant site was prepared using standard surgical protocols, and the implant was placed according to the surgeon's best clinical judgment, based on the 2D radiographic images and intraoperative assessment of the surgical site.

In the experimental group, dental implant placement was facilitated by 3D printing technology. Preoperatively, each patient underwent a CBCT scan to acquire detailed 3D images of their maxillofacial region. The CBCT data was then used to create a virtual 3D model of the patient's jaw, which was used for implant planning and surgical guide fabrication. Implant planning software was used to determine the optimal implant position on the virtual 3D model, taking into account the bone quality and quantity, the location of adjacent anatomical structures, and the desired restorative outcome. Once the ideal implant position was determined, a patient-specific surgical guide was designed using CAD software. The surgical guide was designed to precisely guide the drilling and placement of the implant according to the pre-surgical plan. The designed surgical guide was then fabricated using 3D printing technology. The 3D printer used for this study was a high-resolution stereolithography (SLA) printer, which produces accurate and dimensionally stable surgical guides. The fabricated surgical guide was sterilized and prepared for use in the surgical procedure. During the implant placement surgery, the surgical guide was securely attached to the patient's jaw, providing a physical template for implant placement. The surgical guide ensured that the drilling and implant placement were performed according to the pre-surgical plan, minimizing the risk of human error and ensuring accurate implant positioning.

The study's primary outcome measures were implant placement accuracy and surgical time. Implant placement accuracy was assessed using postoperative CBCT scans, which were taken after the implant placement surgery. The deviation of the actual implant position from the planned implant position was measured in three dimensions: mesiodistal, buccolingual, and apicocoronal. These measurements provided a quantitative assessment of the accuracy of implant placement in all three planes of space. Surgical time was measured from the initial incision to the final suture placement, providing a measure of the efficiency of the surgical procedure. The surgical time was recorded for both the control and experimental groups, allowing for a comparison of the efficiency of conventional freehand implant placement versus 3D printed surgical guide-assisted implant placement. In addition to the primary outcome measures, several secondary outcome measures were assessed to evaluate the overall impact of the intervention on patient outcomes. These secondary outcome measures included postoperative pain, postoperative swelling, and patient satisfaction. Postoperative pain was assessed using a visual analog scale (VAS) at 24 hours, 48 hours, and 7 days after surgery. The VAS is a widely used tool for measuring pain intensity, providing a subjective assessment of the patient's pain experience. Postoperative swelling was assessed by measuring the facial width at the level of the implant site at 24 hours, 48 hours, and 7 days after surgery, providing a measure of the inflammatory response to the surgical procedure. Patient satisfaction with the treatment was assessed using a questionnaire at 1 month and 3 months after surgery. The questionnaire included items related to satisfaction with the treatment outcome, comfort during the procedure, and overall experience with the implant placement process. These secondary outcome measures provided valuable insights into the patient's perspective on the treatment and its impact on their quality of life.

The data collected during the study was analyzed using SPSS software (version 25), a powerful statistical analysis tool widely used in healthcare research. Independent t-tests were used to compare continuous variables between the two groups, while chi-square tests were used to compare categorical variables. A p-value of less than 0.05 was considered statistically significant, indicating that the observed differences between the groups were unlikely to have occurred due to chance alone.

3. Results

Table 1 presents the baseline characteristics of the 60 participants enrolled in the study, divided into two groups: the Control Group (Freehand implant placement) and the Experimental Group (Surgical Guide-assisted implant placement). The table aims to demonstrate the similarity between the two groups in terms of various demographic and clinical factors, ensuring that any observed differences in outcomes can be attributed to the intervention (use of surgical guides) rather than pre-existing differences between the groups. Each group had 30 participants, ensuring adequate statistical power for the analysis. The average age of participants was similar in both groups (42.5 ± 8.7 years in the Control Group vs. 43.2 ± 9.1 years in the Experimental Group). The p-value of 0.65 indicates that this difference is not statistically significant. The distribution of males and females was comparable between the two groups, with no statistically significant difference (p=0.42). The location of the implant (second premolar, first molar, or second molar) was also similar between the groups (p=0.88), indicating that the complexity of the implant site was comparable. The vast majority of participants in both groups were non-smokers, with a small percentage of former smokers. There was no significant difference in smoking status between the groups (p=0.91). Most participants in both groups did not have any systemic diseases. A small percentage had controlled hypertension or controlled diabetes. Again, there was no significant difference between the groups (p=0.75).

Table 1. Participant characteristics.

Characteristic	Control Group (Freehand)	Experimental Group (Surgical Guide)	p-value
Sample size	30	30	-
Age (years)	42.5 ± 8.7	43.2 ± 9.1	0.65
Gender			0.42
Male	17 (57%)	14 (47%)	-
Female	13 (43%)	16 (53%)	-
Implant site			0.88
Second premolar	10 (33%)	12 (40%)	-
First molar	15 (50%)	13 (43%)	-
Second molar	5 (17%)	5 (17%)	-
Smoking status			0.91
Non-smoker	28 (93%)	27 (90%)	-
Former smoker	2 (7%)	3 (10%)	-
Systemic diseases			0.75
None	25 (83%)	26 (87%)	-
Controlled Hypertension	3 (10%)	2 (7%)	-
Controlled diabetes	2 (7%)	2 (7%)	-

Table 2 presents the primary outcome measures of the study, comparing the Control Group (Freehand implant placement) and the Experimental Group (Surgical Guide-assisted implant placement) in terms of implant placement accuracy and surgical time. The results clearly demonstrate the significant advantages of using 3D printed surgical guides for implant placement; Mesiodistal Deviation (mm): This measures the difference between the planned and actual implant position in the front-to-back direction. The Experimental Group showed significantly less deviation (0.5 ± 0.3 mm) compared to the Control Group (1.8 ± 0.8 mm) with a p-value of <0.001. This indicates a much higher accuracy in achieving the planned implant position in the mesiodistal dimension when using surgical guides; Buccolingual Deviation (mm): This measures the difference between the planned and actual implant position in the cheek-to-tongue direction. Again, the Experimental Group demonstrated significantly less deviation (0.4 ± 0.2 mm) compared to the Control Group (1.5 ± 0.7 mm) with a p-value of <0.001, highlighting the improved accuracy with surgical guides; Apicocoronal Deviation (mm): This measures the difference between the planned and actual implant position in the vertical direction (towards the root tip or crown). The Experimental Group showed significantly less deviation (0.6 ± 0.4 mm) compared to the Control Group (2.1 ± 1.0 mm) with a p-value of <0.001. This indicates that surgical guides help achieve the planned implant depth with much higher precision. The Experimental Group had a significantly shorter surgical time (32.8 ± 8.7 minutes) compared to the Control Group (45.2 ± 12.5 minutes) with a p-value of 0.02. This suggests that using surgical guides can streamline the implant placement procedure, potentially leading to increased efficiency and reduced chair time.

Table 2. Primary outcomes.

Outcome measure	**Control Group (Freehand)**	**Experimental Group (Surgical Guide)**	**p-value**
Implant placement accuracy			
Mesiodistal deviation (mm)	1.8 ± 0.8	0.5 ± 0.3	<0.001
Buccolingual deviation (mm)	1.5 ± 0.7	0.4 ± 0.2	<0.001
Apicocoronal deviation (mm)	2.1 ± 1.0	0.6 ± 0.4	<0.001
Surgical time (minutes)	45.2 ± 12.5	32.8 ± 8.7	0.02

Table 3 presents the secondary outcome measures of the study, comparing the Control Group (Freehand implant placement) and the Experimental Group (Surgical Guide-assisted implant placement) in terms of postoperative pain, swelling, and patient satisfaction. These outcomes provide valuable insights into the patient experience and potential benefits of using surgical guides beyond just implant placement accuracy; Postoperative Pain (VAS): Pain levels were assessed at 24 hours, 48 hours, and 7 days after surgery using a Visual Analog Scale (VAS), where higher scores indicate more pain. Although the Experimental Group consistently showed slightly lower pain scores at all time points, the differences were not statistically significant (p-values of 0.31, 0.45, and 0.62 respectively). This suggests that using surgical guides did not significantly impact the level of postoperative pain experienced by patients; Postoperative Swelling (mm): Swelling was measured at 24 hours, 48 hours, and 7 days after surgery. Similar to pain levels, the Experimental Group showed slightly less swelling at all time points, but the differences were not statistically significant (p-values of 0.38, 0.49, and 0.55 respectively). This indicates that the use of surgical guides did not have a major impact on postoperative swelling; Patient Satisfaction: Patient satisfaction was assessed at 1 month and 3 months after surgery. Both groups reported high levels of satisfaction, and there were no statistically significant differences between the groups at either time point (p-values of 0.42 and 0.35 respectively). This suggests that both treatment approaches resulted in comparable levels of patient satisfaction.

Table 3. Secondary outcomes.

Outcome measure	Control Group (Freehand)	Experimental Group (Surgical Guide)	p-value
Postoperative Pain (VAS)			
24 hours	3.2 ± 1.5	2.8 ± 1.3	0.31
48 hours	2.1 ± 1.2	1.9 ± 1.1	0.45
7 days	0.8 ± 0.7	0.7 ± 0.6	0.62
Postoperative Swelling (mm)			
24 hours	4.5 ± 2.1	4.1 ± 1.9	0.38
48 hours	3.2 ± 1.8	2.9 ± 1.6	0.49
7 days	1.5 ± 1.0	1.3 ± 0.9	0.55
Patient Satisfaction			
1 month	4.2 ± 0.8	4.3 ± 0.7	0.42
3 months	4.5 ± 0.6	4.6 ± 0.5	0.35

4. Discussion

The success of dental implant therapy hinges on the precision and accuracy of implant placement within the alveolar bone. Achieving a harmonious integration between the implant and the surrounding biological environment is paramount for ensuring the long-term stability and functional efficacy of the implant-supported restoration. This intricate interplay between the implant's physical placement and the biological response of the surrounding tissues dictates the long-term success of the implant, influencing its ability to withstand functional loads, maintain peri-implant health, and provide enduring aesthetic satisfaction. Accurate implant placement is the cornerstone of successful osseointegration, the biological process by which the implant fuses with the surrounding bone, establishing a stable and enduring foundation for the prosthetic restoration. This intimate bone-to-implant contact is essential for creating a biomechanically sound and biologically compatible environment that promotes long-term implant stability and resists the forces of mastication and parafunctional habits. The precision of implant placement dictates the extent and quality of bone-to-implant contact, influencing the initial stability of the implant and the subsequent osseointegration process. Conversely, deviations from the planned implant position can precipitate a cascade of complications that can compromise the success of implant therapy. These complications can range from impingement on vital anatomical structures to aesthetic deficiencies and biomechanical challenges, all of which can ultimately undermine the long-term viability of the implant. Inaccurate implant placement can lead to encroachment upon vital structures such as nerves, blood vessels, and the maxillary sinus, potentially resulting in sensory disturbances, bleeding, infection, or even more severe sequelae. Moreover, deviations from the planned implant position can compromise the aesthetic outcome of the restoration, particularly in the anterior region of the mouth where even minor discrepancies can be readily discernible. Additionally, inaccurate implant placement can lead to biomechanical complications, such as overloading of the implant or uneven force distribution, potentially increasing the risk of implant failure. Our study unequivocally demonstrates that the use of 3D printed surgical guides significantly improves the accuracy of implant placement in all three dimensions, mesiodistal, buccolingual, and apicocoronal. This enhanced accuracy can be attributed to the meticulous pre-surgical planning and the physical guidance afforded by the surgical guides. The guides eliminate the reliance on freehand drilling and implant placement, which can be susceptible to variations in surgeon experience, hand-eye coordination, and intraoperative visualization. By providing a physical template that guides the surgical instruments along a predetermined path, surgical guides minimize the risk of human error and ensure that the implant is placed in the ideal position according to the pre-surgical blueprint. This precision in implant placement translates to a more predictable and controlled surgical procedure, reducing the risk of complications and optimizing the long-term success of the implant. The posterior mandible, where this study was conducted, presents unique anatomical challenges for implant placement. The inferior alveolar nerve, responsible for sensation in the lower lip and chin, traverses the mandibular body in close proximity to the implant site. Inadvertent damage to this nerve during implant surgery can result in paresthesia, a debilitating condition characterized by numbness or altered sensation. The maxillary sinus, an air-filled cavity in the upper jaw, also poses a risk during implant placement in the posterior maxilla. Perforation of the sinus membrane can lead to sinusitis or other complications, necessitating further intervention and potentially compromising implant success. The proximity of these vital structures necessitates meticulous pre-surgical planning and precise execution of the implant placement procedure to avoid encroachment and potential complications. The use of surgical guides mitigates these risks by providing a physical barrier and guiding the surgical instruments along a predetermined path, minimizing the potential for deviation and ensuring that the implant is placed in a safe zone, away from critical anatomical structures. This precision not only reduces the risk of complications but also optimizes the biomechanical environment surrounding the implant, promoting long-term stability and functional success. By accurately controlling the depth and angulation of the implant, surgical guides ensure that the implant is placed within the confines of the available bone, maximizing bone-to-implant contact and minimizing the risk of impingement on adjacent structures. The enhanced accuracy afforded by 3D printed surgical guides translates to a multitude of benefits for both the patient and the clinician. For the patient, accurate implant placement minimizes the risk of complications, such as nerve damage or sinus perforation, and optimizes the functional and aesthetic outcomes of the implant-supported restoration. The implant is placed in a position that maximizes its integration with the surrounding bone, ensuring long-term stability and resistance to the forces of mastication. This translates to improved chewing efficiency, enhanced speech articulation, and a more natural appearance of the restoration. For the clinician, surgical guides enhance predictability and control over the implant placement procedure. The guides provide a physical framework that eliminates the guesswork and variability associated with freehand implant placement, allowing the clinician to confidently execute the pre-surgical plan and achieve the desired implant position. This reduces the cognitive burden on the surgeon, allowing them to focus on the finer details of the surgical procedure and ensuring a more efficient and predictable workflow. Moreover, the use of surgical guides can facilitate communication and collaboration between the clinician and the patient. The 3D models and surgical guides provide a tangible representation of the treatment plan, allowing the patient to visualize the intended outcome and actively participate in the decision-making process. This shared understanding fosters trust and confidence in the treatment plan, contributing to a more positive patient experience.[11-13]

Efficiency in implant surgery is a multifaceted concept that extends beyond the mere optimization of time and resources. It encompasses a holistic approach that prioritizes patient comfort, safety, and overall satisfaction, while simultaneously streamlining the surgical workflow to enhance predictability and precision. In the realm of implant dentistry, where meticulous execution and attention to detail are paramount, surgical efficiency plays a pivotal role in ensuring favorable treatment outcomes and a positive patient experience. Reducing the overall duration of the surgical procedure is essential for minimizing patient discomfort, anxiety, and the risk of complications. Prolonged surgical time can increase the likelihood of patient movement, swelling, and bleeding, potentially compromising the accuracy of implant placement and increasing the risk of infection or other adverse events. Moreover, extended surgical time can lead to increased patient anxiety and discomfort, potentially affecting their overall satisfaction with the treatment experience. Efficient implant surgeries maximize the use of clinical resources, including operating room time, surgical instruments, and personnel. This not only improves the cost-effectiveness of implant treatment but also increases the availability of care for other patients. By streamlining the surgical workflow and minimizing wasted time and resources, clinicians can provide more efficient and cost-effective care, ultimately benefiting both the patient and the healthcare system. Efficient implant procedures contribute to a more positive patient experience by minimizing chair time, reducing anxiety, and promoting a sense of confidence in the clinician's expertise. Patients are more likely to be satisfied with their treatment when it is performed efficiently and with minimal discomfort. A streamlined and efficient surgical experience can alleviate patient anxiety and enhance their perception of the clinician's competence and professionalism. A streamlined and efficient surgical workflow reduces mental fatigue for the surgeon, allowing them to maintain focus and precision throughout the procedure. This can minimize the risk of errors and contribute to improved patient outcomes. By reducing the cognitive burden on the surgeon, efficient procedures allow them to dedicate their full attention to each step of the surgery, ensuring that every detail is executed with the utmost care and precision. Our study reveals that the use of 3D printed surgical guides significantly reduces surgical time compared to conventional freehand implant placement. This enhanced efficiency can be attributed to the streamlined surgical protocol facilitated by the guides. The guides eliminate the need for intraoperative adjustments and measurements, allowing for a more predictable and efficient surgical procedure. The surgeon can confidently proceed with the implant placement, guided by the pre-surgical plan and the physical constraints of the guide, reducing the need for intraoperative decision-making and adjustments that can prolong surgical time. The streamlined workflow afforded by surgical guides translates to a more efficient and predictable surgical experience. The surgeon can rely on the pre-surgical plan and the physical guidance of the guide to execute the implant placement with precision and confidence, minimizing the need for intraoperative adjustments or improvisation. This not only reduces surgical time but also minimizes the risk of errors and complications. By eliminating the need for intraoperative measurements and adjustments, surgical guides streamline the surgical workflow, reducing the overall duration of the procedure. This translates to less time spent in the operating room, minimizing patient discomfort and anxiety while optimizing the use of clinical resources. This reduction in surgical time translates to several benefits for both the patient and the clinician. Patients experience less chair time, reducing anxiety and discomfort associated with prolonged surgical procedures. The reduced surgical time also minimizes the risk of complications associated with prolonged anesthesia or surgical site exposure. Clinicians can perform implant surgeries more efficiently, potentially increasing patient throughput and optimizing the use of clinical resources. The streamlined workflow allows clinicians to perform more procedures in the same amount of time, increasing their productivity and potentially reducing patient waiting times. This enhanced efficiency can contribute to improved patient access to care and enhanced cost-effectiveness of implant treatment. Moreover, the streamlined workflow can reduce mental fatigue for the surgeon, potentially minimizing the risk of errors and contributing to improved patient outcomes. By reducing the cognitive burden on the surgeon, surgical guides allow them to maintain focus and precision throughout the procedure, ensuring that each step is performed with the utmost care and attention to detail.[14-16]

In the realm of implant dentistry, the pursuit of technical excellence and objective outcomes, such as achieving precise implant placement and minimizing surgical time, must be harmonized with a patient-centric approach that prioritizes the overall patient experience. While achieving functional and aesthetic success is paramount, it is equally important to consider the patient's perspective and ensure that the chosen treatment modality does not compromise their comfort or satisfaction. This holistic approach to implant dentistry recognizes that the patient's perception of treatment success is not solely determined by objective measures but also by their subjective experiences and overall well-being. Patient-reported outcomes (PROs) are essential for capturing the holistic impact of implant treatment on the patient's well-being. PROs encompass a wide range of factors, including pain, discomfort, functional limitations, aesthetic satisfaction, and overall quality of life. By assessing PROs, clinicians can gain valuable insights into the patient's experience and tailor treatment plans to meet their individual needs and preferences. This patient-centric approach recognizes that each patient is unique and that treatment plans should be individualized to optimize both objective outcomes and subjective experiences. In the context of implant surgery, PROs such as postoperative pain, swelling, and satisfaction are particularly relevant. These factors can significantly influence the patient's perception of treatment success and their overall satisfaction with the implant experience. By carefully evaluating and addressing these PROs, clinicians can enhance the patient's experience and foster a sense of trust and confidence in the treatment process. Postoperative pain and swelling are common sequelae of implant surgery, regardless of the technique employed. However, it is essential to evaluate whether the use of surgical guides influences the severity or duration of these symptoms. Our study found no significant difference in postoperative pain or swelling between the control group (freehand implant placement) and the experimental group (surgical guide-assisted implant placement). This suggests that the enhanced accuracy and efficiency afforded by surgical guides do not come at the expense of increased patient discomfort. This finding is particularly reassuring for patients considering implant treatment. It underscores the fact that surgical guides can enhance the precision and predictability of implant placement without compromising patient comfort or increasing the risk of postoperative complications. Patients can be confident that the use of surgical guides will not exacerbate their postoperative pain or swelling, allowing them to focus on their recovery and the long-term benefits of their implant treatment. Patient satisfaction is a multifaceted concept that encompasses not only the objective outcomes of treatment but also the patient's perception of the overall experience. In implant dentistry, patient satisfaction is influenced by factors such as the functional and aesthetic outcomes of the restoration, the comfort and efficiency of the surgical procedure, and the quality of communication and interaction with the dental team. Our study found no significant difference in patient satisfaction between the control and experimental groups. Both groups reported high levels of satisfaction with their treatment, suggesting that the use of surgical guides does not negatively impact the patient's perception of treatment success or their overall satisfaction with the implant experience. This finding reinforces the notion that surgical guides can be seamlessly integrated into implant dentistry without compromising the patient's experience or satisfaction. This finding further strengthens the case for adopting surgical guides as a routine adjunct in implant dentistry. By enhancing the accuracy and efficiency of implant placement without compromising patient comfort or satisfaction, surgical guides offer a patient-centric approach to implant treatment that prioritizes both objective outcomes and subjective experiences. The use of surgical guides allows clinicians to achieve technical excellence while simultaneously ensuring a positive and comfortable experience for the patient.[17,18]

This study, conducted in Semarang, Indonesia, a rapidly developing city that reflects the growing demand for advanced dental care in many regions of the world, has profound implications for the future of implant dentistry in Indonesia and other similar settings. The findings underscore the transformative potential of 3D printing technology in democratizing access to high-quality implant care, elevating the standard of care, and stimulating innovation within the dental profession. 3D printing technology has the potential to democratize access to advanced implant care, enabling clinicians in diverse settings to provide high-quality treatment that rivals that offered in more developed countries. By empowering clinicians with the tools to perform accurate and efficient implant surgeries, 3D printing technology can elevate the standard of care and expand access to innovative treatment modalities for patients in need of dental implant rehabilitation. In Indonesia, a rapidly developing nation with a growing demand for advanced dental care, the adoption of 3D printing technology can significantly improve access to high-quality implant treatment. By empowering Indonesian dentists with the tools and technology to perform implant procedures with enhanced precision and predictability, 3D printing can help bridge the gap between dental care in developing and developed countries. The integration of 3D printing technology into implant dentistry has the potential to elevate the standard of care in Indonesia and other similar settings. By enabling clinicians to perform implant procedures with enhanced accuracy, efficiency, and predictability, 3D printing can contribute to improved treatment outcomes, reduced complication rates, and enhanced patient satisfaction. The adoption of 3D printing technology can also facilitate the dissemination of advanced implant techniques and protocols, allowing Indonesian dentists to stay abreast of the latest developments in the field and provide their patients with cutting-edge care. This can contribute to a more uniform standard of care across different regions and healthcare settings, ensuring that patients receive the highest quality treatment regardless of their location or socioeconomic status. Furthermore, the adoption of 3D printing technology can stimulate innovation and technological advancement within the dental profession in Indonesia. By embracing cutting-edge technologies, Indonesian dentists can position themselves at the forefront of implant dentistry, contributing to the global advancement of the field and attracting patients seeking high-quality care. The integration of 3D printing into dental education and training programs can foster a culture of innovation and technological advancement within the Indonesian dental community. By equipping future generations of dentists with the skills and knowledge to utilize 3D printing technology effectively, Indonesia can establish itself as a hub for implant innovation and expertise. The adoption of 3D printing technology can also promote collaboration and knowledge sharing between Indonesian dentists and their counterparts in other countries. By participating in international conferences, workshops, and research collaborations, Indonesian dentists can contribute to the global advancement of implant dentistry and learn from the experiences of others in the field. This exchange of knowledge and expertise can accelerate the adoption and implementation of 3D printing technology in Indonesia, leading to more rapid improvements in the quality of implant care and patient outcomes.[19,20]

5. Conclusion

In conclusion, this randomized controlled trial conducted in Semarang, Indonesia, provides compelling evidence that 3D printing technology significantly enhances the accuracy and efficiency of dental implant placement in the posterior mandible. The utilization of patient-specific surgical guides, fabricated using 3D printing technology, resulted in more precise implant positioning in all three dimensions (mesiodistal, buccolingual, and apicocoronal) compared to conventional freehand implant placement. This enhanced accuracy can be attributed to the meticulous pre-surgical planning and the physical guidance afforded by the surgical guides, which eliminate the reliance on freehand drilling and implant placement. Furthermore, the study demonstrated that 3D printing technology significantly reduced surgical time compared to conventional freehand implant placement. The streamlined surgical protocol facilitated by the surgical guides eliminates the need for intraoperative adjustments and measurements, allowing for a more predictable and efficient surgical procedure. This reduction in surgical time translates to less chair time for the patient, potentially reducing anxiety and discomfort associated with prolonged surgical procedures. Importantly, the study found that the enhanced accuracy and efficiency afforded by 3D printing technology did not come at the expense of increased patient discomfort or diminished satisfaction. There were no significant differences between the control and experimental groups in terms of postoperative pain, swelling, or patient satisfaction. This underscores the fact that 3D printing technology can enhance the precision and predictability of implant placement without compromising patient comfort or increasing the risk of postoperative complications. The findings of this study have profound implications for the future of implant dentistry in Indonesia and other similar settings. The adoption of 3D printing technology has the potential to democratize access to advanced implant care, enabling clinicians in diverse settings to provide high-quality treatment that rivals that offered in more developed countries. By empowering clinicians with the tools to perform accurate and efficient implant surgeries, 3D printing technology can elevate the standard of care and expand access to innovative treatment modalities for patients in need of dental implant rehabilitation.

6. References

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