Digital Implant Dentistry: Clinical Evaluation of a Complete Digital Workflow

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Abstract

Background:

Digital dentistry has revolutionized implant prosthodontics by integrating cone beam computed tomography (CBCT), intraoral scanning, computer-aided design/computer-aided manufacturing (CAD-CAM), and guided implant surgery. A fully digital workflow aims to improve treatment accuracy, reduce chairside time, and enhance patient comfort.

Aim:

To clinically evaluate the accuracy, efficiency, and clinical outcomes of a complete digital workflow in implant-supported prosthetic rehabilitation.

Materials and Methods:

This prospective clinical study included 20 patients requiring single-tooth implant rehabilitation. A fully digital workflow was employed, involving CBCT-based implant planning, digital intraoral scanning, fabrication of a CAD-designed surgical guide, guided implant placement, digital implant impression using scan bodies, and CAD-CAM fabrication of implant-supported crowns. Clinical parameters evaluated included marginal adaptation of prosthesis, passive fit, chairside time, and patient satisfaction using a visual analog scale (VAS). Data were analyzed using appropriate statistical tests with significance set at $p < 0.05$.

Results:

The digitally fabricated implant-supported prostheses demonstrated satisfactory marginal adaptation and passive fit in the majority of cases. The digital workflow significantly reduced chairside time compared with conventional procedures reported in the literature. Patient satisfaction scores were high, particularly regarding comfort during impression procedures.

Conclusion:

A fully digital workflow in implant prosthodontics provides predictable clinical outcomes, improved efficiency, and enhanced patient comfort. Digital implant dentistry represents a reliable and effective approach for modern implant-supported prosthetic rehabilitation.

Keywords:

Digital dentistry, implant prosthodontics, digital workflow, CAD-CAM, guided implant surgery.

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Introduction

Dental implants are widely used for replacing missing teeth and restoring oral function and esthetics. Conventional implant prosthodontic procedures involve multiple clinical and laboratory steps including physical impressions, stone casts, and manual prosthesis fabrication. These procedures may introduce inaccuracies at various stages of treatment **(1)**. Recent advancements in digital dentistry have introduced technologies such as cone beam computed tomography (CBCT), intraoral scanning, computer-aided design/computer-aided manufacturing (CAD-CAM), and three-dimensional printing. These technologies allow clinicians to perform prosthetically driven implant planning and guided implant surgery with enhanced precision **(2)**.

A fully digital workflow integrates digital diagnostic imaging, implant planning software, guided implant surgery, digital impressions, and CAD-CAM prosthetic fabrication. This workflow aims to improve treatment accuracy, enhance prosthetic fit, and reduce chairside time **(2,3)**.

Intraoral scanners have become an important component of digital dentistry because they enable accurate recording of implant positions while eliminating the discomfort associated with conventional impression materials **(2,4)**. In addition, CAD-CAM technologies allow precise fabrication of implant prostheses with improved marginal accuracy and consistency **(5)**.

Although digital workflows are increasingly adopted in implant dentistry, clinical evidence evaluating their effectiveness remains limited. Therefore, the present study aimed to clinically evaluate the accuracy and outcomes of a complete digital workflow for implant-supported prosthetic rehabilitation.

Materials and Methods

Ethical Approval and Study Design:

The present investigation was designed as a prospective clinical study conducted in the Department of Prosthodontics to assess the clinical performance of a complete digital workflow for implant-supported prosthetic rehabilitation. Ethical clearance for the study was obtained from the Institutional Ethics Committee prior to initiating patient recruitment. All procedures carried out during the study adhered to the ethical principles outlined in the Declaration of Helsinki for research involving human participants. Each participant was informed in detail about the nature and objectives of the study, and written informed consent was obtained before enrollment.

Sample Size Determination

The required sample size was estimated based on previous studies that evaluated digital workflows and implant prosthetic accuracy **(6,7)**. Considering a statistical confidence level of 95% and a study power of 80%, the minimum number of subjects required for meaningful analysis was calculated to be 18. To account for possible dropouts or incomplete follow-up during the study period, the sample size was increased to 20 participants.

Patient Selection

Patients who reported to the Department of Prosthodontics with a single missing tooth in the posterior region and required implant-supported prosthetic rehabilitation were screened for eligibility. Individuals between 20 and 60 years of age with adequate bone volume for implant placement and acceptable oral hygiene status were considered suitable for inclusion in the study. Patients presenting with uncontrolled systemic conditions, heavy smoking habits, or parafunctional activities such as bruxism were excluded to avoid potential complications that could influence implant success.

Digital Workflow Procedure

A comprehensive digital approach was adopted for implant treatment planning, surgical placement, and prosthetic rehabilitation. Initially, cone beam computed tomography (CBCT) scans were obtained to evaluate bone morphology, available bone height and width, and proximity to anatomical structures. In addition, digital impressions of the dental arches were captured using an intraoral scanner to obtain detailed three-dimensional surface images of the dentition and surrounding tissues.

The CBCT datasets and digital scan files were subsequently imported into implant planning software, where the images were superimposed to facilitate prosthetically driven implant planning. Using this integrated digital platform, the ideal implant position, angulation, and depth were determined in accordance with prosthetic requirements. Based on the finalized digital plan, a surgical guide was designed with computer-aided design software to allow accurate transfer of the planned implant position during surgery. The surgical guide was fabricated using three-dimensional printing technology.

Implant placement was performed using the fabricated guide to ensure precise positioning according to the digital plan. After completion of the surgical phase, a healing period was allowed to enable osseointegration of the implants. Following successful healing, scan bodies were attached to the implants and digital impressions were obtained using the intraoral scanner. The digital data generated from the scanning procedure were used for designing the implant-supported crowns through computer-aided design software. The final prostheses were manufactured using computer-aided manufacturing (CAM) milling technology and subsequently delivered to the patients after verifying marginal adaptation, passive fit, and occlusal relationships.

Clinical Evaluation

After placement of the prostheses, several clinical parameters were assessed to evaluate treatment outcomes. Marginal adaptation and passive fit of the implant crowns were examined clinically to ensure proper seating of the prosthetic restoration. The time required for the impression procedure was also recorded to evaluate procedural efficiency. In addition, patient perception and comfort during the treatment process were assessed using a visual analog scale (VAS), where scores ranged from 0 to 10, with higher values indicating greater patient satisfaction.

Statistical Analysis

All recorded data were compiled and analyzed using appropriate descriptive statistical methods. Mean values and standard deviations were calculated for the evaluated variables. A p-value of less than 0.05 was considered statistically significant.

Results :

A total of twenty patients requiring single-tooth implant rehabilitation were included in the study. All participants completed the treatment protocol without any complications during the surgical or prosthetic phases. The implants placed using the digitally planned surgical guides demonstrated successful osseointegration in all cases during the healing period.

The demographic distribution of the participants demonstrated that the majority of patients belonged to the 31–40 year age group (35%), followed by individuals aged 20–30 years (30%). This distribution indicates that implant-supported rehabilitation was more commonly sought by individuals in the middle adult age group. With respect to gender distribution, male participants constituted 55% of the study population, while female participants represented 45%, suggesting a relatively balanced representation of both genders in the study (Table 1).

Table 1. Demographic Distribution of Study Participants

Variable	Category	Frequency (n)	Percentage (%)
Age	20–30 years	6	30
	31–40 years	7	35
	41–50 years	4	20
	51–60 years	3	15
Gender	Male	11	55
	Female	9	45

The descriptive statistical analysis revealed favorable clinical outcomes associated with the complete digital workflow. The mean chairside time required for digital impression procedures was 6.8 ± 1.2 minutes, indicating improved efficiency during the clinical procedure. Furthermore, the mean marginal adaptation score of 9.1 ± 0.6 demonstrated excellent prosthetic accuracy of the digitally fabricated restorations. Similarly, the passive fit score (8.7 ± 0.8) indicated proper seating of implant-supported crowns without the need for extensive adjustments. The patient satisfaction score (8.9 ± 0.7) reflected a high level of acceptance of the digital workflow among participants (Table 2) .

Table 2. Descriptive Statistics of Clinical Parameters

Parameter	Mean	Standard Deviation	Minimum	Maximum
Chairside time for	6.8	1.2	5.0	9.0

Parameter	Mean	Standard Deviation	Minimum	Maximum
digital impression (minutes)				
Marginal adaptation score	9.1	0.6	8.0	10.0
Passive fit score	8.7	0.8	7.5	9.8
Patient satisfaction (VAS score)	8.9	0.7	7.5	10.0

Statistical comparison of chairside time for digital impressions with the conventional technique reported in the literature revealed a statistically significant reduction in clinical procedure time ($p < 0.001$). The digital workflow required significantly less time for impression recording, highlighting its efficiency in reducing treatment duration and improving workflow in implant prosthodontics (Table 3).

Table 3. Comparison of Chairside Time with Reported Conventional Technique (One-Sample t-Test)

Parameter	Mean Time (minutes)	Test Value (Conventional Time)	t-value	p-value
Digital impression	6.8	12	-14.25	<0.001

The comparison of patient satisfaction scores between male and female participants demonstrated no statistically significant difference ($p = 0.42$). Both groups reported similarly high satisfaction levels with the digital treatment procedure. This finding indicates that the acceptance and comfort associated with digital implant workflows are consistent across genders(Table 4).

Table 4. Patient Satisfaction Scores Based on Gender (Independent t-Test)

Gender	Mean VAS Score	Standard Deviation	p-value
Male	8.8	0.8	
Female	9.0	0.6	0.42

Clinical evaluation of prosthetic outcomes demonstrated that the majority of implant-supported restorations exhibited excellent marginal adaptation and passive fit. Fourteen prostheses were categorized as having excellent marginal adaptation, while five were rated as good and only one as acceptable. Similarly, twelve restorations demonstrated excellent passive fit and six showed good adaptation. These findings indicate that the digital workflow provided high accuracy in transferring implant position data from digital planning to prosthetic fabrication, thereby ensuring predictable clinical outcomes (Table 5).

Table 5. Clinical Evaluation of Prosthetic Fit

Parameter	Excellent	Good	Acceptable	Poor
Marginal adaptation	14	5	1	0
Passive fit	12	6	2	0

Discussion

The integration of digital technologies into implant prosthodontics has significantly modified conventional clinical and laboratory procedures. Modern digital workflows combine cone beam computed tomography (CBCT), intraoral scanning, computer-aided design (CAD), and computer-aided manufacturing (CAM) systems to facilitate accurate diagnosis, treatment planning, and prosthetic fabrication. The present study evaluated the clinical performance of a complete digital workflow in implant-supported prosthetic rehabilitation. The findings revealed favorable prosthetic accuracy, reduced chairside time, and high patient satisfaction, supporting the increasing adoption of digital technologies in implant dentistry**(8)**.

One of the important observations in the present investigation was the satisfactory marginal adaptation and passive fit of implant-supported restorations fabricated using CAD-CAM technology. Accurate prosthetic fit is essential for maintaining the long-term stability of implant restorations, as misfit can contribute to biological complications such as peri-implant inflammation or mechanical complications including screw loosening and prosthesis fracture. Digital manufacturing techniques have been reported to produce restorations with high dimensional precision because the fabrication process is standardized and controlled through computerized systems. Recent studies evaluating digital prosthetic workflows have shown that CAD-CAM restorations demonstrate improved marginal adaptation and consistent quality compared with conventionally fabricated prostheses **(9)**.

Another significant outcome of the present study was the reduction in chairside time during the impression procedure. Digital impression techniques eliminate the need for conventional elastomeric materials, tray selection, and cast fabrication, thereby simplifying the clinical procedure. Intraoral scanners capture three-dimensional images of the dental structures directly, allowing the clinician to transfer digital data to the laboratory instantly. Clinical investigations conducted in recent years have demonstrated that digital impression procedures require significantly less time than conventional techniques while maintaining comparable or superior accuracy for implant restorations **(10,11)**. These advantages contribute to improved efficiency of dental treatment and may also enhance communication between clinicians and dental laboratories through digital data transfer.

Patient satisfaction is another important factor when evaluating the effectiveness of new dental technologies. In the present study, participants reported high levels of comfort during digital impression procedures. This finding may be attributed to the absence of impression trays and materials, which often cause discomfort or gag reflex in patients undergoing conventional impressions. Several recent clinical studies have reported that patients generally prefer digital impressions over conventional methods because the procedure is faster, more comfortable, and less invasive **(12,13)**. Improved patient acceptance may therefore contribute to the broader adoption of digital technologies in clinical dental practice.

The use of digital diagnostic tools such as CBCT combined with intraoral scanning also enhances the accuracy of implant treatment planning. By merging radiographic data with digital surface scans, clinicians can visualize both anatomical structures and prosthetic requirements simultaneously. This integration allows prosthetically driven implant placement, which is essential for achieving optimal functional and esthetic outcomes. Recent research evaluating computer-guided implant surgery has shown that digital planning significantly improves the accuracy of implant positioning and reduces deviations from the planned implant location **(14)**. Such improvements in surgical precision can contribute to better prosthetic outcomes and reduced complications.

In addition to improved accuracy, digital workflows facilitate the use of advanced manufacturing technologies such as CAD-CAM milling and three-dimensional printing. These technologies allow fabrication of prosthetic restorations with high precision and reproducibility while minimizing errors associated with manual laboratory procedures. Furthermore, digital data storage allows easy retrieval and modification of prosthetic designs, which may be advantageous in cases requiring prosthesis repair or replacement. Recent systematic reviews have highlighted that CAD-CAM fabricated implant prostheses exhibit reliable mechanical properties and favorable clinical performance in both short-term and medium-term follow-up studies **(9,15)**.

Despite the advantages observed in the present study, certain limitations associated with digital workflows should also be considered. One potential concern is the possibility of inaccuracies introduced during digital data acquisition, particularly during intraoral scanning of multiple implants or edentulous arches. Studies have indicated that scanning accuracy may decrease as the scanned area increases, which may influence prosthetic fit in complex cases **(6)**. Additionally, errors during digital image merging or software processing may affect the accuracy of implant planning if appropriate protocols are not followed.

Another limitation associated with digital implant workflows is the cost of equipment and the learning curve required for clinicians to become proficient in digital technologies. The acquisition of intraoral scanners, planning software, and CAD-CAM systems requires substantial financial investment, which may limit the accessibility of digital dentistry in certain clinical settings. Furthermore, clinicians must undergo adequate training to effectively utilize these technologies and avoid potential errors during digital procedures **(10)**.

In addition, although many studies report positive outcomes with digital workflows, some investigations suggest that digital and conventional techniques may demonstrate comparable long-term clinical success. A recent meta-analysis evaluating implant survival rates reported that both digital and conventional workflows achieved survival rates exceeding 95%, indicating that while digital workflows improve efficiency and patient comfort, their long-term biological outcomes may not differ significantly from conventional approaches **(16,17,18)**.

Overall, the results of the present study support the growing evidence that digital implant workflows can improve treatment efficiency, prosthetic accuracy, and patient satisfaction. The integration of digital diagnostic tools, guided implant surgery, and CAD-CAM prosthesis fabrication provides a streamlined approach to implant prosthodontics. However, further longitudinal clinical studies with larger sample sizes are required to evaluate the long-term outcomes and cost-effectiveness of complete digital workflows in implant rehabilitation.

Conclusion

The findings of the present study indicate that a complete digital workflow in implant prosthodontics provides reliable clinical outcomes with improved prosthetic accuracy, reduced chairside time, and enhanced patient comfort. The integration of digital imaging, intraoral scanning, and CAD-CAM fabrication facilitates efficient treatment planning and prosthesis production. Although digital workflows offer several clinical advantages, adequate operator training and access to appropriate technological resources are essential for successful implementation. Further long-term studies with larger sample sizes are recommended to confirm the long-term effectiveness and clinical predictability of fully digital implant rehabilitation.

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