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Digitally Integrated Workflow Combined with Guided Implant Surgery for Early Functional Loading in Full-arch Rehabilitation: A Case Report

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ABSTRACT

Digitally integrated workflow combined with computer-guided implant surgery has enhanced prosthetically-driven planning in full-arch rehabilitation. This report describes the clinical application of a digitally integrated protocol for early functional loading of implant-supported fixed complete prostheses.

A patient requiring full-arch rehabilitation was treated using cone-beam computed tomography, intraoral scanning, digital wax-up**,** virtual implant planning, CAD-CAM prosthetic design, and 3D-printed surgical guides. Primary implant stability was assessed intraoperatively using a calibrated torque wrench, and an insertion torque exceeding 35 N·cm was verified for each implant. Screw-retained provisional prostheses fabricated in polymethyl methacrylate were additively manufactured and placed into function seven days after implant placement.

In this specific clinical case, the digitally integrated workflow combined with guided implant surgery and early functional loading demonstrated clinical feasibility, with satisfactory clinical and esthetic outcomes over a 12-month follow-up.

Keywords: Computer-aided design, Computer-assisted surgery, Dental implants, Dental prosthesis, Implant-supported, Prosthesis design, Tomography, X-ray computed.

1. Introduction

Digital technologies have increasingly reshaped contemporary prosthetic dentistry. Intraoral scanners (IOSs) are now widely integrated into clinical practice, enabling digital data acquisition with potential benefits in accuracy and procedural efficiency (1). The growing adoption of digital workflows has further enhanced diagnostic assessment and facilitated prosthetically-driven treatment planning.

In implant dentistry, digital workflows enable three-dimensional virtual implant planning and accurate transfer of the planned implant positions to the surgical field. Computer-guided approaches have been associated with improved accuracy, simplified surgical procedures, and greater treatment predictability (2). These benefits are particularly relevant to the rehabilitation of edentulous patients, for whom fixed implant-supported prostheses remain an effective treatment option for restoring masticatory function, facial support, and quality of life (3,4).

Recent clinical studies and systematic reviews suggest that early and immediate functional loading can achieve survival rates comparable to conventional delayed loading when adequate primary stability is achieved (5,6,12,13). These protocols may also reduce

treatment time and surgical interventions while improving patient satisfaction.

The application of digital technologies, including intraoral scanners and computer-aided design/computer-aided manufacturing (CAD-CAM), combined with innovative prosthetic materials, has further facilitated the implementation of early-loading protocols in complete-arch implant rehabilitation (1,7,8). These integrated workflows may reduce procedural time and improve prosthetic precision and esthetic outcomes (1,7,8). Nevertheless, clinical documentation regarding the combined use of a digitally integrated workflow and guided implant surgery specifically for early loading in full-arch rehabilitation remains limited.

Therefore, the present article reports a clinical case illustrating the application of a comprehensive digital workflow combined with guided implant surgery for early loading of implant-supported fixed complete prostheses.

2. Case Report

2.1 Case Presentation

A 73-year-old male with cardiovascular disease, long-term oral anticoagulation for atrial fibrillation, and previous cryoablation for atrial flutter (currently stable) presented for functional prosthetic rehabilitation. Extraoral examination revealed a symmetrical oval face with a convex profile. The temporomandibular joints were asymptomatic, and mandibular opening was straight, with a maximum interincisal distance of 60 mm (Figure 1). Intraoral examination revealed teeth 11, 21, 22, 23, 17, and 27, with poor oral hygiene. Periodontal examination showed gingival recession and Grade III mobility (Miller classification) affecting the anterior teeth. The maxillary second molars were caries-free and stable. The residual alveolar ridges were well developed, with rounded contours and a vertical height >10 mm (Figure 2.a).

Intraoral examination of the mandibular arch revealed teeth from the left first premolar to the right second premolar, with generalized gingival recession but no mobility. Osteomucosal examination showed a U-shaped arch with moderate frenulum attachments (Figure 2.b).



Figure 1. Extraoral photographs at the initial examination: (a) frontal view; (b) right lateral profile view

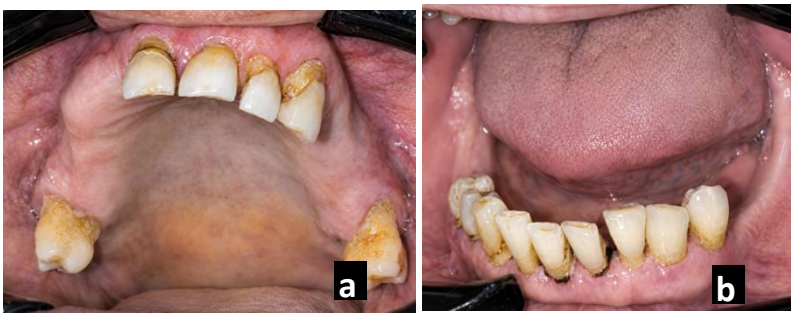


Figure 2. Preoperative intraoral views: (a) maxillary arch; (b) mandibular arch

2.2 Radiographic Assessment

Orthopantomograph showed that maxillary anterior teeth exhibited significant alveolar bone loss, exceeding a half of the root length. These lesions were further aggravated by the presence of caries. Consequently, the prognosis for maintaining these teeth is poor, and extraction is indicated. The maxillary second molars showed slight alveolar bone loss.

Radiographic examination of the mandibular teeth showed no significant abnormalities of the alveolar bone or periodontal structures, except for minor superficial caries, supporting their preservation in the treatment plan (Figure 3.a).

CBCT revealed adequate maxillary bone volume for implant placement, with low density corresponding to D3 bone quality according to the Misch classification. No significant anatomical limitations were identified; the nasal fossae and maxillary sinuses were preserved, allowing implant placement without major anatomical risk (Figure 3.b).

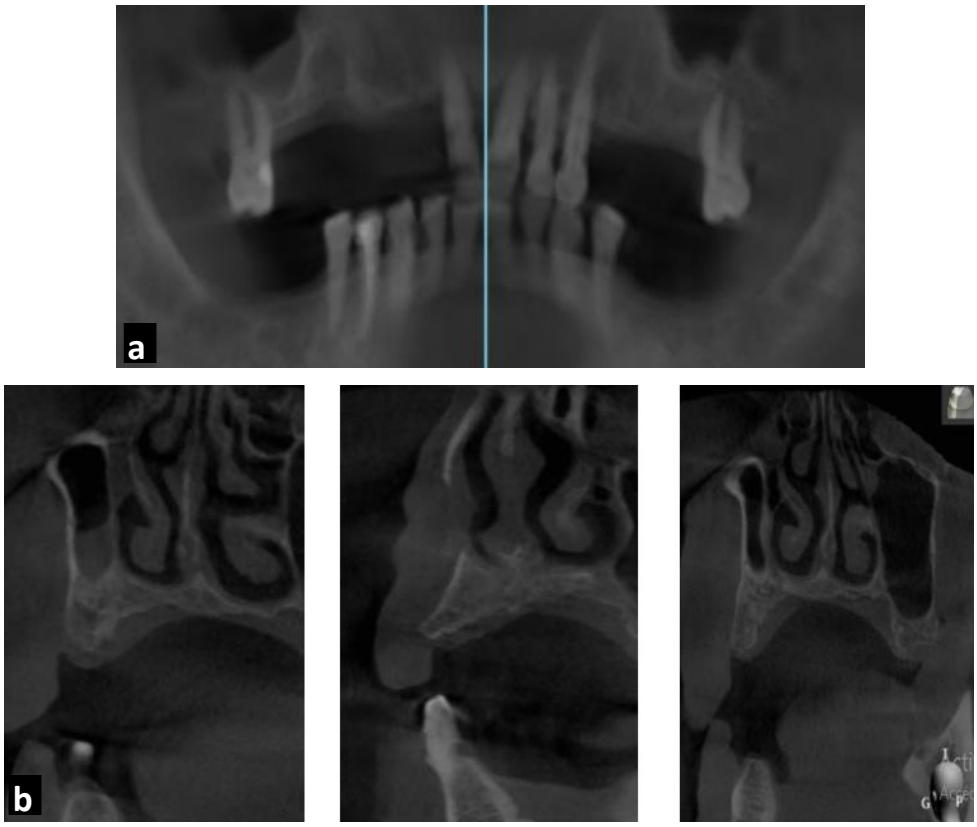


Figure 3. Pre-treatment radiographic assessment: (a) panoramic radiograph; (b) representative coronal CBCT slices of the maxilla

2.3 Treatment Planning

Based on the clinical and radiographic findings, an implant-prosthetic treatment plan was established, considering the patient's systemic condition and functional needs. Six maxillary implants were planned at sites 11, 14, 15, 21, 24, and 25 to provide balanced implant distribution and occlusal support. Three mandibular implants were planned at sites 46, 35, and 36 to restore the posterior edentulous areas and complement the maxillary rehabilitation.

2.4 Digital Planning

Digital planning was performed by merging intraoral optical scans with CBCT datasets in 3Shape Implant Studio (3Shape A/S, Copenhagen, Denmark) for three-dimensional bone assessment and prosthetically-driven implant planning. A pre-operative scan of both arches was obtained before extraction of the maxillary anterior teeth (Figure 4), providing a reference for anterior tooth position, morphology, and occlusal plane. A digital wax-up was then created using the existing occlusal plane as a reference, which was subsequently optimized

to improve the prosthetic arrangement.

A fully guided surgical protocol was adopted using a tooth-supported surgical guide anchored on teeth 17 and 27. The surgical guide was designed within Implant Studio and provided stable support throughout the surgical procedure. The guided protocol was used from osteotomy preparation to final implant placement, allowing accurate transfer of the virtually planned implant positions to the surgical field.

The digital wax-up was then integrated with the pre-operative intraoral scan and CBCT dataset within 3Shape Implant Studio. This allowed the planned tooth positions and prosthetic emergence profiles to be correlated with the available bone volume and adjacent anatomical structures. The resulting prosthetically-driven implant positions were subsequently incorporated into the design of the tooth-supported surgical guide used for fully guided implant placement.



Figure 4. Digital casts obtained from the intraoral scan: (a) maxillary arch; (b) mandibular arch; (c) maxillomandibular occlusal relationship

The maxillary implant plan consisted of six implants from the JDental Care system (JDEvolution/JDEvolution Plus), made of grade 4 titanium. The implants were positioned at sites 11, 14, 15, 21, 24, and 25, with implant dimensions adapted to each site according to the available bone volume and local anatomical constraints. Implant dimensions are presented in Table 1. This planning allowed prosthetically-driven positioning, optimization of implant emergence profiles, and balanced implant distribution to support the definitive full-arch implant-supported prosthesis.

Table 1. Implant dimensions according to implant site

Implant site (FDI)	Diameter (mm)	Length (mm)
11	3.7	11.5
21	3.7	11.5
14	3.7	13
15	4.3	8
24	3.2	10
25	4.3	8

2.4 Ethics and Informed Consent

Written informed consent was obtained from the patient for the proposed dental treatment and for the use of clinical photographs and relevant clinical information for scientific publication. The patient was informed about the nature and purpose of the treatment and the intended use of the clinical data and photographs in this case report.

2.5 Treatment Protocol

A comprehensive clinical evaluation, CBCT imaging, and conventional occlusal registration were performed. A wax occlusion rim was fabricated, and the mandible was manually guided into centric relation. After clinical verification, the maxillomandibular relationship was recorded with the rim in place and then scanned intraorally in the established position, allowing its transfer to the digital workflow.

The intraoral scan and CBCT datasets were integrated and superimposed in 3Shape Implant Studio (3Shape A/S, Copenhagen, Denmark) for three-dimensional assessment of bone volume and prosthetically driven implant planning. A tooth-supported surgical guide, designed in Implant Studio and stabilized on teeth 17 and 27, was used for fully guided, flapless surgery from osteotomy preparation to final implant placement (Figure 5).

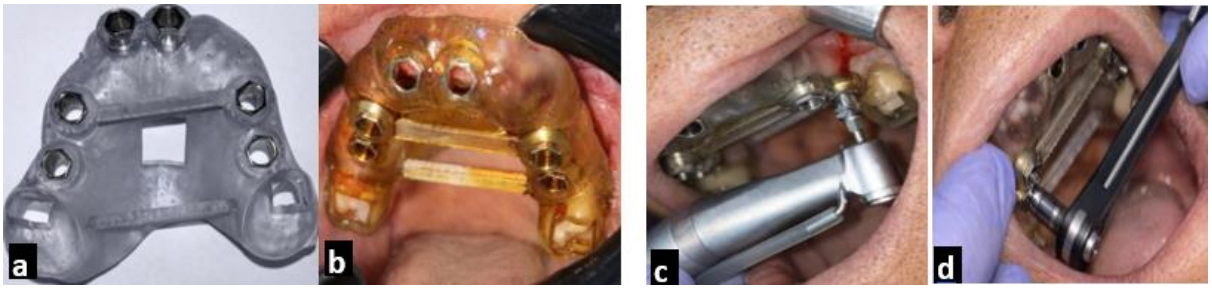


Figure 5. Computer-guided implant surgery: (a) tooth-supported surgical guide; (b) intraoral positioning and stabilization of the surgical guide; (c) guided osteotomy preparation; (d) implant placement with controlled insertion torque.

After clinical verification of the guide seating and stability, osteotomy preparation was performed according to a conventional drilling sequence consisting of a pilot point, followed by a pilot drill and a final drill slightly undersized relative to the corresponding implant diameter.

At the surgical appointment, teeth 11, 21, 22, and 23 were atraumatically extracted, followed immediately by implant placement at sites 11, 14, 15, 21, 24, and 25. Simultaneous alveolar socket grafting was performed using Bio-Oss and a resorbable membrane. Six implants from the JDental Care system (JDEvolution/ JDEvolution Plus), made of grade 4 titanium, were placed at the planned sites using the fully guided surgical protocol.

Primary implant stability was assessed intraoperatively using a calibrated torque wrench. An insertion torque exceeding 35 N·cm was verified for each implant before proceeding with the early functional loading protocol. Multi-unit abutments were immediately connected, and healing caps were placed (Figure 6.a,b).

Seven days post-ooperatively, a digital impression was obtained for fabrication of the provisional fixed dental prosthesis (Figure 6.c). The provisional prosthesis was digitally designed using 3Shape Dental System (3Shape A/S, Copenhagen, Denmark), incorporating the previously established maxillomandibular relationship, and was subsequently additively manufactured in polymethyl methacrylate (PMMA)**.** The provisional bridge corresponded to an implant-supported FP2-type fixed dental prosthesis according to the Misch classification. It was clinically tried in and screw-retained, and placed into function seven days after implant placement, according to an early functional loading protocol (Figure 7). A clinical follow-up examination was performed at 15 days. No ISQ measurement was performed at this stage.



Figure 6. Prosthetic phase following implant placement: (a) placement of angled multi-unit abutments; (b) placement of healing caps; (c) digital maxillary cast with scan bodies for fabrication of the provisional prosthesis



Figure 7. Intraoral views of the screw-retained implant-supported FP2-type provisional PMMA prosthesis

After an eight-month healing period, a clinical and radiographic follow-up was performed before initiation of the definitive prosthetic phase. Periapical radiographs were obtained to assess the radiographic status of the implants and surrounding structures.

The definitive prosthetic phase was then initiated. Maxillary and mandibular digital scans were obtained, incorporating individualized emergence profiles and scan bodies, together with the previously established occlusal relationship (Figure 8). The definitive prosthesis was subsequently digitally designed based on these records.

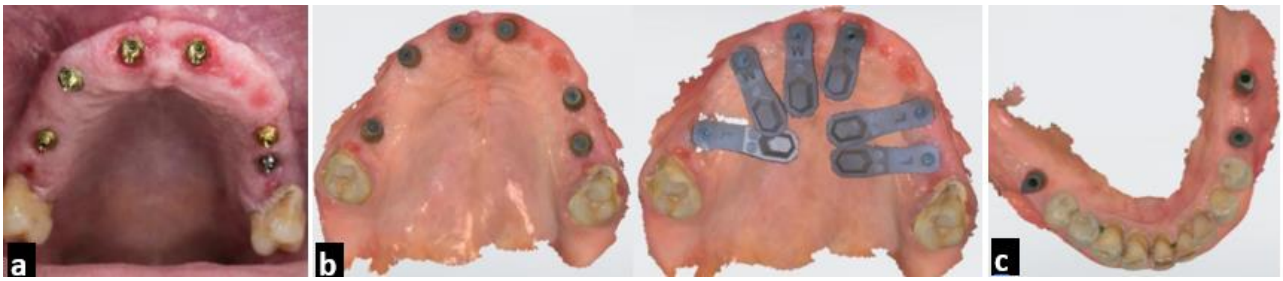


Figure 8. Definitive impression stage: (a) healed peri-implant soft tissues prior to digital impression; (b) digital maxillary cast with scan bodies and healing caps; (c) digital mandibular cast with scan bodies

At the try-in appointment, prosthesis passivity, occlusal plane orientation, midline position, centric relation, vertical dimension of occlusion, peri-implant soft tissue adaptation, and esthetic integration were clinically verified before final delivery and occlusal equilibration.

The definitive prosthesis was fabricated in monolithic zirconia (full-contour zirconia) (Figure 9). This material was selected for its high mechanical strength and rigidity, which are advantageous for a long-span full-arch restoration supported by six implants. The monolithic design also avoids the use of a veneering ceramic layer, thereby reducing the risk of veneer chipping or delamination.



Figure 9. Definitive implant-supported fixed complete prostheses. (a) Intraoral views of the screw-retained definitive maxillary implant-supported fixed complete prosthesis showing the occlusal, mandibular occlusal, and frontal views in maximum intercuspation. (b) Extraoral frontal view after definitive prosthesis delivery

2.6 Clinical and Prosthetic Follow-up

Clinical follow-up included assessment of peri-implant soft tissues, implant stability, prosthetic function, and the occurrence of biological or mechanical complications. At the eight-month follow-up, periapical radiographs were obtained to assess the radiographic status of the implants and surrounding structures.

At the 12-month follow-up, all implants remained clinically stable, with no implant loss observed during the follow-up period. No biological or mechanical complications were clinically identified. In particular, no screw loosening, prosthetic fracture, or other mechanical complication was observed**.** The definitive prosthesis remained functional and demonstrated satisfactory functional and esthetic outcomes.

3. Discussion

Early and immediate loading protocols have been widely investigated in implant-supported rehabilitation and may demonstrate favorable survival outcomes when strict selection criteria are applied. Systematic reviews indicate that immediate or early loading can be successfully performed in selected patients, with adequate primary stability being an important prerequisite (5,6).

Higher insertion torque has been associated with reduced implant micromotion, although this relationship is influenced by bone density and other biomechanical factors (9,10). Consensus statements emphasize that adequate primary implant stability, appropriate case selection, and adherence to appropriate surgical and prosthetic protocols are important prerequisites for predictable loading outcomes (6).

The provisional prosthesis was placed into function seven days after implant placement, constituting early functional loading. This protocol was supported by an insertion torque >35 N·cm for each implant, rigid cross-arch splinting, and careful occlusal control.

Evidence specifically addressing full-arch rehabilitation has shown that immediate loading with fixed full-arch prostheses in the maxilla can achieve high implant and prosthetic survival rates in appropriately selected patients. Peñarrocha-Oltra et al. (11) reviewed the literature on immediate loading with fixed full-arch prostheses in the maxilla and reported implant survival rates ranging from 87.5% to 100% and prosthesis survival rates ranging from 93.8% to 100% across the included studies. Papaspyridakos et al. (12), in a systematic review and meta-analysis including 62 studies, 2,695 patients, 2,757 edentulous arches, and 13,653 implants, reported high implant and prosthesis survival rates across immediate, early, and conventional loading protocols in edentulous patients. In a randomized controlled clinical trial, Cannizzaro et al. (13) compared immediate and early loading of flapless-placed implants supporting maxillary full-arch prostheses; implants were required to achieve a minimum insertion torque of >48 N.cm.

Primary stability represents a fundamental prerequisite for any early or immediate loading protocol. In an experimental study, higher insertion torque was associated with reduced implant micromotion, although this relationship was influenced by bone density (9). Although insertion torque is a simple and reproducible clinical indicator, it should be interpreted in conjunction with other parameters, including bone quality and implant-related factors (10,14). Insertion torque is commonly used as a clinical indicator of primary implant stability. However, torque values should not be interpreted as a direct measurement of micromotion or as a substitute for other stability-related parameters.

Systematic reviews and meta-analyses have reported that computer-aided implant surgery, particularly fully guided approaches, may improve the accuracy of implant positioning compared with freehand approaches, although accuracy is influenced by several clinical and technical factors (2,8).

A fully guided, flapless protocol integrating intraoral scanning, digital planning, and CAD/CAM fabrication streamlined the surgical and prosthetic stages. Conventional procedures were used to record and verify the maxillomandibular relationship. Thus, the protocol represents a digitally integrated workflow with selected conventional procedures, rather than an exclusively digital workflow.

Screw-retained provisional restorations are widely used in early loading protocols. Systematic reviews have reported different patterns of biological and technical complications between screw- and cement-retained implant-supported restorations, with screw-retained full-arch prostheses showing a favorable complication profile in some studies, although technical complications, such as screw loosening, may occur (15,16).

Additively manufactured provisional resin materials may provide suitable mechanical properties for

provisional fixed dental prostheses, although their mechanical performance depends on the material, printing parameters, and post-processing protocol (17). Meticulous occlusal adjustment was incorporated in the present case to limit excessive functional loading. The protocol applied in this case, combining early functional loading with a screw-retained full-arch provisional prosthesis and careful occlusal equilibration, is consistent with these clinical considerations.

Immediate implant placement in fresh extraction sockets may reduce treatment time and surgical interventions. However, case selection should consider infection, socket condition, primary stability in the restoratively-driven position, and patient-related factors (18,19).

In this clinical case, rehabilitation was achieved with a full-arch implant-supported fixed prosthesis supported by six implants. The use of multiple implants to support full-arch fixed prostheses is well documented, with high implant and prosthesis survival rates reported across different implant configurations (4,20). Systematic reviews have not demonstrated a consistent significant difference in implant or prosthesis survival between full-arch prostheses supported by fewer versus greater numbers of implants. Clinical outcomes may be influenced by implant distribution, bone conditions, prosthetic design, loading protocol, and patient selection (4,20). In the present case, six implants were selected to provide the planned distribution of implant support for the maxillary full-arch prosthesis.

As this report describes a single clinical case with only 12 months of follow-up, the findings cannot be generalized or used to assess long-term biological and prosthetic stability. Quantitative peri-implant parameters, including probing depth, bleeding on probing, plaque and gingival indices, were not systematically recorded. Periapical radiographs at 8 months allowed qualitative assessment of the implants and surrounding structures, but quantitative marginal bone-level measurements were not performed.

4. Conclusions

Within the limitations of this single case report, the digitally integrated workflow combined with guided implant surgery and early functional loading demonstrated clinical feasibility for full-arch implant rehabilitation. The favorable 12-month outcome suggests potential applicability in appropriately selected cases; however, larger studies with longer follow-up are needed to assess its clinical effectiveness, predictability, and long-term outcomes.

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