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Original Article

Stackable Surgical Guides for Full-Arch Implant Rehabilitation: A Novel Computer-Aided Approach

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ABSTRACT

This technical report describes a newly designed computer-guided workflow employing titanium-reinforced stackable surgical templates for post-extractive implant placement followed by immediate loading. A patient presenting with complete edentulism of the maxilla was rehabilitated using one-piece implants, beginning from an existing removable denture. Three-dimensional digital scans of the denture and both dental arches were performed. Using these datasets, an ideal functional and esthetic prototype was generated and later reproduced as a custom radiographic guide embedded with reference markers. By superimposing STL and DICOM data, a virtual prosthetically driven plan for one-piece implants was achieved.

The stackable guide system consisted of a fixed base framework and several detachable modules. The base portion was stabilized on the bone using anchor pins and remained stationary throughout the entire procedure. The removable components, fastened to the base, facilitated both implant insertion and immediate prosthetic connection. No intraoperative complications occurred; all implants reached a minimum insertion torque of 35 Ncm, allowing for instant prosthetic loading. The presence of a permanent reference base enhanced workflow precision and streamlined the transition between digital design, surgical execution, and final prosthetic delivery.

Keywords: Computer-guided implantology, Digital workflow, Full-arch rehabilitation, Immediate loading, Stackable templates

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Introduction

The concept of computer-assisted dental implantology emerged over 25 years ago, aimed at optimizing implant positioning in alignment with the prosthetic design [1]. Furthermore, cone-beam computed tomography (CBCT)–assisted planning contributes to the avoidance of surgical risks such as nerve damage, sinus perforation, fenestration, and dehiscence [2]. Considering factors such as implant depth, inter-implant spacing, tooth–implant distance, and relationship to cortical boundaries, virtual planning has become an essential element for achieving predictable clinical results [3, 4].

In guided implantology, implant sites are transferred to the operative field via surgical templates. These templates vary according to their support type:

- Tooth-supported guides rest on the remaining dentition,
- Bone-supported guides are anchored by fixation pins or screws, and
- Mucosa-supported guides rest directly on the soft tissue [5].

The latter category is particularly useful in flapless implant placement, where mucoperiosteal flap elevation is avoided. This minimally invasive approach simplifies the operation, reduces patient discomfort, limits bleeding, preserves vascularization, and minimizes periosteal trauma [6–9]. Such protocols are most effective in cases with adequate bone dimensions and sufficient keratinized tissue, which provide favorable conditions for flapless surgery [10]. Conversely, when deficient bone or soft tissue volume is present, flap elevation becomes necessary to enable simultaneous regeneration or soft tissue augmentation according to prosthetic requirements.

For achieving optimal esthetic and functional outcomes, especially in the anterior maxilla, prosthetic design must guide every stage of the surgical workflow.

Stackable surgical templates, composed of a primary fixed base and exchangeable modular elements, have been introduced to improve control and continuity during both surgical and prosthetic phases. The stackable system permits soft and hard tissue management without removing the base guide, thereby maintaining a constant spatial reference.

Precise implant positioning is crucial in immediate loading protocols, as it allows the pre-fabricated prosthesis to be connected directly after surgery, eliminating the need for intraoperative impressions [11]. However, several cumulative inaccuracies may occur throughout the workflow, particularly during guide stabilization or fixation [12]. In this context, stackable titanium-reinforced systems with fixed reference points have been proposed to enhance implant placement accuracy and facilitate instant prosthetic delivery [13].

These systems shorten operative time, reduce patient discomfort, and enable the immediate restoration of masticatory efficiency, phonetics, esthetics, and comfort, allowing patients to resume normal function quickly. Notably, immediate loading of full-arch rehabilitations has demonstrated high success rates for both maxillary and mandibular arches, confirming the reliability and predictability of this technique [14–17].

When one-piece implants are incorporated within a computer-guided approach, several advantages arise. The absence of an internal connection minimizes bacterial leakage and prosthetic complications, while also reducing the number of clinical stages. Nevertheless, the success of such procedures depends heavily on precise digital planning to secure primary stability and ensure accurate implant positioning [18].

Therefore, this report introduces a novel computer-guided method that integrates titanium-reinforced stackable surgical guides for one-piece implant insertion with immediate loading, illustrating its potential to optimize digital-to-surgical workflow integration.

Materials and Methods

This clinical case report forms part of a larger ongoing prospective investigation performed under the ethical standards for human research established in the World Medical Association's Declaration of Helsinki. Approval was obtained from the institutional review board (Fondazione IRCCS Cà Granda Ospedale Maggiore Policlinico, Milan, Area 2; ID #0002693-U). The participant was a 63-year-old man in good systemic condition (ASA I) who presented with total maxillary tooth loss and was wearing a complete removable prosthesis **(Figure 1)**. Following a discussion of treatment options, the patient consented to a plan involving six one-piece implants supporting a fixed prosthetic restoration. A complete digital workflow was used to enable preoperative planning and to perform fully guided implant insertion together with immediate provisionalization during a single surgery. The protocol combined cone-beam computed tomography (CBCT), intraoral scans, photographic documentation, and digitized casts through specialized software, ensuring accurate pre-surgical simulation, template design, and fabrication of a titanium-reinforced provisional PMMA (polymethylmethacrylate) prosthesis.

Figure 1. Extraoral view with the maxillary denture in place.

Surgical planning

The patient's vertical dimension was satisfactory and used as a reference for the definitive design. Digital three-dimensional scans were obtained from the upper and lower arches and from the inner and outer surfaces of the removable prosthesis with an intraoral scanner (CS 3600; Carestream Dental, Atlanta, GA, USA). Intraoral and facial photographs were collected to create a personalized digital diagnostic wax-up using CAD software (Exocad 3.0 DentalCAD; exocad GmbH, Darmstadt, Germany) **(Figures 1 and 2)**.

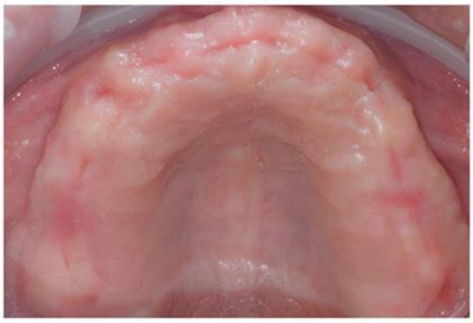
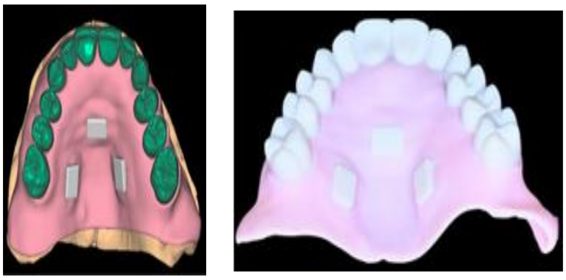


Figure 2. Intraoral appearance.

During virtual design, modifications were made to improve esthetics. A 3D-printed prototype derived from the digital wax-up was produced for intraoral evaluation and also adapted for radiographic use by adding radiopaque reference markers **(Figure 3)**. This prototype was printed from a transparent resin material (Clear MED610™; Stratasys, Edina, MN, USA) using a J5 DentaJet 3D printer (Stratasys, Edina, MN, USA).



a) b)

Figure 3. Digital plan of the radiographic guide. (a) Virtual model. (b) Radiographic guide with radiopaque markers.

A CBCT examination (Carestream CS 9300; Rochester, NY, USA) was performed to assess bone morphology. The standard triangulation language (STL) data from the intraoral scan were merged with the digital imaging and communication in medicine (DICOM) files from the CBCT. Alignment of both datasets was achieved using a surface-matching algorithm (RealGuide; 3DIEMME, Figino Serenza, Italy). The geometric radiopaque markers embedded in the guide were recognized by the software, allowing accurate fusion of digital and radiologic data.

Virtual implant positioning was carried out in dedicated planning software (RealGuide 5.2; 3DIEMME, Como, Italy) to ensure prosthetically oriented placement, based on the digital wax-up **(Figure 4)**. Six pre-angulated, one-piece implants (FIXO; Oxy Implant Dental System, Biomec, Colico, Italy) were selected for the maxilla as follows **(Figure 5)**:

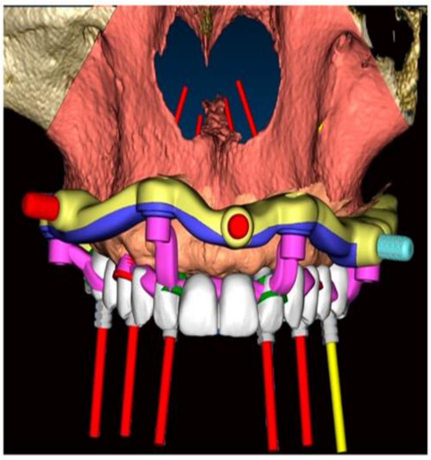


Figure 4. Virtual simulation of implant sites: digital wax-up, main guide (yellow and blue) with anchor sleeves (red), and positioning guide (violet).

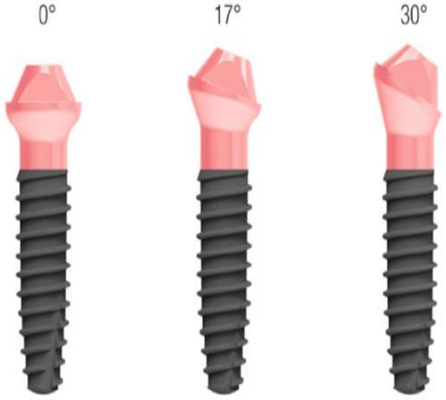


Figure 5. One-piece implant system with integrated MUA available in three angulations: 0°, 17°, and 30°.

- 16: Oxy Implant FIXO Short 30° 4 × 10 mm
- 14: Oxy Implant FIXO Short 17° 4 × 10 mm
- 12: Oxy Implant FIXO Mini 17° 3.5 × 11.5 mm
- 22: Oxy Implant FIXO Mini 17° 3.5 × 13 mm
- 24: Oxy Implant FIXO Short 17° 4 × 11.5 mm
- 26: Oxy Implant FIXO Short 17° 4 × 8.5 mm

A multilayer, stackable guide was produced according to the digital design **(Figure 6)** and included the following parts:

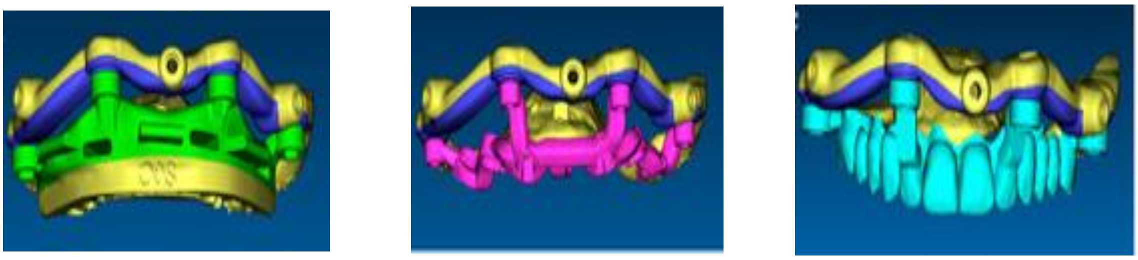


Figure 6. Structure of the stackable guide. (a) Base unit (yellow/blue) with positioning guide (green/yellow). (b) Base and placement guide (violet). (c) Base combined with provisional restoration.

- Base unit (fixed guide): manufactured from clear MED610™ resin (Stratasys, Edina, MN, USA) and reinforced with milled grade 5 titanium (SINERGIA DISK Ti; Nobil Metal, Bergamo, Italy).
- Detachable elements, attached to the base by screws:
    - Positioning guide: Clear MED610™ printed resin (Stratasys, Edina, MN, USA).
    - Implant placement guide **(Figure 7)**: Grade 5 titanium (SINERGIA DISK Ti; Nobil Metal, Bergamo, Italy).
    - Provisional restoration: PMMA disc (Multilayer PMMA Disc; Dentsply Sirona, Verona, Italy) with an internal titanium frame (SINERGIA DISK Ti; Nobil Metal, Bergamo, Italy).

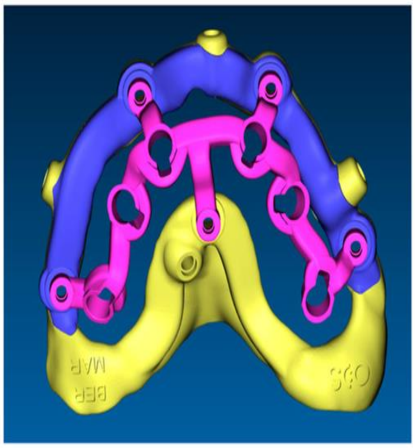
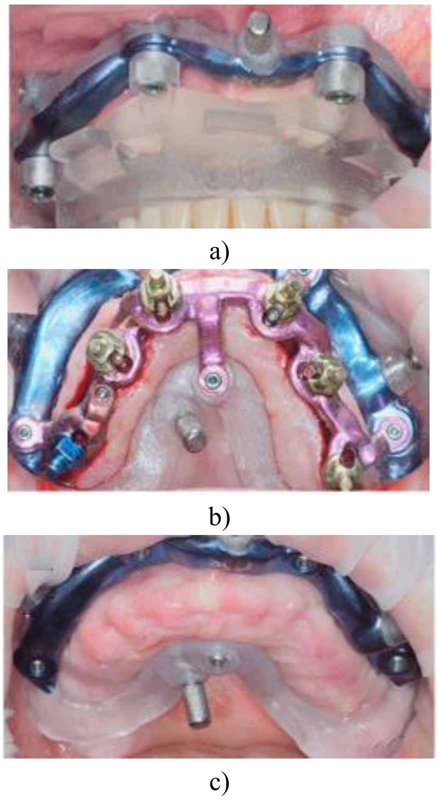


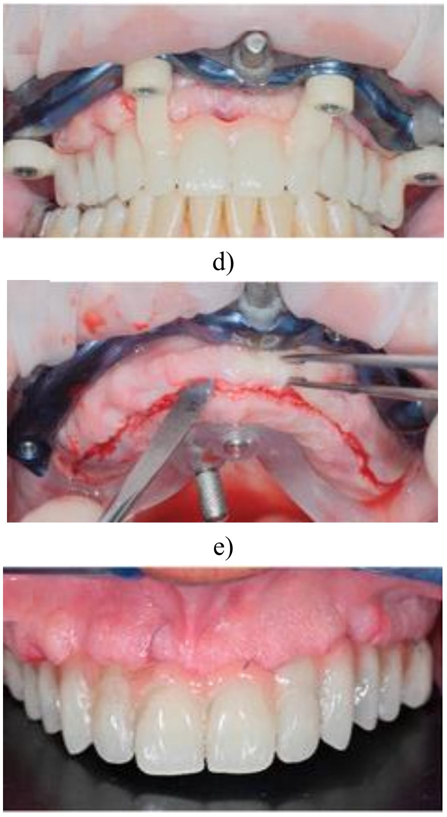
Figure 7. Occlusal illustration showing base guide (yellow/blue) and implant template (violet). The notches in the sleeves define the guided implant trajectory.

Titanium and PMMA parts were milled using a high-precision milling device (XD182; Faimond, Vicenza, Italy). The resin components for the base and positioning templates were produced with a J5 DentaJet 3D printer (Stratasys, Edina, MN, USA).

Surgery

The fixed base guide was secured intraorally by attaching it with screws to the mucosa-supported positioning guide. Proper adaptation of this guide was confirmed by having the patient occlude against specific reference areas on the opposing arch **(Figure 4)**. Once the positioning guide was seated correctly, its placement was verified through the inspection openings. The base guide was then stabilized with anchoring pins inserted into the bone on both buccal and palatal aspects. After fixation, the mucosa-supported component was detached, while the base guide remained attached to the bone throughout the surgical procedure. To preserve the width of the keratinized tissue, a full-thickness mucoperiosteal flap was reflected **(Figure 8)**.





d)

e)

f)

Figure 8. Sequence of edentulous maxillary surgery. (a) Base and positioning guides joined together. (b) Base guide positioned in situ. (c) Reflection of the mucoperiosteal flap. (d) Implant placement following virtual plan. (e) Temporary prosthesis fixed to base guide. (f) Immediate-loading interim prosthesis.

The titanium-grade 5 implant placement guide was then fastened to the base guide, and the fully guided insertion of one-piece implants (FIXO; Oxy Implant Dental System, Biomec, Colico, Italy) was carried out. Angulated implants of 17° and 30° were utilized in the posterior regions to avoid the need for bone grafting. Implant placement was achieved using a dedicated mounter capable of compensating for implant angulation. Proper alignment of each fixture was ensured by matching the mounter's reference notch with the corresponding notch in the guide sleeve, as indicated in **Figure 7**. When both notches aligned, correct apico-coronal depth and rotational orientation were verified. After placement, both the mounters and implant guide were unscrewed from the base guide. Each implant achieved an insertion torque of ≥35 Ncm. The soft tissue flaps were then sutured with 6/0 polyglycolic acid material.

Prosthetic restoration

Provisional abutments, trimmed in height according to the virtual diagnostic waxing, were attached to the placed fixtures. The interim prosthesis—fabricated from PMMA with a metal reinforcement—was affixed to the base guide. This temporary restoration was intraorally relined and connected to the provisional abutments using a self-curing composite resin (RelyX Ultimate; 3M Italia, Milano, Italy) **(Figure 8)**.

Following external finishing and polishing, screw access openings on the provisional abutments were sealed using a light-cured nano-hybrid composite (Tetric EvoFlow; Ivoclar Vivadent, Bolzano, Italy). Final occlusal refinements were completed to ensure even load distribution during mastication. A postoperative panoramic radiograph was taken to confirm implant positioning **(Figure 9)**.

Figure 9. Postoperative panoramic radiograph.

Results and Discussion

Throughout surgery, no adverse events such as excessive bleeding, tissue tearing, guide fracture, or implant deviation leading to fenestration or dehiscence were observed. All implants reached a minimum insertion torque of 35 Ncm, permitting secure immediate loading. The patient was monitored monthly during the first three months following prosthesis delivery. No biological or mechanical complications were recorded during this period. There were no symptoms or signs of peri-implant inflammation, such as erythema, swelling, pain, bleeding on probing, pus formation, or fistulation. Conversely, peri-implant mucosa appeared healthy and well-keratinized around the abutments. Radiographic evaluations taken immediately post-surgery and at three months showed stable marginal bone levels without evidence of crestal remodeling or resorption.

This technical report introduces a novel computer-guided implant approach employing a sequence of stackable templates used in conjunction with one-piece implants to streamline and enhance surgical predictability. Traditionally, surgical guides have been designed based on the tissue type providing support—

teeth, mucosa, or bone. Among these, tooth- and mucosa-supported stents are recognized as more precise compared with bone-supported ones, since imaging errors, segmentation inaccuracies, or irregular bony contours can compromise bone-supported guide accuracy [5, 19, 20].

Conventional guided protocols generally begin with a tooth- or mucosa-supported template used to drill pilot holes for fixation pins. The initial guide is then removed, remaining teeth extracted if needed, and a second implant guide is secured using the same pin sites [11]. However, repeated removal and reinsertion can slightly alter pin trajectory due to bone elasticity, potentially causing guide displacement and resulting in angular or linear deviations [21, 22].

The technique proposed here minimizes such inaccuracies by using a single base guide fixed at the beginning of surgery and maintained throughout. As a result, stabilizing pins are inserted only once, ensuring consistent reference positioning for subsequent guides, consistent with the method described by Granata *et al.* [23]. Moreover, this system replaces traditional pressure-fit pins with threaded anchoring screws that provide improved stabilization [21, 24]. These pins incorporate a 1.5 mm terminal thread, allowing the base guide to conform accurately to the underlying soft tissue. Another benefit of this fixed-base concept is the ability to interchange guides quickly during surgery, reducing operative time while improving workflow precision.

As previously discussed, achieving stability is essential in guided implantology.

Earlier modular techniques connected successive components to the base guide via magnetic or ball attachments [23, 24], which occasionally compromised stability during surgery. In contrast, the present technical approach utilized screw-retained connections between the templates, significantly enhancing both fixation and steadiness of the overall assembly.

A further distinction from earlier stackable template systems is the clinical condition of the subject. Unlike prior reports that primarily addressed post-extraction cases [23–25], this study involved a patient who was fully edentulous.

The choice of materials used in constructing the templates also deserves emphasis. Conventional stereolithographic guides, typically made of resin, are susceptible to warping or breaking during osteotomy preparation [21, 26]. Previous designs employed cobalt-chrome [24, 25] or polymethyl methacrylate (PMMA) throughout [23]. In the current protocol, both the base template and the implant positioning stent incorporated a milled titanium framework **(Figure 6)**, which provided greater stiffness and minimized the potential for deformation or fracture throughout the drilling process [21].

A major drawback of closed surgical stents is the limited irrigation during osteotomy preparation. The inability to cool the drills adequately with saline may elevate bone temperature and negatively affect osseointegration [27], promoting fibrous tissue formation and resulting in fibrointegration rather than osseointegration [28]. The open configuration of the stackable guides used here enabled direct saline cooling during site preparation, addressing this limitation effectively.

The amount and firmness of both hard and soft tissues are vital for long-term rehabilitation success [29, 30]. In standard guided implant procedures, large stents typically obscure the surgical field and hinder the manipulation of peri-implant tissues. In the present workflow, the open and slender base design improved visual access to the site and facilitated intraoperative management of soft tissue. This is particularly advantageous when the mucosa is thin [31], since splitting the keratinized tissue is often required to ensure stable long-term results. Regarding hard tissue, a resective guide could be fixed to the same base template, permitting digitally planned osteoplasty based on the predesigned waxing. Moreover, one-piece implants eliminate the need for bone profiling, which is commonly required with two-piece systems to create prosthetic space. This omission conserves bone tissue and benefits from a thinner implant neck that lacks both an internal connection and a prosthetic screw [18]. Additionally, the absence of an implant–abutment junction reduces bacterial leakage observed in two-piece systems, thereby minimizing biological complications during follow-up [32]. The design also lessens screw-related issues; the implant used here had a 1.8 mm screw diameter, which improved resistance to fracture.

In this workflow, all one-piece implants achieved a minimum insertion torque of 35 Ncm. To avoid bone grafting, posterior implants were inserted at 17° or 30° tilts. During digital planning, the guide included alignment notches to ensure that the abutment axis matched the access channel of the interim restoration. From a prosthetic standpoint, the modular stackable components allowed for precise positioning of the temporary restoration during relining. The interim prosthesis was directly fastened to the base template, faithfully reproducing the digital framework position. This approach enabled immediate prosthesis delivery without the need for impression-taking [33]. Furthermore, the enhanced precision between the provisional restoration and the titanium framework minimized the gap between them. No interference occurred between the prosthesis and temporary abutments, confirming a high degree of accuracy between the planned and actual implant locations.

However, this workflow demands sufficient operator expertise in both digital planning and surgical execution, as mastering the technique involves a learning curve. The deviation between planned and actual implant positions when using modular systems remains a challenge affecting accuracy. Full integration of clinical, surgical, and prosthetic data in a digital environment could minimize data loss associated with traditional manual workflows and enhance procedural accuracy [34]. Finally, extended follow-up studies are required to verify the long-term clinical benefits of stackable systems compared to conventional guided approaches.

Conclusion

The adoption of stackable template systems streamlined the entire process, from implant placement to prosthetic fitting. The base guide provided a stable reference point, enabling quick and safe interchange of subsequent templates, reducing surgical duration, and improving patient comfort. Incorporating a milled titanium structure further reinforced the system's rigidity and stability. The open design facilitated continuous visualization of the surgical field, efficient irrigation, accurate implant seating checks, and real-time management of peri-implant soft tissue.

Screwing the temporary prosthesis onto the base template during relining offered another benefit, ensuring precise positioning. Additionally, the one-piece implants used contributed to bone conservation, eliminated implant–abutment microgaps, and simplified prosthetic procedures. Collectively, these factors yielded sufficient primary stability for immediate loading, ideal soft tissue adaptation around the integrated abutments, and preservation of marginal bone levels at three months post-loading.

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Ethics Statement: None

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