Clinical Feasibility of an Artificial Intelligence-Assisted Digital Workflow for Full-Arch Implant Rehabilitation: A Multicenter Case Series

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Abstract

Fully digital workflows are increasingly used in implant prosthodontics; however, completely edentulous full-arch rehabilitations remain challenging because implant position transfer and passive framework fit are susceptible to cumulative scanning and registration errors. Clinical evidence on artificial intelligence (AI)-assisted complete-arch implant impression workflows remains limited. This multicenter case series aimed to describe the clinical feasibility of an AI-assisted digital workflow (SmartX) combined with extended scan bodies for all-on-X full-arch implant-supported rehabilitations.

Ten completely edentulous patients rehabilitated with all-on-X implant-supported full-arch prostheses were included. Digital impressions were obtained using SmartFlag scan bodies and an AI-assisted SmartX workflow with an intraoral scanner. The primary outcome was clinically acceptable passive fit, assessed qualitatively by visual/tactile inspection, the one-screw (Sheffield) test, and a screw-resistance test, all recorded as dichotomous outcomes (acceptable/not acceptable). Secondary outcomes were implant and prosthesis survival and biological or technical complications during a minimum 6-month follow-up.

A total of 54 implants were placed (mean: 5.4 implants per patient). All 10 cases demonstrated clinically acceptable passive fit according to the three qualitative clinical assessments. Because of the small sample size, the observed 100% positive outcome should be interpreted cautiously; the exact 95% confidence interval for 10/10 positive cases is wide. Progressive screw tightening showed an approximately 60-degree angular displacement from 5 to 20 Ncm in all cases; this observation was used only

Keywords

- artificial intelligence
- complete arch
- implants
- intraoral scanning
- digital impression
- passive fit
- case series

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as an indirect clinical indicator of seating behavior and not as a quantitative measurement of misfit. No implant or prosthesis failures and no biological or technical complications were observed during the short follow-up period.
Within the limitations of a small uncontrolled case series with qualitative outcomes and short follow-up, the investigated AI-assisted workflow appeared clinically feasible for full-arch implant-supported rehabilitation. These findings should be considered preliminary and require confirmation through controlled clinical studies with quantitative trueness/misfit measurements and longer follow-up.

Introduction

Fully digital workflows have progressively transformed implant prosthodontics by supporting data acquisition, prosthetic design, and CAD/CAM (computer-aided design/computer-aided manufacturing) manufacturing.[1] Nevertheless, completely edentulous full-arch implant rehabilitation remains one of the most demanding indications for intraoral scanning because the absence of stable anatomical landmarks, the length of the scanned span, and inter-implant distance may increase the risk of cumulative stitching and registration errors.

In implant-supported full-arch prosthodontics, clinically acceptable passive fit is essential to reduce the risk of mechanical complications, such as screw loosening or framework fracture, and biological complications related to unfavorable stress distribution around implants. Although conventional impressions, desktop scanning, and photogrammetry remain widely used reference approaches, intraoral scanner-based workflows are increasingly adopted because they may simplify chairside procedures and improve patient comfort when appropriately standardized.[2,3]

The accuracy of complete-arch digital implant impressions is influenced by scanner technology, scan-body geometry, scanning strategy, implant number and distribution, operator experience, and software-based alignment procedures. Recent literature has emphasized that scan-body design and artificial intelligence (AI)-assisted recognition may improve the robustness of digital acquisition;[4] however, much of the available evidence remains in vitro, while prospective clinical observations in completely edentulous patients are still limited.

AI is increasingly applied in dentistry for diagnostic support, image analysis, implant planning, prosthodontic workflows, and automated recognition tasks.[5–9] Recent reviews have shown expanding applications of AI in implant dentistry, but they also stress that the field remains under development and requires stronger external and preliminary clinical evaluation. In complete-arch implant impression workflows, AI-assisted scan-body recognition and real-time alignment may theoretically reduce acquisition errors, but clinical data should be interpreted cautiously, particularly when no quantitative trueness or precision measurements are available.

Therefore, the primary aim of this multicenter case series was to describe the clinical feasibility of an AI-assisted digital workflow combined with extended scan bodies for full-arch implant-supported rehabilitation in completely edentulous patients. The primary outcome was clinically acceptable passive fit based on qualitative clinical assessments. Secondary outcomes included short-term implant and prosthesis survival and the occurrence of biological or technical complications. This study was not designed to provide a definitive validation of digital impression accuracy or to compare the investigated workflow with conventional or photogrammetric methods.

Materials and Methods

Study Design and Ethical Considerations

This study was designed as a multicenter descriptive case series. All procedures were performed using European Conformity-marked materials and devices within their intended use and standard clinical practice. This design was intended to report preliminary clinical observations and feasibility data and was not intended to provide quantitative validation of digital impression accuracy.

Treatments were performed at two private dental clinics located in Rome, Italy, and Cairo, Egypt. Data analysis was conducted at the Department of Medicine, Surgery, and Pharmacy, University of Sassari, Italy. The research protocol was evaluated and approved by the British University in Egypt (Research Approval Number: 25–064). All treatments were performed as part of standard clinical care using certified devices within their intended use. Written informed consent was obtained from all patients for treatment and for the anonymized use of clinical and radiographic data for research and publication purposes. All participants signed written informed consent for treatment, data collection, and anonymized scientific use of clinical and radiographic records.

Study Population

Completely edentulous patients aged 18 years or older requiring implant-supported full-arch rehabilitation in either the maxilla or mandible were considered eligible for inclusion. All patients were rehabilitated using an all-on-X protocol supported by four to eight implants with an internal conical connection, converted using multi-unit abutments (TSIII, Osstem Implant, Seoul, South Korea). Only patients with clinically osseointegrated implants demonstrating a

minimum Implant Stability Quotient value of ≥67, measured using a Penguin resonance frequency analysis device (Osstem Implant), were included.

Patients were excluded if they presented with uncontrolled systemic diseases (American Society of Anesthesiologists [ASA] ≥ III); untreated or uncontrolled periodontal disease; active oral infections or peri-implant pathology; history of head and neck radiotherapy; use of medications affecting bone metabolism (e.g., bisphosphonates); severe parafunctional habits (e.g., bruxism); poor oral hygiene; or inability to comply with follow-up visits.

Sample size rationale: because this investigation was conceived as a preliminary descriptive case series evaluating clinical feasibility rather than hypothesis testing, no formal a priori sample-size calculation was performed. Ten consecutive eligible patients were included. This limitation has been explicitly acknowledged in the Discussion section.

Operator training and workflow standardization: before patient enrollment, operators at both centers reviewed the same written scanning protocol, prosthetic sequence, scan-body positioning instructions, and passive-fit assessment criteria. The same intraoral scanner model, scan-body system, implant system, multi-unit abutments, digital workflow, and prosthetic verification procedures were used to reduce procedural heterogeneity. Outcome assessments were performed by an examiner at each center who was not directly involved in the prosthetic treatment.

Prosthetic Protocol

The prosthetic workflow consisted of the following steps.

Digital impressions were acquired using SmartFlag scan bodies (Apollo, Pabianice, Poland) specifically designed for Osstem multi-unit abutments. To ensure accurate three-dimensional capture of implant positions, each SmartFlag scan body was rigidly connected to the multi-unit abutments prior to intraoral scanning. The distinctive geometry of the SmartFlag, characterized by well-defined planar and angular reference surfaces, facilitated consistent detection by the intraoral scanner software. During scanning, operators performed a systematic capture of the edentulous arch, ensuring complete visualization of each scan body from multiple orientations.

During data acquisition, the SmartX workflow provided software-guided recognition of scan-body geometry and matching with the corresponding digital libraries. The software-assisted procedure was used to check scan completeness and support alignment of the scan-body data. The workflow was described in neutral technical terms because the present clinical series was not designed to isolate or quantify the independent contribution of the AI component.

All scans were performed using the Medit i900 intraoral scanner (Medit, Seoul, South Korea) following the dedicated SmartX workflow (Medit, South Korea), which includes a predefined scanning sequence optimized for all-on-X rehabilitations and incorporates AI-based real-time scan body recognition and alignment (►**Fig. 1**).[10] No manual repositioning of implant coordinates was performed after AI-assisted scan-body recognition. Manual intervention was limited to visual verification of scan completeness and routine prosthetic design procedures.

Following definitive impression acquisition, a milled metal verification bar was fabricated and clinically/radiographically evaluated (►**Fig. 2**).

Passive fit of the metal verification bar was assessed using the one-screw test (Sheffield test) combined with tactile verification using a dental explorer. The Sheffield test consisted of tightening a single prosthetic screw to 5 Ncm at one terminal implant or at the most anterior implant, while

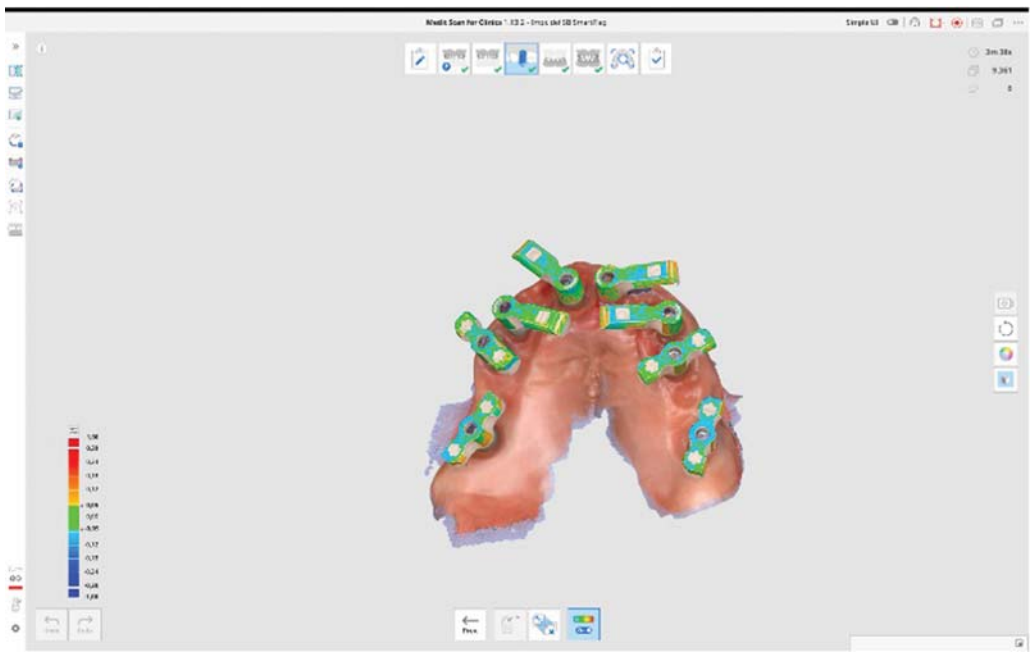

Fig. 1 Digital scanning performed with the Medit i900 intraoral scanner and SmartX workflow (Medit, Seoul, South Korea).

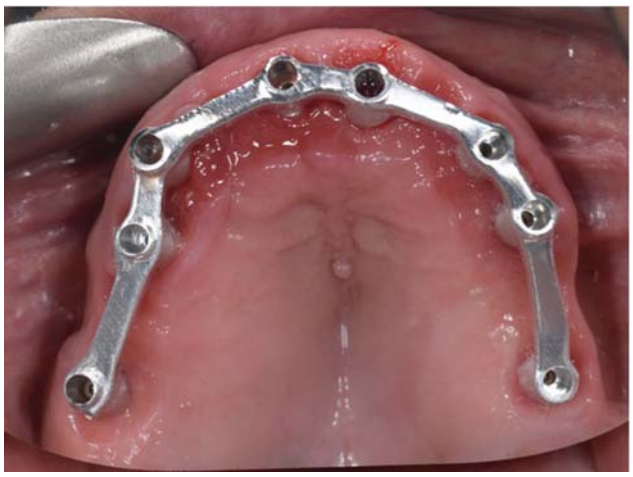

Fig. 2 Fabrication and clinical evaluation of a CAD/CAM-milled metal verification bar following definitive impression acquisition. CAD, computer-aided design; CAM, computer-aided manufacturing.

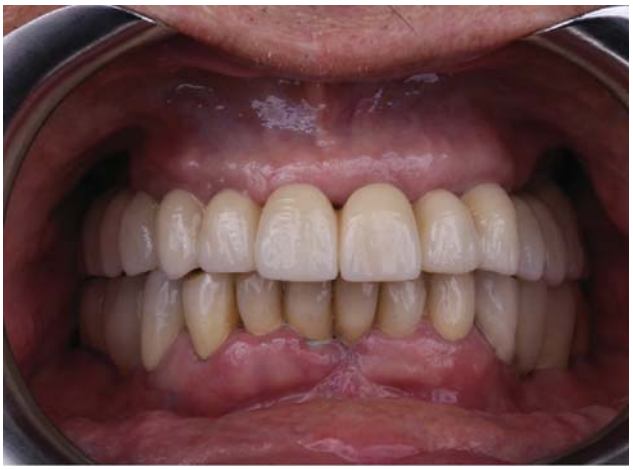

Fig. 4 Definitive prosthesis delivery.

leaving all other screws unfastened (►**Fig. 3**). Standardized periapical radiographs were obtained using a Rinn holder.

Passive fit was assumed when the framework seated completely without visible gaps, rocking, or distortion at the remaining implant interfaces. Conversely, lifting or marginal discrepancies detected clinically or radiographically were interpreted as evidence of misfit.[11,12]

Subsequently, the definitive monolithic zirconia prosthesis bonded to a CAD/CAM titanium bar was delivered following additional visual and tactile verification of passive fit (►**Fig. 4**) according to the screw resistance test. All prosthetic screws were initially tightened to 5 Ncm and then progressively tightened from 5 to 20 Ncm using a calibrated universal torque wrench (Torq Control, Anthogyr). Patients were recalled every 3 months up to a 6-month follow-up period to evaluate the presence of biological or technical complications (►**Fig. 5**).

Primary and Secondary Outcomes

The primary outcome was clinically acceptable passive fit of the verification framework/prosthesis after the AI-assisted digital impression workflow. The term accuracy was avoided as an outcome label because no quantitative trueness, precision, or three-dimensional misfit measurements were performed.

- Visual and tactile inspection—recorded as a dichotomous outcome (acceptable passive fit: yes/no).[13] Visual and tactile assessment of framework fit was performed by alternating finger pressure on the prosthesis while directly inspecting the implant–framework interface and probing it with a dental explorer to detect any visible gaps or lack of complete seating, as commonly described for the clinical evaluation of passive fit in implant-supported full-arch restorations. An independent examiner in each

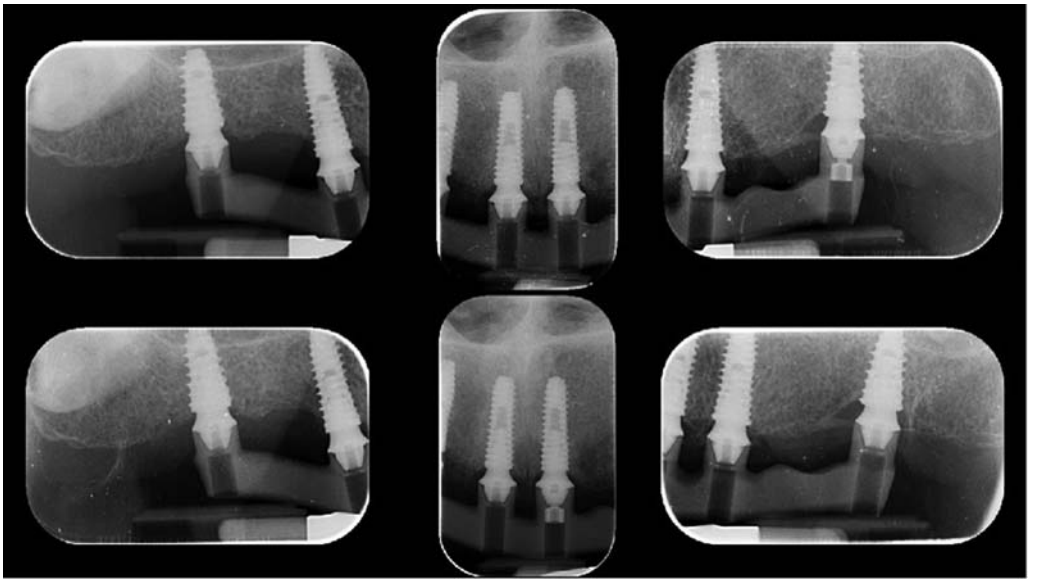

Fig. 3 Periapical radiographs according to the Sheffield test (one-screw test).

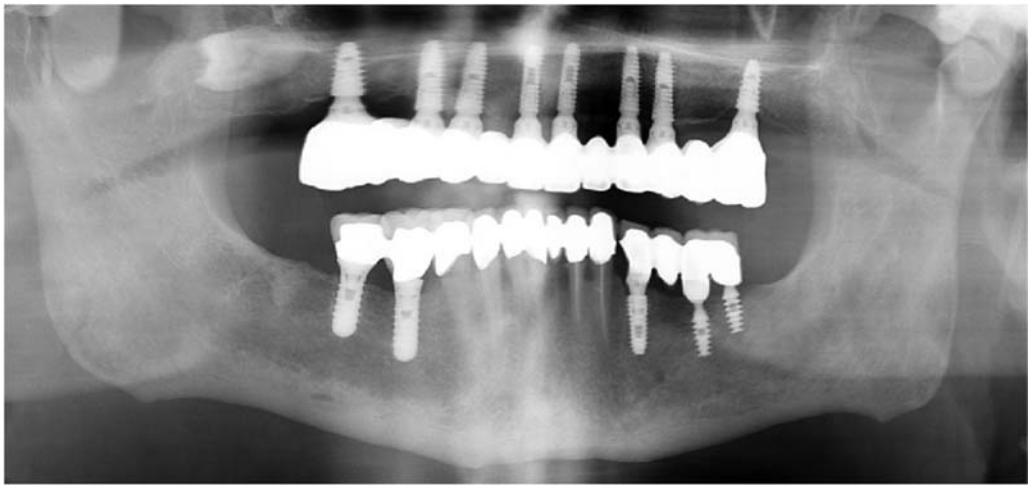

Fig. 5 Six-month orthopantomogram (OPT).

center, not previously involved in the clinical treatments, performed the outcome assessments.

- One-screw (Sheffield) test—recorded as a dichotomous outcome (acceptable passive fit: yes/no).[14] The one-screw (Sheffield) test was performed by sequentially tightening a single prosthetic screw, first at the most distal implant and subsequently at the most anterior implant, while all other screws remained loose; in each condition, periapical radiographs were obtained to assess framework seating and detect any implant–prosthesis misfit. An independent examiner in each center, not previously involved in the clinical treatments, performed the outcome assessments.
- The screw resistance test was recorded as a dichotomous outcome (acceptable passive fit: yes/no) using the manual driver (Torq Control, Anthogyr). All prosthetic screws were initially tightened to 5 Ncm and subsequently progressively tightened up to 20 Ncm, in accordance with the manufacturer's recommendations (Osstem Implant). During progressive tightening, the angular displacement required to reach the final torque value was visually and clinically assessed. The angular displacement (arc length) between the torque values of 5 Ncm (point A) and 20 Ncm (point B) was evaluated and compared as an indirect indicator of framework seating and resistance.[13,15] Based on this assessment, passive fit was classified as acceptable or nonacceptable. An independent examiner in each center, not previously involved in the clinical treatments, performed the outcome assessments.

The secondary outcomes included implant and prosthesis survival rates, as well as the incidence of biological complications (e.g., peri-implant mucositis, peri-implantitis) and technical complications (e.g., screw loosening, framework fracture).

Statistical Analysis

Descriptive statistics were used to summarize demographic, clinical, and outcome variables. Categorical variables were expressed as frequencies and percentages, while continuous variables were reported as mean and standard deviation when appropriate. For dichotomous passive-fit outcomes, exact binomial 95% confidence intervals (CIs) were calculated using the Clopper–Pearson method. No inferential comparison was performed because the study had no control group and was not powered for hypothesis testing.

Results

Study Population and Baseline Characteristics

A total of 10 consecutive completely edentulous patients were enrolled, treated, and followed for a minimum period of 6 months. No patients were excluded after enrollment, and no dropouts occurred during the follow-up period. The study population consisted of 7 males and 3 females, with a mean age of 62 years. A total of 54 implants (TSIII Osstem Implant) were placed, with each patient receiving between 4 and 8 implants (mean: 5.4 implants per patient). All the implants were rehabilitated with multi-abutments (Osstem Implant). Seven patients were rehabilitated in the maxilla and three in the mandible. Implant placement was performed using guided surgery (OneGuide, Osstem Implant) in five patients and free-hand surgery in the remaining five patients. Immediate loading was applied in four cases. Two patients were light smokers (<10 cigarettes/day). Data are summarized in ►**Table 1**.

Primary Outcome: Clinically Acceptable Passive Fit

The primary outcome was clinically acceptable passive fit following the AI-assisted digital impression workflow. All assessments were qualitative clinical evaluations and were recorded dichotomously.

- Visual and tactile inspection demonstrated clinically acceptable passive fit in all 10 cases (10/10; observed proportion 100%; exact 95% CI: ~69 to 100%).
- The one-screw (Sheffield) test showed complete clinical/radiographic seating of the verification framework in all patients, with no detectable gaps, rocking, or

Table 1 Baseline characteristics of the study population and implant-related variables

Variable	Result
Number of patients	10
Sex (male/female)	7 / 3
Mean age (years ± SD)	62.0 ± 9.7
Smoking status	2 light smokers (<10 cigarettes/day)
Treated arch maxilla	7 patients
Treated arch mandible	3 patients
Surgical approach	Guided: 5; free-hand: 5
Immediate loading	4
Total number of implants	54
Implants per patient	4–8 (mean ± SD: 5.4 ± 1.3)
Follow-up duration	≥ 6 months

Abbreviation: SD, standard deviation.

distortion (10/10; observed proportion 100%; exact 95% CI: ~69 to 100%).

- The screw-resistance test was clinically acceptable in all 10 cases (10/10; observed proportion 100%; exact 95% CI: ~69 to 100%). Progressive tightening from 5 to 20 Ncm showed an approximately 60-degree angular displacement in all cases. This observation was interpreted only as a qualitative indicator of consistent seating behavior, not as a calibrated quantitative measurement of framework misfit.

Secondary Outcomes: Implant and Prosthesis Survival

At the 6-month follow-up, no implant failures or prosthesis failures were recorded. No biological complications, including peri-implant mucositis or peri-implantitis, and no technical complications, such as screw loosening or framework fracture, were observed. Because of the short follow-up period, these findings should be interpreted as short-term descriptive outcomes and not as evidence of long-term implant or prosthetic survival. These primary and secondary outcomes are summarized in ►**Table 2**.

Discussion

The present multicenter case series described preliminary clinical observations on an AI-assisted digital workflow combined with extended scan bodies for full-arch implant-supported rehabilitation in completely edentulous patients. The main finding was that all included cases achieved clinically acceptable passive fit according to visual/tactile inspection, the one-screw (Sheffield) test, and the screw-resistance test. These findings should be interpreted as feasibility data rather than as definitive validation of digital impression accuracy.

The SmartFlag scan bodies used in this study feature high-contrast geometry and stable reference surfaces, which facilitate automated recognition and registration within the digital workflow. This design reduces the risk of partial data loss or scan body misalignment, a well-known limitation of intraoral scanning in full-arch cases where anatomical landmarks are scarce or absent.[16–18] The reliable identification of implant position and orientation is particularly critical in completely edentulous arches, where cumulative stitching errors may compromise the accuracy of the digital impression.[17,18]

The consistent achievement of passive fit observed in this study supports the hypothesis that extended scan bodies, when combined with AI-assisted real-time alignment, may improve the robustness of digital full-arch workflows. These findings align with previous systematic reviews reporting that scan body geometry, scanning strategy, and inter-implant distance significantly influence impression accuracy, especially in edentulous scenarios.[17,19]

Passive fit remains a cornerstone concept in implant prosthodontics, as misfit between the prosthetic framework and osseointegrated implants may induce internal stresses within the prosthesis, the implant components, and the surrounding bone.[12,20] Although a universally accepted definition of passive fit is lacking, Jemt proposed that an "acceptable" passive fit corresponds to a misfit below approximately 150 µm, a threshold considered biologically

Table 2 Summary of primary and secondary outcomes

Outcome	Assessment method	Result
Passive fit	Visual and tactile inspection	10/10 cases (100%)—yes
Passive fit	One-screw (Sheffield) test	10/10 cases (100%)—yes
Passive fit	Screw resistance test	10/10 cases (100%)—yes
Screw resistance	Angular displacement (5–20 Ncm)	~60° (≈1/6 turn) in all cases
Implant survival	Clinical and radiographic evaluation	100% (0 failures)
Prosthesis survival	Clinical evaluation	100% (0 failures)
Biological complications	Clinical follow-up	None observed
Technical complications	Clinical follow-up	None observed

tolerable and unlikely to induce long-term complications.[12] Nevertheless, truly ideal passive fit is rarely achievable in clinical practice, and some degree of biologic tolerance to misfit appears to exist.[13]

Several authors have emphasized that even clinically undetectable misfits may generate stresses that contribute to technical complications such as screw loosening or framework fracture, as well as biological complications affecting peri-implant tissues.[20,21] Therefore, the consistent achievement of positive outcomes across all passive fit assessment methods in the present study is clinically relevant, particularly in the context of full-arch rehabilitations, which are more susceptible to cumulative inaccuracies.

The one-screw (Sheffield) test remains one of the most widely used qualitative clinical methods for evaluating the accuracy of implant position transfer and the passive fit of implant-supported frameworks prior to definitive prosthesis delivery.[11] In the present study, the Sheffield test confirmed complete framework seating in all cases, supporting the reliability of the digital impression workflow. In addition, the screw resistance test provided further qualitative assessment of framework accuracy. The consistent angular displacement of approximately 60 degrees observed during progressive torque application from 5 to 20 Ncm suggests uniform seating behavior without localized resistance discrepancies. The pitch of the screws used (defined as the distance between adjacent threads measured parallel to the screw axis) was 0.3 mm. Consequently, a 60-degree rotation —corresponding to one-sixth of a full turn—results in a vertical displacement of approximately 50 microns (μm) of the prosthesis during tightening from 5 to 20 Ncm.

In the present study, a uniform vertical displacement was observed across all tested screws, indicating consistent framework seating. Achieving a passive fit is considered a fundamental prerequisite in implant-supported prosthetic rehabilitations, as it minimizes the induction of preload and residual stresses within the implant–prosthesis complex. Inadequate passive fit may generate tension at the implant–abutment and framework interfaces, leading to unfavorable stress concentration. Over time, these biomechanical imbalances may contribute to mechanical complications, such as screw loosening, screw or framework fracture, and, in severe cases, implant failure.[12,13]

This finding is consistent with recent investigations proposing the screw resistance test as a clinically useful method to detect misfit-related discrepancies in implant-supported prostheses.[13]

The innovative aspect of this study lies in its design as the first clinical evaluation of extended scan bodies combined with the SmartX AI-based workflow for all-on-X full-arch digital implant rehabilitations. Previous investigations on AI-assisted digital impression workflows have been limited to in vitro studies or isolated clinical reports.[10] Therefore, the present work represents the first systematic preliminary clinical evaluation of this methodology.

The results of this clinical study corroborate previous in vitro findings demonstrating high accuracy and precision of AI-based alignment systems for full-arch digital impressions.[10] Importantly, the translation of these results into a clinical setting supports the feasibility and reliability of this approach in routine practice.

This study presents some limitations. First, the relatively small sample size and the short follow-up period limit the generalizability of the results and preclude long-term evaluation of biological and technical outcomes. Even though all cases in the present series resulted in successful outcomes, the limited sample size still allows a relatively wide plausible true success rate at the population level. However, this investigation was primarily designed as a case series study to assess the clinical accuracy of digital impressions, rather than long-term prosthetic performance. Second, the absence of a control group does not allow direct comparison with conventional impression techniques. Finally, the primary outcomes were assessed exclusively using qualitative, dichotomous clinical tests (visual/tactile inspection, Sheffield test, screw resistance test) with no direct quantitative measurements of misfit or trueness.

Conclusion

Within the limitations of this small uncontrolled multicenter case series, the AI-assisted SmartX workflow combined with extended SmartFlag scan bodies appeared clinically feasible for full-arch implant-supported rehabilitation in completely edentulous patients. All evaluated cases achieved clinically acceptable passive fit according to qualitative clinical assessment methods.

These preliminary observations should not be interpreted as definitive validation of digital impression accuracy. Controlled clinical studies with larger sample sizes, standardized operator calibration, quantitative trueness/misfit measurements, and longer follow-up are required to confirm the clinical performance and long-term biological and technical outcomes of this workflow.

Conflict of Interest
None declared.

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