

Evaluation Study

COMPUTER-PLANNED IMPLANT SURGERY: COMPARISON BETWEEN THE USE OF THE SURGICAL GUIDE FOR IMPLANT SITE PREPARATION ONLY OR ALSO FOR IMPLANT INSERTION IN A SINGLE IMPLANT REHABILITATION CASE

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ABSTRACT

The objective of this study was to evaluate differences in implant placement accuracy between the use of a surgical guide throughout the entire procedure and its partial use, limited to implant-site preparation. This distinction may be relevant in patients with anatomical limitations of the oral cavity and because contact between the guide and implant may compromise sterility. A surgical guide was designed for the rehabilitation of a single tooth and used on a 3D-printed mandible containing polystyrene blocks reproducing type IV bone according to the Misch classification. Three implants with different structural characteristics were evaluated. Each implant was inserted into 10 blocks using the guide throughout the entire sequence, from pilot drilling to implant placement, and into 10 blocks using the guide only during the preparation phases. Each procedure was followed by scanning of the mandible, block, and implant, for a total of 60 scans. Digital measurements were performed to compare the accuracy of the two techniques. The use of the surgical guide throughout all phases of implant placement resulted in greater accuracy than its partial use. Although repeated insertions appeared to improve precision, the fully guided technique provided more consistent accuracy and reduced variability between implant placements. The results suggest that the full digital workflow is less dependent on the operator's manual dexterity and the type of implant used, whereas partial guide use requires greater operator skill to achieve comparable accuracy. The full digital workflow may facilitate prosthetic planning and reduce the number of steps required for rehabilitation. However, appropriate patient selection remains essential because anatomical limitations may complicate guide and instrumentation use and may pose challenges to maintaining implant sterility. As this was an *in vitro* study, further clinical investigation is required. Nevertheless, the findings support the prospective advantages of computer-planned, fully guided implant surgery in improving placement accuracy and potentially reducing complications associated with implant positioning.

KEYWORDS: *computer-planned implant surgery, guided implant surgery, surgical guide, dental implant placement accuracy, digital workflow, fully guided surgery, partially guided surgery*

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INTRODUCTION

Computer-Planned Implant Surgery (CAIP) and Computer-Assisted Implant Surgery (CAIS) represent an advanced branch of modern oral implantology based on the synergistic integration of digital planning software, three-dimensional imaging techniques (CBCT), intraoral scans, and 3D printing systems. CAIS enables implant placement based on the patient's anatomy and prosthetic needs, ensuring precision and optimizing the overall time for oral cavity rehabilitation and aesthetics (1).

Currently, the primary indications for CAIS focus on aesthetic and prosthetic optimization of implant restorations, with applications in complex clinical cases (such as total edentulism or areas with high aesthetic value) and in procedures requiring minimal surgical invasiveness. The fundamental clinical advantage is reduced inaccuracy, defined as the geometric deviation between the implant position planned in the software and the one actually obtained in the oral cavity (2).

The international scientific literature shows that CAIS guarantees a statistically significant reduction in spatial deviations (at the apex and neck of the implant) and angular deviations (between the planned and final insertion axis) compared with the traditional free-hand technique. The traditional approach relies exclusively on 2D radiographs and the surgeon's technical skill, exposing the procedure to greater operator-dependent variability. The millimeter accuracy of CAIS not only improves prosthetic alignment and the final aesthetic result, but also enables detailed preoperative evaluation of bone volumes and neurovascular pathways. This three-dimensional visualization significantly reduces the risk of iatrogenic lesions to noble anatomical structures (3, 4). From a clinical perspective, one of the main advantages of computer-assisted surgery is the ability to perform surgeries with a flapless approach (i.e., without elevating a mucoperiosteal flap), resulting in a drastic reduction in postoperative pain, edema, and general discomfort for the patient. Furthermore, reduced chairside operating time, particularly in single-implant rehabilitations, facilitates immediate loading protocols (4, 5).

The main disadvantage of CAIS is the higher initial cost. The estimated cost per single case is 20-31% higher than traditional methods (6). Nonetheless, cost-effectiveness analyses show that this investment is amortized over the long term thanks to reduced late prosthetic complications. Furthermore, the recent introduction of open-access planning software (such as BlueSkyPlan) is steadily reducing operational costs.

Although computer-planned surgery offers high accuracy, it is not free from specific intraoperative complications. Main documented adverse events include fracture or intraoperative instability of the surgical guide, unforeseen deviations due to drill flexion or the resilience of supporting soft tissues, or the need to intraoperatively modify the original treatment plan by shifting to a free-hand technique. These complications show that CAIS requires clinical and surgical skills no less than those needed for the conventional approach: the operator must have the experience to manage the unexpected and complete the surgery if the digital system fails. Despite these observations, observational studies show that implant survival rates in guided surgery are comparable to, if not higher than, those of traditional methods. Clinical parameters such as long-term marginal bone loss, peri-implant tissue health, and biological success rates show no statistically significant differences between the two methods (7).

The current scientific literature has methodological limitations: most research focuses on isolated evaluation of a single surgical procedure (measuring millimeter error) without analyzing the entire therapeutic workflow and the impact of accuracy on the subsequent prosthetic phase. The objective of the study is therefore to compare the fully guided technique (use of the guide for site preparation and implant insertion) and the partially guided technique (use of the guide solely for implant site preparation) to evaluate their differences in accuracy. This is important because not all clinical cases allow guide use, as it could increase the risk of contamination from implant-guide contact.

MATERIALS AND METHODS

The study began with case planning using BlueSkyPlan software. The case, performed *in vitro*, involved rehabilitation via computer-planned implant surgery for a patient in whom a single implant was to be placed to restore tooth 36 in the dental arch. After case planning, the process continued with 3D printing of a resin model reproducing the patient's mandible and the surgical guide. The patient's mandible was printed with a slot at the level of the bone portion that will accommodate polystyrene blocks, in which the implants will be positioned. A dental laboratory created these materials using 3D printers and provided a resin mandible model (Fig. 1) and a resin guide (Fig. 2). Concurrently, 60 polystyrene blocks complementary to the slot were produced in order to obtain *in vitro* conditions that could come as close as possible to those that would be encountered clinically with a type IV bone (Misch classification), which is a low-density bone characterized by a very thin cortical layer and a predominance of trabecular (cancellous) bone.

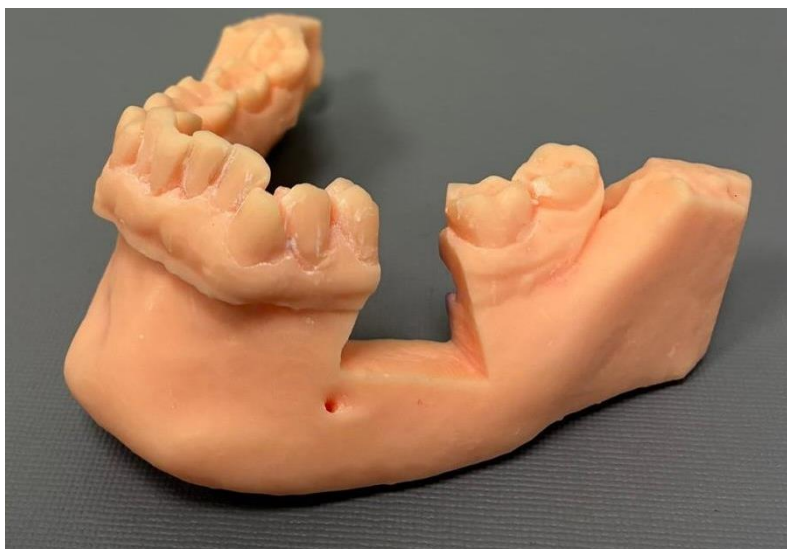


Fig. 1. The resin guide, fabricated with the specific slot, faithfully reproduces the details of the soft tissues and the dental elements present in the arch as detected by the CBCT and the scan.



Fig. 2. The resin surgical guide was fabricated via 3D printing with the sleeve already inserted.

In the present study, three bone-level endosseous implants were used:

- cylindrical FMD UniQo implant with machined collar / $\varnothing$ 3.8×10.0 mm;
- root-form FMD Kreo UniQo implant with polished collar / $\varnothing$ 3.8×10.0 mm.
- Root-form FMD AdaptA implant with machined collar / $\varnothing$ 3.8×10.0 mm

The implants were inserted into the polystyrene blocks. The placement procedure involved 10 insertions for each implant using the guide and 10 without the guide (freehand); in the latter case, the guide was used only to drill the pilot hole and the sequence of drills preceding implant insertion.

To perform implant insertion, three drills of increasing diameter from an FMD surgical kit were used: 2.3, 2.8, and 3.2 mm. The site was under-prepared relative to the implant diameter. This under-preparation of the insertion site was intentionally chosen to faithfully recreate the clinical operative procedure performed on a patient presenting with predominantly trabecular bone.

The torque wrench (ratchet) and screwdriver from the FMD kit were also used to allow controlled implant insertion. For drilling, an HKM micromotor was used, specifically the dental unit DSC electronic 10505000. The micromotor was set to 790 rpm with a torque of 30 Ncm.

The operative sequence consists of several steps: the first step involves inserting a polystyrene block into the dedicated slot (Fig. 3). The blocks were cut to complement the section on the mandible to fit perfectly; their surfaces were kept smooth to avoid interference during scanning.

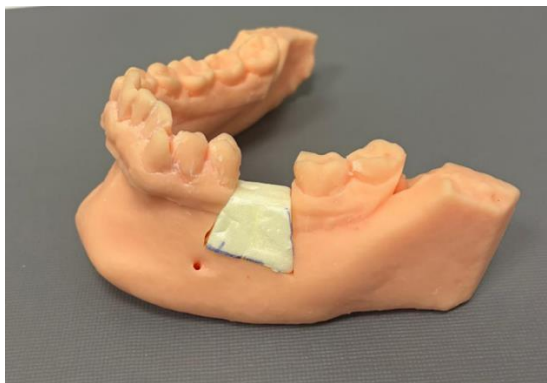


Fig. 3. *The printed model with the polystyrene block inserted inside the slot.*

Once the block is inserted, the surgical guide is positioned. Once the guide is in place, site preparation to accommodate the implant begins. The preparation was carried out through the sequential use of the three aforementioned drills (Fig. 4).



Fig. 4. *Passage of the first green-ring drill ϕ 2.3 mm; subsequently, the purple-ring and the blue-ring drills will be used until completing the preparation of the site into which the implants will then be inserted.*

Once the site is prepared, the process continues with implant insertion. After removing the implant from its packaging, it was inserted into the implant site using the torque wrench. The implant insertion involved two methodologies. The first involved inserting the implant with the guide, while the second involved inserting the implants using a partially guided technique. In the latter case, the guide was therefore used solely to prepare the site to accommodate the implant device. Both methodologies were applied to all three implants, for a total of 10 insertions with the guide (Fig. 5) and 10 without the guide (Fig. 6).



Fig. 5. *Insertion with the guide.*



Fig. 6. *Insertion without the guide.*

Once inserted, each implant was scanned to obtain a digital reproduction of the mandible-block-implant complex, on which measurements were performed to identify the implant position relative to two fixed reference points. The two selected reference points are the premolar and the second molar. The scanner used is the CS3600 by Carestream. Therefore, we performed 60 scans: 20 for each implant type using the two aforementioned methodologies. The scans were then subjected to accurate measurements using specific software: Ceramill 3D View (Fig. 7).

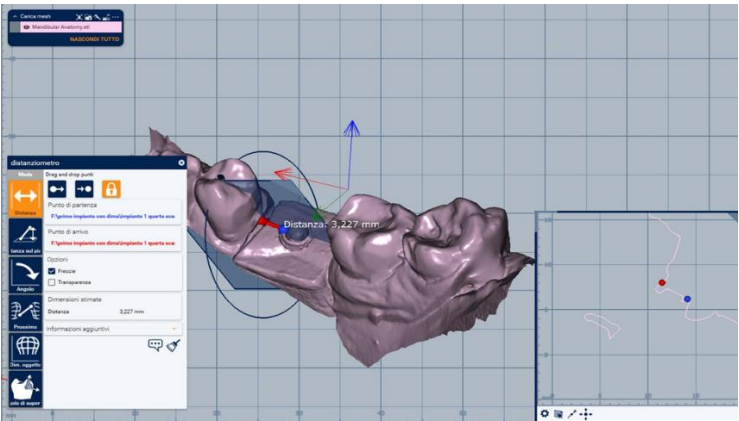


Fig. 7. The software interface during a trial measurement of the distance between the implant and the distal surface of the premolar. In the bottom right, the lateral section of our model is shown, which can be viewed in 3D in the center. On the left is the software's tool menu, where you can view the mode for calculating the distance between two points.

The statistical analysis was performed using the SPSS statistical software program (IBM SPSS Statistics, IBM Corp., Armonk, NY, USA). The measurements obtained from the digital scans were collected and analyzed to evaluate the accuracy of implant positioning in relation to the two fixed anatomical reference points and to compare the results obtained using the two different surgical guide methodologies.

RESULTS

Each measurement taken was recorded in a table, which was subdivided by implant type; all measurements made with the guide (-D) and without (-SD) were reported, and for both, both the mesial measurement (from implant to premolar surface) and the distal measurement (from implant to molar surface) were recorded. Each implant was marked with a specific color to distinguish them (Table I).

Table I. The table shows the columns for UniQo, Kreo Ti, and AdaptA with the corresponding measurements from mesial to distal, with guide (-D) and without guide (-SD).

Type	IMP	MESIAL-D	DISTAL-D	MESIAL-SD	DISTAL-SD
1	1.1	4,161	3,717	4,304	3,429
1	1.2	4,063	3,875	4,467	3,027
1	1.3	4,048	3,766	4,535	3,611
1	1.4	4,107	3,789	4,916	3,083
1	1.5	4,189	3,731	4,648	2,867
1	1.6	3,965	3,968	4,608	3,828
1	1.7	4,183	3,659	4,433	3,675
1	1.8	4,037	3,880	4,582	3,073
1	1.9	4,192	3,726	4,988	3,715
1	1.10	3,838	4,130	4,166	3,734
2	2.1	4,137	3,439	4,037	3,876
2	2.2	4,313	3,660	4,360	4,269
2	2.3	4,351	3,610	3,942	3,806
2	2.4	4,084	3,787	3,098	4,313
2	2.5	4,178	3,735	4,728	3,047
2	2.6	4,557	3,430	4,748	3,178
2	2.7	4,187	3,699	4,102	3,446
2	2.8	4,150	3,913	4,036	4,031
2	2.9	4,196	3,621	3,843	3,774
2	2.10	4,115	3,878	4,694	3,115
3	3.1	4,271	3,915	4,043	3,484
3	3.2	4,284	3,047	3,196	4,760
3	3.3	3,540	4,535	3,925	4,217
3	3.4	3,990	3,751	4,684	3,163
3	3.5	4,421	3,637	4,321	4,549
3	3.6	3,963	4,092	4,220	4,063
3	3.7	4,324	4,175	3,701	3,779
3	3.8	3,967	3,567	4,288	3,867
3	3.9	4,018	3,532	4,688	3,132
3	3.10	4,371	4,009	4,293	3,358

Pink: UniQo; yellow: Kreo Ti; Green: AdaptA.

Descriptive statistics and preliminary analysis

Even at first glance, the measurements appear largely homogeneous. Differences between the two modalities are fractions of a millimeter, suggesting that, based on implant-site preparation alone, the guide provides good baseline accuracy. For a more precise analysis, the data are summarized in Table II.

Table II. *Descriptive statistics table.*

Variable	N	Minimum	Maximum	Mean
MESIAL.D	30	3,54	4,56	4,1400
DISTAL.D	30	3,05	4,54	3,7758
MESIAL.SD	30	3,10	4,99	4,2865
DISTAL.SD	30	2,87	4,76	3,6423

From this analysis, a crucial element emerges: the standard deviation (i.e., the dispersion of the data) shows a wider and higher interval in the insertions performed without the guide (-SD), indicating a lower intrinsic reproducibility of the free-hand technique.

Table III, on the other hand, shows the evaluation of any potential linear relationship between the measurements taken with the guide and those taken without the guide on the same site. In both cases, the two-tailed significance values (p-values) are well above the 0.05 threshold. Clinically, this means that achieving high precision through the fully guided approach does not, in any way, allow for the prediction of a similar behavior or an equally high precision when using the partially guided technique.

Table III. *Statistical correlation analysis table between the study variables.*

Pair	Variables	N	Correlation	p (unil.)
1	MESIAL.D – MESIAL.SD	30	-0,017	0,465
2	DISTAL.D – DISTAL.SD	30	-0,086	0,326

To verify whether the mean discrepancies between the two techniques were due to chance or to systematic method error, a paired t-test was applied (Table IV) to increase the efficacy and sensitivity of the analysis.

Table IV. *Results of the statistical analysis using the t-test.*

Pair	Difference	Mean	Dev. Std.	Error Std.	IC 95% Inf.	IC 95% Sup.	t	gl	p (unil.)	p (bilat.)
1	MESIAL.D – MESIAL.SD	-0,14647	0,49183	0,08980	-0,33012	0,03719	-1,631	29	0,057	0,114
2	DISTAL.D – DISTAL.SD	0,13347	0,57811	0,10555	-0,08240	0,34934	1,265	29	0,108	0,216

Since the p-value is greater than 0.05 in both cases ($p > 0.05$), there is insufficient statistical evidence to reject the null hypothesis, suggesting that the difference between the techniques could be attributable to sampling variability rather than a systematic effect of the methodology. However, the p-value alone is not sufficient, as it is influenced by the sample size. To assess the clinical magnitude of the differences independently of the number of analyzed subjects, the effect size was evaluated using Cohen's d.

In the calculation of Cohen's d, the effect is classified as small (0.2), medium (0.5), and large (≥ 0.8). In the present study, the d-values fall entirely within the small effect size interval. The two techniques therefore yield results that are, on average, comparable, and the actual differences are limited. However, because Cohen's d tends to overestimate the true effect in smaller samples, we applied Hedges' correction (Hedges' g). The Hedges' g values were slightly lower than their respective Cohen's d values, confirming a small effect size and reducing the risk of statistical overestimation (Table V).

Table V. *Using Cohen's d and Hedges' correction, it was found that the effect size is small.*

Pair	Method	Standardizer	Estimate
1	Cohen's d	0,49183	-0,298
1	Hedges' g	0,50503	-0,290
2	Cohen's d	0,57811	0,231
2	Hedges' g	0,59362	0,225

Although not statistically significant, this small effect indicates a systematic trend favoring the fully guided technique in terms of stability, uniformity, and lower variability of the final result.

DISCUSSION

Evaluating the results of this study requires considering that the experiment was conducted exclusively on an *in vitro* model. While on one hand this choice guarantees an ideal standardization to isolate technical variables, on the other hand it determines a drastic reduction in the impact of numerous biological and clinical factors that characterize daily operative reality. Indeed, in a real clinical context, the operator must manage critical elements such as the anatomical characteristics of the tissues, which can deflect the trajectory of the instruments; intraoperative bleeding, resulting in reduced direct visibility of the surgical field; and oral cavity opening limitations, which restrict the maneuvering space and the insertion axis of the handpieces, especially in posterior sectors, thereby increasing the risk of contamination of the implant surface. In the clinical setting, the overlap of these variables significantly increases the complexity of implant insertion, amplifying the risk of deviations from the ideal plan. Consequently, it is reasonable to hypothesize that the actual advantages of computer-planned surgery emerge even more clearly and markedly precisely in the presence of such biological obstacles, making the guided technique a fundamental aid for managing clinical complexity. At the same time, however, the choice must take into account the anatomical-physiological limits of the patient themselves.

A purely focused analysis on mean measurements might lead to the assumption that the two techniques are equivalent, since the mean accuracy values are comparable. However, the study of data dispersion reveals a substantial qualitative difference: the fully guided technique shows clearly superior stability and consistency. Guided surgery strongly tends to standardize the surgical act by reducing the impact of the operator's manual skills, making the results highly reproducible. While it does not necessarily improve "mean accuracy" under ideal conditions, guided surgery acts as a safety system, drastically reducing the probability of committing macroscopic errors or critical deviations (the so-called "outlier errors"). Conversely, the free-hand technique (operator-dependent) remains heavily bound to the experience, manual dexterity, and ability of the clinician to interpret three-dimensional anatomy in real time.

Emerging data indicate that the partially guided technique is not obsolete or outdated. It maintains a certain clinical validity and operative dignity, positioning itself not as a fallback choice, but as an option based on a principle of "selective indication" rather than the "absolute superiority" of its digital counterpart. Guided surgery offers indisputable advantages in terms of detailed preoperative planning, reduction of tissue invasiveness, and fluid communication between the surgeon, prosthodontist, and dental technician. However, in the presence of a professional with consolidated experience and in scenarios where the surgical guide would be cumbersome or unstable, or could increase the risks of implant contamination, free-hand insertion is capable of offering completely comparable results.

The integration of guided surgery into daily practice has been historically limited by economic barriers and logistical complexities. Indeed, the traditional workflow requires significant investments (intraoral scanner, dedicated planning software, production of the surgical guide via stereolithography). These elements can disincentivize clinicians, particularly novices or those managing small volumes of activity. In recent years, however, the introduction of free and open-access software is radically changing this scenario. An example is BlueSkyPlan (BlueSkyBio), a platform that allows for the management of cases of varying complexity (on single or multiple implants) by eliminating fixed software costs and applying extremely low STL file export fees. This lowers the entry costs, offering even less experienced clinicians a tool to approach computer-guided surgery in a safe and sustainable manner, laying the foundations for a future mass diffusion of the methodology.

For a correct interpretation of the data, it is necessary to isolate the intrinsic limitations of this research, which are the sample size (the limited number of analyzed elements reduces the statistical power of the study) and the *in vitro* environment (the total elimination of biological variables prevents verifying the actual performance of the techniques in the presence of live tissues).

The results should not be read as a devaluation of traditional techniques, but as an invitation to precisely study the clinical context to make the best therapeutic choice. Overcoming these limitations will guide future research lines toward three fundamental focus points. The first is a complete three-dimensional analysis, including angular and not just linear deviations, in order to map the displacement of the implant in space across every dimension. The second is the *in vivo* clinical translation, aimed at designing controlled clinical trials on real patients to test the accuracy of the methodologies in the presence of concrete biological variables. The third aspect to consider will be the impact on prosthetic fit, to investigate the time efficiency and precision of guided surgery in relation to the delivery of the prosthetic restoration. This will be useful to evaluate whether greater implant stability translates into a faster and more precise prosthetic coupling.

CONCLUSIONS

From this study, it can therefore be deduced that there is no single technique that is definitively superior; rather, there are specific contexts, such as favorable biological and anatomical conditions or the presence of an experienced operator, that render one technique more suitable and effective. Technological advances have laid the groundwork for abandoning older two-dimensional planning techniques in favor of three-dimensional planning; however, this does not automatically translate into using a surgical guide for actual implant placement. Although the experimental results did not show clear superiority of one methodology over the other with definitive statistical significance, using the guide for implant placement showed that digital planning and fully guided surgical execution trend toward greater stability and reproducibility. This is evidenced by greater consistency in the measurements, reflected in a lower standard deviation than the "free-hand" approach. The latter technique, which benefits from partial use of the guide for implant site preparation, yielded positive outcomes when performed by an experienced operator—producing average results similar to the fully guided approach but with a higher standard deviation and, consequently, lower measurement consistency. This shows that, in terms of precision, guided surgery is superior, though the difference was not statistically significant.

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