# Clinical Outcomes and Cost Effectiveness of Computer-Guided Versus Conventional Implant-Retained Hybrid Prostheses: A Long-Term Retrospective Analysis of Treatment Protocols

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**Running title:** Outcomes of hybrid prosthesis rehabilitation with guided implant surgery.

**Key findings:** Computer-guided implant placement shows higher implant survival and comparable long-term cost to non-guided implant placement.

## Abstract

**Background**

Computer-guided systems were developed to facilitate implant placement at optimal positions in relation to the future prosthesis. However, the time, cost and technique sensitivity involved with computer-guided surgery impedes its routine practice. The aim of this study is to evaluate survival rates and complications associated with computer-guided versus conventional implant placement in implant-retained hybrid prostheses. Furthermore, long-term economic efficiency of this approach was assessed.

**Methods:**

Patients were stratified according to implant placement protocol into a test group, using computer-guided placement, and a control group, using traditional placement. Calibrated radiographs were

used to measure bone loss around implants. Furthermore, the costs of the initial treatment and prosthetic complications, if any, were standardized and analyzed.

**Results:**

Forty-five patients (149 implants in the test group and 111 implants in the control group) with a minimum follow-up of 5 years, and a mean follow up of 9.6 years, were included in the study. While no significant difference was found between both groups in terms of biologic and technical complications, lower incidence of implant loss was observed in the test group ($p$<0.001). A statistically significant difference in favor of the non-guided implant placement group was found for the initial cost ($p$<0.05) but not for the prosthetic complications and total cost ($p$>0.05).

**Conclusions:**

Computer-guided implant placement for implant-supported hybrid prosthesis is a valid, reliable alternative to the traditional approach for implant placement and immediate loading. Computer-guided implant placement showed higher implant survival rates and comparable long-term cost to non-guided implant placement.

**Keywords:** Dental Implants, Computer-Assisted Surgery, Prostheses and Implants, Cone-Beam Computed Tomography, Implant-Supported Dental Prosthesis

## Introduction

Dental implants have transformed the clinical perspective and rehabilitative approach to treating completely and partially edentulous patients[1]. In fact, the presence of implants is considered the most essential modifier of such patient therapy in the last 35 years [2].

A key determinant of clinical implant success is accurate implant positioning and the avoidance of damage to the adjacent anatomical structures [3]. Implementation of this pivotal factor has always been contingent upon operator skill and experience, in addition to other biologic and site-dependent factors [4]. Hence, computer-guided systems were developed to facilitate implant placement in an optimal planned position, to retain the future prosthesis in an optimal biologic position[5]. Such high precision is expected to decrease biologic and prosthetic complications, especially in more complex cases[6]. Implants placed via computer-guided implant placement (CGIP) is reportedly within 1mm and around 5° of deviation from the originally planned implant position [3]. This is further supported by a recent systematic review which examined more than 1,400 CGIP and showed a mean global inaccuracies of 1.1 mm at entry point, 1.4 mm at the apex and a 3.9° angular deviation [7].

Quite helpfully, CGIP protocols uses computed tomography (CT) scan for virtual identification and placement of implants in the exact positions and angulations avoiding surrounding vital anatomical structures [8]. This treatment modality may eliminate the need for bone grafting, and even raising a flap, if appropriate bone dimension and morphology exists [9, 10]. This might in turn improve patient acceptance to the recommended treatment and reduce morbidity post-surgery [8, 11].

Despite high documented survival rates for implants placed using CGIP (approximately 95% at a 7-year follow up period), a higher rate of prosthetic and biologic complications has also been reported [12].It is crucial to keep in mind that precision of implant position remains subject to the

guide accuracy and adherence of the clinician to the proposed surgical protocol [8]. Although these high-precision technologies are used in the fabrication of such guides, several studies have shown some linear and angular deviations between the planned and placed implants [13-16]. This may raise the question as to whether or not the use of a computer-guided protocol by an inexperienced operator expands the probability of technique-dependent complications. Conversely, Van de Wiele et al. reported that guided systems could facilitate and expedite ideal implant placement for clinicians with limited experience [17].

The additional preparation time, greater cost and technique sensitivity associated with CGIP are the chief obstacles to its routine practice[18, 19]. The results of a recent systematic review [20] questioned the economic benefits of utilizing CGIP. Thus, another question that needs to be addressed is the cost-effectiveness of CGIP across short and long-time periods when compared with traditional implant placement. Finally, a commonly overlooked element of investigating the efficiency of CGIP, is whether or not the accuracy of these protocols results in decreasing the incidence of long-term post-operative complications, when compared to traditional non-computer-guided protocols. Thus, the aim of this study was to evaluate the long-term survival rate, complication rate and cost of CGIP compared to traditional protocol. A null hypothesis was formulated, with the authors anticipating no influence using CGIP on the identified outcomes.

## Methods and Materials:

The present study was conducted according to the principles embodied in the Helsinki Declaration of 1975, as revised in 2000 for biomedical research involving human subjects, and was approved by the Institutional Review Board for Human Studies, School of Dentistry, University of Michigan, Ann Arbor, MI, USA (HUM00114382) to be conducted at the Department of Periodontology within the same institution.

This retrospective investigation enrolled all patients treated with implant-retained hybrids between January 1990 and September 2017 at the School of Dentistry, University of Michigan, Ann Arbor, MI, USA. All papers and digital charts of edentulous patients treated with implant-retained hybrid prostheses were carefully scanned and analyzed by two authors (AR, SB). During each stage, all disagreements were resolved through discussion with a third reviewer (JG).

**Inclusion criteria**

1) Edentulous patients treated with implant-retained fixed hybrid prostheses and a documented follow-up of ≥ 5-year after implant placement.

2) Cases where all implant fixtures associated with the prosthesis were placed within the same surgical procedure.

3) Patients who received an implant-retained fixed hybrid prosthesis, returning for regular maintenance, at the University of Michigan School of Dentistry.

**Exclusion criteria**

1) Edentulous patients treated with a removable overdenture or ceramic fixed dental prosthesis

2) Patients with ambiguous or incomplete charts

3) Patients with a < 5-year follow-up

4) Patients treated or maintained in centers outside the University of Michigan School of Dentistry

5) Patients with inaccessible files due to bad debt or decease

**Data collection and Classification**

Within the review period, 222 patients were screened, their data subsequently evaluated against the aforementioned inclusion and exclusion criteria. In total, 45 patients were included in the study, while 175 were excluded for the following reasons: a) 51 implant-retained hybrids with a <5-year follow-up, b) 49 implant-retained overdentures, c) 32 implant-retained fixed bridges, d) 32 inaccessible files, e) 4 files with missing or incomplete data, f) 3 destroyed files, g) 3 deceased patients, and h) 1 removable partial denture.

Later, the selected cases were separated into two groups: computer-guided implant placement (CGIP) as the test group (26 patients) and non-CGIP as the control group (19 patients).

Patient information, such as age (at the day of implant placement), gender, presence of a smoking habit (≥1 cigarette/day), diabetes (verified by checking full medical records) and history of periodontal disease were obtained. History of periodontal disease, determined by reviewing the periodontal chart, was defined as the presence of at least 4 sites with clinical attachment loss (AL) ≥3 mm and past history of scaling and root planing [21, 22]. Additional data including time of implant

placement (immediate, early or delayed), time of implant loading (immediate, early or delayed), number of implants and their positions, implant configuration (brand, length and diameter), and whether or not bone augmentation or a flap procedure were performed.

The following prosthodontic/peri-implant complications and subsequent management were recorded at follow-up appointments: 1) fractured/chipped/replaced prosthetic tooth, 2) fractured prosthesis, 3) fractured bar, and 4) loosened abutment screw.

All complications have been classified into the following:

1) Biologic complications: peri-implant mucositis, peri-implantitis, implant failure and hyperplasias, prosthesis-induced ulcers of fibrous connective tissue, fistula formation, pain or infection.

2) Early or delayed prosthetic complications: early prosthetic complications were defined as those occurring within 1 year of prosthetic loading, whereas late prosthetic complications were defined as those that occur 1 year following prosthetic loading.

3) Minor, moderate or major prosthetic complications: minor complications are those managed within 24 hours of presentation, moderate are those managed between 2 to 7 days, while major complications required >7 days to manage.

**Computer-guided implant placement (CGIP) group**

The CGIP was planned according to manufacturer instruction . Digital 3D diagnostic and treatment planning using manufacturer software defines implant positions and sizes from an anatomical, surgical and prosthetic perspective by combining the 3D future tooth setup according to the patient's anatomy. Anatomical conditions had to permit the placement of at least four implants in the positions ideal for full-arch prosthetic rehabilitation to be achieved. Treatment planning involved Cone Beam Computed Tomography (CBCT) § or CT scans of both the patient and the prosthetic-driven radiographic guide according to the double-scan protocol: an initial scan of the patient wearing the radiographic guide prepared following tooth set-up, and a second scan of the template alone. Next, both scans were superimposed using the dedicated software to establish optimal implant positioning. The planning data was then sent to the manufacturer where a surgical template with hollow metallic sleeves was designed and later produced for implant placement according to the software-identified positions (Figure 1a). When immediate loading was necessary, full acrylic resin screw-retained provisional prostheses were prefabricated based on the surgical guide and the model obtained from the surgical templates were placed intraorally and fixed with ≥3 anchor pins. After correct placement and stabilization of the template, a flapless implant surgery was performed according to manufacturer protocol , and fully guided drilling preceding implant insertion followed. Some patients were restored with a provisional fixed, immediately-loaded prosthesis, while others went for early or delayed loading depending on primary stability.

**Non-computer-guided implant placement (CGIP) group**

Implant rehabilitation was planned on 2D (panoramic XR) or 3D (CBCT or CT) diagnostic imaging. Consequently, surgical guides were constructed from the diagnostic tooth set-up and cast model analysis using a light-polymerized composite material, where drill blanks placed in the prosthodontically-driven implant position were set to assist the free-hand (non-CGIP).

A central, crestal arch incision was made on the alveolar ridge and a full thickness flap was elevated. When necessary, a distal vertical incision was performed. Subsequently, the drilling sequence proceeded according to manufacturer instruction. A variety of implant systems ¶#** were utilized in this group. Guided bone regeneration (GBR) was performed simultaneously, when necessary, using allograft particulate bone †† and an absorbable collagen membrane §§ to repair bone defects and augment horizontal bone volume.

**Peri-implantitis and Implant Failure:**

To classify peri-implantitis, the definitions proposed by the 8th European Workshop on Periodontology in 2011 were adopted [23], where peri-implantitis was defined as clinical inflammation together with radiographic marginal bone loss >2 mm. Peri-implant marginal bone loss was measured at baseline (following the expected period of remodeling) and final follow-up via calibrated periapical and panoramic radiographs using imageJ software‡‡ [24]. Two individual, calibrated examiners (JG & SB) performed the calculations separately using the designated software. Where significant differences were found, a third reviewer (AR) reassessed the radiographs to arrive at a final resolution. Peri-implantitis was evaluated per patient, then per implant individually. The incidence of peri-implantitis was recorded using a binary score for each implant (0 for a healthy implant, 1 for a diseased implant) thus calculating the percentage of diseased implants. Similar

dichotomous values were assigned to patients based on the presentation of peri-implantitis around any implants (0 for a patient with all healthy implants, 1 for a patient with radiographic signs of ≥1 diseased implant). Implant failure was defined as a removed, lost, mobile or fractured implant and calculated for each implant individually and then each patient, with the same standards used previously for peri-implantitis [25] .

Prosthesis design: Only implant-retained fixed hybrid prostheses were included in this article. A titanium or gold bar was used to anchor the acrylic base, with a set of acrylic teeth in place (Figure 1b).

**Cost:**

The analysis of cost in this study was patient-focused, intended to identify all the necessary costs of diagnostic, therapeutic and follow-up procedures. The primary objective of this analysis was to achieve a more comprehensive understanding of cost–effectiveness associated with both approaches, and their complications, discussed in this paper.

The average cost of clinical procedures across the 5 to 25-year follow-up period was determined beforehand and utilized, as a method of standardization among the study sample. The costs were obtained and categorized into the following:

1. Initial Cost: implant + prosthesis placement fees
2. Cost of Complication Management: prosthetic + implant complication management fees
3. Total Cost: Initial Cost + Cost of Complication Management

The cost of all treatments related to initial placement and management procedures were predetermined based on an average of their individual costs every year since 1994, at the University of Michigan, School of Dentistry. This was performed to prevent the regular rate of inflation along the 5 to 23-year period interfering with the standardization and reliability of the cost analysis. After a pricelist was formulated based on these averages, all procedures pertaining to each patient file were scanned and recorded by one study investigator (MT). Wherever doubt arose, an expert in the matter (HLW) was referred to. With these records, the cost of treatment and management performed on each patient was noted and computed into the aforementioned categories of cost.

The purpose of analysis was to simulate a clinical setting where a patient is not pardoned for payments, just as a means to have a fair and elaborate comparison between the two treatment approaches. Therefore, whether or not the patient had actually paid for the provided treatments, actual cost was presumed within the particular patient's cost of treatment.

Within the initial cost, every treatment fee, such as preliminary consultation appointments, use of radiographic and/or laboratory diagnostic aids, laboratory fees and preparations, and the entire cost of surgery, were included. Complication management cost included any fee related to follow-up maintenance, as well as management of any biologic or prosthetic complication pertaining to any of the components.

The average cost of each procedure was calculated as follows:

$Cost_1 + Cost_2 + Cost_3 + Cost_4 .../n$

where:

$Cost_x$ = Procedure Cost at a Given Year

n = Total number of $Cost_x$ events per procedure

**Statistical analyses**

The demographic profile and clinical characteristics of the included sample were analyzed using: 1) descriptive statistics: mean, standard deviation, median; 2) $Chi^2$ homogeneity tests (Chi2); 3) Fisher's exact test (Fis); and 4) Mann-Whitney (MW).

The association between prosthetic complications across both study groups was analyzed using: 1) descriptive analyses: number of cases (%) and mean ± standard deviation; 2) a simple binary logistic regression model for each type of complication: estimation of unadjusted odds ratio (OR); and 3) a Mann-Whitney test for homogeneity test of distributions in continuous variables.

The probability of peri-implantitis and implant failure in both groups was assessed using a generalized estimation equation (GEE): estimation of odds ratio (OR) adjusted by sex, age and follow-up time.

Cost analysis was performed using a general linear model: estimation of coefficients adjusted by number of implants and follow-up time (years).

## Results

**Descriptive Analyses**

A total of 45 patients, 24 males (53.3%) and 21 females (46.7%), with a mean age of 58.9 ± 13.1 years (22 to 83), who received full-arch implant-retained hybrids during the last 27 years at the University of Michigan School of Dentistry, were selected.

Twenty-six (149 implants) of the total cases were treated with CGIP (test group), while the remaining 19 (111 implants) where treated traditionally (control group).

A total of 260 implants were included: 26 patients (80%) received 5 or 6 implants (40% each), 5 patients (11.1%) received 8 implants and 4 patients (8.8%) received 7 or 4 implants (4.4% each) (Figure 2). The average follow-up period was 116.0 ± 45.9 months (9.66 ± 3.82 years), where half the sample was monitored across a minimum of 9 years.

**Demographic profile and clinical characteristics**

No statistically significant difference was observed with age ($p$=0.061), although the test group did demonstrate a greater frequency of increased age, representing a mean age of 62.5 ± 10.7, as opposed to the 53.9 ± 14.7 of the control group. Although not statistically significant ($p$=0.069), the follow-up period was markedly longer in the control group, with an approximately >2-year difference. In order to avoid this difference interfering with the results, considering that it is plausible for a longer follow-up to be associated with more complications, this variable was controlled and adjusted for during statistical analysis. Clinical parameters such as implant loading (immediate versus delayed), the presence of a flap versus lack thereof and bone regeneration as a consequence of surgical planning also demonstrated significant differences between the two groups ($p$<0.01); where guided surgery was normally associated with flapless surgery, immediate loading and no bone grafting procedures. Contrarily, differences between smoking, diabetes, periodontitis, and both arches were not statistically significant ($p$>0.05). The characteristics and demographics of the included patients are summarized in table 1.

**Prosthetic Complications**

For each of the investigated parameters, no statistically significant difference was found between test and control ($p$>0.05).

In both groups, tooth replacement was the most common problem, affecting 55.6% of the total sample. Denture removal, due to bulk fracture, was the second most detected complication (35.6%), followed by partial acrylic fracture (24.4%), (Figure 3).

Regarding the time of complication occurrence, 24.4% and 68.9% of patients presented with early and delayed complications, respectively. However, no statistically significant difference was found between test and control ($p$>0.05), table 2 depicts the incidence of prosthetic complications in both groups.

**Biologic Complications**

Peri-implantitis:

A generalized estimation equation (GEE), adjusted according to sex, age and follow-up time, demonstrated a lower incidence of peri-implantitis within the CGIP group compared to the non-CGIP group; both per patient (34.6% vs. 52.6%) and per implant (13.4% vs. 24.3%). However, this was not statistically significant ($p$= 0.230; $p$= 0.714).

In addition, an observed trend, short of statistical significance ($p$=0.085), depicted a lower probability of peri-implantitis with increasing age (OR=0.95). Specifically, every additional year can be associated with a 5% reduction in risk of peri-implantitis.

Prosthesis-induced biologic complications:

A small number of prosthesis-induced biologic complications were observed within both groups. A clinical observation of an ulcer in one patient and an epulis fissuratum in another were recorded in

the non-CGIP group. Three separate cases of ulcerations and a single presentation of soreness were documented within the CGIP group.

Implant failure:

A statistically significant difference in implant survival rate was found between the control (80.2%) and test group (96.7%) ($p$<0.001). This was not the case when the same analysis was performed per patient ($p$>0.05). The data showed that the 22 implant failures within the non-CGIP group were linked to only 4 patients (21.1%), whereas, the 5 documented failures within the CGIP group were associated with 5 (19.2%) individual patients (Table 1).

**Cost Analyses**

The analysis concluded that, when differences in both implant number and follow-up period where adjusted, neither mean total cost of CGIP versus non-CGIP nor the cost of the associated complications was significant ($p$=0.573) and ($p$= 0.860), respectively (Figure 4). However, a comparison of both procedures' initial cost, considering the same number of implants, displayed statistical significance ($p$<0.05), where CGIP surgery costed an additional $659.10.

## Discussion

Our results confirm that CGIP for implant-retained hybrid prostheses is an effective treatment option for experienced and inexperienced clinicians alike. The predicted null hypothesis for implant survival rate was rejected, since it was higher in CGIP, however, it was verified for the incidence of peri-implantitis, with no differences between both groups. When the cost of managing all complications throughout the follow-up period was considered, no difference was found between both groups; though, initially, the cost was higher in the test group.

Observational studies are able to create credible evidence of intervention effects through tracking large cohorts. This brings the benefits of generalizability, potential for real-world comparisons of treatment efficacy and long-term outcomes[26]. Utilizing up-to-date methodological and statistical strategies can, when appropriately applied on long-term follow-up cohorts with sufficient data, improve results reliability[27]. In the past two decades, the paradigm of a prosthetically-driven implant surgery has been subject to fundamental evolution in practice. Proper implant positioning has obvious advantages, such as long-term stability of peri-implant hard and soft tissues, enhanced oral hygiene procedures, the potential for achieving optimal occlusion, and more favorable esthetic outcomes [28-30]. Not limited to that, several groups advocated tailored, site-specific planning for implant placement, negating the need for augmentation, where several clinical studies reported excellent results for no-augmentation techniques, developed to restore edentulous patients with fixed prostheses [31-33]. Recently, the growing need for patient rehabilitation with implant-retained fixed prostheses was what pushed the industry towards applying present-day technology pursuing well-accepted, highly predictable, less invasive and less technique-sensitive protocols for edentulous patient rehabilitation[18]. The evident success of computer-guided systems means, for patients, that the entire procedure from surgery to final prosthetic restoration can be accomplished with reduced post-operative morbidity and overall treatment time [34, 35].

In the current study, implant survival rate in the CGIP group was statistically more significant than the non-CGIP group ($p$<0.001) with a 96.7% survival rate, concurring with previous studies, reporting 97.8% [18] and 97.6% [36] survival rates at approximately 3 years of follow-up. This proves the external validity of our results, while a robust advantage of our study is the longer range of follow-up, with an average of 9.6 years. It should be highlighted that in our study, a significant difference, in survival, was only observed on an implant level ($p$≤000.1), but not on a patient level ($p$=0.88).

A well-known concern with implant-retained hybrid prostheses is prosthetic complications, most commonly acrylic denture fracture. Similar studies reported a slightly higher rate of acrylic fracture 34.7% [37], 30.3% [38] and 30% [39] , as our in study 23.1% of cases had acrylic fractures. However, the most common technical complication encountered in the current study was prosthetic tooth loss and replacement with a noteworthy rate of 53.8%. Bulk fracture of acrylic teeth is a common observation in implant-retained acrylic prostheses, and recent studies suggested that teeth fabricated with improved materials are expected to perform better long-term[40]. In the current study, different types of acrylic teeth provided by the same manufacturer were used ¶¶.

In order to avoid bias and decrease confusion, we elected to utilize the definition of peri-implantits proposed by the 8th European Workshop on Periodontology in 2011 [23]. According to this definition, the incidence of peri-implantitis in our test group was 13.4%. We are not aware of comparable studies which have used the definition we have adopted, rather, most studies proposed their own definitions for peri-implantitis [37], which generally renders incomparable and erratic results. We, therefore, assume that peri-implantitis incidence has been under-reported in similar studies, where Malo et al. reported 8.7% of cases to have peri-implantitis after one year [37], and Puig et al. reporting an incidence of only 5.6% [41].

One of the virtues of having a long-term follow-up, is the ability to compare the costs of resolving prosthetic and technical complications along a relatively long period. We are also not aware of similar studies that compared costs of managing late complications. It is well known that a computer-guided approach is more expensive than conventional implant placement due to software utilization, denture duplication, scanning patient's denture with CBCT, surgical template fabrication, extra laboratory fees and planning time [42]. However, our study revealed a rather intriguing finding. Though CGIP approach did generate a greater initial cost, no significant difference in mean total

costs was found, when managing short and long-term complications in both groups was taken into account.

In the CGIP group, all surgical templates were produced by the same manufacturer and the same implant system was utilized, which limits the validity of our results to this particular manufacturer. It would be of interest to investigate whether other implant systems would suffer less incidence of peri-implantitis, for instance. Another limitation in our results, is that it include immediately loaded implants, which commonly have different survival rates and marginal bone levels than single or partial tooth rehabilitations [6].

The very nature of this observational study, did not allow for the accuracy of used guides to be tested. However, though a guide was used, in 2 cases an open flap approach was mandatory, to correct fenestrations which occurred during implant placement, these sites were subsequently augmented with bone grafts and protected with barrier membranes.

Finally, 80% of the included cases received 5 or 6 implants, with the remaining 20% restored with 4, 7, or 8 implants. This presents in contrast to other studies that usually investigate a particular configuration like the “All-on-4” or “All-on-6”[32, 41], again, limiting the validity of our results to that particular number of implants utilized for rehabilitation.

Observations from this study strongly suggest that the treatment team must be aware of the various steps involved in prosthesis fabrication, in order to yield an easier troubleshooting process during and after the surgery, if deemed necessary. Finally, upon case planning, it is critical to realize that every step will hold a lifetime consequence for restoration reliability.

## Conclusion

Our clinical results confirm that computer-guided implant placement for implant-supported hybrids is a valid, reliable alternative to the traditional approach of implant placement and immediate loading. Implants placed via guided surgery demonstrated higher survival rates and comparable long-term cost when compared with non-guided implant placement. No difference in technical complications was observed between the two groups. More consideration should be given to the routine use of computer-guided surgery in the treatment of edentulous cases.

**Footnotes:**

NobelReplace® Tapered Groovy implant (Nobel Biocare, Gothenburg, Sweden)

§ (3DX Accuitomo FPD; J Morita Mfg Corp., Kyoto, Japan)

¶ Branemark Mark III® and IV® (Nobel Biocare, Gothenburg, Sweden)

# Zimmer® (Zimmer, Palm Beach Gardens, Florida, US)

** Biohorizons® (BioHorizons IPH, Inc., Birmingham, AL, US)

†† Puros® Zimmer, Palm Beach Gardens, Florida, US

§§ Bio-Gide®, Geistlich Pharma AG, Wolhusen, Switzerland

‡‡ ImageJ, U. S. National Institutes of Health, Bethesda, Maryland, USA

¶¶ Ivoclar Vivadent™, Schaan, Liechtenstein

**Conflict of interest**

The authors declare no conflict of interest within this study. The authors do not have any financial interests, neither directly nor indirectly, in the products or information listed in the paper.



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**Legends:**

**Tables**

Table 1: The characteristics and demographics of patients in control and test groups.

Table 2: The incidence and different types of prosthetic complications in test and control groups.

**Figures**

Figure 1:

A) Prosthetically driven virtual positioning of implants and fixating screws using the software.

B) Hybrid prosthesis (Maxilla) in situ after delivery.

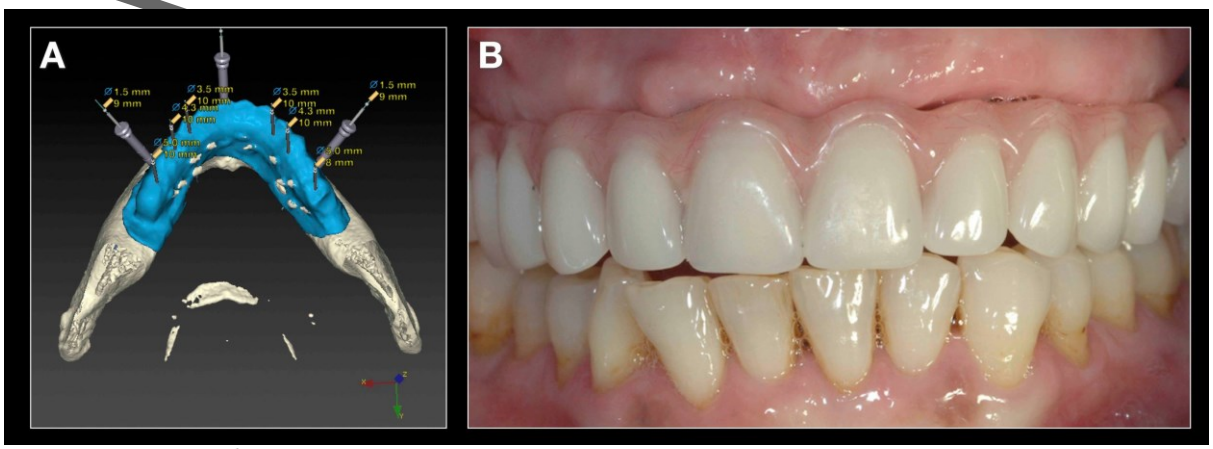

Figure 2: Distribution of patients in test and control groups according to the number of implants supporting the hybrid prosthesis.

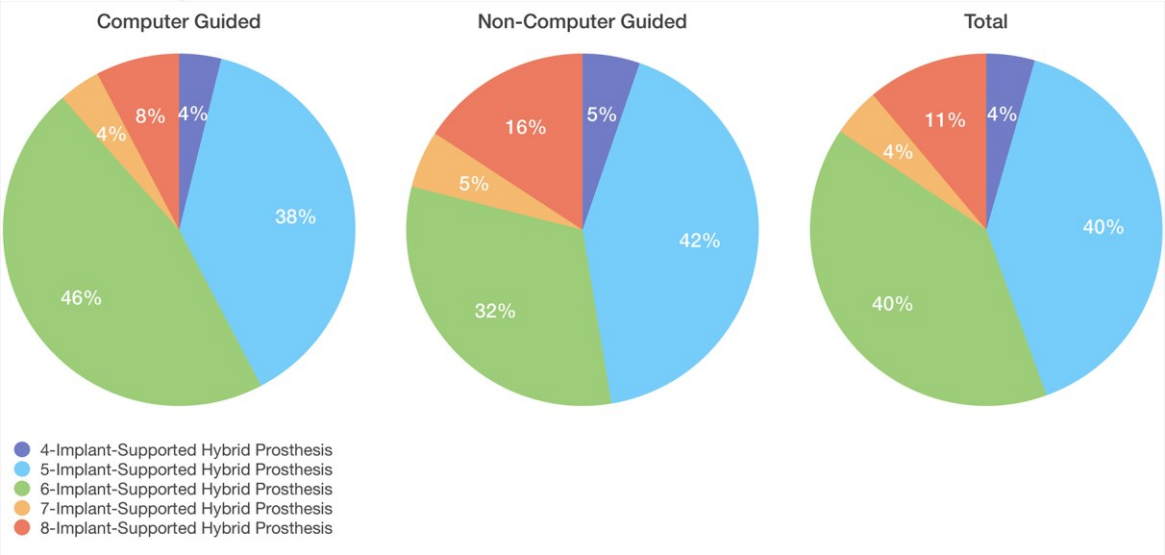


Figure 3: Incidence of each of the prosthetic complications in either groups, and prevalence of prosthetic complications in the total cohort.

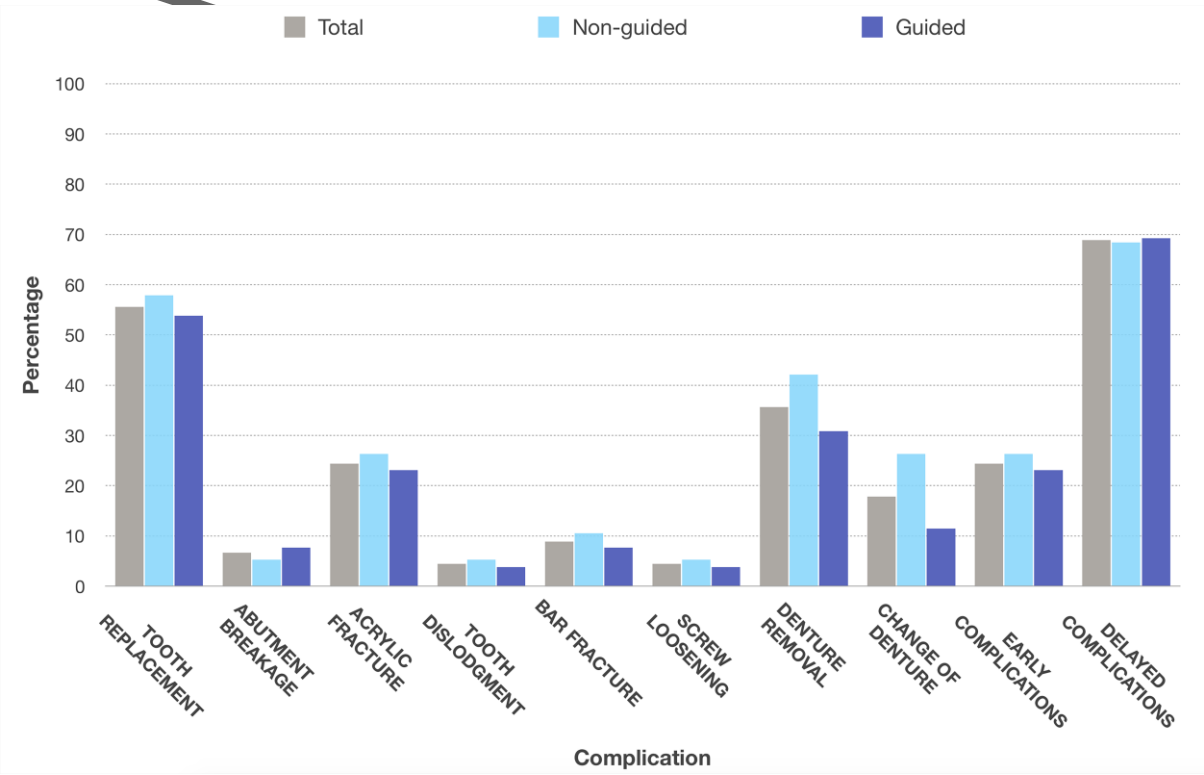

Figure 4: Projection of costs expended through the overall follow-up time, based on the number of implants utilized to support the framework.

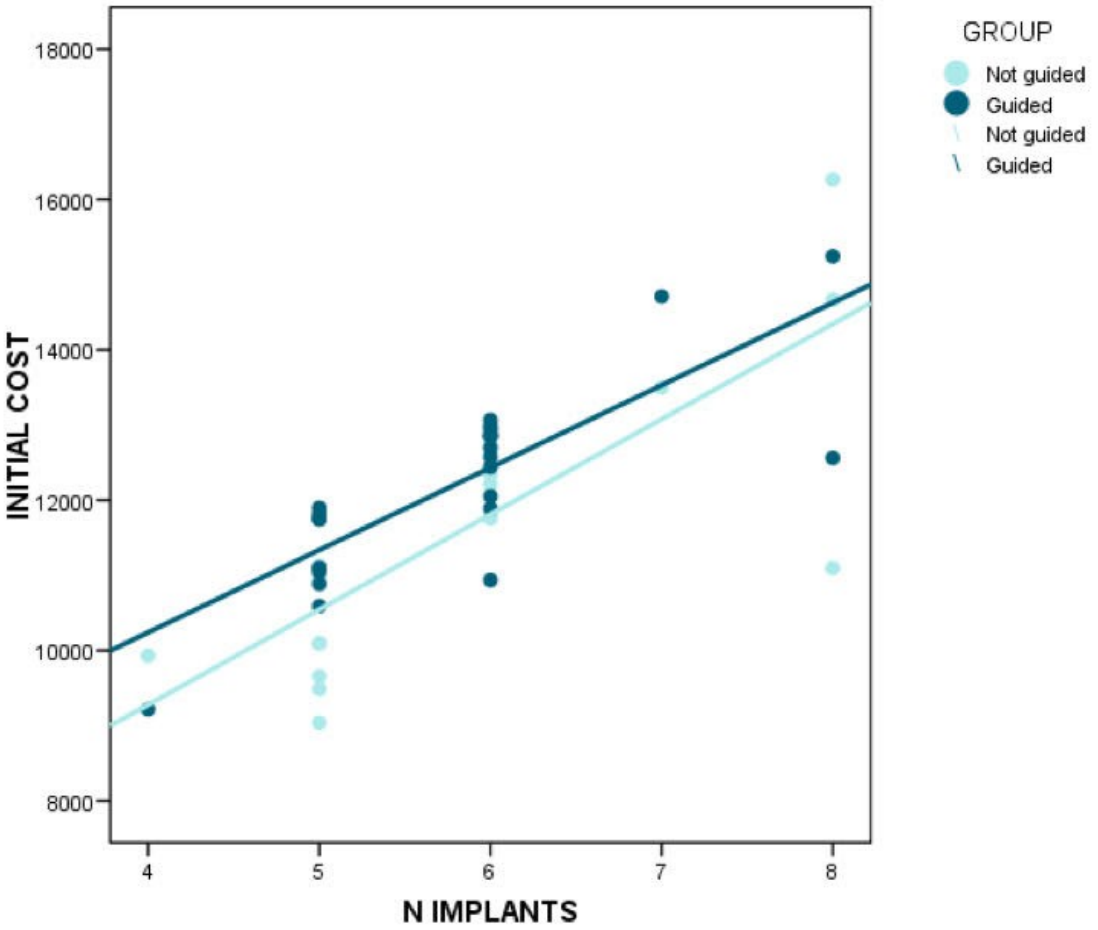

**Table 1**

| | Parameters | Group: Non-Guided | Group: Guided | p-value (test) |
|---|---|---|---|---|
| Patients | N (patients) | 19 | 26 | |
| | Follow up (months) | 128.7 ± 62.3 | 101.0 ± 27.1 | 0.069 (MW) |
| | Age (years) | 53.9 ± 14.7 | 62.55 ± 10.7 | 0.061 (MW) |
| | Male | 6 (31.6) | 18 (69.2) | **0.012 ($Chi^2$)** |
| | Smokers | 3 (15.8) | 2 (7.7) | 0.636 (Fis) |
| | Diabetes | 3 (15.8) | 2 (7.7) | 0.636 (Fis) |
| | History of periodontitis | 5 (26.3) | 4 (15.4) | 0.365 ($Chi^2$) |
| | Maxillary rehabilitations | 8 (42.1) | 15 (57.7) | 0.302 ($Chi^2$) |
| | Immediate implants | 2 (10.5) | 2 (7.7) | 1.000 (Fis) |
| | Immediate loading | 4 (21.1) | 17 (65.4) | **0.003 ($Chi^2$)** |
| | Open Flap | 19 (100) | 2 (7.69) | **<0.001 ($Chi^2$)** |
| | Bone Regeneration | 11 (57.9) | 2 (5.2) | **0.001 ($Chi^2$)** |
| | Screwed prosthesis | 17 (89.5) | 26 (100) | 0.176 ($Chi^2$) |
| | Implant failure (Patient) | 4 (21.1) | 5 (19.2) | 0.880 ($Chi^2$) |
| Implants | n (implants) | 111 | 149 | |
| | Implant failure | 22 (19.8) | 5 (3.3) | **<0.001 ($Chi^2$)** |

Bold indicates statistically significant associations; Chi2 homogeneity tests (Chi2); Fisher's exact test (Fis); Mann-Whitney tests (MW).

**Table 2**

| | GROUP | | | |
|---|---|---|---|---|
| **Complications** | **Non-guided** | **Guided** | **OR (95%CI)** | ***p*-value** |
| N (patients) | 19 | 26 | | |
| Tooth replacement | 11 (57.9) | 14 (53.8) | 0.84 (0.26-2.79) | 0.787 |
| Abutment breakage | 1 (5.3) | 2 (7.7) | 1.50 (0.13-17.9) | 0.748 |
| Acrylic fracture | 5 (26.3) | 6 (23.1) | 0.84 (0.21-3.30) | 0.803 |
| Dislodgment of entire prosthesis | 1 (5.3) | 1 (3.8) | 0.72 (0.04-12.3) | 0.820 |
| Fracture of bar | 2 (10.5) | 2 (7.7) | 0.71 (0.09-5.54) | 0.742 |
| Screw loosening | 1 (5.3) | 1 (3.8) | 0.72 (0.04-12.3) | 0.820 |
| Denture removal | 8 (42.1) | 8 (30.8) | 0.61 (0.18-2.09) | 0.434 |
| Early complications | 5 (26.3) | 6 (23.1) | 0.84 (0.21-3.30) | 0.803 |
| Delayed complications | 13 (68.4) | 18 (69.2) | 1.04 (0.29-3.72) | 0.954 |
| Times without prosthesis (resolved within 1-day) | 2.4 ± 3.6 | 3.2 ± 3.6 | | 0.598 (MW) |
| Times without prosthesis (resolved within 1-week) | 0.4 ± 0.8 | 0.2 ± 0.5 | | 0.516 (MW) |
| Times without prosthesis (resolved after 1-week) | 0.8 ± 1.3 | 0.5 ± 0.8 | | 0.791 (MW) |
| **Mann-Whitney Tests (MW)** | | | | |