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Long-term success following dental implant placement: A comparative analysis

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Abstract:

Dental implant placement techniques influence treatment accuracy, peri-implant health and long-term clinical outcomes. Therefore, it is of interest to compare freehand, static guided and dynamic navigation-assisted implant placement in 120 patients over 24 months. Implant survival, marginal bone loss, peri-implant tissue health, surgical time, complications and patient satisfaction were evaluated. Guided and navigation-assisted techniques showed greater accuracy, reduced bone loss and higher patient satisfaction than freehand surgery. Thus, dynamic navigation achieved the best overall clinical performance, supporting advanced guided techniques for predictable implant therapy.

Keywords: Dental implants, guided implant surgery, dynamic navigation, implant survival, marginal bone loss, osseointegration, peri-implant health

Background:

Dental implants have revolutionized restorative dentistry by offering a predictable and long-lasting solution for replacement of missing teeth. Partially and completely edentulous patients benefit from implant-supported restorations in terms of masticatory efficiency, esthetics, phonetics and quality of life. In the last 20 years, significant progress has been achieved in the design of the implants, biomaterials, surface modifications and surgical techniques, which have led to improved osseointegration and long-term implant success [1, 2]. The most common surgical technique used in the past has been freehand implant placement, which is now the focus of contemporary implant dentistry, in addition to implant survival, preservation of the peri-implant tissues, prosthetic function, patient comfort and minimally invasive techniques. This technique depends on the surgeon's experience and anatomical interpretation during surgery. Freehand surgery has proven to be successful in the hands of an experienced surgeon, but errors in implant angulation, depth and positioning can be made, especially in situations that are anatomically difficult, which can affect the esthetic, occlusal, biomechanical and prosthetic rehabilitation [3-5]. Guided implant surgery has become a significant breakthrough in implantology with the advent of cone beam computed tomography (CBCT) and digital implant planning software. The static guided surgery involves stereolithographic surgical templates produced from digital planning information to translate virtual implant positioning into the clinical environment, improving the accuracy of surgery, minimizing intra-operative errors and enabling flapless minimally invasive

surgery. The use of static guidance is especially beneficial in situations where there is limited bone, near some anatomical structures and immediate implant placement [6, 7]. Another technological improvement is dynamic navigation assisted implant placement, which enables real-time monitoring of surgical drills during placement in relation to patient anatomy. Dynamic navigation offers the same real-time visual guidance as navigation systems in neurosurgery and orthopedics, with the added flexibility of not being limited to a static guide. Dynamic navigation systems have been reported to improve implant positioning accuracy and decrease deviation [8, 9]. Numerous biological and mechanical factors are critical to long-term success of dental implants. The integration of the implant into the bone, the stability of the bone around the implant, the health of the soft tissues around the implant, the loading stress on the implant, the design of the implant, the oral hygiene and systemic health conditions all play a role in treatment outcomes. Marginal bone loss around the implant is an important indicator of implant success and may be associated with biomechanical overload, peri-implant inflammation or surgical trauma [10, 11]. In addition, digital workflows enable prosthetically driven implant placement, which leads to better esthetic and functional results and reduced surgical trauma and postoperative discomfort, thanks to minimally invasive techniques. Despite the benefits, however, they have not been widely adopted due to factors like high costs, a learning curve, reliance on equipment and technical challenges [12]. The role of surgical accuracy for the maintenance of peri-implant tissue stability and implant survival has been emphasized in recent literature. There have

been some comparative studies that have shown differences in accuracy and clinical success with various implant placement techniques, however, there is limited evidence comparing long term clinical outcomes between freehand, static guided and dynamic navigation-assisted implant placement [13]. Therefore, it is of interest to compare implant placement techniques and to assess their effect on long-term implant success.

Materials and Methodology:

This prospective comparative clinical study was conducted in the Department of Prosthodontics and Implantology at a tertiary dental care institution over a period of 3 years from January 2022 to December 2025.

Study population:

A total of 120 patients requiring single-tooth or multiple-tooth implant rehabilitation were included in the study. Patients were randomly allocated into three groups comprising 40 subjects each:

- [1] Group I: Conventional freehand implant placement
- [2] Group II: Static guided implant placement
- [3] Group III: Dynamic navigation-assisted implant placement

Inclusion criteria:

- [1] Patients aged between 20 and 65 years
- [2] Partially edentulous patients requiring implant-supported rehabilitation
- [3] Adequate bone volume for implant placement
- [4] Good oral hygiene and periodontal health
- [5] Patients willing for regular follow-up visits

Exclusion criteria:

- [1] Uncontrolled systemic diseases
- [2] Smokers consuming more than 10 cigarettes/day
- [3] Pregnant or lactating women
- [4] Patients with parafunctional habits
- [5] History of radiotherapy in head and neck region
- [6] Severe bone deficiency requiring extensive grafting

Pre-operative evaluation:

Detailed clinical examination and radiographic assessment were performed using CBCT imaging. Diagnostic impressions and digital scans were obtained for prosthetically driven treatment planning.

Surgical procedure:

Group I: Freehand surgery

Implants were placed using conventional flap elevation and freehand osteotomy preparation based on clinical judgment and CBCT interpretation.

Table 1: Demographic distribution of study participants

Parameter	Group I	Group II	Group III	p-value
Mean age (years)	42.6 ± 8.4	41.8 ± 7.9	43.1 ± 8.2	0.731
Male (%)	57.5%	55%	60%	0.842
Female (%)	42.5%	45%	40%	0.842
Maxillary implants (%)	47.5%	50%	45%	0.781
Mandibular implants (%)	52.5%	50%	55%	0.781

Group II: Static guided surgery

Digital implant planning software was used to fabricate stereolithographic surgical guides. Guided osteotomy preparation and implant placement were performed according to manufacturer protocols.

Group III: Dynamic navigation surgery

Dynamic navigation systems with real-time tracking were used during osteotomy preparation and implant placement. Calibration and navigation protocols were followed meticulously.

Parameters evaluated:

- [1] Implant survival rate
- [2] Marginal bone loss (radiographic assessment)
- [3] Peri-implant probing depth
- [4] Bleeding on probing
- [5] Implant stability quotient (ISQ)
- [6] Surgical duration
- [7] Postoperative pain and swelling
- [8] Patient satisfaction scores

Follow-up:

Patients were evaluated at baseline, 3 months, 6 months, 12 months and 24 months postoperatively.

Statistical analysis:

Data were analyzed using SPSS software version 25. Mean and standard deviation were calculated. Chi-square test was applied. A p-value <0.05 was considered statistically significant.

Results:

The demographic variables among all three groups were statistically comparable (p>0.05), indicating uniform distribution of participants. Mean age ranged between 41 and 43 years. Male participants constituted slightly higher proportions in all groups (Table 1). Dynamic navigation-assisted surgery demonstrated significantly shorter surgical duration and reduced postoperative discomfort compared to freehand surgery (p<0.001). Implant stability values were highest in Group III, indicating improved osseointegration (Table 2). Dynamic navigation-assisted implant placement showed significantly lower marginal bone loss and superior peri-implant soft tissue health compared to conventional freehand surgery. Guided techniques demonstrated better tissue preservation over long-term follow-up (Table 3). Implant survival rates were highest in Group III with 100% success. Patient satisfaction was significantly greater among patients treated with guided and navigation-assisted approaches due to reduced morbidity and improved functional outcomes (Table 4).

Table 2: Comparison of surgical and clinical outcomes

Parameter	Group I	Group II	Group III	p-value
Mean surgical duration (min)	52.4 ± 6.8	45.2 ± 5.1	41.7 ± 4.6	<0.001*
Postoperative pain score	5.8 ± 1.2	3.9 ± 0.9	3.1 ± 0.8	<0.001*
Swelling incidence (%)	32.5%	17.5%	10%	0.014*
ISQ at 6 months	71.2 ± 4.8	74.5 ± 4.1	76.1 ± 3.7	<0.001*

Table 3: Marginal bone loss and peri-implant health at 24 months

Parameter	Group I	Group II	Group III	p-value
Marginal bone loss (mm)	1.62 ± 0.41	1.14 ± 0.33	0.89 ± 0.28	<0.001*
Probing depth (mm)	3.4 ± 0.6	2.9 ± 0.5	2.6 ± 0.4	0.002*
Bleeding on probing (%)	25%	15%	10%	0.031*

Table 4: Implant survival and patient satisfaction

Parameter	Group I	Group II	Group III	p-value
Implant survival (%)	92.5%	97.5%	100%	0.041*
Prosthetic success (%)	90%	95%	97.5%	0.082
Patient satisfaction score	7.2 ± 1.1	8.6 ± 0.9	9.1 ± 0.7	<0.001*

Discussion:

The field of dental implantology has come a long way and has embraced digital technologies to enhance surgical accuracy and treatment outcomes. The present study aimed to assess the effect of conventional freehand implant placement, static guided surgery and dynamic navigation-assisted surgery on long-term implant success. Demographic data of the study participants were similar across all groups, thereby reducing the confounding factors of age, sex and implant location. The same distribution of the population has been reported in previous implant studies with assessment of guided surgical techniques [10]. The present study showed that the duration of surgery was significantly shorter in the dynamic navigation group as compared to freehand surgery. The efficient implant placement was made possible by the real-time visualization and increased osteotomy control. The results are consistent with those of Knipper *et al.* which showed that surgery assisted by navigation was more precise and had a shorter operating time [11]. Guided and navigation-assisted groups experienced significantly less pain and swelling after surgery. The same was observed by Dioguardi *et al.*, who showed better patient comfort after computer-guided implant placement, which was associated with minimally invasive flapless approaches [12]. The dynamic navigation group had the highest implant stability quotient (ISQ) value indicating better primary and secondary stability. Proper preparation of osteotomy and less thermal trauma during drilling can help to improve osseointegration. Prosthetically driven implant positioning with optimal load distribution and bone preservation is possible using digital guidance systems [14]. Marginal bone loss is still one of the most important factors to consider when assessing the success of an implant. The present study showed that freehand implant placement resulted in significantly more crestal bone loss than guided approaches. In freehand surgery, the increased bone resorption may be attributed to excessive surgical trauma, improper angulation and biomechanical overload, which can be avoided by guided surgery by allowing optimal implant placement within the available bone [15]. The dynamic navigation group had the lowest peri-implant probing depth and bleeding on probing, suggesting healthier peri-implant tissues. Better implant positioning and emergence profile help promote better maintenance of oral hygiene and less plaque build-up. Outatzis *et al.* also found that guided implant surgery resulted in better peri-implant tissue stability [16]. In the present study, high implant survival rates were achieved in all groups, similar to the literature reporting survival rates >90 % for modern implant systems, but 100 % implant survival was achieved in the

navigation-assisted surgery group during the follow-up period. This may be due to the increased accuracy and lack of anatomical complications of navigation systems [17]. Patients who received guided and navigation-assisted techniques had significantly higher patient satisfaction scores. Digital workflows also help to reduce surgical discomfort, shorten operative time, improve esthetics and healing, all of which positively influence the treatment experience for the patient and allow for immediate loading and prosthetically driven treatment planning [18]. While there are several benefits to guided implant surgery, there are some drawbacks, including the cost of treatment, equipment requirements and the learning curve. Static surgical guides can have inaccuracies because of improper seating or manufacturing error. Dynamic navigation systems need a lot of training and calibration to get the best performance out of them [19]. The present study offers useful comparative data on long-term results of implant placement techniques. But there are some restrictions to be noted. Follow-up time was restricted to 24 months and larger multicenter studies with longer follow-up periods are required to confirm the long-term clinical performance. Cost-effectiveness, prosthetic complications and esthetic results of digital implant workflows should also be assessed in future studies.

Conclusion:

Dynamic navigation-assisted implant placement showed greater surgical accuracy, better peri-implant tissue health and higher patient satisfaction than conventional freehand surgery. Static guided surgery also showed favorable accuracy and tissue preservation, while all groups achieved high implant survival with greater predictability in digitally guided groups. Thus, data support the integration of digital guidance technologies to improve the predictability and stability of implant therapy and patient-centered outcomes.

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