# Accuracy of Guided Implant Surgery Using Tooth-Supported Surgical Guide for Immediate Versus Late Implant Placement: A Retrospective Clinical Study

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# ABSTRACT

**Aim & Hypothesis:** The aim of this study was to compare the accuracy of immediate implant placement with late implant placement using tooth-supported surgical guide. The hypothesis was that the accuracy of final implant position for late implant placement is greater than immediate implant placement with tooth-supported surgical guide.

**Materials & Methods:** Forty-eight patients treated with fully guided implant surgery using tooth-supported guide were included in the study, which included a total of 92 implants. Patients were distributed into two groups based on the timing of implant placement. Group 1 consisted of 25 patients with immediate implant placement, which included a total of 41 implants; and Group 2 consisted of 29 patients with late implant placement, which included a total of 51 implants. Six patients belonged to both Group 1 and 2. The corresponding implant master casts were collected and scanned using a desktop scanner. The STL files containing three-dimensional implant position were obtained and transferred to the computer implant planning software. The three-dimensional discrepancies between the initially planned implant position and the final implant position were evaluated. Statistical analysis was performed via mixed models to account for the clustering of implants within each subject.

**Result:** The mean value of angular deviation between initially planned implant position and final implant position was 2.83° (SD ± 1.47) for Group 1 and 2.55° (SD ± 1.40) for Group 2. The mean value of 3D offset at implant base was 0.77 mm (SD ± 0.29) for Group 1 and 0.58 mm (SD ± 0.25) for Group 2. The mean value of 3D offset at implant tip was 1.10 mm (SD ± 0.49) for Group 1 and 0.85 mm (SD ± 0.31) for Group 2. The difference for angular deviation was not statistically significant ($p > 0.05$), but the differences for 3D offset at implant base ($p = 0.002$) and 3D offset at implant tip ($p = 0.004$) were statistically significant.

With respect to implant location, the mean values of the angular deviation in Group 1 were greatest in premolar (3.25°), then molar (2.89°), and smallest in anterior (2.83°). The mean values of the 3D offset at implant base and 3D offset at implant tip in Group 1 were greatest in premolar (0.78 mm for 3D offset at implant base and 1.16 mm for 3D offset at implant tip), then anterior (0.77 mm, 1.10 mm), and smallest in molar (0.70 mm, 1.05 mm). In Group 2, the mean values were highest in molar (2.56° for angular deviation, 0.59 mm for 3D offset at implant base, and 0.85 mm for 3D offset at implant tip), then anterior (2.48°, 0.58 mm, 0.83 mm), and lowest in premolar (2.26°, 0.58 mm, 0.81 mm).

**Conclusions:** There were significant differences for 3D offsets at implant base and implant tip between immediate implant placement and late implant placement. Although there were greater discrepancies in immediate implant placement compared to late implant placement, it was a clinically insignificant difference.

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CBCT: cone beam computed tomography

CAD/CAM: computer-assisted design/ computer-assisted manufacturing

SLA: stereolithography

STL: standard tessellation language

DICOM: digital imaging and communication in medicine

BLT: bone level tapered

BL: bone level

TL: tissue level

IRB: institutional review board

PVS: polyvinylsiloxane

SD: standard deviation

# Accuracy of Guided Implant Surgery Using Tooth-Supported Surgical Guide for Immediate Versus Late Implant Placement: A Retrospective Clinical Study

# Introduction

## Success of Dental Implants in the Treatment of Partially Edentulous Jaw

In modern dentistry with a focus the concept of osseointegration, the use of dental implants has become a widely accepted therapy for oral rehabilitation, and implant osseointegration is considered to be predictable with high success rates.[1] In the 1980s, the application of dental implants started to expand from fully edentulous patients into partially edentulous patients, and the percentage of partially edentulous patients has significantly increased in implant dentistry.[2] These days, the success of dental implants is evaluated not only by implant osseointegration, but also for other factors such as healthy peri-implant soft tissue, limited bone loss and absence of marginal peri-implant soft tissue recession.[3] In addition, a relatively high percentage of implant prosthetic complications has been reported in literature and should be taken into account in evaluating the success of implants.[4] Correct three-dimensional implant position has advantages such as a favorable esthetic and prosthetic outcomes, the potential to ensure optimal occlusion and implant loading, and design optimization of the final prostheses.[5] In addition, misplaced implants are more difficult to obtain successful results and more susceptible to biological or technical complications.[6] Prior to implant placement, the preoperative diagnostics and implant planning should be emphasized.

## Emerging New Technology – Computer-Guided Implant Surgery

Conventional two-dimensional radiography has been performed with patients wearing radiographic templates simulating the preoperative prosthetic design in order to plan the optimal implant position on radiographs. The same templates can be used as a prosthetic reference during implant surgery. However, these techniques do not provide three-dimensional (3D) information on the patient's bone and soft tissue anatomy related to the future prosthetic position and the exact 3D guidance.[7] To overcome these limitations, the introduction of cone-beam computed tomography (CBCT), 3D implant planning software, and computer-aided design/computer-assisted manufacturing (CAD/CAM) technology have made it possible to virtually plan the optimal 3D implant position with respect to both prosthetic and anatomical parameters.[8] Therefore, the planning information is used to fabricate surgical guides, which ultimately results in the transfer of the planned implant position from the software to the patient. This entire process can be performed to achieve the ideal implant position without damaging the surrounding anatomical structures. However, a 2 mm safety margin should be always respected.[5]

**Accuracy of Static Guided Surgery**

The value of computer-assisted and template-guided implant surgery is a result of the accuracy with these systems allowing the virtually planned implant position to be transferred to the surgical site. Accuracy of computer-assisted implant surgery is defined as the deviation between the postoperative position and the preoperative plan.[9] The deviations from planned implant positions were apparent at the coronal and apical portions of the implant as well as the angulation.[10] These 3D outcomes can be expressed as angular deviation, 3D offset at implant shoulder or base, and 3D offset at implant apex or tip.

Some systematic reviews assessed clinical studies on the accuracy of computer technology applications in implant dentistry. A systematic review from Schneider et al. (2009) showed mean deviations in implant positions of 1.07 mm at the implant base and 1.63 mm at the tip.[11] This study included 8 articles for accuracy study. Among such articles, 3 studies used tooth supported templates, 4 studies used bone supported templates, and 1 study was performed on model. Another systematic review from Van Assche et al. (2012) indicated a deviation of 0.99 mm at the base (ranging from 0 to 6.5 mm) and 1.24 mm at the apex (ranging from 0 to 6.9 mm), as well as a deviation in angulation of 3.8° (ranging from 0 to 24.9°).[12] 12 in vivo studies were included in this review to analyze the accuracy of the implant placement. 9 out of those 12 studies included tooth supported guide. In the other study from Jung et al. (2009), 19 studies were included for the meta-analysis of the accuracy. 5 studies evaluated guided system and 14 studies evaluated navigation system. With systems using surgical guides, the mean deviations were 1.1 mm (max 4.5 mm) at the base, 1.2 mm (max 7.1 mm) at the tip, and deviations in the implant axis of 4.0° (max 20.4°).[8]

In a study from Nickenig et al (2010) comparing the accuracy of implant placement between conventional free-hand method and virtually planned guided method, significantly more precise transfers of the planned implant position were achieved with the guided method. This study included 10 patients with a Kennedy Class II defect in mandible. 23 implants were placed with tooth supported guides and were compared with the implants placed by way of the free-hand method. This study indicated that the guided method produced significantly smaller variation between the planned and actual implant positions, with mean deviations of 0.9 mm (0 – 4.5 mm) at the shoulder and 0.6 – 0.9 mm (0.0 – 3.4 mm) at the apex, compared to the free-hand method with mean deviations of 2.4 – 3.5 mm (0.0 – 7.0 mm) at the shoulder and 2.0 – 2.5 mm (0.0 – 7.7 mm) at the apex. Accuracy of axis was also significantly improved. The mean deviations of axis were 4.2° (0.0 – 10°) in guided method and 9.8 – 10.9° (2.0 – 20°) in free-hand method.[13]

The review by Van Assche et al. (2012) highlighted that the guidance of the implant from the surgical guide during insertion is crucial and a certain inaccuracy of up to 2 mm in guided implant surgery can be accepted, which is less than that for non-guided surgery.[12] Even though a relative high accuracy of guided implant surgery is expected, a safety margin of 2 mm from the adjacent anatomical structures should be considered.

**Advantages of Immediate Implant Placement**

In the 1970s and 1980s, the original protocols of implant placement required fully healed alveolar ridges. However, in the 1990s, the protocols were modified to include implant placement in fresh extraction sockets.[14] At a consensus conference of the International Team for Implantology (ITI) in 2003 in Gstaad, Switzerland, a classification system of four types of implant placement timing after tooth extraction was developed based on morphologic, histologic, and dimensional changes of the alveolar ridge.[15] Type 1 is defined as implant placement immediately following extraction. Type 2 is defined as early placement with complete soft tissue coverage of the socket which is typically 4 to 8 weeks after extraction. Type 3 is defined as early placement with substantial clinical and radiographic bone fill of the socket, which is 12 to 16 weeks. Lastly, Type 4 is late implant placement on healed site where is typically more than 16 weeks after extraction.

Nowadays, immediate implant placement is an attractive clinical procedure because of its overall shorter treatment time, fewer surgeries, and similar survival rates to late implant placement.[16] However, postoperative complications including peri-implant mucosal recession were reported in literature.[17] One of several factors influencing the peri-implant recession of implant immediately placed is the inadequate implant position. It has been claimed that facially positioned implants showed three times more recession than implants with a lingually positioned shoulder.[18] According to a seven-year clinical follow up study, the mucosal margin was located 1 mm more apically in the sites without buccal bone compared to implants with intact buccal bone.[19] In addition, in order to avoid biological complication, simultaneous regenerative approaches were used, such as bone grafting at the gap between facial bone and implant surface,[20] simultaneous subepithelial connective soft tissue graft,[21] and simultaneous contour provisional restoration or custom healing abutment.[22]

## Limitations of Comparing Accuracy between Immediate and Late Implant Placement

With the advancement of digital technology, current literature shows promising outcomes on the accuracy of guided implant placement. However, there is a lack of scientific evidence in literature that compares the accuracy of guided implant surgery of immediate placement compared with late placement. The present study compared the accuracy of immediate implant placement with the accuracy of late implant placement in order to investigate if the difference between them is within the clinical acceptable range.

# Aim and Hypothesis

## Aim

The aim of this study was to compare the accuracy (concordance of the initial prosthetic plan and final prosthetic outcome) of immediate implant placement and late implant placement using tooth-supported surgical guide.

## Hypothesis

The accuracy of final implant position is greater for late implant placement than immediate implant placement with tooth-supported surgical guide.

## Material and Methods

As a retrospective review, this study analyzed records of patients who had undergone guided implant surgery at Tufts University School of Dental Medicine (TUSDM), postgraduate prosthodontics department and treated in a period from January 1, 2017 to September 30, 2020. Institutional Review Board (IRB) approval was obtained for the study.

### Inclusion criteria

- Patients who had immediate implant placement (at the same time of tooth extraction) or late implant placement (at least 6 months after tooth extraction) through guided surgery process using data superimposition and 3D printed tooth-supported surgical guide at TUSDM postgraduate prosthodontic department.
- Patients who had undergone implant level final impression and presented master cast with the implant analog in position.

### Exclusion criteria

- Patients on whom, for any reason the surgical guide could not be used for the fully guided drilling process.
- Patients who had not undergone guided implant placement following manufacturer’s protocol.
- Patients whose initial digital plan could not be retrieved from the software.
- Patients whose implant master casts were damaged and inappropriate for analysis.

A total of 60 patients and 151 implants were reviewed. This study was conducted on a total of 48 patients and 92 implants, which fulfilled the inclusion criteria under review of the records. All 48 patients were treated with dental implants (Straumann, Basel, Switzerland) with virtual implant planning. The implant surgeries were performed by residents under the supervision of a surgically trained faculty member at TUSDM postgraduate prosthodontics department. After the review of records, two groups were identified based on the timing of implant placement. Group 1 consisted of 25 patients with immediate implant placement, including a total of 41 implants, and Group 2 consisted of 29 patients with late implant placement, which included a total of 51 implants. 6 patients belonged to both groups.

Query was made by the IT department of Tufts Technology Service (TTS) for supplying patients' information regarding age, gender, medical history, and number of remaining teeth at the time of implant placement. Also, the information of implant surgery was obtained from the query including implant flatform, types and lengths, implant position, type of guided sleeves (H4, H6), number of implants placed, flap or flapless implant surgery, and the timing of implant placement.

**Virtual Implant Planning**

Implant surgeries were virtually planned, and the design of surgical guides was performed with the computer implant planning software, Co-Diagnostix (Dental Wings, Montreal, Canada). Cone beam computed tomography (CBCT) images obtained from the same tomographic machine (i-CAT®, Imaging Sciences, Hatfield, PA, USA) taken by a single radiologist. The CBCT images were exported from the medical imaging software, MiPACS Dental Enterprise Viewer (Medicor Imaging, North Carolina, USA) and imported into Co-Diagnostix as DICOM files. CBCT image segmentation was performed to remove unnecessary portion of the images for the purpose of obtaining clearest image for virtual implant planning.

Intra-oral scanning was performed, and scanned images were obtained as STL files from intra-oral scanner, TRIOS (3 Shape, Copenhagen, Denmark). The STL files were imported into Co-Diagnostix and superimposed on CBCT images using stationary landmarks such as teeth or radiopaque markers. Afterwards, either wax-up cast or patient's provisional restoration were scanned with TRIOS and the obtained STL files were superimposed on CBCT images and the scanned intra-oral images. After superimposition of DICOM and two STL files, virtual implant planning was completed for each patient aiming to adequate final prosthetic plan. Implant types, length, and diameter were selected based on the anatomical structures and final prosthetic plan.

**Surgical Guide Design and Fabrication**

All surgical guides were designed on Co-Diagnostix based on the planned implant position. The guide sleeves were placed on the software with two different heights (H4, H6) to avoid interference between the sleeves and underlying soft or hard tissue. Multiple inspection windows were positioned correspondingly to ensure the proper adaptation of the surgical guides to the underlying supporting structure. All surgical guides were printed using 3D printer, Varseo S (BEGO, Bremen, Germany) utilizing stereolithography (SLA) on liquid resin. After completion of printing, metal guide sleeves were placed into preset positions and attached with adhesives.

**Guided Implant Placement**

All patients had undergone guided implant placement with metal guide sleeves installed surgical guides, following implant manufacturer's protocol with guided implant osteotomy kit. Immediate implant placement was done on the same day of tooth extraction. Late implant placement was done on the healed site after equal to or more than six months of extraction.

**Implant Impression and Master Cast Quality Verification**

After guided implant placement and appropriate healing period, implant level final impressions were taken with either open tray or closed tray impression copings using either Poly-vinyl siloxane (PVS) or Polyether impression material. Implant analogs were connected to impression copings and all impressions were poured with type IV die stone, ResinRock (Whip-Mix, Louisville, KY, USA).

Disfigured master casts, such as missing implant analogs, fractured teeth, and damaged anatomical landmarks which can be used as references for superimposition, were excluded from the study. All master casts included in the study were without any conspicuous damage.

**Data Acquisition and Accuracy Evaluation**

CARES Mono Scanbody (Straumann, Basel, Switzerland) was used for master cast scanning. The scanbodies were placed on corresponding implant analogs of master casts, and all implant master casts were scanned using a desktop scanner, 7 Series (Dental Wings, Montreal, Canada). STL files containing three-dimensional implant position were exported from 7 Series and imported to Co-Diagnostix. The discrepancy between initial planned implant position and final implant position was evaluated at the three-dimensional perspectives. The data of angular deviation, 3D offset at base (implant shoulder), and 3D offset at tip (implant apex) were extracted and recorded from the treatment evaluation function in Co-Diagnostix. After data acquisition, analysis of the association between the groups and accuracy of guided implant placement was performed.

**Statistical Analysis**

Convenience sampling was performed from the qualifying records of patients who had undergone guided implant surgery between January 1, 2017 and September 30, 2020. For continuous variables, descriptive statistics (means, standard deviations, minima, and maxima) were computed. Statistical significance was assessed via mixed models to account for the clustering of implants within each subject. The outcome variables were angular deviation, 3D offset at implant base, and 3D offset at implant tip. The level of significance was established at $\alpha = 0.05$. Ninety-five percent confidence intervals were also computed. R version 3.5.3 was used for the statistical analysis.

# Results

## Descriptive data

A total of 48 patients and 92 implants were included in the study. 27 patients were female (56.2%) and 21 patients were male (43.8%). Each patient belonged to one or both of two groups, Group 1 (immediate placement) and Group 2 (late placement), based on the timing of implant placement. In regard to the patient level statistics, 25 patients (14 females and 11 males) were in Group 1, and 29 patients (15 females and 14 males) were in Group 2. A total of 6 patients (2 females and 4 males) had both immediate placed and late placed implants and belonged to both groups. The mean age of the 25 patients in Group 1 was 63.16 years (standard deviation (SD) ± 13.43), and the mean age of the 29 patients in Group 2 was 54.83 (SD ± 16.35).

Each implant belonged to one of two groups: 41 implants were placed immediately, and 51 implants were placed in healed sites. In terms of implant level statistics, the mean age of Group 1 subjects was 62.29 years (SD ± 11.29). 22 implants were placed in female patients (53.7%) and 19 implants were placed in male patients (46.3%) in Group 1. 51 implants belonged to Group 2. The mean age of group 2 subjects was 58.16 years (SD ± 14.78). 27 implants were placed in female patients (52.9%) and 24 implants were placed in male patients (47.1%) in Group 2 (for details see Table 1).

The implant position was divided into three categories: anterior, premolar and molar. Among the 41 implants in Group 1, 23 implants were placed in the anterior area (56.1%), 12 implants were placed in the premolar area (29.3%) and 6 implants were placed in the molar area (14.6%). 29 implants were placed in the maxillary arch (70.7%) and 12 implants were placed in the mandibular arch (29.3%). Out of 51 implants in Group 2, 20 implants were placed in the anterior area (39.2%), 9 implants were placed in the premolar area (17.6%) and 22 implants were placed in the molar area (43.1%). 35 implants were placed in the maxillary arch (68.6%) and 16 implants were placed in the mandibular arch (31.4%).

Three features of each implant case were discerned from the gathered information: macro-design, diameter, and length. Each feature was divided into three sub-categories, and the appropriate sub-category was identified for each implant case. With respect to the macro design, each implant case was identified as one of the following sub-categories: bone level (BL), bone level tapered (BLT), or tissue level (TL). In Group 1, there were 9 BL implants (22.0%), 30 BLT implants (73.2%) and 2 TL implants (4.9%). In Group 2, there were 5 BL implants (9.8%), 33 BLT implants (64.7%) and 13 TL implants (25.5%). For implant diameter, the sub-categories were 3.3 mm, 4.1 mm, and 4.8 mm. In Group 1, 10 implants were 3.3 mm (24.4%), 29 implants were 4.1 mm (70.7%), and 2 implants were 4.8 mm (4.9%). In Group 2, 19 implants were 3.3 mm (37.3%), 23 implants were 4.1 mm (45.1%), and 9 implants were 4.8 mm (17.6%). In terms of implant length, 6 mm and 8 mm implants were grouped together due to small sample sizes. In Group 1, 2 implants were equal to or smaller than 8 mm (4.9%), 15 implants were 10 mm (36.6%), and 24 implants were 12 mm (58.5%). In Group 2, 12 implants were equal to or smaller than 8 mm (23.5%), 27 implants were 10 mm (52.9%), and 12 implants were 12 mm (23.5%).

Based on whether a flapless placement was performed, 27 implants were placed without flap opening (65.9%) and 14 implants were placed with flap opening (34.1%) in Group 1. In Group 2, 9 implants were placed without flap opening (17.6%) and 42 implants were placed with flap opening (82.4%).

In terms of sleeve height, two different heights of metal guide sleeve, H4 (4 mm away from the bone crest) and H6 (6 mm away from the bone crest), were included. In Group 1, 5 implants were placed with H4 (12.2%) and 36 implants were placed with H6 (87.8%). In Group 2, 10 implants were placed with H4 (19.6%) and 41 implants were placed with H6 (80.4%).

**Results of Linear Mixed Models**

Three outcome variables were dealt with in depth for the study, which were angular deviation, 3D offset at implant base, and 3D offset at implant tip. The outcome variables were the deviation between the implant position in the initial virtual implant plan and the implant positions obtained from the scanned master cast with scanbodies. Two groups, Group 1 (immediate placement) and Group 2 (late placement), were analyzed with respect to the three outcome variables via linear mixed model statistical analysis.

The mean values of angular deviation between virtually planned implant position and final implant position were 2.83° (SD ± 1.47) in Group 1 and 2.55° (SD ± 1.40) in Group 2. The mean values of 3D offset at implant base were 0.77 mm (SD ± 0.29) in Group 1 and 0.58 mm (SD ± 0.25) in Group 2. The mean values of 3D offset at implant tip were 1.10 mm (SD ± 0.49) in Group 1 and 0.85 mm (SD ± 0.31) in Group 2. Based on the mixed model including group as the only fixed effect for those three outcome variables, the association for angular deviation was not statistically significant ($p > 0.05$), but the associations for 3D offset at implant base ($p = 0.002$) and 3D offset at implant tip ($p = 0.004$) were statistically significant. (Table 2-1, 2-2, and 2-3)

Regarding the implant position, the mean values of the angular deviation in Group 1 were greatest in premolar (3.25°), then molar (2.89°), and smallest in anterior (2.83°). The mean values of the 3D offset at implant base and 3D offset at implant tip in Group 1 were greatest in premolar (0.78

mm for 3D offset at implant base and 1.16 mm for 3D offset at implant tip), then anterior (0.77 mm, 1.10 mm), and smallest in molar (0.70 mm, 1.05 mm). In Group 2, the mean values were highest in molar (2.56° for angular deviation, 0.59 mm for 3D offset at implant base, and 0.85 mm for 3D offset at implant tip), then anterior (2.48°, 0.58 mm, 0.83 mm), and lowest in premolar (2.26°, 0.58 mm, 0.81 mm). (Table 3)

With respect to the angular deviation, reference categories for the multivariable mixed model were defined as Group 1, 10 mm in length, H4 in sleeve height, anterior in implant position, and maxilla in jaw. In the multivariable model, Group 2 had an estimated coefficient of -0.28 (95% CI: -0.99 to 0.43), indicating lower angular deviation in Group 2 than Group 1 when adjusting for the other variables in the model. Compared to the reference category of 10 mm in implant length, shorter implants had less deviation and longer implants had more deviation. For sleeve height, H6 was estimated to have less deviation compared to H4. Regarding the implant position, premolar had an estimated coefficient of 1.08, and molar had an estimated coefficient of 0.78, with anterior position serving as the reference category. Mandible was estimated to have less deviation than maxilla according to the multivariable model. However, the results of this model were deemed not statistically significant ($p > 0.05$) except for the difference between anterior and premolar ($p = 0.009$). (Table 4-1)

The 3D offset at implant base was also analyzed using a multivariable mixed model with the same reference categories as above. Group 2 had an estimated coefficient of -0.18 (95% CI: -0.32 to -0.05), indicating that late implant placement had less discrepancy of 3D offset at implant base than immediate implant placement. In terms of implant length, sleeve height and jaw, the direction of association was the same as that observed for angular deviation. For implant position, premolar was estimated to have more discrepancy than anterior, whereas molar was estimated to have less discrepancy than anterior. There was a statistically significant difference between Group 1 and Group 2 ($p = 0.010$), but all other differences were not statistically significant ($p > 0.05$). (Table 4-2)

Lastly, the 3D offset at implant tip was also analyzed via a multivariable mixed model with the same reference categories as above. With Group 1 as a reference, Group 2 had an estimated coefficient of -0.22 (95% CI: -0.41 to -0.02), indicating that late implant placement had less discrepancy than immediate implant placement. Similar as the results for angular deviation and 3D offset at implant base, shorter implant, H6 sleeve height, and mandible were estimated to have less discrepancy. For implant position, both premolar and molar had positive estimated coefficients in the model, with anterior as the reference category. There were statistically significant differences between groups ($p = 0.033$) and between anterior and premolar ($p = 0.044$). Other associations were not statistically significant ($p > 0.05$). (Table 4-3)

# Discussion

## Clinical implications

The current study analyzed differences between immediate implant placement and late implant placement in terms of angular deviation, 3D offset at implant base, and 3D offset at implant tip. For immediate implant placement with 41 implants, the mean angular deviation was 2.83°, the mean 3D offset at the implant base was 0.77 mm, and the mean 3D offset at the implant tip was 1.10 mm. For late implant placement with 51 implants, the mean angular deviation was 2.55°, the mean 3D offset at implant base was 0.58 mm, and the mean 3D offset at implant tip was 0.85 mm. The difference between groups in terms of angular deviation was not statistically significant, whereas group differences in terms of 3D offsets at implant base and tip were statistically significant.

A systematic review demonstrated the accuracy of guided surgery of tooth-supported surgical guide.[23] The results demonstrated that the mean angle deviations ranged from 2.91° to 4.88°, the mean 3D deviations at the implant base were from 0.81 mm up to 2.08 mm., and 3D deviation at the implant tip showed from 0.95 mm up to 2.59 mm. In comparison of the values of the current study with those of this systematic review, both groups have acceptable inaccuracy even though immediate implant placement has bigger numbers than late implant placement. Another study compared the accuracy of implant placement using free-hand method and guided method. The outcomes showed that the mean angular deviations were from 9.8 to 10.9°, 3D deviations at the implant base were from 2.4 mm to 2.5 mm, and 3D deviations at the implant tip were from 2.0 mm up to 2.5 mm in free-hand method.[13] For comparison with the values of free-hand implant placement method, the values of both groups in the current study were considerably smaller than the values of free-hand method. Even though immediate implant placement is less accurate than late implant placement, the discrepancy is within the acceptable inaccuracy compare to the value of guided method and free-hand method in other studies.

In the implant position, all positions showed higher values for the three outcome variables in immediate implant placement compared to late implant placement. However, while immediate implant placement cases had overall higher values compared to late implant placement cases, when looking at the values of the three outcome variables within each of the two types of implant placements, the implant placements had their own unique tendencies. For immediate implant placement, the premolar area showed biggest mean values in all outcomes (3.25° of angular deviation, 0.78 mm in 3D offset at base, 1.16 mm in 3D offset at tip). However, it was smallest on the premolar area in late implant placement. (2.26° of angular deviation, 0.58 mm in 3D offset at base, 0.81 mm in 3D offset at tip). These results may be due to the relatively modest and uneven sample sizes for the different implant positions.

According to the results of a multivariable mixed model, longer implants presented higher values of all deviations, although the differences were not statistically significant. This is because the tip of longer implant is further from the metal sleeves of surgical guides, which could make larger discrepancy than shorter implants. Longer implants were used more often on Group 1, due to the need to obtain primary stability in fresh extraction sockets. Implants with 12 mm in length were used more often in immediate implant placement (58.5%), on the other hand, implants with 10 mm in length were the main choice in late implant placement (52.9%). To put that in perspective, the greater use of longer implants could be the one of the factors why immediate implant placement showed bigger deviations compared to late implant placement.

## Limitations

A major limitation of the current study was the sample population. There was a lack of distribution of samples in each category of the independent variables because of the retrospective nature of the study and the convenience sampling method. For example, immediate implant placement in molar area was the least amount (14.6%), but the molar area was the category most represented in late implant placement (43.1%). In terms of implant length, the majority was 12 mm for immediate implant placement (58.5%), but it was 10 mm for late implant placement (52.9%). The even distribution with larger sample size would produce more statistically strong results in this study.

Another limitation was the discrepancy of accuracy that resulted from using two different scanners. Intraoral scanning was used for virtual implant planning, and master cast scanning was used for the final implant position. Discrepancies in accuracy may have been minimized if intraoral scanning was used for the final implant position as well.

## Significance of Current Study and Suggestion for Future Investigations

Guided implant surgery has been demonstrated to increase the predictability of implant surgical procedures and it is important for clinicians to be conscious of potential inaccuracies in guided surgery.

Future investigations should compare the accuracy of immediate implant placement and late implant placement with tooth-supported surgical guide in each position and each independent variable with larger sample size. More cases within the inclusion criteria of the study need be followed and included into future studies to reinforce the sample population and the significant result.

# Conclusion

Within the limitations of this study, the following conclusions can be drawn:

1. When comparing the angular deviation between immediate implant placement and late implant placement, no statistically significant difference was found.
2. When comparing 3D offsets at implant base and 3D offset at implant tip between immediate implant placement and late implant placement, immediate implant placement had significantly higher values than late implant placement.

# APPENDICES

1. Appendix A: Tables
2. Appendix B: Figures

## Appendix A: tables

Table 1. Demographics of patients included in the study, implant position, characteristics and surgical procedure of each studied group (% in parentheses).

| | | Group 1 – Immediate placement | Group 2 – Late placement |
|---|---|---|---|
| **Gender** | | | |
| | Female | 22 (53.7) | 27 (52.9) |
| | Male | 19 (46.3) | 24 (47.1) |
| **Age (Mean / SD)** | | 62.29 / 11.29 | 58.16 / 14.78 |
| **Implant position** | | | |
| | Anterior | 23 (56.1) | 20 (39.2) |
| | Premolar | 12 (29.3) | 9 (17.6) |
| | Molar | 6 (14.6) | 22 (43.1) |
| **Jaw** | | | |
| | Maxilla | 29 (70.7) | 35 (68.6) |
| | Mandible | 12 (29.3) | 16 (31.4) |
| **Implant macro-design** | | | |
| | Bone Level | 9 (22.0) | 5 (9.8) |
| | Bone Level Tapered | 30 (73.2) | 33 (64.7) |
| | Tissue Level | 2 (4.9) | 13 (25.5) |
| **Implant diameter** | | | |
| | 3.3 | 10 (24.4) | 19 (37.3) |
| | 4.1 | 29 (70.7) | 23 (45.1) |
| | 4.8 | 2 (4.9) | 9 (17.6) |
| **Implant length** | | | |
| | ≤ 8 | 2 (4.9) | 12 (23.5) |
| | 10 | 15 (36.6) | 27 (52.9) |
| | 12 | 24 (58.5) | 12 (23.5) |
| **Flapless Placement** | | | |
| | Flapless | 27 (65.9) | 9 (17.6) |
| | Flap | 14 (34.1) | 42 (82.4) |
| **Sleeve height** | | | |
| | H4 | 5 (12.2) | 10 (19.6) |
| | H6 | 36 (87.8) | 41 (80.4) |

Table 2-1. Angular deviation by group, and results of a mixed model including group as the only fixed effect

| | Angle (°) | | | | | |
|---|---|---|---|---|---|---|
| | Mean | SD | Min | Max | Model Coefficient (95% CI) | P |
| **Group 1 – Immediate placement** | 2.83 | 1.47 | 0.4 | 5.6 | Ref | |
| **Group 2 – Late placement** | 2.55 | 1.40 | 0.4 | 6.9 | -0.24 (-0.88, 0.41) | 0.467 |

Table 2-2. 3D offset at implant base by group, and results of a mixed model including group as the only fixed effect

| | 3D offset (Base) (mm) | | | | | |
|---|---|---|---|---|---|---|
| | Mean | SD | Min | Max | Model Coefficient (95% CI) | P |
| **Group 1 – Immediate placement** | 0.77 | 0.29 | 0.11 | 1.37 | Ref | |
| **Group 2 – Late placement** | 0.58 | 0.25 | 0.07 | 1.14 | -0.19 (-0.31, -0.07) | 0.002 |

Table 2-3. 3D offset at implant tip by group, and results of a mixed model including group as the only fixed effect

| | 3D offset (Tip) (mm) | | | | | |
|---|---|---|---|---|---|---|
| | Mean | SD | Min | Max | Model Coefficient (95% CI) | P |
| **Group 1 – Immediate placement** | 1.10 | 0.49 | 0.3 | 2.11 | Ref | |
| **Group 2 – Late placement** | 0.85 | 0.31 | 0.38 | 1.8 | -0.27 (-0.45, -0.09) | 0.004 |

Table 3. Means and standard deviations of each implant position

| | Group 1 – Immediate placement | | | | | | Group 2 – Late placement | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Angle (°)** | | **3D offset (Base) (mm)** | | **3D offset (Tip) (mm)** | | **Angle (°)** | | **3D offset (Base) (mm)** | | **3D offset (Tip) (mm)** | |
| | Mean | SD | Mean | SD | Mean | SD | Mean | SD | Mean | SD | Mean | SD |
| **Anterior** | 2.83 | 1.47 | 0.77 | 0.29 | 1.10 | 0.49 | 2.48 | 1.36 | 0.58 | 0.25 | 0.83 | 0.30 |
| **Premolar** | 3.25 | 1.48 | 0.78 | 0.28 | 1.16 | 0.52 | 2.26 | 1.09 | 0.58 | 0.27 | 0.81 | 0.27 |
| **Molar** | 2.89 | 1.49 | 0.70 | 0.32 | 1.05 | 0.53 | 2.56 | 1.41 | 0.59 | 0.25 | 0.85 | 0.31 |

Table 4-1. Results of a multivariable mixed model for angular deviation

| | | **Angle (°)** | |
|---|---|---|---|
| | | Model Coefficient (95% CI) | **P** |
| **Group 1 – Immediate placement** | | Ref | |
| **Group 2 – Late placement** | | -0.28 (-0.99, 0.43) | 0.427 |
| **Length** | **≤8** | -0.02 (-0.97, 0.93) | 0.965 |
| | **10** | Ref | |
| | **12** | 0.23 (-0.56, 1.03) | 0.556 |
| **Sleeve height** | **H4** | Ref | |
| | **H6** | -0.41 (-1.41, 0.59) | 0.415 |
| **Position** | **Anterior** | Ref | |
| | **Premolar** | 1.08 (0.29, 1.87) | 0.009 |
| | **Molar** | 0.78 (-0.22, 1.78) | 0.124 |
| **Jaw** | **Maxilla** | Ref | |
| | **Mandible** | -0.41 (-1.35, 0.54) | 0.390 |

Table 4-2. Results of a multivariable mixed model for 3D offset at implant base

| | | 3D offset (Base) (mm) | |
|---|---|---|---|
| | | Model Coefficient (95% CI) | **P** |
| **Group 1 – Immediate placement** | | Ref | |
| **Group 2 – Late placement** | | -0.18 (-0.32, -0.05) | 0.010 |
| **Length** | **≤8** | -0.03 (-0.23, 0.17) | 0.777 |
| | **10** | Ref | |
| | **12** | 0.02 (-0.18, 0.14) | 0.804 |
| **Sleeve height** | **H4** | Ref | |
| | **H6** | -0.10 (-0.30, 0.10) | 0.297 |
| **Position** | **Anterior** | Ref | |
| | **Premolar** | 0.03 (-0.14, 0.19) | 0.752 |
| | **Molar** | -0.04 (-0.26, 0.17) | 0.679 |
| **Jaw** | **Maxilla** | Ref | |
| | **Mandible** | -0.04 (-0.21, 0.13) | 0.660 |

Table 4-3. Results of a multivariable mixed model for 3D offset at implant tip

| | | 3D offset (Tip) (mm) | |
|---|---|---|---|
| | | Model Coefficient (95% CI) | **P** |
| **Group 1 – Immediate placement** | | Ref | |
| **Group 2 – Late placement** | | -0.22 (-0.41, -0.02) | 0.033 |
| **Length** | **≤8** | -0.21 (-0.48, 0.05) | 0.114 |
| | **10** | Ref | |
| | **12** | 0.09 (-0.13, 0.31) | 0.407 |
| **Sleeve height** | **H4** | Ref | |
| | **H6** | -0.09 (-0.37, 0.19) | 0.528 |
| **Position** | **Anterior** | Ref | |
| | **Premolar** | 0.23 (0.01, 0.45) | 0.044 |
| | **Molar** | 0.16 (-0.12, 0.44) | 0.264 |
| **Jaw** | **Maxilla** | Ref | |
| | **Mandible** | -0.09 (-0.36, 0.17) | 0.472 |

**Appendix B: Figures**

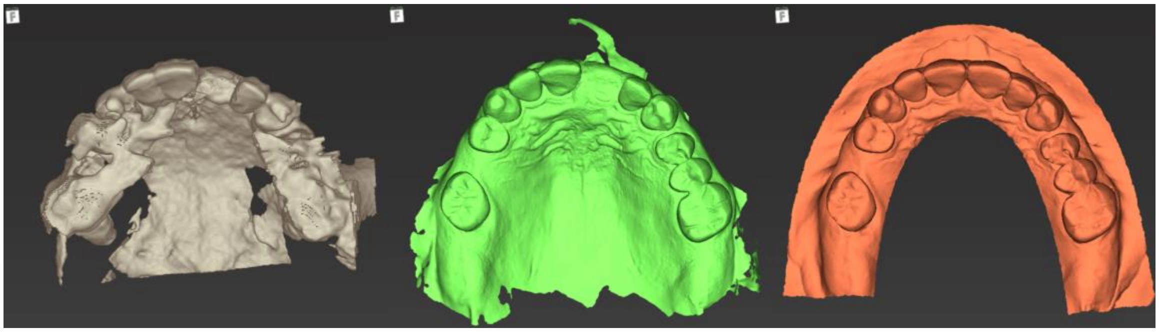

Figure 1: Preparing of patient's preoperative CBCT scan image (DICOM), preoperative intraoral scanned image (STL) and wax-up cast scanned image (STL)

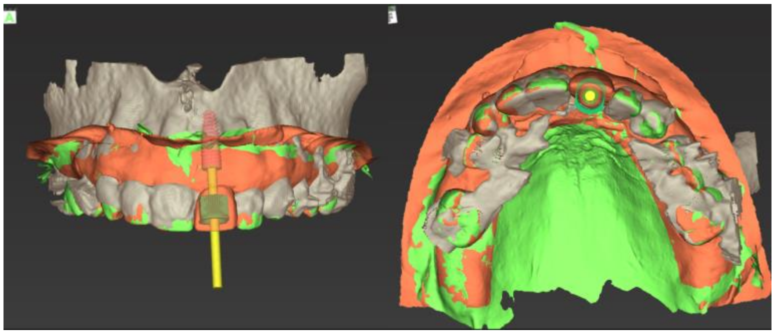

Figure 2: Superimposition of three scanned files, patient's preoperative CBCT scan image (DICOM), patient's preoperative intraoral scanned image (STL), and wax-up cast scanned image (STL)

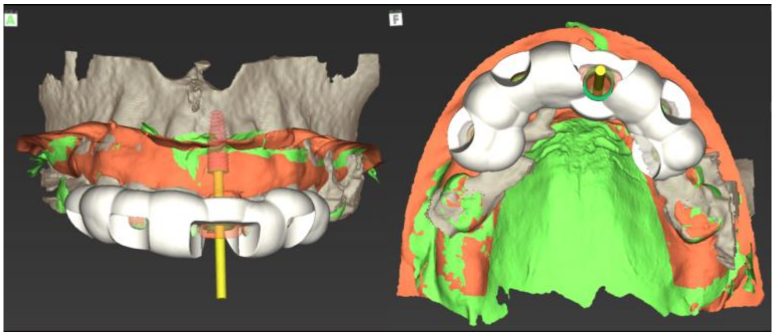

Figure 3: After implant planning, the surgical guide design is done with adequate guide sleeve and multiple inspection windows.

Figure 4: Printed tooth-supported surgical guide

Figure 5: Preoperative #9 site.

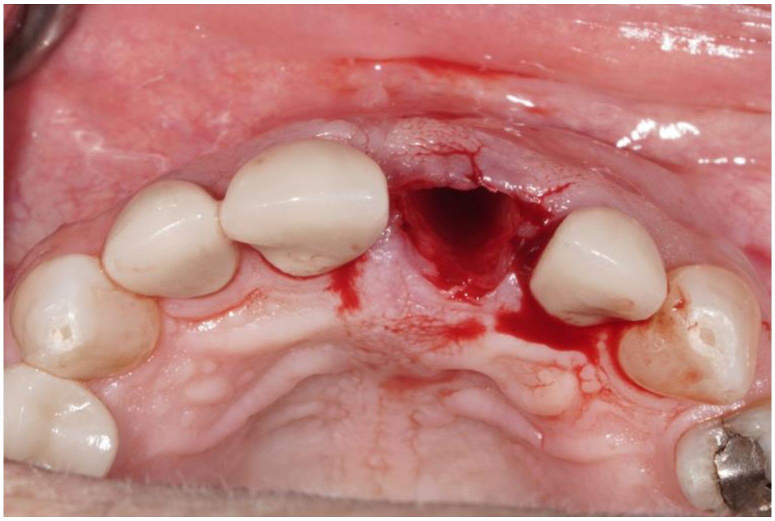

Figure 6: Extraction was done.

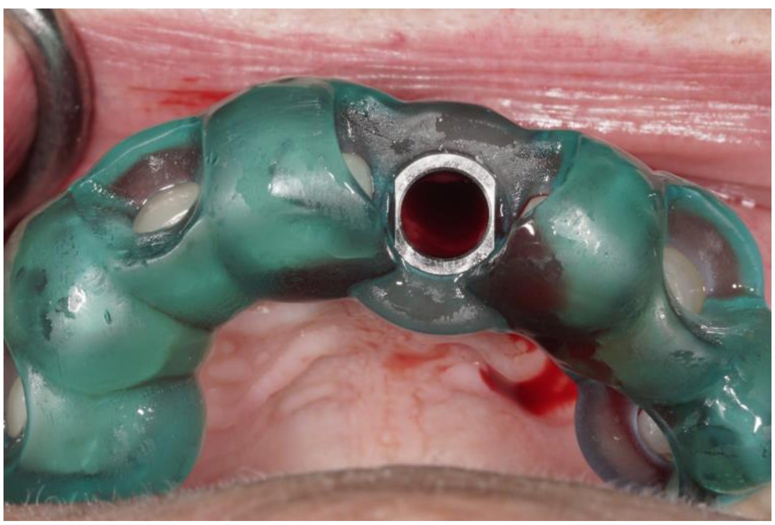

Figure 7: Extraction site with tooth-supported surgical guide

Figure 8: Immediate implant placement was done with tooth-supported surgical guide.

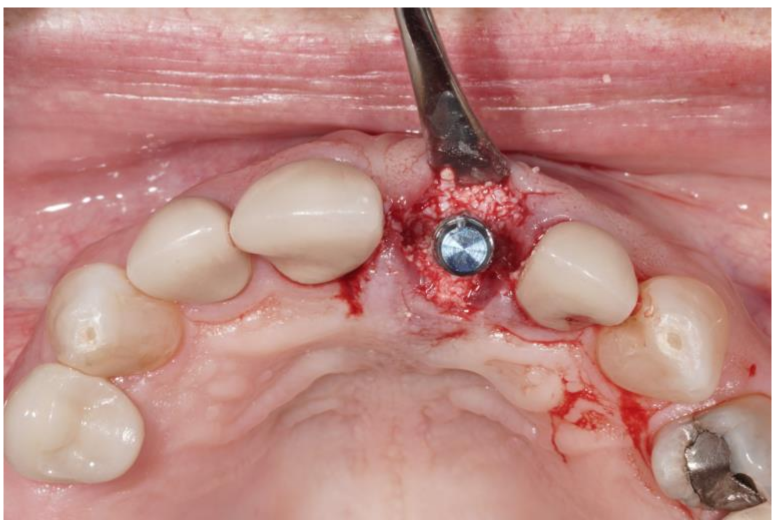

Figure 9: Bone grafting at the gap between bone and implant surface

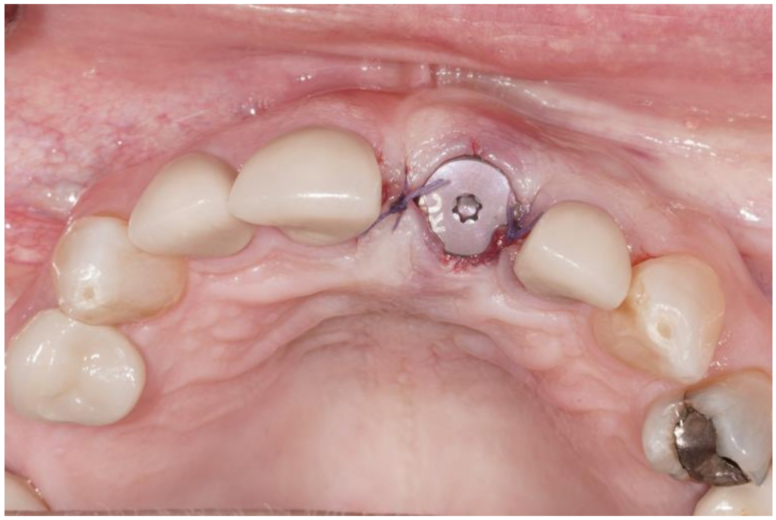

Figure 10: Healing abutment was placed.


Figure 11: Master cast was fabricated with implant analog.


Figure 12: CARES Mono Scanbody (Straumann) was placed.

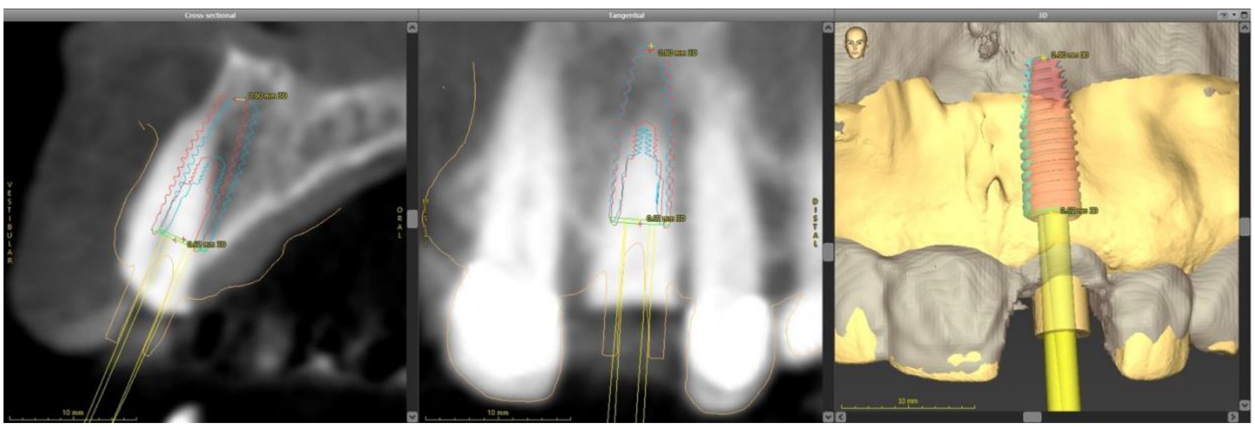


Figure 13: Three-dimensional deviation of implant position was observed between initially planned implant position (blue) and final implant position (red).

# REFERENCES


1. Lang NP, Pjetursson BE, Tan K, Bragger U, Egger M, Zwahlen M. A systematic review of the survival and complication rates of fixed partial dentures (FPDs) after an observation period of at least 5 years. *Clin Oral Implants Res.* 2004;15(6):643-653.
2. Buser D, Weber HP, Bragger U. The treatment of partially edentulous patients with ITI hollow-screw implants: presurgical evaluation and surgical procedures. *Int J Oral Maxillofac Implants* 1990;5:165-175.
3. Papaspyridakos P, Chen CJ, Singh M, Weber HP, Gallucci GO. Success criteria in implant dentistry: A systematic review. *J Dent Res* 2012;91(3):242-248.
4. Papaspyridakos P, Bordin TB, Kim YJ, El-Rafie K, Pagni SE, Natto ZS, Teixeira ER, Chochlidakis K, Weber HP. Technical complications and prosthesis survival rates with implant-supported fixed complete dental prostheses: A retrospective study with 1- to 12-year follow-up. *Journal of Prosthodont* 2020; 29(1):3-11.
5. Tahmaseb A, Wismeijer D, Coucke W, Derksen, W. Computer technology applications in surgical implant dentistry: A systematic review. *Int J Oral Maxillofac Implants* 2014;29 Suppl.:25-42.
6. Berglundh T, Persson L, Klinge B. A systematic review of the incidence of biological and technical complications in implant dentistry reported in prospective longitudinal studies of at least 5 years. *J Clin Periodontol.* 2002;29(3):197-212.
7. Widmann G, Bale RJ. Accuracy in computer-aided implant surgery – A review. *Int J Oral Maxillofac Implants* 2006;21:305-313.
8. Jung RE, Schneider D, Ganeles J, Wismeijer D, Zwahlen M, Hammerle CH, Tahmaseb A. Computer technology applications in surgical implant dentistry: A systematic review. *Int J Oral Maxillofac Implants* 2009;24(7):92-109
9. Van Assche N, van Steenberghe D, Quirynen M, Jacobs R. Accuracy assessment of computer-assisted flapless implant placement in partial edentulism. *J Clin Periodontol*. 2010;37(4):398-403.

10. Cassetta, M, Stefanelli LV, Giansanti M, Calasso S. Accuracy of implant placement with a stereolithographic surgical template. *Int J Oral Maxillofac Implants* 2012;27(3), 655–663.
11. Schneider D, Marquardt P, Zwahlen M, Jung RE. A systematic review on the accuracy and the clinical outcome of computer-guided template-based implant dentistry. *Clin Oral Implants Res.* 2009;20 Suppl 4:73-86.
12. Van Assche N, Vercruyssen M, Coucke W, Teughels W, Jacobs R, Quirynen M. Accuracy of computer-aided implant placement. *Clin Oral Implants Res.* 2012;23 Suppl 6:112-123.
13. Nickenig HJ, Wichmann M, Hamel J, Schlegel Ka, Eitner S. Evaluation of the difference in accuracy between implant placement by virtual planning data and surgical guide templates versus the conventional free-hand method – a combined in vivo – in vitro technique using cone-beam CT (Part II). *J Craniomaxillofac Surg* 2010;38:488-493.
14. Schwartz-Arad D, Chaushu G. The ways and wherefores of immediate placement of implants into fresh extraction sites: A literature review. *J Periodontol* 1997;68:915-923
15. Hammerle CH, Chen ST, Wilson TG Jr. Consensus statements and recommended clinical procedures regarding the placement of implants in extraction sockets. *Int J Oral Maxillofac Implants* 2004;19 Suppl.:26-28.
16. Lang NP, Pun L, Lau KY, Li KY, Wong MCM. A systematic review on survival and success rates of implants placed immediately into fresh extraction sockets after at least 1 year. *Clin Oral Implants Res.* 2012;23(5), 39–66.
17. Chen ST, Buser D. Clinical and esthetic outcomes of implants placed in postextraction sites. *Int J Oral Maxillofac Implants* 2009;24 Suppl.:186–217.
18. Evans CDJ, Chen ST. Esthetic outcomes of immediate im- plant placements. *Clin Oral Implants Res.* 2008;19:73–80.
19. Benic GI, Mokti M, Chen CJ, Weber HP, Hämmerle CH, Gallucci GO. Dimensions of buccal bone and mucosa at immediately placed implants after 7 years: a clinical and cone beam computed tomography study. *Clin Oral Implants Res*. 2012;23(5):560-6.
20. Araújo MG, Silva CO, Souza AB, Sukekava F. Socket healing with and without immediate implant placement. *Periodontol 2000*. 2019;79(1):168-177.

21. Levine RA, Ganeles J, Kan J, Fava PL. 10 Keys for Successful Esthetic-Zone Single Implants: Importance of Biotype Conversion for Lasting Success. *Compend Contin Educ Dent.* 2018;39(8):522-529.
22. Froum SJ, Cho SC, Francisco H, Park YS, Elian N, Tarnow DP. Immediate implant placement and provisionalization - two case reports. *Pract Proced Aesthet Dent*. 2007;19(10):621-8.
23. Raico Gallardo YN, da Silva-Olivio IRT, Mukai E, Morimoto S, Sesma N, Cordaro L. Accuracy comparison of guided surgery for dental implants according to the tissue of support: a systematic review and meta-analysis. *Clin Oral Implants Res*. 2017;28(5):602-612.