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Comparative evaluation of the virtual planned position and actual position of implant in mandibular posterior region using a DIOnavi system: An in-vivo study

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***Abstract*---**Statement of problem: Implant placement in the mandibular posterior regions is often challenging because of limited space and insufficient accessibility. Purpose: The purpose of this clinical study was to investigate the accuracy of computer-guided surgery with a long drill key to place implants in the mandibular posterior regions. Material and methods: Computer-guided implant surgery was performed for 15 participants requiring implants in mandibular posterior region. This procedure involved using 6mm long

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drill key to guide the 2.0 mm diameter drill. The planned and placed implant position were scanned and superimposed to evaluate the accuracy of the guide. Results: A total of 15 implants were place where the mean linear deviation was 0.4 mm (range, 0.15 to 1.30 mm) for the implant shoulder and 0.45 mm (range, 0 to 1.48 mm) for the implant apex. The mean angular deviation was 1.4 degrees (0.38 to 4.89 degrees). The mean depth deviation was 0.61 mm (0.10 to 1.85 mm). The differences between virtually planned implants and actual positions of the implants were statistically significant for all variables ($P<.05$). Conclusion: Within the conditions and the limitations of this study, the following conclusion was drawn: The accuracy of computer-guided implant placement may be enhanced by using a drill key and may thus enable more accurate implant placement in posterior regions.

***Keywords*---**dental implants, accuracy, computer-guided surgery, implant position, displacement measurement.

Introduction

During the eighteenth century, researchers experimented with using noble metals such as gold and silver to rehabilitate missing teeth. Unfortunately, these methods were not successful as the foreign body implants that were used were rejected by the host system.[1-4] Various solutions have been developed over the years to improve the quality of dental implants. One of these is the design of the implant body. This has led to the development of surface treatments that can improve the osseointegration and bone healing.

Despite the limitations of these methods, the scientific literature still supports the concept of implant-prosthetic rehabilitations, which have a 5-year survival rate of over 90%. Today, the advancements in the field of implant surgery have made these procedures more practical and less invasive.[5] Due to the technological advancements in the field of implantology, the use of computer-assisted or computer-guided implant procedures has increased. This concept ensures that the placement of the implant is performed according to the exact anatomical structure of the tooth.

This concept was developed by a group of researchers led by Verstreken et al. Their goal was to create a procedure that can precisely place the implant in the desired location.[6] Modern techniques for performing implant surgery rely on the use of 3D reconstruction techniques. These tools allow the surgeon to visualize the patient's anatomical features and provide him or her with accurate information about the procedure.

The DICOM files generated by these tools are used to create 3D models of the patient's internal structures. These images can then be used to guide the placement of the implant.[7] The superimposition of the DICOM files can be performed manually or automatically depending on the software used for the procedure.

Through the use of imaging techniques, guided implant placement has been shown to reduce the duration of the procedure and improve the quality of the patient's recovery.[8] This technique can also be performed without the need for a traditional open procedure.Today, the use of 3D printed stents and templates is expected to continue to increase. These can be fabricated using various materials such as powder sintering techniques and light polymerizing resins.

The accuracy of the implant placement can also be measured by superimposing the image after it has been placed.Various methods are also available to transfer the information about the planned implant to the clinical situation. In 2009, Jung and colleagues presented two different types of implant planning. The former uses surgical templates or stents, while the latter uses computer-assisted or computer-guided implant procedures.

According to Jung and Vercruyssen, a static implant placement system is more accurate than a computer-assisted or computer-guided approach.[9-13]With the advancements in digital technology, a static computer-assisted implant planning system can be performed using software programs and surgical guides. A fully guided surgical guide is used for the control of the osteotomy and the placement of the implant. On the other hand, a pilot guided surgical guide is used for the pilot drill.[14-17]The surgical guides used for the pilot drill are made of prefabricated metal sleeves and are designed to be used with the appropriate tools and equipment.

For the fully guided protocol, the software combines the CBCT image and the virtual cast to create a 3D model of the patient's internal structures. This model is then used to simulate ideal tooth replacement. After the virtual intact model is created, the simulated bone is placed in a favorable position using the surgical guide.[18]

Various software programs are commercially available for the virtual planning of implants. Some of these include coDiagnostiX, Simplant Pro, and NobelClinician.[19] The software programs use various techniques to collect and interpret the geometric information about the bone surface and the mucosal surface from different perspectives. They can then align the various imaging datasets together to create an accurate registration of the scans.

The increasing acceptance of computer-assisted techniques and the use of digital data in the design and fabrication of surgical stents has led to the development of new procedures that require further investigation. Before the use of guided stents is considered a standard practice, it is important to evaluate the accuracy of the guide and the implant. The objective of the study is to evaluate the accuracy of the implants placed in the lower posterior region and the guided surgical stents used in the virtual plan.

Materials and Methods

15 participants we selected based on the inclusion & exclusion criteria requiring implants in the lower posterior region. Their remaining dentition had a healthy periodontium without any excessive dental pathology. Implants were placed in extraction sockets that had been healed for at least 3 months. Site with any disorders to the planned implant site / area, such as previous tumors, or radiation bone or any bone diseases or poor bone height were excluded.

The study was conducted at Bharati Vidyapeeth Deemed To Be University Dental College & Hospital, Pune, India with 15 participants in need of replacement of missing teeth in the lower posterior region. The clinical protocol was approved by the institutional ethical committees. The participants were explained the procedure and the protocol and a signed consent were obtained from each participant.

Pre-operative implant planning

Cone beam computed tomography (CBCT) data of the maxillary and mandibular jaws were acquired using a dental computed tomography scanner (PlanmecaRomexis 3D ® classic) for implant planning. Where the diagnostic procedure for the CBCT of the upper and the lower arches of FOV (8x8) was performed. The cross sectional slices of resolution 0.15 μm high definition was obtained at 1 μm interval.

Conventional impressions were made for the maxillary and mandibular teeth using Vinyl Polysiloxane impression material (3M ESPE soft putty and 3M ESPE Express XtVps impression material). Casts were poured in die stone (KalabhaiKal) and a digital laboratory scan were made. Digital standard tessellation language (STL) files generated from the lab scan model were then imported into a virtual implant planning software program (Implant Studio; 3Shape A/S). The data acquired from the CBCT scan was also imported into the virtual implant planning software and then merged with the STL files.

Once the data was merged, a prosthetically driven implant planning was conducted in the virtual implant planning software. When implant planning was complete, a static surgical guide with a metal sleeve was designed with the same software and printed by using a commercial printable resin (DIOnavi-SG; DIO Inc) in a 3D printer (Probe; DIO Inc).

Operative phase

Computer-guided flapless implant surgery was performed under local anesthesia. First, the static surgical guide was placed in the patient's mouth, and then the template was evaluated for intraoral fit and stability. The tissue punch was the first drill used in the sequence. After punching the soft tissue, a bone-flattening drill was used to shave the crestal bone surface as flat as possible to guide the first osteotomy drill in the correct direction. After flattening the bone surface, an implant osteotomy was prepared using a 2.0- mm-diameter drill. Drilling with the 2.0-mm diameter drill was guided using a 12-mm-long drill key (DIO Navi Guide;

DIO Inc). The lower part of the drill key was designed to be inserted into the mucosa that had been removed after use of the tissue punch and the bone-flattening drill. Drilling was then performed by using sequential drills with increasing diameters through the guide, without using a drill key. Based on the results of previous studies, all drillings were performed at a low speed (50 rpm) without irrigation. Implants (UFII; DIO Inc) were placed with guidance provided from the static surgical guide. Gingival formers were placed over the implants.

Post-operative implant scanning

All participants underwent postoperative CBCT scanning. To calculate the deviations between the planned and the placed implants, objects in the preoperative images were overlapped with their counterparts in the postoperative images. Overlapping of the images was performed automatically using a software program (Mimics 21.0; Materialise Dental). The software ran until the exact overlap between the images of the preoperative and postoperative objects was identified and did not require intervention from the operator, therefore excluding bias. Four deviation parameters were calculated between the planned and the placed implants:

1. linear deviation at the implant shoulder;
2. linear deviation at the implant apex;
3. angular deviation; and
4. depth deviation

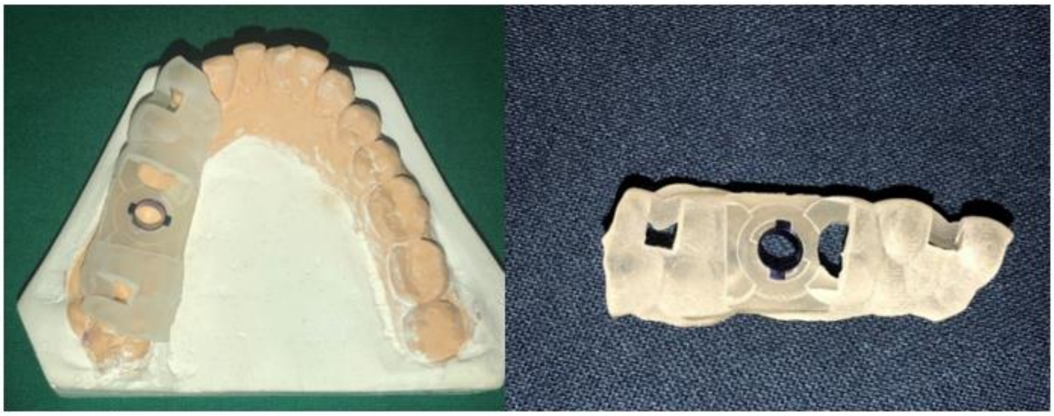

Figure 1. 3D printed static surgical template

Figure 2. Placement of the implant through the guide

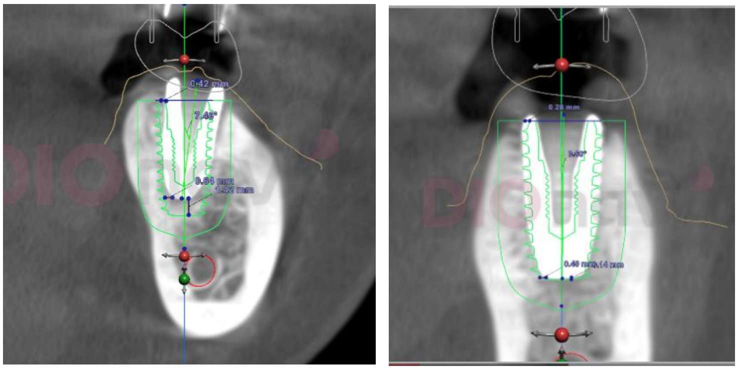

Figure 3. Superimposition scan of the pre planning position and placed implant

Results

Implant placement protocol was performed on all 15 participants. A total of 15 implants were placed. The implants were placed in the mandibular posterior region. The implants placed were 4.5 mm or 5.0 mm in diameter, and where the length of 7 to 11.5 mm varied depending on the bone height and the mandibular canal. All implants were accurately placed relative to the preoperative plan. All implants were restored with a delayed loading protocol.

The mean linear deviation was 0.4 mm (range, 0.15 to 1.30 mm) for the implant shoulder and 0.45 mm (range, 0 to 1.48 mm) for the implant apex. The mean angular deviation was 1.4 degrees (0.38 to 4.89 degrees). The mean depth deviation was 0.61 mm (0.10 to 1.85 mm). The differences between virtually planned implants and actual positions of the implants were statistically significant for all variables ($P<.05$).

Discussion

Computer-aided surgery can be performed using a static surgical template that reproduces the virtual implant position directly from CBCT data or a surgical navigation system (dynamic guide) that reproduces the virtual implant position directly from CT data and allows for intraoperative changes in implant position.[8,9] CAD/CAM surgical guides allow the clinician to satisfy functional and esthetic demands and ensure precise placement and predictable prosthetic outcomes. CAD/CAM surgical guides include a partially guided template, whereby only the osteotomy site is prepared using a pilot drill guide. However, a fully guided static template entails using one guide for osteotomy site preparation and implant delivery. Osteotomy sites are prepared using sequential, removable surgical drilling guides (generated using computer software and SLA). Because surgical templates may affect cooling during osteotomy, partially guided surgical templates are often designed with a single pilot drill guide to avoid excessive bone heating. Moreover, because surgery using a surgical template is often compromised by the patient's mouth opening size, a single drill guide can make preparation easier. Using a fully guided static template may further minimize access points and angular deviations because of the potential influence of operator positioning errors while using more than one guide or during manual implant placement.[20] Computer-assisted surgery is a type of procedure that uses a static surgical template to create a virtual implant position. It does not allow for the modification of the position during the surgery. With the help of 3D printing and computer-assisted design tools, a surgeon can create a customized surgical guide that fits seamlessly into the body.[21]

Modern digital implant planning procedures have plenty of advantages, such as reducing the risk of complications and increasing the efficiency of the operation. However, knowing the various parameters that affect the outcome is very important to avoid potential issues. The planning team also plays a vital role in making the process as successful as possible. The combination of these factors can affect the accuracy of the procedure. The quality of the data collected during a digital implant planning procedure is also affected by the nature of the scan and the patient's movement.[22] For instance, the image quality of a CBCT scan can be affected by various factors such as the contrast resolution and the field of view. Strictly following the correct radiographic procedure can prevent movement artifacts and minimize the effects of radiopaque restorations.[23-24]

According to a study conducted by Fluegge and colleagues, the increasing number of radiopaque restorations can affect the quality of data collected during a digital implant planning procedure[19]. In severe cases, scan prosthesis or a radiographic template can be used to minimize the effects of these restorations. In another study, the researchers found that manual segmentation of the CBCT scans produced better registration results than automated segmentation.[14] They also noted that cumulative errors could affect the quality of data collected during the planning process. The field of view must be appropriately placed to ensure that the data collected during the procedure are superimposable.

The current study was done to evaluate the accurate positioning of implant in mandibular posterior region by superimposing the scanned data of the implant planning position and placed implant position. The superimposition was done using 3 shapes Implant studios software. All implants were accurately placed relative to the preoperative plan. Where the mean linear deviation was 0.4 mm (range, 0.15 to 1.30 mm) for the implant shoulder and 0.45 mm (range, 0 to 1.48

mm) for the implant apex. The mean angular deviation was 1.4 degrees (0.38 to 4.89 degrees). The mean depth deviation was 0.61 mm (0.10 to 1.85 mm). The differences between virtually planned implants and actual positions of the implants were statistically significant for all variables (P<.05).

The first null hypothesis was rejected that no deviations would be found between the planned and placed implant position with a computer-guided surgery system using a long drill key was rejected. The results demonstrated a significant difference between virtually planned implants and placed implants in terms of angular deviations, deviations in position at the platform, and apex and depth deviations. However, although the values were statistically significant, the computer-guided system used in the present study allowed higher accuracy of implant placement than that previously reported. Tahmaseb et al.[33], in a systematic review of data retrieved from 24 studies, reported an inaccuracy at the implant entry point of 1.12 mm with a maximum of 4.5 mm and an inaccuracy of 1.39 mm at the apex of implants with a maximum of 7.1 mm , and the deviation of axis showed an average of 3.89° with a maximum of 21.16°.

Shen et al.[37] reported that from 57 implants inserted with the assistance of surgical templates, variation was 1.18 ±0.72 mm at the implant platform, 1.43 ±0.74 mm at the apex, 4.21 ±1.91 degrees in angulation, and 0.54 ±0.29 mm in depth. Cristache and Gurbanescu[36] reported that from 65 consecutive implants inserted with the direct drill guiding system, the placement errors measured were 0.79 (maximum, 2.30 mm) at the entry point and 1.17 (maximum, 3.22 mm) at the apex; the mean angular deviation was 2.34 (maximum, 4.22 degrees). Schneider et al.,[27] in a systematic review of the accuracy of computer-guided systems, reported that the mean horizontal deviation was approximately 1 mm at the entry point, approximately 1.6 mm at the apex, 0.5 mm in height, and 5 to 6 degrees in axis.

In the present study, the mean angular deviation was 1.4 degrees with a maximum of 4.89 degrees. The mean linear deviation was 0.64 mm with a maximum of 1.48 mm for the implant apex and 0.49 mm with a maximum of 1.30 mm for the implant shoulder. The higher accuracy in implant placement may be from the long drill key that guided the first osteotomy drill (a 2.0-mm-diameter drill) inside the surgical templates. The first drill is the most important because it determines the drilling axis. If an error occurs in the drilling axis inside the bone, it is difficult to correct or adjust the error. Therefore, the drill conditions for the first drill should be optimized to reduce the deviation of the implant placement. In the present study, a long drill channel was created using a 12-mm-long drill key that led to extended guidance for the first drill within the surgical template, thereby reducing the lateral movement of the drill.

There are various factors that can cause errors during a surgical procedure. One of these is the selection of the appropriate surgical equipment. Also, the gap between the drill and the guiding sleeve can affect the angular deviations. According to the various authors, a small gap and a high guiding sleeve can reduce the amount of lateral deviation. However, increasing the distance between the guide and the bone can influence the accuracy.[26] Also, as the guide sleeves are positioned high above the mucosa, it can be a daunting task to ensure that the drill is placed into the sleeve correctly. A study conducted by Bencharit et al. revealed that the fully guided approach is more accurate than the partly guided one. This suggests that it should be utilized to enhance the level of accuracy.[28] Surgical templates can be supported either by teeth, bone, or mucosa. The use of tooth supported surgical template probably provides more predictable outcomes in the term of accuracy in the implant positioning and placement.[29] Ozan et al. found a mean angular deviation of 2.91° in tooth-supported templates, 4.51° in implants placed with mucosa-supported templates, and 4.63° in implants placed with bone-supported templates. The mean coronal and apical deviations displayed a similar picture.[30-31]

In the current study, the use of tooth supported surgical template was used. As various literature supported that more precise placement of implant is observed with a tooth supported surgical template. The mean angular deviation noted was 1.4 degree with a maximum limit of 4.89 degree which is significantly minimal as compared to that with a mucosa supported templates. Fixation pins can also aid in achieving a greater precision, especially in non-tooth-supported templates. Nevertheless, a quintessential requirement for precision, is the adequate and stability of guide during the placement of implant. Anyway, adequate positioning of the template is a fundamental prerequisite for success.[32] The number of teeth and the location of the remaining teeth may impact the reliability of template-supported implant placement. For instance, it was shown that the implant placement in single-tooth gaps shows a minor deviation than in partially edentulous situations.

In 2012, a meta-analysis done by Van Assche et al. revealed that the mean deviation of the entry point was 1.09 mm, while the mean deviation at the apex was 1.28 mm.[25] It is noteworthy, that despite the fact, that a traditional freehand protocol is more commonly practiced, the guided protocol definitely provides an edge where overall deviation is considered. Vermeulen et al. noted that the freehand approach produced an average axial deviation of 7.63 degrees while the guided approach produced a 2.19-degree deviation. The horizontal deviations indicated by the guide and the freehand protocols were 0.42 and 1.27 millimeters. The survival rates of the guided and freehand procedures are comparable. Further, the use of computer-generated templates for implant design allows for better accuracy.[34-35]

The use of surgical template may sometimes interfere with effective surgical instrumentation. This in turn may affect the optimum utilization of the surgical space and precise placement of implants.[30] In this study, interference between the surgical handpiece and the opposing arch did occur when drilling was performed with the long drill key. It may have been because the long drill channel increased the distance between the prospective implant shoulder and the top of the surgical template. The lower part of the drill key was inserted into the mucosa and removed after using a tissue punch and a bone-flattening drill. Another factor leading to interference in some cases, was the limited mouth opening while placing the implants in the mandible second molar region.

The second hypothesis that no statistically significant deviations would be found in any direction in the mandibular implants inserted was rejected. The results demonstrated a significant difference in angular deviations, deviations in position at the platform, and apex and depth deviations. An explanation for this observation could be that the use of short guide keys was facilitated by implant location in posterior regions. Schneider et al.[30] reported that the maximum inaccuracy registered was measured for implants inserted in the posterior maxilla; limited access with surgical instruments in the posterior area caused high implant placement error. In the present study, as all implants were placed in the mandibular posterior region, surgery with a surgical template was compromised by the site of implant placement, mainly in the second molar region. The most notable error with guided surgery occurs in the vertical direction due to the blockage of the implant holders in the sleeves of the template during surgery leading to the implant being positioned more superficially.[21] Blockage is a secondary phenomenon resulting from deviation when drilling. In the present study, blockage did occur as the long drill key optimized the drilling procedure. The mean vertical discrepancy was 0.71 mm. The high accuracy in the vertical direction may be due to minimal error from image fusion, fixation of the surgical guide, and drilling of the osteotomy. In addition, the depth control system indicating the stop point, such as a stopper and a reference line, helped place the implant at the planned depth.

Within the constraints of this current study, it could be claimed that the use of computer-generated templates for the design of the implant placement allows for better accuracy. This advantage can be attributed to the extensive three-dimensional planning that goes into the design of the template, when compared to traditional surgical guides or freehand protocols. However, it would be prudent to note that other factors such as the accuracy of the data collected from the CBCT scan, precision of registration and the expertise of the surgeon or the prosthodontist, can be also influence the outcome of the process.

One limitation of the present study is that radiation exposure from the before and after CBCT scans were required to evaluate the precision of planned and placed implants. In future studies, if implant placement accuracy is assessed by matching the preoperative treatment plan imaging with postoperative digital impression imaging, further radiation exposure may be avoided without the requirement for postoperative CBCT. Another limitation is that the findings were derived from a small number of implant placements. Hence, further studies with a more significant number of participants may be necessary to determine whether these trends continue and how accurate the drill key technique is compared to a conventional control group.

Conclusion

The advantage of computer-generated static guide stents aids in better placement of implants when compared to the pilot-guided or freehand stents. But the accuracy of these stent may vary on the method of data collection and their registration to fabricate a guide. Also, the surgeon’s expertise plays a vital role in accurate implant placement. Thus, within the limitation of the study, the results indicate deviation of the implant at the apex, the shoulder, in the vertical direction and also in the implant axis. But these discrepancies are within the limits of clinical acceptability.

Within the conditions and the limitations of this study, the following conclusion was drawn:
The accuracy of computer-guided implant placement may be enhanced by using a drill key and may thus enable more accurate implant placement in posterior regions.

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