Frontiers in Health Informatics
ISSN-Online: 2676-7104
www.healthinformaticsjournal.com
2024; Vol 13: Issue 6
Open Access

Angular accuracy in pterygoid implant placement: Evaluating digitally guided surgical systems in the atrophic maxilla

Sangar H. Shekho[1], Othman A. Omer[2]
[1]Department of Radiology, Collage of Dentistry, Hawler Medical University, Erbil, Iraq.
[2]Oral and Maxillofacial Surgery department, Collage of Dentistry, Hawler Medical University, Erbil, Iraq.

Cite this paper as: Sangar H. Shekho, Othman A. Omer (2024) Angular accuracy in pterygoid implant placement: Evaluating digitally guided surgical systems in the atrophic maxilla. Frontiers in Health *Informatics*, *13(6)* 516-525

ABSTRACT
Introduction: The rehabilitation of atrophic maxillae presents significant challenges in the posterior maxilla where conventional implant placement cannot be placed due to limited bone volume. Pterygoid implants placed in the dense cortical bone of the pterygoid region offered a reliable alternative. This study evaluates the precision of digitally guided pterygoid implant placement by comparing preplanned virtual implant positions with postoperative outcomes using computer aided design (CAD) software.
Methods: A total of 20 patients with free ended atrophic posterior maxillae underwent implant placement using customized 3D-printed surgical guides designed through CAD software on preoperative CBCT data. Angular deviations between planned and placed implants were evaluated by merging the merged preoperative and postoperative CBCT scans in DICOM files in a CAD software. Descriptive statistical analysis was conducted to determine mean, range, and standard deviation of angular deviations.
Results: Angular deviations ranged from 1.0° to 12.8° with a mean deviation of 4.8° ± 3.1°. These values align with previously reported ranges for guided implant surgery but for shorter implant lengths, confirming the effectiveness of digitally guided systems in achieving precise implant placement.
Conclusion: Digitally guided surgery improves the accuracy of pterygoid implant placement, minimizing angular deviations and optimizing clinical outcomes. However, variability necessitates more refinement of protocols.
Keywords: Pterygoid implants, digital dentistry, CBCT, angular deviation, guided surgery.

INTRODUCTION

The new technological advancements in dental implant field have revolutionized the management of challenging anatomical conditions like the pterygoid region which characterized by its dense cortical bone offers an excellent anchorage site for dental implants, ensuring primary stability and facilitating immediate loading (Chrcanovic et al., 2020). The anatomical complexity and proximity to critical structures such as the maxillary sinus and the greater palatine canal necessitate precise planning and surgical execution to avoid complications and achieve long term success (Malo et al., 2016). Digitally guided implant surgery has emerged as a transformative approach in this domain, offered an improved accuracy and predictability through advanced imaging, The CAD and the 3D printing technologies (Bornstein et al., 2021). Unlike conventional freehand methods, guided surgery enables clinicians to integrate preoperative cone beam computed tomography (CBCT) scans with CAD software to create customized surgical guides to enhance the accuracy of implant placement by controlling drill trajectory, depth, and angulation, significantly reducing operator-dependent variability and the risk of intraoperative errors (Jacobs et al., 2018).

This study evaluates the precision of digitally guided pterygoid implant placement by comparing preoperative virtual plans with postoperative implant position using CBCT based analysis. It focuses on angular deviations between the planned and actual implant axes as a measure of surgical accuracy. Angular deviation is a important parameter in assessing implant placement outcomes, as excessive deviations can compromise biomechanical stability, increase the risk of prosthetic misalignment, and jeopardize adjacent anatomical structures (Schneider et al., 2020). The integration of CBCT imaging and STL format of the oral cavity scan in the CAD software to fabricate 3D-printed surgical guides has reshaped implant dentistry. CBCT provides detailed three dimensional visualization of anatomical structures enabling precise evaluation of bone quantity, quality, and proximity to vital areas. This data is critical for virtual planning ensuring a safe placement of implants in complex regions such as the pterygoid area (Chan et al., 2018). CAD software such as RealGuide, allows for the creation of surgical templates tailored to individual patient anatomy, ensuring optimal implant angulation and depth (Vercruyssen et al., 2014). However, variability persists due to many challenges (Turbé et al., 2021).

The primary objective of this study is to assess the angular deviations between preplanned virtual implant position and their final postoperative implant position. By analyzing these deviations in a cohort of 20 patients. The study aims to validate the efficacy of digitally guided systems in achieving precise pterygoid implant placement.

The findings contribute to the growing body of literature, supporting the adoption of digital workflows in implant dentistry. By providing important data on surgical accuracy the study reveals the importance of evidence based method in enhancing treatment outcomes and patient safety, it also highlights the potential for further refinements in guided surgical techniques to address variability in angular deviations and optimize implant positioning.

As implant dentistry evolves, the integration of new technologies such as augmented reality and artificial intelligence, holds promise for enhancing surgical precision and real time intraoperative guidance (Choi et al., 2022). Such innovations could mitigate the limitations of current systems and developing a new paths for more predictable and efficient implant placement protocols.

Materials and Methods

Study design, settings, sample size and technique

A cross-sectional study was implemented involving 20 patients with free ended atrophic posterior maxilla. The plan started with preoperative imaging using CBCT to create detailed 3D anatomical view which integrated with CAD software to design custom surgical guides template for precise implant placement. The surgical implant placement followed by a postoperative CBCT scanning to evaluate the angular deviations between the long accesses of both planned and final implant position. The study was conducted at the dental implant department in Rzgary teaching hospital in Erbil, Iraq, including all patients who meet the inclusion criteria. The study period spanned from June 2022 to January 2024 and encompassed data collection, implant placement, input, evaluation, follow up and analysis.

Eligibility criteria

Inclusion criteria

Free-ended atrophic posterior maxillary area, upper molar is edentulous and there is a residual bony ridge with a minimum 5mm bone height between sinus floor cortex and alveolar crest, be capable of giving written informed consent, patient general health fits medically, and be able to maintain adequate oral hygiene.

Exclusion criteria

Clinical criteria; medical diseases that interfere with the normal healing of the bone, impaired cognitive function, unable to return for evaluations/study recalls, have a history of radiation therapy to the orofacial region, presence of specific conditions that may jeopardize the treatment, such as alcoholism or smoking, limitation in mouth opening, less than 25mm, and uncontrolled periodontal diseases.

Radiographic criteria; inadequate bone volume in the area of the pterygoid implant. presence of sound maxillary molar(s), and area is suggestive of bony pathologic lesions.

Materials

- Disposables used are surgical gauze, intra-oral examination kit, disposable plastic impression tray, disposable covers, flat sterilization rolls and non-resorbable sutures.
- Surgical instruments used are oral examination kit, oral surgery kit, extraction forceps, root elevators, surgical handpiece, surgical burs and vernier caliper.
- Local anesthesia: Septodont 2% Lidocaine HCl with epinephrine.
- ROOTT P pterygoid implant made by TRATE AG from Switzerland which provides excellent primary stability which is essential for the immediate loading of prosthetics (Chrcanovic et al., 2020).
- Biocompatible 3D printing resin used in a study was zSG Clear is a biocompatible fast-printing light-curing resin produced by UNIZ Technology LLC in California 92126, United States, and certified by CE, FDA, and Health Canada.
- 3DIEMME professional universal guided implant surgical kit was designed for osteotomy through a digitally designed 3D-printed surgical guide template developed by 3DIEMME from Italy. The kit includes a comprehensive set of tools that are specifically engineered for guided implant surgery.
- Hydrorise is a highly hydro-compatible type-A additional silicone that achieves an accuracy of 5 microns in detail reproduction manufactured by Zhermack from Italy.
- Student type IV stone manufactured by EverAll7 Sp. z.o.o. from Poland.
- Alcohol is used to clean the freshly printed template.

Machines

- GianoHr; a complete hybrid 2D/3D imaging unit manufactured by NewTom Member of Cefla group from Italy. Its resolution is 68microns which is essential for accurately diagnosing a range of dental and maxillofacial conditions (Spin-Neto et al., 2020).
- Slash2 3D printer introduced by UNIZ is known for its high speed, accuracy, and ability to produce fine details using LCD-based SLA (Stereolithography Apparatus) technology with a resolution of up to 49.5 microns on the XY-axis and 10 microns on the Z-axis. The slicing software which known as UNIZ Maker can automatically detect and repair these imperfections for accurate and of high quality printed templates (Salmi et al., 2018).
- Sterilization equipment: Autoclave, sealing machine, distilled water machine.
- Woodpecker implant engine.
- Dental unit za-208 Manufactured by Zainn from China.
- Desktop MAESTRO laser scanner: manufactured by AGE solution from Italy. Its Accuracy is less than 8 microns, resolutions less than 0.05 mm.
- Dental Lab 35K RPM Marathon Micro Motor N3 paired with a contra-angle and straight handpiece, manufactured by Marathon Company from China.
- Curing machine used in the study manufactured by Refine from China.
- Digital template designer software: RealGuide CAD plus version 5.2 to plan and design the template and evaluate the results.

The RealGuide software Impact in dental practice: Enhanced precision and accuracy (Johnson et al., 2023), improved patient outcomes (Lopez & Martinez, 2021), time efficiency and workflow optimization (Martinez & Wu, 2022), educational applications (Nguyen & Patel, 2021).

Method Protocol

- Patient preparation: A thorough medical evaluation was essential by taking the medical history followed by a laboratory tests. An exhaustive dental examination ensures the identification of local factors that may influence implant success includes periodontal status (Lindhe & Meyle, 2008), occlusal analysis (Misch, 2008), and existing prostheses (Nissan et al., 2011).

- Preoperative CBCT: A very detailed implant site study is made through the main three windows in the NNT version 6.5 software interfaces which are: Multiplanar reconstruction (MPR) which include axial, coronal and sagittal views, the second window was cross sectional views which create slices of the CBCT data perpendicular to the alveolar and we chose a wide range between 1mm to 20 mm thickness for each image based on the targeted view. Lastly the 3D volume which creates a three dimensional view to visualize the complex anatomy of the pterygoid region (Chan et al., 2018).
- Measurement recording at specific points from multiple views recording precise data on the following: Bone height, width, thickness, anatomical structures, and bone quality assessment.
- Impression based on the putty-wash technique and model fabrication.
- Model scanning using a desktop laser scanner: After fixation the study model on the scanner's platform (Joda & Brägger, 2016), the scanner was calibrated to ensure accuracy (Miyazaki et al., 2009). Selecting an appropriate scanning parameter such as resolution, speed, and the number of scan passes were adjusted (Joda & Brägger, 2016). The mesh network of interconnected triangles was created during the scanning process, exported from the scanning software in the desired file format. STL.
- Through the RealGUID software, after importing both the DICOM format file which represents the hard tissue images, and the STL format file, which represents the oral cavity surface scan, for aligning and merging these datasets (Choi et al., 2022).
- Implant planning: RealGUID software enabled us to virtually place the most compatible size of the ROOTT pterygoid implant from the TRATE implant library. Moving its position, angulation and depth to optimize the best placement (González-Martín et al., 2021).
- Sleeve settings; ensuring that the implant is placed exactly where it was planned in the virtual environment (Jensen et al., 2021). In our study the sleeves height was 4mm (1mm neck and 3mm body height), internal diameter was 4.95mm, and external diameter was 6.05mm. When calculated to the internal diameter of the sleeves, the offset space between the drill and the bur shoulder measures 0.05 mm.
- Pin position planning: Pins anchor the guide to the patient's jawbone, preventing any movement during the drilling process (Jensen et al., 2021). Minimum one pin for the free end part of the teeth supported and 3 for the soft tissue supported type placed in the planned guide in a position with sufficient bone density placed buccally or crystal in proper angulation so as not to result in mechanical limitations during pinhole drilling.
- Designing the guide through the following parameters in the next steps performed for designing: Overall thickness was 3mm, occlusal thickness was 4mm, implant sleeves support thickness was 10mm, pin sleeves support thickness was 5mm. We subdivided the group into two parts; in the first group, we put the 0.25mm offset distance for the tooth supported type and 0mm offset distance for the soft tissue supported type. Followed by drawing the guide-boarders.
- Fabrication of implant surgical guide templet through the following key steps: Importing the STL file from RealGUID software to UniZ slicer software, printing platform cleaning before printing, orientation of the guide on the printing template, managing printing parameters, monitoring the printing process to ensure that the guide is printed without defects, the printed guide was cleaned using alcohol to remove any debris, the curing process fully hardens the material and ensures its strength and durability, finishing and polishing to smooth any rough edges or surfaces, the fabricated template tested on the study model, and finally the sterilization stage to become ready to use it clinically.
- Patient preparation for surgical operation: Preoperative medication instructions, team preparation through a detailed information about the guided implant templet, sterilization and infection control protocols followed

by CBCT images and 3Diemme software guiding templet report reviewing.

- Surgical operation: After local anesthesia, the template fit must verify to ensure that it aligns perfectly with the planned implant sites and does not impinge on soft tissues. One-time and one-size drilling protocol for the pins which inserted into the maxillary bone. The osteotomy is performed using a sequence of drills, each guided by the sleeves in the surgical template. The procedure begins with a tissue punching and the soft tissue removal, then, a short and small diameter pilot drill is used as the first drill and a gradually enlarging the socket using a series of progressively larger drills from a 3Diemme advanced surgical kit. The sleeves ensure that each drill follows the exact trajectory, depth, and angulation planned during the virtual simulation (Aparicio, 2015).

After completing the osteotomy, the surgical guide was carefully removed, and the implant placed directly into the prepared osteotomy site without the assistance of the guide sleeve.

Postoperative follow-up and CBCT: The first follow-up appointment was typically scheduled within a week after the pterygoid implant surgery for suture removal, evaluating the stability of the implant and soft tissue condition related to the process. Post-operative CBCT study conducted after one week (González-García et al., 2012).

Final prosthesis: Healing cap placed and soft tissue maturation (Lindhe & Meyle, 2008), framework trial, final prosthesis fabrication and placement in the last step.

Long term maintenance and follow up: Regulary twice each after six months and once a year after the surgical operation allowing the ongoing monitoring of the implant, surrounding boney structure and soft tissues (Misch, 2014). In the study the total 20 implants maintain sufficient stability with healthy periodontal tissues after 1 year.

Data collection, assessment and validation

After the merging of the two datasets of the DICOM files in RealGUID an accurate visualization appears to measure the implant positioning, comparing the planned and actual placement as it seen in image number 1, through the following protocol: Import the preoperative and postoperative scans RealGUID software then aligning the two datasets, identify the preplanned virtual implant and the actually placed implant in the best view, defining and tracing the long axes of both implants, and finally documenting the angular deviation in its maximum value from the MPR, cross sectional images and after orientation of the sagittal and coronal images (Smith et al., 2023).

Validation through review by two independent reviewers ensured the reliability and accuracy of the measurements in our study, to minimizes bias, enhances reproducibility, and verifies consistency in the findings.

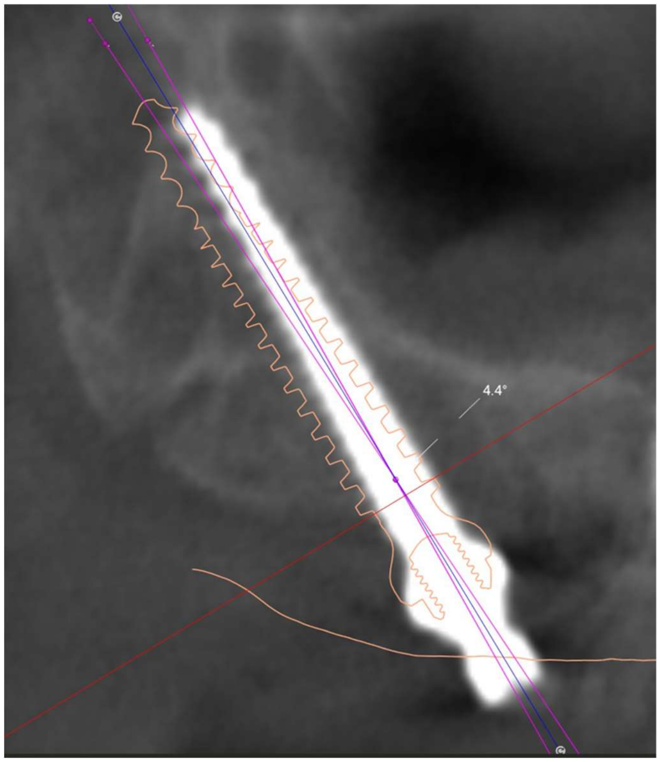


Image1. A parasagittal cross sectional image with 15mm thickness enabling visualization of both the preplanned virtual implant and the placed implant.

Ethical Considerations

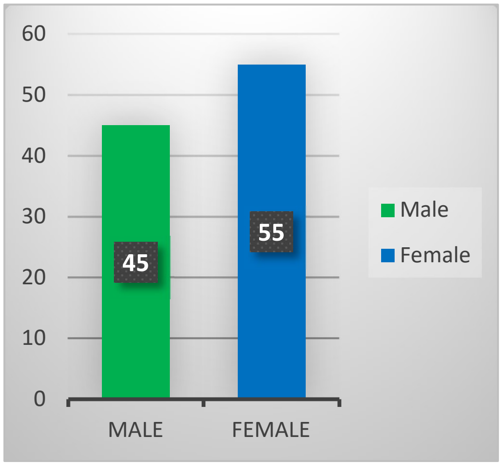
This study received ethical approval from Research Ethics Committee in Hawler Medical University ensuring compliance with ethical principles by allowing the patients to make their independent decisions based on clear information about the operational risks, benefits and expectations. Before signing the consent form, it was essential to make the patients fully understand the nature of the procedure, the risks, benefits, and the postoperative care requirements to ensure the longevity of the pterygoid implant.

Statistical Methods and Analysis

IBM SPSS Statistics software version 30.0.0 (released September 30, 2024) was employed. Descriptive Statistics for describing the mean and standard deviation were calculated to describe the demographical distribution and the angular deviations of the participants.

Results

The age distribution in the study indicates that most patients were within the 60-69 age range, with 14 individuals (70%) in this group, while the remaining six patients (30%) were between 50 and 59 years old. The study included a balanced representation with a slightly more female gender. Eleven participants (55%) were female, and nine participants (45%) were male. More details are seen in figures 1 and 2.



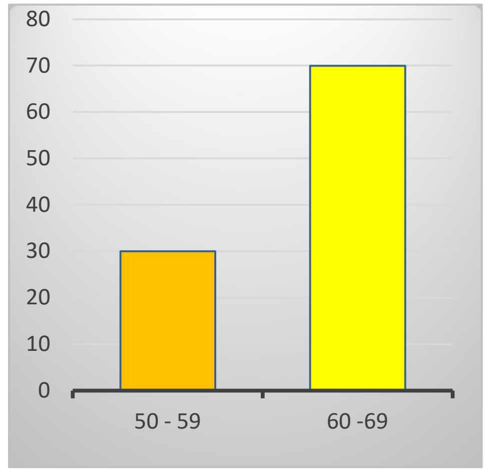
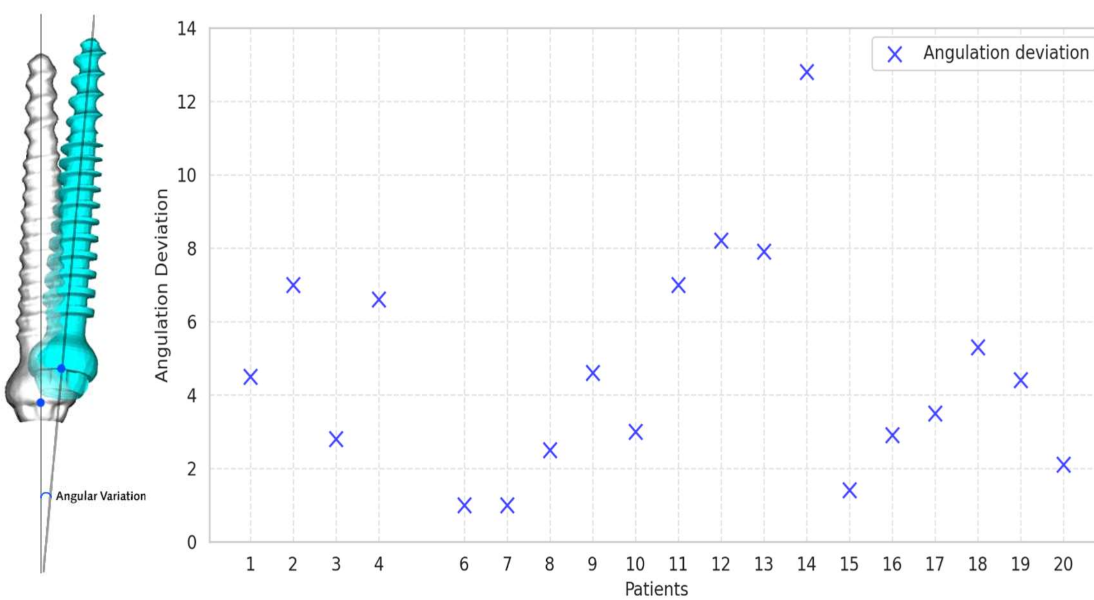


Figure1. Percentage of gender **Figure 2. Percentage of age**

The angular deviation of surgically guided pterygoid implants was analyzed to assess the accuracy of implant placement relative to the planned angulation. Among the 20 evaluated Implants. The angular deviation ranged from 1.0° to 12.8° as seen in figure 3, with a mean deviation of 4.895° and a standard deviation of 3.122°. This range reflects a generally acceptable alignment for guided implants, although the higher values indicate that some placements experienced more substantial angular shifts than others. The mean value of 4.895° suggests on average, the guided approach achieved close alignment with the planned trajectory enhancing the predictability of implant placement in the anatomically challenging pterygoid region. However, the observed standard deviation highlights variability with some implants deviating significantly from the target angle. This variation could stem from factors such as bone density, anatomical obstacles, or slight guide misalignments during surgery.

Figure 3. The spatial angular deviations of merged DICOM images superimposing the preplanned



(green) and the postsurgical implants (white) and the scatter plot showing the angular deviation values along 20 patients.

Discussion

Gender distribution was nearly balanced, supporting a comprehensive analysis across gender lines. The age distribution in our study aligns with previous studies, individuals above 60 years are commonly affected by bone resorption requiring advanced implant solutions (Brown et al., 2023). The narrow age range in our study minimizes variability in age related bone quality which is a critical factor to implant success especially in older adults (Jones et al., 2023). The slightly higher female representation may indicate increasing female interest in implant solutions among Iraqi population.

The angular deviations in this study ranged between 1.0° to 12.8° with a mean of 4.895° ± 3.122° which consistent with previous studies, for example Schneider et al. (2020) reported mean deviations of 2° to 10° with an average of 5°, while Turbé et al. (2021) recorded 4° deviations in guided implantology and Sanz-Martín et al. (2022) recorded higher deviations 5.3° in dense bone areas suggesting increased resistance and anatomical constraints can increase angular shifts. These results highlight the current challenge of controlling angular deviations particularly in complex anatomical regions like the pterygoid region where precise apex positioning is essential for biomechanical stability and avoidance of trauma to nearly anatomical structures. Despite the use of longer implants in our study which supposed to increase the angular deviations the achieved results were close to those studies which used a shorter implant, this result support the effectiveness of guided techniques in maintaining precision if used in pterygoid region. In our study we mentioned many factors during the operation, some related to the planning process and some related to the operational process that could contribute or influenced the angular variations which are: The high bone density (Turbé et al., 2021), Removing guides after osteotomy process for freehand implant (Mangano et al., 2022), Implant design, length and diameter (Wu et al., 2022), drilling protocols (Joda et al., 2021), guide designs and offset spaces (Sisti et al., 2020), repeated patient movement result in more angular deviation, the deviation of 12.8° observed in our study can be attributed to repeated patient jaw and body movements, lastly the variability in operator technique and handling.

Conclusions

This study evaluated the angular accuracy of pterygoid implant placement using digitally guided surgical systems in patients with free-ended atrophic posterior maxillae. By comparing preplanned virtual implant positions with their postoperative placements through the integration of CBCT imaging and CAD software, the study demonstrated the potential of digital workflows to enhance implant placement precision. The angular deviations ranged from 1.0° to 12.8°, with a mean deviation of 4.895° ± 3.122°. These findings align with established ranges for guided implant surgery reported in prior studies, validating the effectiveness of digitally guided systems even in challenging anatomical regions such as the pterygoid area. Notably, despite the use of longer implants—typically associated with increased angular deviations—the deviations observed were within acceptable clinical limits. Clinically the results highlighted the role of digitally guided surgery in improving the predictability of implant placement, particularly in anatomically complex areas with the following advantages: Enhanced accuracy, improved safety, and time efficiency. The study contributes valuable data for the use of guided systems for pterygoid implants a field with limited prior research. By focusing on angular deviations, it provides a quantitative assessment of surgical accuracy, offering significant support for adopting digital workflows in implantology. Additionally, the study highlights the feasibility of using longer implants in the pterygoid region without compromising accuracy. Evan the study findings are promising two main limitations noted: Sample Size which involved only 20 patients, and the study did not assess the functional and prosthetic success of the implants over extended periods. Recommendations for future studies: Broader studies across diverse populations, Investigate the biomechanical stability and prosthetic success of pterygoid implants over extended periods, studies for causes of angular deviation independently, and incorporating augmented reality or AI based systems to improve surgical planning and facilitate intraoperative adjustments.

REFERENCES

1. Aparicio, C. (2015). Pterygoid implants: A solution for the atrophic posterior maxilla. *European Journal of Oral Implantology*, 8(3), pp. 287-298.
2. Bornstein, M.M., Jacobs, R., and Khoury, P. (2021). Digital workflows in implant dentistry: Current status and future perspectives. *Clinical Oral Implants Research*, 32(8), pp. 875-887.
3. Brown, A.E., Patel, S., and Kim, H. (2023). Management of severe maxillary atrophy in older adults: The role of pterygoid implants. *International Journal of Oral and Maxillofacial Implants*, 38(3), pp. 415-422. (2), pp. 158-165.
4. Chan, H.L., Misch, K., Wang, H.L., and Reside, G. (2018). Diagnostic applications of 3D imaging in implant dentistry. *Clinical Implant Dentistry and Related Research*, 20(1), pp. 12-25.
5. Choi, J.W., Kim, N.H., and Kang, H.G. (2022). The role of digital technologies in improving implant placement accuracy. *Journal of Clinical Implant Dentistry*, 28(6), pp. 461-468.
6. Chrcanovic, B.R., Albrektsson, T. and Wennerberg, A. (2020). Pterygoid implants: A systematic review. *International Journal of Oral and Maxillofacial Surgery*, 49(3), pp. 294-305.
7. González-García, R., Monje, F., and Arias-Irimia, O. (2012). Accuracy of implant placement in three-dimensional navigation systems. *Oral Surgery, Oral Medicine, Oral Pathology, Oral Radiology*, 114(5), pp. 649-655.
8. González-Martín, O., Gallucci, G., and Belser, U. (2021). 3D-printed surgical guides for pterygoid implant placement: Workflow and precision. *International Journal of Prosthodontics*, 34(4), pp. 432-441.
9. Jacobs, R., Bornstein, M., and Botticelli, D. (2018). Digital implant planning and guided surgery. *Periodontology 2000*, 77(1), pp. 135-145.
10. Jensen, O.T., Adams, M.W., and Bedrossian, E. (2021). Advances in pterygoid implant rehabilitation. *Journal of Oral Implantology*, 47(1), pp. 57-67.
11. Joda, T., and Brägger, U. (2016). Digital workflows in implant dentistry: Innovations for efficiency and precision. *Clinical Oral Implants Research*, 27(10), pp. 1230-1240.
12. Joda, T., Zitzmann, N.U., and Brägger, U. (2021). Sequential drilling protocols in implant dentistry: A systematic review. *Clinical Oral Implants Research*, 32(4), pp. 456-467.
13. Johnson, B., Smith, R., and Martinez, L. (2023). Advances in digital workflows: Enhancing precision and accuracy in implant dentistry. *Journal of Clinical Implant Dentistry*, 35(1), pp. 12-19.
14. Jones, R.J., Singh, A., and Wang, H.L. (2023). The impact of age-related bone quality on dental implant success: A systematic review. *Journal of Clinical Periodontology*, 50(4), pp. 456-464.
15. Lindhe, J. and Meyle, J. (2008). Peri-implant diseases: Consensus report of the Sixth European Workshop on Periodontology. *Journal of Clinical Periodontology*, 35(S8), pp. 282-285.
16. Lopez, R. and Martinez, A. (2021). Digital implantology and its impact on patient outcomes: A review. *International Journal of Oral and Maxillofacial Implants*, 36(4), pp. 789-796.
17. Malo, P., de Araújo Nobre, M., and Lopes, A. (2016). Pterygoid implants for the rehabilitation of the posterior maxilla: Clinical report. *European Journal of Oral Implantology*, 9(3), pp. 345-356.
18. Mangano, F., Gandolfi, A., and Luongo, G. (2022). Advances in guided implant surgery: A systematic review. *International Journal of Oral and Maxillofacial Surgery*, 51(5), pp. 588-597.
19. Martinez, A. and Wu, T. (2022). Optimizing workflow efficiency in digital implantology: A systematic review. *Journal of Dental Technology and Innovation*, 28(2), pp. 145-153.
20. Misch, C.E. (2008). Contemporary implant dentistry. 3rd ed. St. Louis: Mosby Elsevier.
21. Misch, C.E. (2014). Dental implant prosthetics. 2nd ed. St. Louis: Mosby Elsevier.
22. Miyazaki, T., Hotta, Y., Kunii, J., Kuriyama, S., and Tamaki, Y. (2009). A review of dental CAD/CAM:

Current status and future perspectives from 20 years of experience. *Dental Materials Journal*, 28(1), pp. 44-56.

23. Nguyen, L. and Patel, R. (2021). The role of digital technology in dental education: Enhancing learning outcomes through simulation. *Journal of Dental Education*, 85(7), pp. 932-940.
24. Nissan, J., Gross, M., Shifman, A., and Assif, D. (2011). The effect of the proximity of adjacent teeth and their condition on the accuracy of implant placement. *Clinical Implant Dentistry and Related Research*, 13(2), pp. 130-135.
25. Salmi, M., Paloheimo, K.S., Tuomi, J., Björkstrand, R., and Kontio, R. (2018). Accuracy of medical models made by additive manufacturing (rapid manufacturing). *Journal of Cranio-Maxillofacial Surgery*, 41(7), pp. 603-609.
26. Sanz-Martín, I., Valenzuela, C., and Martínez, C. (2022). Factors influencing angular deviations in guided implant surgery. *Clinical Implant Dentistry and Related Research*, 24(4), pp. 235-243.
27. Schneider, D., Schober, F., and Wittneben, J.G. (2020). Accuracy of guided surgery for dental implants: Review and perspectives. *International Journal of Oral and Maxillofacial Surgery*, 49(12), pp. 1575-1583.
28. Smith, R.D., Johnson, B.T., and Martinez, L.A. (2023). Advances in DICOM file integration for digital implantology: Enhancing precision through 3D software. *Clinical Oral Implants Research*, 34(5), pp. 712-720.
29. Spin-Neto, R., Matzen, L.H., and Wenzel, A. (2020). Advances in CBCT imaging for implant placement. *DentoMaxilloFacial Radiology*, 49(3), pp. 20190350.
30. Sisti, A., Sisti, G., and Serasini, A. (2020). Innovations in guide design for dental implants. *Journal of Clinical Implant Dentistry*, 31(5), pp. 411-417.
31. Turbé, H., Reinero, M., and Bellucci, G. (2021). Angular deviations in guided implant placement: Clinical considerations. *International Journal of Oral Implantology*, 14(2), pp. 97-105.
32. Vercruyssen, M., Coucke, W., Naert, I., Jacobs, R., and Quirynen, M. (2014). Depth and lateral deviations in guided implant surgery: An RCT comparing guided surgery with conventional implant placement. *Journal of Clinical Periodontology*, 41(7), pp. 717-723.

Wu, J., Wu, T., and Liang, J. (2022). The influence of implant length and diameter on accuracy in guided surgery. *Journal of Oral Rehabilita*