Distribution Statement

Distribution A: Public Release.

UNIFORMED SERVICES UNIVERSITY OF THE HEALTH SCIENCES
POSTGRADUATE DENTAL COLLEGE
SOUTHERN REGION OFFICE
2787 WINFIELD SCOTT ROAD, SUITE 220
JBSA FORT SAM HOUSTON, TEXAS 78234-7510
https://www.usuhs.edu/pdc

THESIS APPROVAL PAGE FOR MASTER OF SCIENCE IN ORAL BIOLOGY

Title of Thesis: Three-Dimensional Accuracy of Implant Placement Related to the Use of Dynamic Navigation Compared to Fully Guided and Conventional Implant Placement Using an Out-of-Bounds Guide

Name of Candidate: Dr.Alyssa-Joy T. Oviatt
Master of Science Degree

THESIS/MANUSCRIPT APPROVED:

DATE:

SHUTE.WESLEY.S.1298008080 Digitally signed by SHUTE.WESLEY.S.1298008080 Date: 2022.05.16 11:51:26 -05'00' — 5/16/22

Dr. Wesley Shute
DEPARTMENT OF PROSTHODONTICS, USUHS Postgraduate Dental School
Committee Chairperson

CHECKETTS.MATTHEW.R.1404513954 Digitally signed by CHECKETTS.MATTHEW.R.1404513954 Date: 2022.06.14 10:46:49 -05'00' — 6/14/22

Dr. Matthew Checketts
DEPARTMENT OF PROSTHODONTICS, USUHS Postgraduate Dental School
Committee Member

COLBURN.HANNAH.E.1007885900 Digitally signed by COLBURN.HANNAH.E.1007885900 Date: 2022.06.14 12:37:03 -05'00' — 6/14/22

Dr. Hannah Colburn
DEPARTMENT OF PROSTHODONTICS, USUHS Postgraduate Dental School
Committee Member

SCHLOTTKE.SAE-EUN.1468454226 Digitally signed by SCHLOTTKE.SAE-EUN.1468454226 Date: 2022.05.16 13:15:42 -05'00' — 5/16/22

Dr. Sae-Eun Schlottke
DEPARTMENT OF PROSTHODONTICS, USUHS Postgraduate Dental School
Committee Member

HARDING.AARON.BENJAMIN.1271169031 Digitally signed by HARDING.AARON.BENJAMIN.1271169031 Date: 2022.05.16 18:33:55 -05'00' — 5/16/22

Dr. Aaron Harding
DEPARTMENT OF PROSTHODONTICS, USUHS Postgraduate Dental School
Program Director

LONGO.PAUL.A.1012768601 Digitally signed by LONGO.PAUL.A.1012768601 Date: 2022.06.03 16:33:50 -05'00' — 6/3/22

Dr. Paul Longo
DEPARTMENT OF PROSTHODONTICS, USUHS Postgraduate Dental School
Department Chair

Three-Dimensional Accuracy of Implant Placement Related to the Use of Dynamic Navigation Compared to Fully Guided and Conventional Implant Placement Using an Out-of-Bounds Guide

Dynamic Navigation Accuracy

Alyssa-Joy Oviatt, DDS, Ryan Sheridan, DMD, MS, FACP, Sae-Eun Schlottke, DDS, MS, FACP
USUHS USAF Postgraduate Dental School

Alyssa-Joy Oviatt
2133 Pepperrell St.
Lackland AFB, TX 78236
Alyssajoy.t.oviatt2.mil@mail.mil

Previously presented as a poster at the 2021 American College of Prosthodontics Annual Meeting

The authors do not have any financial interest in the companies whose materials are discussed in this document.

ABSTRACT

Purpose: This study compares the accuracies of dynamic navigation, fully limiting static guide, and out-of-bounds guide modalities for implant planning and placement.

Materials and methods: A master mandibular model had six implants placed. This model was used to plan the implant locations using the three modalities. A single operator prepared osteotomies and placed 120 implants in 20 experimental models, five models per group (dynamic navigation right, dynamic navigation left, fully guided, out-of-bounds guide). Post-placement cone beam computed tomography was performed on each model and compared to the master model. Errors in angle deviation, entry point deviation, and apex deviation were recorded and analyzed.

Results: Dynamic navigation and fully guided were more accurate than the out-of-bounds guide with respect to angular deviation ($P<0.001$), entry point deviation ($P=0.001$), and apex deviation ($P<0.001$) errors. Dynamic navigation was more accurate than fully guided in angular deviation ($P<0.001$, dynamic navigation: 1.27º ± 0.63, fully guided: 2.00 º ±1.08). Fully guided was more accurate in entry point deviation ($P<0.001$, dynamic navigation: 0.66 mm ± 0.32, fully guided: 0.46 mm ± 0.34). No significant difference was found between dynamic navigation and fully guided for apex deviation ($P<0.001$, dynamic navigation: 0.67 mm ± 0.43, fully guided: 0.80 mm ± 0.33).

Conclusion: Dynamic navigation exhibited lower angular errors than fully guided and the out-of-bounds guide, and both were more accurate than the out-of-bounds guide regarding entry point deviations and apex deviations. Dynamic navigation was not inferior to fully guided surgery in apex deviation. Both fully guided and navigated met accuracy standards (1.0-2.0 mm deviation) as seen in previous systematic reviews with meta-analysis. With comparable accuracy to fully guided surgery, dynamic navigation is a promising technology in the field of implant surgical planning and guidance.

KEYWORDS: computer guided surgery, dental implants, computer navigation

INTRODUCTION

A priority for planning the ideal prosthetic result for implant-supported restorations is the ideal implant placement. [1, 2] Cone beam computed tomography (CBCT) is an increasingly common method for evaluating implant sites. Dedicated software allows precise implant planning and production of surgical guides. The precision afforded by virtual implant planning using CBCT allows the surgeon to navigate around vital anatomical structures, a less invasive procedure, and may increase accuracy of implant placement. [3, 4] The benefits of ideal implant placement on the restorative outcome include favorable esthetics, optimal occlusion and immediate implant provisionalization, optimal prosthesis design, and adequate hygiene access, all due to replication of the virtual plan. [5]

Guidance of implant surgery has been associated with a variety of techniques. Level of guidance ranges from freehand or self-guided placement to partial guidance, such as the out-of-bounds guide (OG). Fully guided surgery (FG) is the most restrictive using fully limiting static guides designed via virtual implant planning, a method with documented high levels of accuracy when compared to the surgical plan.[4, 6-9] While accurate, fully guided surgery has some limitations, including bulk and size, of the guide poor visualization of the surgical site, and non-adjustable protocol.[4, 6, 7, 10]

Dynamic navigation (DN) utilizes the same virtual implant planning as with FG. The primary difference between DN and FG is when using DN, the operation of the handpiece is freehand with no physical restrictions. The real-time navigation is provided with motion tracking technology that relates the handpiece to patient's anatomy, following the CBCT based virtual plan. In most systems, optical stereo sensors read markers integrated into devices attached to both the patient's jaw and the handpiece. [11] Visual cues given on a computer screen alert the surgeon to proper handpiece angulation, location, and depth. [6]

Benefits of optical DN systems include rapid and simplified implant planning, and placement, including same-day treatment. [6, 12, 13] Unlike FG, there is no delay from production of the guide. [7, 12] Using the same software to plan and execute the surgery allows changes to the plan during surgery, a difficult task if using a physical fully limiting guide. DN allows the surgeon to stop and use the proprietary software to change the planned implant placement based on real-time surgical findings and immediately implement the new plan.

Dynamic navigation is a burgeoning technology with a growing number of studies. Past studies with models demonstrated that dynamic navigation has accuracy greater than freehand surgery and as accurate as a fully limiting guide. [6, 7, 12, 14, 15] A recent systematic review and meta-analysis concluded that DN accuracy was within a clinically acceptable range, comparing different DN systems and study protocols.[16] Clinical trials have shown that DN is more accurate than freehand surgical placement, and as accurate as fully guided systems for single implant placement. [17-19]

The concept for this study is based on a design by Chen et al in which DN, FG, and freehand implant placement were compared.[15] The key differences in this study are the material of the models, the DN system to be tested, the use of an out-of-bounds guide instead of freehand placement, and placement of implants instead of only drilling the osteotomy.[15] The goal of this study is to test a commercially available DN system for accuracy compared to fully limited static guidance and conventional implant placement using an out-of-bounds guide.

Null hypothesis: There will be no statistical difference in accuracy between dynamic navigation, fully limiting guides, or out-of-bounds guides for implant placement.

MATERIALS AND METHODS

Preparation of the models: 21 identical mandibular models of a partially edentulous patient missing teeth #20-22 and #27-29 were 3-dimenstional (3D) printed with an Objet30 printer (Stratasys, Rehovot, Israel). The models were fabricated from the same 3D model.

One printed mandible was reserved as a master model (Figure 1). 4.1 mm by 13.0 mm T3 tapered Certain dummy implants (Zimmer Biomet, Warsaw, IN) were placed in the master model and used as references for implant planning for all experimental groups. Three of these implants were placed in the #20-22 edentulous site and three in the #27-29 edentulous site. All implants were placed in the crestal position in a freehand manner.

Planning the implant locations: A CBCT (i-CAT FLX, Henry Schein, Queens, NY, voxel size 0.12 mm, volume 16x4 cm, 120 kVp, 5 mA) of the mandibular master model was made and used to digitally plan implant locations based on the reference implants by aligning the digital implant closely to them in all dimensions (Figure 2). The implant planning and design of the fully limiting static guide was completed using Blue Sky Plan (Blue Sky Bio, Libertyville, IL) utilizing a sleeveless guide tube protocol.[20]

The guide tubes were set to a tube height of 10.0 mm. The FG was printed and fit to the master cast (Figure 3).

Two additional CBCTs of the mandible were made with the X-Guide system X-Clip (X-Nav Technologies, Lansdale, PA) attached to the remaining molars, one scan with the X-Clip attached to the right (#30 and 31) and the other to the left (#18 and 19, Figure 4). Implant planning was completed with the X-Guide software according to the master model references as described above (Figure 5).

An out-of-bounds guide was produced in hard clear acrylic (Vitacrilic Universal Clear, Fricke International, Streamwood, IL) on a duplicate cast of the master model made in type IV dental stone (Silky Rock, Whip Mix Corporation, Louisville, KY). Tooth positions were included in the guide. The guide was adjusted to ensure passive fit on experimental models. A survey table was used to mount the master model to a drill press. The location and angulation of each reference implant were aligned with the drill press, and then the duplicate cast was locked into the same position. The out-of-bounds guide was placed on the duplicate cast, and a 3.0 mm drill was used to create the out-of-bounds opening for each implant (Figure 6).

Preparation of the drill models: 10 of the mandibles were used for DN, 5 for the left-sided X-Clip (LXC) and 5 for the right-sided X-Clip (RXC). The remaining 10 mandibles were used for OG and FG placement, 5 for each group. The mandibles were mounted to a dental survey table and clamped to the headrest of a dental chair to approximate clinical position for the X-Guide. Each mandible had implants placed in the same sequence: #20, #21, #22, #27, #28, and #29. The implant placement was accomplished two models at a time for each group before moving to the next group. The order: OG, LXC, FG, and RXC. Three rounds were required to complete all groups. All implants were placed by a single right-handed operator. Resin debris within the osteotomy site were eliminated with bursts of compressed air at 30 PSI between drill changes.

Osteotomy and implant placement: All implants were placed according to manufacturer's instructions with guided surgical kits (Biomet 3i Navigator) or non-guided surgical kit (Biomet 3i Tapered Implant Surgical Tray). The surgical sequencing was as follows: cortical perforator and 1.9 mm twist drill (Navigator) or precision drill and 2.0 mm twist drill (non-guided) and quad shaping drills in increasing sizes of 3.25x8 mm, 3.25x13 mm, and 4.0x13 mm prior to implant placement. Each drill was used in all surgical sites prior to switching to the next instrument.

Out-of-bounds guide. Preparation and implant placement was performed with the non-guided surgical kit. Use of the guide was limited to the precision drill and 2.0 mm twist drill steps. All other drill sequence was accomplished freehand. Depth of osteotomy preparation was indicated by the depth markers on the drills. The implants were placed to a crestal level.

Dynamic navigation. The X-Guide system was set up according to manufacturer's instructions, including calibration of all instruments, tracking devices, and the bur length with each surgical bur used. Osteotomy preparation was performed with the non-guided surgical kit. Positioning of all implant drills and implants was accomplished by viewing the navigation screen which displayed drill position and axial tilt in buccolingual and mesiodistal axes in real time. Depth was displayed once preparation commenced, and visual and auditory signals were used to indicate that the planned depth was met.

Fully limiting static guide. The fully guided osteotomy preparation was performed with the guided surgical kit. A twist drill positioning handle was inserted into the guide tubes for use of the 1.9 mm twist drill. All other instrumentation was guided solely by the guide tubes. Depth was indicated by contact of the implant mount with the guide. One sample group, number 2, did not achieve maximum depth in any of the drills or implant placements. It was discarded and another sample group prepared in its place.

Accuracy measurement: A CBCT of each mandible was made once implants were placed using the same settings as the pre-placement scans. The accuracy of each implant position was determined by comparing the pre-placement target implant position in the master model to the implant positions in the post-placement CBCT scan using GeoMagic 2014 software (3D Systems, Inc, Valencia, CA). The pre-placement and post-placement images were aligned using model geometry. The accuracy was compared in three dimensions: angular deviation (AN), deviation at entry point (EP), and deviation at apex (AP) between planned and placed implants. The three guidance modalities were compared to each other with the two X-clip groups combined as a single data set. Right and left X-clip groups were then compared to each other.

Statistical analysis: SPSS Statistics (IBM, Armonk, NY) was used to perform univariate analysis of variance on the three modalities. Post-hoc analysis was completed with Tukey's test with confirmation by Kruskal-Wallis test in the event of non-normal data distribution. T-test was used to analyze the X-Clip data with Levene's test to evaluate homogeneity.

RESULTS

The mean errors are listed in Table 1. The mean errors in angular deviation for FG, OG, and DN were 2.04° ±1.10, 4.39° ± 2.11, and 1.27° ± 0.63, respectively. The errors for entry point deviation were FG: 0.45 mm ± 0.3417OG: 0.84 mm ± 0.34, and DN: 0.66 mm ± 0.32. The errors for apex deviation were FG: 0.81 mm ± 0.28, OG: 1.21 mm ± 0.55, and DN: 0.86 mm ± 0.43. Errors for left-sided X-Clip were 1.41° ± 0.63 for angular deviation, 0.54 mm ± 0.22 for entry point deviation, and 0.60 mm ± 0.22 for apex deviation. Errors for right-sided X-clip were 1.13° ± 0.61 for angular deviation, 0.68 mm ± 0.28 for entry point deviation, and 0.74 mm ± 0.30 for apex deviation. Representations of the different measured errors are seen in Figure 7.

DN and FG showed lower angular deviation ($P < 0.001$), entry point deviation ($P = 0.001$ DN, $P<0.001$ FG), and apex deviation errors ($P<0.001$) than OG. DN showed lower angular deviation ($P<0.05$) than FG. FG showed lower entry point deviation than DN ($P<0.05$). There was no significant difference between DN and FG for apex deviation ($P=0.204$). Right and left X-clip data showed no significant differences for angular deviation ($P=0.083$), entry point deviation ($P=0.037$), or apex deviation ($P=0.043$). All data displayed homogeneity.

DISCUSSION

In terms of angular deviation, DN had the highest accuracy. This was also found in Chen et al and a retrospective clinical trial by Wu et al that compared DN and FG, however this result was not statistically significant[15, 19]. The average error of 1.27° was less than the averages found in several clinical trials, in vitro studies, and meta-analysis, including a systematic review of fully guided protocols by Van Asshe et al which found an average angular error of 3.81°.[9, 16, 17, 19, 21-24] DN provides the ability to view changes in angle in real time throughout the drilling and implant placement procedure. This can contribute to the decrease in error compared to the other modalities that do not offer real time feedback.

Increased angular error of FG in this study could be due to wear in the guide tubes or fit of the guide. Increasing the length of the guide tube creates a more restrictive guide since there is more surface area to engage the guided drills and implant mounts. This increased restrictiveness increases accuracy.

The use of sleeveless guide tubes removed any potential misfit of metal guide sleeves within the plastic guide, however this also allowed for abrasion of the guide surfaces over the course of 6 drilling sequences and implant placements.[20] This abrasion could increase tolerance of the guide tubes, leading to more error.

OG had the most deviations for angle deviation. The lack of restriction allowed for more error. Greater practitioner experience with implant placement and the desired implant position could mitigate this error. Several studies have shown that freehand is less accurate than DN and FG[6, 15, 17, 23-27].

DN and FG showed no significant difference relative to each other for apex deviation while DN showed the lesser average error. DN showed the highest accuracy for apex deviation in Chen's and Wu's studies showed a greater accuracy in apex deviation in FG compared to DN within its data; however, this was not statistically significant.[15, 19] The average 0.67 mm error for DN was more accurate than studies previously mentioned, including the systematic review of fully guided accuracy which found an average of 1.24 mm.[9] This correlates to accuracy in the angle, as smaller errors in angle deviation create less apex deviation as the implant is placed to depth. Depth control itself could be a factor in apex deviation error. DN had visual and auditory cues to alert the practitioner that the planned depth was met. FG relied on physical contact of the drill and implant mount, lending itself to accurate apex location assuming minimal angular deviation, however the depth of the drill past the restrictive guide tube allows for potential deviations. Incorrect seating of the guide must be considered, as incomplete seating would create a vertical apex deviation error.

OG had the most deviations in apex accuracy. Depth control was measured visually based on markings on the drill and a perceived crestal placement of the implant to match the crestal position of the reference implants. The span of the edentulous space also limited the use of adjacent teeth as landmarks for maintaining correct angulation during osteotomy preparation and implant placement.

For entry point accuracy, FG was found to be more accurate than DN. This correlates to the Chen and Wu studies. The average error of 0.46 mm for FG for this study was less than that found in the previously mentioned studies. The systematic review by Van Assche found average entry point accuracy for fully guided to be 0.99 mm.[9] The fixed position of the FG tubes that allowed little deviation from the starting position for the initial drilling. DN differs in that it was technically a freehand placement with visual aids. Excellent hand-eye coordination was required to create an accurate starting point with the precision drill.

OG had more deviations than both DN and FG, as the width of the guide opening was large enough to allow free placement of the initial precision drill. Knowledge of the drill and implant relationship to adjacent teeth and the proposed plan are required for ideal freehand placement and partially guided surgery.

Comparison of RXC and LXC groups showed no significant difference in all three measurements. This shows that the location of the X-Clip does not impact surgery with a right-handed provider. The only difficulty met in both groups was drilling and placing implants in the edentulous sites directly adjacent to the X-Clip, #20 for LXC and #29 for RXC. Extrusion of the thermoplastic material used to mold the adjacent teeth to the X-Clip into the edentulous space created interferences with the handpiece. Care should be made to remove any excess prior to surgery or limit DN to only unilateral cases so that the X-Clip may be placed contralateral to the surgical site.

Along with problems with FG fit, guide tube abrasion, X-Clip movement, and X-Clip interference, other sources of error were present in this study. Planning in two different virtual planning softwares relied upon clinician judgement and precision to align the virtual implant with the reference implants placed in the master model. Relatedly, both modalities required CBCTs to plan, and CBCTs were used to generate the results. Any distortion in the CBCTs due to the presence of the metal implants[15] could have generated error.

CONCLUSION

Accurate implant placement according to the restorative plan is imperative for implant restoration success. High accuracy for FG has been well documented in the past. DN is a new technology that offers similar benefits for implant surgical accuracy to FG while reducing or eliminating potential setbacks of FG. As a new offering, there are only limited clinical studies regarding the accuracy and success of DN. More studies are required, but the current literature supports the use of DN as a viable option for accurate implant planning and placement.

ACKNOWLEDGEMENTS

I would like to thank Mr. James Pizzini for his help designing and fabricating the mandibular models and fully limiting static guide, Mr. Daniel Sierra for performing the CBCT analysis to generate the raw data, Drs. Jisuk Park and Anneke Bush for the statistical analysis, and Drs. Aaron Harding and Wesley Shute for their assistance editing the manuscript.

REFERENCES

1. Herklotz I, Beuer F, Kunz A, et al: Navigation in implantology. Int J Compu Dent 2017;20:9-19
2. Tarnow J: Fabrication of an implant surgical stent for the edentulous mandible. J Prosthet Dent 1992;67:217-18
3. Laleman I, Bernard L, Vercruyssen M, et al: Guided Implant Surgery in the Edentulous Maxilla: A Systematic Review. Int J Oral Maxillofac Implants 2016;31 Suppl:s103-17
4. Schneider D, Marquardt P, Zwahlen M, et al: 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
5. Soares MM, Harari ND, Cardoso ES, et al: An in vitro model to evaluate the accuracy of guided surgery sustems. Int J Oral Maxillofac Implants 2012;27:824-31
6. Block MS, Emery RW: Static or Dynamic Navigation for Implant Placement-Choosing the Method of Guidance. J Oral Maxillofac Surg 2016;74:269-77
7. Jung RE, Schneider D, Ganeles J, et al: Computer technology applications in surgical implant dentistry. Int J Oral Maxillofac Implants 2009;24:92-109
8. Tahmaseb A, Wismeijer D, Coucke W, et al: Computer technology applications in surgical implant dentistry: a systematic review. Int J Oral Maxillofac Implants 2014;29 Suppl:25-42
9. Van Assche N, Vercruyssen M, Coucke W, et al: Accuracy of computer-aided implant placement. Clin Oral Implants Res 2012;23 Suppl 6:112-23
10. Gargallo-Albiol J, Barootchi S, Salomo-Coll O, et al: Advantages and disadvantages of implant navigation surgery. A systematic review. Annals of Anatomy 2019;225:1-10
11. D'Haese J, Ackhurst J, Wismeijer D, et al: Current state of the art of computer-guided implant surgery. Periodontol 2000 2017;73:121-33
12. Emery RW, Merritt SA, Lank K, et al: Accuracy of Dynamic Navigation for Dental Implant Placement-Model-Based Evaluation. J Oral Implantol 2016;42:399-405
13. Hultin M, Svensson KG, Trulsson M: Clinical advantages of computer-guided implant placement: a systematic review. Clin Oral Implants Res 2012;23 Suppl 6:124-35
14. Block MS, Emery RW, Cullum DR, et al: Implant Placement Is More Accurate Using Dynamic Navigation. J Oral Maxillofac Surg 2017;75:1377-86
15. Chen C, Yuh D, Huang R, et al: Accuracy of implant placement with a navigation system, a laboratory guide, and freehand drilling. Int J Oral Maxillofac Implants 2018;33:1213-18
16. Wei S, Zhu Y, Wei J, et al: Accuracy of dynamic navigation in implant surgery: A systematic review and meta-analysis Clin Oral Implants Res 2021;00:1-11
17. Aydemir C, Arisan V: Accuracy of dental implant placement via dynamic navigation or the freehand method: a split-mouth randomized controlled clinical trial. Clin Oral Implants Res 2020;31:255-63
18. Kaewsiri D, Panmekiate S, Subbalekha K, et al: The accuracy of static vs. dynamic computer-assisted implant surgery in single tooth space: A randomized controlled trial. Clin Oral Implants Res 2019;30:505-14
19. Wu D, Zhou L, Yang J, et al: Accuracy of dynamic navigation compared to static surgical guide for dental implant placement Int J Implant Dent 2020;6
20. Park J, Young W, Park S, et al: Clinical factors influencing implant positioning by guided surgery using a nonmetal sleeve template in the partially edentulous ridge: multiple regression analysis of a prosective study. Clin Oral Implants Res 2020;31:1187-98
21. Pellegrino G, Taraschi V, Zacchino A, et al: Dynamic navigation: a prospective clinical trial to evaluate the accuracy of implant placement. Int J Compu Dent 2019;22:139-47
22. Stefanelli L, DeGroot B, Lipton D, et al: Accuracy of a dynamic dental implant navigation system in a private practice Int J Oral Maxillofac Implants 2019;34:205-13
23. Brief J, Edinger D, Hassfeld S, et al: Accuracy of image-guided implantology. Clin Oral Implants Res 2005;16:495-501
24. Kramer FJ, Baethge C, Swennen G, et al: Navigated vs. conventional implant insertion for maxillary single tooth replacement. Clin Oral Implants Res 2005;16:60-8
25. Alevisakos V, Mitov G, Stoetzer M, et al: A retrospective study of the accuracy of template-guided versus freehand implant placement: a nonradiologic method. Oral and Maxillofacial Surgery 2019;128:220-26
26. Noharet R, Pettersson A, Bourgeois D: Accuracy of implant placement in the posterior maxilla as related to 2 types of surgical guides: a pilot study in the human cadaver. J Prosthet Dent 2014;112:526-32

27. Younes F, Cosyn J, De Bruyckere T, et al: A randomized controlled study on the accuracy of free-handed, pilot-drill guided and fully guided implant surgery in partially edentulous patients J Clin Periodontol 2018;45:721-32

Table 1

Mean Total Errors

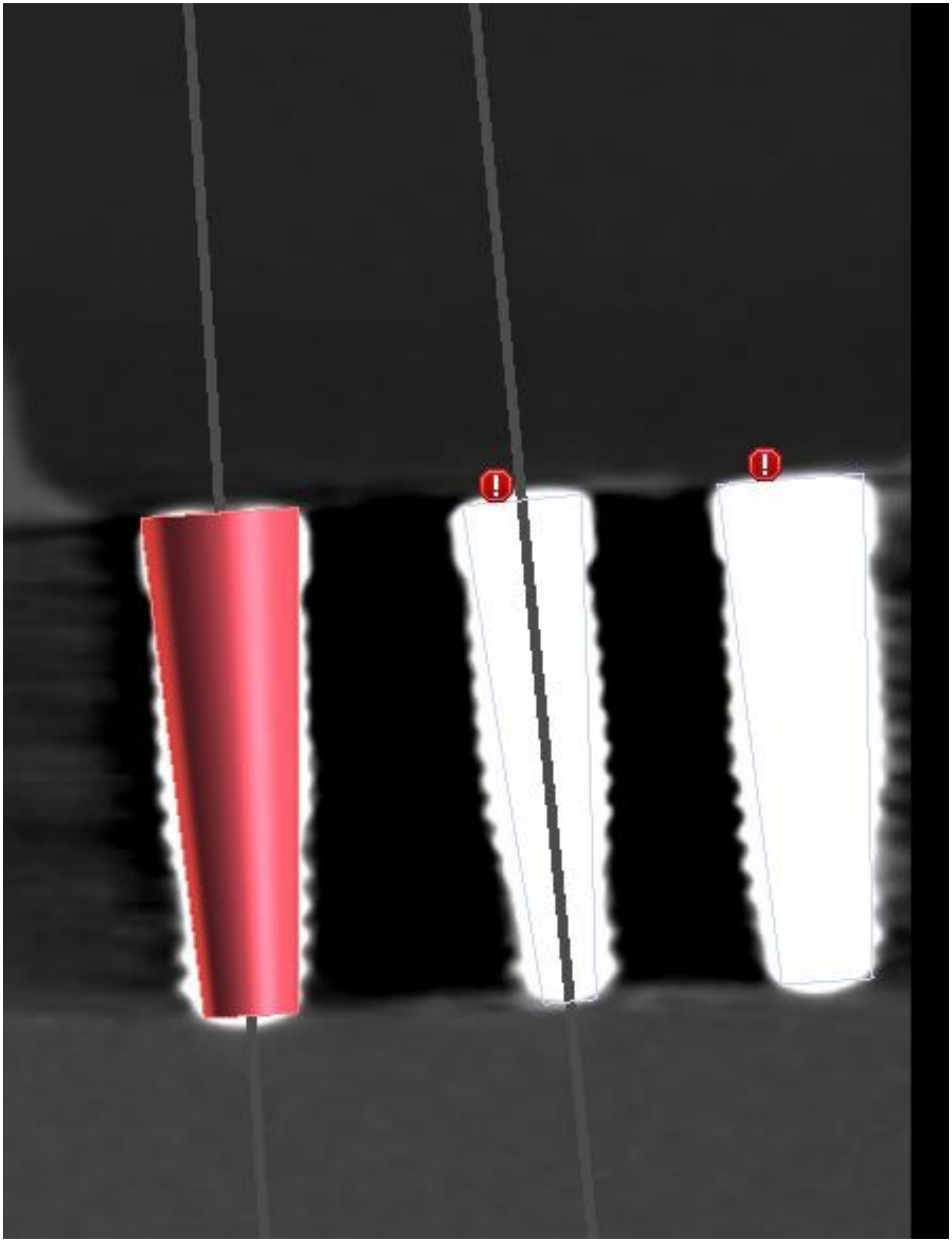
Modality	Total Angular Error (º)	Total Error at Entry (mm)	Total Error at Apex (mm)
OG	4.39 ± 2.11	0.84 ± 0.34	1.21 ± 0.55
FG	2.00 ± 1.08	0.46 ± 0.34	0.80 ± 0.33
DN	1.27 ± 0.63	0.66 ± 0.32	0.67 ± 0.43

Legend: OG - out-of-bounds guide, FG – fully limiting static guide, DN – dynamic navigation

Figure 1

The master model with reference implants in place.

Figure 2

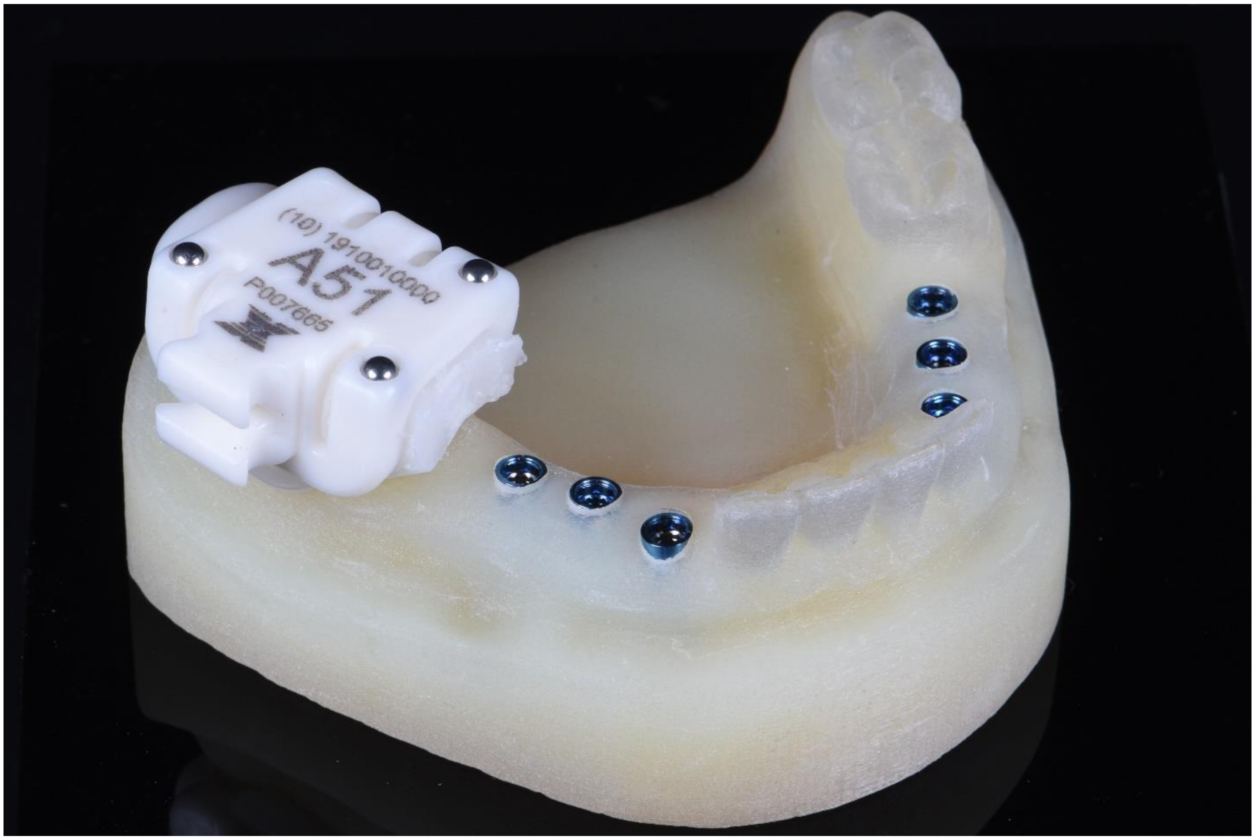


Blue Sky Plan implant planning. The virtual implant analog is superimposed on the CBCT of the reference implant.

Figure 3

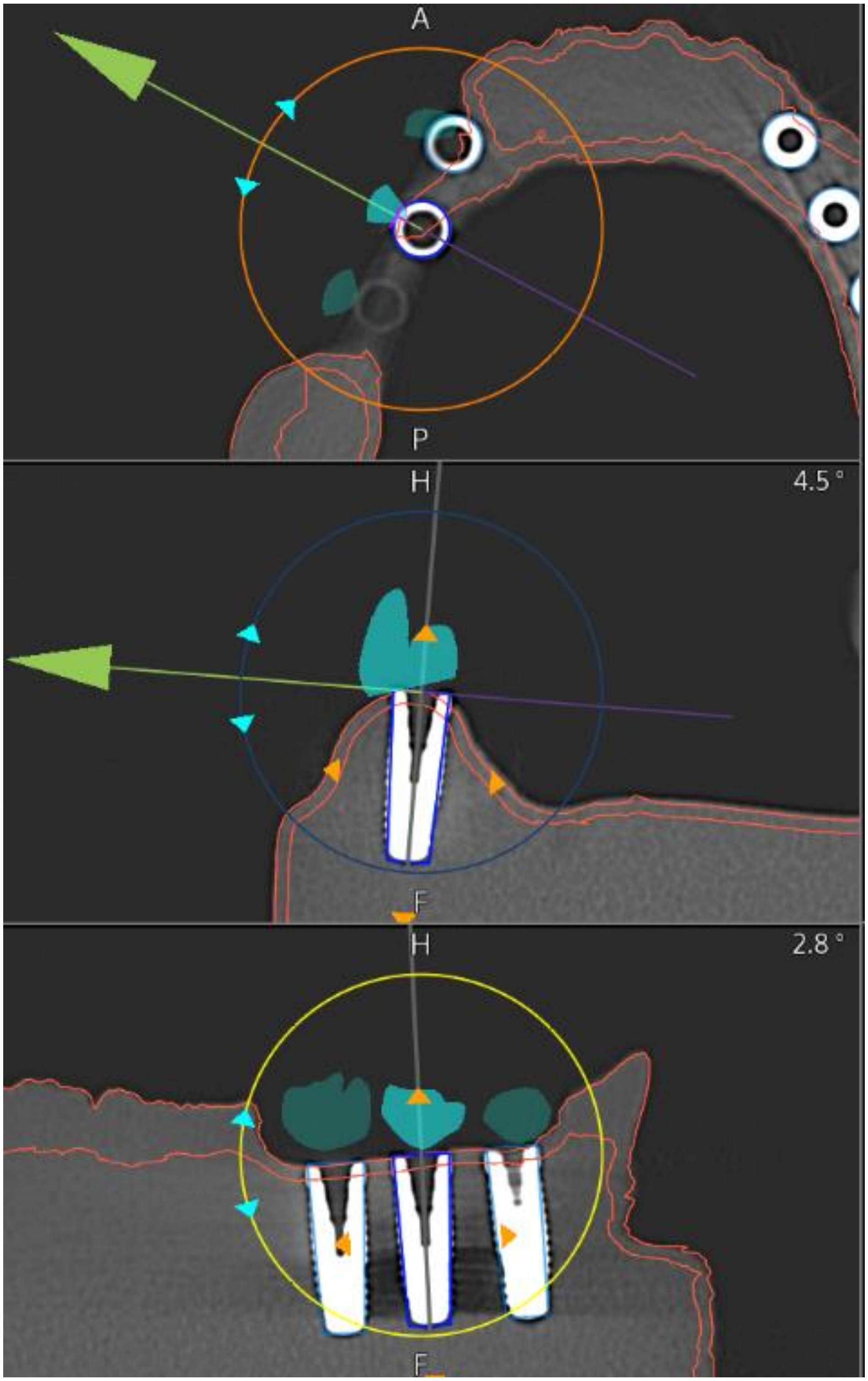
The printed fully limiting static guide.

Figure 4



The master model with the X-Clip mounted on #30 and 31 for right-sided X-Clip protocol.

Figure 5

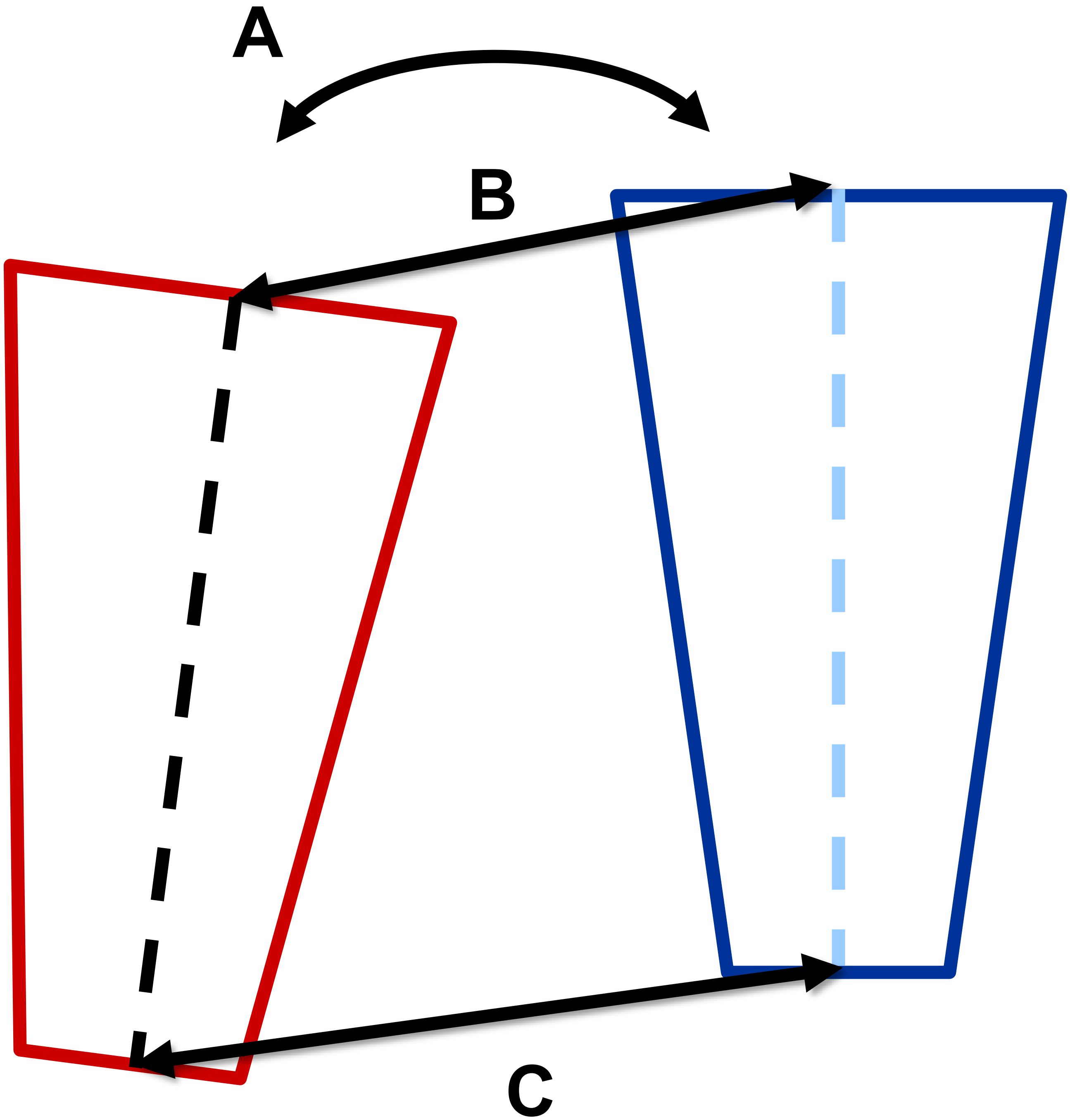


X-Guide implant planning. The blue outlines represent the virtual implant analogs superimposed on the reference implants in all dimensions.

Figure 6

The acrylic out-of-bounds guide with 3 mm drilled openings and reference teeth from the restorative plan.

Figure 7



A. angle deviation, B. entry point deviation, C. apex deviation