12-2016

Accuracy of Implants Placed with Surgical Guides: Thermoplastic vs. 3-D Printed

Caitlyn K. Bell

LOMA LINDA UNIVERSITY
School of Dentistry
in conjunction with the
Faculty of Graduate Studies

Accuracy of Implants Placed with Surgical Guides: Thermoplastic vs. 3-D Printed

by

Caitlyn K. Bell

A Thesis submitted in partial satisfaction of
the requirements for the degree
Master of Science in Periodontics

December 2016

Each person whose signature appears below certifies that this thesis in his/her opinion is adequate, in scope and quality, as a thesis for the degree Master of Science.

____, Chairperson
Erik Sahl, Assistant Professor of Periodontics

Yoon Jeong Kim, Associate Professor of Periodontics

Dwight Rice, Associate Professor of Radiologic and Imaging Sciences, and Associate Professor of Dental Research

ACKNOWLEDGEMENTS

I would like to thank Loma Linda University and the entire department of Graduate Periodontics for the opportunity to pursue my dreams in earning a Master of Science in Periodontics. I would also like to share a special thank you to Anatomage specifically Casey Nguyen who coordinated the project and Tak Yao for all of his hard work with data collection. I would like to thank Dr. Oyoyo from Loma Linda University for helping with the statistical analysis of data.

I would like to show my gratitude and appreciation to my family and friends, and especially my fiancé for his unconditional love and support for me, which has made my achievements possible.

I would also like to thank my co-residents, Fallon Livingston and Munehiko Ro, for their continual support through all of our endeavors over these long three years. Through our moments of hardship and enjoyment we have grown together. So thank you to all because without each of you this would not have been possible.

CONTENT

FIGURES

Figures Page

TABLES

Tables Page

ABSTRACT

Accuracy of Implants Placed with Surgical Guides: Thermoplastic vs. 3-D Printed

by

Caitlyn K. Bell

Master of Science in Periodontics
Loma Linda University, December 2016
Dr. Erik Sahl, Chairperson

Purpose: The purpose of this study was to evaluate the accuracy of placed implants using two different guided implant surgery materials: thermoplastic vs. 3-D printed surgical guides.**Materials and Methods:**Twenty duplicate mandibular models, ten thermoplastic and ten 3-D printed surgical guides were used. Twenty implants were placed following the guided surgery protocol. Cone beam computed tomography scans of placed implants and thecontrol implant were superimposed to measure deviations. **Results:** The thermoplastic group showed average deviations of 3.4 degrees, 1.3mm at the head, and 1.6mm at the apex of the implant compared to 2.36 degrees, 0.51mm, and 0.76mm for the 3-D printed group; p= 0.143, p<0.001, and p<0.001 respectively. **Conclusion:** There is a significant difference in the accuracy of the location of the implant head and apex between thermoplastic and 3-D printed surgical guides.

CHAPTER ONE

INTRODUCTION AND REVIEW OF THE LITERATURE

With rising esthetic concerns of patients and the considerations required for implant location in relation to the bone and soft tissue, treatment planning of ideal implant placement is of utmost importance. Therefore, many clinicians have shifted to the use of cone beam computed tomography (CBCT). The use of CBCT eliminates some of the limitations associated with panoramic radiographs and is recommended as the best method for obtaining necessary information because of the ability to obtain cross-sectional imaging[1].

Three-dimensional (3-D) planning of the implant location allows for manipulation of individual implant positions with regard to depth, mesio-distal angulation and positioning, and labio-lingual angulation and positioning[2]. It also encourages interdisciplinary communication between restorative dentists and surgeons allowing for multiple variations of treatment plans to be evaluated and critiqued until the optimal treatment plan is attained and implemented for superior esthetic results[3-5].The evolution of3-Dimplant planning has also had an effect on the surgical placement. The steps required for execution of the 3-D plan surgically is indicated as the most complicated step in the process of guided implant surgery[6]. 3-D planning and computer-aided design/computer-assisted manufacture technology (CAD/CAM) has made it possible to transfer these virtually planned implants to the surgical site with fabrication of surgical guides[7]. CBCT scans are accurate and cost effective to achieve the desired clinical outcome; however it is important to understand the limitations of such procedures.

The deviations of the placed implant from the 3-D plan may be due to errors that occur during the process. The deviations are a result of the sum of errors from examination, planning, conversion of the data into a guide, and execution; which can be expressed by linear and angular measurements[6]. Accuracy of implant placement can be achieved with computer-assisted implant planning. Multiple uses of drills and titanium sleeves, however, were shown to significantly reduce the system accuracy[8]. Lateral movements allowed by surgical guides have been shown to decrease by narrowing the sleeve diameter, which could improve the accuracy of implant placement[9].

Pre- and post-surgical CT scans have been used to evaluate the difference between 3-D planned implants and the actual location of the surgically placed implants defined as the deviation between the planned implant and position of the implant in the mouth. While computer-aided implant surgery has reduced the inaccuracies of placed implants, deviations still occur[4, 6]. The experience of the surgeon did not affect the accuracy of implants placed during guided surgery using stereolithographic surgical templates[10], however some research states there is a learning curve with the use of guided implant surgery[11] while others disagree[12].

Stereolithographic guide fabrication consists of 3 key steps including a scan to obtain anatomical information, software segmentation of information, and fabrication with rapid prototype technology. Each step is associated with inherent errors. This can lead to a 0.27-0.90mm deviation at the implant head, a 0.37-1.30mm deviation at the implant apex, a 0.32mm deviation in implant depth, and 1.72-4.50 degrees of angular deviation[13-17]. The stereolithographic surgical guide had statistically significant lower variance for all measurements than a conventionally produced scannographic template[14].

In a recent study surgically placed implants with different types of guides were evaluated for location of the implant head and apex, angle of implant, and depth in comparison to the 3-D plan. A simulated clinical scenario using epoxy edentulous mandibles measured the divergence between planned implants and actual location of surgically placed implants comparing two different surgical guides, the CAD/CAM stereolithographic surgical fabricated guide and a conventionally produced guide from a scannographic template. In the scannographic template group the difference between the planned and placed implant head was an average of 1.5mm, 2.1mm at the apex, with an angular deviation of 8 degrees. In the stereolithographic guide group the difference between the location of the planned and placed implant was an average of 0.9mm at the head and 1.0mm at the apex with an angular deviation of 4.5 degrees[14].

The accuracy of the position of the metal guide sleeves of two different guided implant surgery materials, 3-D printed surgical guides and thermoplastic guides, was compared using 3-D printed jaws. The vertical deviation for the 3-D printed guide was 0.35mm with an angular deviation of 0.81 degrees, while the thermoplastic guide had an average of 0.22mm vertical deviation and 1.46 degrees of angular deviation[18].

It is, therefore, important to note that when placing an implant with a fabricated surgical guide the actual location of the implant can vary from the planned location. This is especially important in clinical situations involving the distance of bonerequired between implants-to-teeth as well as implants-to-implants in regards to papilla height (i.e. aesthetic zone). It is also imperative to understand the limitations of the surgical guides available to reduce restorative and esthetic complications caused by malpositioning of implants.

The aim of this study is to evaluate the accuracy of 20 implants placed with the two different surgical guides: thermoplastic surgical guides versus 3-D printed surgical guides. The null hypotheses are that there is no difference in angular deviation, deviation at the head, or deviation at the apex of implants placed using two different surgical guides, thermoplastic vs. 3-D printed.

CHAPTER TWO

MATERIALS AND METHODS

Control, Models, and CBCT Aided Guides

A CBCT scan of one subject with a single edentulous space bounded by natural dentition for a completely tooth-borne surgical guide was used for this study.The control model was made from the surgical plan in a planning software program that was exported as a .STL file(Right Choice Milling, Jeffersonville, IN). Then the control model was fabricated, to accept the 4.3mm x 8.0mm control implant (NobelBiocare Tapered Replace Select; Yorba Linda, CA), with a 3-D printer (StrataSysObject30Orthodesk 3-D printer; Eden Prairie, MN) (*Fig. 1)*. Twenty duplicate mandibular quadrant jaw models from the same CBCT scan were also made with the same 3-D printer.

Two types of CBCT aided guides were used in this study, 10 thermoplastic and ten 3-D printed surgical guides (Right Choice Milling, Jeffersonville, IN). The 10 thermoplastic guides were fabricated utilizing the conventional vacuuform process, in which, the metal guide sleeve was placed and picked up from the control model. The 3-D printed surgical guides were planned with the same planning software, exported as a .STL file, and then printed with the same 3-D printer.

Treatments

Twenty implants with a diameter of 4.3mm and length of8.0mmwere placed, one into each mandibular model utilizing 10 of each type of guide according to the manufacturer recommendation. A CBCT scan, utilizing one scanner (NewtomVGI, Biolase; Irvine, CA) was then acquired of each printed jaw model with the placed implant and the control implant. The scan setting was a field of view of 6 cm x 6 cm, 75μm voxel size, 110 kVp output, 0.55mA, 2.99mAs, and 5.4s managed by capture optimum dose algorithms in the machine.A total of 21 scans were obtained and the same setting was used for all of the scans. The data was saved as digital imaging and communications in medicine (DICOM) file volumes, and loaded into the DICOM viewer software(Invivo5, Anatomage; San Jose, CA). The DICOM file volumes of all 20 placed implants were individually superimposed over the control implantfile volumes according to the software protocol.

The DICOM file volumes of the control implant were uploaded into the software *(Fig. 2)*. The superimposition function in the software was then utilized to important the DICOM file volumes of a test implant *(Fig. 3)* and manual manipulation was completed to approximate the scans into the superimposition position *(Fig. 4)*.An automatic volume based registration at high precision was then completed after adjusting the target volume size and centering the model *(Fig. 5).*This procedure was repeated for each placed implant. The superimposition files of the control and each placed implant were saved as .inv, .odata, and .vdata files.

Once the images were digitally fused together and saved with the corresponding files, the maximum mutual information(MMI) was used to determine the deviation at the head of the implant, the deviation at the apex of the implant, and the angular deviation with parallel lines through the center of the implants in the software (*Fig. 6 and 7).*All superimpositions and measurements were completed by one technician from Anatomage.

Statistical Analysis

The Mann-Whitney u test was used to test the null hypotheses at an alpha level of 0.05 and confidence interval of 95%. Descriptive statistics were used for the average ± standard deviation.

CHAPTER THREE

RESULTS

The angular deviation, deviation at the head of the implant, and deviation at the apex of the implant were measured for each of the 10 implants placed utilizing the 10 thermoplastic surgical guides and each of the 10 implants placed utilizing the ten 3-D printed surgical guides compared to the control implant. The data for all measurements, averages, standard deviations, and *p*-values is presented in *Table 1*.

The results show that implants placed with the thermoplastic guides had a range of angular deviation of 1.25 – 5.31 degrees with an average of 3.40 ± 1.23degreeswhile the implants placed with the 3-D printed surgical guide had a range of angular deviation of 0.49 – 4.40 degrees with an average of 2.36 ± 1.38 degrees. The angular deviation of implants placed with the thermoplastic guides is not statistically different from the implants placed with the 3-D printed surgical guide, at$p = 0.143$ (*Fig. 8).*

Implants placed with the thermoplastic guides had a deviation of 0.71 – 1.72mm with an average of 1.33 ± 0.30mm and implants placed with the 3-D printed surgical guide had a range of deviation of 0.18 – 0.95mm with an average of 0.51 ± 0.24mm at the head of the implant. The deviation at the head of implants placed with the two different surgical guidesis statistically significantly different, at$p < 0.001$ (*Fig. 8).*

The results show that implants placed with the thermoplastic guides had a deviation of 1.06 – 2.07mm with an average of 1.60 ± 0.29mm at the apex of the implant and implants placed with the 3-D printed surgical guide had a range of deviation of 0.24 – 1.29mmwith an average of 0.76 ± 0.36mm. The deviation at the apex of implants placed with two different surgical guide materials is statistically significantly different, at $p < 0.001$ (*Fig. 8).*

CHAPTER FOUR

DISCUSSION

The resultsof this study accept the null hypothesis that there is no difference in the accuracy of implant angulations when using a thermoplastic surgical guide or 3-D printed surgical guide. The results also reject the null hypotheses; there is a significant difference in the accuracy of the implant head and implant apex when using thermoplastic surgical guides and 3-D printed surgical guides.

The measurements of deviations found in this study are consistent with published data from other studies with regards to stereolithographic surgical guides. Previous studies showed 1.72-4.50 degrees of angular deviation, 0.27-0.90mm deviation at the implant head, and 0.37-1.30mm deviation at the implant apex[13-17].

A key point for discussion is the length of the implant. This study used8mm implants due tothe anatomical limitations of the subject and found there was no difference in the angular deviation between groups. However,if a longer implant was placed it is important to note that due to the angular deviations of the implants, an increase in deviation would have been observed at the apex of the placed implant. Placement of implant lengths of larger than 8mm may, therefore, significantly increase the error associated with the location of the apex of the implant.

Other important findings in this study are the handling properties and clinical characteristics of the thermoplastic surgical guides compared to the 3-D printed surgical guides. The first noticeable difference between the two surgical guides is the rigidity of the materials. The thermoplastic guide has more flexure when seated onto the model than the 3-D printed surgical guide. The ability of the thermoplastic surgical guide to move and bend may play a significant role in decreasing the accuracy of implants placed. An increase in deviations may be found if the study was conducted on an edentulous space with multiple missing teeth due to the flex of the thermoplastic surgical guides.

The second distinctive feature between the thermoplastic surgical guides and the 3-D printed surgical guides was their handling properties during actual implant placement into the models. The surgical drill kit from the manufacturer has a ledge on the drill that acts as a depth stop when it comes into contact with the metal guide sleeve. On several occasions the metal guide sleeve could be detected both visually and tactilely moving in the apical direction while placing implants employing thermoplastic surgical guides. This phenomenon was not noted during implant placement utilizing the 3-D printed surgical guides. The inherent characteristic of the thermoplastic guides being less rigid may result in more error of the location of the implant head and apex compared to the planned implant than those placed with the 3-D printed surgical guide.

The study design of this research also had several limitations. The control implant was an implant placed in the model by the lab, from which all placed implants were compared. It would be beneficial to be able to compare the placed implants to the original virtual plan to elimination the possible error in the control implant model fabrication. Another limitation to this study is the small sample size; however even with only ten implants placed for each type of guide the study was able to show significance at an alpha level of 0.05 and confidence interval of 95% for deviations at the head and apex of placed implants.

More studies should be performed to compare and evaluate the accuracy of implants placed using different guided surgical materials. These studies should include surgical guides for partially edentulous areas requiring multiple implant placements, as well as, fully edentulous cases.

CHAPTER FIVE

CONCLUSION

Within the limits of this study, it is concluded that there is no significant difference in the angular deviation of implants using a thermoplastic surgical guide versus 3-D printed surgical guide following the manufacturer surgical guide protocol. However, it can also be concluded that the locations of the head of the implant and apex of the implants placed utilizing a thermoplastic surgical guide are less accurate than those of implants placed using a 3-D printed surgical guide.

Fig 1. Control implant.

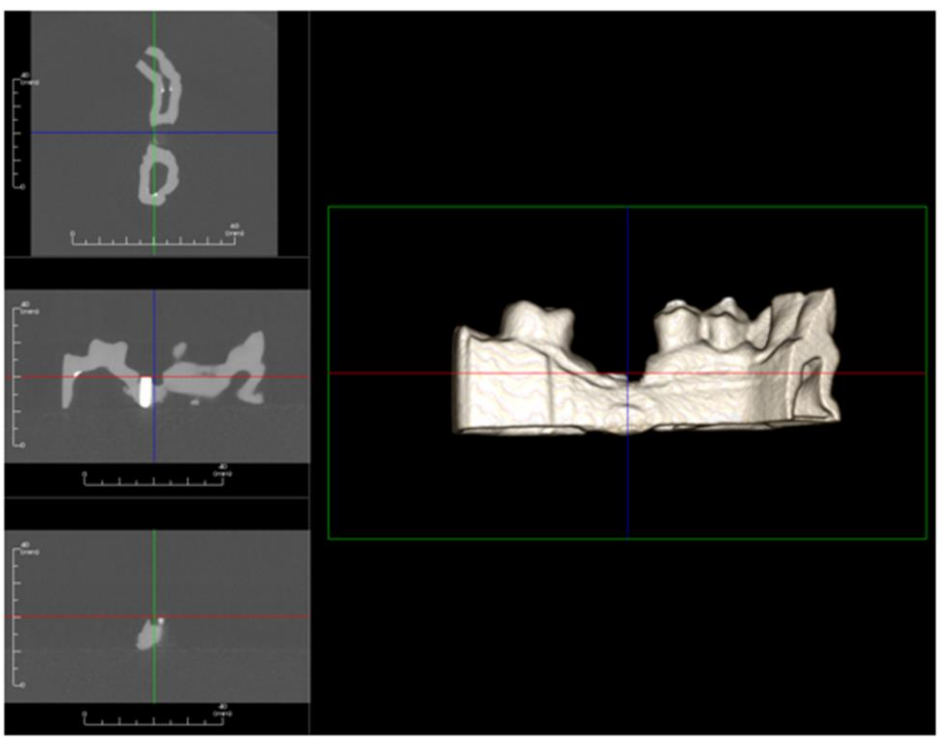

Fig 2. Uploaded DICOM file volumes of the control implant.

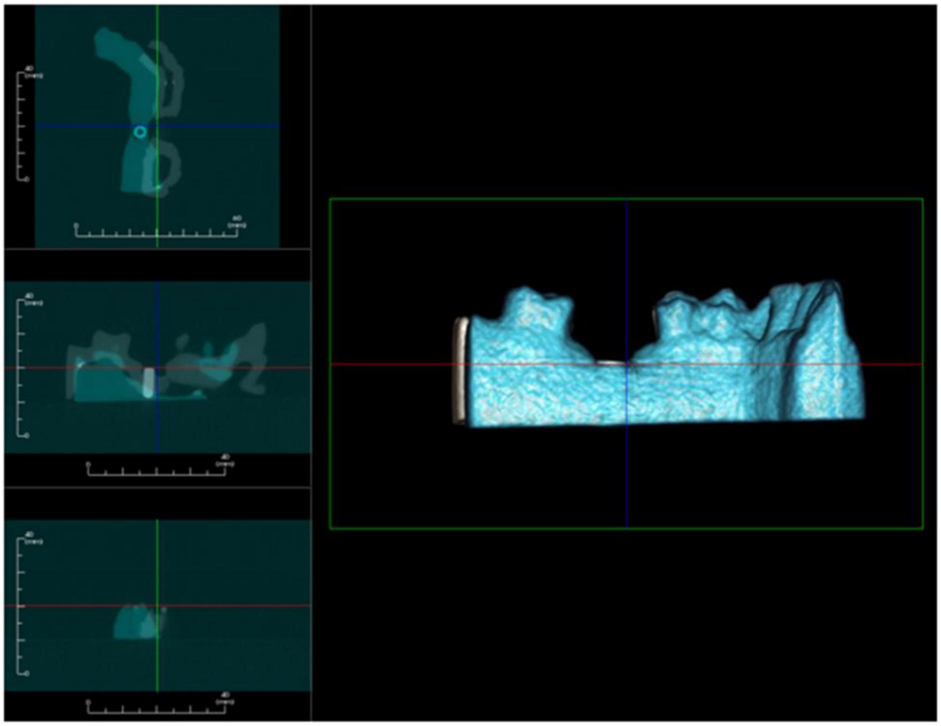

Fig 3. Uploaded DICOM file volumes of a placed implant in the superimposition function.
The DICOM file volumesof a placed implant using the 3D-7 printed surgical guide.

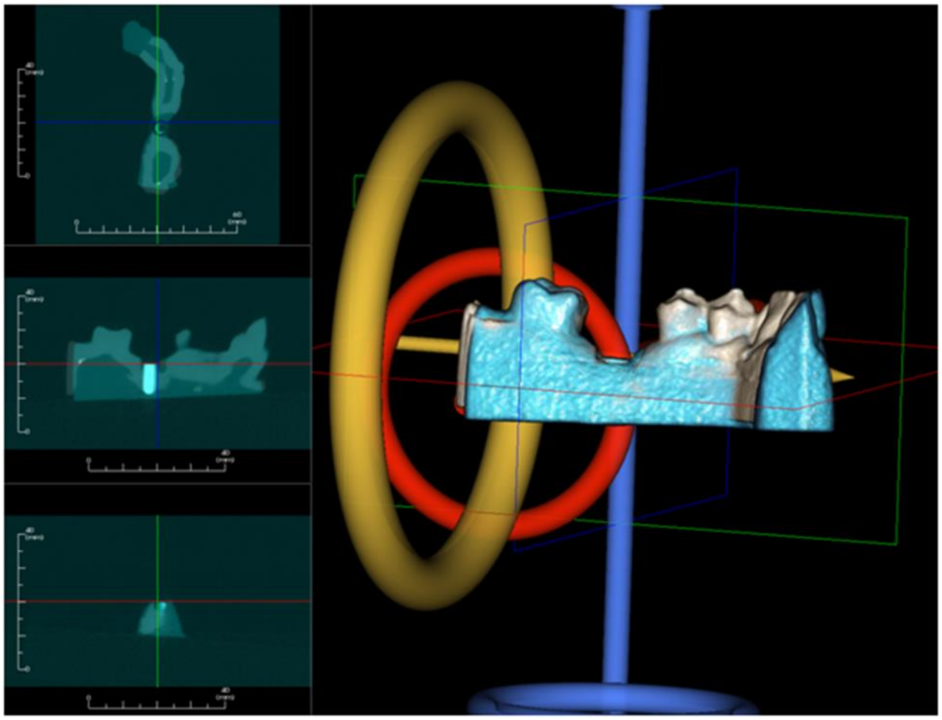

Fig 4. Approximation of the DICOM file volumes into superimposition.
The DICOM file volumesare approximated into the superimposition by manual manipulation(control and 3D-7 are shown).

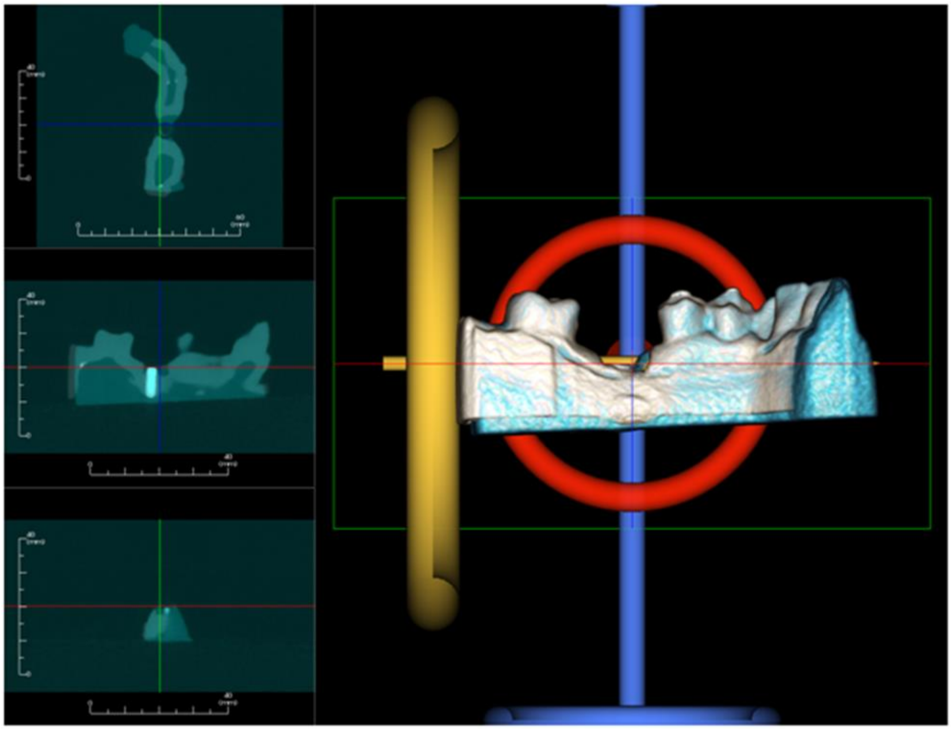

Fig 5. Automatic volume based registration.
The automatic volume based registration at high precision is performed after adjusting the target volume size and centering the model (control and 3D-7 are shown).

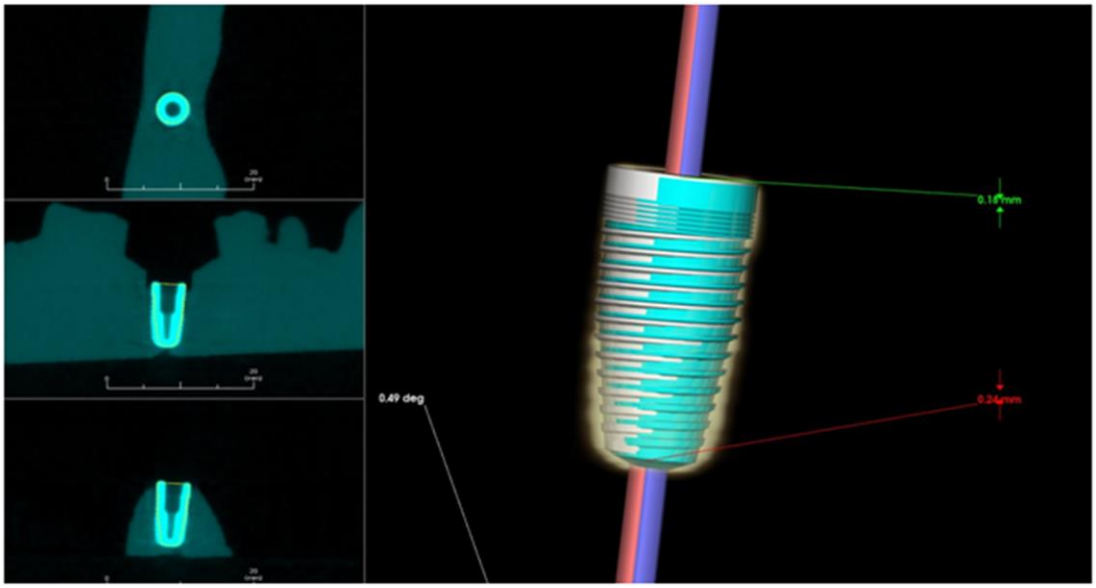

Fig 6. Measurements of deviations (3D-2).
Measurements of the angular deviation (white), deviation at the head of the implant (green), and deviation of the apex of the implant (red) are shown after performing the MMI utilizing .inv, .vdata, and .odata files for the control and 3D-2 printed surgical guide.

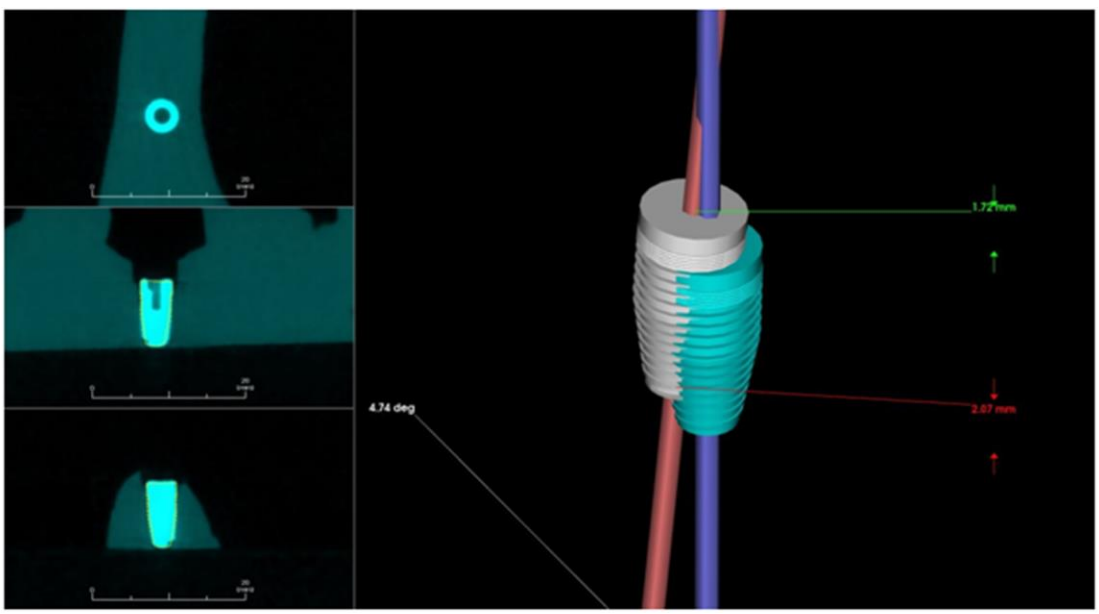

Fig 7. Measurements of deviations (T-8).
Measurements of the angular deviation (white), deviation at the head of the implant (green), and deviation of the apex of the implant (red) are shown after performing the MMI utilizing .inv, .vdata, and .odata files for the control and T-8 surgical guide.

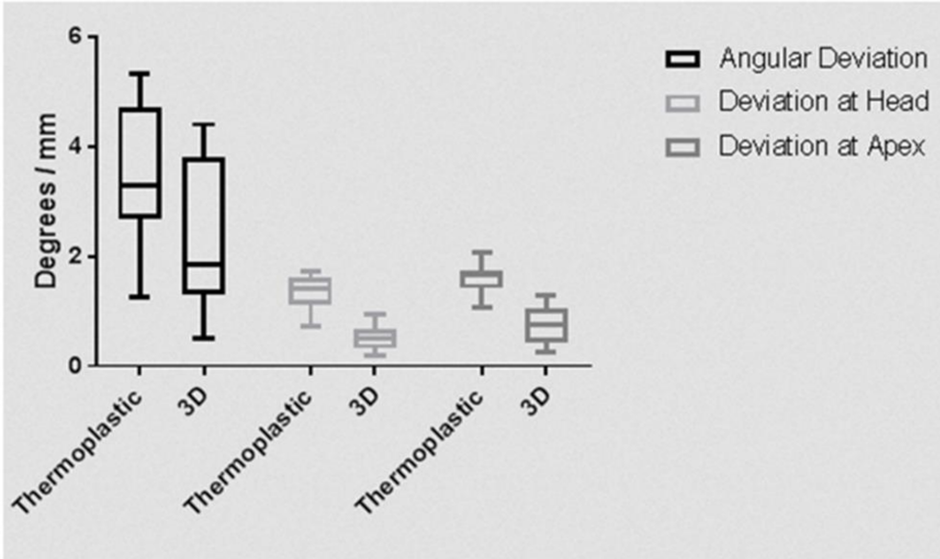

Fig 8. Measurements of deviations for implants placed with thermoplastic and 3-D printed surgical guides

The data is presented in *Table 1.* Angular deviations are represented by degree measurements and deviations at implant head and apex are represented as millimeter measurements.

Table 1. Measurements of deviations.

Surgical Guide	Angular Deviation (°)	Deviation at Head (mm)	Deviation at Apex (mm)
T-1	2.75	0.71	1.06
T-2	2.75	1.64	1.74
T-3	4.71	1.43	1.76
T-4	3.10	1.42	1.64
T-5	3.49	1.13	1.47
T-6	2.43	1.39	1.52
T-7	3.50	1.59	1.75
T-8	4.74	1.72	2.07
T-9	1.25	1.22	1.23
T-10	5.31	1.09	1.71
Thermoplastic Average	**3.40**	**1.33**	**1.60**
Standard Deviation	**1.23**	**0.30**	**0.29**
3D-1	3.29	0.61	0.93
3D-2	0.49	0.18	0.24
3D-3	3.70	0.51	0.99
3D-4	1.41	0.27	0.41
3D-5	1.58	0.50	0.66
3D-6	4.40	0.95	1.29
3D-7	2.04	0.33	0.57
3D-8	1.63	0.62	0.85
3D-9	4.06	0.78	1.24
3D-10	1.00	0.34	0.42
3-D Printed Average	**2.36**	**0.51**	**0.76**
Standard Deviation	**1.38**	**0.24**	**0.36**
P-Value	**0.143**	**<0.001**	**<0.001**

REFERENCES

1. Tyndall DA, Price JB,Tetradis S, Ganz SD, Hildebolt C, Scarfe WC. Position statement of the American Academy of Oral and Maxillofacial Radiology on selection criteria for the use of radiology in dental implantology with emphasis on cone beam computed tomography. Oral Surg Oral Med Oral Pathol Oral Radiol 2012 Jun;113(6):817-26.

2. Lal K, White GS, Morea DN, Wright RF. Use of stereolithographic templates for surgical and prosthodontic implant planning and placement. Part I. The concept.J Prosthodont2006; 15(1):51–8.

3. Worthington P, Rubenstein J. The role of cone-beam computed tomography in the planning and placement of implants. J Am Dent Assoc 2010; 141(10 suppl):19S-24S.

4. Widmann G, Bale RJ. Accuracy in computer-aided implant surgery: A review. Int J Oral MaxilloImpl2006; 21(2):305–13.

5. Brief J, Edinger D, Hassfeld S, Eggers G. Accuracy of image-guided implantology. Clin Oral Implants Res 2005; 16(4):495–501.

6. Vercruyssen M, Laleman I, Jacobs R, Quirynen M. Computer-supported implant planning and guided surgery: a narrative review. Clinical Oral Implants Research 2015; (Supp 11): 69-76.

7. Takeshita F, Suetsugu T. Accurate presurgical determination for implant placement by using computerized tomography scan. J Prosthet Dent 1996; 76(6):590–1.

8. Horwitz J, Zuabi O, Machtei EE. Accuracy of a computerized tomography-guided template-assisted implant placement system: an *in vitro* study. Clin Oral Impl Res 2009; 20(10):1156-1162.

9. Schneider D, Schober F, Grohmann P, Hammerle CHF, Jung RE. *In-vitro* evaluation of the tolerance of surgical instruments in templates for computer-assisted guided implantology produced by 3-D printing.Clin Oral Impl Res 2015; 26(3):320-5.

10. Van de Wiele G, Teughels W, Vercruyssen M, Coucke W, Temmerman A, Quirynen M. The accuracy of guided surgery via mucosa-supported stereolithographic surgical templates in the hands of surgeons with little experience. Clin Oral Impl2015; 26(12):1489-94.

11. Vasak C, Watzak G, Gahleitner A, Strbac G, Schemper M, Zechner W. Computed tomography-based evaluation of template (Nobel-Guide)- guided implant

positions: a prospective radiological study. Clin Oral Impl Res 2011; 22(20): 1157-1163.

12. Valente F, Schiroli G, Sbrenna A. Accuracy of computer-aided oral implant surgery: a clinical and radiographic study. Intl J of Oral and MaxilloImpl 2009; 24(2): 234-242.

13. Beretta M, Poli PP, Maiorana C. Accuracy of computer-aided template-guided oral implant placement: a prospective clinical study. J Periodontal ImplSci 2014; 44(4)184-193.

14. Sarment D, Sukovic P, Clinthorn, N. Accuracy of implant placement with a stereolithographic surgical guide. Int J Oral MaxilloImpl 2003; 18(4):571-7.

15. Tahmaseb A, Wismeijer D, Coucke W, Derksen W. Computer technology applications in surgical implant dentistry: a systematic review. Int J of Oral and MaxilloImpl 2014;29(Suppl):25-42.

16. Geng W, Liu C, Su Y, Li J, Zhou Y. Accuracy of different types of computer-aided design/ computer-aided manufacturing surgical guides for dental implant placement. Int J ClinExp Med 2015; 8(6):8442-8449.

17. Jung R, 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 Maxillo Imp 2009; 24(Suppl):92–109.

18. Hunter, R. A technical comparison of two different guided implant surgery materials: 3D printed vs. thermoplastic. Master of Science in Dentistry manuscript.Loma Linda, Loma Linda University, 2015.