Application of Augmented Reality with Navigation System and Laboratory Guide affected on the Deviation of Dental Implant - A Pilot Clinical Study

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Abstract

Augmented reality (AR) is a new technology that has provided a growing number of applications in the medical field. The goal of AR technology is to make the surgical field more visible during an operation. Currently, this goal is achieved by using special glasses that accurately display either navigation or static diagnostic pictures. Because dental implant procedures demand biomechanical, functional, phonetical, and esthetical results, precise placement and direction are required. The objective of this study is to evaluate the implant deviation between navigation systems and laboratory guides with and without augmented reality techniques. Ten patients who were eligible for single-tooth implant placement were divided into two groups: 1) AR glasses group (navigation system and laboratory guide with augmented reality technique) and 2) non-AR glasses group (navigation system and laboratory guide without augmented reality technique). Each group was composed of five implants. Preoperative Cone-Beam Computed Tomography (CBCT) was transferred along with implant planning software to plan the optimal implant position. All implants were placed by one operator. The cases in which the operator wore the AR glasses when treating were counted in the AR glasses group. The postoperative CBCT was provided to the patients. The postoperative 3D data were then superimposed onto the preoperative plan to evaluate the implant deviation.

The 3D angular implant deviations in the AR glasses group versus the non-AR glasses group were 1.68 ± 1.18 degrees and 2.46 ± 2.17 degrees respectively. Mean 3D entry point and apical implant deviations in the AR glasses group were 1.03 ± 0.39 mm and 1.21 ± 0.36 mm respectively. Mean 3D entry point and apical implant deviations in the non-AR glasses group were 1.05 ± 0.44 mm and 1.27 ± 0.52 mm respectively. No significant differences were found between the two groups. However, the AR glasses group tended to show less deviation. Augmented reality can eliminate the hand-eye coordination problems by allowing the operator to see both the surgical site and the navigation system display in the same field.

Keywords: *Augmented Reality, Navigation system, Laboratory guide stent, Dental implant, Implant deviation*

1. Introduction

Augmented reality is a type of technology that enhances an environment by superimposing computer-generated virtual material onto real structures. AR is a new development in the field of medicine, and its applications are focused on specialties such as neurosurgery, laparoscopic, and plastic surgery. Medical education and training also make extensive use of augmented reality technologies. The AR platform is currently defined as a system that combines virtual and real sources in a single actual environment. This system runs interactively in real-time and reciprocally registers virtual and real objects.

Dentists may use AR when performing oral and maxillofacial surgery, or with dental implant placement and orthognathic procedures. Augmented reality allows the operator to visualize in real-time information projected onto the lenses of AR glasses via wireless technology (Kwon, Park, & Han, 2018; Pellegrino et al., 2019).

Computer-assisted technologies (CAT) are increasingly incorporated into various sectors of dentistry. Several studies have shown that these technologies can decrease the deviation between the virtual and actual position of dental implants. The two major CAT currently in use are the static and navigation systems (Block & Emery, 2016).

Static guided surgery uses laboratory-guided templates to fix implant positions. This system has guided drilling protocols created from software that can be easily followed by the operator. However, printing surgical guided templates can cause possible errors in laboratory processes (Sun, Lee, & Lan, 2020).

The navigation system is largely used in neurosurgery, orthopedic surgery, and increasingly in dental implantology. The system is created by using medical or dental imaging in conjunction with optical tracking. They combine dental implant surgical equipment, 3D imaging, and optical positioning technologies with implant preoperative planning software (Sun, Lan, Pan, & Lee, 2018). This system shows real-time drilling and implant positions on a computer display. The operator must be trained and practice extensively to use the system skillfully. The navigation system uses a mobile screen positioned near the dental chair, which requires the surgeon to monitor both the screen and the surgical site in the oral cavity, which may result in possible errors (Pellegrino et al., 2019). Thus, the operator must pay attention to both the patient and navigation display at the same time.

The application of augmented reality when combined with a navigation system and laboratory guide might improve this issue and decrease the possibility of implant deviation. The AR system recognizes computer hardware and instantly displays current navigation images on the AR lens. The operator can view virtual three-dimensional anatomic components, along with the implant and the surgical guided template, to ensure that the site preparation results match the preoperative plans. Previous studies also showed that intraoperative visual assistance achieved successful implant positions and reduced the risk of iatrogenic damage to nearby anatomic structures such as the mandibular nerve or the maxillary sinus floor (Lin, Yau, Wang, Zheng, & Chung, 2015; Ng, Ho, & Wexler, 2005).

Some studies performed implant placements with the AR system in the model experiments and they showed positive results (Lin et al., 2015; Ma et al., 2019). However, there are few clinical studies currently available concerning the use of augmented reality combined with navigation systems and laboratory guides, and possible dental implant deviation.

2. Objectives

To compare the implant deviations of a navigation system and laboratory guide with augmented reality technique and non-augmented reality technique

3. Materials and Methods

3.1 Population

Each patient's tooth was extracted more than two to three months prior and required a dental implant. Patients were eligible for surgical implant placement at the Faculty of Dentistry, Chulalongkorn University. Participants in this study were required to be over the age of 20 and have acceptable bone volume for implant placements (including simultaneous bone augmentation) that could achieve primary stability (25Ncm insertion torque or more) (Trisi et al., 2009). Patients with systemic diseases that could interfere with osseointegration and/or the healing process, as well as patients with a small mouth opening (inter-incisal range less than 40 mm), were excluded from the study. The study enrolled ten patients who met all the above criteria and gave their consent.

The ten patients were divided into two groups: 1) AR glasses group (navigation system and laboratory guide with augmented reality technique) and 2) non-AR glasses group (navigation system and laboratory guide without augmented reality technique). Each group was composed of five implants. All patients were operated on by the same operator. She practiced 20 implants on models to first familiarize herself with the AR technology before performing the procedures on real patients. The operator had one year of experience with AR and placed about 500 implants per year, both with and without AR technology.

3.2 Presurgical process

The patients provided impressions using irreversible hydrocolloid and poured with stone to make a diagnostic model. Diagnostic models were scanned by a D900L scanner (3shape, Copenhagen, Denmark). The Standard Tessellation Language (STL) files were then exported. Patients also received Cone-Beam

Computed Tomography (CBCT) (X-mind trium, Acteon, Italy). Each 3D implant position was planned with a navigation system (Iris – 100 version 6.8, EPED Inc., Taiwan) and static system software (coDiagnostiX software version 9.7 (Dental Wings inc, Montreal, Canada)). The digital drill guide with sleeves (Figure 1) was designed and printed out using a 3D printer (Straumann P10+, Institute Straumann AG, Germany).

Figure 1 Laboratory guided stent

3.3 Surgical process

The handpiece and patient's jaw position were registered. The surgical procedures were performed under local anesthesia using the navigation system machine and components (Iris – 100 version 6.8, EPED Inc., Taiwan) with a laboratory guide stent in the patient's mouth (Figure 2). The operator wore AR glasses (Moverio BT-300, Seiko Epson Corporation, Tokyo, Japan) in the AR glasses group. The AR glasses were connected wirelessly via Bluetooth with a navigation system. The operator could see the navigation images and movement on the AR glasses (Figures 3 and 4). The bone level implants were placed according to the guided protocol of the Straumann guided surgery system (Straumann, Institute Straumann AG, Basel, Switzerland).

Figure 2 Navigation components and Guided surgery system

3.4 Postsurgical process

All patients were prescribed 1g amoxicillin twice a day and 400mg ibuprofen three times a day for five days.

The patients received postoperative CBCT (X-mind trium, Acteon, Italy). Postoperative 3D data was superimposed onto the preoperative plan using a treatment evaluation tool in the coDiagnostiX software program in order to evaluate the implant deviation (Figure 5).

Figure 3 AR glasses connected with Navigation system

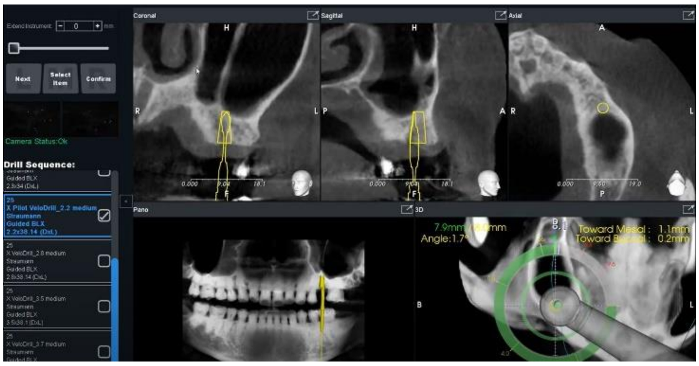

Figure 4 Navigation display

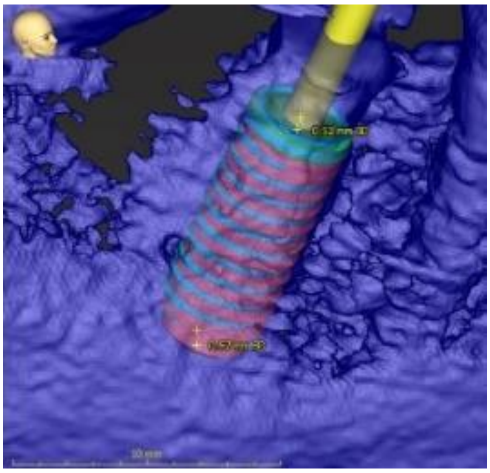

Figure 5 Postoperative 3D data (pink) superimposed onto the preoperative plan (blue)

3.5 Deviation evaluation

Three measuring points were used for implant deviation analysis by comparing the virtual and the actual positions (Figure 6):

1) 3D angular deviation was the angle difference in degrees (°) between the axis line of the implants.

2) 3D entry point deviation was the distance in millimeters (mm) between the implants' shoulders in all directions.

3) 3D apical deviation was the distance in millimeters (mm) between the implants' tip in all direction.

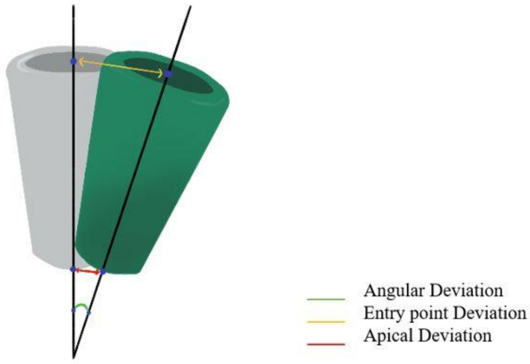

Figure 6 Implant Deviation

3.6 Statistic analysis

The implant deviation data was imported to IBM SPSS Statistics software version 22 (SPSS Inc.). A Chi-square test was used to compare the patients' demographic data and the implant/location characteristics between the AR glasses and the non-AR glasses groups. The normality of data distribution was calculated using the Shapiro-Wilk test. 3D angular deviation, 3D entry point deviation, and 3D apical deviation between the AR glasses and the non-AR glasses groups were compared. An independent two-sample *t*-test was applied in the case that the data was normally distributed. A Mann-Whitney *U* test was applied in the case that the distribution was not normal. A *P*-value < 0.05 was considered statistically significant.

4. Results and Discussion

4.1 Results

Ten patients were divided into two groups (AR glasses and non-AR glasses groups), and each received a single implant. The participants included five males and five females aged 21-67 years. All implants achieved 20 Ncm insertion torque or more. No patient dropped out and all anticipated measurements were conducted. No significant differences were found in sample characteristics between the two groups. The distribution of implant locations and types is presented in Table 1.

The implant deviations between the virtual and the actual positions for the AR glasses group and the non-AR glasses group are presented in Table 2. Briefly, the 3D angular implant deviations in the AR glasses and non-AR glasses groups were 1.68 ± 1.18 degrees and 2.46 ± 2.17 degrees respectively. Mean 3D entry point and apical implant deviations in the AR glasses group were 1.03 ± 0.39 mm and 1.21 ± 0.36 mm respectively. Mean 3D entry point and apical implant deviations in the non-AR glasses group were 1.05 ± 0.44 mm and 1.27 ± 0.52 mm respectively. Normal distribution was observed in all data sets, therefore, an independent two-sample *t*-test was used. No significant differences were found between the two groups, however, the results showed a tendency of less deviation in the AR glasses group. Only mild pain and swelling were observed. No major complications were found.

4.2 Discussion

Computer-guided surgery approaches in implantology showed relatively effective results in terms of implant placement accuracy. Block et al (2017) reported on the implant placement deviation obtained by three operators using dynamic navigation in 100 partially edentulous patients. For the dynamic navigation group, they reported a mean error of 0.87 ± 0.42 mm at the entry point, 1.56 ± 0.69 mm at the tip, and 3.62 ± 2.73 degrees for angular deviations. The entry point, apical, and angular deviations had corresponding mean values of 1.15 ± 0.59 mm, 2.51 ± 0.86 mm, and 7.69 ± 4.92 degrees, respectively for the non-dynamically guided group (Block, Emery, Lank, & Ryan, 2017). Stefanelli et al (2019) reported deviations of 0.71 ± 0.40 mm at the entry point, 1 ± 0.49 mm at the tip and a mean angular deviation of 2.26 ± 1.62 degrees in a retrospective study on 231 implants (Stefanelli, DeGroot, Lipton, & Mandelaris, 2019). Smitkarn et al (2019) studied the accuracy of 60 implants using the static system and freehand method. They reported that the deviations of the static system group were 2.8 ± 2.6 degrees in the angle, 0.9 ± 0.8 mm in the entry point, and 1.2 ± 0.9 mm in the tip and showed fewer deviations than the freehand group in all aspects (Smitkarn, Subbalekha, Mattheos, & Pimkhaokham, 2019). Kaewsiri et al (2019) compared the accuracy of 60 implants between static and dynamic systems. The deviations were found 0.97 ± 0.44 mm at the entry point, 1.28 ± 0.46 mm at the tip, and the angular deviation was 2.84 ± 1.71 degrees in the static system group. The deviations were found at 1.05 ± 0.4 mm at the entry point, 1.29 ± 0.50 mm at the tip, and angular deviation was 3.06 ± 1.37 degrees in the dynamic system group (Kaewsiri, Panmekiate, Subbalekha, Mattheos, & Pimkhaokham, 2019).

Table 1 Distribution of implant

Variables	AR Glasses (n=5)	Non-AR glasses (n=5)	p-value (Chi-square test)
Type of arch			
Maxilla	1	4	0.21
Mandible	4	1	
Implant location			
Premolar	2	1	1.00
Molar	3	4	
Implant diameter (mm)			
3.3	2	0	0.07
4.1	0	2	
4.8	1	3	
5	2	0	
Implant length (mm)			
8	1	3	0.33
10	3	2	
12	1	0	

Table 2 Deviation of implant position

Group	AR Glasses (n=5)	Non-AR glasses (n=5)	p-value (independent two-sample *t*-test)
3D Angular deviation (degree)			
Mean ± SD	1.68 ± 1.18	2.46 ± 2.17	0.50
Median	2.00	2.40	
Min - Max	0.00 – 2.90	0.00 – 5.70	
95% Cl	0.22, 3.14	-0.23, 5.15	
3D Entry point deviation (mm)			
Mean ± SD	1.03 ± 0.39	1.05 ± 0.44	0.96

Group	AR Glasses (n=5)	Non-AR glasses (n=5)	p-value (independent two-sample *t*-test)
Median	0.86	0.97	
Min - Max	0.67 – 1.61	0.70 – 1.79	
95% Cl	0.55, 1.52	0.51, 1.59	
3D Apical deviation (mm)			
Mean ± SD	1.21 ± 0.36	1.27 ± 0.52	0.84
Median	1.14	1.18	
Min - Max	0.87 – 1.79	0.70 – 2.06	
95% Cl	0.77, 1.65	0.62, 1.92	

Although dynamic navigation has some benefits, the operator is required to match and coordinate his view of the screen along with his hand movements when using this system. Turning the head to observe the navigation screen and looking away from the implant site could result in accidental surgical instrument shifting or unexpected patient movement, especially in complex implantology. The usage of augmented reality could solve this problem. Moreover, the AR could also shorten the operating time (Jiang et al., 2018; Pellegrino et al., 2019).

In our study, implant position and deviation mainly depended on the drilling system of the laboratory guide and the optical tracking of the navigation system. There are no reports of implant placements with simultaneous bone augmentation that subsequently affected implant deviation. Nonetheless, one study showed that narrow crestal bone might cause lower accuracy due to initial drill deviation, thus the guided surgery protocol is recommended (Putra et al., 2020). The available and surrounding bone can also affect implant stability (Juodzbalys & Kubilius, 2013; Putra et al., 2020), however, our study did not specifically investigate at this point.

Implant location did not affect the deviation in the *in vitro* study (Abduo & Lau, 2020). No evidence indicated the type of arch or implant dimension which could influence deviations. Errors from guide printing processes could produce implant deviation (Zhou, Liu, Song, Kuo, & Shafer, 2018). Nevertheless, in our study, if minor errors from laboratory procedures existed, they were controlled by the navigation system and AR. One advantage of using the navigation system and laboratory guide with AR glasses is that mistakes will be instantly detected if the guide has major errors and does not match with the navigation plan. However, this situation did not occur during our study.

A previous *in vitro* study, using stereolithographic templates integrated with augmented reality-based surgical simulations, showed mean deviations between planned and prepared sites at the entry point, tip, angle, depth, and lateral locations were 0.50 ± 0.33 mm, 0.96 ± 0.36 mm, 2.70 ± 1.55 degrees, 0.33 ± 0.27 mm, and 0.86 ± 0.34 mm, respectively, for the fully edentulous mandibles, and 0.46 ± 0.20 mm, 1.23 ± 0.42 mm, 3.33 ± 1.42 degrees, 0.48 ± 0.37 mm, and 1.1 ± 0.39 mm, respectively, for the partially edentulous maxilla. They concluded that the deviation of implant placement from the planned position was significantly decreased by integrating surgical templates and augmented reality technology (Lin et al., 2015). The study of Ma et al (2019) showed better results in their model experiment with implant placements using an AR system when compared to a dentist's experience. In the AR system group, the mean target error and mean angle error was 1.25 mm and 4.03 degrees, respectively. In the dentist's experience group, the mean target error and mean angle error was 1.63 mm and 6.10 degrees, respectively. Due to different settings, specific comparisons of the results between the two *in vitro* studies with the 3D-printed models, and our clinical study with real patients cannot be made. Movements of the jaw and soft tissue, saliva, and blood can all influence surgical conditions and possible deviations when working with real patients. Model studies in controlled environments allow better visual lines and mouth access.

Dental implant procedures demand biomechanical, functional, phonetical, and esthetical outcomes, precise placement and direction are necessary, particularly in complex cases (Ewers et al., 2004; Ewers et al., 2005; Ma et al., 2019). Our clinical pilot study showed the beneficial results that augmented reality can provide by eliminating hand-eye coordination problems. A navigation system and laboratory guide with AR glasses allowed the operator to see both the surgical area and the virtual navigation system monitor, which projects implant planning and virtual drilling onto the same field. Wearing the AR glasses, the operator could see the implant location without interference and reduce the chance of overlay errors. This study showed that implant placement using AR glasses tended to show better results than those without AR glasses, but no statistically significant difference. Because this study had a small sample size, further clinical trials with more participants will therefore be required. All implant placements in this study were performed by one experienced operator to avoid any operator effect. However, future studies should utilize a wider range of trained AR users, with both experienced dentists and dental students alike.

Limitations of AR technology include an uncomfortable virtual window positioning and orientation, requiring the operator to tilt his head in an awkward position. However, this inconvenience did not affect the study results (Pellegrino, Tarsitano, Taraschi, Vercellotti, & Marchetti, 2018; Wang et al., 2018). The expense of the technology, setup time, and the additional software required for AR are all downsides. Setbacks from the device's wireless connection and battery storage are also possible, though they were not reported in this investigation. These issues could be resolved by creating dedicated implant software applications and upgrading the accompanying hardware.

5. Conclusion

Implant placement in a single tooth space using a navigation system and laboratory guide along with AR glasses might help operators to reduce the deviation of dental implant position. However, this study did not investigate the type of arch or implant dimension, nor whether they affected the results. These might be interesting for additional research. Future studies will provide multiple implant placements in partially or fully edentulous patients. Further evaluations of the time constraints, cost-benefits, and cost-effectiveness, along with the learning curve required for training, should also be performed.

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7. References

Abduo, J., & Lau, D. (2020). Accuracy of static computer-assisted implant placement in anterior and posterior sites by clinicians new to implant dentistry: in vitro comparison of fully guided, pilot-guided, and freehand protocols. *Int J Implant Dent, 6*(1), 10. doi:10.1186/s40729-020-0205-3

Block, M. S., & Emery, R. W. (2016). Static or Dynamic Navigation for Implant Placement-Choosing the Method of Guidance. *J Oral Maxillofac Surg, 74*(2), 269-277. doi:10.1016/j.joms.2015.09.022

Block, M. S., Emery, R. W., Lank, K., & Ryan, J. (2017). Implant Placement Accuracy Using Dynamic Navigation. *Int J Oral Maxillofac Implants, 32*(1), 92-99. doi:10.11607/jomi.5004

Ewers, R., Schicho, K., Truppe, M., Seemann, R., Reichwein, A., Figl, M., & Wagner, A. (2004). Computer-aided navigation in dental implantology: 7 years of clinical experience. *J Oral Maxillofac Surg, 62*(3), 329-334. doi:10.1016/j.joms.2003.08.017

Ewers, R., Schicho, K., Undt, G., Wanschitz, F., Truppe, M., Seemann, R., & Wagner, A. (2005). Basic research and 12 years of clinical experience in computer-assisted navigation technology: a review. *Int J Oral Maxillofac Surg, 34*(1), 1-8. doi:10.1016/j.ijom.2004.03.018

Jiang, W., Ma, L., Zhang, B., Fan, Y., Qu, X., Zhang, X., & Liao, H. (2018). Evaluation of the 3D Augmented Reality-Guided Intraoperative Positioning of Dental Implants in Edentulous Mandibular Models. *Int J Oral Maxillofac Implants, 33*(6), 1219-1228. doi:10.11607/jomi.6638

Juodzbalys, G., & Kubilius, M. (2013). Clinical and radiological classification of the jawbone anatomy in endosseous dental implant treatment. *J Oral Maxillofac Res, 4*(2), e2. doi:10.5037/jomr.2013.4202

Kaewsiri, D., Panmekiate, S., Subbalekha, K., Mattheos, N., & Pimkhaokham, A. (2019). The accuracy of static vs. dynamic computer-assisted implant surgery in single tooth space: A randomized controlled trial. *Clin Oral Implants Res*, *30*(6), 505-514. doi:10.1111/clr.13435

Kwon, H. B., Park, Y. S., & Han, J. S. (2018). Augmented reality in dentistry: a current perspective. *Acta Odontol Scand*, *76*(7), 497-503. doi:10.1080/00016357.2018.1441437

Lin, Y. K., Yau, H. T., Wang, I. C., Zheng, C., & Chung, K. H. (2015). A novel dental implant guided surgery based on integration of surgical template and augmented reality. *Clin Implant Dent Relat Res*, *17*(3), 543-553. doi:10.1111/cid.12119

Ma, L., Jiang, W., Zhang, B., Qu, X., Ning, G., Zhang, X., & Liao, H. (2019). Augmented reality surgical navigation with accurate CBCT-patient registration for dental implant placement. *Med Biol Eng Comput*, *57*(1), 47-57. doi:10.1007/s11517-018-1861-9

Ng, F. C., Ho, K. H., & Wexler, A. (2005). Computer-assisted navigational surgery enhances safety in dental implantology. *Ann Acad Med Singap*, *34*(5), 383-388. Retrieved from https://www.ncbi.nlm.nih.gov/pubmed/16021229

Pellegrino, G., Mangano, C., Mangano, R., Ferri, A., Taraschi, V., & Marchetti, C. (2019). Augmented reality for dental implantology: a pilot clinical report of two cases. *BMC Oral Health*, *19*(1), 158. doi:10.1186/s12903-019-0853-y

Pellegrino, G., Tarsitano, A., Taraschi, V., Vercellotti, T., & Marchetti, C. (2018). Simplifying Zygomatic Implant Site Preparation Using Ultrasonic Navigation: A Technical Note. *Int J Oral Maxillofac Implants*, *33*(3), e67-e71. doi:10.11607/jomi.6270

Putra, R. H., Yoda, N., Iikubo, M., Kataoka, Y., Yamauchi, K., Koyama, S., . . . Sasaki, K. (2020). Influence of bone condition on implant placement accuracy with computer-guided surgery. *Int J Implant Dent*, *6*(1), 62. doi:10.1186/s40729-020-00249-z

Smitkarn, P., Subbalekha, K., Mattheos, N., & Pimkhaokham, A. (2019). The accuracy of single-tooth implants placed using fully digital-guided surgery and freehand implant surgery. *Journal of clinical periodontology*, *46*(9), 949-957.

Stefanelli, L. V., DeGroot, B. S., Lipton, D. I., & Mandelaris, G. A. (2019). Accuracy of a Dynamic Dental Implant Navigation System in a Private Practice. *Int J Oral Maxillofac Implants*, *34*(1), 205-213. doi:10.11607/jomi.6966

Sun, T. M., Lan, T. H., Pan, C. Y., & Lee, H. E. (2018). Dental implant navigation system guide the surgery future. *Kaohsiung J Med Sci*, *34*(1), 56-64. doi:10.1016/j.kjms.2017.08.011

Sun, T. M., Lee, H. E., & Lan, T. H. (2020). Comparing Accuracy of Implant Installation with a Navigation System (NS), a Laboratory Guide (LG), NS with LG, and Freehand Drilling. *Int J Environ Res Public Health*, *17*(6). doi:10.3390/ijerph17062107

Trisi, P., Perfetti, G., Baldoni, E., Berardi, D., Colagiovanni, M., & Scogna, G. (2009). Implant micromotion is related to peak insertion torque and bone density. *Clin Oral Implants Res*, *20*(5), 467-471. doi:10.1111/j.1600-0501.2008.01679.x

Wang, F., Bornstein, M. M., Hung, K., Fan, S., Chen, X., Huang, W., & Wu, Y. (2018). Application of Real-Time Surgical Navigation for Zygomatic Implant Insertion in Patients With Severely Atrophic Maxilla. *J Oral Maxillofac Surg*, *76*(1), 80-87. doi:10.1016/j.joms.2017.08.021

Zhou, W., Liu, Z., Song, L., Kuo, C. L., & Shafer, D. M. (2018). Clinical Factors Affecting the Accuracy of Guided Implant Surgery-A Systematic Review and Meta-analysis. *J Evid Based Dent Pract*, *18*(1), 28-40. doi:10.1016/j.jebdp.2017.07.007