Comparison of the Accuracy of Dental Implant Placement Using Different Static Computer-Guided Implant Surgery: An *In Vitro* Study

Pisut Thangwarawut[1], Pokpong Amornvit[2] and Sirichai Kiattavorncharoen*[3]

[1]Graduate student, Dental Implant Center, Faculty of Dentistry, Mahidol University, Bangkok, Thailand
[2]Geriatric dentistry amd mazillofacial Prosthetic Clinic, Faculty of Dentistry, Mahidol University, Bangkok, Thailand
[3]Associated Professor, Department of Oral and Maxillofacial Surgery, Faculty of Dentistry, Mahidol University,
Bangkok, Thailand
*Corresponding author, E-mail: sirichai_kia@mahidol.ac.th

Abstract

A surgical guide is widely used in dental implant surgery for positioning a fixture. There are various designs of surgical guides from each company. This study aimed to compare the accuracy of 2 static computer-guided implant systems; a metal sleeve with a key handle (Nobel guide, Nobel Biocare) and a metal sleeve without a key handle (Dentium full guide kit, Dentium), when placing the implant in bone models. A total of 20 polyurethane bone models were fabricated to simulate human bone. The dental implants for each system were placed in the bone models following the company's recommended protocols. After the dental implants were installed, the digital scans were done by an extraoral scanner. The deviations of the implant position were evaluated between the post-implant placement and reference model by GOM inspect software. The data were analyzed using an independent sample t-test. The data were from 20 bone models, 10 models for each system. The accuracy of the dental implant position was not significantly influenced by the difference in the surgical guide system ($p>0.05$). However, more deviation of the implant position was found in a metal sleeve with key handle type (Nobel guide), except in the angular deviation. Within the limitations of this study, the accuracy of implant placement of two types of surgical guides was similar. Hence, the operators can choose the surgical guide system according to the preference.

Keywords: Accuracy, Computer-guided surgery, Dental implant, Surgical guide

1. Introduction

The dental implant is widely used in partially and fully edentulous patients because of the high survival and success rates in clinical use (Adell et al., 1981; Buser et al., 2012; Buser, Sennerby & De Bruyn, 2017; Chappuis et al., 2018). The proper treatment plan is a key to success in the dental implant for the long-term outcome. One of the most complications of dental implant failure is the malposition of the fixture leading to prosthetic failure, peri-implant failure, and unesthetic (Romanos, Delgado-Ruiz & Sculean, 2019). Then the concept of the dental implant placement for high success result is the prosthetic driven design concept. The dental implant fixture should be placed according to the proper position for support restoration and loading. Today, the malposition of the dental fixtures can be solved with the assisted devices to improve the accurate implant placement by using a computer-guided implant system. Many studies have shown more accuracy in the dental implant fixture using guided surgery than conventional surgical guide or free-hand placement (Colombo et al., 2017; D'Haese et al., 2017; Hultin, Svensson & Trulsson, 2012; Park et al., 2009; Schneider et al., 2009). There are two types of computer-guided surgery; static and dynamic (D'Haese et al., 2017). This study will concentrate on the static computer-guided implant surgery that frequency used more than dynamic type when guided surgery is suggested (Kaewsiri et al., 2019).

The static computer-guided implant surgery helps to guide the position of the dental implant fixture to place into the correct position. It also reduced the probability of injury to the vital critical structures such as nerves, maxillary sinus, adjacent roots, and mandibular concavity. Moreover, the guided surgery allows the surgeon to know the implant fixture position before the final implant placement and the ability to create an immediate restoration on the implant on the same day (Johansson, Friberg & Nilson, 2009; Meloni et al., 2010; Tahmaseb et al., 2012). A systematic review and meta-analysis (Tahmaseb et al., 2018) revealed the total mean error of 1.2 mm at the entry point, 1.4 mm at the apical point, and a deviation of 3.5° in the axis. The accuracy of the dental implant placement using the computer-guided implant surgery system depends on many factors. The overall error or deviation can occur from the plan until the placement of the fixture. Errors

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during data acquisition, data transfer, data processing, treatment planning, guide design, and production, as well as surgical performance, might cause increased deviations from the virtually planned implant position (Cassetta, Di Carlo, et al., 2013; Cassetta et al., 2015; Cassetta, Di Mambro, Giansanti, Stefanelli & Barbato, 2013; Cassetta, Di Mambro, Giansanti, Stefanelli & Cavallini, 2013; Cassetta, Giansanti, et al., 2013; Cassetta, Stefanelli, et al., 2013; Muller et al., 2016; Schneider et al., 2015).

Most major implant brands have their own static computer-guided implant surgery system. There are many studies on the accuracy of static computer-assisted implant surgery for implant placement. However, most of the studies chose only one implant system to be compared (El Kholy, Janner, et al., 2019; El Kholy, Lazarin, et al., 2019; Koop et al., 2013; Park et al., 2009; Sarment, Sukovic & Clinthorne, 2003). Studies that examine the accuracy of different computer-guided implant surgery are still lacking. Different guide designs, components, protocols, and the shape of drill designs may affect the efficiency of each guided implant system. Currently, the static surgical guide that available in Thailand can be divided into two major systems; a metal sleeve with a drilling key handle type and a metal sleeve without a key handle type, which are designed for the individual technique and skill of the surgeon. The advantage of using a key handle is to allow the surgeon to reach the planned position of the dental implant fixture. However, the surgeon needs to pay attention to two hands when drilling. The surgical guide without a key handle type was produced for reducing the error of the implant position because the operator can concentrate only one hand when drilling. However, there is no study on the accuracy between two types of static computer-guided implant surgery.

2. Objective

This study aimed to compare the accuracy of dental implant placement using static computer-guided implant surgery between a metal sleeve with a drilling key handle type (Nobel guide, Nobel Biocare) and a metal sleeve without a key handle type (Dentium full guide kit, Dentium) in vitro study. The accuracy of the implant placement was evaluated between the post-implant placement and reference model by GOM inspect software.

3. Materials and Methods

The dental implants were chosen in this study from two companies (Nobel Biocare, Göteborg, Sweden, and Dentium Co, Seoul, Korea). The dental fixture's size used for Nobel Biocare (Nobel active) was 4.3x13 mm and 4.0x12 mm for Dentium (Dentium Superline). The materials used in this study were shown in Table1.

Table 1 Materials used in this study

Material	Manufacturer	Lot number
Guided surgery metal sleeve (RP)	Nobel Biocare, Göteborg, Sweden	126997
Guided surgery metal sleeve	Dentium Co, Seoul, Korea	201809190171
Temporary abutment engaging (RP)	Nobel Biocare, Göteborg, Sweden	13059007
Plastic temporary abutment	Dentium Co, Seoul, Korea	201812040178
Nobel active implant fixture (dummy)	Nobel Biocare, Göteborg, Sweden	-
Dentium Superline (dummy)	Dentium Co, Seoul, Korea	-

3.1 Preparation of surgical guides

The surgical guides were prepared following two company systems; Nobel guide (Nobel Biocare, Göteborg, Sweden) and Dentium full guide kit (Dentium Co, Seoul, Korea). The models were designed by Meshmixer 3.5 software (Autodesk, San Rafael, CA, USA), which can design the 3D model, export into .STL file, and send to the 3D printer (Form 2, Formlabs, Somerville, MA, USA), printing with model resin at 50-micron resolution (Figure 1-2).
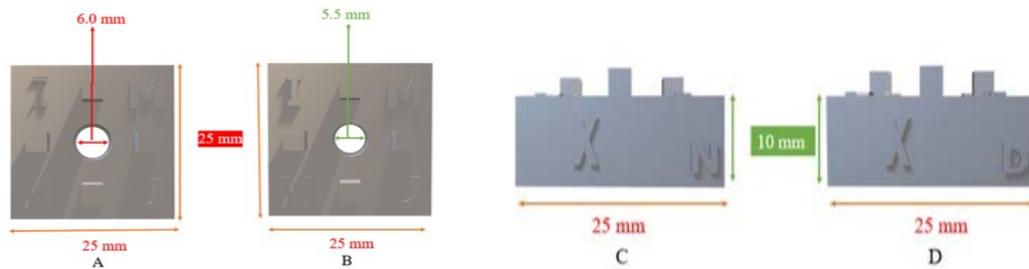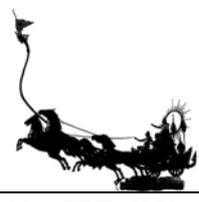
Figure 1 The 3-dimensional design of surgical guides. A) Metal sleeve w/ a key handle (top view), B) Metal sleeve w/o a key handle (top view), C) Metal sleeve w/ a key handle (side view), and D) Metal sleeve w/o a key handle (top view)
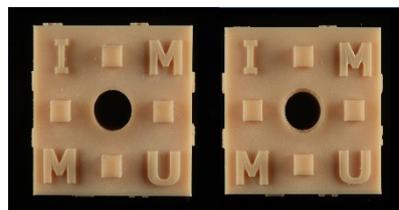

Figure 2 The 3D printing surgical guides (The alphabets on the surface used for indicating side when scanning)

3.2 Preparation of bone models

20 Polyurethane bone models (Shore D 60-70 according to ISO 868), (Axson, Germany) simulating human bone with a cortical thickness of 1 mm and the rest as cancellous bone were prepared (Figure 3).

The guides and bone models were fixed together using cyanoacrylate super glue. Then, the metal sleeves were inserted inside the guide (Figure 4-5).

Figure 3 Bone model (top view, cross-sectional view, and oblique view)
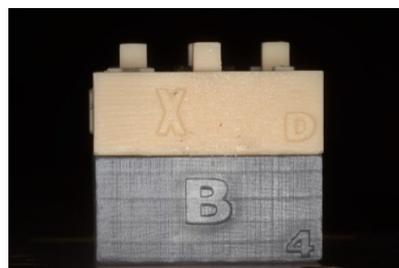

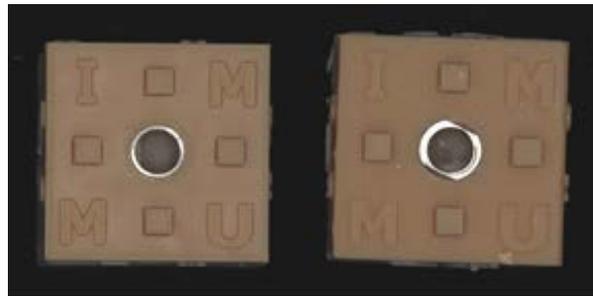**Figure 4** The surgical guide was bonded with bone model

Figure 5 The final preparation of surgical guides with bone models. A metal sleeve w/ a key handle
(Left picture), A metal sleeve w/o a key handle (Right picture)

3.3 Experimental testing

Drilling was done by a single dentist who works in the dental implant field following the protocol from each implant's company as recommended. Then, the implant fixtures were inserted through the surgical guides. After placing the implant fixtures, the metal sleeves were removed and the diameter of the holes was increased with the drill to insert the temporary abutment as the size of the temporary abutments was larger than the metal sleeve diameter (Figure 6).

Then, the surgical guides with the temporary abutments above the implants were scanned with the Extraoral scanner (Ceramill map 600, Amann Girrbach, Koblach, Austria) for scanning the surface. The 3D scanned data were saved as .STL file format for the deviation measurement.

Figure 6 Temporary abutment was inserted into the implant fixture

3.4 Deviation Measurement

A standard 3D model that added the cylinder shape as a temporary abutment for a scan body was designed in Meshmixer 3.5 software (Autodesk, San Rafael, CA, USA) and printed by the 3D printer (Form 2, Formlabs, Somerville, MA, USA). Then, the standard 3D model was scanned with the Extraoral scanner (Ceramill map 600, Amann Girrbach, Koblach, Austria). The 3D scanned data were saved as the .STL file format for the deviation measurement.

The experimental 3D model and standard 3D model files were aligned by GOM inspect software (GOM mbH, Braunschweig, Germany) using the corners and alphabet markers of the surgical guide. For each planned and placed implant, 2 points were located (x, y, and z coordinates) on their long axes, and they were converted into cylinders. The first point was the neck point (center of the most coronal portion of the implants) of the implant whereas the second point was the apical point (center of the implant apex) of the implant. Both the distance between the centers of the simulated and placed implant and the angle that occurred between the long axis of the simulated and placed implants were measured using the software by a single observer. The deviation measurement uses 3 parameters: Angular deviation (degree), 3D deviation at coronal (mm), and 3D deviation at the apex (mm) (Figure 7).
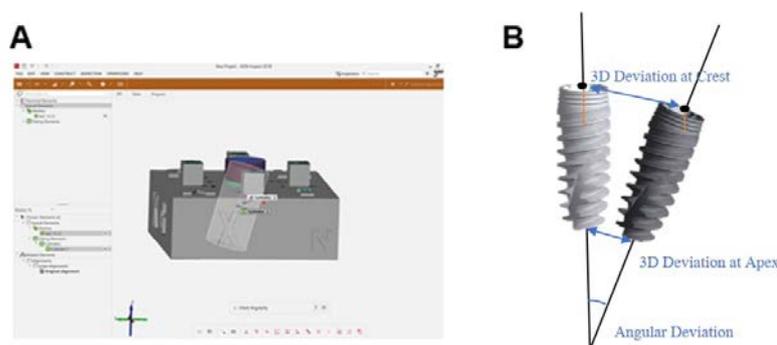
Figure 7 Deviation measurement: A. GOM inspect software and B. Deviation parameters

3.5 Statistical analysis

The statistical evaluation was performed using SPSS® software (SPSS statistics 18.0; Chicago, IL, USA). To test the normality, Shapiro-Wilk Test was done at P-value >0.05. Descriptive statistics (mean, SD) were used. The data were analyzed using an independent sample t-test between the means of the two groups.

4. Results and Discussion

4.1 Results

In this study, 20 dental implants were placed by using static computer-guided implant surgery to mimic human bones (10 models for each system). All of them had primary stability. The mean and standard deviation of implant placement using two types of surgical guides were shown in Table 2. The implant placement using the surgical guide with a key handle revealed more deviation of implant position than another type, except in the angular deviation. However, there was no significant difference in the position of the dental implant found between the two types of static computer-guided implant surgery in all parameters; the angular deviation, deviation at coronal, and deviation at the apex (p>0.05) (Table 3).

Table 2 Mean, standard deviation, minimum, and maximum of different parameters evaluated for the two types of static computer-guided implant surgery groups

Parameter	Sleeve with key handle			Sleeve without key handle		
	Mean ± SD	Minimum	Maximum	Mean ± SD	Minimum	Maximum
Angular deviation (degree)	1.15 ± 0.47	0.45	1.79	1.21 ± 0.33	0.59	1.71
Deviation at coronal (mm.)	0.32 ±0.14	0.11	0.53	0.30 ± 0.10	0.12	0.46
Deviation at the apex (mm.)	0.97 ± 0.39	0.40	1.54	0.76 ± 0.32	0.27	1.21

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Table 3 Independent samples t-test of different parameters evaluated for the two types of static computer-guided implant surgery groups

		Levene's Test for Equality of Variances		t-test for Equality of Means		
		F	Sig.	t	df	Sig. (2-tailed)
Angular	Equal variances are assumed	2.650	.121	-.289	18	.776
	Equal variances are not assumed			-.289	16.085	.776
Coronal	Equal variances are assumed	1.649	.215	.389	18	.702
	Equal variances are not assumed			.389	16.582	.702
Apex	Equal variances are assumed	.517	.481	1.339	18	.197
	Equal variances are not assumed			1.339	17.423	.198

4.2 Discussion

The static computer-guided implant surgery is the tool that assists the surgeon to place a proper position of the dental implant and reduces the complication of implants, such as restorative failure, peri-implant failure, and unesthetic due to misplacement of the implant fixture. Furthermore, the surgical guide reduces the surgical complications, decreases surgical time, controls the implant placement to avoid damage to critical anatomical structures, and improves the patient's confidence (Bencharit et al., 2018; Deeb et al., 2017). There are many designs of static computer-guide according to each manufacturer of the dental implant. This study was done considering the factor of different designs of the surgical guide from two companies (Nobel Biocare and Dentium) that may affect the accuracy of the dental implant placement. The study found that there was no significant difference between the two types of implant surgical guide system. However, the measuring data showed that the 3D deviation at the coronal and apex in the case of the surgical guide using a key handle (Nobel guide, Nobel Biocare) was slightly higher than another type. It may imply that the more components of the surgical guide for drilling and placing the dental implant, the more errors in the implant position will occur. More components will increase the error in the position of the fixture because the surgeon needs to pay attention to two hands while drilling. Furthermore, the previous study (Valente, Schiroli & Sbrenna, 2009) revealed that the gap between the drilling bur, a key handle, and a metal sleeve affected the accuracy of the implant position. Corresponding with Cassetta et al. (Cassetta, Di Mambro, Giansanti, Stefanelli & Cavallini, 2013) who found that the most affecting to the deviation between planned and placed dental implant fixture are the tolerance among mechanical parts of computer-guided surgery causing an error. Higher tolerance between the parts of the surgical guide produces the intrinsic error of the part. On the other hand, lower tolerance between the parts of the guide will increase the friction between the parts of the surgical guide that might cause the attachment of the components while implant bed preparation and implant placement, and this can displace the surgical guide.

Besides the more component of the guide that resulting in implant displacement, the drill bur shape and surgical protocol may be the important factors that affect the accuracy of implant position (Figure 8). In the Nobel guide, the shape of the drilling bur is twist-cylinder then it may slip while drilling. Furthermore, the initial and the final drilling burs for implant bed preparation protocol use the same length of the drill. If the osteotomy with the initial drill is done in the wrong position or angulation, it will be difficult to correct the direction of the dental implant. However, in the Dentium guide, the design of the drilling bur is twist-taper with the side cutting and the initial drilling bur is shorter than the final bur. The slowly increasing the length from the first drill to the final drill can correct the implant angulation and position while drilling because it is easy to resolve the deviation after the initial short drill. However, in this study, the authors found less deviation in angular deviation in the surgical guide that containing a key handle. It could be the longer key handle (6.5 mm) in the Noble guide than the Dentium guide sleeve (4 mm), then the more part of drilling bur in key handle let the more accuracy of implant direction. The more part of the drill is in the key handle/sleeve that reduced the free drilling distance (the distance below the lower border of the key handle/guided sleeve until the bottom point of osteotomy). The previous study (El Kholy, Janner, et al., 2019) found that reducing the free drilling distance led to a significant increase in the accuracy of surgical guides.

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Another important finding of this study was the implant position at the apex had more deviation than the coronal part in both types of the surgical guide, which can be described by the technique of implant drilling and placing through static computer-guided surgery. The more distance from the guided sleeve, the more error will be found, as distinguished by previous studies with higher deviation at the apex than the coronal deviation (Cassetta, Stefanelli, et al., 2013; Tahmaseb et al., 2014; Van Assche et al., 2012).

The results of this study showed a wide range of standard deviation. The large standard deviation indicates that the data points are far from the mean in both groups because the gap between the components of the surgical guide allows the surgeon to place the dental implant in various directions. Moreover, there is a limited sample size in this study. Thus, further study should include a larger amount of sample size.

In this study, the deviation values were similar to the previous study (Yeung et al., 2019) that measured the accuracy of dental implant placement using 3-D printed implant surgical guides with different implant systems in bone models. They found the angular deviation of the dental implant in mesiodistal and labiopalatal were 1.69° and 1.56°, respectively, and the coronal displacement of the dental implant was 0.02 to 1.26 mm. However, our results showed lesser deviation values than the results of a systematic review and meta-analysis that collecting only clinical studies (Tahmaseb et al., 2018). They found the mean angular was 3.5° with deviation at coronal 1.2 mm and 1.4 mm at the apex. The reason for lesser deviation values of the dental implant position in our study because this study was an in vitro study and have excluded various factors such as bone density, saliva, blood, adjacent teeth, tongue, and the other environment in the mouth that can affect the accuracy of implant position. In the future, a similar study can be performed clinically to study the accuracy of implant placement in different types of surgical guides from two companies (Dentium and Nobel Biocare).

(A)   (B)

Figure 8 The drilling burs from initial to final drill: (A) Nobel guide drill, (B) Dentium guide drill

5. Conclusion

Within the limitations of this in vitro study, many factors can affect the implant position such as guide designs, components, protocols, as well as the shape of drill designs. However, it can be concluded from the results that the accuracy of the implant placement evaluated by GOM inspect software between the two types of static computer-guided implant surgery were similar. Then, the surgeons can select the system of the surgical guide according to their preference.

6. Acknowledgements

7. References

Adell, R., Lekholm, U., Rockler, B., & Brånemark, P. I. (1981). A 15-year study of osseointegrated implants in the treatment of the edentulous jaw. *International Journal of Oral Surgery, 10*(6), 387-416. doi: 10.1016/S0300-9785(81)80077-4

Bencharit, S., Staffen, A., Yeung, M., Whitley, D., Laskin, D. M., & Deeb, G. R. (2018). *In vivo* tooth-supported implant surgical guides fabricated with desktop stereolithographic printers: Fully guided surgery is more accurate than partially guided surgery. *Journal of Oral and Maxillofacial Surgery, 76*(7), 1431-1439. doi:10.1016/j.joms.2018.02.010

Buser, D., Janner, S. F., Wittneben, J. G., Bragger, U., Ramseier, C. A., & Salvi, G. E. (2012). 10-year survival and success rates of 511 titanium implants with a sandblasted and acid-etched surface: a retrospective study in 303 partially edentulous patients. *Clinical Implant Dentistry and Related Research, 14*(6), 839-851. doi:10.1111/j.1708-8208.2012.00456.x

Buser, D., Sennerby, L., & De Bruyn, H. (2017). Modern implant dentistry based on osseointegration: 50 years of progress, current trends and open questions. *Periodontol 2000, 73*(1), 7-21. doi:10.1111/prd.12185

Cassetta, M., Di Carlo, S., Pranno, N., Sorrentino, V., Di Giorgio, G., & Pompa, G. (2013). The use of stereolithographic surgical templates in oral implantology. *Annali Italiani di Chirurgia, 84*(5), 589-593.

Cassetta, M., Di Mambro, A., Di Giorgio, G., Stefanelli, L. V., & Barbato, E. (2015). The influence of the tolerance between mechanical components on the accuracy of implants inserted with a stereolithographic surgical guide: A retrospective clinical study. *Clinical Implant Dentistry and Related Research, 17*(3), 580-588. doi:10.1111/cid.12120

Cassetta, M., Di Mambro, A., Giansanti, M., Stefanelli, L. V., & Barbato, E. (2013). Is it possible to improve the accuracy of implants inserted with a stereolithographic surgical guide by reducing the tolerance between mechanical components? *International Journal of Oral and Maxillofacial Surgery, 42*(7), 887-890. doi:10.1016/j.ijom.2013.01.011

Cassetta, M., Di Mambro, A., Giansanti, M., Stefanelli, L. V., & Cavallini, C. (2013). The intrinsic error of a stereolithographic surgical template in implant guided surgery. *International Journal of Oral and Maxillofacial Surgery, 42*(2), 264-275. doi:10.1016/j.ijom.2012.06.010

Cassetta, M., Giansanti, M., Di Mambro, A., Calasso, S., & Barbato, E. (2013). Accuracy of two stereolithographic surgical templates: a retrospective study. *Clinical Implant Dentistry and Related Research, 15*(3), 448-459. doi:10.1111/j.1708-8208.2011.00369.x

Cassetta, M., Stefanelli, L. V., Giansanti, M., Di Mambro, A., & Calasso, S. (2013). Accuracy of a computer-aided implant surgical technique. *International Journal of Periodontics and Restorative Dentistry, 33*(3), 317-325. doi:10.11607/prd.1019

Chappuis, V., Rahman, L., Buser, R., Janner, S. F. M., Belser, U. C., & Buser, D. (2018). Effectiveness of contour augmentation with guided bone regeneration: 10-year results. *Journal of Dental Research, 97*(3), 266-274. doi:10.1177/0022034517737755

Colombo, M., Mangano, C., Mijiritsky, E., Krebs, M., Hauschild, U., & Fortin, T. (2017). Clinical applications and effectiveness of guided implant surgery: a critical review based on randomized controlled trials. *BMC Oral Health, 17*(1), 150. doi:10.1186/s12903-017-0441-y

D'Haese, J., Ackhurst, J., Wismeijer, D., De Bruyn, H., & Tahmaseb, A. (2017). Current state of the art of computer-guided implant surgery. *Periodontol 2000, 73*(1), 121-133. doi:10.1111/prd.12175

Deeb, G. R., Allen, R. K., Hall, V. P., Whitley, D., Laskin, D. M., & Bencharit, S. (2017). How accurate are implant surgical guides produced with desktop stereolithographic 3-dimentional printers? *Journal of Oral and Maxillofacial Surgery, 75*(12), 2559.e2551-2559.e2558. doi:10.1016/j.joms.2017.08.001

El Kholy, K., Janner, S. F. M., Schimmel, M., & Buser, D. (2019). The influence of guided sleeve height, drilling distance, and drilling key length on the accuracy of static Computer-Assisted Implant Surgery. *Clinical Implant Dentistry and Related Research, 21*(1), 101-107. doi:10.1111/cid.12705

El Kholy, K., Lazarin, R., Janner, S. F. M., Faerber, K., Buser, R., & Buser, D. (2019). Influence of surgical guide support and implant site location on accuracy of static Computer-Assisted Implant Surgery. *Clinical Oral Implants Research, 30*(11), 1067-1075. doi:10.1111/clr.13520

Hultin, M., Svensson, K. G., & Trulsson, M. (2012). Clinical advantages of computer-guided implant placement: a systematic review. *Clinical Oral Implants Research, 23 Suppl 6*, 124-135. doi:10.1111/j.1600-0501.2012.02545.x

Johansson, B., Friberg, B., & Nilson, H. (2009). Digitally planned, immediately loaded dental implants with prefabricated prostheses in the reconstruction of edentulous maxillae: A 1-year prospective, multicenter study. *Clinical Implant Dentistry and Related Research, 11*(3), 194-200. doi:10.1111/j.1708-8208.2008.00111.x

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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. *Clinical Oral Implants Research, 30*(6), 505-514. doi:10.1111/clr.13435

Koop, R., Vercruyssen, M., Vermeulen, K., & Quirynen, M. (2013). Tolerance within the sleeve inserts of different surgical guides for guided implant surgery. *Clinical Oral Implants Research, 24*(6), 630-634. doi:10.1111/j.1600-0501.2012.02436.x

Meloni, S. M., De Riu, G., Pisano, M., Cattina, G., & Tullio, A. (2010). Implant treatment software planning and guided flapless surgery with immediate provisional prosthesis delivery in the fully edentulous maxilla. A retrospective analysis of 15 consecutively treated patients. *European Journal of Oral Implantology, 3*(3), 245-251.

Muller, P., Ender, A., Joda, T., & Katsoulis, J. (2016). Impact of digital intraoral scan strategies on the impression accuracy using the TRIOS Pod scanner. *Quintessence International, 47*(4), 343-349. doi:10.3290/j.qi.a35524

Park, C., Raigrodski, A. J., Rosen, J., Spiekerman, C., & London, R. M. (2009). Accuracy of implant placement using precision surgical guides with varying occlusogingival heights: An *in vitro* study. *Journal of Prosthetic Dentistry, 101*(6), 372-381. doi:10.1016/s0022-3913(09)60080-9

Romanos, G. E., Delgado-Ruiz, R., & Sculean, A. (2019). Concepts for prevention of complications in implant therapy. *Periodontol 2000, 81*(1), 7-17. doi:10.1111/prd.12278

Sarment, D. P., Sukovic, P., & Clinthorne, N. (2003). Accuracy of implant placement with a stereolithographic surgical guide. *International Journal of Oral & Maxillofacial Implants, 18*(4), 571-577.

Schneider, D., Marquardt, P., Zwahlen, M., & Jung, R. E. (2009). A systematic review on the accuracy and the clinical outcome of computer-guided template-based implant dentistry. *Clinical Oral Implants Research, 20 Suppl 4*, 73-86. doi:10.1111/j.1600-0501.2009.01788.x

Schneider, D., Schober, F., Grohmann, P., Hammerle, C. H., & Jung, R. E. (2015). *In vitro* evaluation of the tolerance of surgical instruments in templates for computer-assisted guided implantology produced by 3-D printing. *Clinical Oral Implants Research, 26*(3), 320-325. doi:10.1111/clr.12327

Tahmaseb, A., De Clerck, R., Aartman, I., & Wismeijer, D. (2012). Digital protocol for reference-based guided surgery and immediate loading: a prospective clinical study. *International Journal of Oral & Maxillofacial Implants, 27*(5), 1258-1270.

Tahmaseb, A., Wismeijer, D., Coucke, W., & Derksen, W. (2014). Computer technology applications in surgical implant dentistry: a systematic review. *International Journal of Oral & Maxillofacial Implants, 29 Suppl*, 25-42. doi:10.11607/jomi.2014suppl.g1.2

Tahmaseb, A., Wu, V., Wismeijer, D., Coucke, W., & Evans, C. (2018). The accuracy of static computer-aided implant surgery: A systematic review and meta-analysis. *Clinical Oral Implants Research, 29 Suppl 16*, 416-435. doi:10.1111/clr.13346

Valente, F., Schiroli, G., & Sbrenna, A. (2009). Accuracy of computer-aided oral implant surgery: a clinical and radiographic study. *International Journal of Oral & Maxillofacial Implants, 24*(2), 234-242.

Van Assche, N., Vercruyssen, M., Coucke, W., Teughels, W., Jacobs, R., & Quirynen, M. (2012). Accuracy of computer-aided implant placement. *Clinical Oral Implants Research, 23 Suppl 6*, 112-123. doi:10.1111/j.1600-0501.2012.02552.x

Yeung, M., Abdulmajeed, A., Carrico, C. K., Deeb, G. R., & Bencharit, S. (2019). Accuracy and precision of 3D-printed implant surgical guides with different implant systems: An *in vitro* study. *Journal of Prosthetic Dentistry*. doi:10.1016/j.prosdent.2019.05.027