The Effect of Bone Density on The Accuracy of Dynamic Navigation System: In Vitro study

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Abstract

The quality of bone can impact the precision of implant placement, hence determining both the quantity and quality of bone prior to the surgery is very critical in implant placement. In recent years, the computer-assisted implant placement system (CAIS) technology has been established, which may be classified as static or dynamic. Literature illustrated higher accuracy in both static and dynamic than the freehand placement. Although the accuracy of implant placement utilizing a CAIS has been demonstrated the improve result, the accuracy of implant placement using a dynamic CAIS in different bone conditions remains uncertain. As a result, the purpose of this study was to examine how bone density impacts implant placement with Dynamic CAIS. According to this study overall's design, a single doctor plans each implant using a CBCT scan of a jaw model and performs a mock surgery and implant delivery on a maxilla edentulous model, while performing dynamic CAIS in varied bone densities. The placement and axis of the implant were compared to the virtual plan to verify the deviation. One-way ANOVA and Welch test were used to determine differences between groups, the Post Hoc test (Tukey HSD) was used to determine differences within groups, The Pearson correlation coefficient was used to assess the relationship between each bone density and implant accuracy parameters. with a 0.05 significant level. No significant difference was found between the four groups of bone in all parameters; the angular deviation (p=0.308), the implant 3D platform deviation (p=0.459), and the 3D apex deviation (p=0.068). Nonetheless, the lowest bone density group (D 4) showed the largest deviation, hence there was a statistically negative correlation between the bone density and apex deviation (P=0.020). No statistically significant correlation was found in angular and 3D platform deviation. The effect of the bone condition on implant placement accuracy with dynamic computer-guided surgery is statistically unaffected within the limitation of this study; however, low bone density may be a risk factor that affects implant placement precision.

Keywords: *Dynamic navigation system, Bone Density, Implant accuracy, Edentulism, Computer-assisted implant placement system*

1. Introduction

Recently, prosthetically driven implant placement has been introduced. Due to their advanced technology and effective outcomes, dental implants have become a popular solution for persons who have lost teeth. Particularly in fully edentulous patients, the dental implant must be placed at a correct angle and appropriate position according to an optimal treatment plan and good surgical procedure to achieve the successful implant-retained restoration in both functioning and aesthetics (Emery et al., 2016) to avoid complications such as sinus penetration, nerve injury, damage to the adjacent tooth (Greenstein et al., 2008; D'haese et al.,2010).

When performing conventional methods that rely on two-dimensional patient anatomical data, the clinical outcomes are frequently unpredictable, which can lead to implant malposition followed by undesirable problems (Widmann & Bale, 2006). Furthermore, surgical guide stents made on diagnostic casts do not show underlying anatomical structure or bone deficiency (Jung et al., 2009). Anatomical structures that differ from the norm can also contribute to greater errors in a freehand technique, according to the previous study (Tang et al., 2019; Ruppin et al., 2008). In recent years, the technology of a computer-assisted implant placement system (CAIS), which can be static or dynamic, has been introduced. According to the literature, the CAIS method provides superior accuracy over the freehand method (Block et al., 2017a; Schneider et al., 2009).

Both static and dynamic image navigations are quite precise, in which dynamic navigation is similar in accuracy to static implant placement in terms of angular deviation, platform, and apical positioning (Somogyi-Ganss, Holmes, & Jokstad, 2014; Wu et al., 2020). However, a dynamic navigation system has superior benefits to static CAIS (Wang, Wang, & Zhang, 2021). Dynamic CAIS provides clear visualization and irrigation via intraosseous irrigation, as well as real-time virtual planning adjustments in the event of critical anatomy and adjacent tooth root damage. Dynamic CAIS is also recommended for use in second molar regions and patients with limited mouth opening. According to various in-vitro studies, dynamic navigation systems have a mean entrance deviation of 1.0 mm and a mean angle deviation inaccuracy of lesser than 4 degrees (Chen et al.,2018; Block et al., 2017b; Stefanelli et al., 2019), which these simulations of dynamic navigation showed incredibly precise implant placement.

Several in vitro studies stated that primary stability is negatively impacted by low bone density. Higher primary implant stability is associated with better bone quality. As a result, the percentage of bone-to-implant contact (BIC) and compressive stresses at the implant-bone interface are the most important parameters impacting primary stability (Gehrke et al., 2018; Tsolaki et al., 2016). Artificial bone blocks were chosen over animal or cadaver bone, owing to their similar cellular structure and constant mechanical properties. Polyurethane foam could be a good replacement material for human bone mechanical tests. Its properties make it an excellent material for comparing implant materials and standardizing methods by removing anatomical and structural variances in bone (Comuzzi et al., 2019)

The quality of available bone can reflect the long-term effectiveness of implant placement, notably the position and stability, hence determining accessible bone is especially notable in implant placement. It also aids in the prediction of the healing process and the loading of the prosthesis. Previous research has shown that bone structure influences implant accuracy; for example, there were more errors between planning and implant placement in the maxilla than in the mandible (Emery et al., 2016; Behneke, Burwinkel, & Behneke, 2012). However, the impact of bone density on dynamic CAIS accuracy is still a subject of controversy. The amount of evidence in the literature about the effect of recipient bone quality on static CAIS accuracy is low. Some clinical studies found a statistically significant negative correlation between bone density and static CAIS accuracy. (Ozan, Orhan, & Turkyilmaz, 2020; Putra et al., 2020; Kivovics et al.,2020). Besides, the study evidence on the effect of recipient bone quality on dynamic CAIS accuracy is still lacking.

2. Objectives

To analyze the influence of bone density on the accuracy of implant position using a dynamic CAIS system (navigation system) in an edentulous area

3. Materials and methods

This study is a randomized controlled trial experiment to determine the accuracy of implant placement in dental models using the Navigation implant placement system as a guide (Iris – 100, EPED Inc., Taiwan). The experiment comprises four groups of bone (types 1-4) and was performed by a single surgeon with high experience who conducted more than 20 implant placements with the dynamic CAIS. The sample size was obtained using the angle deviation values of the edentate mandible and maxilla with dynamic CAIS systems from a prior study (1.25 ± 2.47 degrees vs. 1.26 ± 2.18 degrees) (Emery et al., 2016), the minimum required sample size of 32 implants was calculated using statistical software (G*Power software version 3.1, Faul, Erdfelder, Buchner, &Lang, 2009) for One-way ANOVA, with 80% of study power and significant level (α) of 0.05. There were four groups in this trial, each with 32 subjects divided into eight implants.

This study also used a poly-urethane maxillary edentulous arch model with synthetic bone type D1-D4 (Sawbone®; Pacific Research Laboratories Inc., Washington, USA) (Figure 1). These polyurethane foam bones were used for mechanical testing and were considered to be a standard for performing orthopedic implant mechanical testing. According to Misch's defined bone tissue classification D1–D4, the low-to-high densities of polyurethane foams represent distinct bone densities. Artificial bone's characteristics included a wide range of densities. D1 bone stimulation used 40 pounds per cubic foot (PCF) with a bone density of 0.64 g/cm3 polyurethane foam. D2 bone was stimulated using 30 PCF polyurethane foam with a bone density of 0.48 g/cm3. D3 bone imitated 20 PCF polyurethane foam with a bone density of 0.32 g/cm3 while D4 bone used 10 PCF with 0.16 g/cm3 to stimulate the artificial bone. The surgeon inserted three mini-implants (S-Mini Ball Type RBM Surface & For Over-Denture, NeoBiotech) to support the occlusal stent before the CBCT examination. The cone-beam computed tomography (CBCT) scan was done using the i-CAT machine (Imaging Science International LLC. Hatfield, PA, USA). On the mini-implant supported guide of the maxillary model, an occlusal guide device with four radiopaque fiducial markers (Iris-100, EPED Inc., Taiwan) was put during the CBCT scan. The DICOM data set was merged into the dynamic navigation planning program (Iris-100, EPED Inc. Taiwan) to identify the arch and describe the implant’s dimensions, following that the implant’s optimal 3-dimensional position was planned. the drilling sequence protocol was created. To utilize for registration, the four visible radiopaque fiducials on the CBCT image were labeled respectively. The passive arrays were registered before implant placement to examine the connection between the geometry of the handpiece tracking array and the bur’s axis. The surgical implant preparation and insertion protocol for each group was followed. Afterwards all models with an occlusal guided device were scanned with the same CBCT machine. DICOM data from the post-operative procedure was imported and overlapped with the previous implant planning data.

Implant accuracy was assessed using implant planning software (CoDiagnostiX 9.12 Dental Wings Inc, Montreal, QC, Canada). The software automatically measured the primary outcomes, which were 3D platform deviation (dislocation between the center at the platform of the planned and placed implant), 3D apex deviation (dislocation between the center at the apex of the planned and placed implant), and angular deviation (deviation between the axis of the planned and placed implant) (Figure 2).

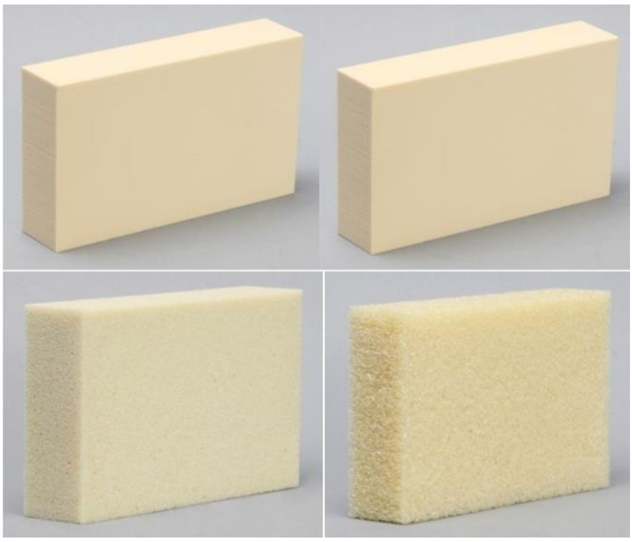

Figure 1 Illustrations of Synthetic bone blocks that demonstrated bone type 1 (upper left), 2 (upper right), 3 (lower left), and 4 (lower right).

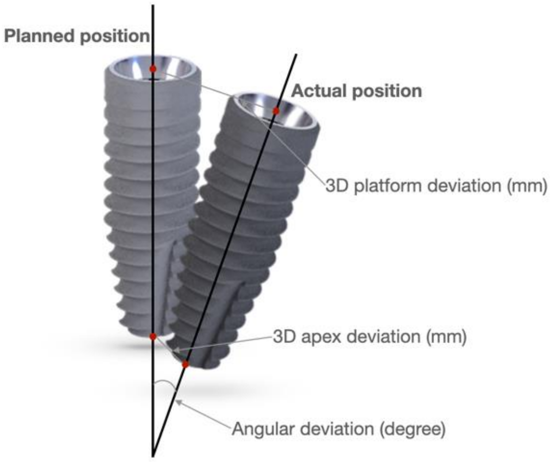

Figure 2 Illustration of the parameters indicates the implant deviations.

3.3. Statistical analysis

SPSS Statistics program version 27.0 (SPSS 27.0, Inc., Armonk, NY) was able to import measurements. To determine the normality of the bone type and tooth site, the Shapiro-Wilk test was used. One-way ANOVA was used to assess if there were any significant differences in the characteristics and deviation of the groups for homogenous variances and the Welch test was used for non-homogenous variances. To evaluate the difference between groups, the Post Hoc test was used while the Pearson correlation was analyzed to identify the relationship. A significance level of 0.05 was found statistically relevant.

4. Results and Discussion

4.1 Results

In total, 32 dental implants were implanted in edentulous models, which were separated into four bone densities with eight implants in each group. The overall result illustrated an angle(degree) deviation was 2.29 ±0.15°, Mean implant deviations at platform and apex were 1.17±0.09 and 1.13±0.10, respectively

All data sets of primary outcomes had normal distributions and homogeneous variances, so One-way ANOVA was performed to compare them. In all parameters; The angular deviation, Implant 3D platform deviation, and 3D apex deviation, there were no significant differences were identified between the four groups of bone density. The results of all deviations in each bone type were shown in Table 1. All deviations of implant placement between the left and right Quadrant were analyzed and shown in Table 2, Figure5-1, Figure5-2, and Figure5-3

No significant differences were found between the left and right quadrant of the edentulous arch. Nonetheless, the lowest bone density group (type4) indicated the highest deviation for all parameters. Moreover, there was a statistically significant negative correlation (P=0.020) between apex 3-D deviation and bone density and all deviations also trend toward a negative correlation. The correlation of all deviations was analyzed with Pearson correlation shown in Table 3 and Figure 3.

Table 1 The 3D deviations of the planned and placed implant using DNS at the platform, apex, and angle deviation of the axis. DNS: dynamic navigation system

Parameter	**Bone Type**	**Deviation**	**ρ-value (0.05)**
3D Platform deviation (mm)	D1	1.01±0.13	0.459
	D2	1.08±0.19	
	D3	1.20±0.22	
	D4	1.41±0.18	
3D Apex deviation (mm)	D1	0.86±0.15	0.068
	D2	1.09±0.15	
	D3	1.02±0.22	
	D4	1.56±0.22	
Angular deviation (degree)	D1	1.87±0.38	0.308
	D2	2.40±0.19	
	D3	2.24±0.27	
	D4	2.67±0.32	

Table 2 The 3D deviations of the right and left Quadrant implant using DNS at the platform, apex, and angle deviation of the axis. DNS: dynamic navigation system

Parameter	**Right Quadrant**	**Left Quadrant**	**ρ-value (0.05)**
3D Platform deviation (mm)	1.21±0.13	1.45±0.13	0.737
3D Apex deviation (mm)	1.05±0.13	1.22±0.16	0.411
Angular deviation (degree)	2.25±0.20	2.38±0.23	0.793

Table 3 Pearson correlation between bone density and all implant deviations
A statistically significant difference is *

	Bone density	**Angle deviation**	**3D- Platform deviation**	**3D-Apex deviation**
Pearson Correlation	1	-2.98	-2.88	-.410*
Sig. (2-tailed)		0.98	.110	.020
N	32	32	32	32

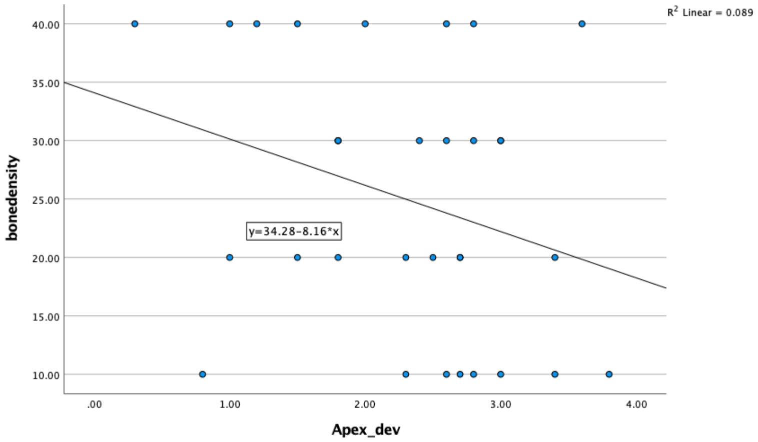

Figure 3 Scatter plot shows a significant negative correlation between the 3D apex deviation (mm) and bone density

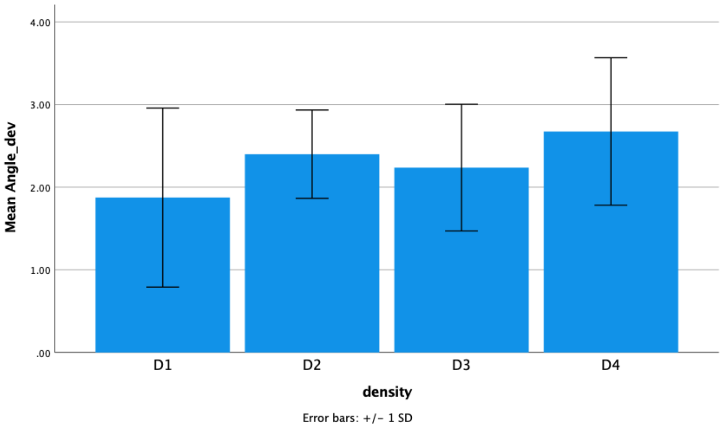

Figure 4-1 Bar graphs show the angular deviation (degree) in each bone density

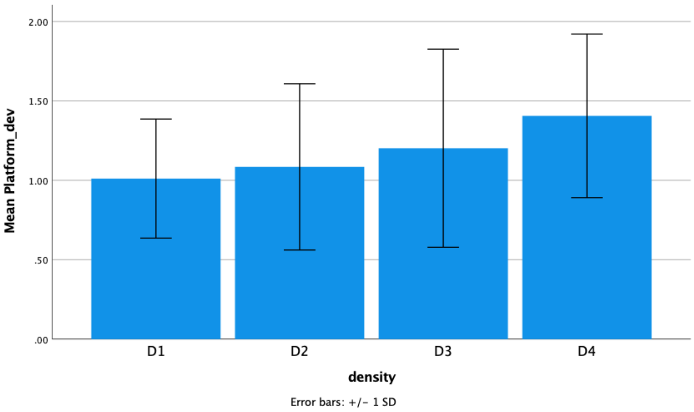

Figure 4-2 Bar graphs show the mean platform deviation (degree) in each bone density

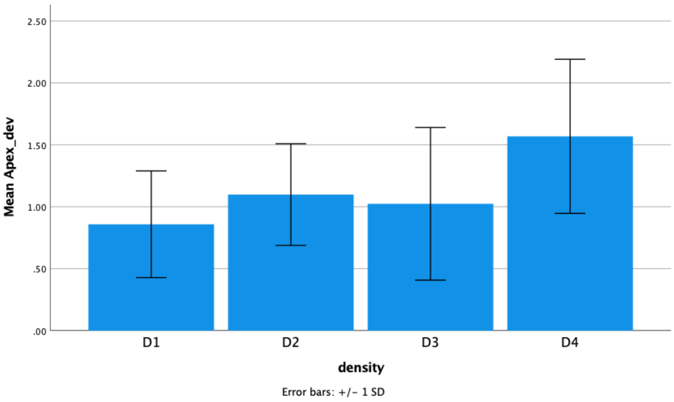

Figure 4-3 Bar graphs show the mean apex deviation (mm) in each bone density

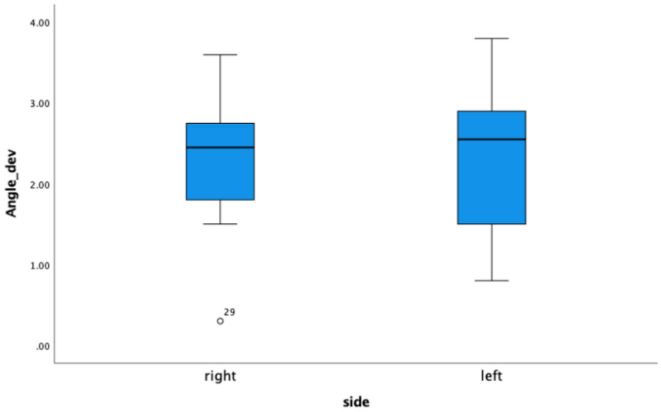

Figure 5-1 Box plots of the angular deviation (degree) observed in the right and left quadrants. The horizontal in each box represents the median values.

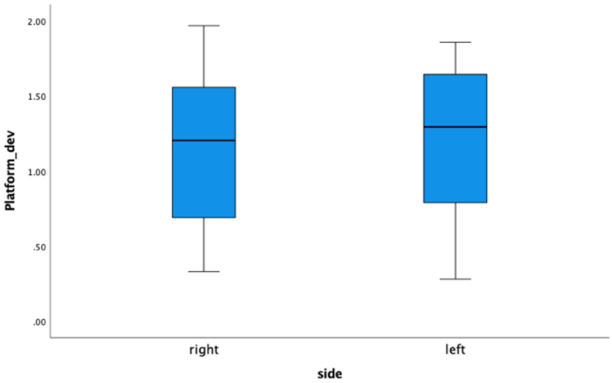

Figure 5-2 Box plots of the 3D Platform deviation (degree) observed in the right and left quadrants. The horizontal in each box represent the median values.

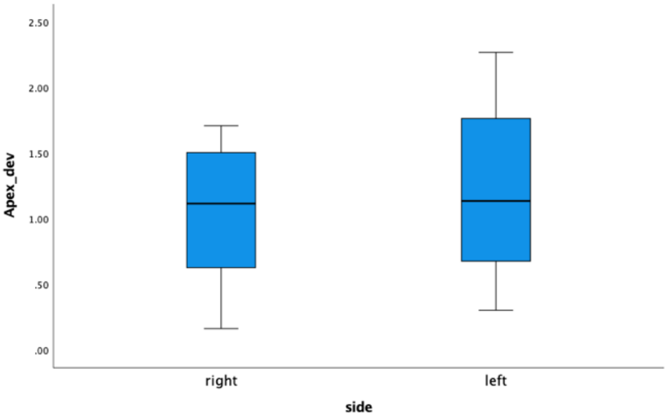

Figure 5-3 Box plots of the 3D Apex deviation (degree) observed in the right and left quadrants. The horizontal in each box represents the median values.

4.2 Discussion

Prior to implant placement operation, bone condition evaluation is should be performed to identify the implant number, size, and angulation. After that, three-dimensional CT imaging can provide precise anatomical information regarding the condition of the bone. When the implant is firstly placed, it is related to bone contact and the biomechanical properties of the surrounding bone. Following that, secondary stability became to affect osteointegration. Additionally, bone density can affect treatment planning, implant design, surgical technique, and the early loading of a prosthesis. Low bone density has been implicated in an increased risk of implant failure due to a lack of implant stability and excessive bone resorption. Bone densities and implant planning positions at the recipient site must be appropriately identified before, during, and after the implant is delivered for long-term success.

Compared with a conventional method, the experimental dynamic CAIS system significantly improves implant placement accuracy in all types of bone densities. Several in vitro experiments have shown that the CAIS method achieves more precise implant placement than the traditional technique (Kaewsiri et al., 2019). The accuracy of dynamic navigation was higher than that of freehand procedure, and the accuracies of dynamic navigation and static guiding were similar for platform deviation, apical deviation, or angular deviations. Furthermore, the navigation system enabled real-time monitoring of drilling depth, allowing the dentist to make more confident decisions about when to cease drilling. Accordingly, the risk of damage to essential anatomical structures such as the mandibular nerve, maxillary sinus floor, and incisive canal can be reduced using dynamic CAIS. However, a prior study found that fluctuating bone densities along the drilling socket might impair a surgeon's ability to conduct implantation effectively. Gaggl, Schultes, and Kärcher (2001) suggested that dense bone could allow for a better implant-placed position.

There is discussion in the literature on whether bone quality impacts dynamic CAIS accuracy, with some research indicating a statistically significant negative correlation between bone density and static CAIS accuracy (Putra et al., 2020; Kivovics et al.,2020). Despite the fact that other research has found no association (Noharet, Pettersson, & Bourgeois, 2014) or a statistically significant positive correlation between bone density and static CAIS accuracy (Casetta et al., 2013), there is a lack of data on the accuracy of implant placement in different bone densities performing through the dynamic CAIS system.

The null hypothesis of this study was rejected since the results revealed no statistically significant differences in the total accuracy measurement in each bone type ($P>0.05$). The overall result illustrated angle(degree) deviation was 2.29 ±0.15°, Mean implant deviations at platform and apex were 1.17±0.09 and 1.13±0.10, respectively. Furthermore, in terms of implant placement precision. The results of previous in-vitro experiments by Chen et al. (2018), who examined preoperative and postoperative CT scans in maxilla and mandible models employing navigation systems, guided and freehand installation, were larger than our study in both the angular and apex deviations (4.45±1.97, 1.35±0.55) but smaller in the platform deviation (1.07±0.48). There was a statistically negative correlation between the bone density (D4) and apex deviation of the implant ($P=0.02$). Nevertheless, in other accuracy parameters, the results also trend towards a negative correlation; in the angular deviation ($P= 0.59$) and the platform deviation ($P=0.55$), which is the borderline of the statistical analysis with the Pearson correlation. Additionally, the findings of this study revealed that the lowest bone density (D4) of implant location has the biggest variation in all parameters. Although no significant difference in the accuracy was identified between the implant placements between the left and right quadrants, the deviations of all parameters in the left quadrant were larger than those in the right, which could be due to the field of vision being influenced by the location of registrational fiducial markers on an occlusal stent. Including a dynamic CAIS system is basically a "freehand" surgical placement that is done by manually direct vision. CBCT images, the tracking system, the registration procedure, and human errors are all potential sources of inaccuracy in the navigation system. Despite this, there was no evidence that such a factor influenced overall accuracy results. These findings may provide guidelines for dental implant surgical treatments to the clinician. As a result, even when using dynamic navigation for implantation, the dentist should proceed with caution when placing a dental implant in a poor-quality bone location, such as the posterior maxilla.

However, there were certain limitations to the current study. All experiments were carried out using cast models in this experiment. Because there was no blood, saliva, or other clinical interferences during drilling, the cast models were ideal for evaluating accuracy. They were also stable throughout the drilling. However, crucial clinical concerns such as existing sockets, which would make steady and precise drilling more difficult, were not replicated in this model. Furthermore, the outcomes of this experiment were not removed from the influence of operator experience. TRE, or restrictions relating to the learning curve of utilizing the navigation system, are prevalent limitations and faults in dynamic CAIS. As a result, the findings of this investigation could differ in a clinical environment. Additionally, future studies should also focus on more complicated implant placement situations, such as the utilization of CAIS in multiple implant placement circumstances.

5. Conclusion

Within the limits of our investigation, the influence of bone conditions on implant placement accuracy with dynamic computer-guided surgery is statistically unaffected. Low bone density is a risk factor for implant implantation errors. As a result, even when using dynamic computer-assisted surgery, the surgeon should consider these bone conditions when performing implant insertion surgery. Other well-designed studies with a larger sample size will be required to confirm these findings.

6. References

Behneke, A., Burwinkel, M., & Behneke, N. (2012). Factors influencing transfer accuracy of cone beam CT-derived template-based implant placement. *Clinical oral implants research*, *23*(4), 416–423. doi: 10.1111/j.1600-0501.2011.02337.x

Block, M. S., Emery, R. W., Cullum, D. R., & Sheikh, A. (2017a). Implant Placement Is More Accurate Using Dynamic Navigation. *Journal of oral and maxillofacial surgery : official journal of the American Association of Oral and Maxillofacial Surgeons*, *75*(7), 1377–1386. doi: 10.1016/j.joms.2017.02.026

Block, M. S., Emery, R. W., Lank, K., & Ryan, J. (2017b). Implant Placement Accuracy Using Dynamic Navigation. *The International journal of oral & maxillofacial implants*, *32*(1), 92–99. doi: 10.11607/jomi.5004

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

Chen, C. K., Yuh, D. Y., Huang, R. Y., Fu, E., Tsai, C. F., & Chiang, C. Y. (2018). Accuracy of Implant Placement with a Navigation System, a Laboratory Guide, and Freehand Drilling. *The International journal of oral & maxillofacial implants*, *33*(6), 1213–1218. doi:10.11607/jomi.6585

Comuzzi, L., Iezzi, G., Piattelli, A., & Tumedei, M. (2019). An In Vitro Evaluation, on Polyurethane Foam Sheets, of the Insertion Torque (IT) Values, Pull-Out Torque Values, and Resonance Frequency Analysis (RFA) of NanoShort Dental Implants. *Polymers*, *11*(6), 1020. doi:10.3390/polym11061020

D'haese, J., Van De Velde, T., Komiyama, A., Hultin, M., & De Bruyn, H. (2012). Accuracy and complications using computer-designed stereolithographic surgical guides for oral rehabilitation by means of dental implants: a review of the literature. *Clinical implant dentistry and related research*, *14*(3), 321–335. doi:10.1111/j.1708-8208.2010.00275.x

Emery, R. W., Merritt, S. A., Lank, K., & Gibbs, J. D. (2016). Accuracy of Dynamic Navigation for Dental Implant Placement-Model-Based Evaluation. *The Journal of oral implantology*, *42*(5), 399–405. doi:10.1563/aaid-joi-D-16-00025

Faul, F., Erdfelder, E., Buchner, A., & Lang, A.-G. (2009). Statistical power analyses using G*Power 3.1: Tests for correlation and regression analyses. *Behavior Research Methods*, *41*, 1149-1160.

Gaggl, A., Schultes, G., & Kärcher, H. (2001). Navigational precision of drilling tools preventing damage to the mandibular canal. *Journal of cranio-maxillo-facial surgery : official publication of the European Association for Cranio-Maxillo-Facial Surgery*, *29*(5), 271–275. doi:10.1054/jcms.2001.0239

Gehrke, S. A., Guirado, J., Bettach, R., Fabbro, M. D., Martínez, C. P., & Shibli, J. A. (2018). Evaluation of the insertion torque, implant stability quotient and drilled hole quality for different drill design: an in vitro Investigation. *Clinical oral implants research*, *29*(6), 656–662. doi:10.1111/clr.12808

Greenstein, G., Cavallaro, J., Romanos, G., & Tarnow, D. (2008). Clinical recommendations for avoiding and managing surgical complications associated with implant dentistry: a review. *Journal of periodontology*, *79*(8), 1317–1329. doi:10.1902/jop.2008.070067

Jung, R. E., Schneider, D., Ganeles, J., Wismeijer, D., Zwahlen, M., Hämmerle, C. H., & Tahmaseb, A. (2009). Computer technology applications in surgical implant dentistry: a systematic review. *The International journal of oral & maxillofacial implants*, *24*, 92–109.

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

Kivovics, M., Pénzes, D., Németh, O., & Mijiritsky, E. (2020). The Influence of Surgical Experience and Bone Density on the Accuracy of Static Computer-Assisted Implant Surgery in Edentulous Jaws Using a Mucosa-Supported Surgical Template with a Half-Guided Implant Placement Protocol-A Randomized Clinical Study. *Materials*, *13*(24), 5759. doi:10.3390/ma13245759

Noharet, R., Pettersson, A., & Bourgeois, D. (2014). Accuracy of implant placement in the posterior maxilla as related to 2 types of surgical guides: a pilot study in the human cadaver. *The Journal of prosthetic dentistry*, *112*(3), 526–532. doi:10.1016/j.prosdent.2013.12.013

Ozan, O., Orhan, K., & Turkyilmaz, I. (2011). Correlation between bone density and angular deviation of implants placed using CT-generated surgical guides. *The Journal of craniofacial surgery*, *22*(5), 1755–1761. doi:10.1097/SCS.0b013e31822e6305

Putra, R. H., Yoda, N., Iikubo, M., Kataoka, Y., Yamauchi, K., Koyama, S., Cooray, U., Astuti, E. R., Takahashi, T., & Sasaki, K. (2020). Influence of bone condition on implant placement accuracy with computer-guided surgery. *International journal of implant dentistry*, *6*(1), 62. doi:10.1186/s40729-020-00249-z

Ruppin, J., Popovic, A., Strauss, M., Spüntrup, E., Steiner, A., & Stoll, C. (2008). Evaluation of the accuracy of three different computer-aided surgery systems in dental implantology: optical tracking vs. stereolithographic splint systems. *Clinical oral implants research*, *19*(7), 709–716. doi:10.1111/j.1600-0501.2007.01430.x

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*(4), 73–86. doi:10.1111/j.1600-0501.2009.01788.x

Somogyi-Ganss, E., Holmes, H. I., & Jokstad, A. (2015). Accuracy of a novel prototype dynamic computer-assisted surgery system. Clinical oral implants research, *26*(8), 882–890. doi:10.1111/clr.12414

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. *The International journal of oral & maxillofacial implants*, *34*(1), 205–213. doi:10.11607/jomi.6966

Tang, T., Huang, Z., Liao, L., Gu, X., Zhang, J., & Zhang, X. (2019). Factors that Influence Direction Deviation in Freehand Implant Placement. *Journal of prosthodontics : official journal of the American College of Prosthodontists*, *28*(5), 511–518. doi:10.1111/jopr.13065

Tsolaki, I. N., Tonsekar, P. P., Najafi, B., Drew, H. J., Sullivan, A. J., & Petrov, S. D. (2016). Comparison of Osteotome and Conventional Drilling Techniques for Primary Implant Stability: An In Vitro Study. *The Journal of oral implantology*, *42*(4), 321–325. doi:10.1563/aaid-joi-D-15-00176

Wang, F., Wang, Q., & Zhang, J. (2021). Role of Dynamic Navigation Systems in Enhancing the Accuracy of Implant Placement: A Systematic Review and Meta-Analysis of Clinical Studies. *Journal of oral and maxillofacial surgery : official journal of the American Association of Oral and Maxillofacial Surgeons*, *79*(10), 2061–2070. doi:10.1016/j.joms.2021.06.005

Widmann, G., & Bale, R. J. (2006). Accuracy in computer-aided implant surgery--a review. *The International journal of oral & maxillofacial implants*, *21*(2), 305–313.

Wu, D., Zhou, L., Yang, J., Zhang, B., Lin, Y., Chen, J., Huang, W., & Chen, Y. (2020). Accuracy of dynamic navigation compared to static surgical guide for dental implant placement. *International journal of implant dentistry*, *6*(1), 78. doi:10.1186/s40729-020-00272-0