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Three-dimensional Accuracy of Angled Dental Implant Placement: A Comparison Study of the Dynamic Navigation System and Free-hand Method

Açılı Dental İmplant Yerleşiminde Üç Boyutlu Doğruluk: Dinamik Navigasyon Sistemi ve Serbest El Yöntemi Karşılaştırma Çalışması

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Keywords
Implant accuracy, dynamic navigation system, free-hand method, angled implant placement

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Abstract

Objective: This study aimed to compare the success of the free-hand technique and dynamic navigation system in a completely edentulous patient model. The two methods were compared by comparing the results achieved after the surgery against the planning made before the surgery.

Materials and Methods: The cone-beam computed tomography imaging data obtained after the implants were placed and the previously planned results of the procedure were overlapped in a three-dimensional space and compared. Four types of deviations were measured in the evaluation of each implant: coronal, apical, depth and angular deviations.

Results: The mean deviation values in the coronal, apical and angular deviation parameters were higher in the free-hand technique (group 1) compared to the dynamic navigation method (group 2). Statistically significant differences between the two groups of angle implants were found in the coronal and apical positions of implants, and in the angular deviation ($p<0.001$).

Conclusion: Angled implant applications could be performed with higher accuracy with the dynamic navigation system than the free-hand method. Dynamic navigation increases the quality and accuracy of the surgical procedure by offering a high level of precision and ease of use. Its precision and accuracy are particularly high when placing angled implants.

Öz

Amaç: Bu çalışma tam dişsiz hasta modelinde serbest el tekniğinin ve dinamik navigasyon sisteminin başarısını karşılaştırmayı amaçlamıştır. Çalışmada operasyon sonrası elde edilen sonuçların operasyon öncesi yapılan planlama ile karşılaştırılmasına göre iki yöntemin karşılaştırması yapılmıştır.

Gereç ve Yöntemler: İmplantlar yerleştirildikten sonra elde edilen konik ışınlı bilgisayarlı tomografi verileri ve işlemin daha önce planlanan sonuçları, 3 boyutlu alanda üst üste bindirilerek karşılaştırma yapıldı. Her implant için değerlendirmede dört tür sapma ölçüldü: Koronal, apikal, derinlik ve açısal sapma.

Bulgular: Koronal sapma, apikal sapma ve açısal sapma parametrelerindeki ortalama sapma değerleri, serbest el tekniğinde (grup 1) dinamik navigasyon yöntemine (grup 2) göre daha yüksek bulundu. İki grup açılı implantlar arasında implantların koronal pozisyonunda, implantların apikal pozisyonunda ve açısal sapmada istatistiksel olarak anlamlı fark bulundu (p<0,001).
Sonuç: Dinamik navigasyon yöntemi ile açılı implant uygulamaları serbest el tekniğinden daha yüksek doğrulukla yapılabilmektedir. Dinamik navigasyon, yüksek düzeyde hassasiyet ve kullanım kolaylığı sunarak cerrahi prosedürün kalitesini ve doğruluğunu artırır. Özellikle açılı implantları yerleştirirken hassasiyeti ve doğruluğu yüksek olarak görülmüştür.

Introduction

Resorption in the alveolar bone in completely edentulous patients may often lead to the loss of sufficient vertical bone distance for dental implant placement. In cases of severe vertical insufficiency as a result of this situation, advanced surgical procedures, including bone augmentation, may be required to achieve the ideal implant length. However, instead of extensive and advanced surgical procedures, different solutions can also be put forward with more up to date and minimally invasive approaches. In cases where advanced surgical procedures are not preferred, angled implant applications performed as an alternative method to avoid critical anatomical regions have taken place in the literature (1-3).

Successful angled implant applications are provided by implant planning in the appropriate region, at the appropriate angle and in the appropriate position in three dimensions. Although there are conventional approaches in implant surgery that can be called free-hand techniques as no stent is used, computer-aided dynamic navigation systems are also employed (4). Dynamic navigation is a system that allows the precise and continuous detecting and tracking of the location of the patient and the instruments used during surgery in 3-dimensional (3D). This method is based on the use of a stereotaxy map in which each reference point is linked with a particular external reference mark in a coordinate system. The software makes a 3-dimensional position determination on this map. Thus, it enables the surgeon to relate the anatomy of the operation region with the tomography information acquired before surgery, which makes it possible to find critical anatomical and pathological structures without any damage. The system enables dynamic navigation to be operated simultaneously and in real-time with the surgical procedure (5-7).

This study aimed to compare the success of the free-hand technique and dynamic navigation system in a completely edentulous patient model. The comparison of the two methods was made according to the comparison of the results achieved after the operation against the planning made before the operation. Deviations in vertical, horizontal, and sagittal planes compared to surgical planning in 3D and the accuracy achieved were evaluated. In other words, evaluating which surgical method provides results more in accordance with surgical planning was the main objective of our study.

Materials and Methods

Power analysis was performed to determine the required sample size in this study (GPower, Düsseldorf, Germany). As a result of the power analysis, fifty polyurethane jaw models and 200 implants with four implants in each model were included in this study. In group 1, 100 implants on 25 models were set to be applied by dynamic navigation method, and in group 2, 100 implants on 25 models were set to be applied by the free-hand technique (Table 1). Before making implant planning, removable complete mandibular dental prostheses were made using barium sulfate teeth on polyurethane jaw models. In these models, the exit points of the mental foramen were marked with a radiopaque composite filling material. The images of the prepared models were taken using cone-beam computed tomography (CBCT) (Planmeca Promax 3D Mid, Planmeca, Finland) and these images were uploaded to computers as Digital Imaging and Communications in Medicine data.

Table 1. Distribution of study groups	
Group 1 (n=25) dynamic navigation system	Implant 1= Vertical-right
	Implant 2= Vertical-left
	Implant 3= 30° Angel-left
	Implant 4= 30° Angel-right
Group 2 (n=25) free-hand technique	Implant 1= Vertical-right
	Implant 2= Vertical-left
	Implant 3= 30° Angel-left
	Implant 4= 30° Angel-right

To achieve standardization between groups, standard 10x3.5 mm implants and the same plans were used on the models. In implant planning, the findings showed that that the right and left distal implants would be placed at an angle of 30° in front of the mental foramen, and the medial implants would stand vertical in the anterior region and be placed parallel to each other (Figures 1, 2). Accordingly, the exit points of the distal implants were determined to be between the teeth numbered 5 and 6, and the exit points of the anterior implants were determined to be teeth numbered 2 (Figure 3).

Implants were applied in group 1 by Dynamic Navigation System (Navident®, ClaroNav Inc., Toronto, Canada) and in group 2 by free-hand technique. The free-hand technique was determined as the conventional method. The regions of the previously prepared complete prosthesis in which implants will be placed were scraped and these scrapings were used as a manual guide for free-hand surgery.

The Evalunav® (ClaroNav Inc., Toronto, Canada) program was used to compare the post-operative accuracy of implants versus surgical planning in the planar three dimensions. The CBCT imaging data obtained after the implants were placed, and the previously planned results of the procedure were overlapped in the 3-dimensional space and then

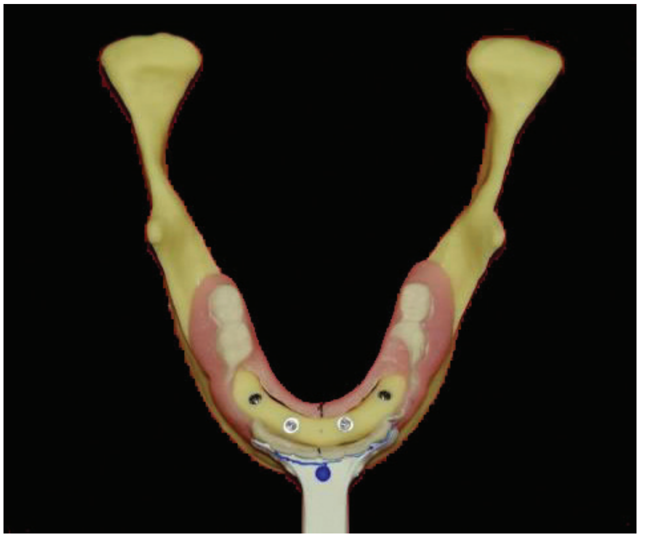

Figure 1. Implant placement on polyurethane jaw models

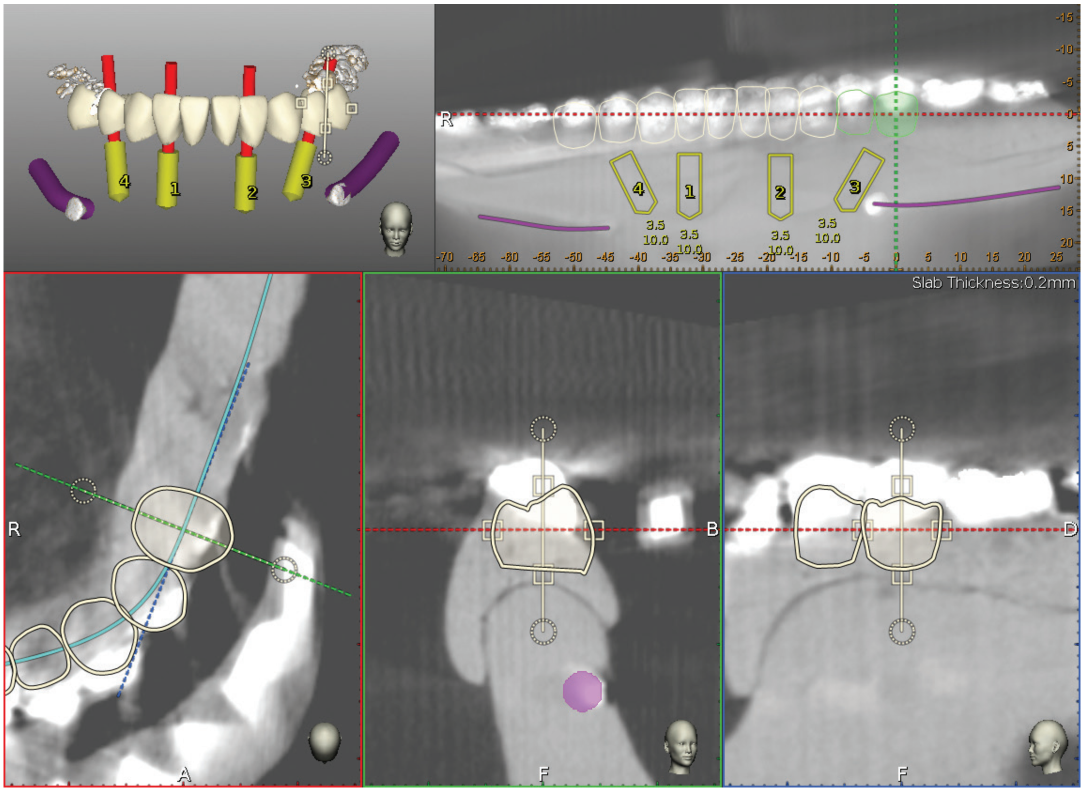

Figure 2. Implant planning with using dynamic navigation system software. Standard implants and the same plans were used on the models

a comparison is made (Figure 4). Four types of deviations were measured in the evaluation for each implant:

- Coronal-entry deviation (2D): The 2D sum of the deviation between the planned (yellow) and actual (red) implant in the occlusal plane, vectorially, and in millimeters.
- Depth-vertical deviation: A numerical statement of the distance between the apex points of the planned and actual implants in the occlusal plane.
- Apical-apex deviation (3D): The 3D sum of the 3D distance between the apex points of the planned and the actual implants, vectorially and in millimeters.
- Angular-angle deviation: A numerical statement of the angle between positions of the planned and actual implants.

In our study, mean deviations between planned and post-operative positions of implants were analyzed in both groups for all implants (Figure 5).

Statistical Analysis

Normality was assessed using the Kolmogorov-Smirnov test within the groups. Data were compared both as independent groups and as dependent groups. In the independent group analyses, the independent samples t-test was used for variables with normal distribution, and the Mann-Whitney

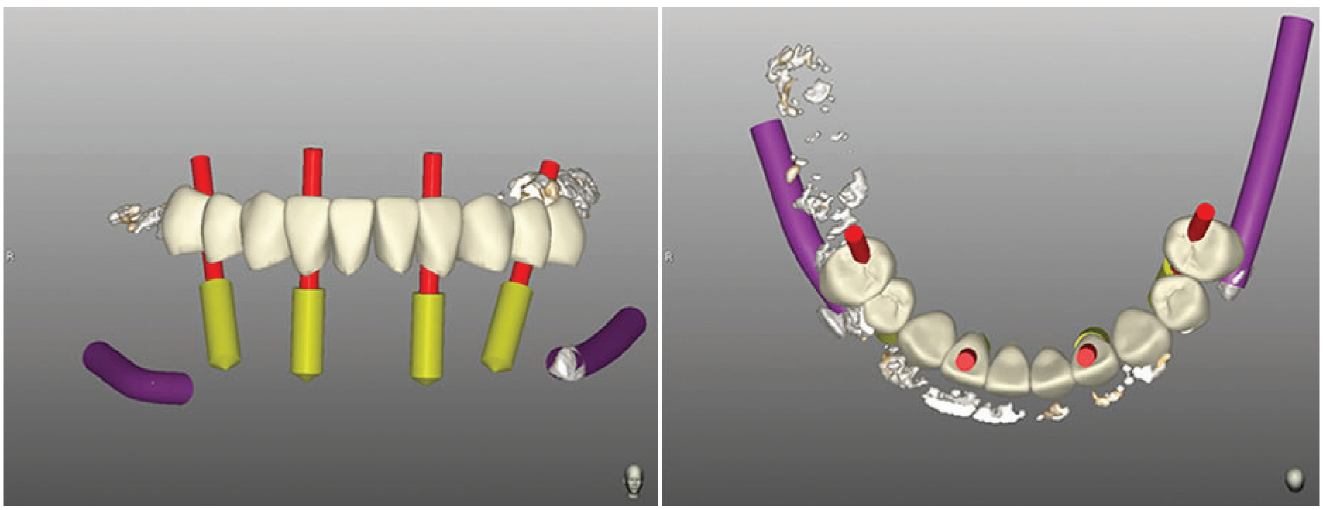

Figure 3. Implant positions in the occlusal plane

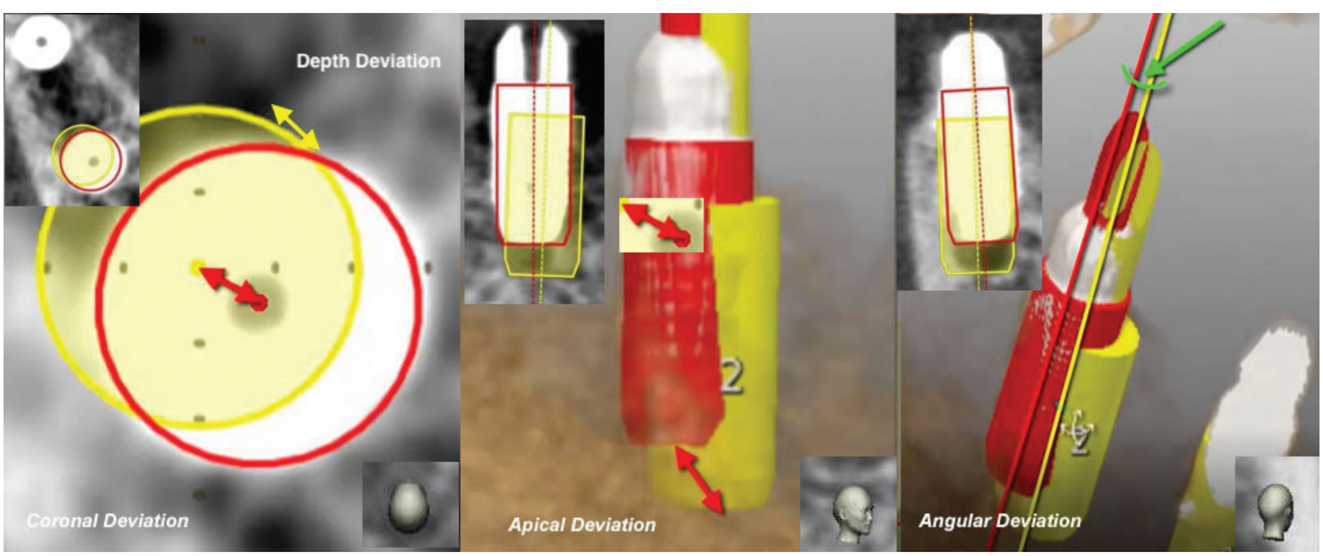

Figure 4. Schematic representation of deviations on the program. The difference between the planned implant position and the post-operative implant position in 3-dimensional space

U test was used for variables not showing normal distribution. Descriptive statistics were presented as mean ± standard deviation for normally distributed variables and as median (25th-75th percentile) for non-normally distributed variables. A p-value of <0.05 was considered statistically significant.

Results

In our study, it was observed that the mean deviation values in the coronal deviation, apical deviation and angular deviation parameters were higher in the free-hand technique (group 1) compared to the dynamic navigation method (group 2). The depth deviation was the parameter with the least difference between the planning and results of the operation in both techniques. In addition, the depth deviation parameter has been the only parameter in which implants applied with free-hand technique can achieve the closest accuracy compared to implants applied with dynamic navigation. Angular deviation was the parameter in which the maximum deviation occurred in the free-hand technique, particularly in angled implants (Table 2).

In our study, mean deviations between planned and post-operative positions of implants were compared in both groups for angled implants and vertical implants. In group 1, where dynamic navigation was performed, the average coronal deviation was 0.89 mm in vertical implants and 1.01 mm in those planned with 30° inclination. When the apical deviation parameter was evaluated, it was 0.93 mm in vertical implants and 1.27 mm in angled implants. Looking at the depth deviation

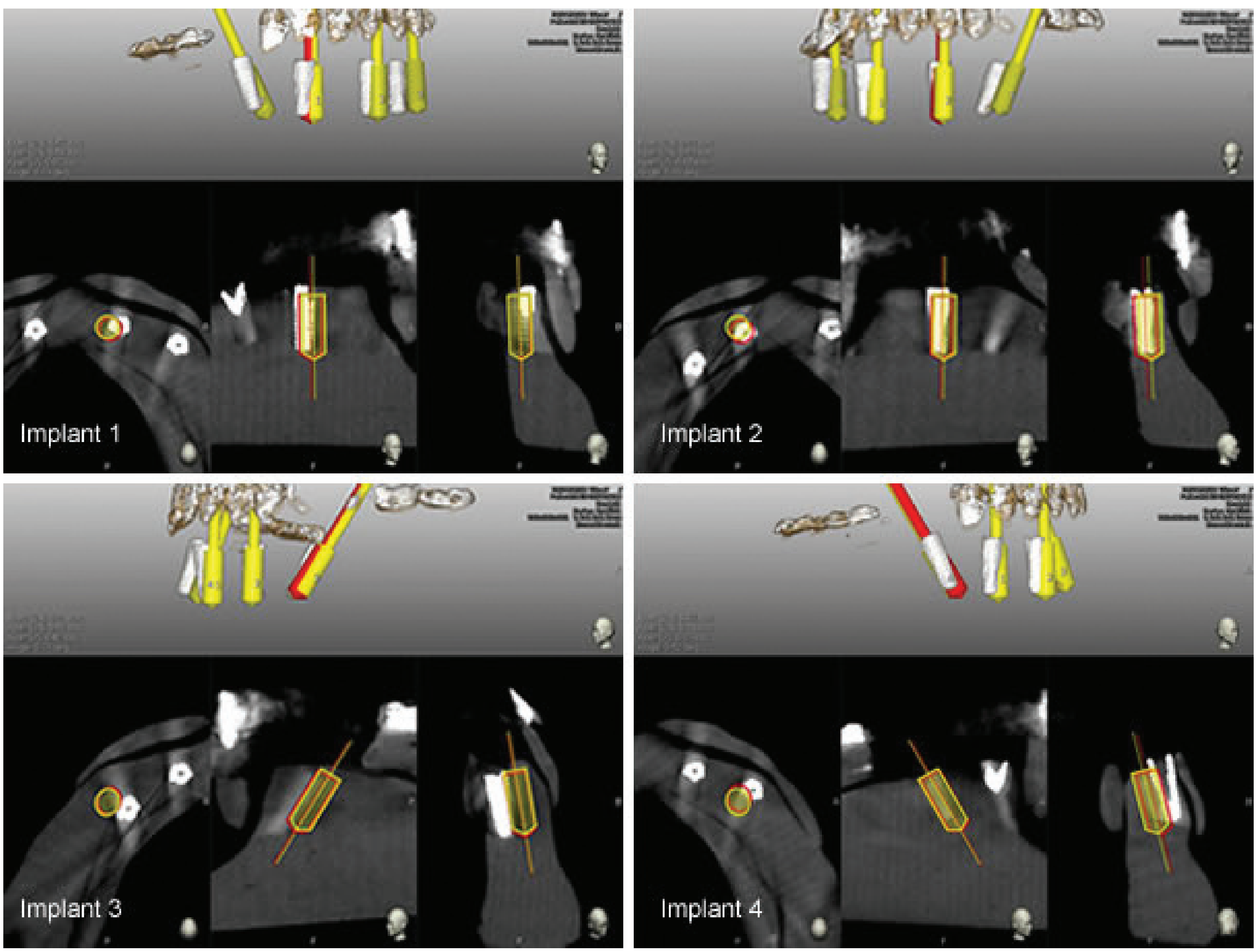

Figure 5. The deviations between planned and actual implant positions were measured by matching the pre- and post-operative images for each implant

parameter, it was 0.19 mm for vertical implants and 0.30 mm for angled implants. The mean angular deviation was 0.53° in vertical implants and 0.94° in angled implants. In group 2, where the free-hand technique was performed, the average coronal deviation was 1.48 mm in vertical implants and 2.20 mm in those planned with 30° inclination. When the apical deviation parameter was evaluated, it was 2.12 mm in vertical implants and 3.62 mm in angled implants. Looking at the depth deviation parameter, it was 0.28 mm for vertical implants and 0.39 mm for angled implants. The mean angular deviation was 2.34° in vertical implants and 6.73° in angled implants (Table 3).

When the table is examined, there was a statistically significant deviation in all parameters except for the coronal deviation in the dynamic navigation group in

Table 2. The mean deviation values calculated by including each implant in group 1 and group 2 and comparison between groups

	Implant	Group 1	Group 2	p
Coronal deviation	Vertical right*	0.93±0.44	1.17±0.41	<0.001
	Vertical left*	0.86±0.42	1.56±0.40	<0.001
	Angel left**	1.31 (0.86-1.42)	2.32 (1.83-2.58)	<0.001
	Angel right*	0.86±0.31	2.17±0.40	<0.001
Apical deviation	Vertical right*	1.03±0.39	2.12±0.25	<0.001
	Vertical left*	0.92±0.31	2.12±0.16	<0.001
	Angel left**	1.55 (1.09-1.65)	3.65 (3.23-3.87)	<0.001
	Angel right*	1.08±0.37	3.66±0.54	<0.001
Depth deviation	Vertical right**	0.12 (0.03-0.29)	0.25 (0.16-0.35)	0.006
	Vertical left**	0.19 (0.09-0.34)	0.30 (0.21-0.34)	0.103
	Angel left*	0.32±0.23	0.36±0.17	0.503
	Angel right**	0.26 (0.13-0.36)	0.38 (0.23-0.70)	0.017
Angular deviation	Vertical right*	0.58±0.36	2.14±0.54	<0.001
	Vertical left**	0.34 (0.25-0.79)	2.41 (1.98-2.91)	<0.001
	Angel left*	0.86±0.43	6.25±2.09	<0.001
	Angel right*	1.01±0.36	7.20±2.33	<0.001

*Results acquired using the t-test: Mean deviation and (± standard deviation) values are given for the implants marked with the number 1-2-3-4 in both groups

**Results acquired using the Mann-Whitney U test: Median and (25th-75th percentile) values are given for implants marked with the number 1-2-3-4 in both groups

Table 3. Comparison of the mean deviation values of angled and vertical implants within their groups

		group 1	p	group 2	p
Coronal deviation	Verticals'	*0.89±0.35	0.277	**1.48 (1.40-1.41)	<0.001
	Angles'	*1.01±0.24		**2.20 (1.95-2.57)	
Apical deviation	Verticals'	**0.93 (0.80-1.16)	0.019	*2.12±0.19	<0.001
	Angles'	**1.27 (1.01-1.41)		*3.62±0.54	
Depth deviation	Verticals'	*0.19±0.13	0.041	**0.28 (0.20-0.32)	0.003
	Angles'	*0.30±0.15		**0.39 (0.28-0.48)	
Angular deviation	Verticals'	*0.53±0.28	<0.001	*2.34±0.53	<0.001
	Angles'	*0.94±0.33		*6.73±1.94	

*Data showing normal distribution and analyzed with paired t-test: mean deviation value between planned and post-operative positions was given as ± standard deviation

**The data that did not show the normal distribution and analyzed by Wilcoxon t-test were given as median and (25th-75th percentile) values angled implants compared to vertical implants. In the free-hand technique, the findings showed that the deviation amount of angled implants was significantly higher than vertical implants in all parameters. In addition, it was observed that the deviation between the planned and post-operative positions in all parameters and both groups in angled implants was greater than in vertical implants. The least difference between angled and vertical implants was seen in the depth deviation parameter. The greatest difference was observed in apical deviation and angular deviation. Again, the amount of angular deviation in angled implants is significantly higher in the free-hand technique. This increase in deviation in angled implants appears to be even greater in the free-hand technique.

In our study, the average deviation amounts of the angled implants for group 1 and group 2 were calculated separately. Then, whether there was a difference between these two groups concerning angled implants was compared and presented in Table 4. More errors occurred in the free-hand technique compared to dynamic navigation, except for the depth deviation (Table 4). No significant difference was found in the depth deviation parameter of the angled implants applied with the dynamic navigation method compared to the free-hand technique. In the depth deviation parameter, there were similar results between the free-hand technique and the dynamic navigation method. However, in all other parameters, the deviation amount in the dynamic navigation technique was less than in the free-hand technique.

In our study, the angled implants on the right and left sides were compared with each other, and the results are presented in Table 5 for both groups. The purpose of this comparison is to determine the amount of deviation between the planned and post-operative positions in the implants applied in the right and left jaw by a right-handed physician. In the dynamic navigation group, it was observed that the amount of deviation of the implants in the left jaw was greater than the right ones in all parameters except angular deviation. It was observed that the angular deviation parameter was higher on the right side than on the

Table 4. Comparison of mean deviation amounts of angled implants for group 1 and group 2

	Group 1	Group 2	p
Coroal deviation*	1.01±0.24	2.19±0.44	<0.001
Apical deviation**	1.27 (1.01-1.41)	3.65 (3.31-3.95)	<0.001
Depth deviation**	0.28 (0.15-0.44)	0.39 (0.28-0.48)	0.148
Angular deviation*	0.94±0.33	6.73±1.94	<0.001

*Data showing normal distribution and analyzed with paired t-test: Mean deviation value between planned and post-operative positions was given as ± standard deviation

**The data that did not show the normal distribution and analyzed by Wilcoxon t-test were given as median and (25^{th}-75^{th} percentile) values

Table 5. Comparison of the deviation values of the angled implants located on the right and left sides with respect to each other

		Group 1	p	Group 2	p
Coronal deviation	Left	**1.31 (0.86-1.42)	0.005	*2.21±0.49	0.340
	Right	**0.97 (0.62-1.07)		*2.17±0.40	
Apical deviation	Left	**1.55 (1.09-1.65)	0.030	*3.58±0.60	0.292
	Right	**1.13 (0.74-1.40)		*3.66±0.54	
Depth deviation	Left	*0.32±0.23	0.579	**0.34 (0.25-0.48)	0.115
	Right	*0.28±0.18		**0.38 (0.23-0.70)	
Angular deviation	Left	*0.86±0.43	0.090	*6.25±2.09	0.035
	Right	*1.01±0.36		*7.20±2.33	

*Data showing normal distribution and analyzed with paired t-test: mean deviation value between planned and post-operative positions was given as ± standard deviation

**The data that did not show the normal distribution and analyzed by Wilcoxon t-test were given as median and (25^{th}-75^{th} percentile) values left side. Among these differences, coronal deviation and apical deviation values were statistically significant for the dynamic navigation group. In the free-hand technique group, the deviation seen in the right implants in all parameters except the coronal deviation was higher than the left ones. In the coronal deviation parameter, it was observed that the left side implants deviated more than the right side ones. Among these differences, only the angular deviation amount was statistically significant for the free-hand group.

Discussion

Navigation in implant surgery is the process of transferring correct implant planning made based on computed tomography data to the patient accurately. This process can be performed statically with the help of stents prepared in the laboratory or dynamically with computer-aided navigation instruments. Besides, implants can be applied by the free-hand technique based on the surgeon's clinical experience. In this method, the surgeon provides navigation by comparing the distances to the reference points he sees in the patient's mouth with patient radiographs. However, this would be the most error-prone method given that the precision in this method depends entirely on the clinical experience of the surgeon and it will not be possible to control the three-dimensional placement of the implants. Placement of the implants in the correct position is essential for a successful and sustainable prosthetic treatment. The success of the implant application is achieved by obtaining the correct data with the methods listed above and transferring the planning made on these data into the mouth in the most accurate way (8,9).

Although the development of advanced imaging methods enables us to make more accurate planning, transferring this planning to the patient is one of the biggest problems. Guided surgical applications provide great advantages for placing implants in planned positions. Taruna et al. (10) stated that hybrid prostheses using angled implants are very sensitive and should be applied with a surgical guide. In the same study, it was stated that it is not always possible to achieve the implant positions required for the prosthesis using the free-hand technique. The preferred guided surgery procedures should be applicable in terms of reliability and practicality and should have reasonable learning time. Authors showed that the utilization of static or dynamic navigation systems is superior to free-hand implant placement in transferring the position planned to the patient's mouth accurately (11,12).

Dynamic navigation allows critical anatomical structures to be found in real time without being damaged during surgery, enabling the operation to proceed with safe surgical distances. Compared to static navigation, the most prominent advantage of dynamic navigation is that it enables planning at the bedside and changes in the plan during surgery. In addition to all these, the locations where dental crowns will be placed in the region of defect can be determined on the computer screen during the planning phase. The positions of the crowns can be adjusted in three dimensions in mesio-distal, bucco-lingual and vertical directions. The size of the crowns can be altered in three dimensions and the crowns can be adjusted at ideal angles. After determining the ideal positions and sizes of the crowns, adjustments can be made by evaluating the most appropriate positions, angles and exit profiles of the implants according to the placement of the crowns, which ensures that the correct implant position and angle can be provided in accordance with the superstructure (5,6).

Somogyi-Ganss et al. (13) reported in their study that the amount of deviation seen in implants applied with dynamic navigation in the laboratory is less than the deviations seen in clinical studies. In this study, entry point deviation amount was determined as 1.14 mm±0.55 mm, apical deviation amount was determined as 1.18 mm±0.56 mm, depth deviation amount was determined as 1.04 mm±0.71 mm, total apical deviation amount was determined as 1.71±0.61 mm, and angular deviation amount was determined as 2.99°±1.68°. Emery et al. (14) compared the angular and linear deviations of implants placed with a dynamic navigation system (X-Guide, X-Nav Technologies, LLC, Lansdale, PA) in dentulous and edentulous models in their model-based study. The angular accuracy of the implants placed using the tested instrument was reported as 0.89°±0.35° in dentulous models and 1.26°±0.66° in edentulous models. 3D positional accuracy for dentulous models was reported as 0.38 mm±0.21 mm, while it was 0.56 mm±0.17 mm for edentulous models.

Stefanelli et al. (15) used the same navigation instrument as in our study in their retrospective study, in which they included 231 implants. In this study, implant placement was performed in 89 jaws in total, which includes 106 implants for partially edentulous patients and 125 implants for completely edentulous patients applied by a single surgeon. In partially edentulous patients, deviation values between planned and post-operative positions were reported as 0.70 mm at the entry point, 0.96 mm at the apex and angle deviation was 2.21°. The deviation values of the last 50 implants (entry point: 0.59 mm, apex: 0.85 mm, angular: 1.98°) placed in the study were significantly lower than the first 50 implants (entry point: 0.94 mm, apex: 1.19 mm, angular: 3.48°) was interpreted as the learnability of the dynamic navigation system.

Mediavilla Guzmán et al. (16) compared the accuracy of 40 implants they placed using static and dynamic navigation systems. There was no statistically significant difference between static and dynamic navigations at coronal (p=0.6535) and apical (p=0.9081) levels. However, a statistically significant difference was shown between angle deviations (p=0.0272). In the same study, the amount of coronal deviation was determined as a mean of 0.78 mm±0.43 mm in dynamic navigation and 0.85 mm±0.48 mm in static navigation, apex deviation was reported as a mean of 1.20 mm±0.4 8 mm in dynamic navigation, 1.18 mm±0.60 mm in static navigation, and deviation in implant angles was reported as a mean of 2.95°±1.48° in dynamic navigation and 4.00°±1.41° in static navigation.

In our study, apical deviation, depth deviation and angular deviation amounts showed a statistically significant increase in angled implants applied in the dynamic navigation group compared to vertical implants. In the free-hand group, a statistically significant increase was observed in deviation amounts of all parameters in angled implants compared to vertical implants. In addition, dynamic navigation and free-hand technique for angled implants were compared. In this comparison, the amounts of coronal deviation, apical deviation and angular deviation were significantly higher in the free-hand group than the dynamic navigation group. Especially in the apical deviation and angular deviation parameters, it was observed that the free-hand technique group had higher deviation amounts compared to the dynamic navigation group. This shows how difficult it is to get the right angle in angled implants with the free-hand technique. The depth deviation parameter showed almost identical deviation amounts in the free-hand technique with a dynamic navigation method because the reference lines showing drill depth on the implant drill systems can be followed during the procedure. Thus the planned vertical depth can be precisely applied in both techniques. However, the ability to control other parameters during the operation depends entirely on the experience and skills of the surgeon in the free-hand technique. On the contrary, the dynamic navigation technique constantly guides the surgeon during the operation and allows implant placement with a closer accuracy to the planning accordingly. Aydemir and Arısan (17) also showed in their studies that the accuracy of the dynamic navigation system is higher than the free-hand technique.

Dynamic navigation systems enable flapless surgery in clinical practice. This provides great comfort for the patient in the post-operative period. In addition, since the continuity of the periosteum is not disturbed, complaints, such as edema and pain, will be minimal after the operation, which will reduce the recovery time after the operation and eliminate the fears of patients about implant surgery. Besides, not using flaps during the operation increases the success of the implant placement by reducing the risk of infection. Since there is no flap removal, bleeding will be minimal during surgery, which will increase the surgeon's field of vision, making the surgery easier. The use of the dynamic navigation method is not limited to implant applications. Nowadays, the frequency of utilization of this method in anesthesia applications, endodontics and oral surgery is increasing (18-20).

On the other hand dentistry practice is one of the areas where there is much close contact with the patient, and the risk of infectious diseases is very high. Therefore, minimizing contact with the patient in today's pandemic conditions, which deeply affect public health, is a must. Performing an operation using a screen instead of looking directly at the patient's mouth is quite significant in reducing the risk of infection. The improvement and renovation of dynamic navigation systems in future studies, especially the inclusion of artificial intelligence technologies, will prepare the ground for safer operations. The increase in technological advancements, the development of robotic surgery and artificial intelligence will facilitate surgical procedures in the future and minimize medical malpractices.

Conclusion

The findings obtained in this study showed that angled implant applications could be performed with higher accuracy by the dynamic navigation method than the free-hand technique. Dynamic navigation systems increase the quality and accuracy of the surgical procedure by offering a high level of precision and ease of use. Its precision and accuracy are particularly high when placing angled implants.

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Ethics

Ethics Committee Approval: The ethics committee approval is not required as it is a model study.

Informed Consent: Informed consent was not obtained as it is a model study.

Peer-review: Externally peer-reviewed.

Authorship Contributions

Concept: H.O.Ş., Design: H.O.Ş., Supervision: H.O.Ş., Fundings: H.O.Ş., Data Collection or Processing: G.K.Ü., Analysis or Interpretation: H.O.Ş., G.K.Ü., Literature Search: H.O.Ş., G.K.Ü., Writing: H.O.Ş., G.K.Ü., Critical Review: H.O.Ş.

Conflict of interest: The authors declare that they have no conflict of interest.

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