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Guided vs. conventional surgery for anterior maxillary implants: does experience still matter? – An in vitro study

Cirurgia guiada x convencional para implantes na região anterior da maxila: a experiência ainda importa? – Estudo in vitro

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ABSTRACT

Objective: To evaluate the accuracy of immediate implant placement in the anterior maxilla, comparing guided and conventional surgical methods according to operator expertise. **Material and Methods:** Twenty operators participated: ten used guided techniques and ten used conventional approaches, all in the region of teeth 12 and 22. Cases were randomly assigned to four groups: experienced–guided (EG), experienced–conventional (EC), inexperienced–guided (IG), and inexperienced–conventional (IC), with ten implants in each group (40 implants total). Standardized training models were scanned with cone beam computed tomography (CBCT) for virtual planning and surgical guide fabrication using coDiagnostiX® software. After implant placement, new CBCT scans were obtained. Virtual planning and postoperative scans were superimposed to assess accuracy, measuring global (3D), angular, and linear deviations in mesiodistal (MD), buccolingual (BL), and apicocoronal (AC) dimensions. **Results:** Among experienced operators, guided surgery showed significantly lower angular and linear deviations at the platform and apex in 3D, MD, and BL measurements. In inexperienced operators, similar advantages were observed for guided surgery in BL and in 3D and MD deviations at the apex. Overall, guided surgery consistently achieved greater accuracy, regardless of operator experience. **Conclusion:** Guided surgery demonstrated greater accuracy than conventional surgery for immediate implant placement in the anterior maxilla, regardless of operator experience, highlighting its potential to enhance surgical precision and clinical outcomes.

KEYWORDS

Accuracy; Dental implants; Digital technology; Guided surgery; Mouth rehabilitation.

RESUMO

Objetivo: Avaliar a acurácia da instalação imediata de implantes na região anterior da maxila, comparando as técnicas cirúrgicas guiada e convencional de acordo com a experiência do operador. **Material e Métodos:** Participaram 20 operadores: dez utilizaram a técnica guiada e dez a técnica convencional, todos atuando na região dos dentes 12 e 22. Os casos foram distribuídos aleatoriamente em quatro grupos: experiente–guiada (EG), experiente–convencional (EC), inexperiente–guiada (IG) e inexperiente–convencional (IC), com dez implantes em cada grupo (total de 40 implantes). Modelos padronizados foram submetidos à tomografia computadorizada de feixe cônico (TCFC) para o planejamento virtual e confecção dos guias cirúrgicos no software CoDiagnostiX®. Após a instalação dos implantes, novas TCFC foram obtidas. As imagens do planejamento e do pós-operatório foram sobrepostas para avaliar a acurácia, mensurando desvios globais (3D), angulares e lineares nas dimensões mésio-distal (MD), vestíbulo-lingual (BL) e ápico-coronal (AC). **Resultados:** Entre os operadores experientes, a cirurgia guiada apresentou desvios angulares e lineares significativamente menores na plataforma e no ápice nas medidas 3D, MD e BL. Entre os operadores inexperientes, vantagens semelhantes foram observadas na dimensão BL e nos desvios 3D e MD no ápice. De forma geral, a cirurgia guiada demonstrou maior acurácia, independentemente da experiência do operador. **Conclusão:** A cirurgia guiada apresentou maior acurácia que a cirurgia convencional na instalação imediata de implantes na região anterior da maxila, independentemente da experiência do operador, destacando seu potencial para aumentar a precisão cirúrgica e contribuir para melhores resultados clínicos.

PALAVRAS-CHAVE

Implantes dentários; Cirurgia guiada; Acurácia; Reabilitação bucal; Tecnologia digital.

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INTRODUCTION

There has been significant advancement in the field of Implantology, particularly regarding the ability to plan and execute guided surgeries. This progress has ushered in a new era of rehabilitative treatments characterized by enhanced precision, speed, and predictability. The digital visualization of the optimal implant placement, aligned with anatomical considerations and the desired final prosthetic outcome, supports professionals in decision-making prior to surgery, helping to prevent complications and streamline treatment procedures [1-4].

The static modality is a widely used approach, in which cone beam computed tomography images (CBCT-DICOM) and Standard Tessellation Language (STL) files derived from intraoral or extraoral scans are imported into specialized software, enabling the reconstruction of dental anatomy, including both soft and hard tissues. This digital integration makes it possible to perform virtual 3D planning of the optimal implant position. Subsequently, a surgical guide is fabricated through 3D printing [4,5].

Although scientific evidence supports that static guided surgery is a safe and efficient approach to improve implant positioning, and consequently treatment outcomes and patient satisfaction, it is imperative to acknowledge that operator experience can still represent a limiting factor. Moreover, the learning curve for achieving proficiency in these techniques can be considerable [6,7].

The anterior region of the maxilla presents unique challenges for implant placement due to its high esthetic demands, reduced bone volume in certain cases, and the proximity of anatomical structures. Even minor deviations in implant positioning can compromise both function and esthetics, directly impacting patient satisfaction. For these reasons, accuracy in this region is of paramount importance, making it an ideal scenario to assess the potential of guided surgery to minimize deviations and standardize clinical results across operators with different levels of experience.

Since the application of static guided surgery holds the potential to enable accurate implant placement irrespective of the operator's level of experience, the aim of this study was to evaluate the accuracy of immediate implant placement in the anterior maxilla using either guided or conventional surgery, performed by operators with varying degrees of expertise.

MATERIAL AND METHODS

Ten inexperienced surgeons (with less than 3 years of experience in Implantology) and 10 experienced surgeons installed both guided and conventional implants in the regions corresponding to teeth number 12 and number 22 using standardized models. The sample size calculation was performed based on a collection of literature data to estimate the standard deviation and detect the minimum difference, considering a significance level of 5% (α=0.05) and a β-error of 20%. The operators provided their consent to participate in the study through the authorization obtained from the TCLE, and the study was conducted at the premises of the Science and Technology Institute of UNESP, São José dos Campos campus. The study received approval from the ethics and research committee, with CAAE: 48570421.5.0000.0077 and opinion No. 5,006,584.

The models were obtained from a standardized dental manikin (MOM, Marília, São Paulo, Brazil), in which teeth number 12 and number 22 were removed for later scanning with iTero® Scanner (California, USA). New models were obtained from the Meshmixer software scan files on a 16 mm base with the alveoli referring to teeth number 12 and number 22 for exporting the STL file and 3D printing. The positioning on the platform and the slicing of the file for 3D printing in Anycubic Photon S resin (Shenzhen, China) was performed with Chitubox Software (Guangdong, China) The models were solid, made of beige resin (Anycubic, Shenzhen, China), washed with isopropyl alcohol at 99.5% for 3 minutes according to the manufacturer's recommendations and placed in a curing chamber with UV light 405 nm 40 W for 60 minutes. A model was submitted to cone beam tomography by Planmeca Promax 3D® tomographer (Planmeca, Helsink, Finland) with the following configuration: 90 Kv, 10 mA, 13.9 seconds of exposure, 0.4 voxel, generating a DICOM file for export to virtual planning software.

To carry out the digital planning the coDiagnostiX® software (DentalWings, Montreal, Canada) was used in which the images from the STL file were superimposed by the DICOM file of the TCFC of the resin model. Implants were planned on the region of tooth 12 and 22 and surgical guides were generated for 3D printing on Anycubic® printer (Shenzhen, China) with transparent Cosmos resin (Pelotas, Brazil) and the washers were manually fitted.

The entire process of pre-planning, virtual planning, guides printing and washers placing were performed by the same investigator.

Dentists participating in the research received information about the virtual planning performed with access to all information and images, as well as the guided implant system to be used. The region where the implants were installed on a guided or freehand way was randomly defined by the Excel software (Microsoft, Redmont, WA, USA). The models were fixed on the articulated bases of the standardized dental manikin (MOM, Marília, SP, Brazil) fitted on the head so that the scenario was as close as possible to the clinical situation. Four groups were composed of 10 samples: experienced and guided (EG), experienced and conventional (EC), inexperienced and guided (IG) and inexperienced and conventional (IC) (Figure 1).

Strong model, morse taper implants measuring 3.5 mm in diameter and 13 mm in length (SIN® Implantes, São Paulo, Brazil) were installed ending with manual ratchet. A specific milling system indicated by the manufacturer was used for the implants installed in a guided manner.

The models containing the implants underwent CBCT scanning (Planmeca Promax 3D®), and the resulting DICOM files were superimposed with the virtual planning using coDiagnostiX® software. Accuracy analysis included angular and linear deviations between planned and placed implant positions.

Linear deviations were measured at both implant platform and apex levels in mesiodistal (MD), buccolingual (BL), and apicocoronal (AC) directions. Three-dimensional deviations (P-3D and A-3D) represented the global spatial discrepancy between planned and placed implant positions at platform and apex levels. Angular deviation was calculated as the angle between the long axes of planned and placed implants.

Three dental cusps were used as reference points for image superimposition. Deviations were calculated using distal surfaces of teeth 11 and 21, mesial surfaces of teeth 13 and 23, and alveolar crest height as reference landmarks (Figure 2).

The evaluator responsible for superimposing the images of implants installed as planned for each sample had no information about the surgeon and the way the implant was installed (guided or freehand) and all the cases were identified only numerically. The data obtained were tabulated and submitted to statistical analysis by two-factor ANOVA test.



Figure 1 - Sample groups.

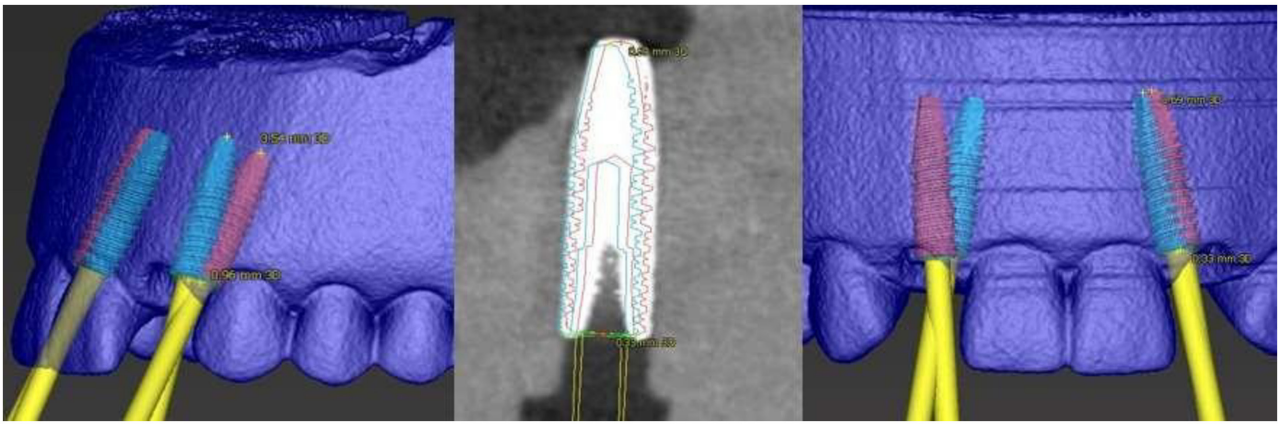


Figure 2 - coDiagnostiX® software images representing the superimposed image of the installed implant (red) and the planned implant (blue).

RESULTS

After implant placement, CBCT scans were obtained and superimposed with virtual planning data using coDiagnostiX® software. Accuracy measurements were then calculated for angular and linear deviations (Figure 3).

Overall, guided surgery demonstrated lower deviations than conventional surgery in both experienced and inexperienced operators. Smaller deviations were particularly observed at platform and apex levels in mesiodistal and buccolingual directions, indicating greater positional accuracy with the guided approach (Figures 4 and 5).

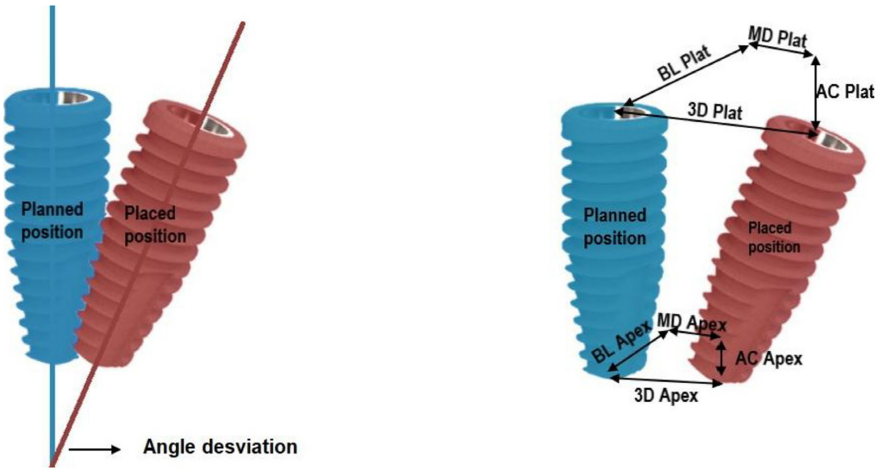


Figure 3 - Representation of angular deviation and linear deviations at platform and apex levels. P-3D = platform three-dimensional deviation; P-MD = platform mesiodistal deviation; P-BL = platform buccolingual deviation; P-AC = platform apicocoronal deviation; A-3D = apex three-dimensional deviation; A-MD = apex mesiodistal deviation; A-BL = apex buccolingual deviation; A-AC = apex apicocoronal deviation. Adapted from reference: Accuracy of implant position when placed using static computer-assisted implant surgical guides manufactured with two different optical scanning techniques: a randomized clinical trial, from P. Kiatkroekkrai et. al, 2020.

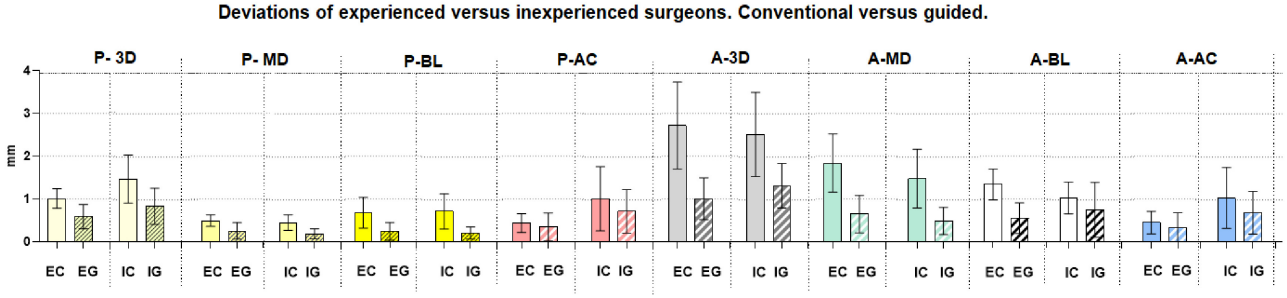


Figure 4 - Graph of means and standard deviation (P-3D = platform three-dimensional deviation; P-MD = platform mesiodistal deviation; P-BL = platform buccolingual deviation; P-AC = platform apicocoronal deviation; A-3D = apex threedimensional deviation; A-MD = apex mesiodistal deviation; A-BL = apex buccolingual deviation; A-AC = apex apicocoronal deviation), related to variables evaluated (EC = experienced conventional; EG = experienced guided; IC = inexperienced conventional; IG = inexperienced guided).

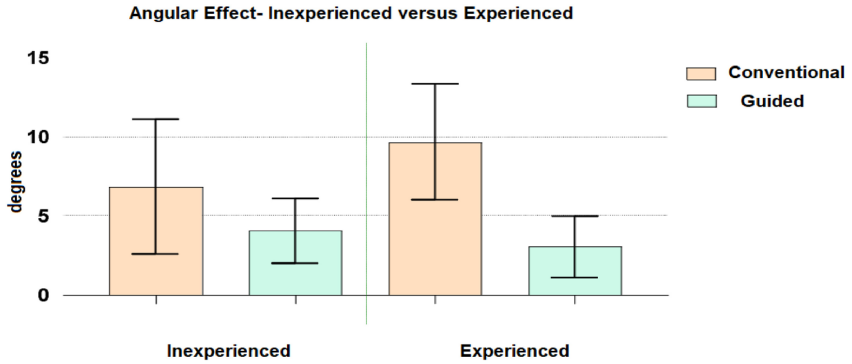


Figure 5 - Angular deviation according to surgical technique and operator experience.

Statistical comparisons were performed considering two perspectives: (1) experienced versus inexperienced operators within the same surgical approach (Table I) and (2) guided versus conventional surgery within the same experience level (Table II).

Table I - Comparison between conventional and guided techniques according to operator experience (experienced and inexperienced)

	Experienced Conventional	Experienced Guided	Inexperienced Conventional	Inexperienced Guided
Angle 3D°	9.67(3.67)	3.04(1.943)	6.85(4.25)	4.05(2.039)
	p=0.0001*		p=0.1047	
P-3Dmm	1.012(0.232)	0.581(0.284)	1.485(0.565)	0.849(0.427)
	p=0.0413*		p=0.0021*	
P-MDmm	0.492(0.136)	0.253(0.193)	0.459(0.186)	0.199(0.12)
	p=0.0042*		p=0.0019*	
P-BLmm	0.681(0.361)	0.243(0.206)	0.728(0.415)	0.218(0.142)
	p=0.0051*		p=0.0012*	
P-ACmm	0.433(0.221)	0.344(0.328)	1.022(0.757)	0.727(0.515)
	p=0.9053		p=0.351	
A-3D mm	2.716(1.019)	1.005(0.49)	2.514(0.971)	1.327(0.524)
	p=0.0001*		p=0.0037*	
A-MD mm	1.841(0.679)	0.645(0.439)	1.496(0.691)	0.5(0.322)
	p=0.0001*		p=0.0006*	
A-BL mm	1.341(0.359)	0.549(0.358)	1.043(0.376)	0.767(0.644)
	p=0.0007*		p=0.3266	
A-AC mm	0.447(0.265)	0.334(0.344)	1.042(0.715)	0.693(0.504)
	p=0.8463		p=0.2233	

p<0.05. *Statistically significant.

Table II - Comparison between guided and conventional surgery within experienced and inexperienced operators. p values compare guided versus conventional surgery within the same experience level

	Conventional Experienced	Conventional Inexperienced	Guided Experienced	Guided Inexperienced
Angle 3D°	9.67(3.67)	6.85(4.25)	3.04(1.943)	4.05(2.039)
	p=0.1016		p=0.7261	
P-3Dmm	1.012(0.232)	1.485(0.565)	0.581(0.284)	0.849(0.427)
	p=0.0235*		p=0.2634	
P-MDmm	0.492(0.136)	0.459(0.186)	0.253(0.193)	0.199(0.12)
	p=0.8714		p=0.7089	
P-BLmm	0.681(0.361)	0.728(0.415)	0.243(0.206)	0.218(0.142)
	p=0.9272		p=0.9788	
P-ACmm	0.433(0.221)	1.022(0.757)	0.344(0.328)	0.727(0.515)
	p=0.0242*		p=0.1803	
A-3D mm	2.716(1.019)	2.514(0.971)	1.005(0.49)	1.327(0.524)
	p=0.8160		P=0.6008	
A-MD mm	1.841(0.679)	1.496(0.691)	0.645(0.439)	0.5(0.322)
	p=0.3172		p=0.3172	
A-BL mm	1.341(0.359)	1.043(0.376)	0.549(0.358)	0.767(0.644)
	p=0.2741		p=0.4911	
A-AC mm	0.447(0.265)	1.042(0.715)	0.334(0.344)	0.693(0.504)
	p=0.0196*		p=0.2058	

p<0.05. *Statistically significant.

When comparing experienced and inexperienced operators within the same surgical approach, no statistically significant differences were observed for guided surgery. Conversely, conventional surgery demonstrated significant differences in P-3D, P-AC and A-AC deviations. These findings suggest that guided surgery may reduce the influence of operator experience on implant positioning accuracy.

Among experienced operators, guided surgery resulted in significantly lower deviations than conventional surgery for angular deviation, P-3D, P-MD, P-BL, A-3D, A-MD and A-BL measurements ($p<0.05$). Among inexperienced operators, guided surgery also showed significantly lower deviations for P-3D, P-MD, P-BL, A-3D and A-MD ($p<0.05$).

DISCUSSION

The learning curve of professionals who perform implant surgeries can take a few years as it requires clinical accumulated experience through practice leading to unsatisfactory outcomes. The virtual planning of implants to be placed and the subsequent implementation of this plan in the clinical setting through the production of a surgical guide using additive manufacturing can greatly shorten the learning curve for novice professionals and reduce the occurrence of treatment failures. Furthermore, this approach can improve predictability, minimize complications, and yield superior outcomes, even for highly experienced dentists. Ensuring the proper placement of an implant with a focus on restoration-oriented criteria offers significant long-term benefits, guaranteeing favorable aesthetics, functionality, optimal occlusion, and effective implant loading [6-9].

Digital planning makes feasible to simulate future dental prosthesis, improving the three-dimensional orientation of the implants, combined with the superimposition of the images of the prosthesis and the bone ridge, which enables the evaluation of the implant emergence profile and avoid relevant angulation errors to the prosthetic execution, that can compromise the result [6,10-15].

The maximum horizontal deviation could be 1.3 mm for the platform implant and 2.4 mm for the apex implant, justifying the deviations found in the literature [4]. Linear and angular deviations of up to 2° are not clinically significant and are considered acceptable, safe, and accurate [6,14,15]. There are linear deviations that are fixed on the surgical guide in a range of 0.07-0.38 mm and angular of 0.4 º to 3.3º and greater errors seem to occur during the surgical procedure, such as inadequate positioning of the surgical guide [3]. This angulation can justify the angular and linear deviations in the positioning of the implant installed when compared to the planned one.

Significant statistical differences were observed in the group of inexperienced operators in 5 measurements: in the deviations of three-dimensional platform, mesiodistal platform, vestibule palatine platform, three-dimensional apex, mesiodistal apex. In another study [9], the authors obtained significant differences in 2 measurements, being the apical linear at the vestibule-palatal direction with 1.62 mm (± 0.62) of deviation with conventional surgical guide and 1.21 mm (±0.46), for static guided surgery and in the angular deviation. In the lingual vestibule, the mean was 6.42º (±4.21) and on surgery with a conventional guide it was 3.35º (±1.65).

There were no statistically significant differences for the group of inexperienced surgeons in the global deviation: freehand of 6.85º (±4.25) and guided of 4.05º (±2.03), at the platform and apex at the vertical direction (coronal apex) and at the apex at the vestibule-palatal direction. Other studies have also reported statistically significant differences between the types of surgeries, with lower vertical deviations [3]. The authors reported improvements in angular deviations on freehand cases with a mean of 4.79º (±2.08) and on guided surgery of 2.42º (±0.98); horizontal apex deviations of 1.12 mm on freehand surgery (±0.71) and on guided surgery of 0.71 mm (±0.24) and at horizontal platform deviations on freehand surgery of 0.79 mm (±0.26), on guided surgery of 0.47 mm (± 0.25) and highlight that these deviations are within the recommendations of up to 2 mm for linear and 2.5º for angular.

In the group of experienced guided operators could be observed a 3D platform deviation of 0.58 mm (±0.28), mean apical deviation of 1.00 mm (±0.49) and angular deviation of 3.04º (±1.9). Other authors also presented 3D platform deviation of 0.75 mm (±0.18), the mean apical deviation was 1.02 mm (±0.44), and the mean angular deviation was 3.07º (±2.70).

It was concluded that the performance with guided surgery was better only in the angular deviation [10]. Experienced surgeons in the guided group had better results in angular deviation with guided surgery compared to conventional surgery, as well as in linear deviations. The smallest deviations were the vertical ones, with no significant differences. Other authors also did not observe significant differences in vertical deviations in the group of experienced surgeons [10,11].

Significant differences were found in the experienced operators group when comparing guided and freehand surgery, in 7 parameters, namely: angular deviation (p=0.0001), 3D platform linear deviation (p=0.0413), 3D implant platform of 0.58 mm on guided and 1.01 mm on freehand, MD platform (p=0.0042), BL platform (p=0.0051), 3D apex (p=0.0001), at the 3D implant apex deviation of 1.00 mm on guided surgery and 2.71 mm on freehand, apex MD (p=0.0001), apex BL (p=0.0007). In a randomized controlled clinical study [5], significant statistical differences were found in 6 of the 9 parameters, namely: angular deviation (p=0.001), 3D platform linear deviation (p=0.001), towards the 3D platform of implant the authors reported 0.9 mm deviations on guided surgery and 1.2 mm on freehand, at the MD platform (p=0.001), AC platform (p=0.43), 3D apex (p=0.001), at the 3D implant apex on guided surgery the deviation was 1.3 mm and 2.2 mm on freehand, apex MD (p=0.001), global deviation on guided surgery was 2.8º and 7º on freehand, resulting in a deviation of 9.67º in experienced surgeons with a decrease to 3.04°on guided surgery.

Some factors that may explain the differences would be the limitation for being an in vitro study and the implant placement region. Since it was on the anterior of the maxilla visualization could be considered facilitated. Additionally, the mouth opening degree may be greater with the use of a dummy without movement and absence of fluids such as saliva and blood, which may also have contributed to some differences.

Significant differences were observed in angular deviations which were higher for experienced operators with a mean of 3.04° on guided surgery and 9.67° for freehand. Contrary to these results, other authors did not find statistically significant differences in the group of experienced operators for angular deviation with guided surgery [7,12].

On freehand surgery, significant differences were obtained between the experienced and inexperienced groups in 3 linear deviations: towards the three-dimensional platform (P-3D), coronal apical platform (P-AC), and apical (A-AC). These differences show that experience makes a difference on conventional surgery, and an advantage of guided surgery would shorten the learning curve for inexperienced surgeons and bring the results closer to those obtained by an experienced surgeon.

Therefore, experienced operators obtained greater global implant deviations on freehand group. Only significant differences were not observed in the coronal apical direction. There is the possibility that experienced surgeons decrease the accuracy in relation to the planning due to less caution because they have practiced the technique for many years while inexperienced surgeons demonstrate smaller deviations, possibly because they are more cautious with the guide being an important tool for reducing unwanted angulations in implants that will be installed.

There are different study methodologies to evaluate the positioning of the installed implant in relation to the planned one, such as in vitro, in vivo, or cadaveric studies. In vitro studies showed smaller deviations than in vivo and cadaveric studies in apical horizontal and angular directions [8]. However, in all methodologies studied, fully guided surgery achieved greater precision than partially guided and freehand surgery [3,5,7,8,10-15].

CONCLUSION

According to the results obtained and considering the limitations of the present study, it can be concluded that the implant position accuracy placed by guided surgery was higher compared to the conventional approach, regardless of the operator's degree of experience.

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Data availability

Research data is only available upon request.

Author's Contributions

TCP, ALG: Investigation. MBM, FVA: Project Administration. GSFAS, RDN: Supervision. TCP: Writing – Original Draft Preparation.

Conflict of Interest

No conflicts of interest declared concerning the publication of this article.

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Regulatory Statement

The operators provided their consent to participate in the study through the authorization obtained from the TCLE, and the study was conducted at the premises of the Science and Technology Institute of UNESP, São José dos Campos campus. The study received approval from the ethics and research committee, with CAAE: 48570421.5.0000.0077 and opinion No. 5,006,584.

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