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EVALUATION OF THE ACCURACY AND PRECISION OF TWO STATIC COMPUTER-ASSISTED GUIDED SURGERY SYSTEMS: AN IN VITRO EXPERIMENTAL STUDY

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ABSTRACT

Computer-guided surgery is an established technique in dentistry, with current research focusing on optimizing the three-dimensional positioning of implants to achieve superior esthetic and functional outcomes. The precision of implant placement is a critical factor for long-term success. This study aimed to compare the accuracy of two static guided surgery systems that differ primarily in their drill-guiding method, in an in vitro laboratory simulation. For the study, a mandibular arch model with four missing premolars was created. The surgery was planned using virtual planning software after acquiring images via cone-beam computed tomography and scanning the model. Twenty implants were placed in five models, with ten implants for each system evaluated. Group 1 utilized a system with a guide sleeve and a handle to direct the drills, while Group 2 used a system where the drills were guided directly by the sleeve, without the use of a handle. The final position of the implants was measured by scanning the models after placement and superimposing them with the virtual plan using metrology software. The mean deviations for Group 1 were 0.308 mm (mesio-distal), 0.361 mm (vestibulo-lingual), and 0.449 mm (vertical). The mean deviations observed in Group 2 were 0.119 mm (mesio-distal), 0.398 mm (vestibulo-lingual), and 0.342 mm (vertical). Although both systems demonstrated accuracy compatible with established clinical standards, a statistically significant difference in the mesio-distal deviation ($p = 0.006$) favored the system without a handle, suggesting that its design may contribute to greater implant positional stability. No statistically significant differences were observed in the vestibulo-lingual and vertical deviations. In conclusion, while both systems demonstrate high accuracy and are clinically acceptable, the static guided surgery system without a handle offers a significant advantage in the precision of mesio-distal implant positioning.

Keywords: Computer-Aided Design. Surgery. Computer-Assisted. Patient Care Planning. Surgical Templates. Imaging. Three-Dimensional.

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AVALIAÇÃO DA EXATIDÃO E PRECISÃO DE DOIS SISTEMAS ESTÁTICOS DE CIRURGIA GUIADA POR COMPUTADOR: UM ESTUDO EXPERIMENTAL IN VITRO

RESUMO
A cirurgia guiada por computador é uma técnica estabelecida em odontologia, com pesquisas atuais focadas na otimização do posicionamento tridimensional de implantes para alcançar resultados estéticos e funcionais superiores. A precisão da colocação do implante é um fator crítico para o sucesso a longo prazo. Este estudo teve como objetivo comparar a precisão de dois sistemas de cirurgia guiada estática que diferem principalmente em seu método de guiamento por broca, em uma simulação laboratorial in vitro. Para o estudo, foi criado um modelo de arco mandibular com quatro pré-molares ausentes. A cirurgia foi planejada usando um software de planejamento virtual após a aquisição de imagens por tomografia computadorizada de feixe cônico e escaneamento do modelo. Vinte implantes foram colocados em cinco modelos, com dez implantes para cada sistema avaliado. O Grupo 1 utilizou um sistema com uma luva-guia e uma alça para direcionar as brocas, enquanto o Grupo 2 utilizou um sistema em que as brocas eram guiadas diretamente pela luva, sem o uso de uma alça. A posição final dos implantes foi medida escaneando os modelos após a colocação e sobrepondo-os ao plano virtual usando um software de metrologia. Os desvios médios para o Grupo 1 foram de 0,308 mm (mésio-distal), 0,361 mm (vestíbulo-lingual) e 0,449 mm (vertical). Os desvios médios observados no Grupo 2 foram de 0,119 mm (mésio-distal), 0,398 mm (vestíbulo-lingual) e 0,342 mm (vertical). Embora ambos os sistemas tenham demonstrado acurácia compatível com os padrões clínicos estabelecidos, uma diferença estatisticamente significativa no desvio mésio-distal (p = 0,006) favoreceu o sistema sem alça, sugerindo que seu design pode contribuir para uma maior estabilidade posicional do implante. Não foram observadas diferenças estatisticamente significativas nos desvios vestíbulo-lingual e vertical. Em conclusão, embora ambos os sistemas demonstrem alta acurácia e sejam clinicamente aceitáveis, o sistema de cirurgia guiada estática sem alça oferece uma vantagem significativa na precisão do posicionamento mésio-distal do implante.

Palavras-chave: Desenho Assistido por Computador. Cirurgia. Assistida por Computador. Planejamento de Cuidados ao Paciente. Templates Cirúrgicos. Imagem. Tridimensional.

EVALUACIÓN DE LA EXACTITUD Y PRECISIÓN DE DOS SISTEMAS DE CIRUGÍA GUIADA ASISTIDA POR COMPUTADORA ESTÁTICA: UN ESTUDIO EXPERIMENTAL IN VITRO

RESUMEN
La cirugía guiada por computadora es una técnica consolidada en odontología, y la investigación actual se centra en optimizar el posicionamiento tridimensional de los implantes para lograr resultados estéticos y funcionales superiores. La precisión en la colocación de los implantes es un factor crucial para el éxito a largo plazo. Este estudio tuvo como objetivo comparar la precisión de dos sistemas de cirugía guiada estática, que difieren principalmente en su método de guía de fresado, en una simulación de laboratorio in vitro. Para el estudio, se creó un modelo de arcada mandibular con cuatro premolares ausentes. La cirugía se planificó mediante un software de planificación virtual tras adquirir imágenes mediante tomografía computarizada de haz cónico y escanear el modelo. Se colocaron veinte implantes en cinco modelos, con diez implantes por cada sistema evaluado. El Grupo 1 utilizó un sistema con una vaina guía y un mango para dirigir las fresas, mientras que el Grupo 2

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utilizó un sistema donde las fresas fueron guiadas directamente por la vaina, sin el uso de un mango. La posición final de los implantes se midió escaneando los modelos tras su colocación y superponiéndolos con el plano virtual mediante un software de metrología. Las desviaciones medias del Grupo 1 fueron de 0,308 mm (mesiodistal), 0,361 mm (vestibulolingual) y 0,449 mm (vertical). Las desviaciones medias observadas en el Grupo 2 fueron de 0,119 mm (mesiodistal), 0,398 mm (vestibulolingual) y 0,342 mm (vertical). Si bien ambos sistemas demostraron una precisión compatible con los estándares clínicos establecidos, una diferencia estadísticamente significativa en la desviación mesiodistal (p = 0,006) favoreció al sistema sin mango, lo que sugiere que su diseño podría contribuir a una mayor estabilidad posicional del implante. No se observaron diferencias estadísticamente significativas en las desviaciones vestibulolingual y vertical. En conclusión, si bien ambos sistemas demuestran una alta precisión y son clínicamente aceptables, el sistema de cirugía guiada estática sin mango ofrece una ventaja significativa en la precisión del posicionamiento mesiodistal del implante.

Palabras clave: Diseño Asistido por Computadora. Cirugía. Cirugía Asistida por Computadora. Planificación de la Atención al Paciente. Plantillas Quirúrgicas. Imágenes. Tridimensionales.

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1 INTRODUCTION

Modern implantology has evolved into a predictable and highly successful treatment for tooth replacement. With the high success rate of osseointegration, the focus of current research has shifted to the optimal three-dimensional positioning of implants. Correct placement is a fundamental prerequisite for achieving ideal aesthetic outcomes and the long-term success of implant-supported prostheses (Abu Alfaraj et al., 2023).

Static Computer-Aided Implant Surgery (sCAIS) has demonstrated greater **precision** in implant placement compared to conventional freehand techniques. The ability to visualize and refine implant positions in a pre-surgical virtual environment improves the evaluation and optimal placement relative to vital anatomical structures, tissues, and the planned final prosthesis. However, transferring the virtually planned position to the surgical site is a critical step, and accuracy is defined as the deviation between the planned position and the final implant position (Lee et al., 2016; Tahmaseb et al., 2018).

The accuracy of sCAIS can be affected by variables that result in inaccuracies, and these variables are still largely unknown. Laederach et al. (2017) highlighted that overall accuracy depends on the sum of individual errors at each stage of the protocol, from radiographic assessment to surgical implant placement. These errors can be caused by incorrect image acquisition and processing, surgical guide fabrication, improper guide positioning, and mechanical errors during drilling (Laederach et al., 2017).

The literature describes a variety of guided surgery systems with different mechanisms for orienting drills. Guentsch et al. (2023) classified the systems into five configurations, including the system with a guide sleeve and a drill key (handle) and the system with a mounted drill sleeve that eliminates the need for a handle. This latter system, by dispensing with the handle, offers the operator more freedom and reduces the complexity of the surgery (Guentsch et al., 2023).

Although static guided implant surgery is widely accepted, the literature still lacks direct comparative studies evaluating the impact of drilling system design on the **accuracy** of implant placement. One of the main variations among available systems is the presence or absence of an intermediary, such as a handle or drill key, to guide the drill. This design difference may influence not only surgical precision but also the ergonomics and predictability of the procedure (Ballesteros et al., 2025).

Given this gap, the present study aims to investigate, through a laboratory simulation model, the differences in accuracy between two surgical guide systems that incorporate

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distinct design principles. By comparing the final implant position with the virtual plan, we seek to provide objective evidence on the role of guide design in the three-dimensional precision of the procedure, contributing to more informed clinical decisions in system selection.

2 METHODS

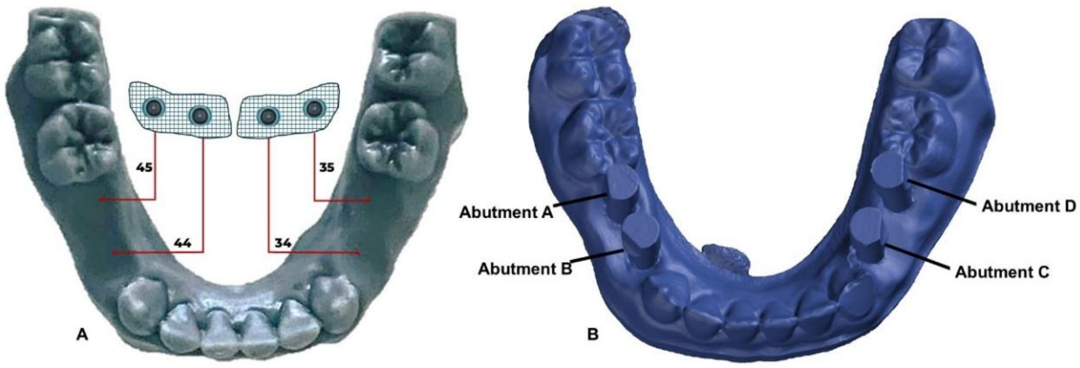
The present *in vitro* experimental study was designed to compare the precision of two static computer-aided implant surgery (sCAIS) systems with distinct surgical guide designs. A model of an edentulous mandibular arch, missing the second premolars (elements 34 and 44) and first molars (elements 35 and 45), was digitally designed and fabricated by 3D printing (XYZprinting da Vinci Pro 1.0 Printer, XYZprinting Inc., Taiwan).

2.1 VIRTUAL PLANNING

Surgical planning was performed using EXOPLAN v3.0 software (EXOCAD GmbH, Germany). For data fusion, a computed tomography (CT) scan and a scan of the printed model were used. Four Master Torq Morse taper implants (Conexão Sistemas de Prótese Ltda., Brazil) were virtually positioned in the edentulous areas, with their ideal position and angulation defined. The sleeve from the Sensitive system (Conexão Sistemas de Prótese Ltda., Brazil) was selected, and the surgical guide planning was based on the orientation of the implant's prosthetic hexagon.

Figure 1

A) Three-dimensional representation of the edentulous mandible model with the identification of implant abutments (A, B, C, and D) planned for guided surgery. B) Illustration of the fusion of the computed tomography scan with the model scan, demonstrating the ideal positioning of the implants and the surgical guide design.



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2.2 EXPERIMENT PREPARATION

Five identical models were printed for the installation of implant analogs, totaling 20 implants. The sample size was determined based on previous studies where 10 samples per group are considered adequate for precision analysis.

The models were allocated to two groups via simple randomization with a sequence generated by software (Random.org). The allocation was carried out by an independent researcher not involved in the execution of the experiment:

- **Group 1:** Used the Sensitive guide system with a guide sleeve (Conexão Sistemas de Prótese Ltda., Brazil) and a "handle" (drill key), part of the Speed Guide surgical kit (Conexão Sistemas de Prótese Ltda., Brazil).
- **Group 2:** Used the system that does not require a "handle," where the drills fit directly into the Sensitive sleeve, part of the ExpertGuide surgical kit (Conexão Sistemas de Prótese Ltda., Brazil).

All procedures were performed by two previously calibrated operators. Calibration consisted of three training sessions with pilot models until inter-operator variation was less than 0.1 mm in repeated measurements.

2.3 ACCURACY ANALYSIS

After the implants were installed in the models, scan bodies were attached. The final position of the implants was recorded with an Omnicam intraoral scanner (Dentsply Sirona, USA, version 5.2.2), generating STL mesh files.

The accuracy analysis was conducted using GOM Inspect Pro v2022 metrology software (Carl Zeiss GOM Metrology GmbH, Germany). The planned three-dimensional position (initial STL model) was superimposed on the position obtained after implant installation (final STL model) using a best-fit alignment. Deviations were measured along three axes: mesio-distal (LY), vestibulo-lingual (LX), and vertical (LZ).

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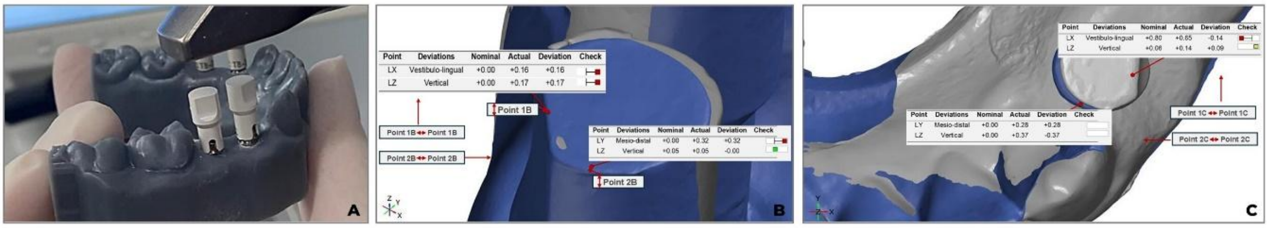
Figure 2

A) Three-dimensional representation of the edentulous mandible model with the identification of implant abutments (A, B, C, and D) planned for guided surgery. B) Illustration of the fusion of the computed tomography scan with the model scan, demonstrating the ideal positioning of the implants and the surgical guide design.



Source: Authors.

3 RESULTS

The analysis of the positional accuracy of the implants was conducted in an *in vitro* model to compare two guided surgery systems. The means and standard deviations of the linear, vestibulo-lingual, vertical, and mesio-distal deviations for Group 1 (system with handle) and Group 2 (system without handle) are presented in Table 1.

Table 1

Means, standard deviations, and p-values for linear deviations between the groups

Variables	Group 1 (mean±SD)	Group 2 (mean±SD)	*p*
Vestibulo-lingual Deviation (mm)	0.36±0.27	0.40±0.15	*0.227*
Vertical Deviation (mm)	0.45±0.37	0.34±0.22	*0.118*
Mesio-distal Deviation (mm)	0.31±0.17	0.12±0.09	*0.067*

Note. Group 1 (System with Handle) and Group 2 (System without Handle)
Source: Authors.

The normality of the data was confirmed by the Shapiro-Wilk test, with p>0.05 for all variables. The comparison between the groups was performed using Student's t-test for independent samples, as shown in Table 2.

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Table 2

Student's t-test for comparison of linear deviations

Variables	Statistic	gl	p
Vestibulo-lingual Deviation (mm)	t (0.382)	18.0	*0.707*
Vertical Deviation (mm)	t (-0.790)	18.0	*0.440*
Mesio-distal Deviation (mm)	t (-3.141)	18.0	*0.006*

Nota. H_0: μB ≠ μA. O teste de Levene foi significativo para o desvio mésio-distal ($p < 0.05$), indicando a violação do pressuposto de homogeneidade de variâncias.
Source: Authors.

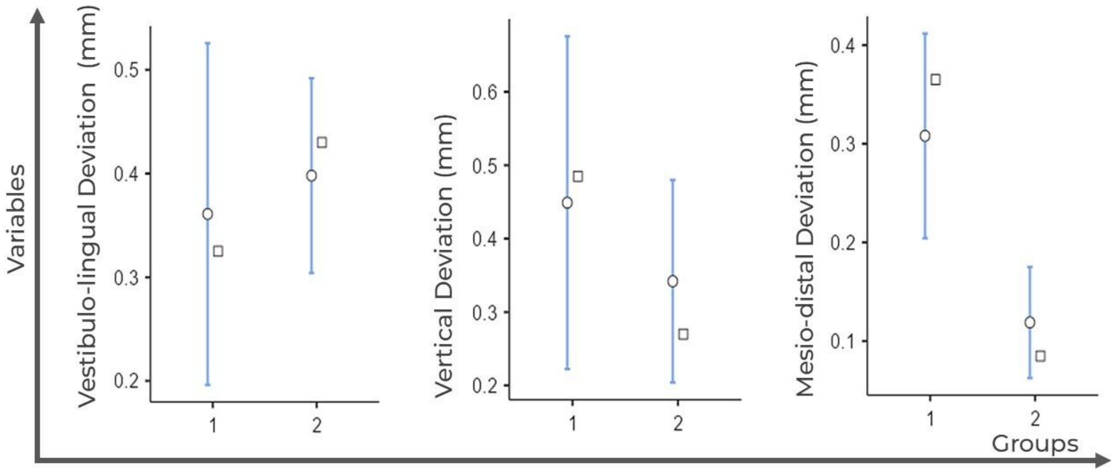
Levene's test indicated a violation of the assumption of equal variances for the mesio-distal deviation (p<0.05), so a corrected t-test for unequal variances was applied.

Statistical analysis revealed a significant difference only for the mesio-distal deviation (p=0.006), which favored the system without a handle (Group 2). No statistically significant differences were observed for the vestibulo-lingual (p=0.707) and vertical (p=0.440) deviations.

These findings are visually represented in Figure 3. The error bars for the mesio-distal deviation do not overlap, corroborating the statistical significance. Conversely, the overlap of the bars in the vertical and vestibulo-lingual deviation plots reinforces the absence of a difference between the groups.

Figure 3

Boxplots comparing linear deviations between the groups with and without a handle. A) Vertical deviation (LZ), B) Vestibulo-lingual deviation (LX), C) Mesio-distal deviation (LY). A statistically significant difference was observed only in the mesio-distal deviation (p = 0.006). No significant difference was observed for the vertical and vestibulo-lingual deviations (p > 0.05).



Source: Authors.

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4 DISCUSSION

The main objective of this study was to evaluate the positional accuracy of implants by comparing two static guided surgery systems from the same manufacturer. The key differentiator was the presence or absence of a handle in the surgical guide's design. This distinction represents a relevant technical variable that's still underexplored in the literature, yet can directly influence the procedure's precision. Recent studies demonstrate that guide design can significantly impact surgical accuracy, especially in static computer-assisted approaches (sCAIS) (El Kholy et al., 2019; Kasradze et al., 2025).

Statistical analysis revealed a significant difference only in the **mesio-distal deviation**. The system without a handle showed less variation (0.12 ± 0.09 mm) compared to the system with a handle (0.31 ± 0.17 mm), as evidenced by the t-test adjusted for unequal variances (p=0.006). On the other hand, the vestibulo-lingual (p=0.707) and vertical (p=0.440) deviations showed no statistically significant differences between the groups. This directional selectivity may be attributed to the handle's configuration, which, by resting on the lateral surfaces of the guide, could induce unwanted micromovements along the mesio-distal axis during drilling. This effect isn't observed in the handle-free protocol. This hypothesis is corroborated by Pattanasirikun et al. (2024), who demonstrated that the sleeve-in-sleeve design shows less angular and linear deviation compared to the sleeve-on-drill, suggesting that minor structural variations can affect positional stability.

Furthermore, El Kholy et al. (2019) showed that the number and location of teeth supporting the surgical guide significantly influence implant accuracy. Guides supported by four teeth demonstrated precision equivalent to that of full-arch guides, while guides with only two teeth showed significantly greater deviations. Additionally, posterior tooth support demonstrated greater stability than anterior tooth support, reinforcing that the geometry and distribution of support are decisive for final precision.

In concordance, Kasradze and Kubilius (2025) demonstrated that the type of guide support, whether by two teeth, four teeth, or a full arch, significantly influences accuracy in different edentulous regions. Guides with reduced support, when well-distributed, showed less three-dimensional and angular deviation, especially in single anterior and posterior areas. These findings reinforce that the guide’s design and configuration, including the presence of intermediaries like handles, can selectively affect the positional stability of the implant (Raabe et al., 2023; Kasradze et al., 2025).

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In absolute terms, the deviations observed in this study are within the clinically acceptable limits described in the literature. Brandt et al. (2018) reported mean deviations of 1.2 mm at the platform and 1.8 mm at the apex in template-guided implants, with variations depending on the residual dentition and the type of surgical approach. The values obtained here, for both systems, are at the lower end of this range, reinforcing the high precision of the evaluated methods, even with the observed statistical difference.

To ensure the validity of the findings, the normality of the data was verified with the Shapiro-Wilk test, and the violation of the homogeneity of variances for the mesio-distal deviation was appropriately handled by applying a Student's t-test with Welch's correction for unequal variances. These measures ensure the validity of the findings and strengthen the reliability of the results, as recommended in methodological studies on guided surgical precision (El Kholy et al., 2019).

Despite the inherent limitations of the *in vitro* model—such as the absence of anatomical variability, soft tissues, and real clinical conditions—this study provides relevant quantitative evidence on the impact of surgical guide design on the positional accuracy of implants. The main finding is that the handle-free system demonstrated superiority in the accuracy of mesio-distal positioning. Studies like that by Huang et al. (2023) reinforce that positional guides can significantly improve precision compared to the freehand technique, even when used only for initial drilling. The findings of El Kholy et al. (2019) also highlight that distal extension situations, where the guide is unilaterally supported, tend to show greater deviations, which reinforces the importance of avoiding structural imbalances in guide design.

The data obtained justify the need for future clinical studies to explore the practical implications of these differences, especially in contexts of high esthetic demand or proximity to critical anatomical structures, which highlight the need for clinical validation of findings obtained from highly standardized *in vitro* models (Huang et al., 2023; Kasradze et al., 2025).

5 CONCLUSION

The study demonstrated that the guided surgery system without a handle is superior to the system with a handle in terms of positional accuracy, specifically for mesio-distal deviation. The choice of surgical guide configuration therefore has a selective impact on implant positioning precision, indicating that the absence of a handle can optimize stability in the mesio-distal plane. No difference was observed between the groups for vestibulo-lingual and vertical deviations.

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