CESPU
INSTITUTO UNIVERSITÁRIO
DE CIÊNCIAS DA SAÚDE

Accuracy between fully guided, half-guided and freehand implant placement on single tooth.

Killian Pierre Serge Furdin

Dissertação conducente ao Grau de Mestre em

Medicina Dentária (Ciclo Integrado)

Gandra, 29 de junho de 2021

CESPU
INSTITUTO UNIVERSITÁRIO
DE CIÊNCIAS DA SAÚDE

Killian Pierre Serge Furdin

Dissertação conducente ao Grau de Mestre em

Medicina Dentária (Ciclo Integrado)

Accuracy between fully guided, half-guided and freehand implant placement on single tooth.

Trabalho realizado sob a Orientação de Mestre Mª Arminda Santos

Declaração de Integridade

Eu, acima identificado, declaro ter atuado com absoluta integridade na elaboração deste trabalho, confirmo que em todo o trabalho conducente à sua elaboração não recorri a qualquer forma de falsificação de resultados ou à prática de plágio (ato pelo qual um indivíduo, mesmo por omissão, assume a autoria do trabalho intelectual pertencente a outrem, na sua totalidade ou em partes dele). Mais declaro que todas as frases que retirei de trabalhos anteriores pertencentes a outros autores foram referenciadas ou redigidas com novas palavras, tendo neste caso colocado a citação da fonte bibliográfica.

CESPU
INSTITUTO UNIVERSITÁRIO
DE CIÊNCIAS DA SAÚDE

Agradecimentos

A minha família, pai, mãe, irmão, avós que me acompanharam ao longo destes cincos anos sem duvidarem de mim. Obrigado pelo seu amor, apoio e confiança infalível. Je vous aime.

Ao meu binomio e melhor amigo, Malek, sempre presente qualquer que seja a situação. Um amigo para toda a vida.

Para minhas amigas e amigos, obrigado por tudo.

Á minha orientadora de tese, Mestre Mª Arminda Santos, obrigado por seu ensino e paciência, fiquei muito feliz por poder trabalhar com a professora.

CESPU
INSTITUTO UNIVERSITÁRIO
DE CIÊNCIAS DA SAÚDE

Resumo

O objetivo deste estudo foi realizar uma revisão integrativa sobre a precisão das técnicas totalmente guiadas, semiguiadas e de mão livre de um dente unitário e determinar qual delas é a mais precisa. Uma busca sistemática da literatura foi realizada na plataforma eletrônica MEDLINE (PubMed), utilizando a combinação dos seguintes termos científicos: Accuracy, Guided surgery, Dental implant, Computer-assisted, Single tooth. O desvio da colocação do implante é o resultado cumulativo de erros que podem ocorrer durante todas as fases dos protocolos. Pode ser um erro de aquisição da tomografia computadorizada de feixe cônico (CBCT) erros esses que podem surgir com movimentos do paciente, artefatos de imagem. Podem ainda estar relacionados com outros fatores tais como o suporte da guia cirúrgico; o tipo de edentulismo ou até mêsmo a experiência do medico dentista. Os estudos selecionados relataram que o desvio angular, o desvio coronal e o desvio apical apresentaram diferenças significativas entre os grupos, apesar da falta de dados de desvio coronal e apical. Em contraste, a precisão do desvio longitudinal não mostrou diferenças significativas. Assim, esta revisão conclui que a cirurgia de colocação de implante totalmente guiada, quando realizada corretamente, tem uma maior precisão que a cirugia parcilamente guiada semdo que a de cirurgia de colocação de implante de mão livre é a que apresenta menor precisão. No entanto, mais estudos serão necessários para comfirmar o que está escrito nos estudos que analisamos.

Palavras-chave: "Accuracy" OR "Accurateness" OR "Exactitude" OR "Efficiency" OR "Certainty" AND "Guided surgery" AND "Dental implant" AND "Computer-assisted" OR "Computer aid" AND "Single tooth" OR "Individual tooth" OR "One tooth" OR "Unique tooth".

Abstract

This study seeks to compare the accuracy of fully guided, half-guided and freehand techniques on single tooth and determine which one is the most accurate. A systematic literature search was conducted on MEDLINE (PubMed) electronic database using a combination of the following terms: accuracy, guided surgery, dental implant, computer-assisted and single tooth. Implant placement deviation is the cumulative result of errors which may possibly occur during all phases of protocols. It can be a cone beam computerized tomography (CBCT) acquisition errors which include patient movement, imaging artifacts or other factors such as surgical guide support related to the type of edentulism or surgeon experience. The selected studies reported that the angle deviation, coronal deviation and apical deviation showed significant differences amongst the groups, and this despite the lack of data for coronal and apical accuracy. In contrast, longitudinal deviation accuracy failed to show significant differences. Thus, this review consequently concludes that fully guided implant navigation surgery has the highest accuracy for transmitting the presurgical positioning planning to the patient, followed by static half-guided surgery, while the freehand implant placement provides the least accuracy. However, further investigations are needed to verify the clinical implications of these findings.

Keywords: "Accuracy" OR "Accurateness" OR "Exactitude" OR "Efficiency" OR "Certainty" AND "Guided surgery" AND "Dental implant" AND "Computer-assisted" OR "Computer aid" AND "Single tooth" OR "Individual tooth" OR "One tooth" OR "Unique tooth".

CESPU
INSTITUTO UNIVERSITÁRIO
DE CIÊNCIAS DA SAÚDE

Table of Contents

1. Introduction

Dental implant prostheses have been shown to be a really successful treatment modality for replacement of missing teeth (1). Nevertheless, proper implant position is considered as an essential prerequisite to ensure successful treatment outcomes, as well as long-term maintenance of the prosthesis and the peri-implant tissue health. Poor treatment planning and deficient surgical procedures may cause improper implant position which will inevitably lead to predispose compromise outcomes and short or long-term complications (2).

Proper angulation and positioning of dental implants is essential to achieve acceptable prosthetic outcomes. Poor accuracy of the implant is associated with an increased risk of complications, such as perforation of the lingual plate or inferior alveolar canal. Anatomical concerns, such as the impact of the inter-implant distance on crestal bone height and papilla contour are based on accurate planning and placement (3). The challenge being that all surgical sites are different. Improving implant accuracy has been the subject of substantial interests (4).

Nowadays, the result of conventional planning has been achieved with the utilisation of a radiographic stent with a radiopaque marker, produced from duplicating the wax-up of the perfect prostheses on study models. The radiographic stent is then worn by the patient during a pre-operative cone beam computerized tomography (CBCT) scan, thereby allowing transposition of the ideal prosthesis shape to the alveolar ridge and indicating the perfect prosthetic position for the implant. This technique is enabling the surgeon to visualise the best prosthetic position intraoperatively. Generally, the surgeon decides in situ on the chosen implant position once the flap is raised and the bone is exposed (5). For these reasons, this technique is often described as "freehand", and the accuracy of the final implant position depends on the surgeon's skills and experience (6).

Digital technology is changing with each passing day. In 1995, Fortin et al. (7) proposed computer-assisted implant surgery (CAIS), which involves placing implants in a relative position through preoperative planning. With this new technique in dentistry, the half-guided technique can be performed, using surgical guide at start and ending with freehand placement. Full guided technique can also be used thanks to computer-assisted surgery (CAS) for dental implant placements, and this including static and dynamic systems (7).

Dynamic guided surgery, i.e. guided surgery during which the operator receives real-time information on the position of the drill in the operative field through the utilisation of visual imaging tools on a monitor, has become available with acceptable accuracy. Static guided surgery systems are template-based and have shown to be more practical in dental offices as they are less costly and occupy less space (8,9).

But these techniques are not fool proof as the accuracy of the sCAIS, they are often affected by several factors. Studies further highlighted the importance of guide fixation and stabilisation insofar as it was shown that mobility of the surgical guide during the implant bed preparation can be responsible for high deviation values in the final implant position (10). There is no doubt that advancements in digital technology and its application in dentistry have greatly increased in the daily workflow (11).

Therefore, the aim of this systematic review was to compare the accuracy of implant position achieved with freehand, half guided and fully guided technique on single tooth. This study will seek to demonstrate that implants placed with fully guided technique will have a better accuracy when compared to those placed with freehand and half-guided surgery.

2. Method

A literature search was performed on PUBMED (via National Library of Medicine) on May 10, 2021 using the following combination of search terms: ((((((Accuracy) OR (accurateness) OR (exactitude) OR (efficiency) OR (certainly))) AND (Guided surgery)) AND (Dental implant)) AND (((Computer-assisted) OR (computer aid)))) AND (((Single tooth) OR (individual tooth) OR (one tooth) OR (unique tooth))). The inclusion criteria involved articles published during the last 10 years reporting the accuracy of Fully guided implant surgery, Half guided implant surgery and Freehand implant surgery.

The eligibility inclusion criteria used for article searches also involved: articles written in English, Portuguese and French; Full text. The total of articles was compiled for each combination of key terms and therefore the duplicates were removed using Mendeley citation manager

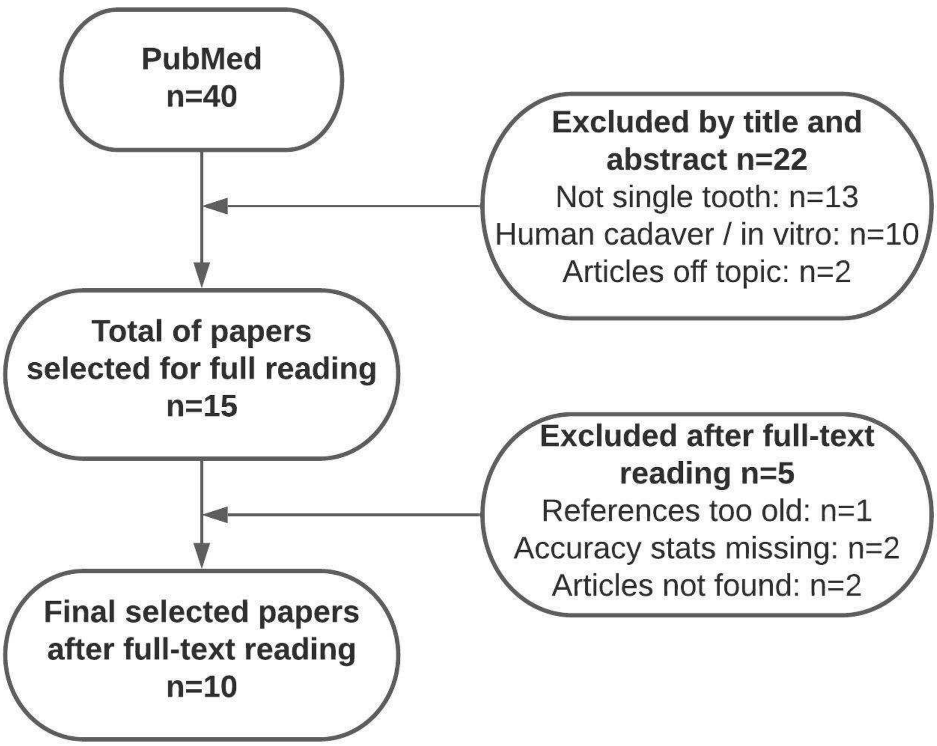
A preliminary evaluation of the abstracts was realised to establish whether the articles met the purpose of the study. Selected articles were individually read and evaluated with respect to the purpose of this study. The following factors were retrieved for this review: author names, publication year, purpose, type of study (Randomized controlled clinical trial), type of follow up (ex: CBCT), type of surgery performed: fully guided, half guided or freehand, number of implants and patients, localisation of the implant, navigation system and software, type of support, implant characteristics, accuracy (coronal, apical, longitudinal and angular accuracy) of the techniques used.

To compare the results of each accuracy several comparison tables were produced. Indeed Mean and Confidence Level (95%) of each accuracy (where data were available) of each technique were calculated with 'Data Analysis'; 'Descriptive statistics'; 'Summary statistics'; 'Confidence level for Mean' in Excel software (Annex).

3. Results

The literature search on PUBMED identified a total of 40 articles, as seen in Figure 1. Once the titles and abstracts of the articles were read, 13 articles were excluded due to the facts that patients had partial or total edentulism. Then, 10 articles were excluded for having conducted studies in vitro and on human cadavers and 2 articles were excluded for not using any guided or freehand techniques. At last, following the complete reading of the articles, 2 articles were excluded for not having the information desired. In that respect, 1 article was excluded due to old references and 2 articles were excluded for not being found.

Figure 1. Schematics of the selection of articles.



3.1 Charactristicse of the review

All 10 studies selected for this review were RCTs aimed at evaluating the accuracy of fully guided, half-guided or freehand implant placement protocols, comparing presurgical and post-surgical CBCTs. All studies were published in English language. Three studies consisted of Fully guided treatment with 2 sCAIS techniques (12,13) and one was comparing sCAIS technique with dynamic CAIS technique (2). Three studies performed the Half-guided technique using surgical guide at start and ending with freehand placement. (14–16). Only one study employed the conventional Freehand technique (4) while the rest of them compared the three protocols between them. (Full guided vs Half-guided vs Freehand (7); Full guided vs Freehand (6) and Full guided vs Half-guided (17).)
This review is composed of American (4,12,15), Thai (2,6), German (16,17), Taiwainese (7), Austrian (13) and Saudi (14) papers.

At last, ten studies were included in this review. Within the selected studies, 776 implants were placed, including 300 (39%) with Freehand technique, 157 (20%) with Half-guide technique and 308 (41%) with Full guide technique. All of it were placed on single tooth.

3.2 Synthesis of Results

The clinical outcomes from the included RCTs were extracted and organized into tables to condense an overview.

Table 1: General overview of the included trials

Study (year)	Study	Follow-up	Protocols	Number of patients/implants	Arch	Navigation system and software	Type of support	Implant characteristics
Smitkarn P, (2019) (6)	RCT	CBCT	Full guide (sCAIS) vs Freehand	52/60	Maxilla / Mandible	coDiagnostiX(Straumann)	Tooth	Straumann Bone-level
Kaewsiri D, (2019) (2)	RCT	CBCT	Full guide sCAIS vs dCAIS	60/60	Maxilla / Mandible	coDiagnostiX (sCAIS) Iris–100 (CAIS)	Tooth, Mucosa, Bone	Straumann Bone-level; Bone-level trapper; Tissue level
Sompop Bencharit, (2018) (15)	RCT	CBCT	Half-guide	NA/11	Maxilla / Mandible	Preform software	Tooth	BioHorizon; Zimmer
William Choi, (2017) (4)	RCT	CBCT	Freehand	NA/238	Maxilla / Mandible	EZ3D	Tooth, Mucosa,Bone	Hiossen Implant System
Ting-Mao Sun, (2020) (7)	RCT	CBCT	Full guide (CAIS) vs half-guide vs Freehand	NA/128	Maxilla / Mandible	AQNavi, SmilePlan	Tooth, Mucosa, Bone	MaxFit

Hesham F. Marei, (2019) (14)	RCT	CBCT	Half-guide	20/40	Maxilla / Mandible	Simplant kit, Simplant pro 17	Tooth	Tapered Screw Vent mtx, Zimmer Dental
Eleni Naziri, (2016) (17)	RCT	CBCT	Half-guideFull guide (sCAIS)	181/246	Maxilla / Mandible	coDiagnostiX (Straumann)	Tooth	Astra Tech Osseospeed; Straumann ITI Bone Level; Camlog Promote Plus
Caitlyn K. Bell, (2018) (12)	RCT	CBCT	Full guide (sCAIS)	20/20	Maxilla / Mandible	Nobel Biocare protocol, BlueSkyBio	Tooth	One Nobel Biocare
Sigmar Schnutenhaus, (2016) (16)	RCT	CBCT	Half-guide	24/24	Maxilla / Mandible	Camlog guide protocol, Swissmeda online implant planning (SMOP)	Tooth, mucosa, bone	Camlog
Rudolf Fürhauser, (2014) (13)	RCT	CBCT	Full guide (sCAIS)	27/27	Maxilla	NobelClinician™	Tooth	NobelReplace® TiU

RCT: randomized clinical trial; NA: not available; CBCT: Cone Beam Computerized Tomography ; sCAIS: Static Computer-assisted implant surgery; dCAIS: Dynamic Computer-assisted implant surgery

The outcome of coronal deviation was based on eight trials (2,6,12,13,16) apical deviation was based on six (2,6,12,13,16,17), longitudinal deviation was based on four (4,6,7,16) and lastly, angular deviation was based on all of the papers considered in this review (2,4,6,7,12–17).

Mean and Confidence level (95%) (Lower; Higher) were calculated in order to be able to compare coronal, apical, longitudinal and angular accuracies.

Table 2: Full guide Accuracy

Study/N°implants	**Coronal deviation (mm) Mean (SD)**	**Apical deviation (mm) Mean (SD)**	**Longitudinal deviation (mm) Mean (SD**	**Angular deviation (degrees) Mean (SD)**
Smitkarn P, (2019) (6) / 30	1.0 (0.6)	1.3 (0.6)	0.7 (0.6)	3.1 (2.3)
Kaewsiri D, (2019) (2) /60 sCAIS	0.97 (0.44)	1.28 (0.46)	NA	2.84 (1.71)
dCAIS	1.05 (0.44)	1.29 (0.50)	NA	3.06 (1.37)
Ting-Mao Sun, (2020) (7) / 32	NA	NA	0.52 (0.20)	2.20 (0.38)
Eleni Naziri, (2016) (17) / 150	NA	1.3 (NA)	NA	3.3 (NA)
Caitlyn K. Bell, (2018) (12) /20 Thermoplastic average	1.33 (0.24)	1.60 (0.36)	NA	3.40 (1.38)
3D-printer average	0.51 (0.24)	0.76 (0.36)	NA	2.36 (1.38)
Rudolf Fürhauser, (2014) (13) / 27	0.84 (0.44)	1.16 (0.69)	NA	2.7 (2.6)
Mean	0,95 (0.27)	1.24 (0.25)	0.61 (0.13)	2.87 (0.43)
Confidence Level (95%) (Lower; Higher)	(0.67 ; 1.23)	(1.01 ; 1.47)	(-0.53 ; 1.75)	(2.51 ; 3.23)

Table 3: Half-guide Accuracy

Study/N°implants	Coronal deviation (mm) Mean (SD)	Apical deviation (mm) Mean (SD)	Longitudinal deviation (mm) Mean (SD)	Angular deviation (degrees) Mean (SD)
Ting-Mao Sun, (2020) (7) / 32	NA	NA	0.73 (0.13)	3.24 (0.36)
Hesham F. Marei, (2019) (14) / 40	NA	NA	NA	3.7 (3.35)
Eleni Naziri, (2016) (17) / 50	NA	1.55 (NA)	NA	4.7 (NA)
Sompop Bencharit, (2018) (15) / 11	NA	NA	NA	4.4 (6.83)
Sigmar Schnutenhaus, (2016) (16) / 24	0.9 (0.5)	1.5 (0.7)	0.5 (0.7)	4 (1.5)
Mean	0.9 (0.5)	1.53 (0.035)	0.62 (0.16)	4.01 (0.57)
Confidence Level (95%) (Lower; Higher)	NA	(1.21 ; 1.84)	(-0.85 ; 2.08)	(3.30 ; 4.72)

Table 4: Freehand Accuracy

Study/N°implants	Coronal deviation (mm) Mean (SD)	Apical deviation (mm) Mean (SD)	Longitudinal deviation (mm) Mean (SD)	Angular deviation (degrees) Mean (SD)
Smitkarn P, (2019) (6) / 30	1.5 (0.7)	2.1 (1.0)	1 (0.8)	6.9 (4.4)
William Choi, (2017) (4) / 238	NA	NA	0.79 (0.78)	4.79 (3.56)
Ting-Mao Sun, (2020) (7) / 32	NA	NA	1.42 (0.25)	6.12 (0.12)
Mean	1.5 (0.7)	2.1 (1.0)	1.07 (0.32)	5.94 (1.07)
Confidence Level (95%) (Lower; Higher)	NA	NA	(0.27 ; 1.87)	(3.29 ; 8.59)

4. Discussion

Coronal deviation

In this review, according to the results of the various papers the coronary accuracy can only be appropriately determined for the full guide technique with a Mean of 0,95mm and a Confidence Level (95%) of (0,67mm; 1,23mm). (Table 2)

Indeed, papers on the coronary accuracy of half-guided and freehand techniques are not substantial enough to compare them to the full guide technique.

Despite this, the average coronary accuracy of the full guide technique; Mean: 0.95mm and Confidence Level (95%): (0,67mm; 1,23mm) (Table 2) and half-guide technique; Mean: 0.9mm (Table 3) seems to be more precise than the freehand technique; Mean: 1.5mm (Table 4).

Apical deviation

Regarding Apical precision, by comparing results of Full guide: Mean of 1.24mm, a Confidence Level (95%) of (1,01mm; 1,47mm) (Table 2) and Half-guide (HG): Mean of 1.53mm, a Confidence Level (95%) of (1,21mm; 1,84mm) (Table 3), Full guide (FG) seems to be more accurate with a difference of accuracy of: (-0.20mm; -0.37mm)

For Freehand (FH) technique, data is not tedious enough to be able to compare it to the other techniques. All in all, if we take the averages, full technical guide appears to be more precise: Mean FG: 1.24mm (Table 2); Mean HG: 1.53mm (Table 3); Mean FH: 2.1mm (Table 4).

Longitudinal deviation

As demonstrated, this comparison did not establish a significant weighted mean difference between the three techniques. In that, if we compare Mean FG: 0.61mm (Table 2) a Confidence Level (95%) of (-0,53mm; 1,75mm) (Table 2) and Mean HG: 0.62mm (Table 3) a Confidence Level (95%) of (-0,85mm; 2,08mm) (Table 3), the difference Mean (-0.01mm) and CL (95%) (0.32mm; -0.33mm) of accuracy FG and HG are not significantly different. Regarding the freehand technique, the results are also equivalent, for CL (95%) the differences are not important enough: Confidence Level

(95%) (0,27mm; 1,87mm) (Table 4). By contrast, the mean of the longitudinal accuracy is less precise than FG and HG techniques: Mean FH: 1.07mm (Table 4); Mean FH vs Mean HG= 0.45mm; Mean FH vs Mean FG= 0.46mm.

Angular deviation

Comparing the Full guide with the Half-guide and the Freehand techniques, approaches demonstrated a significant weighted mean difference in favour of the Full guide approach: Mean FG: 2.87° (Table 2) a Confidence Level (95%) of (2,51°; 3,23°) (Table 2) vs Mean HG: 4.01° (Table 3) a Confidence Level (95%) of (3,30°; 4,72°) (Table 3), Difference Mean: -1.14°, Difference CL (95%): (-0.79°; -1.49°). With respect to the freehand technique as opposed to the Full guide technique, the results are more significant, Mean FH: 5.94° (Table 4) a Confidence Level (95%) of (3,29; 8,59) (Table 4); Difference Mean: -3.07°, Difference CL (95%): (-0.78°; -5.36°).

Additionally, the results of the present review demonstrated a smaller difference in the accuracy between the fully guided and half-guided techniques (weighted mean difference of 0.05 mm for coronal deviation, -0.29 mm for apical deviation, 95% CI of (-0.2mm; -0.37mm), -0.01 mm for longitudinal deviation, 95% CI of (0.32mm; -0.33mm)) but a larger angular variation -1.14°, 95% CI of (0.79°; -1.49°).

While where we compare the fully guided with the freehand approach the difference between these two techniques is significant. Indeed, weighted mean difference of -0.46 mm, 95% CI of (-0.8mm; -0.12mm) for longitudinal deviation and -3.07°, 95% CI of (0.78°; -5.36°) for angular deviation were calculated.

Finally, if we compare HG technique and FH technique, the results are equivalent to the comparison between FG technique and FH technique, the result being that HG is more accurate than FH (weighted mean difference of -0.45 mm, 95% CI of (-1.12mm; 0.21mm) for longitudinal deviation and -1.93°, 95% CI of (0.01°; -3.87°) for angular deviation.

The findings from the meta-analyses of Jordi Gargallo-Albiol (11) based on partially and completely edentulous patients revealed that the static fully guided technique provided the most accurate static implant navigation system, while the freehand surgical approach had the least accuracy amongst the three tested techniques. Additionally, the results of the review demonstrated a smaller difference in the accuracy between the fully guided and half-guided techniques (11) (weighted mean difference of 0.51 mm for coronal deviation, 0.75 mm for apical deviation, 0.23 mm (vs 0.46 mm in our study) for vertical deviation, and 3.63° (3.07° in our study) for apical angle deviation). In this review, it was confirmed from all the above that indeed, accuracy between FG and HG has shown a small difference.

In another review of Rafael Siqueira (18), the accuracy utilising partially and fully digital workflows was evaluated. This review is suggesting that the accuracy of s-CAIS fully-guided tooth-supported systems exhibited less deviations compared to other types of support mechanisms and partially-guided protocols (19,20). The review reported a FG mean global deviation of 1.03 mm (95% CI: 0.88-1.18 mm) at the shoulder (mean 0.95 mm and 95% CI: (0,67 mm; 1,23 mm) in our study) and 1.33 mm (95% CI: 1.17-1.50 mm) (19) at the apex (mean 1.24 mm and 95% CI: (1,01 mm; 1,47 mm) in our study), which was similar between groups. Tahmaseb (19) reported similar mean errors of 0.9 mm (95% CI: 0.79-1.00 mm) at the entry point and 1.2 mm (95% CI: 1.11-1.20 mm) at the apex for partially edentulous cases. Therefore, the results of our study coincide with these findings.

Implant placement deviation is the cumulative result of errors which may possibly occur during all phases of protocols. It can be CBCT acquisition errors which include patient movement (21) and imaging artifacts (18).

In a review from Jordi Gargallo-Albiol (11) the longitudinal deviation accuracy had non-significant results. In the present study we can confirm these facts for FG and HG but not for FH, which is significantly less accurate than the other two techniques.

According to Ver cruyssen (22) this drop of accuracy could be caused by the fact that fully guided templates do not have a physical stop, and the fact that the depth of the preparation have to be visually checked during the implant drilling.

Other factors have been identified as a potential source of errors in the implant positioning accuracy, including the surgical guide support (bone, mucosa, or tooth) (2,4,7,16), which is related to the type of edentulism (partially edentulous and completely edentulous patients). In the present study all of the implants were placed on a single tooth area (2,4,6,7,12–17). And, if we compare the present study on single tooth implant placement with Albiero (23) which Is studies with fully edentulous patients, our present study revealed to achieve the highest implant positioning accuracy except longitudinal deviation accuracy. Indeed Albiero (23) has a mean global coronal deviation for FG technique group of 1.12mm (0.5) (compare to 0.95mm (0.27) (Table 2) In our study), a mean global apical deviation of 1.36mm (0.7) (1.24mm (0.25) (Table 2)), a mean angular deviation of 3.16° (1.8) (2.87° (0.43) (Table 2)), and a mean longitudinal deviation of 0.51mm (0.7) (0.61mm (0.13) Table 2)).

Otherwise, the experience of the surgeon has been previously described as a crucial factor influencing the resulting implant placements.(24) Surgeon experience affects all different surgical approaches, albeit freehand placement seems to need more surgical experience to beat its limitations in relation to the smallest amount of positioning accuracy. (6,7,14) Furthermore, surgical experience is additionally highly recommended where fully guided or half-guided approaches are used, and this to prevent any error from occurring during the presurgical planning or within the guided system. In fact, an error would inevitably lead to a wrong implant positioning.(24) However, Van de Wiele (25) considered that surgical experience has a little influence on the accuracy of implant placements when a totally guided approach is correctly used along with the supervision of an experienced instructor.(11)

The accuracy of implant surgery significantly depends on the surgeon's experience when it comes to operating by hand, with free-hand, static, dynamic navigation or on the robot's stabilisation using robotic surgery. A totally autonomous system could automatically regulate the movement during the operation and directly execute operation tasks on the patient. All of this leading to the avoidance of human surgical errors at the value of the surgeon's experiences; albeit, to a lesser extent, the surgical accuracy is also suffering from the robotic arm and optical navigation system, which is not ideal as exposed in the reports aforementioned. (26)

Furthermore, to raise a comprehensive assessment of the clinical benefits of such technology, further studies will have to tackle other parameters such as cost-effectiveness, duration of the surgical intervention and patient-reported outcome measures (PROMs). (6)

5. Conclusion

In this present review, fully guided implant surgery has been identified as the most accurate of techniques, followed by half-guided surgery, while freehand implant placement provides the least accuracy. The angle deviation, coronal deviation and apical deviation showed significant differences amongst the groups, and this despite the lack of data for coronal and apical accuracy. In contrast, longitudinal deviation accuracy failed to show significant differences. Further investigations are needed to verify the clinical implications of these findings.

6. References

1. Jung RE, Zwahlen M. A systematic review of the 5-year survival and complication rates of implant-supported single crowns. 2007;

2. Kaewsiri D, Panmekiate S, Subbalekha K, Mattheos N, Pimkhaokham A. The accuracy of static vs. dynamic computer-assisted implant surgery in single tooth space: A randomized controlled trial. Clin Oral Implants Res. 2019;30(6):505–14.

3. Tarnow DP, Cho SC, Wallace SS. The Effect of Inter-Implant Distance on the Height of Inter-Implant Bone Crest *. 71(4):546–9.

4. Choi W, Nguyen BC, Doan A, Girod S, Gaudilliere B, Gaudilliere D. Freehand Versus Guided Surgery: Factors Influencing Accuracy of Dental Implant Placement. Implant Dent. 2017;26(4):500–9.

5. Velde T Van De. A model study on flapless implant placement by clinicians with a different experience level in implant surgery. 2008;66–72.

6. Smitkarn P, Subbalekha K, Mattheos N, Pimkhaokham A. The accuracy of single-tooth implants placed using fully digital-guided surgery and freehand implant surgery. J Clin Periodontol. 2019;46(9):949–57.

7. Sun TM, Lee HE, Lan TH. Comparing accuracy of implant installation with a navigation system (NS), a laboratory guide (LG), NS with LG, and freehand drilling. Int J Environ Res Public Health. 2020;17(6).

8. Younes F, Cosyn J, De Bruyckere T, Cleymaet R, Bouckaert E, Eghbali A. A randomized controlled study on the accuracy of free-handed, pilot-drill guided and fully guided implant surgery in partially edentulous patients. J Clin Periodontol. 2018;45(6):721–32.

9. Katsoulis J, Pazera P. Planning for the Edentulous Maxilla : 2008;238–45.

10. El Kholy K, Lazarin R, Janner SFM, Faerber K, Buser R, Buser D. Influence of surgical guide support and implant site location on accuracy of static Computer-Assisted Implant Surgery. Clin Oral Implants Res. 2019;30(11):1067–75.

11. Gargallo-Albiol J, Barootchi S, Marqués-Guasch J, Wang H-L. Fully Guided Versus Half-Guided and Freehand Implant Placement: Systematic Review and Meta-analysis. Int J Oral Maxillofac Implants. 2020;35(6):1159–69.

12. Bell C, Sahl E, Kim Y, Rice D. Accuracy of Implants Placed with Surgical Guides: Thermoplastic Versus 3D Printed. Int J Periodontics Restorative Dent. 2018;38(1):113–9.

13. Fürhauser R, Mailath-Pokorny G, Haas R, Busenlechner D, Watzek G, Pommer B. Esthetics of Flapless Single-Tooth Implants in the Anterior Maxilla Using Guided Surgery: Association of Three-Dimensional Accuracy and Pink Esthetic Score. Clin Implant Dent Relat Res. 2015;17:e427–33.

14. Marei H, Abdel-Hady A, Al-Khalifa K, Al-Mahalawy H. Influence of Surgeon Experience on the Accuracy of Implant Placement via a Partially Computer-Guided Surgical Protocol. Int J Oral Maxillofac Implants. 2019;34(5):1177–83.

15. Bencharit S, Staffen A, Yeung M, Whitley D, Laskin DM, Deeb GR. In Vivo Tooth-Supported Implant Surgical Guides Fabricated With Desktop Stereolithographic Printers: Fully Guided Surgery Is More Accurate Than Partially Guided Surgery. J Oral Maxillofac Surg [Internet]. 2018;76(7):1431–9. Available from: https://doi.org/10.1016/j.joms.2018.02.010

16. Schnutenhaus S, Edelmann C, Rudolph H, Luthardt RG. Retrospective study to determine the accuracy of template-guided implant placement using a novel nonradiologic evaluation method. Oral Surg Oral Med Oral Pathol Oral Radiol [Internet]. 2016;121(4):e72–9. Available from: http://dx.doi.org/10.1016/j.oooo.2015.12.012

17. Naziri E, Schramm A, Wilde F. Accuracy of computer-assisted implant placement with insertion templates. GMS Interdiscip Plast Reconstr Surg DGPW. 2016;5:Doc15.

18. Dds RS, Dds ZC, Dds HC. Does a fully digital workflow improve the accuracy of

computer-assisted implant surgery in partially edentulous patients ? A systematic review of clinical trials Study registration. 2020;(May):1–12.

19. Tahmaseb A, Wu V, Wismeijer D, Christopher WC. The accuracy of static computer-aided implant surgery : A systematic review and meta- - analysis. 2018;i(December 2017):416–35.

20. Derksen W, Tahmaseb A, Wismeijer D, Flügge T, Hassan B. The accuracy of computer - guided implant surgery with tooth - supported , digitally designed drill guides based on CBCT and intraoral scanning . A prospective cohort study. 2019;(February 2018):1005–15.

21. Pettersson A, Komiyama A, Hultin M, Näsström K, Klinge B. Accuracy of Virtually Planned and Template Guided Implant Surgery on Edentate Patients. :1–11.

22. Coucke W, Naert I, Jacobs R, Teughels W, Quirynen M. Depth and lateral deviations in guided implant surgery : an RCT comparing guided surgery with mental navigation or the use of a pilot-drill template. 2014;1–6.

23. Albiero AM, Quartuccio L, Benato R. Accuracy of Computer-Guided Flapless Arches and in Edentulous Arches With. 2019;18–22.

24. Gargallo-albiol J, Barootchi S, Salomó-coll O, Wang H. Annals of Anatomy Advantages and disadvantages of implant navigation surgery . A systematic review ☆. Ann Anat [Internet]. 2019;225:1–10. Available from: https://doi.org/10.1016/j.aanat.2019.04.005

25. Temmerman A. The accuracy of guided surgery via mucosa-supported stereolithographic surgical templates in the hands of surgeons with little experience. 2014;1–6.

26. Cheng K, Kan T, Liu Y, Zhu W, Zhu F. Accuracy of dental implant surgery with robotic position feedback and registration algorithm : An in-vitro study. Comput Biol Med [Internet]. 2021;129(November 2020):104153. Available from: https://doi.org/10.1016/j.compbiomed.2020.104153

7. Annex

Full Guide technique: Excel calculation table of Confidence Level (95%) for the different types of accuracy.

1	*Coronal deviation*		Lower	
0,97				0,667235998
1,05	**Mean**	**0,95**		
1,33	Standard Error	0,11	Higher	
0,51	Median	0,985		1,232764002
0,84	Mode	#N/A		
	Standard Deviation	0,269443872		
	Sample Variance	0,0726		
	Kurtosis	1,530585343		
	Skewness	-0,467905911		
	Range	0,82		
	Minimum	0,51		
	Maximum	1,33		
	Sum	5,7		
	Count	6		
	Confidence Level(95,0%)	**0,282764002**		

1,3	*Apical deviation*		Lower	
1,28				1,009390654
1,29	**Mean**	**1,241428571**		
1,3	Standard Error	0,094828883	Higher	
1,6	Median	1,29		1,473466489
0,76	Mode	1,3		
1,16	Standard Deviation	0,250893641		
	Sample Variance	0,062947619		
	Kurtosis	2,882474978		
	Skewness	-0,96691604		
	Range	0,84		
	Minimum	0,76		
	Maximum	1,6		
	Sum	8,69		
	Count	7		
	Confidence Level(95,0%)	**0,232037917**		

0,7	*Longitudinal deviation*		Lower	
0,52				-0,533558426
	Mean	**0,61**		
	Standard Error	0,09	Higher	
	Median	0,61		1,753558426
	Mode	#N/A		
	Standard Deviation	0,127279221		
	Sample Variance	0,0162		
	Kurtosis	#DIV/0!		
	Skewness	#DIV/0!		
	Range	0,18		
	Minimum	0,52		
	Maximum	0,7		
	Sum	1,22		
	Count	2		
	Confidence Level(95,0%)	**1,143558426**		

3,1	*Angular deviation*		Lower	
2,84				2,510608229
3,06	**Mean**	**2,87**		
2,2	Standard Error	0,151986842	Higher	
3,3	Median	2,95		3,229391771
3,4	Mode	#N/A		
2,36	Standard Deviation	0,429883705		
2,7	Sample Variance	0,1848		
	Kurtosis	-1,012794256		
	Skewness	-0,457818947		
	Range	1,2		
	Minimum	2,2		
	Maximum	3,4		
	Sum	22,96		
	Count	8		
	Confidence Level(95,0%)	**0,359391771**		

Half Guide technique: Excel calculation table of Confidence Level (95%) for the different types of accuracy.

3,24	*Angular deviation*		Lower
3,7			3,295453613
4,7	**Mean**	**4,008**	
4,4	Standard Error	0,256639825	Higher
4	Median	4	4,720546387
	Mode	#N/A	
	Standard Deviation	0,573864095	
	Sample Variance	0,32932	
	Kurtosis	-0,971351528	
	Skewness	-0,199736567	
	Range	1,46	
	Minimum	3,24	
	Maximum	4,7	
	Sum	20,04	
	Count	5	
	Confidence Level(95,0%)	**0,712546387**	

1,55	*Apical deviation*		Lower
1,5			1,207344882
	Mean	**1,525**	
	Standard Error	0,025	Higher
	Median	1,525	1,842655118
	Mode	#N/A	
	Standard Deviation	0,035355339	
	Sample Variance	0,00125	
	Kurtosis	#DIV/0!	
	Skewness	#DIV/0!	
	Range	0,05	
	Minimum	1,5	
	Maximum	1,55	
	Sum	3,05	
	Count	2	
	Confidence Level(95,0%)	**0,317655118**	

0,73	*Longitudinal deviation*		Lower
0,5			-0,846213545
	Mean	**0,615**	
	Standard Error	0,115	Higher
	Median	0,615	2,076213545
	Mode	#N/A	
	Standard Deviation	0,16263456	
	Sample Variance	0,02645	
	Kurtosis	#DIV/0!	
	Skewness	#DIV/0!	
	Range	0,23	
	Minimum	0,5	
	Maximum	0,73	
	Sum	1,23	
	Count	2	
	Confidence Level(95,0%)	**1,461213545**	

Freehand technique: Excel calculation table of Confidence Level (95%) for the different types of accuracy.

6,9	*Angular deviation*			1	*Longitudinal deviation*		Lower
4,79			Lower	0,79			
6,12	**Mean**	**5,936666667**	3,28638936	1,42	**Mean**	**1,07**	0,273137563
	Standard Error	0,615963563			Standard Error	0,185202592	Higher
	Median	6,12	Higher		Median	1	1,866862437
	Mode	#N/A	8,586943973		Mode	#N/A	
	Standard Deviation	1,066880187			Standard Deviation	0,320780299	
	Sample Variance	1,138233333			Sample Variance	0,1029	
	Kurtosis	#DIV/0!			Kurtosis	#DIV/0!	
	Skewness	-0,750448294			Skewness	0,93521953	
	Range	2,11			Range	0,63	
	Minimum	4,79			Minimum	0,79	
	Maximum	6,9			Maximum	1,42	
	Sum	17,81			Sum	3,21	
	Count	3			Count	3	
	Confidence Level(95,0%)	**2,650277306**			**Confidence Level(95,0%)**	**0,796862437**	