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ACURÁCIA DE CIRURGIA ESTÁTICA ASSISTIDA POR COMPUTADOR DE IMPLANTES DENTÁRIOS EM PACIENTES COM EDENTULISMO TOTAL: UMA REVISÃO SISTEMÁTICA

Florianópolis
2020

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Dissertação submetida ao Programa de Pós-graduação em Odontologia da Universidade Federal de Santa Catarina como requisito para a obtenção do Grau de Mestre em Clínica Odontológica.

Orientador: Prof. Dr. Luis André M. Mezzomo

Florianópolis

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O presente trabalho em nível de mestrado foi avaliado e aprovado por banca examinadora composta pelos seguintes membros:

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Prof. Dr. Luis André Mendonça Mezzomo

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Florianópolis, 2020.

Dedico esse trabalho a todas as pessoas que estiveram ao meu lado nesta trajetória da minha carreira acadêmica.

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Um passo de cada vez. Não consigo imaginar nenhuma outra maneira de realizar algo. (JORDAN M, 2009)

RESUMO

Objetivo: Responder à seguinte pergunta focada: *"Em arcos totais, qual a acurácia da colocação de implantes dentários por meio de cirurgia estática assistida por computador (E-CAC)?"*

Materiais e Métodos: Uma busca abrangente na literatura foi realizada. Dois revisores independentes e calibrados selecionaram os estudos baseados em critérios de elegibilidade pré-definidos e extraíram os dados de características dos estudos, da população, da intervenção e dos desfechos (acurácia). A avaliação do risco de viés e da qualidade da evidência dos artigos incluídos foi realizada por um revisor independente e cegado. A qualidade da evidência foi avaliada de acordo com a *Grading of Recommendations Assessment, Development and Evaluation* (GRADE). A meta-análise foi conduzida usando o modelo de efeitos randômicos a um nível de significância de 5%.

Resultados: Dezenove estudos (2 RCTS, 13 CCTs, 1 Coorte e 3 Séries de Casos) atenderam aos critérios de elegibilidade e foram incluídos. Ao todo, 1.884 implantes distribuídos nos 2 arcos de 369 pacientes (homens n = 182; mulheres n = 152) foram avaliados. A meta-análise de efeitos randômicos revelou distorções lineares horizontais médias estatisticamente significativas aos níveis do pescoço e do ápice do implante de 1,09mm (IC 95%: 0,71 - 1,47) (p <0,001) e 1,44mm (IC 95%: 0,94 – 1,94) (p <0,001), respectivamente, uma distorção linear vertical média de 0,16mm (IC 95%: -0,04 - 0,35) estatisticamente significativa (p = 0,113) e uma distorção angular média de 3,46º (IC 95%: 2,52 – 4,40) estatisticamente significativa (p <0,001). A acurácia não foi diferente entre maxilla e mandíbula em todos os parâmetros avaliados (p > 0.05).

Conclusões: A acurácia de cirurgia guiada assistida por computador estática (e-CAC) em pacientes edêntulos totais está dentro de uma variação clinicamente aceitável e uma margem de segurança horizontal de 2mm e vertical de 1mm deve sempre ser respeitada no planejamento.

Palavras-chave: arcada edêntula, implantação dentária, cirurgia assistida por computador, precisão da medição dimensional, impressão tridimensional, revisão sistemática.

ABSTRACT

Objectives: To answer the following focused question: *"In full arches, what is the accuracy of dental implants placed by means of static computer-assisted implant surgery (s-CAIS)?"*

Materials and Methods: A comprehensive literature search was performed. Two independent and calibrated reviewers selected studies based on pre-defined eligibility criteria and extracted data on *study*-, *population*-, *intervention*- and *outcome* (accuracy) characteristics. Risk of bias and the quality of evidence assessments of the included articles were performed by an independent and blinded reviewer. The quality of evidence was evaluated according to the Grading of Recommendations Assessment, Development and Evaluation (GRADE). Meta-analysis was conducted using the random-effects model at a 5% significance level.

Results: Nineteen (2 RCTs, 13 CCTs, 1 Cohort and 3 Case Series) studies met the inclusion criteria and were included. Overall, 1,816 implants distributed among arches in 369 patients (males $n = 182$; females $n = 152$) were assessed. Random-effects meta-analysis revealed statistically significant mean horizontal linear distortions at the implant neck and apex levels of 1.09mm (95% CI: 0.71 - 1.47) ($p < 0.001$) and 1.44mm (95% CI: 0.94 - 1.94) ($p < 0.001$), respectively, significant mean vertical linear distortion at implant depth level of 0.16mm (95% CI: -0.04 - 0.35) ($p = 0.113$) and significant mean angular distortion of 3.46º (95% CI: 2.52 - 4.40) ($p < 0.001$). Accuracy did not differ significantly between maxilla and mandible at all parameters assessed ($p > 0.05$).

Conclusion: The accuracy of static computer-assisted implant surgery (s-CAIS) in edentulous patients is within a clinically acceptable range and a 2-mm horizontal and 1-mm vertical safety margin should always be respected at planning.

Key-words: edentulous jaw, dental implantation, computer-assisted surgery, dimensional measurement accuracy, three-dimensional printing, systematic review.

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LISTA DE ABREVIATURAS E SIGLAS

RP	*Rapid Prototyping* (Prototipagem Rápida)
CAD	*Computer-Aided Design* (Desenho Assistido por Computador)
CAM	*Computer-Aided Manufacturing* (Manufatura Assististida por Computador)
TCFC	Tomografia Computadorizada de Feixe Cônico
TC	Tomografia Computadorizada
SLA	Estereolitografia
SLS	Sinterização Seletiva a Laser
mm	Milímetros
3D	Tridimensional
Dr. (a)	Doutor (a)
et al.	e outros (abreviatura de *et alli*)
Fig.	Figura
DICOM	*Digital Imaging and Communications in Medicine* (Imagens e Comunicações Digitais em Medicina)
STL	*Standard Tesselation Language* (Linguagem Padrão de Mosaicos)
NASA	*National Aeronautics and Space Administration*
FDA	*US Food and Drug Administration*
CAIS	*Computer-Assisted Implant Surgery*

Artigo inglês

SR	*Sistematic Review*
MA	*Meta-analysis*
PROSPERO	*Prospective Register of Systematic Reviews*
PRISMA	*Preferred Reporting Items for Systematic Reviews*
MA	*and Meta-Analysis*

LISTA DE SÍMBOLOS

±	Mais ou menos
®	Marca registrada
×	Vezes
%	Por cento
/	Ou
=	Igual a
>	Maior que
<	Menor que
≥	Maior igual a
≤	Menor igual a
-	Hífen
*	Asterisco
™	*Trademark* (marca registrada)
Ø	Diâmetro
X	Vezes
º	Graus
♂	Masculino
♀	Feminino

SUMÁRIO

1 INTRODUÇÃO

A prevalência de edentulismo em pessoas com idade superior a 65 anos na população mundial é alta (ORGANIZAÇÃO MUNDIAL DA SAÚDE, 2013). No Brasil, esta condição é ainda mais frequente (63,1%), de acordo com o último levantamento epidemiológico (SB BRASIL 2010). As próteses totais suportadas por implantes dentários, fixas ou removíveis, têm sido empregadas como uma solução eficaz para o edentulismo há décadas, devolvendo aos pacientes a função mastigatória, a estética, a fonética e, por consequência, sua qualidade de vida (BRÅNEMARK *et al*. 1969; BOERRIGTER *et al*. 1995; FEINE *et al*. 2002; MEIJER *et al*. 2003; RAGHOEBAR *et al*. 2003; WOLFINGER *et al*. 2003; ÅSTRAND *et al*. 2004; DE BRUYN *et al*. 2013). Entretanto, o sucesso estético e funcional de longo prazo dos implantes dentários depende do seu correto posicionamento tridimensional. Por isso, estas soluções de tratamento obedecem a um rigoroso e integrado planejamento cirúrgico-protético, onde os implantes são instalados preferencialmente com o auxílio de guias de resina acrílica obtidas a partir da duplicação da própria prótese ou do enceramento diagnóstico do paciente (BRÅNEMARK *et al*. 1999; MARCHACK *et al*. 2003).

Os avanços nos exames de imagem (tomografia de feixe cônico) permitiram o planejamento tridimensional digital de cirurgias de implantes através de arquivos compactados (DICOM) exportados para programas de computador (p. ex. coDiagnostiX®, BlueSky Plan® (gratuito), NobelClinician®, Simplant Planner®, etc.) (TYNDELL, BROOKS, 2000; VAN *et al*. 2003; NOCINI *et al*. 2013; DERKSEN *et al*. 2019). A engenharia computadorizada permite não somente o planejamento virtual da posição dos implantes, mas também o desenho e produção de guias cirúrgicas customizadas de acordo com o planejamento realizado (DE OLIVEIRA *et al*. 2019). Estas guias oferecem melhorias significativas na precisão, tempo, eficiência e redução do erro cirúrgico, beneficiando assim o paciente, o cirurgião e o protesista (GANZ *et al*. 2005; OZAN *et al*. 2007; VAN *et al*. 2011; YOUNES *et al*. 2018). Chen *et al*. (2018), em um estudo em cadáveres, afirmaram que cirurgias guiadas realizadas por computador foram mais acuradas quando comparadas às cirurgias convencionais realizadas à mão livre, tanto em desvios lineares quanto angulares. Por isso, a técnica cirúrgica sem levantamento de retalho

mucoperiostal (*flapless*) para colocação de implantes, que reduz significativamente o trauma e a morbidade para o paciente, pode ser otimizada pela cirurgia assistida por computador.

A colocação de implantes dentários por meio de cirurgia estática assistida por computador (e-CAC) em arcos *parciais* tem revelado uma alta acurácia (WISMEIJER *et al*. 2018; SCHNEIDER *et al*. 2019; YOUNES *et al*. 2019). A presença de ótimas referências anatômicas nos dentes remanescentes adjacentes à região edêntula contribui significativamente para a perfeita sobreposição das imagens DICOM e STL (escaneamento) adquiridas no planejamento (FÜRHAUSER *et al*. 2014; GALLUCCI *et al*. 2015; MAGRIN *et al*. 2020). Isto, por sua vez, permite a visualização simultânea, na tela do computador, de estruturas tanto em nível ósseo, quanto em nível de dentes e tecidos moles, ampliando o leque de informações disponíveis para o planejamento. Choi *et al*. (2017), em um estudo clínico, encontraram que, quanto maior o espaço edêntulo interdental reabilitado com implantes, maior a distorção de posição e de angulação entre eles.

Um fluxo de trabalho totalmente digital e minimamente invasivo para pacientes edêntulos totais, por meio de cirurgia guiada por computador sem retalho, é um protocolo viável de tratamento (VIEIRA *et al*. 2013; DI TORRESANTO *et al*. 2014; GASTALDI *et al*. 2018). Nestes pacientes, a cirurgia sem retalho assistida por computador está associada à diminuição do tempo de tratamento na cadeira, bem como à redução da morbidade trans- e pós-operatória (DI TORRESANTO *et al*. 2014). Isto é particularmente relevante levando-se em consideração que boa parte dos pacientes edêntulos são idosos usuários contínuos de anticoagulantes orais (MADRID, SANZ, 2009; GÓMEZ-MORENO *et al.* 2018). Assim, um procedimento menos invasivo, mais rápido e mais acurado atenderia melhor às necessidades deste grupo de pacientes.

A acurácia da E-CAC em arcos edêntulos está dentro da faixa clinicamente aceitável na maioria das situações clínicas (TAHMASEB *et al*. 2018; ALBIERO *et al*. 2019). No entanto, embora a colocação de implantes guiada por computador forneça benefícios importantes nestes casos, desvios da colocação planejada do implante, pela simples ausência de estruturas intraorais rígidas de ancoragem, podem representar riscos significativos (VIEIRA *et al*. 2013). Estes incluem o comprometimento do posicionamento e estabilidade da guia cirúrgica,

o que, por sua vez, pode acarretar desvios lineares e angulares do implante em relação à posição planejada (ALBIERO *et al*. 2019). Em um estudo clínico com quatorze pacientes desdentados, Vieira *et al*. (2013) encontraram desvios lineares aproximados de 2mm na maxila e 1,5mm na mandíbula entre a posição real e a planejada dos implantes. Desta forma, uma margem de segurança de pelo menos 2 mm deve ser sempre respeitada no planejamento (MARLIÈRE *et al*. 2018; TAHMASEB *et al*. 2018).

A acurácia da colocação de implantes dentários por meio de cirurgia estática assistida por computador (e-CAC) em implantes unitários e arcos parciais é bem documentada na literatura (VALENTE *et al*. 2009; TAHMASEB *et al*. 2018; DERKSEN *et al*. 2019; SMITKARN *et al*. 2019). No entanto, pouco se sabe ainda sobre a acurácia desta técnica em arcos totais. Desta forma, o objetivo deste estudo é responder, por meio de uma revisão sistemática da literatura, à pergunta: *"Em arcos totais, qual a acurácia da colocação de implantes dentários por meio de cirurgia estática assistida por computador (E-CAC)?"*

2 REVISÃO DE LITERATURA

2.1 Edentulismo Total

A falta de cuidados com a saúde bucal pode causar doenças como a cárie e doença periodontal, as quais são responsáveis por um grande número de perdas dentárias. A perda total dos dentes acarreta consequências de saúde geral para os pacientes devido a uma redução na sua alimentação, que inclui frutas, fibras e caroteno. Esta deficiência nutricional aumenta o colesterol e gorduras saturadas, levando a uma maior prevalência de obesidade, a qual está relacionada com o risco de doenças cardiovasculares e distúrbios gastrointestinais (SIERPINSK *et al*. 2007; ÖSTERBERG *et al*. 2010). Além disso, as evidências apontam para uma diminuição da função diária, atividade física e domínios físicos da qualidade de vida relacionada à saúde (MACK *et al*. 2005; MOLLAOGLU *et al*. 2005).

Os dados demográficos sobre o envelhecimento da população mostram que a necessidade de reabilitar pacientes edêntulos permanecerá considerável por muito mais décadas. As soluções protéticas mais utilizadas para pacientes edêntulos totais são as próteses totais convencionais mucossuportadas, as quais se apresentam como um tratamento que reconstitui a fonética, a estética oral e a função mastigatória ao paciente, o que por consequência melhora a sua qualidade de vida (VEYRUNE *et al*. 2005; PAREL 2018). Apesar das vantagens proporcionadas por este tipo de prótese, ela ainda apresenta limitações, sendo a dificuldade de retenção mecânica a principal delas. Por isso, os implantes dentários foram introduzidos por Brånemark *et al*. (1969) como pilares de ancoragem para as próteses totais. As próteses totais suportadas por implantes dentários, fixas ou removíveis, têm sido empregadas como uma solução eficaz para o edentulismo há décadas, devolvendo aos pacientes a função mastigatória, a estética, a fonética e, por consequência, sua qualidade de vida (BRÅNEMARK *et al*. 1969; FEINE *et al*. 2002; RAGHOEBAR *et al*. 2003; ÅSTRAND *et al*. 2004; DE BRUYN *et al*. 2013). Ambos os tipos de próteses sobre implantes proporcionam melhora na estabilidade e retenção, e como consequência um aprimoramento na qualidade da mastigação, da fonação e da satisfação do paciente (DOUNDOULAKIS *et al*. 2003; ATTARD; ZARB, 2004;

WENNERBERG; ALBREKTSSON, 2011; COMPAGNONI *et al*. 2014; MICHELON *et al*. 2019).

2.2 Planejamento Reverso

O planejamento da posição do implante deve ser baseado na posição tridimensional ideal da futura prótese (planejamento reverso). Esta, por sua vez, é derivada de um enceramento diagnóstico, o qual contempla referências intra- e extra-orais na reconstituição fisionômica e restabelecimento do equilíbrio do sistema estomatognático. Ao se planejar o posicionamento da futura prótese, deve-se avaliar as condições de tecidos duros e moles que possam interferir na estética e função da mesma, garantindo assim a melhor posição tridimensional para a instalação do implante. Este planejamento é fundamental e necessário para guiar a posição do implante, visando assim o sucesso estético e funcional de longo prazo (MARTIN *et al.* 2006; MORTON *et al.* 2014).

O planejamento cirúrgico pré-operatório consiste na união do planejamento protético com exames de imagens, que devem fornecer três principais informações: as características morfológicas da crista alveolar residual, a orientação do rebordo alveolar e os limites anatômicos ou patológicos no local da colocação do implante (HARRIS *et al*. 2002; HARRIS *et al*. 2012; BORNSTEIN *et al*. 2014).

O método mais utilizado de preparar um paciente edêntulo para o exame de imagem é a confecção de um guia radiográfico, o qual é baseado na prótese total do paciente que, quando em boas condições, é duplicada com resina acrílica. Esta duplicação recebe marcadores radiopacos (guta-percha, resina composta, etc.) em pontos de referência estratégicos (na posição idealizada para os implantes e/ou nas flanges) (Figura 1). Para que o exame tomográfico seja acurado, é imprescindível que a guia radiográfica seja estável e confortável para o paciente, ou seja, deve estar bem adaptada aos tecidos bucais e não sofrer deslocamento no momento do exame. Para tal, é possível realizar um registro interoclusal para estabilizá-la em boca. Este registro ajuda o paciente a ocluir com o antagonista em uma posição mandibular horizontal e vertical correta (relação cêntrica e dimensão vertical de oclusão), evitando assim sua

movimentação (DE SANTIS *et al.* 2019; VERHAMME *et al.* 2012; VERCRUYSSEN *et al.* 2015; SUN *et al.* 2013).

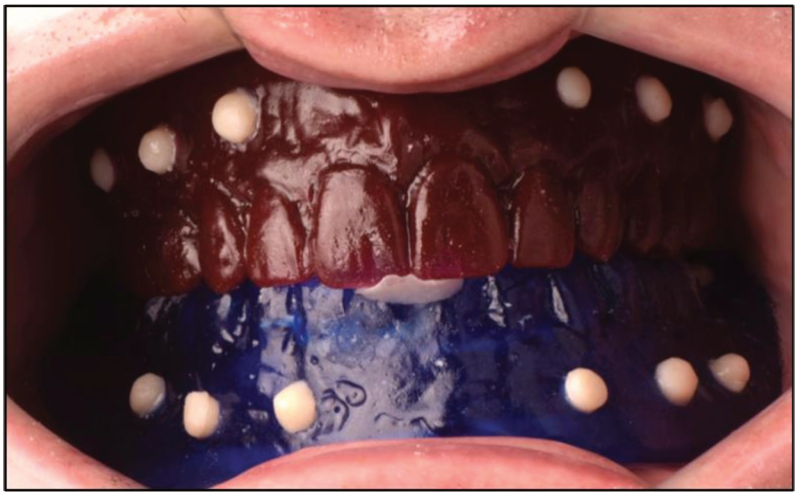

Figura 1. Guias radiográficos analógicos obtidos a partir da duplicação do enceramento diagnóstico de duas próteses totais novas (planejamento reverso). Fonte: Projeto de Extensão Prótese Digital (UFSC).

2.3 Aquisição de Imagens

2.3.1 Tomografia Computadorizada

A Tomografia Computadorizada (TC) é uma ferramenta útil não apenas para diagnóstico, mas também para o planejamento cirúrgico tridimensional do local do implante, para a avaliação da densidade óssea e análise de estruturas anatômicas (TYNDELL; BROOKS, 2000; VAN *et al.* 2003). Mais recentemente, as TCs evoluíram para Tomografia Computadorizada de Feixe Cônico (TCFC), proporcionando benefícios como a diminuição da dose de radiação para o paciente. Na TCFC, a imagem volumétrica adquirida fornece uma imagem com maior resolução espacial, além de fornecer campo de visão escalável, o qual pode incluir toda a região maxilofacial: maxila, mandíbula e base de crânio (CHOI *et al.* 2011). A imagem pode ser reconstruída em diferentes planos, chamada de reconstrução multiplanar e possui a capacidade de formar imagens em planos ou curvas. Os dados obtidos podem ser reformatados ou realinhados criando vários tipos de imagens diferentes, aumentando a eficiência diagnóstica (ANGELOPOULOS 2008).

A partir da TCFC é gerado um conjunto de arquivos salvos em um formato comum a todas as áreas da saúde, o *Digital Imaging and Communications in Medicine* (DICOM). O arquivo DICOM permite a comunicação entre programas de computador, facilitando assim a sua aplicabilidade não só para finalidades de diagnóstico, mas também para fins de planejamento. Neste último, é possível simular tridimensionalmente a posição dos implantes, avaliando estruturas anatômicas e seu posicionamento em relação à prótese, além de realizar o desenho de guias cirúrgicas para orientar a instalação dos implantes (EGGERS *et al.*2009) (Figura 2). O arquivo DICOM também pode dar origem, por meio de renderização, a um modelo tridimensional (3D) o qual pode ser manufaturado através da manufatura aditiva por impressão 3D (JACOBS R; QUIRYNEN M. 2014; JODA *et al.* 2017; MANDELARIS *et al.* 2017; GALLUCI *et.al.* 2019).

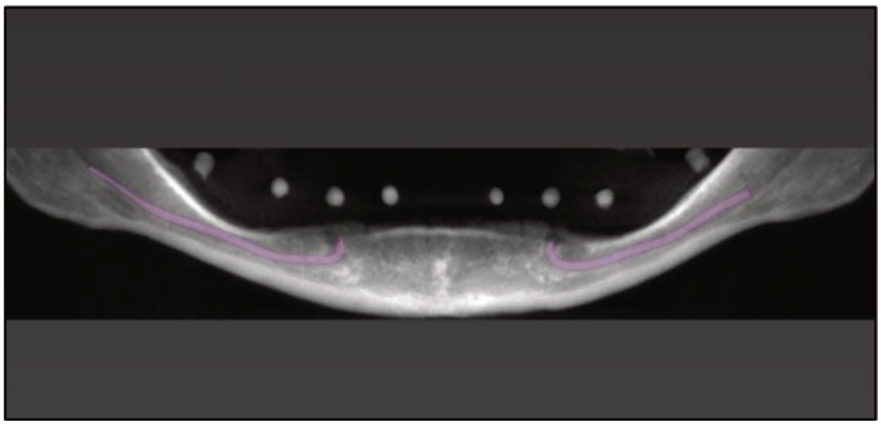

Figura 2. Tomografia computadorizada de feixe cônico (TCFC) de uma mandíbula edêntula, reconstrução panorâmica. Fonte: Projeto de Extensão Prótese Digital (UFSC).

2.3.2 Arquivos de Digitalização de Superfícies

A tecnologia de digitalização de superfícies (ou escaneamento) permite transformar as estruturas anatômicas analógicas visíveis da boca em um modelo digital tridimensional, gerando um arquivo de superfície em formato *Standard Tesselation Language* ("*STL*"). O STL consiste em uma malha tridimensional formada por milhares de pequenos triângulos unidos por pontos ou nós, que auxilia no planejamento digital com informações do rebordo, dentes e estruturas anatômicas do paciente (Figura 3). Além do mais, após as imagens das estruturas serem renderizadas para gerar o arquivo STL, a manufatura assistida

por computador (*Computer-Aided Manufacturing, CAM*) pode ser empregada para a confecção de guias cirúrgicas, próteses (unitárias, parciais ou totais) e biomodelos, através da manufatura aditiva ou impressão 3D (LEE *et al*. 2016).

Outros tipo de arquivos de superfícies incluem os formatos *Object File Wavefront 3D* "*OBJ*" e *Polygon File Format* "*PLY*". O "*OBJ*" é um formato de arquivo de definição de geometria universalmente aceito, que representa informações tridimensionais de cor e textura (JODA & GALLUCCI 2014). O "*PLY*" é um formato de arquivo também similar ao STL, porém contém dados de cor e superfície, diferente do STL que só contém dado de superfície (GRANATA *et al*. 2019).

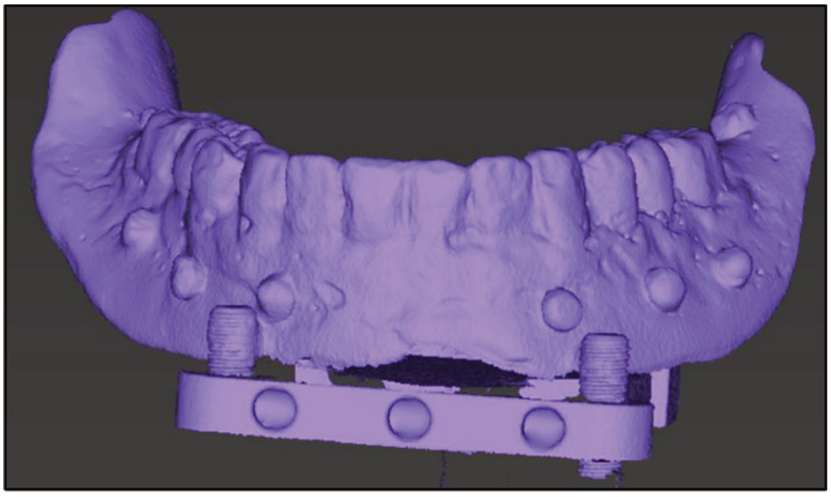

Figura 3. Arquivo STL obtido a partir da digitalização (escaneamento) da montagem de dentes de uma prótese total inferior. Fonte: Projeto de Extensão Prótese Digital (UFSC).

2.3.3 Programas de Planejamento Cirúrgico Virtual

Para realização de planejamentos virtuais é necessária a utilização de programas de planejamento cirúrgico de implantes, tais como o BlueSky Plan® (BlueSkyBio®, EUA), coDiagnostiX® (Dental Wings®, Canadá), NobelClinician® (Nobel Biocare®, Suíça), Simplant Planner® (Dentsply-Sirona®, EUA), Implant Studio® (3Shape®, Dinamarca), entre outros. Cada vez mais, os fabricantes de implantes vêm desenvolvendo e aprimorando seus próprios programas de planejamento (D'HAESE *et al*. 2017).

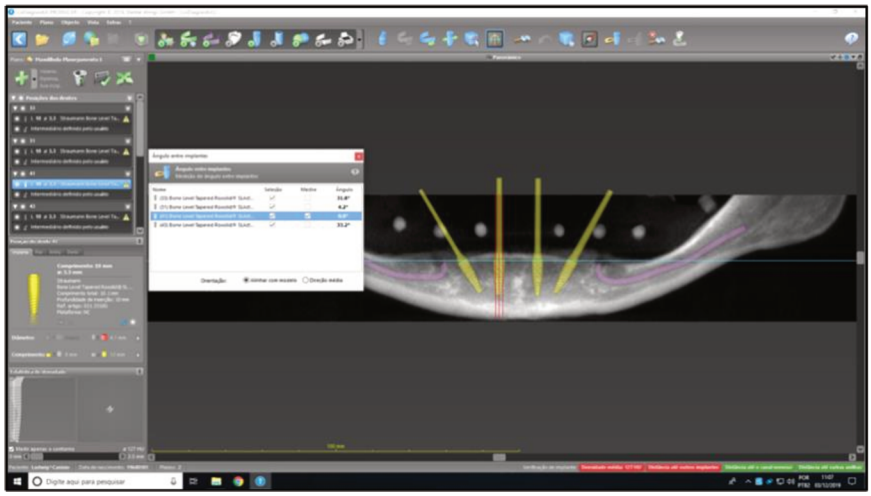

Figura 4. Interface de usuário do programa de planejamento cirúrgico virtual coDiagnostiX® (Dental Wings, Canadá). Fonte: Projeto de Extensão Prótese Digital (UFSC).

Para utilização dos programas de planejamento cirúrgico, são necessárias as informações anatômica e protética do paciente. A informação anatômica é fornecida pelo arquivo DICOM, enquanto a protética pode ser obtida de duas maneiras – 1) uma TCFC realizada a partir da guia tomográfica (protocolo *Dual Scan*, ou duplo escaneamento); ou 2) pelo escaneamento intraoral ou de bancada (modelos ou moldes do paciente) das estruturas anatômicas (dentes, rebordo e tecidos moles). Ambos os métodos de aquisição da informação protética dão origem a um arquivo STL, o qual necessita ter pontos anatômicos de referência comuns com o arquivo DICOM, para que possam ser unidos (*merging*) pelo programa, permitindo a realização de um planejamento digital e a simulação de várias situações restauradoras, reabilitadoras e possibilidades cirúrgicas (VIEGAS *et al.* 2010; HASSAN *et al.* 2017; TAHMASEB *et al.* 2018).

Estes programas possuem uma ampla biblioteca de implantes, a qual permite ao clínico a simulação de vários planejamentos diferentes. Além de possibilitarem um planejamento da cirurgia de implantes, estes programas permitem também o desenho de guias cirúrgicas, a criação de um protocolo de fresagem cirúrgica para ser utilizado durante a cirurgia, e a exportação do planejamento para aplicativos de visualização digital em dispositivos eletrônicos. Por último, alguns programas permitem também a sobreposição das TCFCs pré- e pós-operatórias, permitindo a comparação da posição que foi planejada com a posição final do implante (acurácia).

2.4 Manufatura Aditiva

A manufatura aditiva (MA) vem sendo aplicada na Odontologia por meio de diferentes métodos - através da estereolitografia (SLA), da sinterização seletiva a laser (*Selective Laser Sintering*, SLS) e do processamento de luz digital (*Digital Light Processing*, DLP). O que diferencia entre os métodos é basicamente o tipo de material utilizado e a fonte de luz. No SLA, são utilizados polímeros líquidos, enquanto no SLS podem ser utilizados polímeros em pó, mas também aço, níquel e titânio, possibilitando até mesmo a impressão de implantes dentários. Isso torna o SLS um processo de fabricação mais complexo e com um custo mais elevado (BERRY *et al*. 1997). No DLP, a principal diferença para o método SLA está no tipo de luz emitida na impressora (REVILLA-LEÓN & ÖZCAN 2019).

A estereolitografia (SLA) consiste em um método de manufatura aditiva que produz uma imagem tridimensional, física, e que solidifica seletivamente por meio de tecnologia de feixe de laser uma resina líquida sensível ao ultravioleta (Figura 5). Este método tem sido o mais utilizado para manufatura de guias cirúrgicas em cirurgia assistida por computador pois, além das vantagens de produção, ajuda a reduzir o tempo cirúrgico e as complicações cirúrgicas (SCHWARZ *et al*. 1989; ISRAELSON *et al*. 1992). As guias cirúrgicas SLA devem ser projetadas e usadas para serem utilizadas em ambas as etapas de perfuração e colocação de implante, de maneira que os desvios lineares e angulares dos implantes sejam menores (KÜHL *et al*. 2015).

Figura 5. Guia cirúrgica logo após a impressão em impressora 3D: Micron® P305 Dental 3D (Micron® Dental, EUA), por meio de prototipagem rápida. Fonte: https://www.microndental.com.

2.5 Cirurgia Assistida por Computador

A criação da tomografia por Godfrey Hounsfield (1919-2004), e a criação do exame de TCFC permitiram o desenvolvimento de técnicas que possibilitassem a transformação de imagens bidimensionais em imagens tridimensionais, com a digitalização de cabeças humanas (BROWN 1979). Em 1988, a *Columbia Scientific Inc.* (Glen Burnie, USA) introduziu a Odontologia tridimensional aplicada a programas com a conversão de cortes de imagens tomográficas. Em 1991, um programa de combinação, o *ImageMaster®*-101 permitiu o recurso adicional de colocação de imagens gráficas de implantes dentários nas imagens transversais. A primeira versão do *SimPlant®*, produzida pela *Columbia Scientific* em 1993, permitiu a colocação de implantes virtuais em dimensões exatas. Em 1999, o Simplant® 6.0 introduziu a renderização tridimensional (geração de arquivos STL de superfície). Em 2002, a *Materialize (Leuven, Bélgica)* adquiriu a *Columbia Scientific* e introduziu a tecnologia para transferir o planejamento do programa de computador para o leito cirúrgico, permitindo a realização de fresagens ósseas a uma profundidade e direção exatas através de um guia cirúrgico. Desde então, novas evoluções nos programas de cirurgias guiadas vem sendo introduzidas (JAVAID & HALEEM 2017; D'HAESE, J. *et al.* 2017).

Ao se conduzir uma cirurgia de instalação de implante, é crucial que se mantenha a posição tridimensional planejada anteriormente pelo enceramento diagnóstico resultante do planejamento. Quando o paciente possui perdas dentárias unitárias ou espaços pequenos a serem restaurados, os dentes adjacentes acabam auxiliando na posição espacial durante a cirurgia. Por outro lado, em pacientes edêntulos totais, o controle da posição dos implantes, junto com abertura bucal do paciente, inserções musculares baixas e rebordo reabsorvido, torna-se um processo mais difícil, onde a cirurgia assistida por computador torna-o mais seguro de ser realizado (CHEN *et al.* 2018).

Ronald Jung *et al.* (2009) descreveram duas técnicas cirúrgicas que podem ser utilizadas na instalação do implante: os sistemas estáticos, ou também conhecidos como *s-CAIS* (*static Computer-Assisted Implant Surgery*), e os sistemas dinâmicos, podendo ser tanto o *n-CAIS* (*navigated Computer-Assisted Implant Surgery*), onde ocorre a comunicação em tempo real entre o

cirurgião e um computador na colocação do implante, sem a utilização de guias intra-orais, e o *r-CAIS* (*robotic Computer-Assisted Implant Surgery*), onde um computador reproduz em tempo real, em um robô, os movimentos da mão do cirurgião na execução da cirurgia. Cada tipo de cirurgia assistida por computador apresenta suas vantagens e desvantagens, e seu nível de acurácia (CASSETA *et al*. 2011) (Quadro 1):

Quadro 1. Resumo das principais características dos sistemas de cirurgia de implantes dentários assistida por computador.

SISTEMA	Utilização de Guia Físico Durante a Cirurgia	Presença do Cirurgião no Ato Cirúrgico	Acurácia
Estático	SIM	SIM	MÉDIA
Dinâmico			
Navegado	NÃO	SIM	ALTA
Robótico	NÃO	NÃO	ALTA

2.5.1 Cirurgia Assistida por Computador Estática (e-CAC)

Nas cirurgias assistidas por computador estáticas (e-CACs), os arquivos digitais são importados para um programa de planejamento. Após realizar o posicionamento virtual dos implantes no programa (Figura 4), o dentista passa para a fase de desenho da guia. Este desenho é exportado em um arquivo STL (Figura 6A) para manufatura aditiva (impressão 3D). A guia, depois de impressa, passa pelo seu processo de cura e encaixe de anilhas metálicas, as quais servem como indexador de alinhamento e profundidade durante a fresagem (Figura 6B). Com estas guias, a posição final do implante não pode ser modificada, porém pode ocorrer desvios de posição durante a sua utilização, visto que o posicionamento da guia está sujeito a fatores externos, que não podem ser controlados durante o ato cirúrgico (JUNG *et al*. 2009).

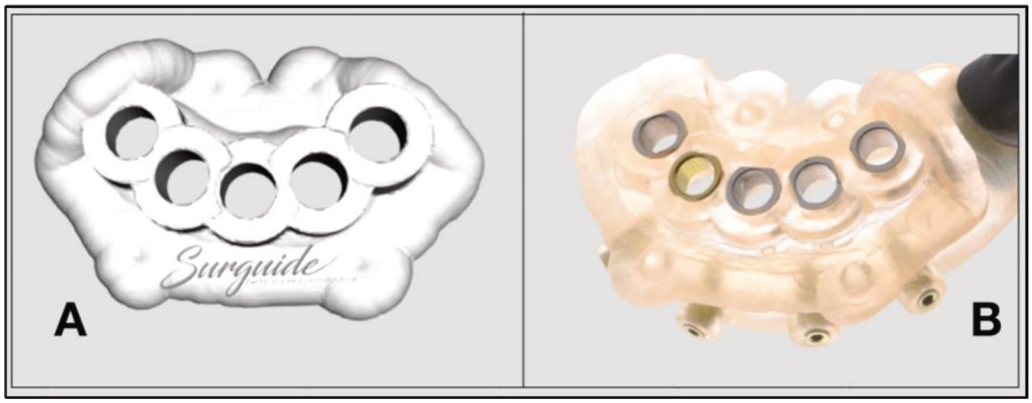

Figura 6. Guia cirúrgica utilizada em cirurgia guiada estática (e-CAC). (A) Arquivo STL gerado a partir do desenho da guia cirúrgica. (B) Guia (SLA) impressa pronta para utilização. Fonte: Projeto de Extensão Prótese Digital (UFSC).

Vercruyssen *et al.* (2014), em um ensaio clínico randomizado, avaliaram 72 arcos totais (maxila/mandíbula) em que foram instalados implantes por diferentes métodos, sendo dois tipos de guias cirúrgicas apoiadas em osso, dois tipos de guias apoiadas em mucosa e um grupo sem ter suporte de guia. Os autores concluíram que houve um desvio maior com cirurgia guiada na profundidade do implante (orientação vertical) e que nas orientações horizontais os desvios foram menores. Já em implantes instalados sem guia cirúrgico, os desvios encontrados foram maiores em todos os sentidos.

Implantes instalados pela técnica de cirurgia guiada estática podem até ser precisos, mas desvios significativos devem ser levados em consideração, onde um maior desvio na região apical do implante e desvios de angulação podem ser esperados (VAN *et al.* 2011; ARISAN *et al.* 2010; DI GIACOMO *et al.* 2011). Um dos principais fatores que podem causar desvios dos implantes instalados por cirurgia guiada pode ser dar pelo posicionamento da guia e não pelo método como um todo (VAN DE WIELE *et al.* 2014).

2.5.2 Cirurgia Guiada Navegada (n-CAC)

No sistema dinâmico de navegação, o programa de computador é usado para planejar a posição do implante, e dispositivos de rastreamento óptico são utilizados para facilitar a inserção do implante na posição pré-planejada através da visão estereoscópica, em tempo real. Para detectar e rastrear o movimento da fresa, são conectados à peça de mão e na arcada do paciente objetos

marcados que, através de uma tela, conseguem exibir a localização em tempo real da ponta do instrumento via imagens 2D (Figura 7). Isso permite ao cirurgião acompanhar em modo real a cirurgia podendo modificar o procedimento caso necessário (MILLER, BIER, 2006; GALLUCI *et al.* 2019).

Em um estudo *in vitro* realizado por Kramer *et al.* (2005), a precisão de implantes dentários unitários instalados por cirurgia convencional e cirurgia guiada navegada foi comparada. Os autores concluíram que implantes instalados pela cirurgia navegada tiveram uma precisão melhor do que aqueles instalados pelo método convencional. O sistema de cirurgia navegada por imagem fornece alta precisão no posicionamento do implante e o relatório preciso oferecido no momento da cirurgia ajuda a controlar situações onde se tem limitações de estruturas anatômicas, permitindo assim ao cirurgião transferir com maior segurança o planejamento realizado no pré-operatório para o posicionamento do implante em boca. No entanto, os autores afirmam que são necessários mais estudos clínicos que avaliem em longo prazo implantes instalados por essa técnica cirúrgica (KRAMER *et al.* 2005; KOULECHOV, LUETH, 2004).

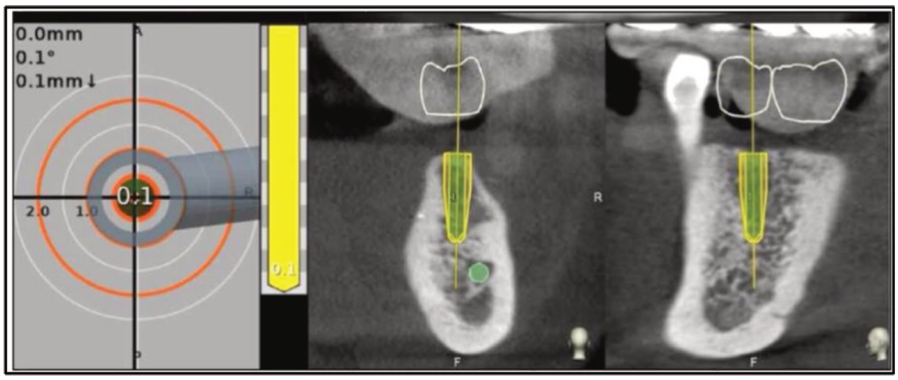

Figura 7. Cirurgia Guiada Navegada para a colocação de implantes dentários. Navident® (Claron Technology Inc, Canadá). Fonte: https://www.claronav.com/navident/.

2.5.3 Cirurgia Guiada Robótica (r-CAC)

A cirurgia robótica foi implementada pela *National Aeronautics and Space Administration* (NASA) e aprovada em 2000 pela *US Food and Drug Administration* (FDA). Esta técnica revolucionária vem sendo aplicada em diferentes procedimentos cirúrgicos, principalmente nas especialidades

médicas, onde se buscam cirurgias minimamente invasivas. Ao se incorporar na histeroscopia em tempo real, a cirurgia robótica permitiu uma melhora no campo de visão operatório, eliminou o efeito de tremores de mão ou instrumento e permitiu uma precisão que não se pode alcançar pela mão e pulso de um cirurgião. Mesmo com todas as vantagens da cirurgia robótica, seu uso é de altíssimo custo e até meados de 2009 não era permitida sua utilização em boca (VINCI *et al*. 2010; CHIARELLI *et al*. 2012; YU *et al*. 2015).

A *Trans-Oral Robotic Surgery* (TORS) hoje além de ser usada para procedimentos de lesões benignas e malignas de orofaringe, língua e laringe, pode também ser aplicada na Odontologia (CERNEA *et al*. 2009). Em 2009, a empresa Yomi® (Neocis® Inc., EUA) lançou o primeiro sistema robótico para cirurgias odontológicas (Figura 8). O sistema fornece um programa para planejamento e orientação de navegação para instrumentação durante a cirurgia de implantes. Além de fornecer um *feedback* tátil e controlar a posição, profundidade e angulação durante a osteotomia, permite a realização de cirurgias com uma precisão a qual não é possível alcançar com as mãos. Porém, trata-se de procedimentos de custos muito elevados que ainda estão em desenvolvimento (NATARAJAN 2018; YU *et al*. 2015). Portanto, a precisão de cirurgia robótica de implante dentário está começando a ganhar força com apenas alguns estudos clínicos no momento. Estudos *in vitro* observaram que cirurgias de osteotomia robótica apresentaram desvios lineares de menos de 1 mm, e desvios angulares de 2º ou menos. No entanto, ainda não foi possível determinar o torque de inserção de implantes (KRAMER *et al*. 2005; WU *et al*. 2019). Apesar das limitações e dificuldades iniciais de desenvolvimento, o uso futuro da robótica neste campo parece florescer à medida que os sistemas melhoram e os custos diminuem (VICINI *et al*. 2010; VERCRUYSSEN *et al*. 2014).

Figura 8. Cirurgia Guiada Robótica (r-CAC) para a colocação de implantes dentários. Yomi® (Dental Implant Pro Inc., EUA). Fonte: https://www.dentalimplantpro.com/dental-implants/yomi-robotics/

2.6 Tipos de Suporte da Guia

Embora a prototipagem rápida ofereça métodos altamente acurados para a fabricação de guias cirúrgicas, estas ainda são propensas a causar desvios angulares e lineares na posição final do implante. Estas falhas são atribuídas tanto a erros na aquisição das imagens DICOM e STL (tomografia e escaneamento, respectivamente), quanto a problemas de mau posicionamento da guia no momento da cirurgia, o que por sua vez está ligado ao tipo de suporte.

As guias podem ser suportadas por dentes, mini-implantes provisórios, osso ou mucosa, e cada tipo de suporte pode apresentar uma distorção diferente no posicionamento final do implante (ARISAN *et al.* 2010; VERHAMME *et al.* 2016; OCHI *et al.* 2013). Guias dento- ou implanto-suportadas possuem uma melhor estabilidade, enquanto guias ósteo-suportadas necessitam de um bom descolamento de retalho, o que dificulta muitas vezes a ancoragem da guia, e guias muco-suportadas permitem a utilização da técnica sem retalho (*flapless*). Entretanto, nesta última, a espessura e resiliência da fibromucosa podem interferir na sua retenção e estabilidade durante a cirurgia (ARISAN *et al.* 2010).

Casseta *et al.* (2011) avaliaram em um estudo retrospectivo a precisão da colocação de implantes através de imagens onde mensuraram desvios globais

(apical e coronal), mas principalmente desvios de profundidade. Os autores concluíram que a precisão depende da capacidade de posicionamento da guia de perfuração com apoio nos tecidos afim de manter essa posição estável durante todas as fases do procedimento. A ancoragem da guia é essencial, portanto os autores recomendam que sejam utilizados pelo menos três parafusos de auxiliem na estabilização da guia, formando um triângulo de superfície de ancoragem.

Em uma revisão sistemática realizada por Seo & Juodzbalys (2018), os autores avaliaram a precisão de guias cirúrgicos com suporte mucoso em pacientes edêntulos. As conclusões indicam que sempre haverá um desvio na posição final do implante, e que o cirurgião deve estar preparado para esse desvio, uma vez que os motivos que o provocam são multifatoriais, tais como tabagismo, densidade óssea, arco a ser reabilitado, comprimento do implante e espessura da mucosa.

2.7 Acurácia de Cirurgia Guiada Estática

A acurácia em cirurgia guiada estática é verificada por meio de tomografia computadorizada pós-operatória, pela coincidência entre a posição do implante planejado virtualmente no programa de computador com a posição real do implante na boca do paciente (Figura 9). No entanto, por motivos éticos, financeiros e de proteção à radiação ionizante, este tipo de comparação acaba ficando restrito a pesquisas científicas. Nelas, a acurácia do implante ou do local da osteotomia é principalmente expresso em desvios lineares (milímetros) e angulares (º) em quatro pontos de referência: no ponto de entrada do implante (*neck*), no ápice (*apex*), no longo eixo (*long axis*), e em altura/profundidade (*depth*) (PETTERSSON *et al.* 2010; VERCRUYSSEN *et al*. 2014)

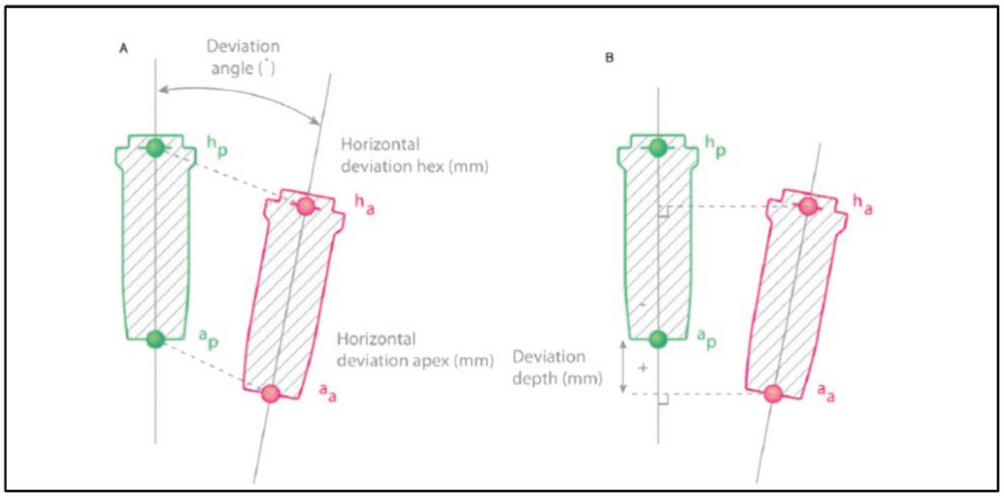

Figura 9. Esquema ilustrando a mensuração dos desvios horizontais (A) e verticais (B) entre a posição planejada (verde) e real (vermelha) do implante. Adaptado de Pettersson *et al*. (2010).

A acurácia é avaliada ao sobrepor a tomografia (CT) pré-operatória com a tomografia (TCFC) pós-operatória (Figura 9). A imprecisão mais importante com cirurgia guiada é na direção vertical (profundidade). As imprecisões horizontais são claramente menores. Por outro lado, em cirurgia convencional não guiada, as imprecisões são significativamente maiores em todos as orientações (VERCRUYSSEN *et al*. 2014).

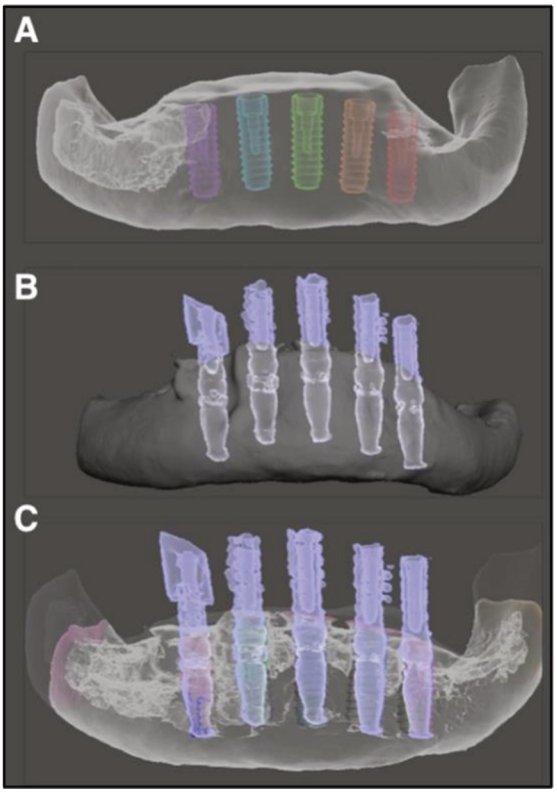

Figura 10. (A) Planejamento virtual realizado no programa BlueSky Plan® (BlueskyBio, EUA) sobre uma tomografia pré-operatória da mandíbula edêntula de uma paciente do Projeto de Extensão "Prótese Digital", da Universidade Federal de Santa Catarina. (B) Tomografia pós-operatória da mandíbula com os implantes instalados por meio de cirurgia guiada estática assistida por computador (e-CAC) analisada no programa Meshmixer® (Autodesk®, EUA). (C) Sobreposição das imagens radiográficas no programa Meshmixer® (Autodesk®, EUA). É possível observar que os ápices dos cinco implantes se encontram em uma posição mais apical e vestibular do que a posição planejada virtualmente. Cortesia das imagens: Dr. Luiz Carlos Carmo Filho (Curitiba, PR).

Digiacomo *et al.* (2012) mensuraram a precisão de guias produzidas através do sistema de prototipagem rápida e sinterização seletiva a laser (SLS). Ao todo, 12 pacientes foram reabilitados com implantes utilizando guias cirúrgicas produzidas através do método de SLS. Sessenta implantes foram planejados e avaliados após a instalação. O desvio angular (DA) médio entre implantes planejados e instalados foi de 6,53º, enquanto os desvios lineares (DL) médios foram de 1,35 mm na plataforma do implante e 1,79mm no ápice do implante. Em 82,67% dos implantes foram observados desvios coronais e 58,33% observados desvios apicais. Os autores não encontraram diferenças de desvios entre maxila e mandíbula e também entre região anterior ou posterior do arco. O estudo mostrou que o uso de SLS em guias cirúrgicos teve um desvio

linear médio <1,8mm e desvio angular médio de 6,53º, e que 41,67% dos implantes instalados mostraram um desvio apical >2mm.

D'haese *et al*. (2012) realizaram um estudo em pacientes edêntulos totais maxilares avaliando a precisão de guias cirúrgicas apoiadas totalmente em mucosas. Cinquenta e cinco por cento (55%) dos implantes instalados apresentaram desvios lineares apicais maiores que 1mm. O processo de produção da guia não influencia na precisão de um guia cirúrgico total fabricado pelo método de estereolitografia que tem como suporte a mucosa do paciente. O estudo permitiu concluir que os cirurgiões devem estar cientes que desvios na posição dos implantes são esperados, e essas razões são multifatoriais. Além disso, guias suportadas pela mucosa devem cobrir uma superfície máxima, oferecendo ao cirurgião uma maneira mais reproduzível de posicionar o guia na mucosa mole, levando a menos erros de posicionamento.

3 OBJETIVOS

3.1 Objetivo Geral

Responder, por meio de uma revisão sistemática de literatura, à pergunta: *"Em arcos totais, qual a acurácia da colocação de implantes dentários por meio de cirurgia estática assistida por computador (e-CAC)?"*

3.2 Objetivos Específicos:

- Avaliar os desvios lineares e angulares médios de implantes dentários colocados por meio de cirurgia estática assistida por computador (e-CAC) em edêntulos totais;
- avaliar qual a região de implantes dentários colocados por meio de cirurgia estática assistida por computador (e-CAC) apresenta maiores desvios lineares;
- avaliar o papel dos diferentes tipos de suporte (dento-, implanto-, osteo-, ou muco- suportada) da guia cirúrgica na acurácia de implantes dentários colocados por meio de cirurgia estática assistida por computador (e-CAC) em edêntulos totais;
- comparar a acurácia de implantes dentários colocados por meio de cirurgia estática assistida por computador (e-CAC) em maxila ou mandíbula;
- comparar a acurácia de diferentes sistemas de implantes dentários indicados para colocação por meio de cirurgia estática assistida por computador (e-CAC).

4 ARTIGO CIENTÍFICO

Este trabalho foi escrito na forma de artigo científico e preparado de acordo com as normas para submissão ao periódico *Clinical Oral Implants Research* (Qualis A1, Fator de Impacto 3.825).

ACCURACY OF STATIC COMPUTER-ASSISTED IMPLANT SURGERY IN TOTALLY EDENTULOUS PATIENTS: A SYSTEMATIC REVIEW

Running tittle: Guided implant surgery and edentulism

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Authors' Contributions:

Dr. Tarla Taynara Oliveira dos Santos worked on study conceptualization, design, data collection, data analysis, drafted the initial manuscript and approved the final manuscript as submitted.

Dr. Patricia Pauletto worked on data collection, data analysis, drafted the initial manuscript and approved the final manuscript as submitted.

Dr. Gabriela Sabatini worked on risk of bias assessment, drafted the initial manuscript and approved the final manuscript as submitted.
Dr. Franciele Floriani worked on drafting the initial manuscript and approving the final manuscript as submitted.
Dr. Vinicius Dutra worked on data analysis and approving the final manuscript as submitted.
Dr. Luis André Mezzomo worked on study conceptualization, design, data analysis, drafted the initial manuscript and approved the final manuscript as submitted.

Conflict of Interest
The authors declare that have no conflict of interest.

ABSTRACT

Objectives: To answer the following focused question: *"In full arches, what is the accuracy of dental implants placed by means of static computer-assisted implant surgery (s-CAIS)?"*
Materials and Methods: A comprehensive literature search was performed. Two independent and calibrated reviewers selected studies based on pre-defined eligibility criteria and extracted data on *study*-, *population*-, *intervention*- and *outcome* (accuracy) characteristics. Risk of bias and the quality of evidence assessments of the included articles were performed by an independent and blinded reviewer. The meta-analysis was conducted using the random-effects model at a 5% significance level.
Results: Nineteen (2 RCTs, 13 CCTs, 1 Cohort and 3 Case Series) studies met the inclusion criteria and were included. Overall, 1,884 implants distributed among arches in 369 patients (males $n = 182$; females $n = 152$) were assessed. Random-effects meta-analysis revealed statistically significant mean horizontal linear distortions at the implant neck and apex levels of 1.09mm (95% CI: 0.71 - 1.47) ($p < 0.001$) and 1.44mm (95% CI: 0.94 - 1.94) ($p < 0.001$), respectively, significant mean vertical linear distortion at implant depth level of 0.16mm (95% CI: -0.04 - 0.35) ($p = 0.113$) and significant mean angular distortion of 3.46º (95% CI: 2.52 - 4.40) ($p < 0.001$). Accuracy did not differ significantly between maxilla and mandible at all parameters assessed ($p > 0.05$).
Conclusion: The accuracy of static computer-assisted implant surgery (s-CAIS) in edentulous patients is within a clinically acceptable range and a 2-mm

horizontal and 1-mm vertical safety margin should always be respected at planning.

Keywords: dental implants, computer-assisted guided surgery, edentulous jaw, three-dimensional printing, dimensional measurement accuracy, systematic review.

INTRODUCTION

Edentulism is a prevalent oral condition among elderly people (World Health Organization 2013) and causes several limitations such as functional (phonetics, masticatory capacity and nutritional intake), aesthetical and psychosocial impairments (Emani *et al.* 2013; De Marchi *et al.* 2010). Implant-supported prosthesis have already been employed for decades, successfully restoring the quality of life of edentulous patients (Brånemark *et al*. 1969; Boerrigter *et al*. 1995; Feine *et al*. 2002; Meijer *et al*. 2003; Åstrand *et al*. 2004; De Bruyn *et al*. 2013). However, the long-term functional and aesthetical success of dental implants depends on their correct three-dimensional (3D) positioning (Katsoulis *et al*. 2009; Zitzmann & Marinello 1999). Therefore, the implant-supported prosthesis must obey a meticulous surgical and prosthetic planning, where implants should be placed to achieve an adequate 3D position within the alveolar bone in relation to the planned prosthetic restoration (Blanes *et al*. 2007).

Recent advances in image acquisition (cone beam computed tomography as well as intraoral and desktop scannings) have enabled digital three-dimensional planning of surgeries through files (*dicom* and *stl*), which when exported to specific softwares can be merged to create a 3D virtual patient (Van Steenberghe *et al*. 2003; Nocini *et al*. 2013; Derksen *et al*. 2019). This virtual patient can be viewed in the implant planning software, where data on hard and soft dental tissues, prosthetic treatment proposals and bone volume can be viewed as different layers (Lee *et al*. 2015), enabling the clinician to perform the virtual implant placement according to future prosthetic needs. This information can be used to design and manufacture customized surgical drilling guides, which offer significant improvements in terms of accuracy, timing, efficiency and reduction of the surgical error, thus benefiting the patient, the surgeon and the prosthodontist

(Ganz *et al*. 2005; Ozan *et al*. 2007; Van Steenberghe *et al*. 2011; Younes *et al*. 2018; De Oliveira *et al*. 2019). Experimental clinical (Pozzi *et al*. 2014; Tallarico *et al*. 2018), *in vitro* (Viegas *et al*. 2010; Soares *et al*. 2012) and cadaver (Pettersson *et al*. 2010; Chen *et al*. 2018) studies, as well as systematic reviews (Moraschini *et al*. 2015; Carbajal Mejía *et al*. 2016; Laleman *et al*. 2016), have shown a superior accuracy (reduced linear and angular deviations) of fully guided (FG) compared to free-hand implant surgery. Because of that, a flapless procedure, that significantly reduces the trauma and morbidity to the patient, became in some specific cases a remarkable advantage offered by the computer-assisted implant surgery (Azari & Nikzad 2008; Vieira *et al*. 2013; Albiero *et al*. 2019).

A fully digital and minimally invasive workflow for totally edentulous patients, using computer-guided surgery without a flap, is a viable treatment protocol (Vieira *et al*. 2013; Di Torresanto *et al*. 2014; Gastaldi *et al*. 2018). In these patients, computer-assisted flapless surgery is associated with reduced treatment time in the chair, as well as reduced discomfort and trans- and postoperative morbidity (Di Torresanto *et al*. 2014). This is particularly relevant considering that most edentulous patients are elderly users of oral anticoagulants (Sanz & Naert 2009). Thus, a faster, less invasive and more accurate procedure would better address the needs of this specific group of patients.

The accuracy of s-CAIS in edentulous arches is within the clinically acceptable range in most clinical situations (Tahmaseb *et al*. 2018; Albiero *et al*. 2019). However, although computer-assisted implant placement provides important benefits in these cases, deviations from planned implant placement, due to the simple absence of rigid intraoral anchoring structures, can represent significant risks (Vieira *et al*. 2013). These include, but are not limited to, the compromised positioning and stability of the surgical guide, which, in turn, can lead to linear and angular deviations of the implant in relation to the planned position (Albiero *et al*. 2019). In a clinical study with fourteen edentulous patients, Vieira *et al*. (2013) found linear deviations of approximately 2mm in the maxila and 1.5mm in the mandible between the actual and the planned implant position. Thus, a safety margin of at least 2 mm must always be respected when planning (Marlière *et al*. 2018; Tahmaseb *et al*. 2018).

An increasing number of papers have been published in the literature showing the accuracy of dental implants placed by means of static computer-assisted surgery (s-CAIS) in single and partially edentulous cases (Valente *et al*. 2009; Tahmaseb *et al*. 2018; Wismeijer *et al*. 2018; Derksen *et al*. 2019; Schneider *et al*. 2019; Smitkarn *et al*. 2019; Younes *et al*. 2019). In these cases, the existence of excellent anatomical references in the remaining teeth significantly contributes to the proper merging of the images acquired in the planning (Fürhauser *et al*. 2014; Gallucci *et al*. 2015). Nevertheless, little is known about the accuracy of this technique in totally edentulous patients. Therefore, the aim of this study is to answer, by means of a systematic review of the literature, to the following question: "*In full arches, what is the accuracy of dental implants placed by means of static computer-assisted implant surgery (s-CAIS)*?"

MATERIALS AND METHODS

Protocol and Registration

This systematic review followed the Preferred Reporting Items for Systematic Reviews and Meta-Analysis Protocols (PRISMA-P) 2015 statement (Moher *et al*. 2009). A study protocol was elaborated and registered at the International Prospective Register of Systematic Reviews (PROSPERO) under identifier CRD42020202461.

Eligibility Criteria

The PICOS acronym (Participants, Intervention, Comparison, Outcomes, Studies), was used to formulate the focused question of this systematic review, where *P*: fully edentulous arches, *I*: static computer-assisted dental implant placement, *C*: (there was no comparison group, for ethical reasons), *O*: primary outcomes (accuracy, as expressed by means of linear and angular deviations) and secondary outcomes (implant failure, implant survival rate, marginal bone loss and PROMS (patient-reported outcome measures, such as degree of satisfaction and VAS pain)), and *S*: clinical prospective experimental and observational studies with a sample size of at least 10 implants. The following

exclusion criteria were adopted: 1) studies in which only single missing-tooth or partially edentulous arches were considered; 2) studies in which sample included non-conventional implants, such as zygomatic implants; 3) studies with <10 implants placed by means of s-CAIS; 4) no primary (accuracy) outcomes reported; 4) retrospective studies; 5) *in vitro* studies; and 6) reviews, case-reports, protocols, short communications, personal opinions, letters, posters and conference abstracts.

Information Sources and Search Strategy

Comprehensive electronic search strategies were developed for EMBASE, Latin American and Caribbean Center on Health Sciences (LILACS), PubMed, SCOPUS, Web of Science, Cochrane Central Register of Controlled Trials, EBSCO and SciELO. Additionally, a grey literature search was performed on Google Scholar, Open Grey and ProQuest Thesis & Dissertations databases. There was no time period restriction. Furthermore, hand-searches were performed on the reference lists of included articles. Experts were also consulted in order to improve search findings. Two reference management softwares (EndNote® X7, Thomson Reuters, USA) were used to exclude duplicates and organize references (Rayyan® QCRI, Qatar Computing Research Institute, Qatar) (Ouzzani *et al*. 2016).

Study Selection

A two-phase process was conducted by the same two reviewers to select studies. In phase-one, two reviewers (T.T.O.S. and P.P.) independently screened the titles and abstracts of all identified references. Studies that did not fulfill the above noted eligibility criteria were excluded. In phase-two, the same two reviewers applied the eligibility criteria to the full-text of the studies. A third reviewer (L.A.M.M.) was consulted in the event of unresolved rating disagreements between the two reviews following a consensus discussion.

Data Collection Process

Two reviewers (T.T.O.S. and P.P.) independently collected data from included studies. Any disagreements were discussed with a third reviewer (L.A.M.M.). Data collected according to the nature of the study consisted of: study characteristics (author, year of publication, study design, country), population characteristics (sample size, gender, age of participants, arch (maxilla or mandible), residual dentition status), intervention characteristics (data acquisition, guided surgery and implant systems details) and outcome characteristics (means and standard deviations of linear and angular distortions, as well as implant survival rates, mean marginal bone loss and patient-reported outcome measures (PROMS)). To retrieve any pertinent unreported information up to three attempts via e-mail, on a weekly basis, were made to contact corresponding authors.

Risk of Bias in Individual Studies

Methodological quality and risk of bias were independently assessed by an independent and blinded examiner (G.P.S.) using different critical appraisal tools, according to each type of study. The Cochrane Collaboration's tool (Risk of Bias 2, RoB 2) was used to analyze the randomized clinical trials, whereas the non-randomized clinical trials were assessed by means of the Joanna Briggs Institute Critical Appraisal Checklist for Quasi-Experimental (Non-Randomized Experimental Studies) tool. Decisions about scoring were agreed upon by all reviewers before critical appraisal assessments, and studies were characterized according to the following: risk of bias was categorized as "high" when the study reached up to 49% score "yes"; "moderate" when the study reached 50% to 69% score "yes"; and "low" when the study reached more than 70% score "yes". Figures were made using the Robvis® software (Evidence Synthesis Hackathon, United Kingdom) (McGuinness & Higgins 2020).

Confidence in Cumulative Evidence

The overall strength of the evidences available was analyzed and categorized by groups using the Summary of Findings (SoF). Tables were produced with the aid of the GRADE online software (GRADEpro® GTD, Copenhagen, Denmark)

provided by the GRADE Working Group in association with the Cochrane Collaboration and Members of McMaster University.

Statistical Analysis

The means and standard deviations from the original articles were extracted. To perform the meta-analysis, the following variables of interest were evaluated: (a) deviation at the neck point (mm), (b) deviation at the apex point (mm), (c) deviation in depth (mm) and (d) angular deviation in degrees (º). The data for the above variables extracted from the original studies were considered as continuous. The analyzes were conducted for global deviations and in relation to the location of the jaw (maxilla/mandible). The weighted mean (WM) and its respective 95% confidence intervals (95% CI) were used as a measure of effect size (deviation). In the absence of standard deviation values for the studies, the lowest value available among the included studies was imputed. The meta-analysis was conducted using the random effects model. Statistical heterogeneity was assessed using Cochrane's Q statistic ($p < 0.001$), later transformed into I^2 (95% CI) (Higgins & Thompson 2002). The I^2 was interpreted according to the general rule as low (25%), moderate (50%) and high (75%) (Higgins *et al*. 2003). All analyzes were conducted using the Comprehensive Meta-Analysis® software version 2.0 (Biostat®, USA).

RESULTS

Study selection

Final electronic search was conducted on the 3rd of August 2020. From main electronic database searches, a total of 1,651 references were identified (details of the search strategy as well as the results for each database are given in Appendix 1). A total of 657 articles remained after duplicated studies had been removed. Among the 657 titles and abstracts read in phase one, 61 articles were selected for phase two (full-text reading) (*Kappa* score = 0.79). Nineteen (19) articles met all the inclusion criteria and were considered for qualitative synthesis. Handsearches as well as gray literature search did not add any relevant paper

for qualitative synthesis. Forty-two (42) references were excluded and the reasons for exclusion are listed in Appendix 2. The complete process of identification and selection of studies is provided in the flowchart in Figure 1.

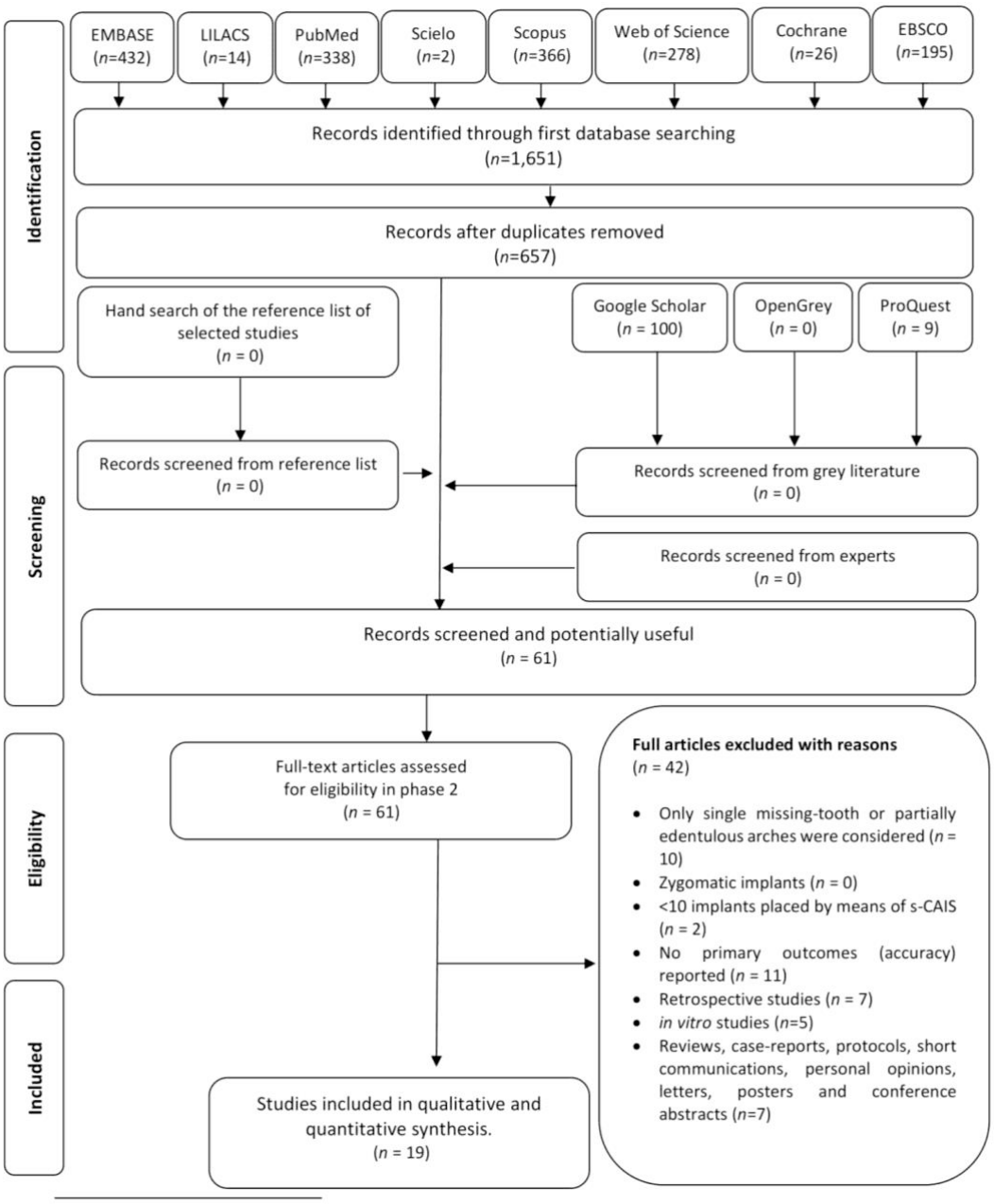


Figure 1. Flow diagram of the literature search and selection criteria (Adapted from PRISMA).

Study characteristics

A summary of the overall study characteristics is given in Table 1. There were 2 RCTs (Vercruyssen M *et al.* 2014; Vercruyssen M *et al.* 2015), 13 CCTs (Al-Harbi

& Sun 2009; Albiero *et al*. 2017; Albiero *et al*. 2019; Arisan *et al*. 2010; De Santis *et al*. 2019; Di Giacomo *et al*. 2012; Ochi *et al*. 2013; Ozan *et al*. 2009; Pettersson *et al*. 2010; Sun *et al*. 2013; Van de Wiele *et al*. 2014; Verhamme *et al*. 2014; Verhamme *et al*. 2016); 01 cohorts (De Oliveira *et al*. 2019); and 03 case series (Borges *et al*. 2012; Ersoy *et al*. 2008; Verhamme *et al*. 2012). Studies included were published between 2009 and 2019 and were conducted in different countries, as follows: Belgium (04 studies), Italy (03 studies), Turkey (03 studies), Netherlands (03 studies), Brazil (03 studies), Saudi Arabia (01 study), Sweden (01 study) and Japan (01 study). A wide range of journals published the articles: Clinical Oral Implants Research (04 studies), Journal of Periodontology (04 studies), Clinical Implant Dentistry and Related Research (03 studies), Implant Dentistry (02 studies), International Journal of Oral & Maxillofacial Surgery (01 studies), Computers in Biology and Medicine (01 study), BioMed Research International (01 study), The International Journal of Oral & Maxillofacial Implants (01 study), The Journal of Oral Implantology (01 study), Implant news (01 study) and Computers in Biology and Medicine (01 study).

Demographics

Overall, 1,884 implants distributed among arches (maxila *n* = 151; mandible *n* = 125) in 369 patients (males *n* = 182; females *n* = 152) with a mean age of 47 years were assessed. Eleven (11) different implant systems were used, whereas the planning softwares more often used to virtually plan implant placement were the Simplant® Planner (*n* = 6), Procera® (*n* = 6) and Nobel Biocare® (*n* = 3).

Data Acquisition

All studies used any sort of prosthetic reference to fabricate radiographic stents before pre-operatory CT examination. The majority of the studies used the dual scan protocol (dual CT scans) to obtain data from both bone anatomy and prosthetic references. Lastly, twelve studies employed an intraoral bite index to stabilize patients' arches during data acquisition.

Implant Guided Surgery

At surgery, only two studies (Albiero *et al.* 2017 and Ozan *et al.* 2009) did not use any additional fixation screws to stabilize the surgical guide. Only the studies of Di Giacomo *et al.* (2019) and Vercruyssen *et al.* (2015) reported post-operative surgical complications. At surgery, 4 implants underwent diameter changes for wider implants to improve stability, but the length was maintained Di Giacomo *et al.* (2019). In cases that had a limited access in the posterior region occurred, the implants were slightly tilted to mesial Di Giacomo *et al.* (2019). Two patients developed gingival inflammation Di Giacomo *et al.* (2019).

Accuracy Assessments

One single study (Al-Harbi & Sun 2009) did not make post-operative CT examination to assess the accuracy of implants placed by means of s-CAIS. Instead, this study used a Coordinating Measuring Machine (CMM). Only 5 studies clearly separately assessed linear and angular distortions of maxilla and mandible. The threshold error was evaluated only at the study of Verhamme *et al.* (2012).

Table 1. Summary of the main findings of the included studies.

Study Characteristics	**Population Characteristics**		**Intervention Characteristics**			**Outcomes Characteristics**	
	Patients	**Arch Status**	**Data Acquisition**	**Guided Surgery**	**Implant**	**Accuracy**	
First Author, Year Study Design Country	**1.** *n* total **2.** Gender (♂;♀) **3.** Age (mean; range) **4.** Confounding Factors (YES/NO)	**1.** Location (Maxilla/ Mandible/ Both) **2.** Residual Terminal Dentition (YES/NO)	**1.** Radiographic Stent fabrication method **2.** Occlusal Index (YES/NO) **3.** Protocol **4.** CT/CBCT **5.** Tomographic Unit & Parameters **6.** Pre- and post-operative tomographic units were the same (YES/NO)	**1.** Planning Software **2.** Type of Support (mucosa/provisional implant/bone/tooth) **3.** Additional Fixation Screws Used (YES/NO) **4.** Surgeon's Level of Experience **5.** Surgeon different from Planner (YES/NO) **6.** Simultaneous Bone Reduction/ Osteotomy (YES/NO) **7.** Flapless (YES/NO) **8.** STL guide stabilized by an index (YES/NO)	**1.** Implant System **2.** *n* total (maxilla/mandible) **3.** Implant Surface **4.** Diameter (narrow ø/ regular ø / wide ø) (*n*) **5.** Length (short <8-mm; conventional ≥8-mm) **6.** Software used to assess accuracy	**1.** Linear Distortion in mm (mean ± sd) **1.1.** Vertical **1.1.1.** Depth **1.2.** Horizontal **1.2.1.** Neck **1.2.2.** Apex **2.** Angular Distortion in º (mean ± sd)	**Main Conclusions**
Al-Harbi & Sun 2009 CCT Saudi Arabia	**1.** 5 **2.** 3♂; 2♀ **3.** 53 yrs **4.** Unclear	**1.** Both **2.** NO	**1.** Diagnostic work-up **2.** NO **3.** Radiographic template **4.** CT **5.** Unclear **6.** NO	**1.** Simplant Planner® (Dentsply-Sirona, USA) **2.** Mucosa **3.** Unclear **4.** Unclear **5.** Unclear **6.** YES **7.** NO **8.** NO	**1.** Brånemark System® (Nobel Biocare®, Switzerland) **2.** 40 (24;16) **3.** TiUnite® **4.** Unclear **5.** Unclear **6.** Coordinating Measure Machine (CMM® Coating Technology Industries Base, China)	Linear **1.1.** Vertical **1.1.1.** - **1.2.** Horizontal **1.2.1.** 0.20 ± 0.36 **1.2.2.** - Angular **2.1.** MD: 0.17º ± 5.02 **2.2.** BL: 0.46º ± 4.48	The use of the stereolithographic surgical template provided an accurate method for transferring the planned implant position to the surgical field, as measured in regard to the implant point of entrance and resultant angulations.

Albiero *et al*. 2017 CCT Italy	**1.** 10 **2.** 6♂; 4♀ **3.** 52.4 yrs (43-79) **4.** YES Light (< 20 cigarettes) Tabagism	**1.** Both **2.** YES	**1.** Diagnostic work-up **2.** NO **3.** Dual Scan **4.** CBCT **5.** Kavo® 3D (Imaging Sciences International LLC, UK) at 120 kV and 0.02mAs, 0.4mm slice thickness, voxel size 0.4mm **6.** YES	**1.** Simplant Planner® (Dentsply-Sirona, USA) **2.** Mucosa/Tooth **3.** NO **4.** Unclear **5.** NO **6.** NO **7.** YES **8.** NO	**1.** Ankylos Plus® (Dentsply, Germany) **2.** 60 (42;18) **3.** Friadent Growth® **4.** Narrow ø (*n* = 60) **5.** Conventional (*n* = 60) **6.** Mimics® (Materialise, Belgium)	Linear **1.1.** Vertical **1.1.1.** 0.53 ± 0.95 **1.2.** Horizontal **1.2.1.** 1.12 ± 0.60 **1.2.2.** 1.36 ± 0.71 Angular **2.** 3.42º ± 1.52	The use of the intraoral welding technique to immediately load computer-assisted implants could be a successful treatment approach, allowing the creation of an immediate and passive definitive restoration that could limit complications reported in the past when combining computer-assisted surgery with an immediately loaded prefabricated restoration.
Albiero *et al*. 2019 CCT Italy	**1.** 20 **2.** 10♂; 10♀ **3.** 58.9 yrs (43-86) **4.** Unclear	**1.** Both **2.** YES	**1.** Prosthesis transformation **2.** NO **3.** Dual Scan **4.** CBCT **5.** Kavo 3D® (Imaging Sciences International LLC, UK) at 120 kV and 0.02mAs, 0.4mm slice thickness, voxel size 0.4mm **6.** YES	**1.** Simplant Planner® (Dentsply-Sirona, USA) **2.** Mucosa **3.** YES **4.** Unclear **5.** NO **6.** YES **7.** YES **8.** YES	**1.** Ankylos Plus® (Dentsply, Germany) **2.** 114 (88;26) **3.** Friadent® **4.** Narrow ø (*n* = 114) **5.** Conventional (*n* = 114) **6.** Mimics® (Materialise, Belgium)	Linear **1.1.** Vertical **1.1.1.** 0.52 ± 0.85 **1.2.** Horizontal **1.2.1.** 1.20 ± 0.56 **1.2.2.** 1.51 ± 0.71 Angular **2.** 3.30º ± 1.65	Clinicians should be warned that higher apical deviations may be expected when a CGFI surgery is planned in edentulous arches with fresh extraction sockets using a multipiece radiographic guide.
Arisan *et al*. 2010 CCT Turkey	**1.** 54 **2.** 16♂; 38♀ **3.** 48.4 yrs (28-73) **4.** NO	**1.** Both **2.** YES	**1.** Diagnostic work-up/ Duplication of old denture **2.** NO **3.** Dual Scan **4.**CBCT **5.** ILUMA® (IMTEC Imaging, USA) at 120 kilovolt (peak), 3.8 mA with an exposure time of 40 seconds. **6.** Unclear	**1.** stentCad® (Ay Tasarim, Turkey) and SimPlant® (Dentsply-Sirona, USA) **2.** Mucosa/Bone/Tooth **3.** YES (osteosynthesis screws) **4.** ≥ 5 years of experience **5.** YES **6.** NO **7.** YES **8.** NO	**1.** Catia® (Dassault® Systems, France) **2.** 279 (unclear; unclear) **3.** Unclear **4.** Narrow ø (*n* = 279) **5.** Conventional (*n* = 279) **6.** Analyze® 9.0 (AnalyzeDirect, USA)	Linear **1.1.** Vertical **1.1.1.** - **1.2.** Horizontal **1.2.1.** 1.78 ± 0.19 **1.2.2.** 1.19 ± 0.35 **1.2.3.** 1.03 ± 0.35 Angular **2.1.** 4.24º ± 0.75 **2.2.** 3.67º ± 0.95	Computer-aided planning and manufacturing of surgical guides in accordance with CB(CT) images can help clinicians to place implants. Rigid screw fixation of a single guide incorporating metal sleeves and a special drill kit further minimizes deviations.

Borges *et al*. 2012 Case Series Brazil	**1.** 4 **2.** 4♂ **3.** Unclear **4.** NO	**1.** Maxilla **2.** NO	**1.** Diagnostic work-up **2.** YES **3.** Dual Scan **4.** CT **5.** Unclear **6.** YES	**1.** Nobel Guide® Nobel Biocare Holding AG, Switzerland) **2.** Mucosa **3.** YES **4.** Unclear **5.** NO **6.** NO **7.** Unclear **8.** YES	**1.** Conexão Implantes HE® (Conexão) Prosthetics Systems, Brazi) **2.** 23 (23;0) **3.** Master Grip Porous® **4.** Regular ø (*n* = 23) **5.** Conventional (*n* = 23) **6.** DentalSlice® Converter v.2.2.0 (Bioparts Biomedical Prototyping, Brazil)	Linear **1.1.** Vertical **1.1.1.** - **1.1.2.** - **1.2.** Horizontal **1.2.1.** 0.72 ± 0.17 **1.2.2.** 1.45 ± 0.90 Angular **2.** 1.92º ± 0.11	The results revealed the satisfactory transfer of the prosthetic-surgical planning prior to the operative field.
De Oliveira *et al*. 2019 Cohort Brazil	**1.** 18 **2.** unclear♂; unclear♀ **3.** Unclear **4.** NO	**1.** Both **2.** NO	**1.** Duplication of old denture **2.** YES **3.** Dual Scan **4.** CBCT **5.** iCAT® (Imaging Sciences International, USA) thickness 0.25-mm, 0.25-mm interval 120 kV exposure factors 36.12 mAs **6.** Unclear	**1.** Dental Slice® (Bioparts® Biomedical Prototyping, Brazil) **2.** Mucosa **3.** YES **4.** Unclear **5.** NO **6.** NO **7.** YES **8.** NO	**1.** Conexão Implantes® (Conexão Prosthetics Systems, Brazi) **2.** 115 (81;34) **3.** Unclear **4.** Unclear **5.** Unclear **6.** Dental Slice® (Bioparts® Biomedical Prototyping, Brazil)	Linear **1.1.** Vertical **1.1.1.** - **1.1.2.** - **1.2.** Horizontal **1.2.1.** 1.78 ± 0.07 **1.2.2.** 2.30 ± 0.16 Angular **2.** 2.46º ± 0.06*	The placement of implants using the CT-guided surgery technique promoted the installation of implants with accuracy and allowed the installation of straight abutments in all cases evaluated. The linear deviations were not different in the different regions of the mouth or in the different regions of the implants.
De Santis *et al*. 2019 CCT Italy	**1.** 15 **2.** 7♂; 8♀ **3.** 54.7 yrs **4.** YES Light (<10 cigarettes) Tabagism	**1.** Both **2.** NO	**1.** Duplication of old denture/ prosthesis transformation **2.** YES **3.** Dual Scan **4.** CT **5.** Unclear **6.** Unclear	**1.** NobelGuide® (Nobel Biocare Holding AG, Switzerland) **2.** Mucosa/Tooth **3.** YES **4.** Unclear **5.** NO **6.** NO **7.** YES **8.** NO	**1.** Brånemark System® (Nobel Biocare®, Switzerland) **2.** 50 (unclear; unclear) **3.** NobelActive® **4.** Narrow ø (*n* = unclear)/ Wide ø (*n* = unclear) **5.** Conventional (50) **6.** Rhinoceros_4.0 (McNeel Europe, Spain)	Linear **1.1.** Vertical **1.1.1.** 0.13 ± 1.15 **1.2.** Horizontal **1.2.1.** 1.13 ± 0.03 **1.2.2.** 1.67 ± 0.03 Angular **2.1.** MD: 4.21º ± 1.98* **2.2.** BL: 5.44º ± 1.817*	The pilot-drill guided technique has shown similar results in almost all variables and could be suggested as reliable surgical guide in simple cases and a useful prosthetic guide in other cases. Considering the overall accuracy of both computer-guided surgeries, these techniques should be chosen for more difficult cases only if influencing factors are favourable.
Di Giacomo *et al*. 2012	**1.** 12 **2.** 4♂; 8♀	**1.** Both **2.** NO	**1.** Duplication of old denture	**1.** ImplantViewer 1.9 (Anne Solutions, Brazil)	**1.** e-Fix® (Titanium Fix, Brazil)	Linear **1.1.** Vertical	The computer-aided dental implant surgery should still

CCT Brazil	**3.** 60.3 yrs (41-71) **4.** NO		**2.** YES **3.** unclear **4.** CBCT **5.** NewTom® 3G (Quantitative Radiology, Italy) at unclear parameters **6.** Unclear	**2.** Mucosa **3.** YES **4.** Unclear **5.** NO **6.** NO **7.** YES **8.** NO	**2.** 62 (22;38) **3.** Polished Surface® **4.** Narrow ø (*n* = unclear)/ Regular ø (*n* = unclear) **5.** Conventional (*n* = 62) **6.** Rhinoceros® 4.0 (McNeel, USA)	**1.1.1.** - **1.2.** Horizontal **1.2.1.** 1.35 ± 0.65 **1.2.2.** 1.79 ± 1.01 Angular **2.** 6.53º ± 4.31	be considered as being in the developmental stage. Global planning and the transfer approach still need to be improved to reduce inaccuracies and complications. Additional long-term evaluation of implant survival, bone loss, and clinical complications is required.
Ersoy *et al*. 2008 Case Series Turkey	**1.** 7 **2.** unclear♂; unclear♀ **3.** 43 ± 14 yrs **4.** YES Light (<20 cigarettes) Tabagism	**1.** Both **2.** NO	**1.** Diagnostic work-up **2.** NO **3.** Conventional **4.** CT **5.** Discovery® 16 ST (General Electric, USA) at unclear parameters **6.** YES	**1.** Stent Cad® (La Spezia, Italy) **2.** Mucosa/Bone **3.** NO **4.** Unclear **5.** Unclear **6.** NO **7.** YES **8.** NO	**1.** Swiss-Plus® (Swiss-Plus, Zimmer Dental, USA) **2.** 65 (unclear; unclear) **3.** MTX® **4.** Unclear **5.** Unclear **6.** Rhinoceros® 4.0 (McNeel, USA)	Linear **1.1.** Vertical **1.1.1.** - **1.2.** Horizontal **1.2.1.** 1.28 ± 0.92 **1.2.2.** 1.6 ± 1.08 Angular **2.1.** 5.1 ± 2.59	Clinical data suggested that computer-aided SLA surgical guides might be accurate tools for transferring ideal implant position from computer planning to the actual implant surgical phase of treatment. Also, flapless implant placement was possible with these guides.
Ochi *et al*. 2013 CCT Japan	**1.** 15 **2.** 7♂; 8♀ **3.** 67.1 yrs **4.** NO	**1.** Mandible **2.** NO	**1.** Duplication of old denture **2.** NO **3.** Dual Scan **4.** CBCT **5.** Finecube® (Yoshida, Japan) at voxel size 0.157mm, slice thickness 0.146mm, 19s, FOV 82 mm 75.1mm, 90kV, 4mA **6.** Unclear	**1.** Procera® (Nobel Biocare, Sweden) **2.** Mucosa **3.** YES **4.** ≥12 years of experience **5.** Unclear **6.** NO **7.** YES **8.** NO	**1.** Nobel Speedy Groovy® (Nobel Biocare, Sweden) **2.** 30 (0;30) **3.** TiUnite® **4.** Regular ø (*n* = unclear) **5.** Conventional (*n* = unclear) **6.** Mimics ® (Materialise, Belgium)	Linear **1.1.** Vertical **1.1.1.** -0.29 ± 0.55 **1.1.2.** -0.30 ± 0.61 **1.2.** Horizontal **1.2.1.** 0.89 ± 0.44 **1.2.2.** 1.08 ± 0.47 Angular **2.** -	Mucosa-supported surgical guides have high accuracy and that factors such as bone density and mucosal thickness could affect accuracy.
Ozan *et al*. 2009 CCT Turkey	**1.** 30 **2.** 16♂; 14♀ **3.** 47 yrs ± 10 **4.** YES Light (<20 cigarettes) Tabagism	**1.** Unclear **2.** YES	**1.** Duplication of old denture **2.** YES **3.** 3D reconstruction **4.** CT **5.** Discovery® 16	**1.** Stent Cad® (Media Lab., Italy) **2.** Mucosa/Bone/Tooth **3.** NO **4.** Unclear **5.** Unclear **6.** NO	**1.** Swiss-Plus® (Swiss-Plus, Zimmer Dental, USA) **2.** 110 (58;52) **3.** MTX® **4.** Unclear **5.** Unclear	Linear **1.1.** Vertical **1.1.1.** - **1.2.** Horizontal **1.2.1.** 1.11 ± 0.7 **1.2.2.** 1.41 ± 0.9	CT-derived SLA surgical guides supported by either tooth, bone, or mucosa provided a precise tool for both flapless and conventional flap implant insertion.

			ST (General Electric, USA) at unclear parameters **6.** YES	**7.** YES **8.** NO	**6.** Rhinoceros® 4.0 (McNeel, USA)	Angular **2.** 4.1° ± 2.3°	
Pettersson *et al*. 2010 CCT Sweden	**1.** 30 **2.** 10♂; 20♀ **3.** 72.1 yrs **4.** NO	**1.** Both **2.** NO	**1.** Duplication of old denture **2.** YES **3.** Dual Scan **4.** CBCT **5.** NewTom® QR-DVT 9000 (QR s.r.l., Italy), at 4 and 6 mAs and 110 KV with 0.3mm in voxel size, thickness 0.3 mm. **6.** YES	**1.** Procera® (Nobel Biocare AB, Sweden) **2.** Mucosa/Tooth **3.** YES **4.** Unclear **5.** YES **6.** YES **7.** YES **8.** NO	**1.** Brånemark System® (Nobel Biocare®, Switzerland) **2.** 139 (89;50) **3.** TiUnite® **4.** Unclear **5.** Unclear **6.** Nobel Guide Validation 2.0.0.4	Linear **1.1.** Vertical **1.1.1.** -0.15 ± 0.76 **1.1.2. -** **1.2.** Horizontal **1.2.1.** 0.80 ± (0.10 to 2.68) **1.2.2.** 1.09 ± (0.24 to 3.62) Angular **2.** 2.26º (0.24 to 11.74)	The results give us a better understanding of the deviations that could occur when using the guided surgery concept for dental implants. Furthermore, the findings could be used to implement more structured directions on how to use computerized planning software, such as instructions for clinicians to take into consideration when planning their treatments.
Sun *et al*. 2013 CCT Belgium	**1.** 15 **2.** 5♂; 10♀ **3.** 57.5 yrs ± 8.0 (45-69) **4.** Unclear	**1.** Both **2.** NO	**1.** Duplication of old denture **2.** YES **3.** Dual Scan **4.** CBCT **5.** Galileos® (Sirona, Germany) at 85 kV, 21 mAs, and VO2 low contrast mode; 85 kV, 42 mAs, and Volume 1 (VO1) high contrast mode **6.** YES, but parameters were different (85 kV, 42 mAs, and VO1 high contrast mode)	**1.** Procera® (Nobel Biocare AB, Sweden) **2.** Mucosa **3.** YES **4.** Unclear **5.** NO **6.** NO **7.** YES **8.** YES	**1.** Brånemark System® (Nobel Biocare®, Switzerland) **2.** 80 (44;36) **3.** NobelSpeedy™ **4.** Unclear **5.** Conventional (*n* = 80) **6.** Procera® (Nobel Biocare AB)	Linear **1.1.** Vertical **1.1.1.** 0.84 ± 0.27 **1.2.** Horizontal **1.2.1.** 1.16 ± 0.09 **1.2.2.** 2.05 ± 0.35 Angular **2.** 3.33º ± 2.32	When using CBCT-derived mucosa-supported SLA templates, clinicians should be aware that the angular deviation of the implants placed in the mandible is significantly larger than in the maxilla. During virtual implant planning, the average maximum linear deviation should be considered as a safety margin at the implant apex.
Van de Wiele *et al*. 2014 CCT Belgium	**1.** 16 **2.** 10♂; 6♀ **3.** 59.5 yrs (35-78) **4.** YES	**1.** Both **2.** NO	**1.** Prosthesis transformation **2.** YES **3.** Dual Scan **4.** CBCT	**1.** Simplant Planner® (Dentsply-Sirona, USA) **2.** Mucosa **3.** YES **4.** 3-year postgraduate **5.** NO	**1.** Astra Tech® (Dentsply® Implants, Sweden) **2.** 76 (unclear;unclear) **3.** OsseoSpeed® Tx **4.** Unclear **5.** Unclear	Linear **1.1.** Vertical **1.1.1.** 0.5 ± (0.0 to 2.4) **1.2.** Horizontal **1.2.1.** 0.87 ± 0.50 **1.2.2.** 1.10 ± 0.53	Surgical experience has no major influence on the accuracy of implant placement with mucosa-supported stereolithographic

	3 patients (Tabagism)		**5.** Scanora® 3D (Soredex, Finland) at 85 kV and 6 mA, voxel size 250 lm. **6.** NO	**6.** NO **7.** YES **8.** YES	**6.** Mimics® (Materialise, Belgium)	Angular **2.** 2.8° ± (0.2 to 7.0)	drill guides in fully edentulous jaws, when all steps needed for the procedure are supervised by experienced dentists. The major factor of inaccuracy can be found in malpositioning of the guide. Implants placed at the right side of the patient by a righthanded surgeon are more accurate than those placed at the left side.
Vercruyssen *et al.* 2014 RCT Belgium	**1.** 60 **2.** 29♂; 31♀ **3.** 58 yrs **4.** YES 7 patients (Tabagism)	**1.** Both **2.** NO	**1.** Prosthesis transformation **2.** YES **3.** Dual Scan **4.** CT **5**. MSCT® Scan (Siemens, Germany) at 120 kV and 90 mAs, 0.6 mm slice thickness, voxel size 330 lm **6.** NO	**1.** Simplant Planner® (Dentsply-Sirona, USA) **2.** Mucosa/Bone **3.** YES **4.** Unclear **5.** Unclear **6.** NO **7.** YES **8.** YES	**1.** Astra Tech® (Dentsply® Implants, Sweden) **2.** 311 (unclear;unclear) **3.** OsseoSpeed® Tx **4.** Narrow ø (*n* = unclear)/ Regular ø (*n* = nuclear) **5.** Conventional (*n* = 311) **6.** Mimics® (Materialise, Belgium)	Linear **1.1.** Vertical **1.1.1.** 0.74 ± 0 **1.1.2.** 1.09 ± 0.13 **1.2.** Horizontal **1.2.1.** 0.71 ± 0.21* **1.2.2.** 0.61 ± 0.20* Angular **2. -**	The most important inaccuracy with guided surgery is in vertical direction (depth). Horizontal inaccuracies are clearly less. For non-guided surgery, the inaccuracies are significantly higher in all directions.
Vercruyssen *et al.* 2015 RCT Belgium	**1.** 16 **2.** 12♂; 3♀ **3.** 60 yrs ± **4.** YES 2 patients (Tabagism)	**1.** Maxilla **2.** NO	**1.** Prosthesis transformation/ Duplication of old denture **2.** YES **3.** Dual Scan **4.** CT **5.** MSCT® Scan (Somatom Definition Flash, Siemens, Germany) at 120kV and 90 mAs, 0.6mm slice thickness, voxel size 330lm **6.** NO	**1.** Simplant Planner® (Dentsply-Sirona, USA) **2.** Mucosa **3.** YES **4.** Unclear **5.** NO **6.** NO **7.** YES **8.** YES	**1.** Ankylos Plus® (Dentsply® Implants, Sweden) **2.** 90 (90; unclear) **3.** Friadent Plus Narrow ø (*n* = nuclear)/ Regular ø (*n* = unclear) **5.** Conventional (*n* = 90) **6.** Mimics® (Materialise, Belgium)	Linear **1.1.** Vertical **1.1.1.** 0.11(-3.18 to 1.79) **1.2.** Horizontal **1.2.1.** -0.12 (-2.25 to 1.33) **1.2.2.** -0.02 (-2.17 to 1.65) Angular **2.** 2.7º (0.0 to 6.6)	The accuracy of a novel CT-based guide (ExpertEase™) is comparable to accuracy data of other systems.

Verhamme *et al*. 2012 Cases Series Netherlands	**1.** 5 **2.** unclear♂; unclear♀ **3.** Unclear **4.** Unclear	**1.** Maxilla **2.** NO	**1.** Prosthesis transformation **2.** NO **3.** Dual Scan **4.** CBCT **5.** iCAT® 3D (Imaging Sciences International, USA) at of 120 kV peak, pulses of 3-8 mA, 8 cm scan height, exposure time of 20 s and were reconstructed with 0.3 mm isotropic voxel size. **6.** YES	**1.** Procera® (Nobel Biocare, Switzerland) **2.** Mucosa **3.** Unclear **4.** Unclear **5.** Unclear **6.** NO **7.** YES **8.** Unclear	**1.** Brånemark System® (Nobel Biocare®, Switzerland) **2.** 20 (20;0) **3.** TiUnite® **4.** Narrow ø (*n* = 20) **5.** Conventional ø (*n* = 20) **6.** Procera® (Nobel Biocare®, Switzerland)	Linear **1.1.** Vertical **1.1.1.** 0.05 ± 0.02 **1.2.** Horizontal **1.2.1.** 0.05 ± 0.02 **1.2.2.** 0.04 ± 0.02 Angular **2.** 0.04º ± 0.02	This study provided a clear insight in the inaccuracies introduced by computer aided surgery and the used implant validation method. The IPOP validation method can also be used to evaluate implant placement after bone augmentation procedures as also for the evaluation of extra-oral implants.
Verhamme *et al*. 2014 CCT Netherlands	**1.** 25 **2.** 12♂; 13♀ **3.** 59.1 yrs (45-79) **4.** Unclear	**1.** Maxilla **2.** NO	**1.** Prosthesis transformation **2.** YES **3.** Dual Scan **4.** CBCT **5.** i-CAT® 3D Imaging System (Imaging Sciences International, USA) at 120 kV peak, pulses of 3-8 mA, 8 cm scan height, exposure time of 20 seconds and were reconstructed with 0.3 mm isotropic voxel size. **6.** YES	**1.** Procera® (Nobel Biocare®, Switzerland) **2.** Mucosa/Bone **3.** YES **4.** Unclear **5.** Unclear **6.** NO **7.** YES **8.** NO	**1.** Brånemark System® (Nobel Biocare®, Switzerland) **2.** 150 (150;0) **3.** TiUnite® **4.** Unclear **5.** Unclear **6.** Nobel Guide® (version 2.0.0.4, Belgium)	Linear **1.1.** Vertical **1.1.1.** -0.584 ± 0.155 **1.2.** Horizontal **1.2.1.** 1.27 ± 0.22 **1.2.2.** 1.49 ± 0.24 Angular **2.** 3.92° ± 0.41	The surgeon should take into account that deviations are larger compared with implant placement without augmentation procedure and are mainly caused by angulations and translations of the surgical template. Nevertheless, computer-aided implant planning of the augmented maxilla seems a useful method to perform transmucosal implant placement.
Verhamme *et al*. 2016 CCT Netherlands	**1.** 12 **2.** 5♂; 7♀ **3.** 63.5 yrs (53.4-74.8) **4.** UNCLEAR	**1.** Maxilla **2.** NO	**1.** Prosthesis transformation **2.** NO **3.** Dual Scan **4.** CBCT **5.** i-CAT 3D Imaging System (Imaging Sciences International Inc., Pa) at 120 kV	**1.** Maxilim® Software (Medicim NV, Belgium) **2.** Mucosa **3.** YES (osteosynthesis screws) **4.** Unclear **5.** Unclear **6.** NO **7.** YES	**1.** Brånemark System® (Nobel Biocare®, Switzerland) **2.** 72 (72; 0) **3.** NobelSpeedy™ **4.** Unclear **5.** Unclear	Linear **1.1.** Vertical **1.1.1.** -0.59 ± 0.25 **1.2.** Horizontal **1.2.1.** 2.05 ± 0.07 **1.2.2.** 1.59 ± 0.07 Angular **2.** 5.02º ± 0.19	Implant placement in the augmented maxilla using surgical templates that are supported by the osteosynthesis screws from the previous stage augmentation procedure is accurate.

			peak, pulses of 3–8 mA, 8 cm scan height, and an exposure time of 20 s. **6.** YES	**8.** NO	**6.** IPOP (Implant Position Orthogonal Projection)	
OVERALL	**1.**369 **2.**152♂; 182♀; 35 unclear; **3.** 47 yrs **4.**YES (37% of the studies)	**1.** Only Maxila: 26% Only Mandible: 5% Both Maxilla and Mandible: 63% Unclear: 5% **2.** YES: 21% NO: 79%	**1.** Diagnostic work-up: 26% Prosthesis transformation: 37% Duplication of old denture: 37% **2.** YES: 58% NO: 42% **3.** Dual Scan: 79% Other: 21% **4.** CT: 37% CBCT: 63% **5.** i-CAT®: 21% Kavo®: 11% MSCT®: 11% Galileus: 5% Scanora®: 5% Others: 58% **6.**YES: 53% NO: 21% Unclear: 26%	**1.** Procera®: 26% Simplant® Planner: 32% Maxilim®: 5% Stent Cad®: 11% ImplantViewer®: 5% Nobel Guide®: 11% Dental Slice®: 5% **2.** Mucosa: 48% Bone: 26% Tooth: 26% **3.** YES: 74% NO: 15% Unclear: 11% **4.** Unclear: 84% Between 1 and 5 years: 11% >5 years: 5% **5.** YES: 11% NO: 47% Unclear: 42% **6.** YES: 15% NO: 85% **7.** YES: 90% NO: 5% Unclear: 5% **8.** YES: 32% NO: 63% Unclear: 5%	**1.** Anklylos Plus®: 16% Brånemark System®: 37% Catia®: 5% AstraTech®: 10% Conexão Implants®: 10% Swiss-Plus®: 10% e-Fix®: 5% Nobel Speedy Groovy®: 5% **2.** *n* = 1,869 (788 maxilla; 300 mandible; unclear 781) **3.** NobelSpeedy™: 11% Friadent®: 15% TiUnite®: 26% OsseoSpeed®: 16% MTX®: 11% Others: 21% **4.** Narrow (*n* = 273) Regular (*n* = 23) Wide *(n* = unclear) **5.** Conventional (*n* = 1,089) **6.** CMM: 5% Nobel Guide®: 10% Procera®: 11% Mimics®: 32% Rhinoceros®: 21% Analyze®: 5% IPOP: 5% Dental Slice®: 11%	Linear **1.1.** Vertical **1.1.1.** 0.16mm (95%CI: -0.04 - 0.35) ($p = 0.113$) **1.2.** Horizontal **1.2.1.** 1.09mm (95%CI: 0.71-1.47) ($p < 0.001$)* **1.2.2.** 1.44mm (95% CI: 0.94 - 1.94) ($p < 0.001$)* Angular **2.** 3.46º (95% CI: 2.52 - 4.40) ($p < 0.001$)*

* Statistically significant.

PRIMARY OUTCOMES: ACCURACY

Linear Distortions: Vertical

Vertical Linear Distortion at Implant Depth Level: *Overall*

A total of 1,884 implants from 10 studies were available for statistical analysis. The random effects model revealed a not significant overall mean linear distortion (MLD) at the implant depth level of 0.16mm (95% CI: -0.04 - 0.35) (p = 0.113) (Figure 2). The heterogeneity (I^2) of the studies was 99% (Chi^2 = 9.77; df = 9; p <0.001). Since there were not studies with sufficient information about the comparison of the vertical linear distortion at implant depth level either in the maxilla or in the mandible, a comparative meta-analysis could not be run.

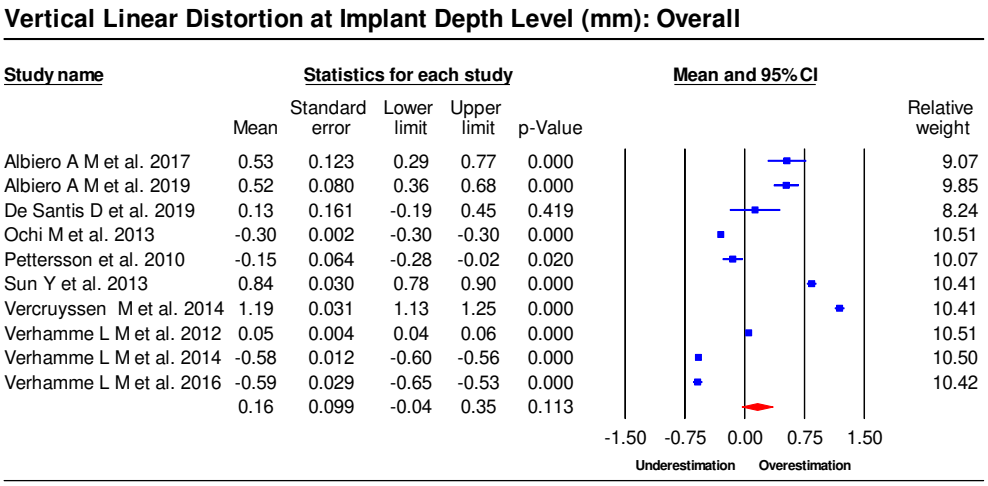


Figure 2. Forest plot of the mean overall vertical linear distortions at implant depth level.

Linear Distortions: Horizontal

Horizontal Linear Distortion at Implant Neck Level: Overall

A total of 1,884 implants from 17 studies were available for statistical analysis. The random effects model revealed a significant overall mean linear distortion (MLD) at the implant neck level of 1.09mm (95% CI: 0.71 - 1.47) (p <0.001) (Figure 3A). The heterogeneity (I^2) of the studies was 99% (Chi^2 = 775.22; df = 16; p <0.001).

Horizontal Linear Distortion at Implant Neck Level: *Maxilla vs. Mandible*

Five studies were available for statistical analysis in the maxilla and the mandible, accounting for 504 implants. The heterogeneity (I^2) of the studies was 98% (Q = 138.72; df = 3; p <0.001) and 95% (Chi^2 = 57.95; df = 3; p <0.001) for the maxilla and the mandible, respectively. The random effects model revealed significant mean linear distortions (MLD) at the implant neck level of 1.32mm in the maxilla (95% CI: 0.88 - 1.85) (p <0.001) and 1.41mm in the mandible (95% CI: 0.97 - 1.85) (p <0.001) (Figure 3B), but this difference was not statistically significant (Chi^2 = 0.07; df = 1; p = 0.784).

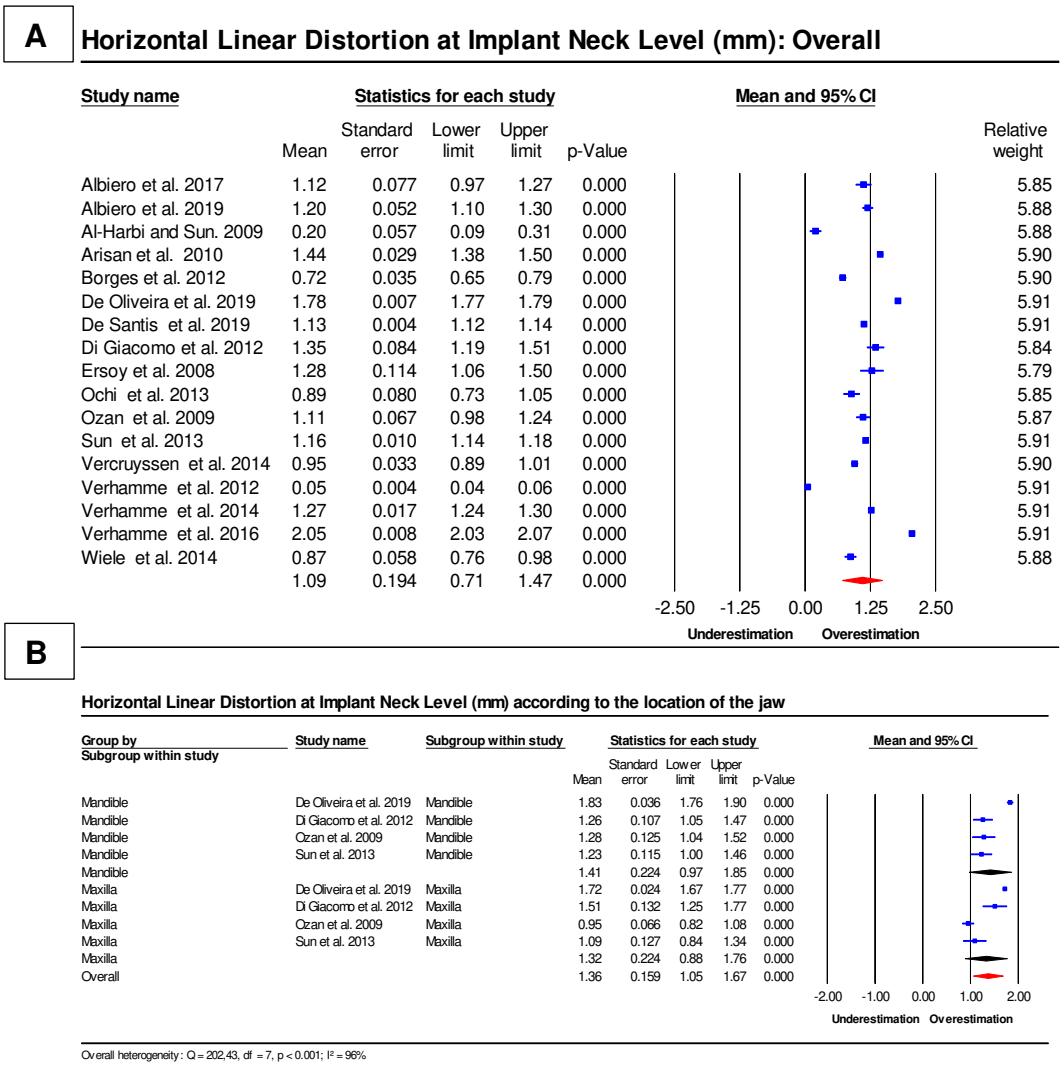


Figure 3. Forest plots of the means horizontal linear distortions at implant neck level: (A) Overall; (B) Mandible vs. Maxilla.

Horizontal Linear Distortion at Implant Apex Level: *Overall*

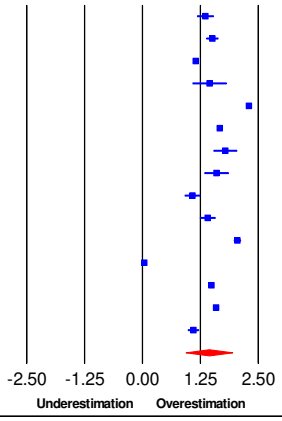
A total of 1,884 implants from 15 studies were available for statistical analysis. The random effects model revealed a significant overall mean linear distortion (MLD) at the implant apex level of 1.44mm (95% CI: 0.94 - 1.94) (p <0.001) (Figure 4A). The heterogeneity (I^2) of the studies was 99% (Chi^2 = 543.490; df = 14; p <0.001).

Horizontal Linear Distortion at Implant Apex Level: *Maxilla vs. Mandible*

Three studies were available for statistical analysis in the maxilla and the mandible, accounting for 504 implants. The heterogeneity (I^2) of the studies was 95% (Q = 42.0; df = 2; p <0.001) and 93% (Chi^2 = 30.67; df = 2; p <0.001) for the maxilla and the mandible, respectively. The random effects model revealed significant mean linear distortions (MLD) at the implant apex level of 1.90mm in the maxilla (95% CI: 1.29 – 2.51) (p <0.001) and 1.78mm in the mandible (95% CI: 1.18 – 2.38) (p <0.001) (Figure 4B), but this difference was not statistically significant (Chi^2 = 0.074; df = 1; p = 0.785).

A **Horizontal Linear Distortion at Implant Apex Level (mm): Overall**

Study name	Mean	Standard error	Lower limit	Upper limit	p-Value	Relative weight
Albiero A M et al. 2017	1.36	0.092	1.18	1.54	0.000	6.66
Albiero A M et al. 2019	1.51	0.066	1.38	1.64	0.000	6.68
Arisan V. 2010	1.15	0.024	1.10	1.20	0.000	6.71
Borges M G et al. 2012	1.45	0.188	1.08	1.82	0.000	6.48
De Oliveira G J P L et al. 2019	2.30	0.015	2.27	2.33	0.000	6.71
De Santis D et al. 2019	1.67	0.004	1.66	1.68	0.000	6.71
Di Giacomo A. G et al. 2012	1.79	0.130	1.53	2.05	0.000	6.60
Ersoy et al. 2008	1.60	0.134	1.34	1.86	0.000	6.59
Ochi M et al. 2013	1.08	0.086	0.91	1.25	0.000	6.66
Ozan O et al. 2009	1.41	0.086	1.24	1.58	0.000	6.66
Sun Y et al. 2013	2.05	0.039	1.97	2.13	0.000	6.70
Verhamme L M et al. 2012	0.04	0.004	0.03	0.05	0.000	6.71
Verhamme L M et al. 2014	1.49	0.019	1.45	1.53	0.000	6.71
Verhamme L M et al. 2016	1.59	0.008	1.57	1.61	0.000	6.71
Wiele V G et al. 2014	1.10	0.061	0.98	1.22	0.000	6.69
	1.44	0.257	0.94	1.94	0.000	



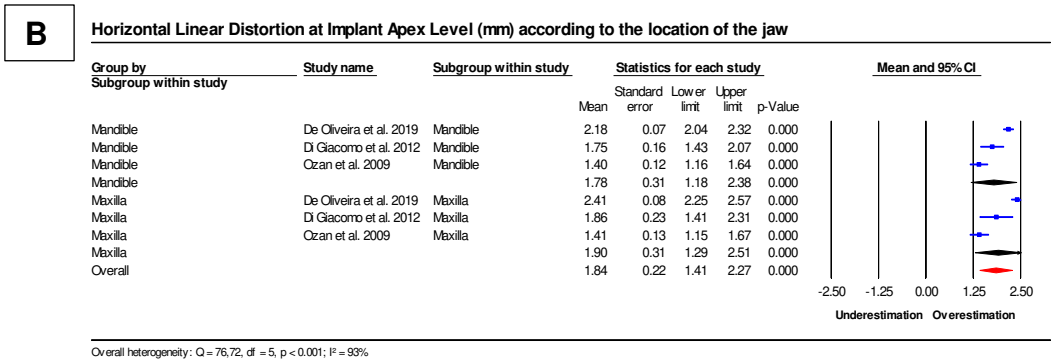


Figure 4. Forest plots of the means horizontal linear distortions at implant apex level: (A) Overall; (B) Mandible vs. Maxilla.

Angular Distortions

Angular Distortions: *Overall*

A total of 1,884 implants from 15 studies were available for statistical analysis. The random effects model revealed an overall significant mean angular distortion (MAD) of 3.46º (95% CI: 2.52 - 4.40) (p <0.001) (Figure 5A). The heterogeneity (I^2) of the studies was 99% (Chi^2 = 156.32; df = 14; p <0.001).

Angular Distortions: *Maxilla vs. Mandible*

Four studies were available for statistical analysis in the maxilla and the mandible, accounting for 504 implants. The heterogeneity (I^2) of the studies was 97% (Q = 109.61; df = 3; p <0.001) and 91% (Chi^2 = 34.34; df = 3; p <0.001) for the maxilla and the mandible, respectively. The random effects model revealed significant mean angular distortions (MADs) at the implant apex level of 4.17º in the maxilla (95% CI: 3.06 – 5.29) (p <0.001) and 3.69º in the mandible (95% CI: 2.57 – 4.80) (p <0.001) (Figure 5B), but this difference was not statistically significant (Chi^2 = 0.37; df = 1; p = 0.544).

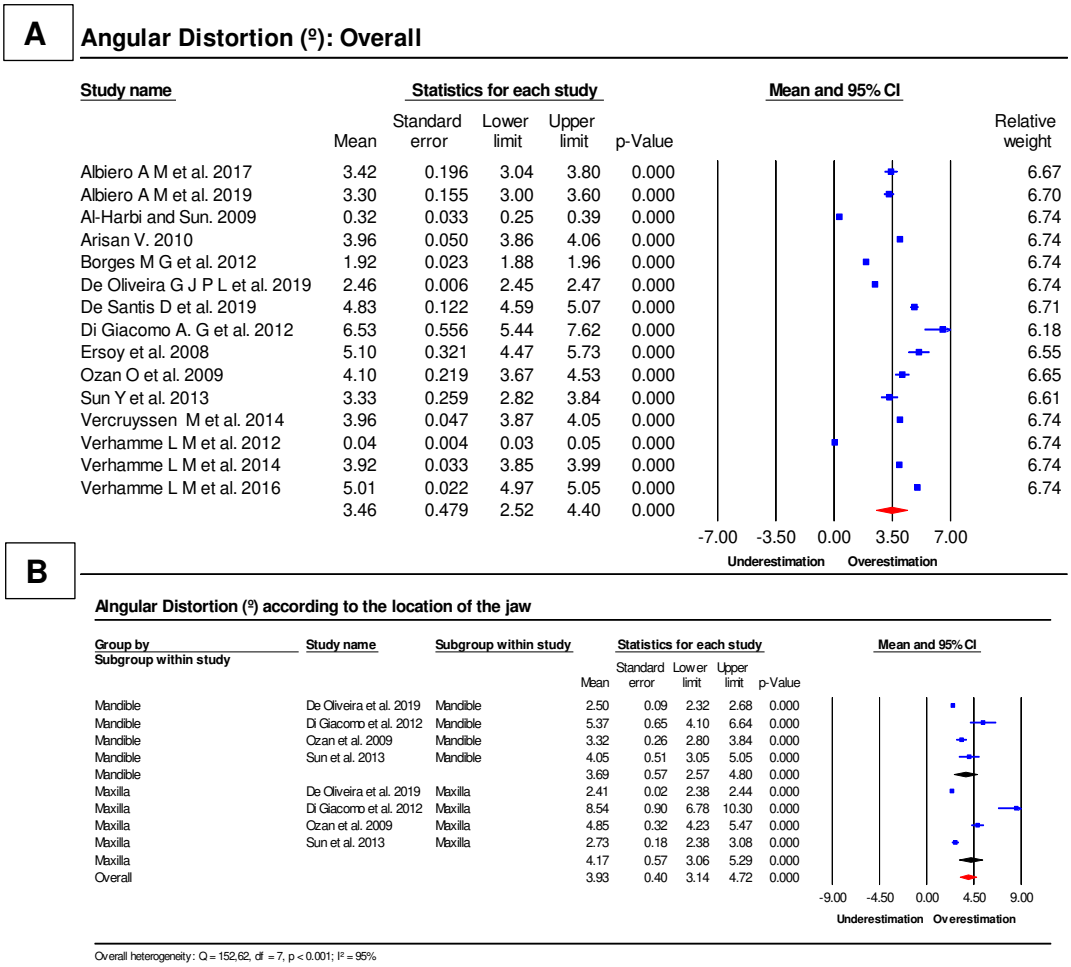


Figure 5. Forest plots of the means angular distortions: (A) Overall; (B) Mandible vs. Maxilla.

SECONDARY OUTCOMES

Implant Survival Rate and Marginal Bone Loss

Only one study evaluated the implant survival rate: Di Giacomo *et al*. (2012) followed up the patients after surgery for 24 hours, 2 weeks, 3 weeks and 6 months, and then every 6 months for 30 months. In 6 months, the prostheses were removed and assessments of peri-implant tissues, abutments and implants were made, and a 20 N.cm torque was applied to the abutment screw. Three implants were removed shortly after placement (1 due to poor primary stability and 2 implants for placement in the tuberosity region). The cumulative survival rates for implants and prostheses were 98.33% and 91.66%, respectively, at the 30-months follow-up.

Patient-Reported Outcome Measures (PROMS)

Only the study by Vercruyssen et al. (2015) applied a questionnaire (McGill Pain Questionnaire MPQ-DLV) assessing the patient-reported postoperative pain. Patients were asked to fill the VAS at the day of surgery and then every 4 hours later, daily. Patients were asked to score their pain three times; the pain they felt at the time of questioning, and the minimum and maximum pain they experienced during the last 4 or 24 hours. There was a bias when comparing the groups of immediate and late loading. The group that received late loading was instructed not to use their prostheses, which could cause them to report less pain than the group with immediate loading. No differences could be shown between treatment groups on pain response (MPQ-DLV), treatment perception (VAS).

Results of Risk of Bias of Individual Studies

For ethical reasons, a desired comparative group (CBCT-based assessment of the accuracy of implants placed by means of conventional surgery) was not feasible. Thus, the original design of the studies was considered for Risk of Bias assessments. According to this, only two original RCTs (studies nr. 15 and 16) met the eligibility criteria and the RoB 2 (Risk of Bias 2, The Cochrane Collaboration) tool was applied to them. Question nr. D3 *"Blinding of participants and personnel"* was answered as "*no*" for both studies. Study nr. 15 (Vercruyssen *et al.* 2014) positively answered to 5 out of 6 questions (83.33%), indicating a low risk of bias, whereas study nr. 16 (Vercruyssen et al. 2015) positively answered to only 3 out of 6 questions (50%), showing a moderate risk of bias (Figure 6).

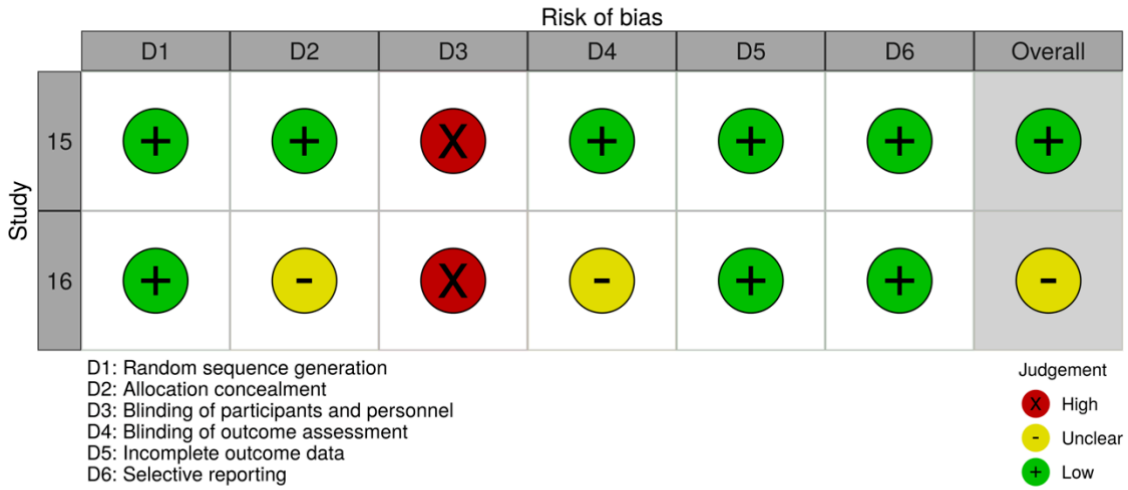


Figure 6. Risk of bias of the randomized controlled trials according to the RoB 2 (Risk of Bias 2, The Cochrane Collaboration) tool.

The Joanna Briggs Institute Critical Appraisal Checklist for Quasi-Experimental (Non-Randomized Experimental Studies) tool was applied for the remaining seventeen studies. Questions nr. D4 "*Were there multiple measurements of the outcome both pre and post the intervention/exposure?*" and D6 "*Were outcomes measured in a reliable way?"* were positively answered by all seventeen non-randomized studies. Question nr. D1 "*Is it clear in the study what is the "cause" and what is the "effect" (i.e. there is no confusion about which variables comes first)?*" was answered as "*yes*" in 16 (94.12%) out of the seventeen studies. Questions nr. D5 "*Was follow up completed and if not, were differences between groups in terms of their follow up adequately described and analyzed?*", D2 "*Were the participants included in any comparisons receiving similar treatment/care, other than the exposure or intervention of interest?*" and D7 "*Was appropriate statistical analysis used?*" were answered as "*yes*" in 14 (82.35%), 6 (35.29%) and 4 (23.52%) out of seventeen studies, respectively. According to this, 15/17 (88,23%) studies (nr. 1,2,3,4,5,6,7,8,9,10,11,12,13,14 and 17) were considered as "low risk of bias", whereas 2/17 (11,76%) studies (nr. 18 and 19) were considered as "moderate risk of bias" and 0/17 studies (0%) were considered as "high risk of bias" (Figure 7).

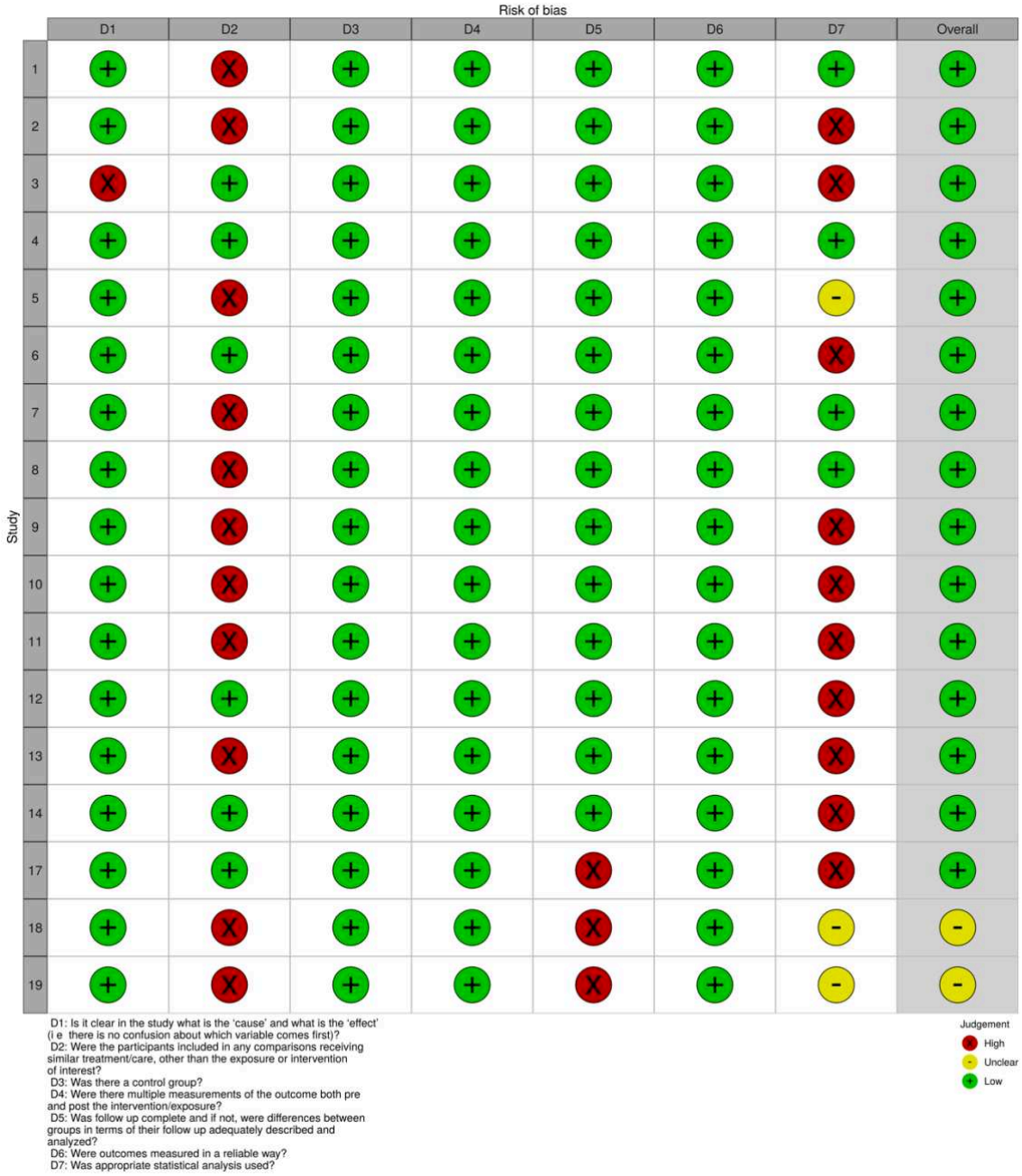


Figure 7. Risk of bias of the non-randomized experimental studies according to the Joanna Briggs Institute Critical Appraisal Checklist for Quasi-Experimental (Non-Randomized Experimental Studies) tool.

Results of Confidence in Cumulative Evidence

The GRADE evaluation was done according the primary overall outcomes (Vertical Linear Distortion at Implant Depth Level, Horizontal Linear Distortion at Implant Neck Level, Horizontal Linear Distortion at Implant Apex Level, Angular

Distortions). The confidence in cumulative evidence was considered very low all. The domains that downgrade the certainty were the RoB of included studies (-1 point), the inconsistency (-2 points), due to high statistical and methodological heterogeneity of the studies, and the imprecision (-1 point) attributable to wide confidence intervals and low interposition of confidence intervals between studies. The publication bias was not detected due to the broad search. More information can be found on Table 2.

Table 2. GRADE Summary of information.

	Certainty assessment							Certainty
Outcome	**№ of studies**	**Study design**	**Risk of bias**	**Inconsistency**	**Indirectness**	**Imprecision**	**Other considerations**	
Vertical Linear Distortion at Implant Depth Level	10	randomised trials, and non-randomised intervention studies.	serious [a]	very serious [b]	not serious	serious [c]	none	⊕◯◯◯ VERY LOW
Horizontal Linear Distortion at Implant Neck Level	17	randomised trial, and non-randomised intervention studies.	serious [a]	very serious [b]	not serious	serious [c]	none	⊕◯◯◯ VERY LOW
Horizontal Linear Distortion at Implant Apex Level	15	randomised trials, and non-randomised intervention studies.	serious [a]	very serious [b]	not serious	not serious	none	⊕◯◯◯ VERY LOW
Angular Distortions	15	randomised trials and non-randomised intervention studies.	serious [a]	very serious [b]	not serious	serious [c]	none	⊕◯◯◯ VERY LOW

Explanations
a. All studies presented at least one question regarding the risk of bias at high risk.
b. The results of the meta-analysis, show high statistical heterogeneity. Different study methodologies demonstrate high methodological heterogeneity.
c. Wide confidence intervals. Low interposition of confidence intervals between studies.

DISCUSSION

Recent advances in digital technologies have contributed to the development of tools that allow computer-assisted dental implant placement. Although artificial intelligence (A.I.) resources promise dental implant placement either without the aid of surgical guides (navigated surgery) or even without the presence of the surgeon (robotic surgery) (Kramer *et al.* 2005; Gallucci *et al*. 2019; Wu *et al*. 2019), the static computer-assisted implant surgery (s-CAIS) is the most feasible option to clinicians at the moment. Many have been the benefits attributed to the s-CAIS on the rehabilitation of totally edentulous patients with dental implants, such as a greater accuracy, reduced surgical time, reduced morbidity and reduced bleeding. This should be highlighted when dealing with elderly patients, since many of them are dependent of oral anticoagulants (Sanz & Naert 2009). Thus, a minimally invasive and more accurate procedure with s-CAIS would better address the needs of totally edentulous patients.

This systematic review aimed at answering the focused question: *"In full arches, what is the accuracy of dental implants placed by means of static computer-assisted implant surgery (s-CAIS)?"*. The digital workflow by means of static computer-assisted implant surgery (s-CAIS) proved in the present study to be a predictable and viable solution for the treatment of edentulous patients with implants, and this is in agreement with the previous systematic review by Laleman and coworkers (2016). Nevertheless, although a comprehensive literature search has been performed, this study failed to prove a superiority of s-CAIS over conventional implant surgery in terms of accuracy. A preliminary search run by our group revealed a lack of controlled studies with a group where accuracy of dental implants placed by conventional surgery was assessed by means of CBCT scans. This might be explained because of ethical issues – an additional radiation dose in patients who underwent conventional implant surgery would not be justifiable.

It is well documented that the correct 3D positioning plays a crucial role on the long-term prognosis of dental implants Martin *et al. (*2006); Morton *et al. (*2014). Particularly in edentulous patients, a facially-oriented full-arch teeth setup, reestablishing the phisiognomy of the lower third of the face, should be achieved

whenever the current conventional complete dentures are not satisfactory Feine *et al*. (2002). This information, alongside with the underlying hard tissues anatomy, should be obtained by means of surface digitalization techniques (scanning) and CBCT scans, respectively, to create a 3D virtual patient. Particularly relevant in this regard is the role of the intra-oral anatomical references. In partially dentate patients, the remaining dentition works as an optimal landmark for the merging of different digital files (*dicom* and *stl*). On the other hand, remarkable deviations at data acquisition in edentulous patients, especially when a reverse planning is not considered, when reference points are not properly built, and/or when the stent is not comfortably seated in the patient's mouth (all situations manageable by the clinician), might be expected thanks to the lack of anatomical references. These deviations at image acquisition might compromise virtual planning up to an extent that, even with the aid of a rapidly prototyped surgical drilling guide and assisted by a computer, final implant position will result in significant linear and angular distortions Arisan *et al.* (2010). This was confirmed in the systematic review by Tahmaseb *et al*. (2018), where accuracy of s-CAIS in partially edentulous patients was significantly greater than in totally edentulous patients. In this review, a lack of standardization of the image acquisition methods, either at the method of fabrication of the radiographic stent, or at the occlusal stabilization of the stent, or at the tomographic unit and parameters used was found within original studies, and this finding agrees with the study by Tahmaseb and coworkers (2018). Therefore, a standardization of the image acquisition protocols should strongly be considered.

Linear and angular deviations of dental implants placed by means of static computer-assisted implant surgery (s-CAIS) may occur at different stages of the treatment. Factors related to the *imaging examinations* (image acquisition, reliability of landmark references) Verhamme *et al.* (2016), to the *patient* (mouth opening, resilience of the fibromucosa) Verhamme *et al.* (2012), to the *implant site* (local anatomy, bone density, muscle insertions, location of the jaw, severe ridge resorption and posterior regions) De Santis *et al.* (2019), to the *surgical procedure* (anesthetic technique, type of support for the guide, number and arrangement of fixation pins, adaptation and stability of the surgical drilling guide, additional fixation screws, accidental fracture of the drilling guide, implant placement fully guided or not) Verhamme *et al.* (2014), to the *implant system*

(auxiliary surgical instruments) and to the *operator* (level of experience, right or left-handed) (Ochi et al. 2013) are likely to affect accuracy. Therefore, a meticulous and multidisciplinary approach must be employed in order to minimize risks that may interfere with the treatment success.

The linear distortions values found for implants placed by means of s-CAIS in totally edentulous patients (mean horizontal linear distortions at the implant neck and apex levels of 1.09mm and 1.44mm, respectively), in the present study, are within the mean observed in another systematic review in the same topic. Tahmaseb *et al.* (2018) found a clinical deviation of 1.2mm, being within acceptable standards of distortions for the conventional implant surgery. Furthermore, linear distortions may exhibit different patterns according to each implant regions, either in the horizontal (neck and apex) or in the vertical (depth) orientation. The mean linear distortion found in our review (1.09mm) may interfere with the position of the implant prosthetic platform and is in line with the study by Albiero *et al.* (2017). However, the greater linear distortion found in this study occurred in the horizontal orientation, at the implant apex level (1.44mm), and this agrees with the study by. It might have been influenced by the length and mean angular deviation (3.46º) of the surgical drill at drilling. This distortion may interfere with safety in borderline cases where there is not a safe distance to relevant anatomical structures Vercruyssen *et al.* (2015). Another relevant finding was that the vertical distortion in depth of the whole implant body was lower than the horizontal distortion, which corroborates the results of Verhamme *et al.* (2014) Surgical cassettes that provide instruments such as cylinders of drill handle with sleeve height reducers, as well as surgical drills with stops that control the depth of the drilling may have contributed to this finding. With that in mind, a 2-mm horizontal and 1-mm vertical safety margin must always be considered at treatment planning, as a prevention to complications with relevant anatomical structures.

Someone could expect a greater accuracy of implants placed by means of static computer-assisted implant surgery (s-CAIS) in the totally edentulous maxilla, because of the wider basal area. In this systematic review, even though the linear and angular distortions showed different behaviors between the maxilla and the mandible, these differences were not significant, which agrees with the findings of Ozan et al. (2009). This might be explained by the low number of studies that

clearly stated at their publications the investigated jaw with sufficient information (means and either standard deviations or confidence intervals). It should also be highlighted that in the present study only prospective studies assessing totally edentulous patients were included, and although this strategy may have increased the level of cumulative evidence, it may also have narrowed the scope of the literature searched.

The findings of the present systematic review pointed out three main types of support for the surgical guide in edentulous patients: mucosa, bone and teeth. The most prevalent type of support in this study was the mucosa-supported (48%). Although this type of support can suffer interference from the musculature and supporting tissues at the time of the surgical guide positioning, it can offer in edentulous patients some benefits such as the possibility of using the flapless technique, providing patients with less bleeding and morbidity (Arisan *et al.* (2010). Seo & Juodzbalys (2018), in a systematic review of s-CAIS in totally edentulous patients, found a mean apical distortion of 2.19mm, a mean coronal distortion of 1.68mm and a mean angular distortion of 4.67º. These values were higher than those found in the present review. It can be justified by the small number of articles included ($n = 6$) in that study, evaluating a total of 572 implants placed with the aid of surgical guides supported exclusively by the mucosa. In our study, different types of support were considered, which may have broadened the scope of the search and caused different results. However, the insufficient quantitative data from the original studies did not allow us to run a statistical analysis on this topic. Therefore, the role of the type of support for the guide on the accuracy of static computer-assisted guided surgery (s-CAIS) in totally edentulous patients is still to be answered. Tooth-, bone- and provisional implants-supported guides are little related in the literature, but all of them show the advantage of offering a rigid anchorage for the guide. Thus, studies that assess the accuracy of implants placed by s-CAIS with the aid of tooth-supported guides in patients with terminal dentition who will migrate to a total edentulism, for instance, as well as bone supported guides and provisional implants-supported guides are still lacking.

In despite of the advantages offered by the s-CAIS in totally edentulous patients, this method needs further improvement, especially when immediate prosthetic loading with full-arch guided prosthesis (either milled or printed) is considered. In

these cases, the digital design and manufacturing of perfect fitting of prosthetic platforms on the base of the prosthesis are not recommended. In order to overcome this situation, a wider opening over the likely position of the abutments should be designed at the software, allowing the clinician to predictably perform the prosthesis installation with temporary materials. Lastly, patient's occlusion in the correct centric relation and vertical dimension of occlusion play a key role in the accuracy of prosthesis installation. This may be complemented by additional devices, such as niobium magnets combined in both the surgical guide and the guided prosthetics, to help the prosthodontist to better install the guided prosthesis.

Due to a strict protocol and eligibility criteria, some studies assessing the longitudinal survival rates and marginal bone loss of dental implants placed by means of s-CAIS in totally edentulous patients that did not report primary (accuracy) outcomes were excluded. Only one included study (Di Giacomo et al. 2012) reported cumulative survival rates for implants and prostheses of 98.33% and 91.66%, respectively. Besides that, the overall complication rate reported by that study was 34.41%, with a surgical complication rate of 17.74% and a prosthetic complication rate of 16.67%. Although not included for data compilation in this systematic review, the study of D'haese et al. (2013) is noteworthy. In that study, 114 implants placed by means of s-CAIS in 26 totally edentulous patients were followed-up for 1 years. Implant survival rate was 98.7%, whereas mean marginal bone loss was 0.47mm. Both findings seem to be in agreement with the general literature of dental implants conventionally placed in totally edentulous patients D'haese et al. (2013)

Patient-reported outcomes (PROMS) was reported by only one included study. Vercruyssen *et al*. (2015) applied a questionnaire (McGill Pain Questionnaire MPQ-DLV) assessing the patient-reported postoperative pain. The resuts showed that No differences could be shown between treatment groups on pain response (MPQ-DLV), treatment perception (VAS), number or kind of pain killers, or for the HRQOLI instrument.

To the best of our knowledge, this is the first systematic review assessing the accuracy of dental implants placed in totally edentulous patients with the aid of s-CAIS that evaluated the risk of bias of the included studies and the cumulative level of evidence. The overall risk of bias of the studies included in this review

was low. The positive aspects of the studies included the randomization method and the unbiased report of outcomes (Vercruyssen et al. 2014, 2015), the reliability of the outcomes assessments, the multiple measurements of the outcome, the clear cause and effect variables and the follow-up completion. On the other hand, the most common shortcomings included lack of blinding of participants and personnel Vercruyssen et al. (2014), 2015), and inappropriate statistical analysis studies Albiero *et al.* (2017); Abiero *et al*; (2019); De Oliveira *et al.* (2019); Ersoy *et al.* (2008); Van Wile *et al.* (2014) and Verhammne *et al.* (2012).

In despite of the relevant findings of this study, further randomized controlled clinical studies with larger sample sizes and longer follow-up periods, assessing the role of different image acquisition protocols, different types of support for the drilling guide, different resiliences of fibromucosa, different bone densities, different jaws, different implant systems, the number and distribution of fixation pins, the fully guided implant placement, and the level of experience of the surgeon, are still necessary.

CONCLUSIONS

Within the limitations of the present systematic review, it can be concluded that:

- The accuracy of implants placed by means of static computer-assisted implant surgery (s-CAIS) in edentulous patients is within a clinically acceptable range. Overall mean *horizontal* distortions at the implant *neck* and *apex* levels of 1.09mm and 1.44mm, respectively, mean *vertical* distortion (*depth*) of 0.16mm, and mean angular distortion of 3.46º, were found;
- the greater linear distortion occurs at the implant apex level and this seems to be directly related to the length and angular deviation of the surgical drill at drilling;
- the vertical distortion in depth was lower than the horizontal distortion;
- the location of the jaw (maxilla or mandible) does not seem to have influenced the accuracy of dental implants placed by means of static computer-assisted implant surgery (s-CAIS) in totally edentulous patients;
- the role of the type of support of the guide and the implant system on the accuracy of static computer-assisted guided surgery (s-CAIS) in totally edentulous patients remains unclear;
- a 2-mm horizontal and 1-mm vertical safety margin must always be considered at treatment planning;
- the digital workflow by means of static computer-assisted implant surgery (s-CAIS) proved to be a predictable and viable solution for the treatment of edentulous patients with implants.

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Appendix 1. Details of the search strategy as well as the results for each database.

Database	Search (August 3rd, 2020)
PubMED/Medline (*n* = 338)	(accuracy[All Fields] OR precision[All Fields] OR Quality[All Fields] OR "angular deviation"[All Fields] OR "angular measurements"[All Fields]) AND ("Surgery, Computer-Assisted"[Mesh] OR "Computer-Assisted Surgeries"[All Fields] OR "Computer-Assisted Surgery"[All Fields] OR "Computer Assisted Surgery"[All Fields] OR "Computer-Aided Surgery"[All Fields] OR "Computer Aided Surgery"[All Fields] OR "Computer-Aided Surgeries"[All Fields] OR "guided surgery"[All Fields] OR "Guided Surgeries"[All Fields] OR (drill-guiding[All Fields] AND system[All Fields]) OR ("surgery, computer-assisted"[MeSH Terms] OR ("surgery"[All Fields] AND "computer-assisted"[All Fields]) OR "computer-assisted surgery"[All Fields] OR ("surgery"[All Fields] AND "image"[All Fields] AND "guided"[All Fields])) OR "Computer-Aided Design"[Mesh] OR "Computer Aided Design"[All Fields] OR "Computer Aided Design"[All Fields] OR "Computer-Aided Designs"[All Fields] OR "Computer-Assisted Design"[All Fields] OR "Computer Assisted Design"[All Fields] OR ("computer-aided design"[MeSH Terms] OR ("computer-aided"[All Fields] AND "design"[All Fields]) OR "computer-aided design"[All Fields] OR ("computer"[All Fields] AND "assisted"[All Fields] AND "designs"[All Fields])) OR "Computer-Aided Manufacturing"[All Fields] OR "Computer Aided Manufacturing"[All Fields] OR "Computer-Assisted Manufacturing"[All Fields] OR "Computer Assisted Manufacturing"[All Fields] OR "CAD-CAM"[All Fields] OR "Printing, Three-Dimensional"[Mesh] OR "Printing Three-Dimensional"[All Fields] OR "Three-Dimensional Printings"[All Fields] OR "3-Dimensional Printing"[All Fields] OR "3 Dimensional Printing"[All Fields] OR ("printing, three-dimensional"[MeSH Terms] OR ("printing"[All Fields] AND "three-dimensional"[All Fields]) OR "three-dimensional printing"[All Fields]) OR "3-D Printing"[All Fields] OR "3 D Printing"[All Fields] OR ("printing, three-dimensional"[MeSH Terms] OR ("printing"[All Fields] AND "three-dimensional"[All Fields]) OR "three-dimensional printing"[All Fields]) OR "Three-Dimensional Printing"[All Fields] OR "Three Dimensional Printing"[All Fields] OR "3D Printing"[All Fields] OR "3D Printings"[All Fields] OR "stereolithography"[MeSH Terms] OR ("stereolithography"[MeSH Terms] OR "stereolithography"[All Fields]) OR ("stereolithography"[MeSH Terms] OR "stereolithography"[All Fields] OR "stereolithographies"[All Fields]) OR "Stereo lithography"[All Fields] OR (Stereo[All Fields] AND lithographies[All Fields]) OR "standard triangle language"[All Fields] OR "Standard tessellation language"[All Fields] OR STL[All Fields] OR "planning surgery"[All Fields] OR "Surgical planning"[All Fields]) AND ("Mouth, Edentulous"[Mesh] OR ("mouth, edentulous"[MeSH Terms] OR ("mouth"[All Fields] AND "edentulous"[All Fields]) OR "edentulous mouth"[All Fields] OR "edentulous"[All Fields]) OR "Denture, Complete"[Mesh] OR "denture complete"[All Fields] OR "Complete Dentures"[All Fields] OR "full arch"[All Fields] OR "full arches"[All Fields] OR "full-arch"[All Fields] OR "full-arches"[All Fields]) AND ("Dental Implants"[Mesh] OR "implants"[All Fields] OR "implant"[All Fields] OR "Dental Prostheses"[All Fields] OR "Dental Prosthesis"[All Fields] OR "Implantation"[All Fields])
Embase (*n* = 432)	('accuracy'/exp OR accuracy OR 'precision'/exp OR precision OR 'quality'/exp OR quality OR 'angular deviation' OR 'angular measurements') AND ('surgery, computer-assisted'/exp OR 'surgery, computer-assisted' OR 'computer-assisted surgeries' OR 'computer-assisted surgery'/exp OR 'computer-assisted surgery' OR 'computer assisted surgery'/exp OR 'computer assisted surgery' OR 'computer-aided surgery'/exp OR 'computer-aided surgery' OR 'computer aided surgery'/exp OR 'computer aided surgery' OR 'computer-aided surgeries' OR 'guided surgery' OR 'guided surgeries' OR 'drill-guiding system' OR 'surgery, image guided' OR 'computer aided design'/exp OR 'computer

	aided design' OR 'computer-aided designs' OR 'computer-assisted design'/exp OR 'computer-assisted design' OR 'computer assisted design'/exp OR 'computer assisted design' OR 'computer-assisted designs' OR 'computer-aided manufacturing'/exp OR 'computer-aided manufacturing' OR 'computer aided manufacturing'/exp OR 'computer aided manufacturing' OR 'computer-assisted manufacturing' OR 'computer assisted manufacturing' OR 'cad-cam'/exp OR 'cad-cam' OR 'printing three-dimensional'/exp OR 'printing three-dimensional' OR 'three-dimensional printings' OR '3-dimensional printing'/exp OR '3-dimensional printing' OR '3 dimensional printing'/exp OR '3 dimensional printing' OR '3-dimensional printings' OR '3-d printing'/exp OR '3-d printing' OR '3 d printing'/exp OR '3 d printing' OR '3-d printings' OR 'three-dimensional printing'/exp OR 'three-dimensional printing' OR 'three dimensional printing'/exp OR 'three dimensional printing' OR '3d printing'/exp OR '3d printing' OR '3d printings' OR 'stereolithography'/exp OR stereolithography OR stereolithographies OR 'stereo lithography'/exp OR 'stereo lithography' OR 'stereo lithographies' OR 'standard triangle language' OR 'standard tessellation language' OR stl OR 'planning surgery' OR 'surgical planning'/exp OR 'surgical planning') AND ('mouth, edentulous'/exp OR 'mouth, edentulous' OR edentulous OR 'denture, complete'/exp OR 'denture, complete' OR 'denture complete'/exp OR 'denture complete' OR 'complete dentures' OR 'full arch' OR 'full arches' OR 'full-arch' OR 'full-arches') AND ('dental implants'/exp OR 'dental implants' OR 'implants'/exp OR 'implants' OR 'implant'/exp OR 'implant' OR 'dental prostheses'/exp OR 'dental prostheses' OR 'dental prosthesis'/exp OR 'dental prosthesis' OR 'implantation'/exp OR 'implantation')
LILACS (*n* = 14)	(accuracy OR precision OR quality OR "angular deviation" OR "angular measurements" OR acurácia OR precisão OR qualidade OR "desvio angular" OR precisión OR calidad OR "desviación angular") AND ("Surgery, Computer-Assisted" OR "Computer-Assisted Surgeries" OR "Computer-Assisted Surgery" OR "Computer Assisted Surgery" OR "Computer-Aided Surgery" OR "Computer Aided Surgery" OR "Computer-Aided Surgeries" OR "Cirurgia Assistida por Computador" OR "Cirurgias Assistidas por Computador" OR "Cirurgia Guiada por Imagem" OR "Cirugía Asistida por Computador " OR "guided surgery" OR "Guided Surgeries" OR "Cirurgia Guiada" OR "Cirurgias Guiadas" OR "Cirugía guiada" OR "Cirugías guiadas" OR "drill-guiding system" OR "guia de broca" OR "Surgery, Image Guided" OR "Computer Aided Design" OR "Computer Aided Design" OR "Computer-Aided Designs" OR "Computer-Assisted Design" OR "Computer Assisted Design" OR "Computer-Assisted Designs" OR "Computer-Aided Manufacturing" OR "Computer Aided Manufacturing" OR "Computer-Assisted Manufacturing" OR "Computer Assisted Manufacturing" OR "CAD-CAM" OR "Projeto Auxiliado por Computador " OR "Fabricação Assistida por Computador" OR "Fabricação Auxiliada por Computador" OR "Projeto Assistido por Computador" OR "Diseño Asistido por Computador" OR "Printing Three-Dimensional" OR "Three-Dimensional Printings" OR "3-Dimensional Printing" OR "3 Dimensional Printing" OR "3-Dimensional Printings" OR "3-D Printing" OR "3 D Printing" OR "3-D Printings" OR "Three-Dimensional Printing" OR "Three Dimensional Printing" OR "3D Printing" OR "3D Printings" OR "Impressão Tridimensional" OR "Impressão em 3D" OR "Impressão 3D" OR "Impresión Tridimensional " OR "Impresión 3D" OR stereolithography OR stereolithographies OR "Stereo lithography" OR "Stereo lithographies" OR "standard triangle language" OR "Estereolitografia" OR "Standard tessellation language" OR stl OR "Linguagem padrão do triângulo" OR "Idioma estándar de triángulo" OR "planning surgery" OR "Surgical planning" OR "planejamento cirurgico" OR "planificación quirúrgica") AND ("Mouth, Edentulous" OR edentulous OR edentulo OR edentulismo OR "Denture, Complete" OR

	"denture complete" OR "Complete Dentures" OR "dentatura completa" OR "full arch" OR "full arches" OR "full-arch" OR "full-arches" OR "arco completo") AND ("Dental Implants" OR "implants" OR "implant" OR "Dental Prostheses" OR "Dental Prosthesis" OR "Implantation" OR "implante" OR "implantes" OR "protese dentária" OR "Proteses dentarias" OR "protesi dentales" OR "Protesis dentales" OR "implantes dentales")
Web of Science (*n* = 278)	TS=(accuracy OR precision OR quality OR "angular deviation" OR "angular measurements") AND ("Surgery, Computer-Assisted" OR "Computer-Assisted Surgeries" OR "Computer-Assisted Surgery" OR "Computer Assisted Surgery" OR "Computer-Aided Surgery" OR "Computer Aided Surgery" OR "Computer-Aided Surgeries" OR "guided surgery" OR "Guided Surgeries" OR "drill-guiding system" OR "Surgery, Image Guided" OR "Computer Aided Design" OR "Computer Aided Design" OR "Computer-Aided Designs" OR "Computer-Assisted Design" OR "Computer Assisted Design" OR "Computer-Assisted Designs" OR "Computer-Aided Manufacturing" OR "Computer Aided Manufacturing" OR "Computer-Assisted Manufacturing" OR "Computer Assisted Manufacturing" OR "CAD-CAM" OR "Printing Three-Dimensional" OR "Three-Dimensional Printings" OR "3-Dimensional Printing" OR "3 Dimensional Printing" OR "3-Dimensional Printings" OR "3-D Printing" OR "3 D Printing" OR "3-D Printings" OR "Three-Dimensional Printing" OR "Three Dimensional Printing" OR "3D Printing" OR "3D Printings" OR stereolithography OR stereolithographies OR "Stereo lithography" OR "Stereo lithographies" OR "standard triangle language" OR "Standard tessellation language" OR stl OR "planning surgery" OR "Surgical planning") AND ("Mouth, Edentulous" OR edentulous OR "Denture, Complete" OR "denture complete" OR "Complete Dentures" OR "full arch" OR "full arches" OR "full-arch" OR "full-arches") AND ("Dental Implants" OR "implants" OR "implant" OR "Dental Prostheses" OR "Dental Prosthesis" OR "Implantation")
Cochrane (*n* = 26)	(accuracy OR precision OR quality OR "angular deviation" OR "angular measurements") AND ("Surgery, Computer-Assisted" OR "Computer-Assisted Surgeries" OR "Computer-Assisted Surgery" OR "Computer Assisted Surgery" OR "Computer-Aided Surgery" OR "Computer Aided Surgery" OR "Computer-Aided Surgeries" OR "guided surgery" OR "Guided Surgeries" OR "drill-guiding system" OR "Surgery, Image Guided" OR "Computer Aided Design" OR "Computer Aided Design" OR "Computer-Aided Designs" OR "Computer-Assisted Design" OR "Computer Assisted Design" OR "Computer-Assisted Designs" OR "Computer-Aided Manufacturing" OR "Computer Aided Manufacturing" OR "Computer-Assisted Manufacturing" OR "Computer Assisted Manufacturing" OR "CAD-CAM" OR "Printing Three-Dimensional" OR "Three-Dimensional Printings" OR "3-Dimensional Printing" OR "3 Dimensional Printing" OR "3-Dimensional Printings" OR "3-D Printing" OR "3 D Printing" OR "3-D Printings" OR "Three-Dimensional Printing" OR "Three Dimensional Printing" OR "3D Printing" OR "3D Printings" OR stereolithography OR stereolithographies OR "Stereo lithography" OR "Stereo lithographies" OR "standard triangle language" OR "Standard tessellation language" OR stl OR "planning surgery" OR "Surgical planning") AND ("Mouth, Edentulous" OR edentulous OR "Denture, Complete" OR "denture complete" OR "Complete Dentures" OR "full arch" OR "full arches" OR "full-arch" OR "full-arches") AND ("Dental Implants" OR "implants" OR "implant" OR "Dental Prostheses" OR "Dental Prosthesis" OR "Implantation"
Scopus (*n* = 366)	TITLE-ABS-KEY (accuracy OR precision OR quality OR "angular deviation" OR "angular measurements") AND ("Surgery, Computer-Assisted" OR "Computer-Assisted Surgeries" OR "Computer-Assisted

	Surgery" OR "Computer Assisted Surgery" OR "Computer-Aided Surgery" OR "Computer Aided Surgery" OR "Computer-Aided Surgeries" OR "guided surgery" OR "Guided Surgeries" OR "drill-guiding system" OR "Surgery, Image Guided" OR "Computer Aided Design" OR "Computer Aided Design" OR "Computer-Aided Designs" OR "Computer-Assisted Design" OR "Computer Assisted Design" OR "Computer-Assisted Designs" OR "Computer-Aided Manufacturing" OR "Computer Aided Manufacturing" OR "Computer-Assisted Manufacturing" OR "Computer Assisted Manufacturing" OR "CAD-CAM" OR "Printing Three-Dimensional" OR "Three-Dimensional Printings" OR "3-Dimensional Printing" OR "3 Dimensional Printing" OR "3-Dimensional Printings" OR "3-D Printing" OR "3 D Printing" OR "3-D Printings" OR "Three-Dimensional Printing" OR "Three Dimensional Printing" OR "3D Printing" OR "3D Printings" OR stereolithography OR stereolithographies OR "Stereo lithography" OR "Stereo lithographies" OR "standard triangle language" OR "Standard tessellation language" OR stl OR "planning surgery" OR "Surgical planning") AND ("Mouth, Edentulous" OR edentulous OR "Denture, Complete" OR "denture complete" OR "Complete Dentures" OR "full arch" OR "full arches" OR "full-arch" OR "full-arches") AND ("Dental Implants" OR "implants" OR "implant" OR "Dental Prostheses" OR "Dental Prosthesis" OR "Implantation")
Scielo (*n* = 2)	((accuracy OR precision OR quality OR "angular deviation" OR "angular measurements" OR acurácia OR precisão OR qualidade OR "desvio angular" OR precisión OR calidad OR "desviación angular") AND ("Surgery, Computer-Assisted" OR "Computer-Assisted Surgeries" OR "Computer-Assisted Surgery" OR "Computer Assisted Surgery" OR "Computer-Aided Surgery" OR "Computer Aided Surgery" OR "Computer-Aided Surgeries" OR "Cirurgia Assistida por Computador" OR "Cirurgias Assistidas por Computador" OR "Cirurgia Guiada por Imagem" OR "Cirugía Asistida por Computador " OR "guided surgery" OR "Guided Surgeries" OR "Cirurgia Guiada" OR "Cirurgias Guiadas" OR "Cirugía guiada" OR "Cirugías guiadas" OR "drill-guiding system" OR "guia de broca" OR "Surgery, Image Guided" OR "Computer Aided Design" OR "Computer Aided Design" OR "Computer-Aided Designs" OR "Computer-Assisted Design" OR "Computer Assisted Design" OR "Computer-Assisted Designs" OR "Computer-Aided Manufacturing" OR "Computer Aided Manufacturing" OR "Computer-Assisted Manufacturing" OR "Computer Assisted Manufacturing" OR "CAD-CAM" OR "Projeto Auxiliado por Computador " OR "Fabricação Assistida por Computador" OR "Fabricação Auxiliada por Computador" OR "Projeto Assistido por Computador" OR "Diseño Asistido por Computador" OR "Printing Three-Dimensional" OR "Three-Dimensional Printings" OR "3-Dimensional Printing" OR "3 Dimensional Printing" OR "3-Dimensional Printings" OR "3-D Printing" OR "3 D Printing" OR "3-D Printings" OR "Three-Dimensional Printing" OR "Three Dimensional Printing" OR "3D Printing" OR "3D Printings" OR "Impressão Tridimensional" OR "Impressão em 3D" OR "Impressão 3D" OR "Impresión Tridimensional " OR "Impresión 3D" OR stereolithography OR stereolithographies OR "Stereo lithography" OR "Stereo lithographies" OR "standard triangle language" OR "Estereolitografia" OR "Standard tessellation language" OR stl OR "Linguagem padrão do triângulo" OR "Idioma estándar de triángulo" OR "planning surgery" OR "Surgical planning" OR "planejamento cirurgico" OR "planificación quirúrgica") AND ("Mouth, Edentulous" OR edentulous OR edentulo OR edentulismo OR "Denture, Complete" OR "denture complete" OR "Complete Dentures" OR "dentatura completa" OR "full arch" OR "full arches" OR "full-arch" OR "full-arches" OR "arco completo") AND ("Dental Implants" OR "implants" OR

	"implant" OR "Dental Prostheses" OR "Dental Prosthesis" OR "Implantation" OR "implante" OR "implantes" OR "protese dentária" OR "Proteses dentarias" OR "protesi dentales" OR "Protesis dentales" OR "implantes dentales"))
EBSCO (*n*= 195)	((accuracy OR precision OR quality OR "angular deviation" OR "angular measurements") AND ("Surgery, Computer-Assisted" OR "Computer-Assisted Surgeries" OR "Computer-Assisted Surgery" OR "Computer Assisted Surgery" OR "Computer-Aided Surgery" OR "Computer Aided Surgery" OR "Computer-Aided Surgeries" OR "guided surgery" OR "Guided Surgeries" OR "drill-guiding system" OR "Surgery, Image Guided" OR "Computer Aided Design" OR "Computer Aided Design" OR "Computer-Aided Designs" OR "Computer-Assisted Design" OR "Computer Assisted Design" OR "Computer-Assisted Designs" OR "Computer-Aided Manufacturing" OR "Computer Aided Manufacturing" OR "Computer-Assisted Manufacturing" OR "Computer Assisted Manufacturing" OR "CAD-CAM" OR "Printing Three-Dimensional" OR "Three-Dimensional Printings" OR "3-Dimensional Printing" OR "3 Dimensional Printing" OR "3-Dimensional Printings" OR "3-D Printing" OR "3 D Printing" OR "3-D Printings" OR "Three-Dimensional Printing" OR "Three Dimensional Printing" OR "3D Printing" OR "3D Printings" OR stereolithography OR stereolithographies OR "Stereo lithography" OR "Stereo lithographies" OR "standard triangle language" OR "Standard tessellation language" OR stl OR "planning surgery" OR "Surgical planning") AND ("Mouth, Edentulous" OR edentulous OR "Denture, Complete" OR "denture complete" OR "Complete Dentures" OR "full arch" OR "full arches" OR "full-arch" OR "full-arches") AND ("Dental Implants" OR "implants" OR "implant" OR "Dental Prostheses" OR "Dental Prosthesis" OR "Implantation"))
Google Scholar (*n* = 100)	(accuracy OR precision) AND ("Computer Assisted Surgery" OR "guided surgery" OR "Computer Aided Design" OR stereolithography OR "standard triangle language" OR "planning surgery") AND (edentulous) AND ("Dental Implant")
Proquest - Dissertation and Theses (*n* = 9)	(accuracy OR precision OR quality OR "angular deviation" OR "angular measurements") AND ("Surgery, Computer-Assisted" OR "Computer-Assisted Surgeries" OR "Computer-Assisted Surgery" OR "Computer Assisted Surgery" OR "Computer-Aided Surgery" OR "Computer Aided Surgery" OR "Computer-Aided Surgeries" OR "guided surgery" OR "Guided Surgeries" OR "drill-guiding system" OR "Surgery, Image Guided" OR "Computer Aided Design" OR "Computer Aided Design" OR "Computer-Aided Designs" OR "Computer-Assisted Design" OR "Computer Assisted Design" OR "Computer-Assisted Designs" OR "Computer-Aided Manufacturing" OR "Computer Aided Manufacturing" OR "Computer-Assisted Manufacturing" OR "Computer Assisted Manufacturing" OR "CAD-CAM" OR "Printing Three-Dimensional" OR "Three-Dimensional Printings" OR "3-Dimensional Printing" OR "3 Dimensional Printing" OR "3-Dimensional Printings" OR "3-D Printing" OR "3 D Printing" OR "3-D Printings" OR "Three-Dimensional Printing" OR "Three Dimensional Printing" OR "3D Printing" OR "3D Printings" OR stereolithography OR stereolithographies OR "Stereo lithography" OR "Stereo lithographies" OR "standard triangle language" OR "Standard tessellation language" OR stl OR "planning surgery" OR "Surgical planning") AND ("Mouth, Edentulous" OR edentulous OR "Denture, Complete" OR "denture complete" OR "Complete Dentures" OR "full arch" OR "full arches"

	OR "full-arch" OR "full-arches") AND ("Dental Implants" OR "implants" OR "implant" OR "Dental Prostheses" OR "Dental Prosthesis" OR "Implantation")
OpenGrey (*n* = 0)	"guided surgery" AND “edentulous”

Appendix 2. Excluded articles and reasons for exclusion (*n* = 42).

Nr.	First Author, Year	Reason for Exclusion*
1.	Alsharbaty *et al.* 2018	1
2.	Bodard *et al.* 2010	7
3.	Cassetta *et al.* 2013 (A)	5
4.	Cassetta *et al.* 2014 (A)	5
5.	Cassetta *et al.* 2013 (B)	5
6.	Cassetta *et al.* 2014 (B)	5
7.	Cassetta *et al.* 2012 (A)	5
8.	Cassetta *et al.* 2012 (B)	5
9.	Cassetta *et al.* 2011	5
10.	Chen, H. & Longquan S. 2018	7
11.	Chiarelli *et al.* 2012	1
12.	Choi *et al.* 2017	1
13.	D'Haese *et al.* 2013	4
14.	Di Torresanto *et al.* 2014	4
15.	Farley *et al.* 2013	1
16.	Fortin *et al.* 2004	3
17.	Gaggl & Schultes 2002	6
18.	Gastaldi *et al.* 2018	4
19.	Gherlone *et al.* 2016	4
20.	Giordano *et al.* 2012	4
21.	Horwitz *et al.* 2017	7
22.	Katsoulis *et al.* 2009	6
23.	Komiyama *et al.* 2009	4
24.	Lee *et al.* 2013	1
25.	Lindeboom & van Wijk 2010	4
26.	Liu *et al.* 2010	6
27.	Liu *et al.* 2019	6
28.	Meloni *et al.* 2013	7
29.	Meloni *et al.* 2016	4
30.	Ozan *et al.* 2011	1
31.	Platzer *et al.* 2011	1
32.	Rungcharassaeng *et al.* 2015	1
33.	Sarment *et al.* 2003	6
34	Shen *et al.* 2015	1
35.	Siessegger *et al.* 2001	1
36	Souza *et al.* 2012	3
37.	Tahmaseb *et al.* 2012	7
38.	Wittwer *et al.* 2007	4
39	van Steenberghe *et al.* 2005	4
40.	Vercruyssen *et al.* 2014	4
41.	Vercruyssen *et al.* 2014	7
42.	Vercruyssen *et al.* 2014	7

* Reasons for exclusion:
1) Studies in which only single missing-tooth or partially edentulous arches were considered.
2) Studies in which sample included non-conventional implants, such as zygomatic implants.
3) Studies with <10 implants placed by means of s-CAIS;
4) No primary (accuracy) outcomes reported.
5) Retrospective studies.
6) in vitro studies.
7) reviews, case-reports, protocols, short communications, personal opinions, letters, posters and conference abstracts.

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5 CONSIDERAÇÕES FINAIS

Dentro das limitações da presente revisão sistemática, pode-se concluir que:

- A acurácia dos implantes colocados por meio de cirurgia assistida por computador estática (e-CAC) está dentro de uma variação clinicamente aceitável. Distorções horizontais médias nos níveis do pescoço e ápice do implante de 1,09mm e 1,44mm, respectivamente, uma distorção vertical média (profundidade) de 0,16mm e uma distorção angular média de 3,46º foram encontradas.
- A maior distorção linear ocorre no ápice do implante e isso parece estar diretamente relacionado ao comprimento e desvio angular da broca durante a fresagem – quanto mais distante estiver a extremidade do instrumento (comprimento da ponta ativa da broca) do seu ponto de entrada (pescoço do implante), e quanto maior for o ângulo da distorção, maior será a distorção linear horizontal na sua extremidade (ápice do implante). Isto pode influenciar na segurança em casos limítrofes onde não há uma distância segura de acidentes anatômicos importantes, assim como na posição da emergência das plataformas protéticas dos implantes;
- A distorção vertical em profundidade foi menor do que a distorção horizontal. Instrumentos redutores de anilha e brocas com “stops” que controlam a profundidade da fresagem podem ter contribuído para este achado;
- A localização do maxilar (maxila ou mandíbula) parece não ter influenciado na acurácia de implantes dentários colocados por meio de cirurgia assistida por computador estática (e-CAC) em pacientes edêntulos totais;
- A e-CAC pode oferecer inúmeras vantagens em pacientes edêntulos totais, como a diminuição do tempo cirúrgico, da morbidade e do sangramento. No entanto, a técnica precisa ser aperfeiçoada, principalmente quando o carregamento protético imediato com prótese

guiada é considerado. Nestes casos, o desenho e manufatura digital de encaixes perfeitos de plataformas protéticas na base da prótese não são recomendados;

- Fatores relacionados aos *exames de imagem* (aquisição da imagem, confiabilidade dos pontos de referência), ao *paciente* (abertura de boca, resiliência da fibromucosa), ao *procedimento cirúrgico* (adaptação e estabilidade do guia cirúrgico, técnica anestésica, colocação do implante totalmente guiada ou não), ao *sistema de implante* (instrumentos cirúrgicos auxiliares) e ao *operador* (nível de experiência, mão dominante) podem afetar a acurácia de implantes dentários colocados por meio de cirurgia assistida por computador estática (e-CAC) em pacientes edêntulos totais;
- O papel do tipo de suporte da guia e do sistema de implante na acurácia de cirúrgica guiada estática assistida por computador (E-CAC) em edêntulos totais permanecem indefinidos.
- Uma margem de segurança horizontal de 2mm e vertical de 1mm, como prevenção de complicações com estruturas anatômicas importantes deve ser considerada no planejamento;
- O fluxo digital por meio de cirurgia guiada estática assistida por computador (E-CAC) provou ser uma solução viável e previsível para o tratamento de pacientes edêntulos totais com implantes.

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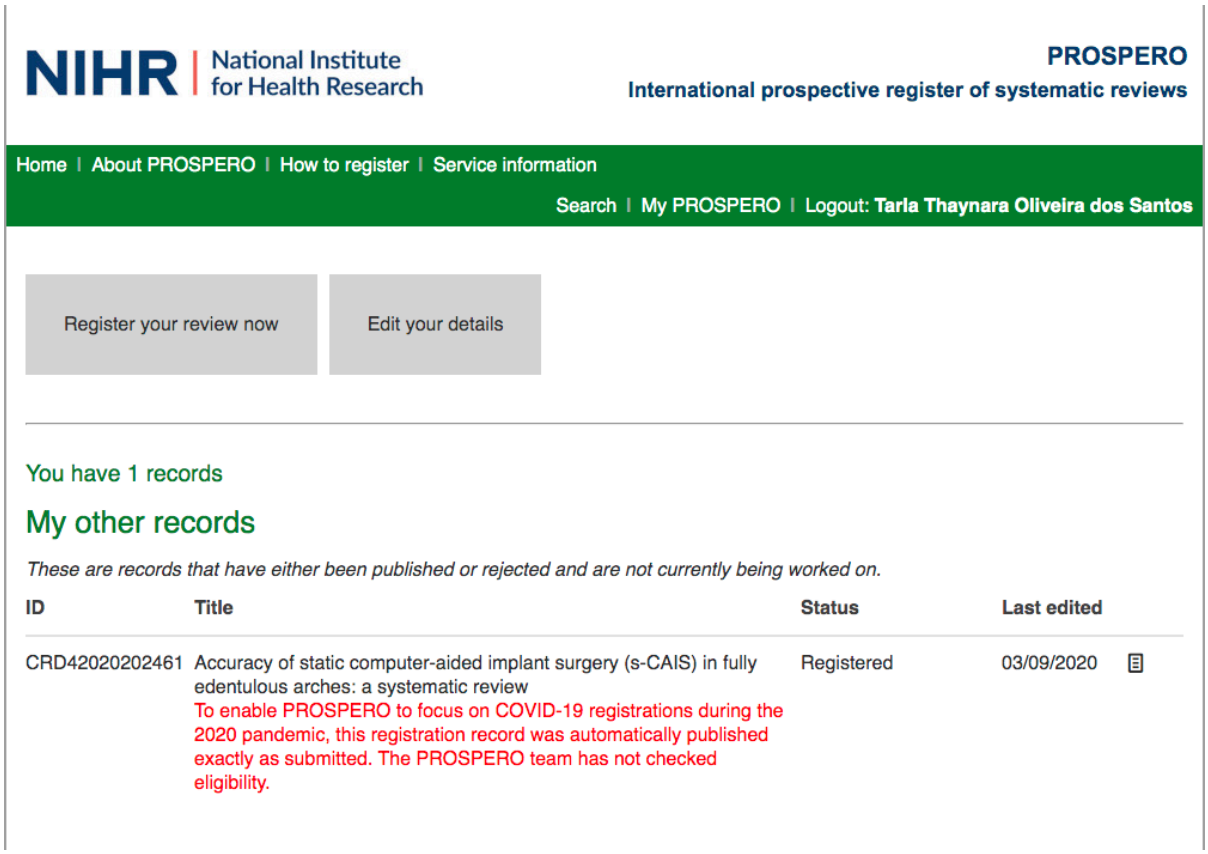
7 ANEXOS

Anexo 1. Registro do protocolo da revisão sistemática no PROSPERO.



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ID	Title	Status	Last edited
CRD42020202461	Accuracy of static computer-aided implant surgery (s-CAIS) in fully edentulous arches: a systematic review To enable PROSPERO to focus on COVID-19 registrations during the 2020 pandemic, this registration record was automatically published exactly as submitted. The PROSPERO team has not checked eligibility.	Registered	03/09/2020

Anexo 2. Normas da revista *Clinical Oral Implants Research*.

CLINICAL ORAL IMPLANTS RESEARCH WILEY

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Book edition

Bradley-Johnson, S. (1994). Psychoeducational assessment of students who are visually impaired or blind: Infancy through high school (2nd ed.). Austin, TX: Pro-ed.

Internet Document

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