Review Article

The Art of Using Computer-Assisted Navigation Systems in Guided Implant Surgery: A Review

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ABSTRACT

Background and Aim: Computer-aided design/computer-aided manufacturing (CAD/CAM) has been widely used in implant dentistry. Recent computer-guided dynamic navigation systems promise an accurate approach to minimally invasive implant placement. Robot-assisted surgery has been used in dentistry since 2017. The present study aims to review the properties, clinical outcomes, advantages, and limitations of navigation, robotics, and CAD/CAM in implant placement surgery.

Materials and Methods: An electronic search of the literature was conducted mainly through PubMed, ScienceDirect, Cochrane Library, and Google Scholar databases. Studies in the English language were considered for inclusion if they evaluated robotics, CAD/CAM, and navigation in implant placement. Finally, 21 articles were selected.

Results: Guided implant surgery is assumed accurate, precise, and reliable; it also has a lower complication rate compared to freehanded implant surgery. Surgical guides could be indicated for patients with limited mouth opening, tight interdental spaces, a strong gag reflex, and distal implants. Several studies have reported that computer-assisted surgery improves the accuracy of implant placement. Expensive equipment, high costs, and gaps between the guides and drill bite are the disadvantages of digital implant placement.

Conclusion: Computer-aided implant navigation systems can improve implant placement outcomes. Digital procedures have shown accurate outcomes in implant surgery. Despite the advantages of guided surgery, deviation of implant position from the planned position still occurs. However, improvements in digital dentistry are slowly overcoming these challenges.

Keywords: Dental Implants, Clinical Outcomes, Computer-Assisted Surgery, Robotics, Surgical Procedures

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Introduction:

Dental implant placement has become a predictable treatment plan for edentulous patients. It has some benefits over alternative restorative options, such as bridges and dentures. (1) Implant placement has been a challenging procedure. Freehanded placement is an error-prone, time-consuming, and complex procedure.(2)

Dental implant placement has progressed through the introduction of images obtained using computed tomography (CT), computer-aided design/computer-aided manufacturing (CAD/CAM), navigation surgery, digital workflow, and robotic assistance. These modalities have been used for planning and designing implant placement.(3,4)

Digital dentistry began in the 1990s and has improved widely since then. Fortin et al presented the first computer-assisted implant surgery (CAIS) in 1995.(5)

Navigation surgery was originally introduced in neurosurgery as a non-invasive approach. Navigation has resulted in less postoperative morbidity, accurate angulation, and time effectiveness. Also, it allows minimal flap surgery, reduces patient discomfort, and minimizes postoperative complications.(6-8) Navigation systems are safe for nerves, bones, adjacent dental roots, and sinus cavities.(5,9) Guided implant surgery is assumed accurate, precise, and reliable with a lower complication rate compared to freehanded implant surgery.(2) Guided implant surgery has increased patient satisfaction and acceptance. It has decreased chances of clinical complications and has reduced surgical time.(2,10) It allows planning and optimizing the implant position.

There are two types of computer-assisted surgical implant navigation placement: static navigation and dynamic navigation.(11) Static navigation fabricates surgical templates using three-dimensional (3D) data obtained from cone-beam computed tomography (CBCT), scanning, and CAD/CAM. (2) Dynamic navigation uses computer-assisted navigation software during surgery (intraoperative).

Robotics has been used in the surgical field after finding its way into medicine. It has been increasingly used for different dental surgical procedures since 2017. Microrobots and nanorobots have been used in endodontics.(12)

Dental implant placement requires accurate depth, angulation, direction, and crestal position.(7,13) The accuracy could be evaluated by pre- and postoperative CBCT superimpositions. Many digital systems have developed pre- and postoperative procedures.(14)

The present study aims to review the properties of navigation systems, robotics, and computer-guided surgery in implant placement surgery. Also, we review the properties, outcomes, clinical success, and accuracy of these modalities to clarify the terminology and describe the advantages and disadvantages of each procedure.

CBCT:

Implant placement has been historically performed with 2D imaging (periapical and panoramic views) that presented distorted bone anatomy.(15) 2D imaging can only relate information about the height and the mesiodistal width. It cannot describe bone density, the thickness of cortical plates, or the true relationship of the natural tooth with the alveolar housing.(16) Dental CT scans have been used as an adjunctive diagnostic virtual simulation and treatment-planning tool for implant placement.(17,18) In 2003, Fortin and colleagues described a CT-based computer-aided implant planning method that uses CAD implant software.(19) Several studies have reported CBCT and CAD/CAM procedures to be more accurate compared to the freehand method.(1,3,6,18)

There are several design software programs in the market for CBCT units, such as Galileos system (Sirona Dental Systems Inc., Charlotte, NC, USA), TxSTUDIO software (i-CAT, Imaging Sciences International LLC, Hatfield, PA, USA), and NewTom implant planning software (NewTom, Verona, Italy).(10)

Digital workflow and prosthetic procedures:

Digital workflows have improved the accuracy, outcomes, and precision of dental implant placement.(20) Digital implant placement combines patients' anatomical data from CBCT in digital imaging and communications in medicine (DICOM) file format with an intraoral scan in the stereolithography (STL) file format.(3,10)

The process could be divided into clinical diagnostics, data collection (CBCT, scanning, and STL files), digitization with CBCT scan, 3D diagnostics and treatment planning, data importing to the software, guide virtual designing (segmentation, orientation, panoramic curve definition, nerve tracking, and merging of CBCT and surface datasets), prosthesis manufacturing, fabrication of surgical guides (subtractive or additive), delivery, and surgery.(2,4)

It should be mentioned that surgical templates could be fabricated using CAD/CAM technology or manually using dental casts.(21) CAD/CAM has been reported to be more predictable, fast, and accurate, and less stressful and expensive compared to the free-hand method.(4,6,15)

Considering the development of new software and hardware, there are several available CAD/CAM systems, such as NobelGuide (Nobel Biocare, Yorba Linda, CA, USA), SimPlant (Materialise, Leuven, Belgium), and Implant Master (I-Dent Imaging, Ft. Lauderdale, FL, USA) for presurgical procedures.(1,22)

With the development of CAD/CAM technology, implant restorations could be fabricated in a single chair-side appointment. After extraoral scanning of the stone cast, the STL file could be printed or milled. There are several software programs available for designing the restoration.[23] Roig et al reported that digital impressions are superior to conventional impressions for placing two implants in a single quadrant.[24]

Computer-guided implant surgery:
Recently, surgical guides have become more popular in implant placement surgery for their accuracy, predictability, and better visualization.[25,26] They reduce the risk of damage to the alveolar nerve, sinus perforation, fenestration, and dehiscence.[25]

After digital processing via the planning software, an STL template would be produced via a prototyping system.[25] The STL template can be used to guide the position and the direction of certain implants during surgery.[9] There are several types of surgical guides, such as tooth-supported, mucosa-supported, bone-supported, and specially supported (mini implant and pin-supported) surgical guides. Bone-supported surgical guides were the first templates used in implant dentistry with the highest rate of inaccuracy.[25,27] Surgical guides could be indicated for patients with limited mouth opening, tight interdental spaces, a strong gag reflex, and distal implants[1]. Several studies have reported that computer-assisted surgery improves the accuracy of implant placement.[1,28,29]

Implant navigation surgery:
Navigation surgery was introduced to neurosurgery for minimally invasive brain biopsy.[25]
There are two approaches to implant navigation surgery: static navigation and dynamic navigation.

Static navigation can be divided into full-guided (FG), half-guided (HG), open-guided, closed-guided, mucosa, bone, and tooth/crown-supported guides.[25] Static systems require surgical templates during drilling.[11] Custom drilling guides are digitally designed before the surgery via software. During the surgery, they are positioned on the jaw, mucosa, or teeth.[8] Static navigation does not allow changes in the presurgical planning position during surgery unless the approach is changed to the conventional method.[25] A bone-supported guide requires reflection of a full-thickness flap. However, a mucosa-supported guide allows a flapless approach. The flap surgical approach increases morbidity, postoperative pain, analgesic consumption, postoperative swelling, and chair time. (25) Closed guides cover the entire surgical field and do not allow the cooling fluids to be in direct contact with the drills during bone preparation. They do not allow visibility of the bone or the mucosa during bone drilling. However, open guides allow buccal view and direct visual control. Full-guided surgery is the most accurate method when there is enough keratinized mucosa and bone in flapless surgery.[25]

There are different non-computer-fabricated surgical stents, such as drilling-guided, pilot-drill-guided or non-computer-guided.[25]
Dynamic navigation allows monitoring of bone drilling and implant placement during surgery through 3D software.[7] It shows the differences between the position of the drill tip and the ideal (planned) position, angulation, and depth. The navigation system minimizes trauma by showing the implant placement position without the need for an open flap.[30] It allows changing the surgical plan, implant size, implant system, and location parameters of the implant according to the actual clinical situation without the delay or the cost of a static surgical guide.[30,31] It should be considered that dynamic navigation has some disadvantages, such as the need for precaution during all the steps, high costs, a learning curve, and software error between the reference points.[7,25]

The navigation method could be indicated for high-risk patients, cardiovascular patients taking anticoagulation medicine, and patients with tight interdental spaces and limited mouth opening. It also could be indicated for sites with difficult visualization and atrophic mandibles and to avoid nerve trauma.[7,11,30]

There is a learning curve with the application of new technology. However, the increased experience level of clinicians with navigation systems will improve the accuracy of the outcome.[8] Several studies have reported both dynamic and static systems to have accurate outcomes.[32]

There are many planning software options for surgical-guided (static) implant placement, such as Ay Tasarim (Turkey), 3D StendCad (Media Lab, Italy), Biodental Models (BioMedical Modeling, USA), EasyGuide (Keystone Denta, USA), Guide (Bioparts, Brazil), Implant 3D (Med30, Switzerland), and ImplantViewer (Anne Solutions, Brazil). The Dynamic software programs (navigation) include IGI (Image Navigation, USA), OnDemand3D Implant (Cybermed, Korea), Robodent (Robodent, Germany), Treon (Medtronic Navigation, USA), VISIT (Austria), and Voxim (IVS, Germany).[33]

Robotics in dental implantology:

Robotics has been used widely in general surgery, urology, and gynecology.[29] The first case of a robot-assisted surgical procedure was used in a neurosurgical biopsy via the Programmable Universal Manipulation Arm (PUMA 560) robotic system in 1985.[34] "Remote Surgical Robotic Arm" (Michigan University) and ROSY robot system "Autonomous Surgical Robots" (InTouch Health Ltd.) are examples of surgical and medical assistive robotics.[12,35] Robotics has been used in endodontics and orthodontics. Robotics has advantages such as being minimally invasive, having depth control, real-time controlling, and better visualization, as well as being easy-to-use in an operative field. Nevertheless, robotic surgery is a challenging method. Robotics has disadvantages such as prolonged surgery time, the need for the skill, high costs, safety requirements, and system complexities.[36] It should be mentioned that, despite the advantages, the use of robotics in implant placement is limited.

The first robotics used in dental implantology was Yomi (Neocis Inc., Miami, FL, USA) in 2017. Several prototype systems have been developed in many centers, including the University of Kentucky, Ecole des Mines de Paris, Umea Universitet, the University of Coimbra, and the University of Dusseldorf.[34]

The software consists of robot calibration, drill plan, load plan, drill execution, and acquisition data modules.[34]

The procedure is planned and designed virtually using patients' CBCT and STL files from the scanners. The robot includes a robot guidance arm, planning software, a monitor, a surgical navigation system, and an optical tracking device. The robotic arm can automate the drilling process.[35] The software is used for planning and guiding the instrumentation. It would give feedback about the position, depth, and angulation. The feedback prevents virtual plan deviation. Yomi's arm would move while the surgeon applies a force. Arms would be fixed when the planned angulation, location, and depth are achieved. During the surgery, the positions of the handpiece and the 3D image of the patient are shown on the monitor. Yomi is expensive and should be used under supervision.

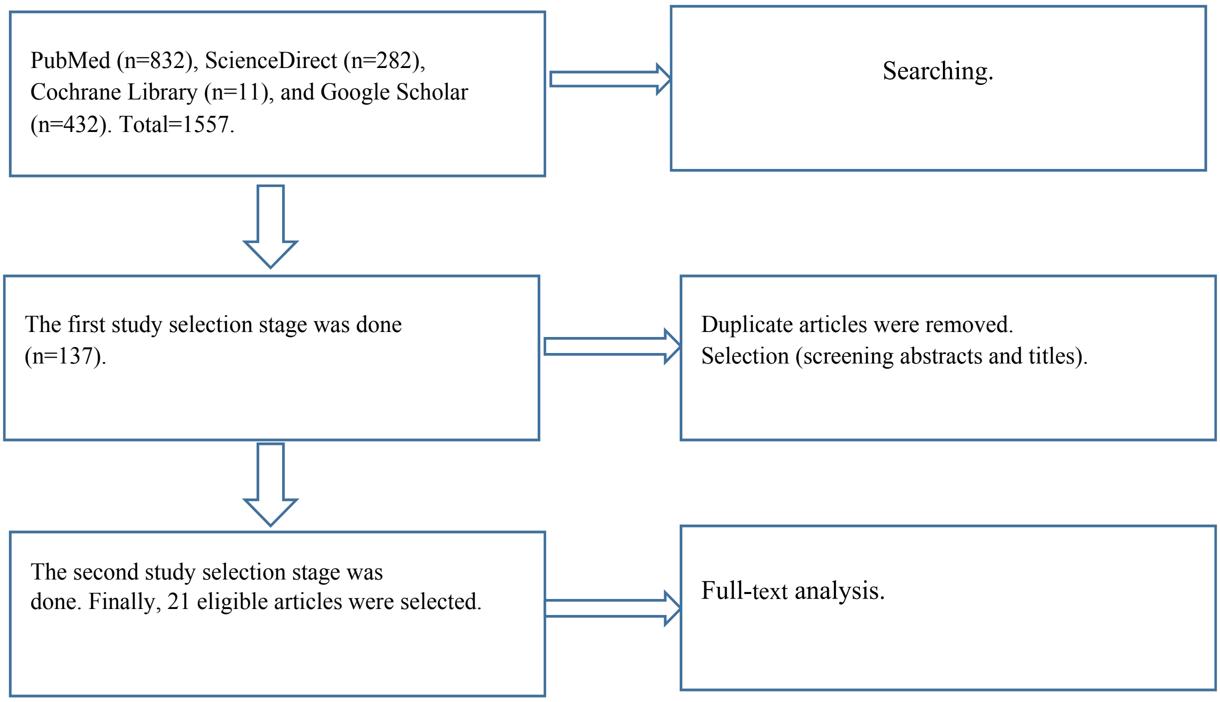
Robotics reduces surgical time. Bolding and Reebye have reported that the surgical time per arch averaged 20.5±10.3 minutes for osteotomies and 9.9±7.9 minutes for implant placement.[20]) Syed and colleagues reported errors in the range of 0.55-0.23mm at a 20mm/s velocity. Robotics is an accurate, untiring, and minimally invasive procedure.[14] Rawal and colleagues reported the robotic procedure to be an accurate method.[37] However, it only can judge quantitative information.[34] Human error, fatigue during surgery, and mouth opening limitation could affect surgical outcomes. With the advancement of navigation surgery, robotics is under development in implant surgery. Robotics has the potential to improve clinical outcomes.

Materials and Methods:

An electronic search of the literature was conducted mainly through PubMed, Google Scholar, ScienceDirect, and Cochrane Library using "dental implant" and "computer-guided" OR "robotics" OR "static navigation" OR "dynamic navigation" OR "digital" OR "computer-assisted" as keywords from 1986 to 2020. The first study selection (screening) was according to the relevance of the titles and the keywords. A study was considered for inclusion if it evaluated robotics, CAD/CAM, and navigation in implant placement and published in the English language. The second study selection was according to full-text analysis. Studies were included according to the following inclusion criteria: technique and accuracy evaluation of computer-aided dynamic/static navigation for dental implant placement, comparison of dynamic and static navigation, evaluating computer-guided implant surgery, and robotics evaluation in implant surgery. We included human randomized clinical trials (RCTs), non-randomized clinical trials, and ex-vivo and in-vitro studies. The search strategy is described below. The search aimed to collect all English articles from 1986 to 2020 (n=822). Duplicate articles were removed.

Flowchart of the search strategy and selection process:

Search date: January 17



Results:

Table 1 summarizes the findings of the 21 reviewed articles. The evaluation of the studies yielded different results. The accuracy of implant placement is one of the most important factors for outcomes. Several studies have reported that fully guided implant surgery had greater accuracy than half-guided surgery.[6,9,38]

Studies have reported that partially edentulous was more accurate than fully edentulous. [29] The deviation has been reported to be greater in unilateral support or free-end.[39,40]

A single implant restoration placement had better results than placement of an implant in a free-end dental arch.[21,41] Mello and colleagues reported that CAD/CAM systems are more accurate and improve the marginal fit compared to the conventional method.[41] Joda et al reported that CAD/CAM implant crowns showed promising radiographic and clinical outcomes after 5 years of function.[42]

Tahmaseb et al stated that static navigation had a significant horizontal deviation at the coronal entry point and apical endpoint of 1.2mm (1.04-1.44 mm) and 1.4 mm (1.28-1.58 mm).[29]

Mediavilla Guzmán et al described a mean deviation of 1.2 (0.3-2.1 mm) at the apical endpoint.[11] It should be considered that deviations in clinical studies were significantly more compared to in-vitro studies.[8]

Raico Gallardo et al informed that the tissue that supports the guide affects the accuracy of computer-aided implant surgery placement.[43] Ozan et al reported that tooth-supported guides offer more accuracy than mucosa-supported guides.[44] Studies have reported that tooth-supported surgical guides may be more accurate than mucosa-supported guides.[28,44]

Sun and colleagues held that the same level of accuracy could be obtained for maxillary and mandibular implants.[31]

Table 1- Summary of the findings:

Authors\Year	Type of study	Implant placement method	Number of implants	Main outcome	Deviation/Result	Software
Kiatkroekkrai et al 2020	RCT	computer-assisted implant surgery	60	No statistically significant difference between the groups (P>0.05).	Average deviation for the intraoral vs. model scan groups was 2.42°±1.47° vs. 3.23°±2.09° for implant angle, 0.87±0.49mm vs. 1.01±0.56mm for implant platform, and 1.10±0.53mm vs. 1.38±0.68mm for implant apex	coDiagnostiX 9.7 software (Dental Wings Inc., Montreal, Canada)
Pelegrino et al 2020	In vitro	Dynamic navigation	112	Reliable technique	The overall 3D deviation measured was 1.58 ± 0.80 mm at the entry point (3D E) and 1.61 ± 0.75 mm at the apical point	ImplaNav, BresMedical, Sydney, Australia
Henprasert et al 2020	In vitro	Subtractive/additive guides	30	Same accuracy	Mean apical deviation 0.84 mm in the printed group and 0.80 mm in the milled group.	BlueSky Plan 4 software
Stefanelli et al 2020	Case series	Dynamic navigation/Full arch	77	Accurate outcomes	Statistically significant mean difference between the two groups in the coronal position of implants (3–4 teeth group: 0.720 ± 0.322 mm; 5–4 group: 0.61 ± 0.328 mm; P<0.001), the apical position of implants (3–4 teeth group: 1.168 ± 0.313 mm; 5–4 group: 0.877 ± 0.370 mm; P<0.001)	Navident software (ClaroNav Inc., Toronto, ON, Canada)
Sun et al 2020	In vitro	Navigation System, a Laboratory Guide, Freehand Drilling	128	Navigation systems had accurate outcomes	Total, longitudinal, and angular deviation were significantly different (P<0.0001). Coronal deviation: Maxilla 1.82±0.04/Mandible 1.97±0.07. Combination of a dental implant navigation system and a surgical guide kit achieved the highest accuracy.	SmilePlan, TITC Ltd., Kaohsiung, Taiwan
Vinci et al 2020	Multicenter study	Three-dimensional (3D) planning (14 patients)	100	Accurate	1mm mean horizontal deviation in the neck point and a 1.6mm deviation in the apex point. A mean 5° angular global deviation. Greater errors in the mandible were detected as compared to the maxilla.	RealGUIDE, 3DIEMME, and Geomagic software.
Roig et al 2020	In vitro	Free-handed with digital impression	2	Optical scanning impressions showed improved accuracy compared to elastomeric impressions.	TRIOS3 (0.029) and CS3600 (0.042) showed a significantly improved mean accuracy compared to closed tray, CEREC Omnicam, and TrueDefinition.	Geomagic Control X (3D Systems Inc., Rock Hill, SC, USA)

Authors\Year	**Type of study**	**Implant placement method**	**Number of implants**	**Main outcome**	**Deviation/Result**	**Software**
Bolding and Reebye 2020	Clinical study	Robotic-guided	58	Accurate	Yomi edentulous patient splint affixation and removal times averaged 6.5±3.9 and 1.1±0.3 minutes, respectively. Surgical time per arch averaged 20.5±10.3 minutes for osteotomies and 9.9±7.9 minutes for implant placement.	Yomi Plan software (Neocis Inc., Miami, FL, USA)
Guzman et al 2019	In vitro	Static navigation-dynamic navigation	40	Both had accurate outcomes	Statistically significant differences were observed (P=0.0272). Mean deviations of 1.20±0.48 mm (min: 0.30 mm; max: 2.10 mm) and 1.18± 0.60mm (min: 0.20 mm; max: 2.50 mm) were observed at the apical endpoint.	Static navigation system (NemoStudio®, Nemotec, Madrid, Spain)
Skjervan et al 2019	In vivo	Full Digital Planning and Stereolithographic Guides	27	Comparable to the conventional method.	The mean lateral deviation at the coronal point was 1.05 mm. The mean lateral deviation at the apical point was 1.63 mm. The mean depth displacement was +0.48 mm. The mean angle of deviation was 3.85 degrees. The main deviation between the planned and achieved implant was angular.	3Shape implant studio
Kaewsiri et al 2019	RCT	Static/Dynamic navigation	60	Same accuracy	The mean deviation at implant platform and implant apex in the static CAIS group was 0.97±0.44 mm and 1.28±0.46 mm, while that in the dynamic CAIS group was 1.05±0.44 mm and 1.29±0.50 mm, respectively. The angular deviation in static and dynamic CAIS groups was 2.84±1.71 degrees and 3.06±1.37 degrees.	DiagnostiX software version 9.7 (Dental Wings Inc., GmbH)
Bencharit et al 2018	In vivo	Desktop stereolithographic 3D printer	31	Fully guided implant surgery is more accurate than partially guided implant surgery.	The mesial, distal, buccal, and lingual dimensions and buccolingual angulations with the fully guided protocol (n=20) were 0.17±0.78 mm, 0.44±0.78 mm, 0.23±1.08 mm, -0.22±1.44 mm, and -0.32°±2.36°. No statistically significant difference was found between the software programs.	3Shape implant studio
Tan et al 2018	In vitro	Stereolithographic virtually planned and guided technique	30	Greater accuracy than the freehand technique	Implant shoulder displacement, depth displacements, and direction of displacement did not differ between the groups. Implant angulation and apical displacement were significantly closer to the planned position in the guided group.	Implant Studio software

Authors\Year	Type of study	Implant placement method	Number of implants	Main outcome	Deviation/Result	Software
Kasten et al 2018	Review	Dynamic-static navigation	150	New level of predictability and precision	Static navigation showed 1.4 mm apical horizontal, 1.1 mm coronal horizontal, 0.74 mm vertical, and 3.98° angular deviations. Dynamic navigation is reported to have 0.4mm horizontal/vertical and 4° angular deviations.	SmilePlan, TITC Ltd., Taiwan- dental navigation system (AQNavi, TITC Ltd., Taiwan)
Sun et al 2018	In vitro	Dental implant navigation system	15	Similar accuracy for both maxillary and mandibular dental implants	The average deviation of the total, longitudinal, and angular errors were respectively 1.55 ±0.37 mm, 0.47± 0.36 mm, and 3.65 ± 0.92. Total, longitudinal, and angular errors differed significantly (P<0.0001, <0.0001, and =0.0153).	SmilePlan software
Deeb et al 2017	In vitro	Static stereolithographic	10	Accurate, convenient, and cost-effective.	Mean mesiodistal angulation deviation was 0.84° (range: 0.08° to 4.48°), and the mean faciolingual angulation deviation was 3.37° (range: 1.12° to 6.43°).	3Shape Implant Studio
Emery et al 2016	In vitro	Dynamic navigation system	231	Accurate	3D positional accuracy was 0.38±0.21 mm for dentate and 0.56±0.17 mm for edentulous (from the implant apex).	System: X-Guide, X-Nav Technologies, LLC, Lansdale, Pa, USA
Naziri et al 2016	Clinical study	Computer-assisted	246	Accurate	Median deviation was 1.0 mm (shoulder) and 1.4 mm (apex). The median angular deviation was 3.6º.	CoDiagnostiX Software
Vercruyssen et al 2015	RCT	Guided implant	288	Non-guided surgery had higher inaccuracy.	The overall mean vertical deviation for the guided surgery groups was 0.9±0.8mm and 0.9±0.6mm in the horizontal direction. The most important inaccuracy with guided surgery is in the vertical direction (depth). There is less inaccuracy in the MD or BL directions.	Materialise Universal
Geng et al 2015	Clinical study	CAD/CAM	111	Accurate	The mean angular deviations were 1.72±1.67 and 2.71±2.58. The mean deviations in position at the neck were 0.27±0.24 and 0.69±0.66 mm. The mean deviations in position at the apex were 0.37±0.35 and 0.94±0.75 mm. Tooth-supported surgical guides may be more accurate than mucosa-supported guides.	3Shape
Fortin et al 2005	In vivo	Image-guided implant placement	30 patients	Clinically acceptable	The Kendall correlation was 0.8 for the diameter and 0.82 for the length. The Kappa concordance was 0.87 for both dehiscence and bone graft, 0.88 for osteotomy, and 1.0 for fenestration.	3Shape

However, Vinci et al reported greater errors in the mandible.[26] Some studies have reported higher accuracy of surgery in the mandible.[9,31] Several studies have shown no statistically significant differences among different implant sites.[21,45] It has been reported that the posterior section shows more discrepancies than the anterior section.[13,26,45] Anterior implants showed less displacement compared to posterior implants in all dimensions.[6]

The fixation and support of the surgical guide affect the accuracy. To improve the accuracy, it is recommended to fix the guide with pins or temporary implants.[9,46]

Guided systems using fixed screws with a flapless approach are more accurate.[9] Zhou and colleagues concluded that a flapless approach is more accurate than an open-flap approach.[9] The flapless technique reduces the healing period, patient discomfort, surgical time, and postoperative bleeding.[6,19,25]

The use of titanium sleeves for directing the drill increases guide deflections.[46] Using closed-sleeve-design templates with closed holes improves the accuracy.[45]

Several model-based studies have been done to evaluate the accuracy. Compared to in-vitro studies, clinical studies have reported greater deviations and errors.[4] Unsal and colleagues indicated that the clinician should be aware of angular and linear deviations up to 5° and 2.3mm. [4] It has been reported that the implant position shows more deviation at the apical portion compared to the coronal portion.[47]

For eccentric drilling, the Camlog guide showed the highest (5.64°) and Straumann-guided surgery showed the lowest (0.00°) angular deviation.[39]

The main deviation between the planned and achieved implant positions was angular (range: 1.25-8.6 degrees) followed by global deviation coronal site apical point (range: 5.16-0.56).[48] The deviation may be a result of the aforementioned anatomical structures, tolerance of the guiding sleeve, precision in guide fitting, range of implant drill swing, deviation of self-tapping implants, and protocols for measuring implant position.[3,38,49]

Naziri and colleagues showed that the accuracy of implant placement decreases with increasing implant length; they recommended using implants smaller than 11 mm for guided surgery.[21]

Several studies have reported statistically significant differences between different implant systems.[21,39] However, some studies reported no differences between implant systems.[6] Laederach et al reported that Straumann-guided surgery had the lowest axial deviation (0°), and the Camlog guide had the highest axial deviation (5.64°). The SIC guide had the lowest apical deviations (0.01 mm) and NobelGuide had the highest (3.2 mm). The SIC guide had the lowest coronal deviations (0.01mm) and NobelGuide had the highest (1.60 mm).[39]

Chen et al reported that navigation systems are more accurate than laboratory guides.[50] However, Sun et al informed that the combination of navigation systems and surgical guides yields the highest accuracy.[13] Desktop stereolithographic printers have been reported to be convenient, cost-effective, and accurate.[6] In-office fabricated guides showed similar accuracy to laboratory prepared guides.[3] Kiatkroekkrai et al concluded that implant placement with CAIS fabricated guides after intraoral scanning is at least as accurate as CAIS fabricated guides after extraoral scanning.[51] Several studies have proven that guided system techniques are superior to the conventional method, especially in difficult anatomical regions.[52]

Both additive and subtractive surgical guides can provide high accuracy for implant positioning.[47]

Bell et al reported no difference between thermoplastic surgical guides and 3D-printed surgical guides in angular deviations.[53] However, the locations of implant head and apex were significantly more accurate for implants placed with 3D-printed surgical guides.[53]

Lee et al reported that the use of a CAD/CAM screw channel-drilling guide improved the accuracy of the screw access channel and minimized damage to the crown and abutment. They recommended CAD/CAM screw channel drilling guides for less destructive channel preparation and facilitating crown retrieval, particularly for angled implants.[54]

Both computer-aided static and dynamic navigation procedures allow accurate implant placement.[11,32] It has been reported that computer-guided methods show more accurate results compared to the free-hand method.[1,3,6,15,18,50] Several studies have conveyed acceptable accuracy and clinical outcomes.[48,55]

Several factors could affect the outcomes, including errors while scanning, CT scan method, CT static guide design, software error (type of software, error during image acquisition and data processing, and errors during designing), error during surgical template production, drilling technique, difficulty of drilling, flap versus flapless approach, error during template positioning, movement of the template during drilling guide positioning, stability of the surgical guide, depth and angulation of implant in the bone, type of guide, manufacturing inaccuracies, and clinician's experience.[2,9,29,46,47,49]

It is important to know which implant systems are compatible with a specific intraoral scanning system or CAD/CAM software to reduce errors.[56] Sun et al reported that the operational accuracy of a dental implant navigation system is not restricted by the experience of the clinician.[13] Rungcharassaeng et al studied the effect of operator's experience on the accuracy of implant placement and reported no significant differences in angular and linear deviation at the coronal and apical levels between experienced and inexperienced operators.[57] Pellegrino et al reported that dynamic navigation renders accurate outcomes that are independent of operators' skills in implantology and their knowledge of navigated surgery.[58]

The ability to place dental implants in the correct positions and high accuracy are the advantages of digital implant surgery.[27,29]

Surgical navigation in implant placement and positioning has been reported accurate and reliable.[29,44] Also, clinical studies have evaluated the accuracy and reported accurate and predictable outcomes.[21] Expensive equipment, high costs, and gaps between the guides and drill bite are the disadvantages of digital implant placement. [13,29,31]

It should be considered that in-vitro studies render better outcomes and higher accuracy due to better access, better visual axis of osteotomy, no patient movement, no saliva, and no blood.[38] Nowadays, navigation and robotics are improving worldwide. They have emerged into a patient/clinician-friendly procedure. It should be considered that milling machines and 3D printers have become smaller. Clinicians should choose an implant placement procedure according to their work habits and anatomical considerations. To the best of our knowledge, at the time of writing this manuscript, despite limitations and early development, digital implant placement allows accurate dental implant placement. Looking at the literature, the authors suggested that using digitalized procedures would improve clinical outcomes. There is a great need for dentists to improve their skills and knowledge in the digital field. Finally, there is still limited evidence to support digital implant placement. Nevertheless, the future of dentistry is unpredictable.

Conclusion:

Based on the findings of this study, the following conclusions were drawn:

1) The future of robotics in the implant field seems promising, and the costs will decrease. Clinical evaluations of robotics are recommended.

2) Computer-aided static and dynamic navigation procedures have shown accurate outcomes in implant placement.

3) Surgical navigation and guides are not yet free from errors and complications. Despite the advantages of guided surgery, deviation of implant position from the planned position still occurs. However, improvements in digital dentistry are slowly overcoming these challenges.

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