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Short Communication

Navigation in Implant Dentistry

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"Navigation in surgery" spans a broad area, which, depending on the clinical challenge, can have different meanings. Over the past decade, navigation in surgery has evolved beyond imaging modalities and bulky systems into the rich networking of the cloud or devices that are pocket-sized.

Navigation is the process or activity of accurately tracking ones position and planning and following a route. This is similar to driving a car, using a smartphone, piloting a boat, or even geocaching with a friend. Technology aids with navigating many aspects of life.

Over the last three decades, technical advances have significantly changed the way we live. From computers to smartphones, from single purpose to multipurpose devices, technology has become an intrinsic part of our daily routine. Navigation in surgery is an important example of today's technological capabilities being applied to medicine. It has emerged as one of the most reliable representatives of technology as it continues to transform surgical interventions into safer and less invasive procedures. In surgery, navigation has spurred technical progress, enabled more daring procedures, and unlocked new synergies. What was once a simple localization tool has evolved into a centerpiece of technology in the surgical theater.

"Navigation in surgery" spans a broad area, which, depending on the clinical challenge, may have various interpretations. The meaning of navigation in surgery is most accurately defined by the questions posed: "Where is my (anatomical) target?", "How do I reach my target safely?", "Where am I (anatomically)?", or "Where and how shall I position my implant?". Apart from these important anatomical orientation questions, surgical navigation is also used as a measurement tool and an information center for providing surgeons with the right information at the right time.

Traditionally, determining implant position, size, number, direction, and placement depended on the presurgical diagnostic imaging, which often, was limited to two-dimensional radiographs, and on the guiding acrylic stents usually prepared over duplicated casts of diagnostic wax-up. However, limitations of two-dimensional imaging and inaccuracies in the stent fabrication or guide channels often lead to erroneous implant placement, which results in complications and implant failure, especially in anatomically complicated situations. To overcome these limitations, many advancements have taken place, which have computerized the implant-dentistry. These include:

- Three-dimensional computed tomography (CT) imaging
- CT-based implant-planning software
- Computer-aided-design/computer- aided-manufacturing (CAD/CAM) technology
- Computer guided implant surgery (CGIS)
- Computer navigated implant surgery (CNIS)
- Robotic-implant-dentistry.

Three-Dimensional Computed Tomography Imaging

Two-dimensional imaging techniques like orthopantomogram and intra oral periapical radiography are affordable, economical and easy means of implant site selection. Yet, they tend to produce errors as they have many shortcomings like image superimposition, limited reproducibility, and production of a projected image of three-dimensional object onto a two-dimensional plane as well as distortion and variable magnification of the image. Considering these shortcomings of two-dimensional imaging techniques, three-dimensional imaging has become an essential diagnostic tool and is considered the gold standard in implant-dentistry, for it:

- Allows three-dimensional views of the region of interest and relevant jaw anatomy such as the maxillary sinus and mandibular nerve.
- Can also be utilized for the estimation of alveolar bone density
- Overcomes the limitations of traditional two-dimensional imaging modalities and provides uniform magnification, multiplanar views, and simultaneous study of multiple implants.

Yet, certain limiting factors as follows are also associated with CT:

- Beam hardening artifact or scatter due to adjacent metal structures
- High costs associated with CT examinations
- Relatively high radiation dose to the patient.

Considering these limitations, cone-beam computed tomography (CBCT) imaging might be a viable, more practical and perhaps even better alternative to CT in the preoperative radiographic assessment of potential dental implant sites. Recently, Esmaeili., *et al*. 2013 compared CBCT and a 64-slice CT scanner for the beam hardening artifacts produced by dental implants and suggested that given the higher resolution of the images produced by CBCT and its lower doses and costs compared with CT scanner, CBCT should be recommended in order to produce images of higher diagnostic values, especially in patients with extensive restorations, multiple prostheses or previous implant treatments. Furthermore in 2012, Pires., *et al*. in his study demonstrated that presence, location, and dimensions of the mandibular incisive canal are better determined by CBCT imaging than by panoramic radiography.

The patient is thenceforth, scanned with either fiducial (artificial) radiographic markers that are placed in stent, jaws etc., or with anatomic (natural) markers such as teeth or bony landmarks and then the digital images, in digital imaging and communications in medicine format, which are derived this way are imported into one of the implant-planning software programs and converted into a virtual three-dimensional model of the treatment area to provide a realistic view of the patient's bony anatomy, thus permitting a virtual execution of the surgery in an ideal and precise prosthetically driven manner. Yet, whichever diagnostic scan is advised, a risk/benefit analysis must be carried out before.

Computer-Aided-Design/Computer-Aided-Manufacturing Technology

Transferring the virtual treatment plan into actual patient treatment has been made possible by the revolutionary CAD/CAM technique, which is used in two guided surgery systems that is, (1) "Static" or "template-based system," that communicates predetermined sites using "surgical templates" or implant guides in the operating field, manufactured via rapid prototyping technologies such as three-dimensional printing and stereolithography or "computer-driven drilling" and (2) dynamic system or "surgical navigation/computer-aided navigation" technology, which communicates virtual treatment plan to the operative field with visual imaging tools on a computer monitor, rather than the intraoral guides.

Advantages of CAD/CAM technology are:

- It facilitates minimally invasive surgical procedures with surgical guides (CGIS) along with greatly improving the predictability of implant surgery.
- It allows immediate loading by enabling the presurgical construction of master cast and accurately fitting, custom designed restorations.

Computer Guided Implant Surgery (Static System)

The static system, which employs use of a static surgical template/guide to reproduce virtual implant position in the surgical field, can be categorized into two types based on the CAD/CAM technology used for the surgical guide production.

Computer Guided Implant Surgery (Static System)

- It precisely guide the osteotomy drills
- Directs the surgeon in the exact location and angulation to place the implant based on virtual treatment plan
- It allows flapless surgery, which entails less bleeding, less swelling, decreased healing time and postoperative pain
- Aids in the preservation of hard and soft tissue and maintains blood circulation to the surgical site
- Considerably increased accuracy of implant placement
- Avoidance of vital structures
- Shorter period required for surgery.

Out of the various types of surgical guides (classified according to the type of support: Bone, mucosa, tooth, or combination tooth-mucosa), Arisan., *et al*. in 2010, demonstrated that Implants that were placed by bone-supported guides had the highest mean deviations (1.70 ± 0.52 mm for implant shoulder), whereas the lowest deviations (0.7 ± 0.13 mm for implant shoulder) were measured in implants that were placed by mucosa-supported guides fixed with osteosynthesis screws. Though implant placement through the static surgical guide system is significantly more accurate than freehand, a higher accuracy can be achieved by sleeve-in-sleeve concept in which multiple sleeves are placed in the guide to properly orient the implant drills with increasing diameters and also by the fixation of the guide onto the surrounding alveolar ridge or mucosa for the stabilization. In 2007, Nickenig and Eitner had demonstrated that virtual plans based on CBCT scans could be reproduced during implant placement surgery, and hence, validated the reliability of the CGIS method for safe and predictable implant placement, and enabling wider use of flapless surgery. Based on the systematic review regarding accuracy and clinical application of computer-guided template-based implant-dentistry, Schneider., *et al*. in 2009 showed high implant survival rates ranging from 91% to 100%, following CGIS method. The meta-regression analysis also revealed a reasonable accuracy with a mean deviation of 1.07 mm (95% confidence interval [CI]: 0.76 - 1.22 mm) at the entry point and 1.63 mm (95% CI: 1.26-2 mm) at the apex. Precise transfer of implant replica position by means of simulated guided implant insertion, into a preoperative cast and a postoperative cast has also been demonstrated by Platzer., *et al*. in 2013. Vasak., *et al*. (2014) also verified the viability of the CGIS concept and revealed a cumulative survival rate and success rate of 98.8% and 96.3% of immediate and delayed loaded implants respectively, placed using CGIS technique. Recently, Meloni., *et al*. conducted a clinical trial where in 23 edentulous jaws were treated with three-dimensional software planning, guided surgery, and immediate loading and restored with CAD-CAM full arch frameworks and concluded that computer-guided surgery and immediate loading seem to represent a viable option for the immediate rehabilitations of completely edentulous jaws with fixed implant supported restorations. Though CGIS technique has been proven as an accurate and viable technique, it also has certain drawbacks and limitations, which have to be considered as well. The most common drawbacks and limitations associated with CGIS include:

- Error in data acquisition or incorrect processing of the image
- Deviations from planned implant positions especially in the coronal and apical portions of the implants as well as with implant angulation
- Inaccurate fixation of the guide resulting in displacement during perforation
- Mechanical errors caused by angulation of the drills during perforation
- Changed positioning of surgical instruments due to reduced mouth opening
- Fracture of the surgical guide
- Complexity of the whole system
- The total cost of tools needed including the software program and surgical templates
- The potential for thermal injury secondary to reduced access for external irrigation during osteotomy preparation during flapless implant placement with surgical guides
- Does not allow intraoperative modification of implant position.

Hence, care should be taken whenever applying this technique on a routine basis. Yet, with the progression towards CNIS many of the limitations and drawbacks of CGIS technique have been evaded.

Computer Navigated Implant Surgery (Dynamic System)

Computer navigated implant surgery involves the use of a surgical navigation system that reproduces virtual implant position directly from CT data with the optical bur tracking system without the requirement of an intraoral surgical guide. There are several navigation or positional tracking systems available in implant-dentistry but few meet the computer-aided-surgery requirements in terms of accuracy (about 1 mm in 1 m^3), reliability, and clinical usability. In CNIS, the natural and fiducial markers that were used during the radiological scan as reference points are needed for the registration of the instruments. Watzinger., *et al*. In his case report promoted the use of optical tracking system for the intraoperative transfer of preoperative planning on CT scans, in real-time, since, the motor of the implant drill produced considerable distortion of the magnetic field and hindered the direct visualization of implant socket drilling when the electromagnetic tracking system were employed formerly. Sensors attached to both the patient and the surgical hand-piece transmit three-dimensional positional information to a camera or detector that allows the computer to instantaneously calculate and display the virtual position of the instruments relative to the image data and also allows the visualization of the movements of the instruments in real-time to the surgeon via side-viewers or advanced see-through viewers.

Computer navigated implant surgery has many advantages over CGIS in that:

- It allows intraoperative changes in implant position that is, the virtual surgical plan can be altered or modified during surgery and the clinician can use the navigation system to concurrently visualize the patient's anatomy, permitting the surgeon to steer around obstacles, defects etc., that were not apparent on the presurgical scan
- Bur tracking allows the drill to be continuously visualized on a computer screen in all three-dimensions (x, y and z)
- It overcomes other limitations of CGIS like secondary thermal injury, displacement or fracture of guide etc.

The image guided implantology (IGI) system, which is a CNIS system, has been shown to provide highly accurate navigation with overall mean spatial navigation error of 0.35 mm, which is acceptable in dental implantology. The accuracy in implant placement by the CNIS system (IGI) has also been illustrated in a recent study by Elian., *et al*. who demonstrated a mean linear accuracy of less than 1 mm at both the implant neck and apical tip and the reported mean angular deviation of less than 4° for the implants placed via CNIS system that is, an accurate match between the planned implant and final implant was revealed. In contrast, a mean linear accuracy ranging between 1.1 mm and 1.45 mm at the implant neck and between 1.41 mm and 2.99 mm at the implant apical tip along with a mean angular deviation ranging between 2° and 7.25° in the implants placed with stereolithographic guides has been reported. Based on the preceding studies, it can be assumed that CNIS system provides higher accuracy than the CGIS system. Yet, in one of the studies evaluating the accuracy of optical tracking versus stereolithographic system for implant placement, no statistically significant differences were found between the two systems. Recently in 2014, accuracy of a dynamic CNIS system was compared with three commercial CGIS static systems and the use of an acrylic stent for implant osteotomy preparation. It was revealed that the dynamic and static systems provided superior accuracy versus a laboratory-made acrylic guide and that both dynamic and static systems showed an average error of < 2 mm and 5°.

Though CNIS technology (using optical tracking systems) has been widely used with superb accuracy but it also suffers the following limitations:

- They are sensitive to reflections and interference with the line of sight between the sensors and the cameras that is, a line-of-sight between the tracking device and the instrument to be tracked has to be maintained, which is not always convenient especially with the typical seating arrangement of dental surgeon and assistant and hence may preclude tracking of instruments
- More expensive and requires an expensive hardware
- Requires rigorous intraoperative referencing
- Significant learning curve.

However, compared with CNIS that can cost about $60,000-$200,000 (Rs. 75 lakhs to Rs. 118 lakhs), CGIS is less expensive and outsourcing is possible with CGIS, as a remote company can fabricate surgical template, omitting the need to purchase expensive hardware by the clinician. In India, a computer guided surgical guide (excluding the cost of implant being placed) costs Rs. 20,000/- approximately, though the prices can vary depending on the complexity of situation. However, based on the 7 years of clinical experience in CNIS, Ewers., *et al*. in 2004 revealed that handling of the software is quite easy due to a logical, self-explanatory menu structure which can be learned within a short time. The authors also validated that CNIS is a promising technology, already successfully tested in routine clinical application, that can substantially contribute to an increase in quality and intraoperative safety for the insertion of implants. Computerization of implant-dentistry has opened up new vistas and has eased implant placement in patients with complex problems following a significant alteration of the bony anatomy as a result of benign or malignant pathology of the jaws or trauma and in patients with physical and emotional problems (that limited the amount of time a patient could sit in a dental chair). Computerized-implant-dentistry being minimally invasive in nature has also enabled implant placement in patients with medical comorbidities (e.g. radiation therapy, blood dyscrasias).

Robotic-Implant-Dentistry

Robots are expected to be more accurate and more reliable than a human being and can work as part of an interactive system, are immune to radiation and can be automatically programmed for documentation, evaluation and training protocols. As such, in the cranial area, robotic systems have already been considered for defined drilling of holes or implant beds with an automatic stop, for milling of the bone surfaces, for performing deep saw-cuts for osteotomies and allowing for the precise three-dimensional transportation of the subsequent bone segments or CAD/CAM transplant etc. In fact, a partial section of robot-assisted dental surgery project has already been attempted to develop fully aided system on navigated, guided and assisted surgical performance.

With significant achievements accomplished in the field of computerized implant-dentistry implant placement has become highly predictable, even in patients where implant surgery was contra-indicated formerly. As a result, attempts are now been made toward complete automation of implant-dentistry. Yet, keeping the limitation of high radiation dose, computerized implant-dentistry must be limited to anatomically complicated cases. Future tasks include advanced intraoperative imaging techniques for navigated surgeries along with sophisticated mechanized surgical tools and new robotic developments, which will revolutionize the field of implantology.

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