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Computer aided implant placement, have we reached the pinnacle yet

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Abstract

Digital dentistry has moved the implant planning and placement from realms of clinical practice to the cyber space. It is an imperative innovation and has led to the concept of Guided Implantology which involves a reverse prosthetically driven planning to achieve ideal implant position and angulation. Not only has the computer guided implantology assured the safety and accuracy of surgical procedures it renders desirable outcomes in terms of aesthetics, function, hygiene and longevity. Also the 3d printing of the surgical guides helps in establishing the fidelity between the planning and the surgical phases of implant placement. Nonetheless it also has lead to certain inaccuracies and errors. The object of this paper is to review the associated literature and highlight certain imprecisions and errors of the computer aided systems which need to be further worked upon for better precision and user control.

Keywords: computer aided surgical guides, stereo lithographic, 3D printing, and implant placement.

Introduction

Dental Implantology has emerged as a feasible option to conventional Prosthodontics. In the past the implant site and inclination were dictated by the residual bone quality nowadays the implant treatment is laden with expectations to be permanently functional, aesthetic, hygienic solution for partial and complete edentulism. Anatomic limitations and restorative demands encourage the clinician to gain precision in planning and surgical position of implants.

The desire for predictable Implantology along with the current trends of minimally invasive procedures has led to the concept of Prosthetically driven or Guided Implantology. According to this concept an accurate prosthesis of an implant is established at the diagnostic phase as per the planned restoration.[1] Misch added that fidelity must be sought in planning to avoid iatrogenic damage during implant placement.[2] Therefore it is logical to establish a continuity between the planned restorations and surgical phases. Translation of preoperative implant planning in the intraoperative clinical stage is the critical point that defines how the results will match expectations.

To achieve this continuity between planning and placement of implants, in the most controlled environment, visualisation and navigation tools are used grouped under the conceptual name of surgical guides.[3] According to GPT 9 "A surgical guide is a guide used to assist in proper surgical placement and angulations of dental implants." Typically, the surgical guide consists of two components; The guide body (contact surface) which fits either on an element of a patient′s gingiva, bone or teeth. The other component is the guiding cylinder (sleeve) placed within the drill guides to aid in transferring the plan by guiding the drill in the exact location and orientation.

Currently CBCT is used as the most appropriate method of bone evaluation and its role is defined by numerous studies.[4,5,6,7] Bone zones are analysed qualitatively and quantitatively in the areas of implantation. This modality has grown in popularity and prevalence owing to its ability to capture three dimensional structures with relative short scan times and low dosage when compared to medical grade computer tomography.

In addition to planning the implants relative to the bone sites they occupy, most current implant planning programs allow for true prosthetically driven implant planning. This is accomplished with import of information regarding the presurgical condition of the patient via digitized casts or an intraoral scan and the proposed restorative plan by means of diagnostic wax up and merging those files with the CBCT of the patient. This can also be accomplished in an edentulous patient with a slightly different approach called the Double Scan protocol, the patient wears his well fitting complete denture with fiduciary markers and a CBCT is taken, another CBCT of the removed denture alone is taken and the files are merged.[8] The information hence obtained from the merged images is used to design a surgical guide.

Computer guided implant surgery protocols.

Currently there are two concepts static and dynamic guides. Computer guided dynamic is also called Navigated implantology (NI) they involve the use of computer guided navigation system that reproduces virtual implant position. It is based on motion tracking technology as it helps the clinician in real time bur tracking during the implant positioning, according to the preoperative planned trajectory through visual imaging tools on a monitor. These methods although very interesting in future perspectives are not currently widespread as they require additional expensive equipment and software.[9] RoboDent® system (Berlin, Germany, 2001), today not for sale, was the first implant navigation system introduced on the market and made the history of dynamic surgery; X-Guide (Nobel Biocare, 2017), a dynamic computer assisted system that uses the principles of stereoscopic triangulation by optical video cameras. The Navident® dynamic navigation system (Toronto, Canada, 2015), produced by the Canadian company ClaroNav, evolved from the Navient brand used in orthopaedic surgery, neurosurgery and otolaryngology, sharing the motion tracking technology[10].

The "static" method employ static surgical guide that reproduces the virtual implant position directly from the CT data, it does not permit modification of implant position during surgery. Commercially planning software such as SimPlant® and Nobel Clinician®, in combination with three-dimensional (3D) tissue information obtained from cone beam computed tomography (CBCT) and optical scan, opened the possibility for adequate preoperative design. [11-15] These methods include the use of surgical guides that can be produced by conventional procedures, modifying a radiographic scan prosthesis, or by CAD/CAM technologies as milling and stereolithography.[16,17] The static navigation is generally based on sleeves integrated into the guides, through which the drill bits of corresponding size are passed. Sleeve guided methods are prone to imprecision due to nature of the method and precision also varies depending on the manufacturer.

They are classified into various types depending on their method of fabrication, to the intraoral support they require to function, and the amount of guidance they generate for the drills to place implants.

On the basis of the method of fabrication they can be radiographic stents or templates, traditional lab designed surgical guides and CAD/CAM generated 3D printed guides.On the basis of support they can be teeth supported, mucosa supported and bone supported, while the teeth supported guides are relatively stable, mucosa supported and bone supported guides need miniscrews for improved stability. Design concepts are classified into simplistic non limiting which indicate only as to where the proposed prosthesis is in relation to the selected implant site. Partially limiting design offers the possibility to have a guide sleeve direct the first drill used for osteotomy. The remainder of the osteotomy is finished free hand. Completely limiting designs that restrict all the instruments used for osteotomy in a buccolingual as well as mesiodistal plane.in addition drill stops limit the depth of the preparation and thus the position of the prosthetic table of the implants.[18]

The workflow for computer guided implant placement

1. Planning

The procedure begins with acquisition of CT or CBCT imaging and intraoral scanning data or scan of models. A virtual model of the patient is created by superimposing the DICOM(digital imaging and communications in dentistry) files obtained from the CBCT and the STL(standard Triangulated language) file obtained from the scan, allowing for detailed visualisation of remaining dentition, surrounding intraoral soft tissue and underlying bone tissue. Most planning software's necessitate the marking of specific reference points or fiducially preferably on residual dental hard tissue, for superimposing the files. The planning software features a database of common implants or allows such data to be imported. The information inherent in the existing bone situation can be used to select a suitable implant fixture, taking into consideration the anatomical condition and planned prosthetic outcome in addition to the specific indications for each implant as approved by its manufacturer.[19].Furthermore, a potential need for augmentation procedures can be identified at this point. Other aspects such as eventual axis of the screw access channel, the vertical position if the implant shoulder in relation to adjacent teeth or thickness of the soft tissue can also be accommodated at the planning stage.[20]Afer the prospective implant positions identified; they are translated into the design of surgical guide. The software provides a planning report specifying the type size and position of planned implants. The "drilling protocol" provides the surgeon with relevant technical information on the correct use of system specific surgical instruments.[21]

Designing and printing of the surgical guide

As soon as the design process has been completed, the data set can be exported as an STL file and converted directly into a physical surgical guide by means of subtractive or additive CAM procedures. Integrating the guide sleeves is a manual process, as is the removal of holding or supporting structures and the finishing of the surgical guide. The printing of surgical guide mainly involves the additive procedures as although more accurate, subtractive techniques involve substantial wasting of raw materials. In additive procedures commonly adopted are the stereo lithographic (SLA) and selective laser sintering (SLS). Stereo lithography uses a basin of light- polymerising resin illuminated with a laser polymerising small areas at a time much like a inkjet printer depositing ink on paper, the laser turns off and on based on information it receives from the computer aided design model on the computer. The basin is then moved down over a small distance and the laser travels over the field again, the process is repeated over a period of time building up the object.[18] SLS however uses a carbon dioxide laser to fuse together layers of a fine polyamide powder. Compared to SLA, SLS has an advantage of not requiring support structures because the unsintered powder particles support during the build of models.SLS models are opaque while the SLA models are transaparent.SLA is more suitable for implant purpose because it allows to be made of transparent material (photopolymer) which further increases the inraoperative control and generates smaller spatial deviation compared with the technique of SLS.[22]

Computer aided implant planning are we there yet

Computer aided implant placement is more precise than free manual procedures and conventional guides with respect to the linear deviations from the intended position and depth of the osteotomy. At the onset, planning requires some training and experience along with an acumen to interpret the radiological findings. Placing a virtually planned implant using a bone supported stereolithographic guide, the experience level of the operator contributes to increased accuracy of the guided placements[23]. Longer time is required for guided implant pre-surgical planning in comparison to conventional protocols. Economic aspects also need to be evaluated regarding planning and , instrumentation.[24].During planning with CBCT's artefacts of prosthetic structures makes it impossible to determine the contours of fixation areas and designing the guide. The limiting resolution of the best CBCT's so far cannot be under 150 µ. They serve as the basis on which the guides are made. The DICOM files are transferred with CAD software into usable STL files. Hence if the scanning resolution is low, surface details generated of the STL objects are lower. Even by using double scan protocols accuracy under 150µ cannot be achieved. A recommended resolution for prosthetic designs should be around 50µ as recommended by Gonzales et al [25]Solutions need to be sought in superimposition of images with bigger than the above mentioned resolution. In cases with severe restoration-associated artefacts it is recommended to use a scan prosthesis or radiographic template. This technique is synonymous with placing the structures to be superimposed at an adequate distance to interfering materials but is inevitably resulting in complicating the procedure.[26-32]

During the surgical phase many factors constituting the intrinsic design if the guide and also the topography of the support structures affect the precision. In the bone and Tooth supported guides micro movements have been observed during implantation. Use of more drills[33,34], number and distribution of the remaining teeth height of the sleeves and the number of sleeves have also been reported to have a affect on the placement. In the mucosa supported guides thickness of the mucosa has been observed to affect the stability. Poor stability of guides due to hypertrophy of mucosa has been noted.[13]

Many often after guide's attachment the limited intra oral space most often in the molar areas makes it impossible to introduce implant drills in the osteotomy sites.

Printed guides are made up of hard prototype material, which is too rigid and lack the plasticity to overcome the equator of the teeth in the tooth supported templates, undercut areas in bone and mucosa supported variants. This makes them movable in a vertical direction and creates an opportunity for different stable positions of the guide which displace the position of the planned one in the cannula. To be stable they need additional lab processing and intraoperative fixation. Additional fixing with guides and locking pins will not solve the problem because they can be wrongly positioned before fixation.[3]

Accuracy also differs amongst the jaws Computer guided surgery performed on the mandible was shown to have a more angular accuracy than that on the maxilla[9], a possible explanation provided might be the bone anatomy and bone density; where the structure of the mandible is straight with an arcuate shape, but the shape of maxilla is a circular curve, which restrains the angulations control. Moreover, the mandible bone is denser.[35]

Bone overheating is more crucial in guided implant surgery than conventional surgery. Owing to the presence of an intimately fitting surgical guide and insertion instrumentation, concerns aroused about whether cooling irrigation is able to reach the osteotomy site when using guided surgery; if it is not, overheating the bone becomes a major concern. The internal bone temperature changes were registered during guided surgery preparations and it was found that when using surgical stents, osteotomy preparation generated higher bone temperatures than did conventional drilling. The heat generation, however, did not reach temperature levels that were dangerous to the bone. Thus, an adequate irrigation system is critical for thermal lowering during a guided implant osteotomy mainly in the coronal and middle third of the implant site. Copious irrigation should be provided during process since greater thermal heat is generated, Lower temperature increases could be achieved by reducing drill-to-bone contact, i.e. cutting surface length, due to short frictional force exposure.[36] The use of surgical templates may affect cooling during osteotomy, partially guided surgical templates are often designed with a single pilot drill guide to avoid bone burns.[37]

Surgical templates without metallic sleeves were more accurate in the vertical plan and angle compared to the conventional template with metallic sleeves. A possible explanation is that the holes within the templates without metallic sleeves can be customized compared with standard metallic sleeves. On the contrary, the metallic sleeves cannot be modified in case of collision with soft or hard tissues. Hence, a flap must be elevated to avoid misfitting of the surgical template during its insertion.[38]

Diameter of the surgical guide sleeve had some degree of dimensional difference from that of the implant carrier and allows slight movement; this movement may result in 0.25mm discrepancy for the guided placement. Differences in diameter between the surgical guide and the implant carrier are inevitable. Two metal components must have clearance to avoid excessive friction if the diameters of the two components are identical. Clinically, this would result in the binding of components during the implant placement procedure and incomplete seating of the prosthesis. This binding and frictional force could dislodge the guide itself. However, excessive space between components may result in an unacceptable variation in implant position, while some systems build in clearance for these components others do not. Therefore, different systems may result in different levels of accuracy in terms of the implant position. Further studies are required to assess the optimal dimensions of the components used in the guide. Diameter discrepancies between the implant carrier and the channel of the guide may be the key to optimization.[39]

Length of channels have been noted to be the primary controlling factor in minimising the angular deviations as compared to the diameter of the surgical guide and length and distance from the recipient site[40].however longer channels often makes it difficult for the surgeons to accurately place drills in the areas of the posterior ridge due to insufficient interocclusal distance.

Error during manufacturing of the surgical guide, typically around 0.1 to 0.2 mm with stereolithography [41] The typical accuracy for additive fabrication was found by Van Steenberghe., et al.[31] to be between 0.1 to 0.2 mm. Subtractive milling, which is more laborious and expensive, may be superior in terms of manufacturing accuracy compared with rapid prototyping technologies. Nowadays, the most popular method of surgical template production is represented by photo-polymerisation, more precisely stereolithographic technologies, which provide layer thickness ranging from about 50 to 100 microns or even less is possible.

The ISO value is another major factor affecting the accuracy and distortion of the stereolithographically printed guides. These values as set are used by the computer to build a virtual model of the scanned denture. If set low the visual inspection is not discriminatory and if set high model is clearly defective. It would perhaps be more advantageous if the software could be developed that would automate the setting of the ISO values additionally the manufacturer should be able to indicate the amount of distortion there is between the produced stereolithographic guide and original scan denture.[18]

For a minimal deviation during the surgery with a stereolithographic guide, it is very important to use the drill in a centric position, parallel to the cylinder. The use of longer drill keys and sleeves are critical for optimal accuracy.[34]

Conclusion

The computer guided placement offers a very holistic, less invasive and precise approach in implant planning and placement. Many articles and studies support the acceptable and reliable results with this approach however some imprecision's and errors have also been reported . There has been no substantive evidence as to how efficient this protocol is in terms of safety, treatment outcomes and morbidity as compared to conventional protocols. The elimination of direct vision makes the clinician dependant on this technology of keyhole surgery hence it needs to be highly trustworthy and user friendly.

The proceedings of the 5th ITI consensus conference[16] on computer-guided surgery revealed an inaccuracy at the implant entry point of, on average, 1.12 mm (maximum 4.5 mm) and an inaccuracy of, on average, 1.39 mm at the apex of implants (maximum 7.1 mm) and the mean angular deviation was 3.9 degrees. Due to these potential errors, virtual planning should be performed judiciously, with an appropriate safety margin secured to avoid damaging the vital structures

Certain inaccuracies and imprecision's need to be addressed and fine tunings need to be done besides more long term studies and randomised clinical trials are needed to identify the factors affecting accuracy.

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