

RESEARCH ARTICLE

DIGITAL WORKFLOW IN IMPLANTOLOGY: THE STEPS OF CAD/CAM PLANIFICATION

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ABSTRACT

Thanks to the evolution of radiological acquisition techniques, the use of CT and CBCT by practitioners allowed visualization of bone structures and anatomical obstacles in three dimensions and after implant simulation in the planification software we can place the implant in the ideal position from a prosthetic and surgical point of view. The digital evolution then led us to the manufacture of surgical guides thus eliminating operator-dependent errors. The aim of this work is to review the workflow since the acquisition of DICOM (Digital imaging and communications in medicine) images and / or STL (stereolithography) files (from the scanning of plaster models or) until the final prosthetic steps, a through the preparation of several guides: surgical, implant positioning and graft harvesting.

INTRODUCTION

X-ray imaging have evolved a lot in the last decade, now a third dimension (the thickness) is accessible to operators which reduces errors made during surgery; Moreover, thanks to the integration of implant planning software this surgery has become accessible which popularized the implant act. As soon as the positioning of the implant is validated; we can choose the abutment and adapt the prosthesis, and in light of this data several guides can be designed: implant positioning, bone harvesting and the immediate pros the sispositionning. The latter can also be designed and printed in 3D prior to surgery. This workflow also allows the acquisition of the bio-model that serves not only as a tool of communication with the patient and the various actors during the surgery but also as a support for adapting the titanium mesh and simulate upstream surgery.

MATERIALS AND METHODS

Design of the prosthetic project: The prosthetic project serves as a reference point throughout the implant therapy, it is this one that we must find in the mouth, once the treatment is finished. This is why it must meet certain criteria:

- It must take into account the position of the teeth, their dimensions and their occlusal relationships with opposing teeth,

- It allows to objectify the labial support, the vertical dimension and the aesthetics,
- It gives the patient a first impression and allows him to validate the prosthetic project before starting the treatment. This directing wax-up is whetherealized by the traditional method or digittaly thanks to the Computer Aided Design and Manufacture (CAD / CAM). However, if there is an existing suitable prosthesis, it can serve as a guide for further therapy (Missika, 2003).

Obtaining the virtual model: There are two methods to obtain the virtual model

- The direct method (or optical scanning) is done using an intraoral scanner. It has the advantage of being in color and providing information on soft tissue (muco-gingival line, aspect of the gingiva, periodontal biotype) wich are impossible to have on a plaster model.
- The indirect method is done using an optical laboratory scanner: The impression is made conventionally with a conventional material, then a plaster model is cast from it. The model is then scanned to render the virtual model on the computer, whatever the method chosen the goal is to obtain an STL file (stereo lithographic) of the prosthetic project (Rulliere, 2013).

Trial and validation of the prosthetic project: During fitting, we verify that the prosthetic project meets the clinical requirements. This step allows the patient to validate the aesthetic choices with the practitioner.

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Realization of the radiological guide: The type of radiological guide depends on the extent of edentulness; as part of a unitary toothlessness, it has an extra cost making its use derisory; In contrast, in the case of quite extensive partial edentulousness, its use is much more common and is done conventionally, transforming the wax up into a transparent resin filled with opaque radio product (Zoe or cavite) and the obtained DICOM radiological image are with the STL files achieved by the prosthodontic project's scanning project. In parallel, in case of total edentulness, a complete removable denture is designed or duplicated to be transformed into a radiological guide whose base is transparent and the teeth are opaque, if the surgical guide is bone-supported; otherwise the whole is radiopaque in case of mucosal-supported guide, according to the protocol followed, the practitioner is led to perform a double scanner (the first is the radiological acquisition of the patient with the radiological guide worn the second of the radiological guide only) or a triple scanner adding to the previous technique an optical acquisition of the prosthetic project (Margossian, 2009; Tardieu, 2007).

Whether it is conventional or digital method, the radiological guide must meet a very precise specifications, it must be rigid, radiopaque, stable, without emitting artifacts, it must also allow objectifying soft tissue height and the ideal axis of the implants. It is done in the same way for the numerical method as for the conventional method. However, in the case of total edentulness, Nobel Biocare®, for example, recommends in its Nobel Guide® protocol specific X-ray guide characteristics (minimum thickness, sufficient buccal cover, sufficient radiopaque markers). Whatever the system used, training the patient to correctly position the guide is essential to avoid the maximum errors during the radiological examination. The following figure shows the various cases of realization of the radiological guides (van Steenberghe, 2005).

Radiological examination: After having sent the patient for radiological examination (CT or CBCT) the radiological data acquired in DICOM format (Digital Imaging and Communications in Medicine), will be transferred in to CAD software (computer-aided design).

The implant planning: After transferring the DICOM images with or without the STL file from the virtualized prosthetic project to the planning software, it is easy to measure edentulous areas and to visualize the height, available bone crest width, and bone density in Hounsfield units, thus the practitioner has a more precise vision of the operating sites. At the clinical level, the management of these elements is interesting to plan in advance the type of implant (cylindrical or conical) and its ideal axis, the drilling sequence, the size of the healing abutment to use, the possibility of regeneration bone, the need for soft tissue augmentation, the prognosis of healing and the aesthetic result (Cavézian, 2012). The DICOM files obtained are segmented into isolated 3D structures (bone, nerve, gingiva, teeth). These 3D structures will then be cleaned, aligned to the files from the Optical Scanner, and imported into the 3D modeling software. In the latter the planning starts with the definition of the virtual prosthetic project, in the light of which the implants will be positioned, at this stage it is easy to measure the edentulous areas and to objectify the height, the available bone crest width and its density bone in a Hounsfield unit, so the practitioner has a more precise vision of the operative sites. At the clinical level,

the management of these elements is interesting to plan in advance the type of implant (cylindrical or conical) and its ideal axis, the drilling sequence, the size of the healing abutment to use, the possibility of regeneration bone, the need for soft tissue augmentation, the prognosis of healing and the aesthetic result (Cavézian, 2012). Once the positioning is validated, the surgical guide is edited according to the desired support (mucous, dental or bone). At this stage nothing prevents the practitioner from parallelizing the implant abutments and designing the immediate prosthesis. Finally, the surgical guide, the bio-model and the immediate prosthesis can be exported in STL format, to be printed in 3D, in machining centers or in the dental private office if the practitioner has the necessary tools. In this workflow he can stop at any level of the digital chain as in the segmentation by editing a bio-model on which he can recognize his surgical environment and simulate upstream his surgery. As he can go into the final planning phase and stop there, or move towards the design of the surgical guide. To achieve all digitally with the design of the immediate prosthesis upstream, for the most expert practitioners (Fortin, 2009).

Segmentation: Classically, it can be defined as being a partition of an image I into a number N of subsets R called regions, homogeneous insofar as each pixel must be assigned to a gray level, with interconnection of the pixels belonging to the same class of gray. The purpose of segmentation is to enable the exploitation of the digital content of the image for interpretation, diagnosis, planning, as well as quality control and therapeutic follow-up (Davaranah, 2012). There are many image segmentation methods, which can be grouped into four main classes (Chamroukhi, 2012):

- Segmentation based on regions; it corresponds to the algorithms for increasing regions.
- Segmentation based on contours
- Segmentation based on the classification or thresholding of pixels according to their intensity
- Segmentation based on cooperation between the first three techniques, often used in medical imaging (Monga, 1987).

If we are interested in dimensionality we can divide the segmentation into two groups: 2D segmentation and 3D segmentation. The 2D segmentation method aims to define the region of interest on all sections separately, regardless of the difference in the results obtained between sections. The 3D reconstruction is done by stacking the different sections, which forms a volume of interest (which is then reconstituted by the superposition of the regions of interest). This type of segmentation offers relatively satisfactory results, however one of these disadvantages is that it does not take the spatial interaction expressed by the pixels along the third dimension, which can lead to a reconstruction of a volume inhomogeneous. This problem has been circumvented in part by an exploitation of the volumetric information of the organ initially observed. In the case of an immediate extraction implantation and thanks to the segmentation, a correct implant planning can be carried out by going upstream by a virtual extraction of the teeth (Elmoutawakkil, 2014).

Workflow in Computer Assisted Implant Planning

The positioning of the implants: Implant positioning can be done freely with the command "place implant" or "add an

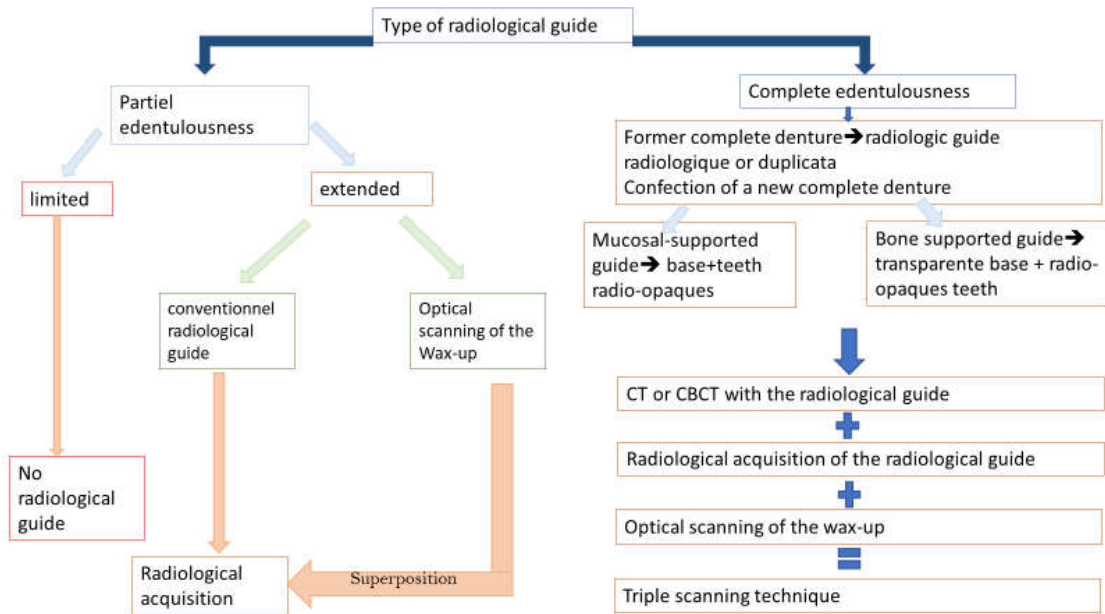


Figure 1. Choice of the type of the radiological guide according to the extent of the edentulousness



Figure 2. Image showing improved quality of segmented images after cleaning {Dr N. Hacib and Dr. Delmoutawakkil's case} [11]

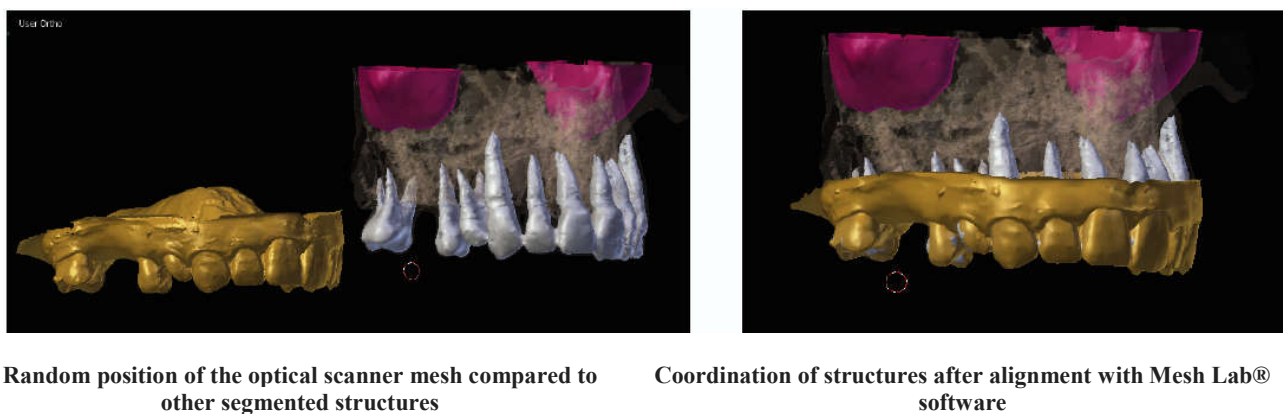


Figure 3. Image showing the alignment of an optical scanning of the impressions on implant planning based on DICOM images {Dr N. Hacib and Dr. DELmoutawakkil's case} [11]

implant”, or following the prosthetic axis with the command “implant from crown”, so the implant will be positioned optimally with respect to the prosthetic axis of the replaced tooth. Once placed, the implant can be visualized immediately in the three planes of space on several sections (coronal, panoramic and sagittal); it can then be moved, rotated or modified in diameter and length. Implant planning software has an implant library, either from a single manufacturer such as the Nobel Clinician®, or from several manufacturers, such as SimPlant®, EasyGuide® (Georgel, 2009).

The choice of abutments: The software allows to choose the most suitable abutment from a specific library and also to design customized abutments. Thanks to the virtual prosthetic project, the practitioner can anticipate the characteristics of the abutment, by choosing its trans-gingival height and degree of angulation.

Collision Detection and Preview of Bone Fills: Most existing software can detect collisions between two implants or between the implant any adjacent anatomical entity (teeth, nerves,

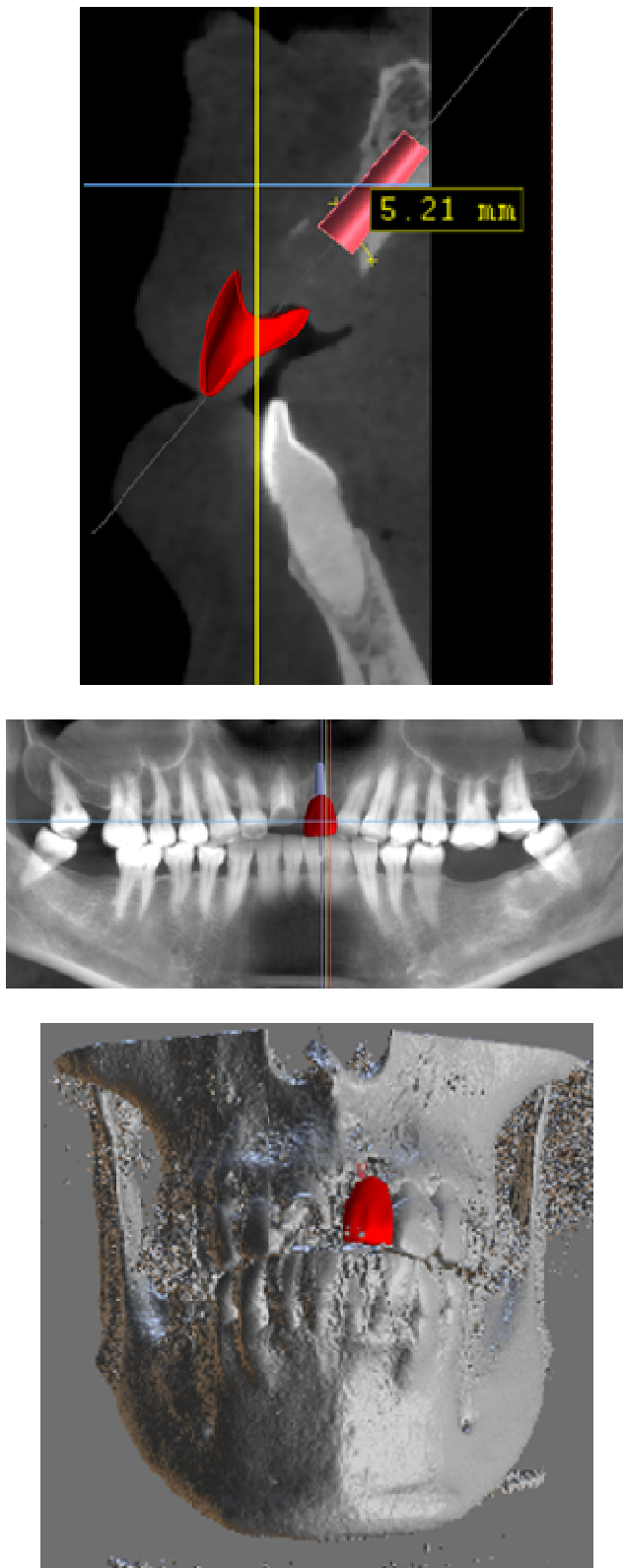


Figure 4. Images showing computer-assisted virtual implant placement on the 21 in different sections {Dr N. Elmoutawakkil's case}

sinuses), they also allow the simulation of sinus lift since the sinus becomes an editable mesh. Thus the practitioner can push back the sinus membrane in the three directions of space, measure the amount of displacement of the latter and evaluate the quality of his sinus lift and the relationship with the implant.

Similarly, they allow preoperative visualization of bone volume A repair following the layout of the mesh of the latter which allows to anticipate upstream bone grafts (Elmoutawakkil, 2014).

RESULTS

As a result of this workflow, an implant roadmap should be developed which can guide the implant placement while calibrating the practitioners to minimize operator-dependent errors, or once the surgical guide support (bone mucosa or teeth and mucosa) is chosen, we start drawing the base of the guide with a Bezier curve that is transformed into a gutter by customizing its thickness. Then each guide cylinder relative to an implant is added then we define "the inner cylinder" corresponding to the drilling hole that will allow the passage of drills, we continue with the edition of the guide to which we can add a crossbar to stiffen the guide and then for fixation of osteosynthesis screws to increase its stability. At this stage the practitioner can choose the ring or spoon that corresponds to his drill, and edit a guide with a female part corresponding to the ring. In this way, the latter becomes part of the guide after its manufacture (Elmoutawakkil, 2014; Perisse, 2009). Guided surgery requires the use of an adapted surgical kit, the investment is consequent. With Blender the practitioner can overcome by designing personalized rings corresponding to his drills, or even design custom drills through a pre-established library (Dreiseidler, 2012). Modern radiography technologies (CT and CBCT) allow clinicians to obtain very reliable images of the patient's bone anatomy. Integrating the interactive planning and implant treatment software, it is possible to simulate bone or sinus grafts, which allows the realization of bone harvesting guides and sinus lift's windows positioning guides on 3D printed bio models from STL files derived from design or directly designed and printed individually (Rinaldi, 2015). The following case of Dr. Naheed Mohamed illustrates the workflow leading to the preparation of the harvesting guides: from the implant planning based on the radiological images in DICOM format, a harvesting guide respecting the integrity of the vasculo-nervous elements was designed and exported in STL format, the guide was printed in transparent resin while the bio-model was printed in colored resin, after the detachment of a muco-periosteal flap and once the harvesting guide positioned the grafts were withdrawn (<http://forum.dentalxp.com/case/details/digitally-guided-bone-augmentation/7555>).

The sinus window localisation's guides not only allow to position these well but also to circumvent and preserve certain anatomical elements identified during the implant planning, the following cases show some types of these guides (<http://forum.dentalxp.com/case/details/digitally-guided-bone-augmentation/7555>). Among the results of the implant and surgical planning is also the bio-model (or biological model), the latter with several uses firstly as a communication support to the dental office to explain to the patient the progress and completion of the steps Surgical or at universities as a teaching tool, then it can serve as a support to design maxillofacial prosthesis, simulate surgery, evaluate the proximity to the lower alveolar nerve, it can also be used to adapt the titanium mesh and osteosynthesis screws in upstream of surgery it also allows dry implant placement and management of immediate prosthesis (Georgel, 2009).

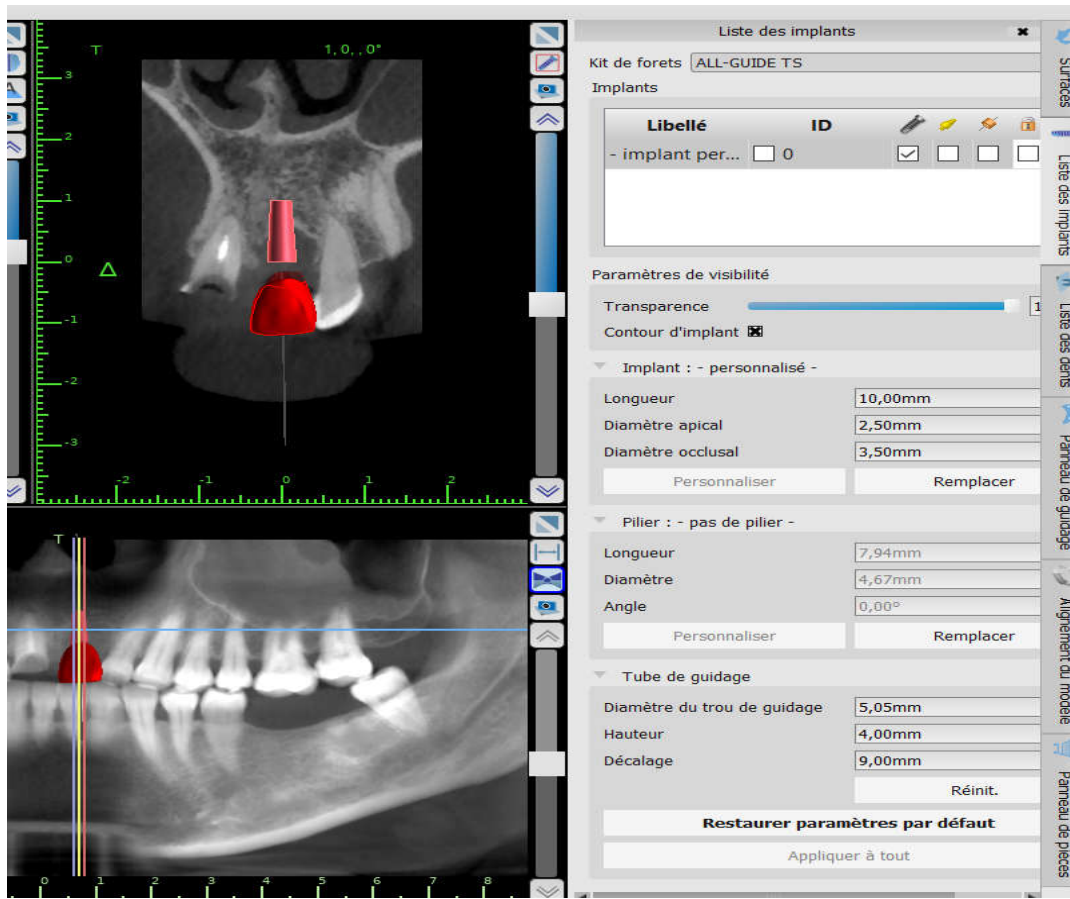


Figure 5. Image showing the characteristics of the chosen implant (Blueskyplan® software){Dr N. Elmoutawakkil’s case}

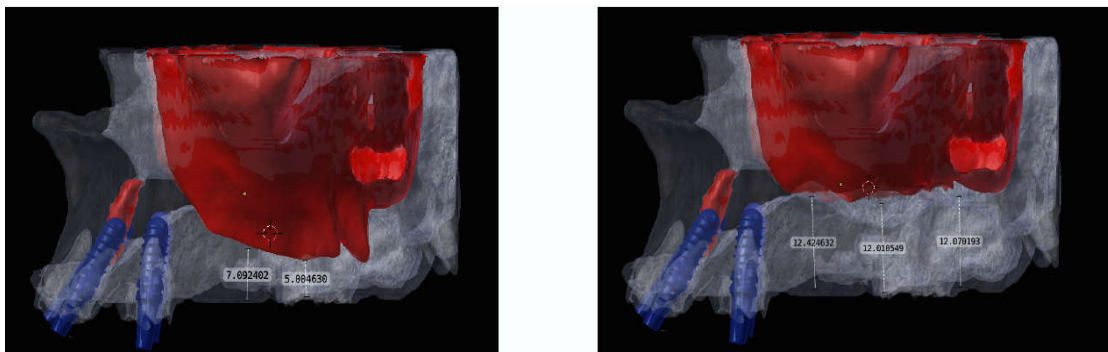


Figure 6. Images showing the simulation of a sinus lift on the Blender® software {Dr N.Hacib and Dr.DELmoutawakkil’s case}[11]

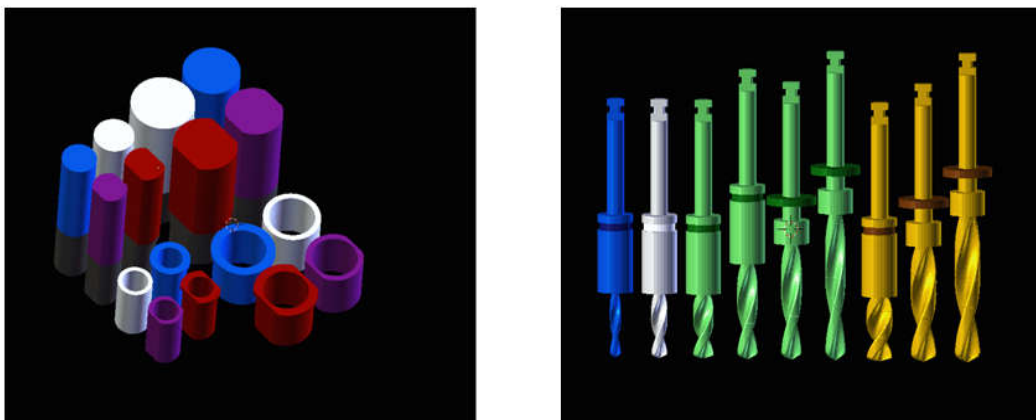


Figure 7. Rings and drills Library in Blender® Software {Dr N.Hacib and Dr.DELmoutawakkil’s case}[11]

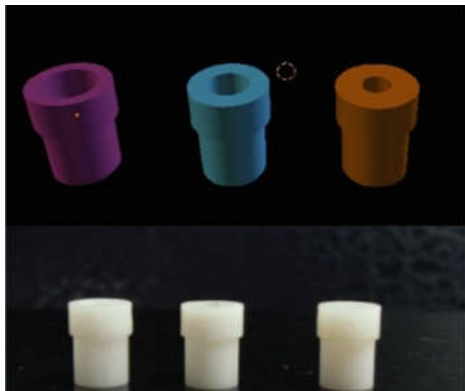


Figure 8. Virtual and real personalized rings for the drills of the surgical kit Atoll@concievedby Blender@{Dr N.Hacib and Dr.DElmoutawakkil's case} [11]

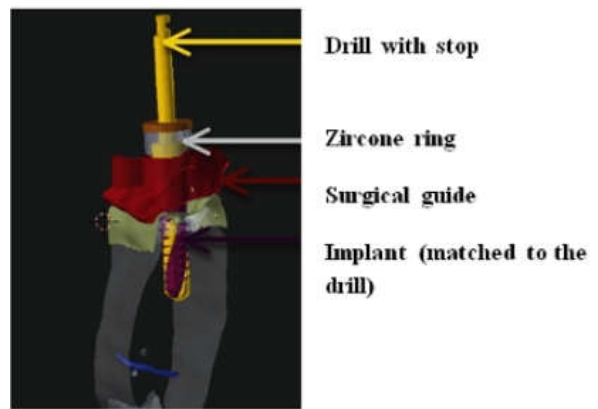


Figure 9. Slice Cup simulating the passage of the drill with the stop in the sleeve positioned in the guide{Dr N.Hacib and Dr.DElmoutawakkil's case} [11]



Figure 10. 3D Design and Printing of the Symphysialharvesting Guide{Dr N.Mohammed's case} [16]



Figure 11. Bone grafts harvested using the harvesting guide{Dr N.Mohammed's case} [16]



Figure 12: images showing the positioning guide of the sinus lift's window placed on the biological model and in the mouth {Dr M.Rinaldi and Dr.S.Ganz's case} [16]

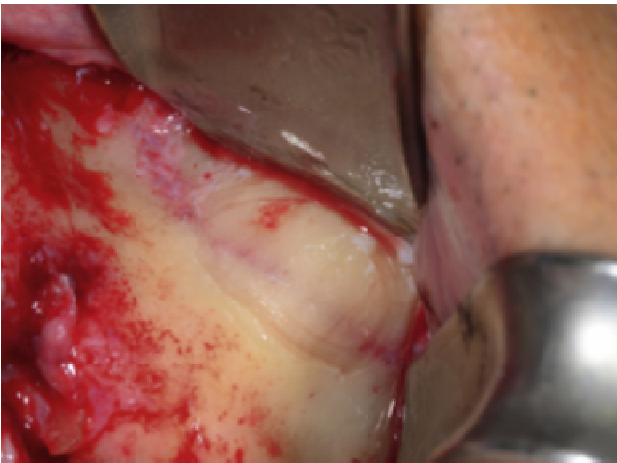


Figure 13: images showing the interest of the sinus lift's window positioning guide first in the choice of the flap first afar from the antral artery {Dr M. Rinaldi and Dr. S. Ganz's case} [16]

DISCUSSION

Computer aided planning has facilitated the implant surgical protocol, however, the resulting workflow requires a skilled surgeon with good manual dexterity and good ken of anatomical and radiological knowledge. To evaluate this workflow several authors have studied the success rate of implants posed by different surgical guides from this chain, thus, Malo *et al.* reported in a prospective study (13 months of follow-up) a survival of implant of 97.2% in the maxilla and 100% in the man dibble with two failures of maxillary implants (Malo, 2007). Ozan *et al.* reported in a prospective trial (9 months of follow-up) a success rate of 98.3% on 56 inserted implants (Ozan *et al.*, 2007), Wittwer *et al.* reported in a prospective study (2 years) a success rate of 97.7% (88 implants immediately loaded, 2 implants failed) (Adeyemo, 2007). Yong and Moy reported data from patients treated consecutively with a success rate of 91% (78 implants with immediate loading of 8 failed implants), after an average follow-up period of 26.6 months (Yong, 2008). Berdougo *et al.* reported in a controlled study a success rate of 96.30% (test group, 271 implants placed flapless, 10 implants failed), with a follow-up period of up to 4 years (Berdougo *et al.*, 2010).

Meloni *et al.* reported in a retrospective study a success rate of 97.8% (90 implants immediately loaded, 2 implants failed), after 18 months of follow-up (Meloni, 2010). Gillot *et al.* in a clinical study, a success rate of 98.1% (211 implants inserted, 4 implants failed), with a follow-up of 12-51 months (Gillot, 2010). Many authors have indicated that the risk of error during computer-assisted surgery. In an in vitro study, Dreiseidler *et al.* (2012) reported that different CBCT acquisition's devices could influence the 3D printed surgical guide's transfer accuracy with an axis deviation up to 0.6 μ m and a linear deviation approximating 0.5mm. Vasak *et al.* (2011) reported that the average implant shoulder spacing is 0.43 mm (bucco-lingual), 0.46 mm (mesio-distal) and 0.53 mm (depth) this difference is greater at the apical level of the implant (on average 0.7 mm (bucco-lingual), 0.63 mm (mesio-distal) and 0.52 mm (depth)). The maximum deviation (2.02 mm) existed in the corono-apical direction. According to Sicilia *et al.* (1998), The importance of the use of surgical guides in the maxilla is greater for the rehabilitation of the completely edentulous arches of the toothless jaw; however, this technique has two limitations: the average mouth opening amplitude should be 5 cm; and the compulsory stabilization of the surgical guide obtained, to avoid the latter problem, the guides are attached to the bone with anchoring pins (or with osteosyn this is screws (Ozan, 2007). In an in vitro study (Park, 2009) to demonstrate the impact of occluso-gingival size variation on the accuracy of digital surgical guides, three groups of these guides were manufactured with occluso-gingival heights of 4, 6 and 8 mm, respectively. A template has been fabricated to allow precise positioning in bone substitute blocks. 90 implants were placed in the first man dibularmolar on a manikin. Thirty implants (Astra Tech AB) were placed for each group, with 15 implants posed with the guide and 15 implants freehand. The discrepancies between a reference implant and each placed implant were measured at the implant and the abutment using a three-dimensional measuring machine, the vertex position and the angul a deviations were calculated using the coordinates of the centers of the implant platform and the occlusal aspect of the casting. Data were evaluated using a 2-way ANOVA ($\alpha = 0.05$). The results show that the height of the guide does not influence the implant placement accuracy which exceeds the conventional free hand method.

Conclusion

The technological advances of the last three decades have revolutionized the treatment of unitary, partial and total edentulism, in fact implantology, one of the greatest advances in modern dentistry, is now part of our therapeutic arsenal and allow sour patients to find what Bränemark called "the third dentition". However, if the notion of minimally invasive treatment is now recognized, the Predictability of the result become simperative; a well-planned treatment is the guarantor of a successful implant supported prosthesis. The use of implant simulation software allows for better identify the anatomy of each patient and codify the implant surgery, which hallowed us to demystify the implant surgery while calibrating the operators.

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