Digital Dental Implantology

From Treatment Planning to Guided Surgery

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Prologue

Fusing CBCT and CAD/CAM technologies seems to be the right path to follow if wanting to improve accuracy and predictability in surgical dental treatments. Another great advantage about using a digital approach is time reduction in surgical procedures, thus decreasing patient morbidity significantly.

On one hand, CBCT is one of the most helpful diagnostic tools available nowadays and has become mandatory whenever indicating implant therapy. This new tomography system has evolved to give detailed information about tissue topography while reducing radiation exposure time for the benefit of the patient. Its usefulness in surgical diagnosis is far beyond questionable. Usually, CBCT images are presented in printed paper and slices are defined by the professional in charge of performing the study. Nevertheless, slices can always be customized, segmentations can be done, and other parameters can be managed to obtain specific information. For that means, an image processing software is needed.

On the other hand, a new era has recently begun, where physical objects can be digitalized in order to manipulate them, make modifications or even create a new object based on the original. To accomplish that, every object has to be scanned and turned into a digital surface image. Again, this process requires a specific software.

To resume, two different technologies are available in dental daily practice: CBCT and digital casts. Many advantages come from fusing the digitalized "external surface" of an object (i.e., dental arch) with the digital image of the object "inner aspect" (i.e., maxillary tomography). This book explains the merging process involved, its advantages, and its applications in oral surgery.

The first step to begin understanding the fusing process is to highlight the need of two different digital files, DICOM and STL files. These are two different languages to express a digital file, like .doc and .pdf files. To simplify, DICOM files are created from CBCT equipments, while STL files are created from scanners. A combined image can be obtained by merging both files using a software. Tooth anatomy is usually used as reference point to put images together, as its surface is registered both by the CBCT and the scan. Merging process is the most critical step of the whole virtual planning. Accuracy is essential at this point to assure predictability. Patients prostheses or templates are also used in cases where tooth anatomy is partially or totally absent.

The second step is to determine your treatment plan. For that means, digital wax up can be used to stablish a prosthetically driven surgery, if not been done previously. Prosthodontic plan leads to surgical plan and so, the software allows to perform virtual surgery practice. If implant placement is the main objective, virtual implants are placed; if bone regeneration needs to be addressed, virtual implants are placed and bone is virtually shaped to contain said implants.

The third step is template manufacturing. In other words, once surgical project is reviewed and accepted, accurate template must be fabricated to reproduce virtual planning. Even though this process is done fluidly, careful assessment during template construction is necessary to obtain a perfect fit. Materials used to fabricate surgical guides vary according to the surgical protocol.

The digital approach proposed in this book stablishes a paradigm shift. Despite general belief, this approach demands a lot of time, hard work, and a rather slow learning curve to get the best out of it. Moreover, guided surgery protocols stand for exhaustive diagnosis and increasing time spent on the virtual phase in order to decrease chair-side time. Thus, the aim of guided surgery philosophy is to improve diagnosis, be able to reproduce the planning and reduce patient morbidity. This book serves as a guide to initiate clinicians in the exciting world of technology fusion and to understand the advantages and limitations of the digital approach.

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Part I

Digital Workflow in Dental Surgery

1.1 CAI/CAD/CAM Concept

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The dental digital workflow can be divided into three global steps, regardless the process involved; either for surgical, prosthodontic or orthodontic use. Each step has to be carefully addressed in order to achieve a precise outcome. Errors in the initial phase can lead to serious mistakes, despite meticulous treatment planning. Said steps in the digital workflow refer to:

– Computer-Assisted Imaging (CAI): It is the initial step of the process and stands for digital data acquisition. Although often disregarded, this stage is critical to ensure a reliable result. While digital planning seems to be easy-going, no software will indicate if the uploaded data is erroneous, altered or does not match patient clinical situation. Therefore, special considerations have to be taken into account for the optimization of the image capturing procedure.
– Computer-Assisted Design (CAD): It represents the surgical virtual planning stage and uses a dental software. A huge variety of these computer programs can be found, from license restricted to license free; from simply image viewers to advanced planning software. They serve as great tools for diagnosis and treatment planning and additionally, allow to export data to help accomplish the desired outcome. The designing phase demands expertise and therefore, a time-consuming training.
– Computer-Assisted Manufacturing (CAM): To translate the virtual plan to the analog and tangible scenario, a device needs to be manufactured. Moreover, ad hoc tools, such as specific surgical drills, are necessary during the clinical procedure. Also, a special software is needed to control the machines in charge of the manufacturing process. This step is usually trusted to the dental technician, as it implies additional equipment.

To summarize, the first important step is to acquire digital data from patient anatomy while minimizing volume alterations and maximizing surface definition (CAI). Next, the information is uploaded into a dental software where the virtual surgery is performed and the whole planning is confirmed (CAM). Afterwards, data is exported to a machine which creates a physical object to be used prior or during surgery (CAD).

It is important to outline that the clinician can interact and participate actively in every phase or trust some steps to a third party. Nevertheless, knowledge of the whole process is mandatory to ensure a predictable outcome.

1 CAI: Computer-Assisted Imaging

Nicolás A. Rubio

1.1 Introduction

Acquiring reliable digital data from the patient is fundamental for accomplishing a correct diagnosis and a trustworthy treatment plan. For that means, clinicians need to obtain 2 types of data: surface scans from patient oral cavity and medical images from the underlying tissue anatomy.

On one side, knowledge of bone anatomy and tissue thickness is undoubtedly necessary when planning surgery. Thus, medical instruments have evolved to provide neat and detailed images, which can be displayed in any computer in order to achieve a precise diagnosis. Therefore, a universal medical language has been stablished to visualize these images: the DICOM file. It should be noted that DICOM files can come from x-rays, cone beam computed tomography (CBCT), magnetic resonance imaging (MRI), or any other in-depth medical study. However, CBCT images are the only files needed for the protocols described in this textbook, as all surgical planning programs demand this kind of DICOM file.

On the other side, implant surgery should be fully driven by the prosthetic plan. For that means, a digital image from patient dental arches is needed to set up said plan and later fabricate a template to reproduce it. Although CBCT images can give detailed information of tissue anatomy, surface definition of tooth and mucosa tends to be poor, especially at the occlusal level. Moreover, metal artifacts can cause great distortion over the images whenever present in the oral cavity. These are the main reasons why another file is needed, containing the external topography of the jaws. That is, a surface scan file, broadly known as STL file.

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1.2 Surface Scans (STL Files)

Whenever there is a need of fabricating prosthetic restorations, surgical templates, or any other device that demands a correct fit in the oral cavity, jaw replicas are necessary to undertake said processes. Registration of the area of interest and its relation with neighboring teeth, opposing jaw and surrounding tissues is mandatory to develop a prosthetic plan to guide surgical protocols and then, fabricate a template to translate what has been digitally planned to the real-world scenario.

As stone casts have historically been used to work with, a necessity of a virtual model arises if wanting to do a digital planning. Therefore, a file that represents the surface geometry of a three-dimensional object has to be created [1]. Even though there is a huge variety of computer file extensions for 3D digital objects (such as .ply, .obj, .dcm), one specific file stands out among others, the .stl file (Fig. 1.1).

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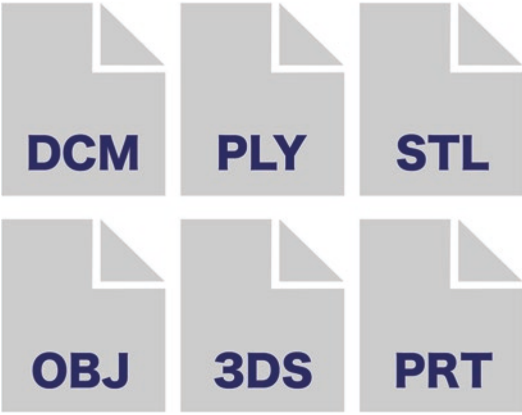

Fig. 1.1 Different file types for 3D objects

The original STL file was created for a vintage stereolithography CAD software by 3D Systems® Company in order to enhance data process for 3D printing and computer aided manufacturing. Despite originally been named as an abbreviation of "stereolithography", STL has also other backronyms, such as "Standard Tessellation Language" or "Standard Triangle Language", as it uses triangle forms to represent the shape of the object (Fig. 1.2). Nowadays, STL files are supported by many software programs and have become a universal CAD language. Contrary to this, some software systems utilize other file types to store data; some of them only valid within its own corresponding software (i.e., DCM file used by 3Shape®, Denmark; PLY used by Carestream®, USA), and some others may be used by multiple software packages (i.e., OBJ file). These files can store additional information, such as color, while this metadata is not present in an STL format (Fig. 1.2b).

Two methods for digitalizing patient dental arches are nowadays available: intraoral and extraoral scanning. On one hand, impression materials have been used to record teeth surfaces and its surrounding areas for a long period of time; improving accuracy, hydrophilic properties, and volume stability through time. Following this method, physical stone models can be created and then digitilized with an extraoral scanner to obtain a digital file. On the other hand, a direct digitalization of the oral cavity can be accomplished with intraoral scanners, avoiding conventional impression techniques and thus, improving accuracy, saving time and easing patient experience (Fig. 1.3).

1.2.1 Intraoral Scanners

The implementation of intraoral scanners (IOS) in dentistry comes along with the development of CAD/CAM systems and enhances the digital workflow, providing fluency and precision. It also aims to reduce operative and treatment time, improve communication with laboratories, and reduce unnecessary storage space [2].

Optical, non-contact intraoral scanners are devices comparable to portable cameras used to record the surface of the oral topography. This camera needs to project a light (as it works in a dark environment) (Fig. 1.4) and record the oral situation within an integrated sensor, either as individual images or as a video. Different technologies are available for IOS, such as confocal imaging (iTero®, Netherlands), optical coherence tomography (E4D®, USA), or active wavefront sampling (3M True Definition®, USA) [3]. A description of all technologies used for scanner devices will not be addressed as it is not the purpose of this textbook. Although some scanners demand the use of powder-coating to reduce reflectivity, current tendency is to fabricate powder-free scanners to ease the scanning process and provide more comfort to the patient.

1.2.1.1 Scanning Technique. Tips and Recommendations

To assist data acquisition, some clinical tips may be stated:

- Use of retractor devices and moist control is recommended to get a better image. Some clinicians tend to switch the chair lamp off or dim the office light to avoid lighting interference [4]. Instruments used to separate oral tissues, such as mirrors, can be covered with a black nitrile finger glove (or similar) if metal reflection complicates the scanning process.
- Despite most systems have inbuilt heating elements to reduce fogging of the glass sur-

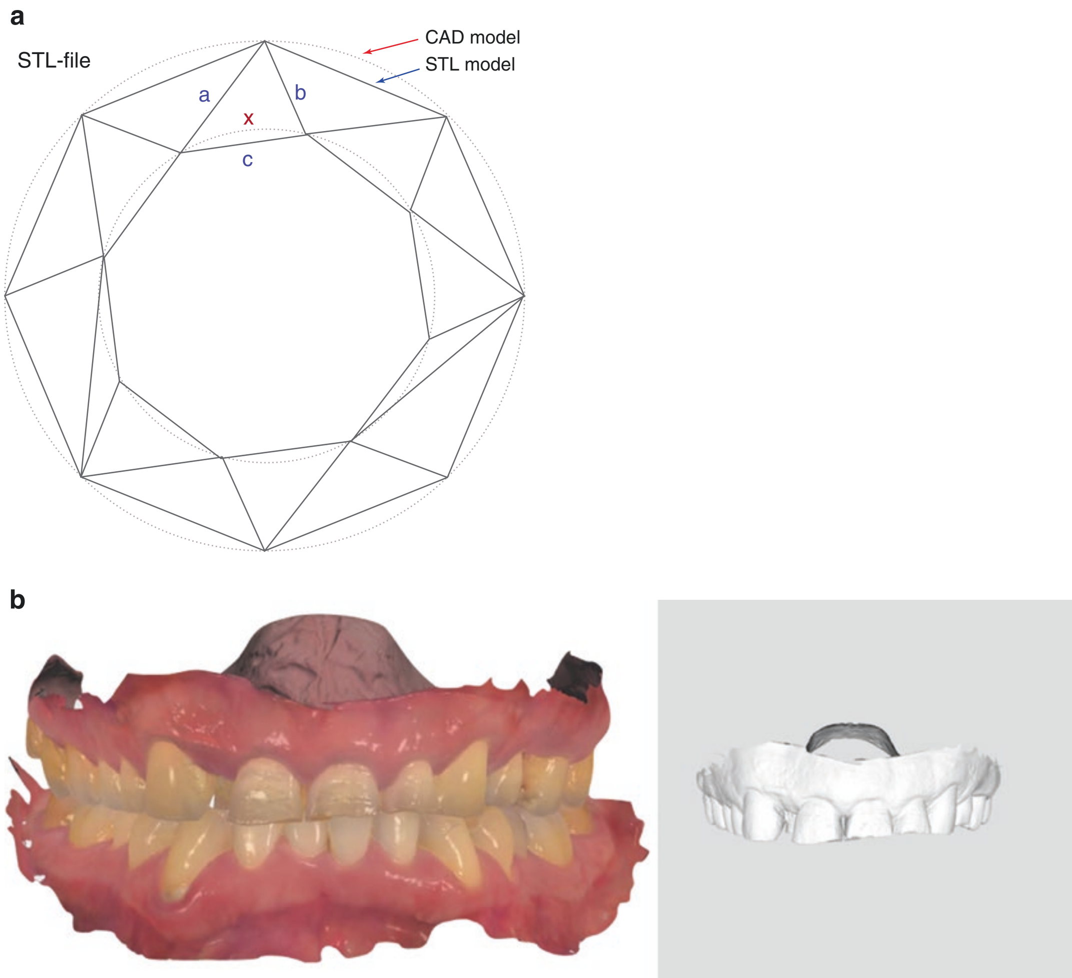

Fig. 1.2 (**a**) Standard Triangle Language (STL) stands for the reconstruction of an object based on triangular forms. (**b**) Surface scan in DCM format (left) and STL format (right). This DCM file is used by 3Shape® to add features such as color. When transforming this file into a plain STL file, only surface topography remains. Although not altered, the scan loses metadata

Fig. 1.3 Extraoral (left) and intraoral (right) scanners from 3 Shape®, Denmark

Fig. 1.4 Light emitted by the intraoral scanner to record the clinical situation

face that rests inside the scanner tip, moisture contamination or fogging can slow down the procedure.

- As data is captured, the software recognizes similar points to stitch images together. The rendering of the oral cavity is then constructed by merging images containing identical points. Typically, reference marks are taken from tooth anatomy, especially from occlusal surfaces. Thus, when the scanner loses track, it is advisable to go back to the previously scanned occlusal areas to let the software identify an already recognized spot.
- If multiple teeth are missing, soft tissue mobility can interfere with scanner recognition. Scanning Extended edentulous areas can be challenging; thus, conventional impression and extraoral scanning can be considered a suitable option in these cases.
- Some software may present a recommended scanning path to match its preset algorithms used to reconstruct the image. Deviation from the path may create inaccuracies in the data captured [5].
- Depending on the optical scanning technique employed, powder-coating with a titanium or magnesium dioxide powder may be required to enable the scanner capture the image. Latest IOS are designed powder-free to improve scanning experience. However, shiny metallic objects can disturb the process and so, may require some coating to capture the image (Fig. 1.5).
- Although it is not relevant for the overall outcome, continuous training with IOS will help reduce the number of images stored to com-

Fig. 1.5 Powder used to reduce reflectivity over shiny objects

plete the render. An efficient scanning technique will not only reduce operative time, but also reduce file processing time, improve computer performance, and minimize digital storage.

1.2.2 Extraoral Scanners

Dental technicians use a desktop laboratory scanner to digitalize stone casts or even conventional dental impressions. This turns out to be a perfect solution if not having an IOS in the dental office. Extraoral scanners (EOS) can be subdivided into two types: contact or contact-less. While the first refers to former digitalizing methods (i.e., Procera®, Nobel Biocare), non-contact or optical scanners are widely used today. Initially, contact or mechanical scanners used a probe to go across the object surface to detect its morphology. Naturally, the size of the probe and the angle of incidence influence scanning accuracy (Fig. 1.6).

Nowadays, optical scanners rely on a ray of light or laser to illuminate the object and collect information of the tridimensional surface using triangulation principles (Fig. 1.7). The light projected onto the object is reflected and captured by the receptor unit. The sensor measures the angle of the reflected light and so calculates the 3D data by means of triangulation principle (Fig. 1.8).

Fig. 1.6 Former contact scanners. Procera® by Nobel Biocare

Fig. 1.7 Extraoral optical (non-contact) scanner. Autodesk® by Shining 3D

Since the model is exposed to a static light-emitting/light-receiving device, the rendering of the image is completed in a single plane. This offers the advantage of greater interpositional accuracy of the components within the model [5]. Thus, EOS are preferred in extended edentulous patients and full-arch reconstructions.

1.3 CBCT Images (DICOM Files)

DICOM comes from Digital Imaging and Communications in Medicine and it is considered to be the standard for sharing and management of medical imaging information and related data. In other words, DICOM is the extension file exported from a medical equipment after performing a study.

Most of the times, once image is acquired, the technician in charge of the study evaluates the outcome and assesses the visibility of relevant anatomic structures to dismiss the patient. Afterwards, the file containing the slices is processed by a software to determine jaw horizontal orientation, panoramic curve, and distribution of the axial slices. Said data processing, together with implant measurements, recognition of nerve canals and any other relevant information is

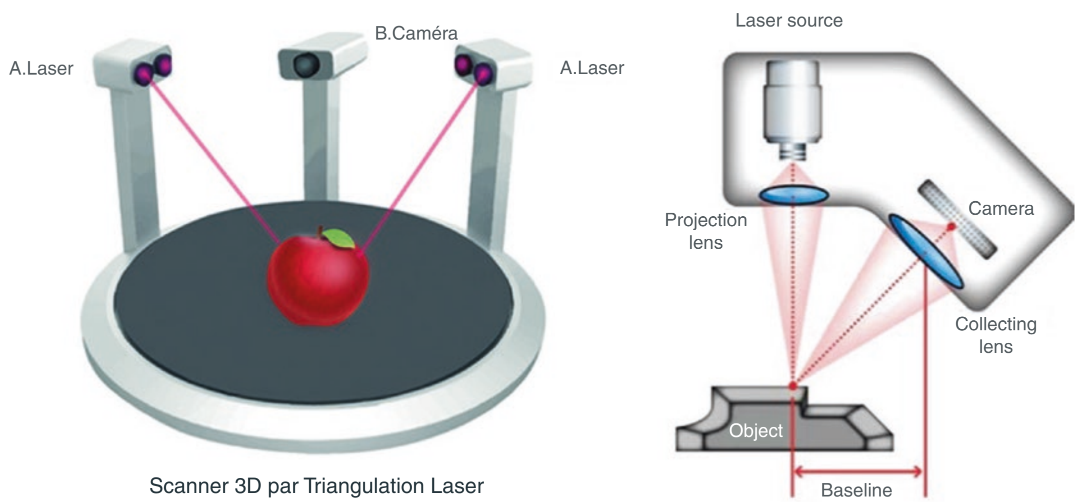

Fig. 1.8 Triangulation principle. A light is projected over an object and the reflection is captured by a camera. The angle of reflection is measured to determine the surface of the scanned object

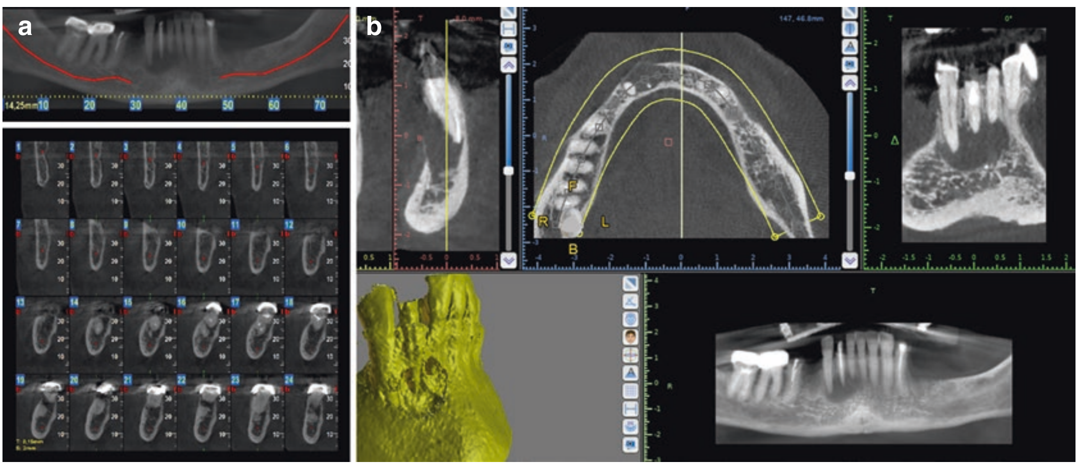

Fig. 1.9 CBCT visualization in conventional JPG file (**a**) and in software viewer (DICOM file manipulation). Panoramic curve, slices and 3D rendering can be customized and the study can be navigated to get as much information as possible (**b**)

exported as a printable format (such as JPG or PNG files) and delivered to the patient (Fig. 1.9a).

Traditional implant planning usually relies on this processed image analysis to plan implant osteotomies. Nevertheless, additional surgical planning can be made by manipulating the file exported from the CBCT equipment. For that means, said file can be also delivered to the patient together with a CBCT basic software in a CD or USB portable device. The use of this viewer tends to be advantageous, as it offers more information than printed images and allows the professional to go across all slices and even simulate virtual implant placement (Fig. 1.9b).

Furthermore, the DICOM files contained in this CD/USB can be visualized either with the provided software or can be uploaded into a surgical planning software (Fig. 1.10). Each of these diagnostic options have its advantages and disadvantages, as it will be discussed in Chap. 2.

DICOM files can be often found in a folder named “images” or “data” inside the CD (Fig. 1.11). Also, these files can be sent by mail to avoid image printing and/or CD burning processes.