Digital Dental Implantology

From Treatment Planning to Guided Surgery

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Editors

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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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Contents

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

CAI: Computer-Assisted Imaging

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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.

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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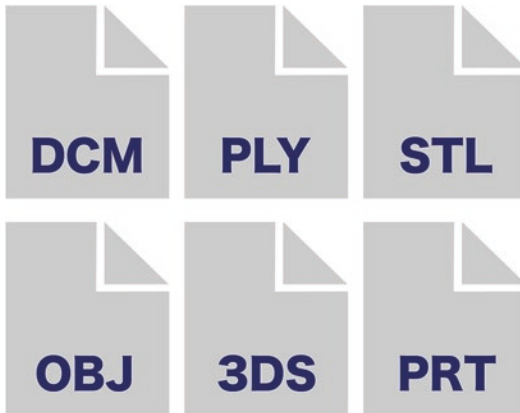Ciudad Autónoma de Buenos Aires, Argentina

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-
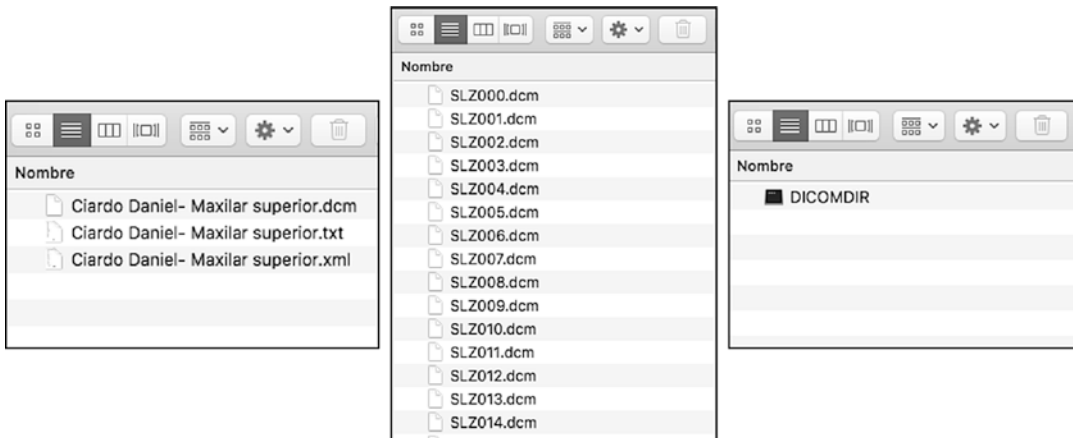
Fig. 1.12 Possible DICOM file storage: multi frame (left), single frame (center) and directory or DICOMDIR (right)

1.3.1 General Considerations for Justified Imaging Prescription

Any radiation exposure entails a risk to the patient. In concordance, it is essential that every radiographic examination shows a benefit to the patient [6]. The use of imaging modalities for pre-surgical dental implant planning should provide information supporting the following three goals: establish bone volume and quality, determine orientation of this bone in relation with the prosthetic plan, and identify anatomic or pathologic boundaries limiting implant placement [7]. Any study performed that does not deliver or add relevant information to the diagnosis should be avoided. This statement needs to be clear in order to understand that images must be carefully prescribed to prevent repeating the study and/or overexposing the patient.

According to the SEDENTEXCT Project [8], radiation doses, and hence risks, from dental Cone Beam Computed Tomography (CBCT) are generally higher than conventional dental radiography (intraoral or extraoral x-rays) but lower than Multi-Slice Computed Tomography (MSCT) scans. Overall, CBCT delivers better image quality and resolution compared with MSCT [9], which may also be important for fine detail of cortical bone thickness visualization [10]. Some studies suggest correlations between Hounsfield Units (HU) derived from CBCT scans and bone density, serving these images as predictors of

implant stability [11]. Yet, other authors do not establish this measurement as trustworthy [12].

Awareness of relevant structures proximity could be one of the justifying premises for CBCT prescription. Although it would be difficult to trace among literature a significant benefit of tridimensional imaging, such as CBCT, over conventional two-dimensional imaging, such as panoramic X-ray, with respect to potential surgical harm to neurovascular structures, it should be noted that guided surgery relies only on virtual planning and data collected preoperatively. In traditional planning, whenever intraoperative situation does not meet the expectation, osteotomies can be modified to solve problems like implant position and angulation, implant type, length and diameter, and implant distribution. However, if a clinical situation does not meet a virtual planning, surgery is no longer driven by the virtual plan and has to be replaced by a free-hand protocol. Thus, it is mandatory to have trustworthy information of the underlying structures if wanting to set a guided approach. That is why a CBCT is always needed to perform the virtual surgery.

Optimization of radiation dose should follow the ALARA principle postulated by the International Commission on Radiology Protection (ICRP), which states that radiation dose should be kept as low as reasonably achievable (ALARA). Therefore, practitioners who prescribe or use CBCT units should ask for studies based on individual patient history and clinical

examination and should specify exposure and image-quality parameters to achieve a proper diagnosis of the region of interest [13].

1.3.2 Techniques to Improve CBCT Imaging

Although prescribing a cone beam tomography tends to be a routine process, specifications on the demanded study can help the technician deliver a useful and high-quality tomography. As usual, good communication between professionals is mandatory. Thus, to optimize daily workflow, some details have to be taken into account.

1.3.2.1 Interarch Distance
Correct separation between the jaw of interest and its antagonist is of extreme importance.

Normally, a CBCT is performed while the patient is in occlusion and his/her chin rests on a mental support provided by the device. This allows the patient to remain still during the exam and avoid major deformation among images. This technique establishes an image in which upper and lower teeth are stitched together, with no space between them. Thus, occlusal surface and cusps cannot be distinguished properly (Figs. 1.13 and 1.14).

In order to compare and merge a surface scan of the jaw and a CBCT image from the same patient, tooth anatomy tends to be the best reference. For that means, separation between jaws allows the CBCT to give a neat image of the incisal edges and the occlusal surfaces. However, this image lacks of precision to make a virtual prosthodontic planning, a correct wax up, and a surgical template.
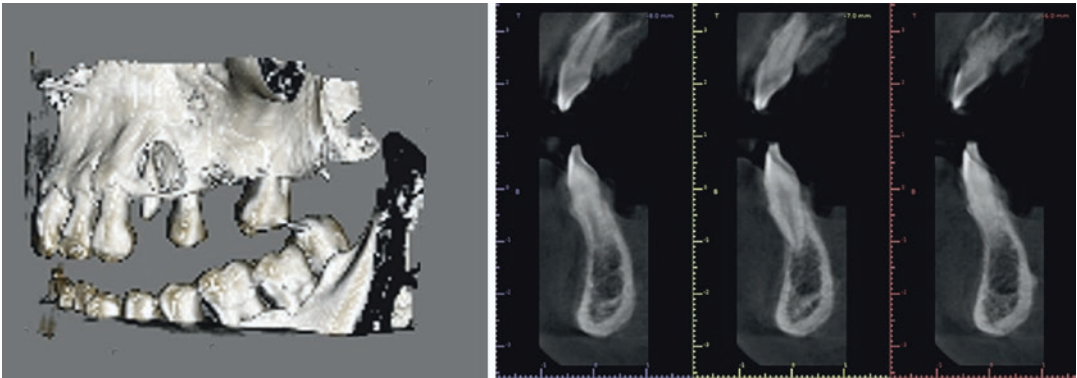

Fig. 1.13 Correct interarch separation allows visualization of the occlusal aspect of the teeth
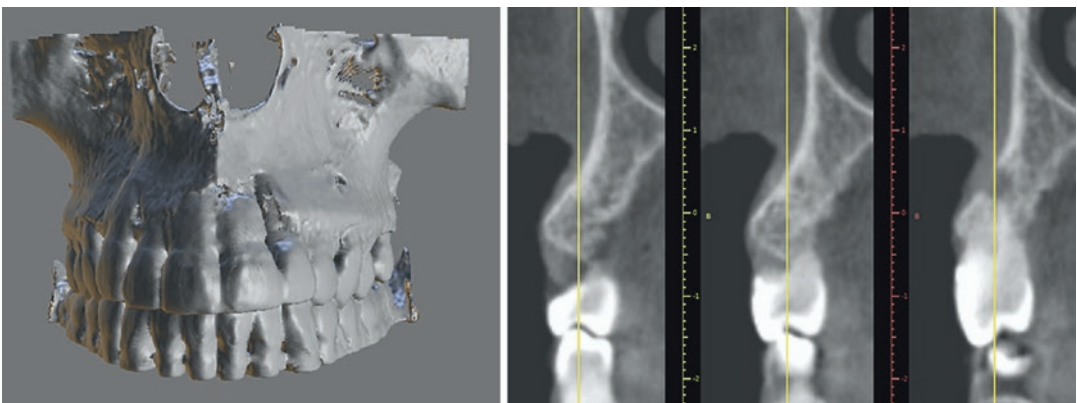

Fig. 1.14 Incorrect interarch separation. Occlusal surfaces are not visible

Sometimes, cotton rolls can serve as an occlusal stop to establish said interarch space. At least 10 mm distance is recommended and this can be hardly accomplished with only one roll. Other times, bite splints can be prepared previous to the CBCT. No specific jaw position needs to be addressed (i.e., centric relation registration) as correct occlusal relationship between arches will be present in surface scans. Bite registration materials can also interfere with tomography imaging. Though, it is important to evaluate possible material radiopaque properties.

Indications of interarch separation must be clearly stated on exam prescription.

1.3.2.2 Soft Tissue Separation

Indications on lips and cheeks displacement can help improve tooth, crestal bone and gingiva contour visualization. Usually, position of surrounding soft tissues is not considered when delivering a CBCT and lips and cheeks are in plain contact with jaw structures. Thus, delimitation between gingiva and neighboring oral mucosa is almost

Fig. 1.15 Correct buccal tissue separation allows gingiva contour visualization. Usually, the tongue can be seen in plain contact with the palate. Instructions on tongue position can be useful to help assess the image merging process

impossible when inspecting the study. This is also present when the tongue rests over the palate and lingual aspect of the jaws (Fig. 1.15).

Correct diagnosis on crestal bone and gingiva thickness is useful when assessing an axial image in dental tomography. If the lip is displaced buccally, full contour of bone plates can be displayed to contribute with patient phenotype diagnosis, and considerations that comes ahead said diagnosis. Moreover, this contour visualization enhances the assessment of the image merging process, between surface scan and DICOM files (See 2.3 Image Merging Process).

Separation can be accomplished also with cotton rolls, but to ensure full tissue displacement, a lip retractor is preferred. Januário et al. [14] developed this novel method to improve buccal tissue visualization in order to measure its thickness and width using dental tomography and avoiding invasive techniques like bone sounding or transgingival probing (Fig. 1.16).

In summary, it is recommended to ask the technician to use a lip retractor and cotton rolls to perform the study. Instrument and materials can be provided to the patient when indicating a CBCT, just like when a radiographic template is delivered.
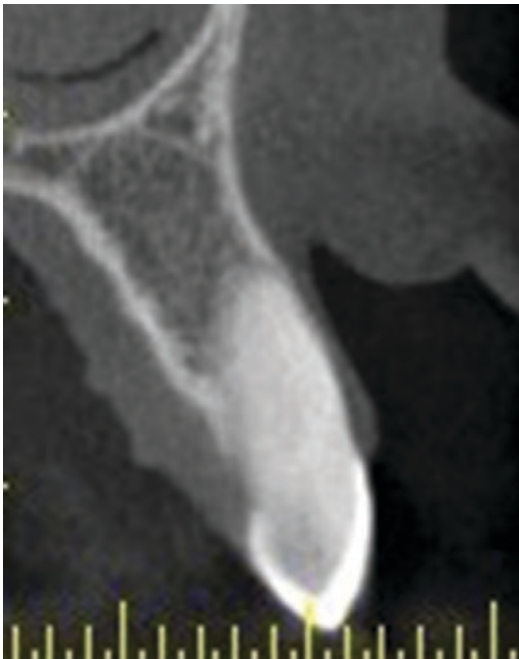
1.3.2.3 Field of View

The field of view (FoV) refers to the area of the patient that will be irradiated. In other words, it relates to the anatomic area that will be visualized on the study. Different FoV sizes can be used depending on the equipment and dental treatment indication. They can be divided into small, medium, or large:

– *Small FoV*: It covers around 6 in. diameter and allows proper visualization of 5 anterior or 3 posterior teeth. It is often used for endodontic purposes or to exam periodontal ligament, root fracture, periapical lesion, root canal morphology, and relation of an impacted tooth with the surrounding anatomical structures (Fig. 1.17).

It has the advantage of delivering high-quality image together with low 3D distortion, being the most accurate method in CBCT imaging. Equipments can either vary their fields of view to sat-
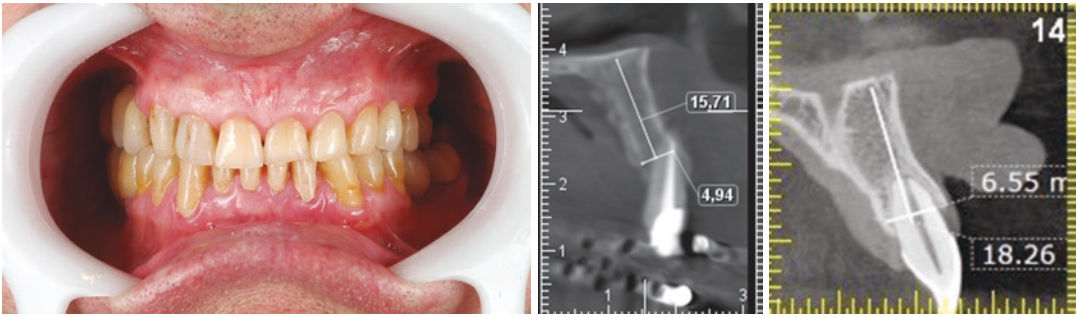
Fig. 1.16 Method published by Januário et al. [14] for soft tissue separation
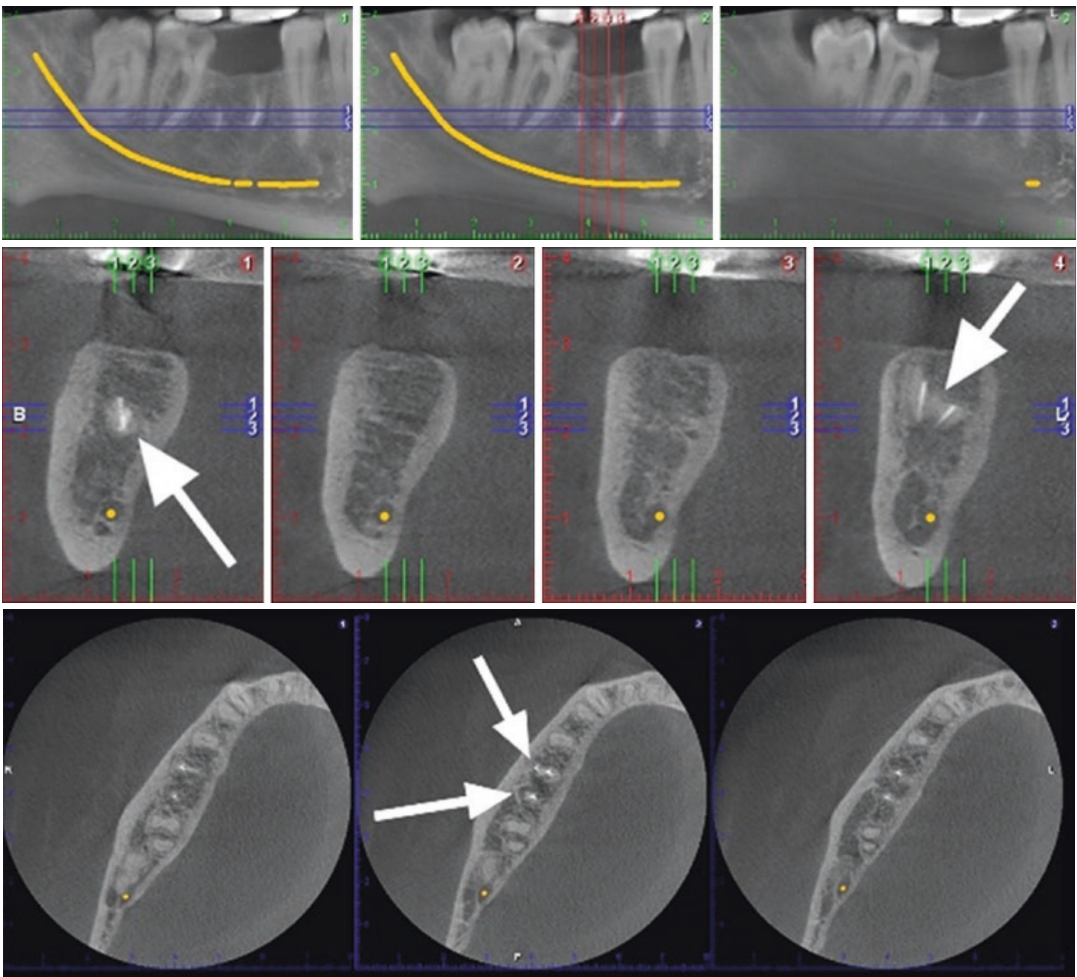

Fig. 1.17 CBCT taken with a small FoV. A small portion of the mandible can be assessed. Thus, image quality is improved and radiation dose is reduced

isfy every need or posses a fixed FoV. Thus, equipments having a fixed small FoV will require multiple scans to capture a complete arch, meaning more radiation to the patient. Therefore, multiple scans are superimposed to create a single image, which is usually seen as 3 circles superimposed in a horizontal view (one scan for the anterior region and one for each posterior zone) (Fig. 1.18).

– *Medium FoV*: It covers around 9 in. diameter; which is wide enough to visualize an entire arch with broad apical extension (Fig. 1.19). Usually, antagonist is seen up to bone crest level. Dental elements of both arches can be seen if apical extension is reduced and patient is in occlusion. Nevertheless, visualization of one arch, correct apical extension, and inter-arch separation are recommended when indicating virtual planning protocols. Also, extension of this FoV allows display of adjacent cusps, to serve as merging references. Moreover, it can be used to diagnose temporo-mandibular joint alterations. Despite increasing the area of examination, whenever assessing implant placement, a medium FoV shows simi-
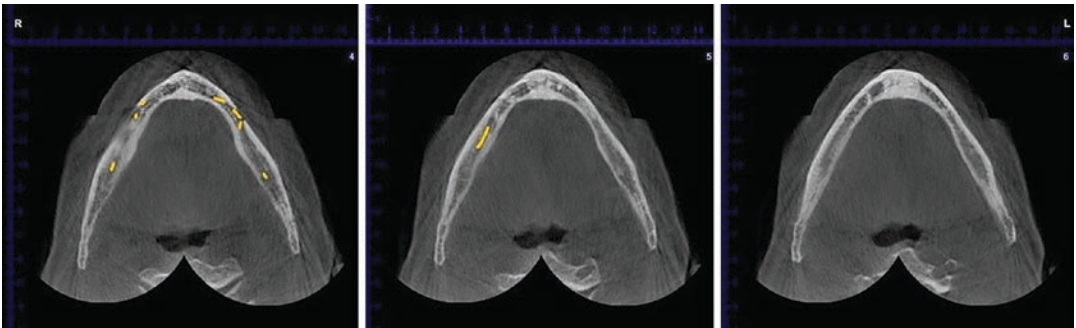

Fig. 1.18 A small FoV is used to get an image of the whole mandible. For that means, 3 separate scans are superimposed. Horizontal view shows three circles (scans) superimposed. Radiation dose is increased and so, a bigger FoV size is recommended in these cases
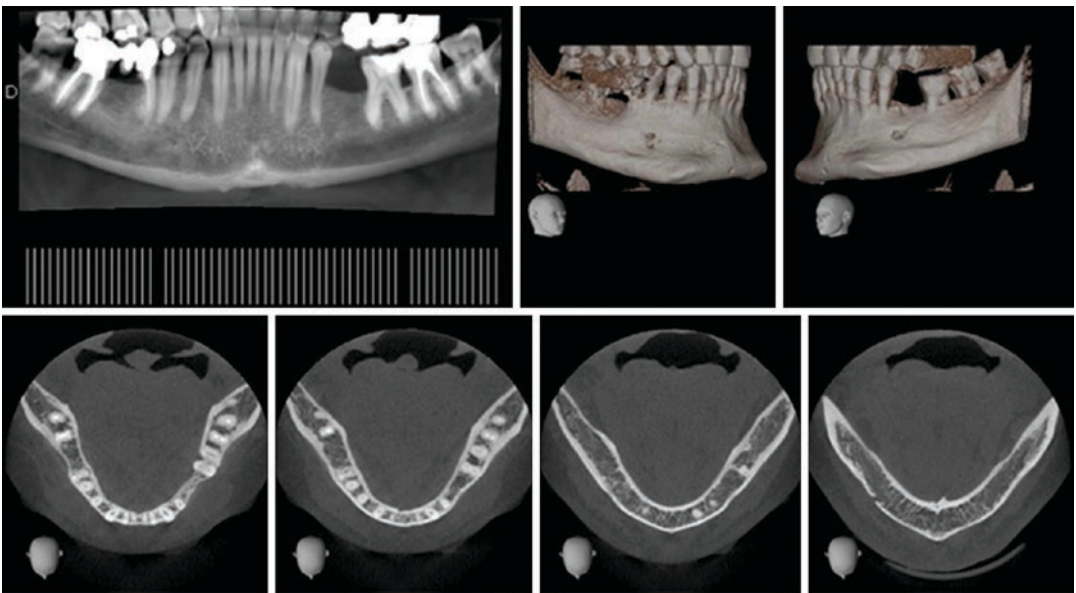

Fig. 1.19 Medium FoV can give an image of the whole jaw or maxilla. If arches are separated, opposing jaw is usually not visible

lar characteristics to a small one in terms of volume accuracy and image resolution [15].

– *Large FoV*: It covers around 12 in. diameter and is capable of delivering an image of the whole craniofacial area. This is especially useful in orthognathic surgery, skeletal anom-

alies, vast pathologies, or trauma cases. It can be also indicated to assess both jaws and contiguous regions, such as maxillary sinus, in one image (Fig. 1.20).

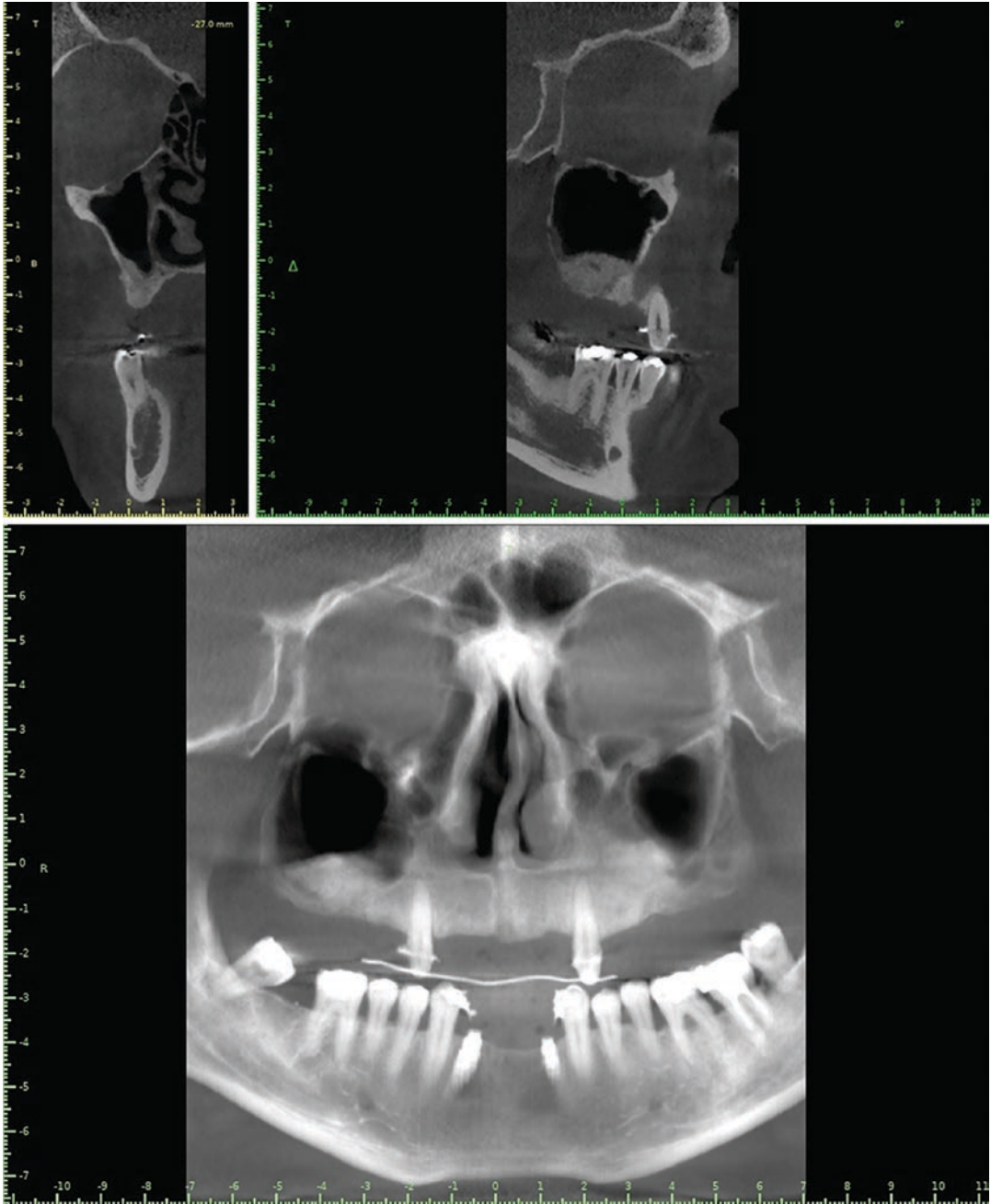Implant planning can be accomplished successfully with every FoV size; however,

Fig. 1.20 Large FoV is useful to evaluate both arches and contiguous regions. Radiation with these scans is high, so cost-effect ratio should be analyzed carefully

major volume alterations can be expected when using a large FoV. Although said alterations should not affect conventional implant placement, virtual planning demands accuracy. Static guided surgery does not allow osteotomy modifications if bone topography does not resemble the CBCT image. Additionally, radiation dose should always be as low as possible. Therefore, large FoV indication should rely on cost-effect analyses (Fig. 1.21).

1.3.2.4 Voxel Size

A voxel is for the CBCT what the pixel is to an image. While a pixel is represented as a square (2 dimensions), a voxel is pictured as a cube (3 dimensions). The same concept known for a pixel works for a voxel: the smaller the pixel/voxel, the higher the quality of the image/CBCT. It can also be stated that, as the voxel become smaller, the detail captured in the study is higher, as well as time exposure and radiation dose. As a rule, smaller FoVs use smaller voxel sizes in order to obtain information from small structures. Thus, FoV indication comes along with voxel size unless otherwise specified. Such cases, as periodontal ligament changes, are not required for implant therapy analysis.

Additionally, as smaller voxel sizes demand more exposure time, patients having difficulties remaining still might need faster scannings; meaning voxel size increment. As always, a balance between image quality and radiation dose has to be assessed.

1.3.3 Segmentation and 3D Reconstruction

Segmentation is the process used by a tomography software to separate one specific anatomic structure from the rest of the volume. This is a fundamental aspect of the CBCT, as virtual reconstructions help evaluate certain areas without other tissue interference. Segmentation comes along together with the process of 3D reconstruction, which involves the creation of a render from the gathering of sequential slices taken from the patient. This 3D reconstruction can be accomplished with or without selecting what tissue or area wants to be separated from the rest (segmentation). Surely, not selecting a specific tissue to be isolated will not deliver a neat image, as different tissues are superimposed.

Automatic segmentation is the most commonly used method and can be done in two ways: either by selecting a Hounsfield Unit (HU) threshold (each tissue has an average HU value) or by selecting a preset rendering configuration, previously defined by the software (Fig. 1.22).

Moreover, there are manual methods to accurately segment an area containing one or more tissues. These techniques vary among software programs but, in general aspects, clinician is guided through the slices to detect and select the area to be included in the reconstruction. Finally, a customized segmentation
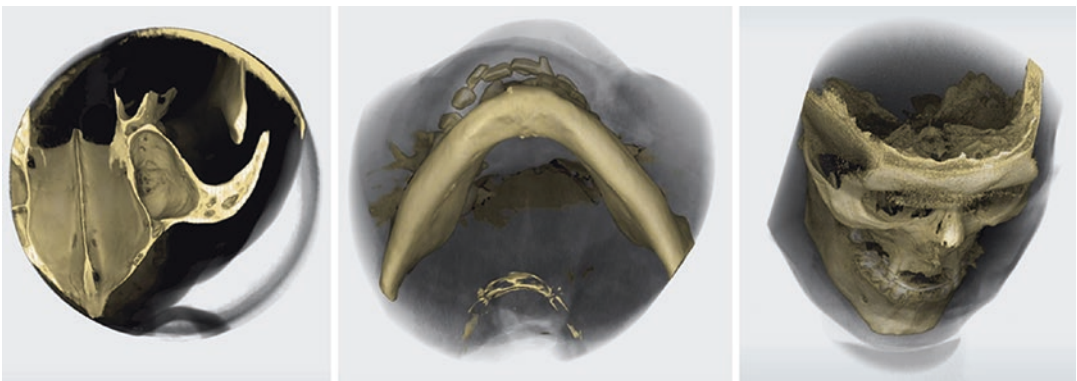

Fig. 1.21 Different FoV sizes. Small (left), medium (middle), and large (right). Radiation dose can be inferred from this representation
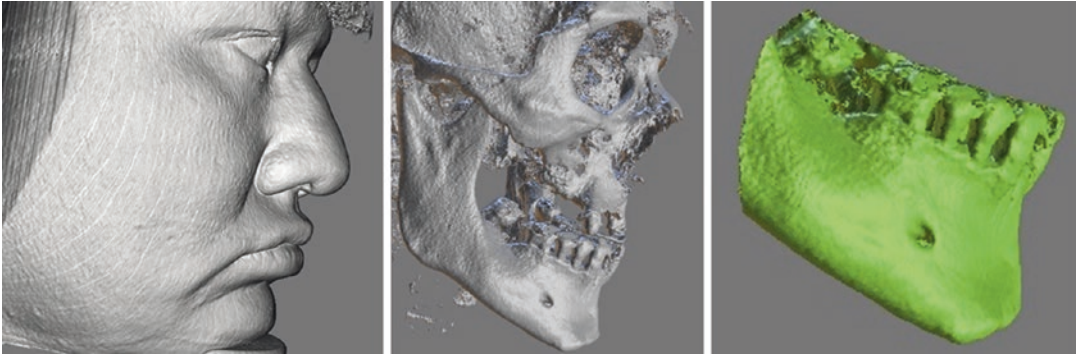
Fig. 1.22 Initial 3D reconstruction (left) with tissue superimposition (without segmentation); automatic segmentation by the HU delimitation process to visualize only hard tissue (middle), and customized segmentation to isolate a specific part of the mandible (right)
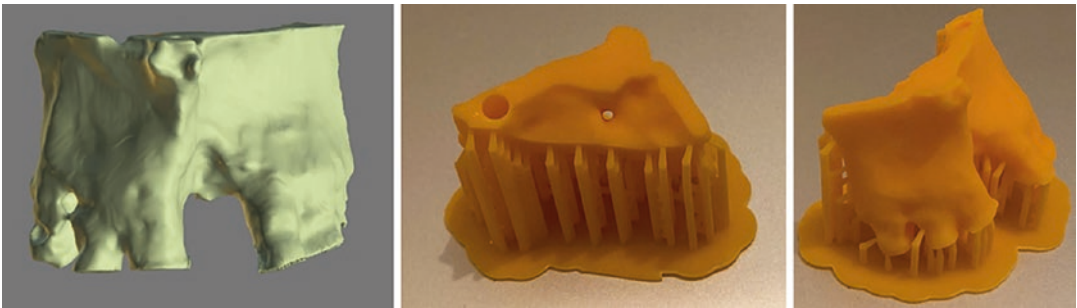

Fig. 1.23 Customized (advanced) segmentation and 3D printing of the surface model

is accomplished and a 3D rendering can be visualized.

As a final step, the render can be exported as a surface image (STL file) either to be manipulated in other software or to be printed by an additive method (3D printing) to obtain a stereolithographic model (Fig. 1.23). This process will be discussed in Part II.

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CAD: Computer-Assisted Design

2

Nicolás A. Rubio

2.1 Introduction

In digital implant dentistry, two different kinds of software packages can be found. Therefore, each dental program can be catalogued either as a prosthetic planning software or an implant planning software. While the first ones are used mainly by dental labs, the second ones are used by clinicians to visualize CBCT images, plan implant placement, and design surgical templates.

An implant planning software allows the surgeon to navigate the tomography through the slices and personalize its visualization. Panoramic curve, distance between slices, bone density threshold, brightness and contrast are examples of parameters that can be customized by these programs. Moreover, virtual implants can be placed to make the most out of the surgical plan.

Finally, after diagnosis and virtual implant placement is achieved, a surgical template can be fabricated to reproduce said planning during surgery. This template can be designed by making use of a virtual cast taken from the patient, in order to be supported by teeth, mucosa, or even bone structures.

Implant brand, model, length and diameter can be selected from software library. Drilling system usually comes along with implant selection, but sometimes can be modified. Thus,

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instruments used to perform the desired surgery will depend on software settings.

Understanding the design itself helps clinician recognize the importance of the data collection process that takes place previously. Fortunately, learning curve tends to be more easygoing with implant planning software rather than with prosthetic planning software, as surgeons are normally familiarized with tomography viewers.

2.2 Planning Software

Even though both programs (prosthetic and surgical software) are basically CAD programs (as they are set to design), the term "CAD software" in dentistry normally refers to the group of technology used to design restorations, bite splints, abutments, and other prosthetic elements. It is important to differentiate between prosthetic planning software (Fig. 2.1) and implant planning software (Fig. 2.2). In this textbook, focus will be made on programs that allows the visualization of CBCT images and the design of a virtual surgical procedure, that is, implant planning software.

As described in Chap. 1, two types of files are managed in these programs, one to assess bone anatomy (DICOM file taken from CBCT images) (Fig. 2.3) and one to perform the prosthetic design and fabricate a template for guided surgery (STL file or equivalent taken from intraoral or extraoral surface scanners) (Fig. 2.4). Thus, if
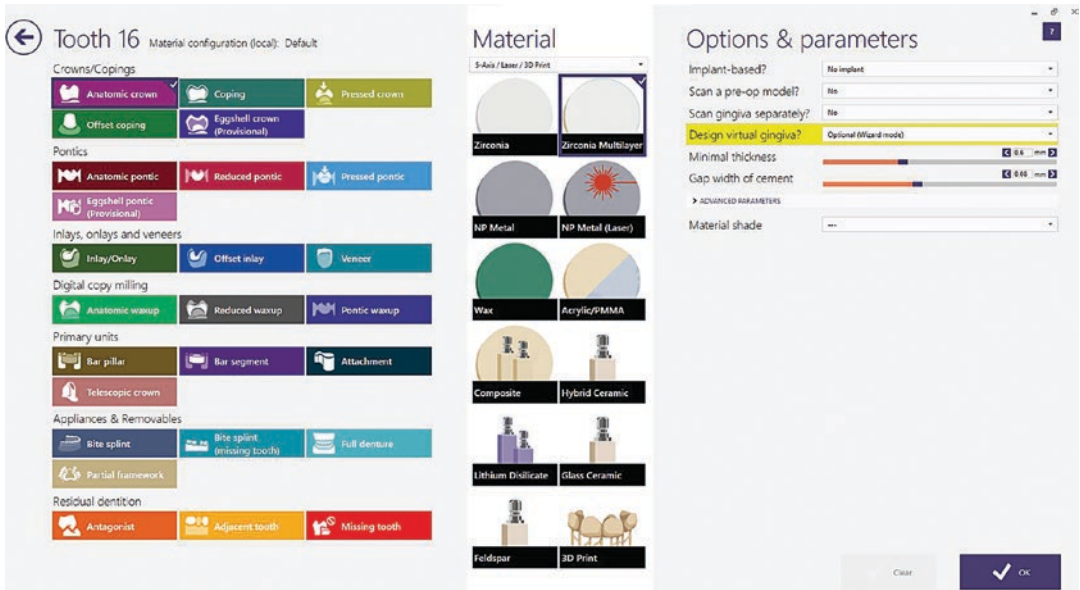
Fig. 2.1 Job definition in a prosthetic planning software (CAD program, Exocad®, GmbH)

Fig. 2.2 Job definition in an implant planning software (CBCT viewer and virtual implant placement program, Implant Studio®, 3Shape)
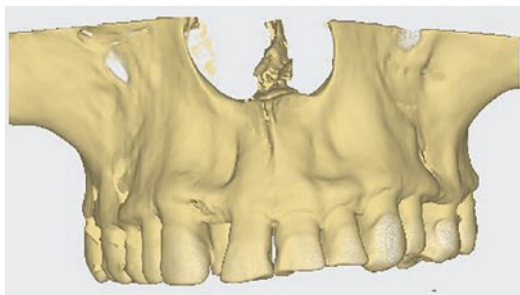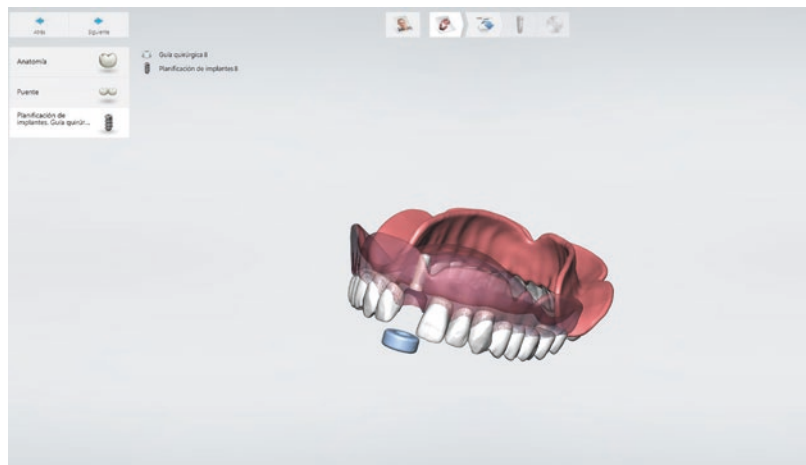

Fig. 2.3 DICOM file from patient CBCT

Fig. 2.4 Surface scan from patient oral situation. This DCM file contains additional information, such as color, and can be transformed into a conventional STL file

only a DICOM file is uploaded in an implant planning software, clinician will be able to navigate the study, measure distances or place a virtual implant, but won't be able to determine a precise prosthetic plan (digital wax-up and future crown position) or even deliver a surgical template [1].

As simple as it sounds, each file allows a job to be made and so, both are needed to get the most out of the software. Complete patient diagnosis involves getting all the information from patient initial situation to anticipate intraoperative risks, evaluate site conditions, and determine the best treatment option for the patient. Getting involved into the digital world implies gathering more patient information, spending more time on the preoperative phase to improve diagnosis in order to reduce clinical time and deliver more predictable treatments.

2.2.1   Available Software

In the market we can easily come across with different software options: free demo programs, which are usually called "viewers", open-source software and full version programs.

- *Tomography Viewers*: usually, they come with data delivered to the patient in a CD/portable device, together with the study. Depending on the tomography equipment used, a free version of the same brand is provided; i.e., Planmeca® equipments use Romexis® Viewer, a compact version of a broader planning software that only allows navigation through the tomography (Fig. 2.5). Additionally, full version of Romexis® software can be purchased to access all features. Moreover, the same files that are visualized in the corresponding viewer can be imported to a third-party software, thanks to the described universal language: the DICOM file.

- *Open-source software*: broadly used nowadays, free implant planning software can be downloaded from internet and offer a huge variety of tools. They are a very good option to enter the digital world as they require almost no cost and allow the clinician to navigate DICOM files, perform a simple wax-up to serve as prosthetic plan, place virtual implants, and attach surface scans to design a surgical template. In summary, surgeons can get more information with these programs than with traditional asseesment of printed
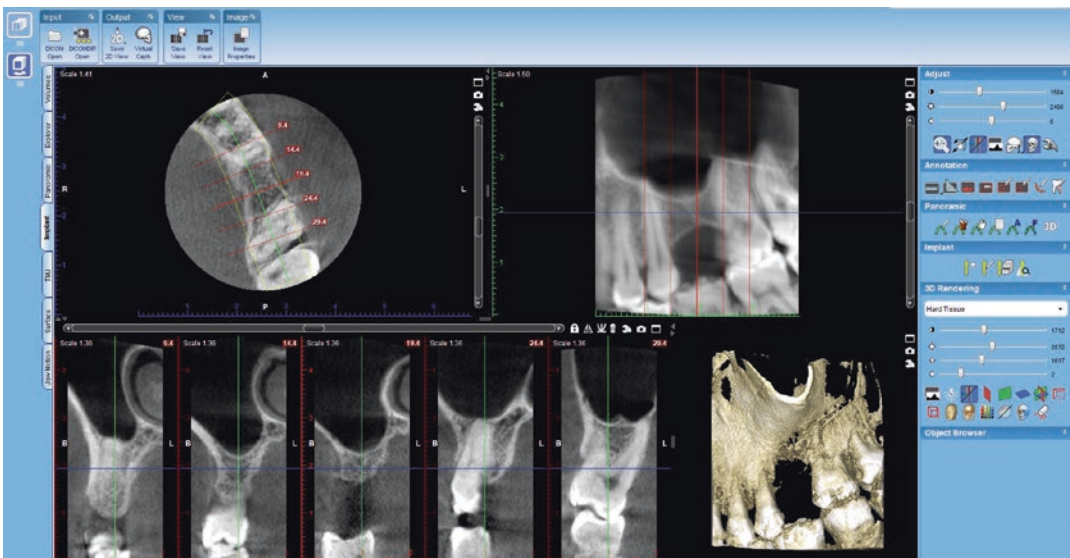

Fig. 2.5 Romexis® CBCT viewer from Planmeca

images or conventional tomography viewers, without falling into any costs. The software permits template fabrication to go into a fully guided surgical procedure but charge to export said design. To clarify, in order to obtain an STL file to manufacture the template with a CAM procedure, the program needs to export the file. Although planning is free of charge, exporting files is not. This action would be comparable to designing a presentation on PowerPoint or Keynote, so to practice the lecture, without being able to save the project and actually reproducing it with a projector.

Nevertheless, the cost of exporting files is low and can be a good option to get inside the digital planning environment without almost any investment. Perhaps the most known and used free program is BlueSkyBio® (Fig. 2.6).

- *(Full Version Programs - Purchased) Implant Planning Software*: The above described open-source software has limitations, such as poor tooth wax-up, and advantages, such as multiple surface scans uploading, CBCT customized segmentation and combination of different drilling systems. However, unexperienced dentists can easily get lost among the
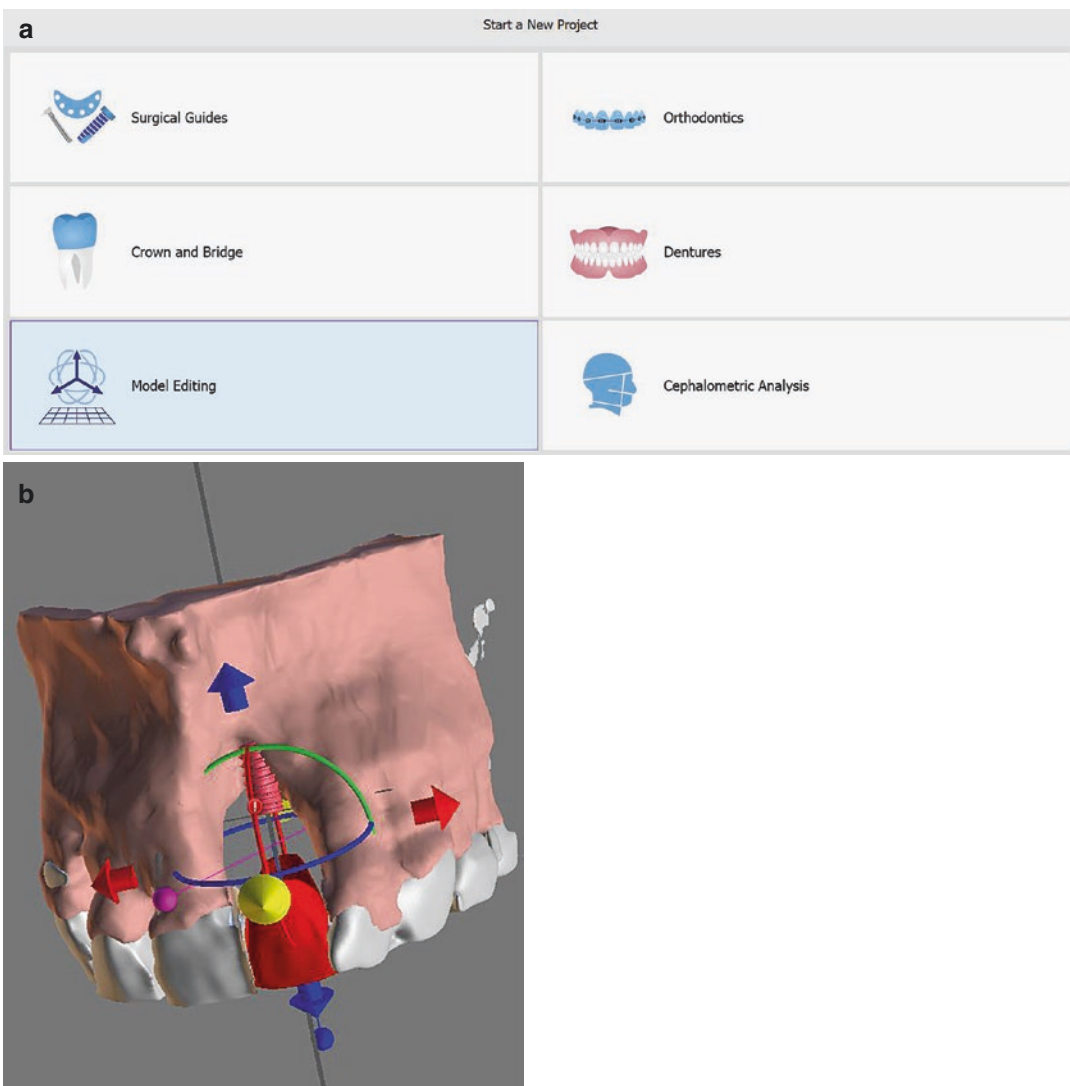
Fig. 2.6 Virtual implant planning with an open source software (BlueSkyPlan 4® from BlueSkyBio) (**a**, **b**)

many features and combinations offered by these programs. Moreover, multiple designing options can incur into errors and potential risks for the surgical guided treatment [2]. Therefore, advance interfaces are offered in full version programs, where an easygoing protocol leads the clinician into a path that begins with file uploading and finalizes with template design. Normal values are preset to assure good clinical performance and warning signs alert the user from potential misfits or surgical risks (Fig. 2.7). Graphics are enhanced and the planning experience is more friendly (Fig. 2.8). At the end of the path, an STL file is delivered for the guide to be manufactured (Fig. 2.9). Although the overall
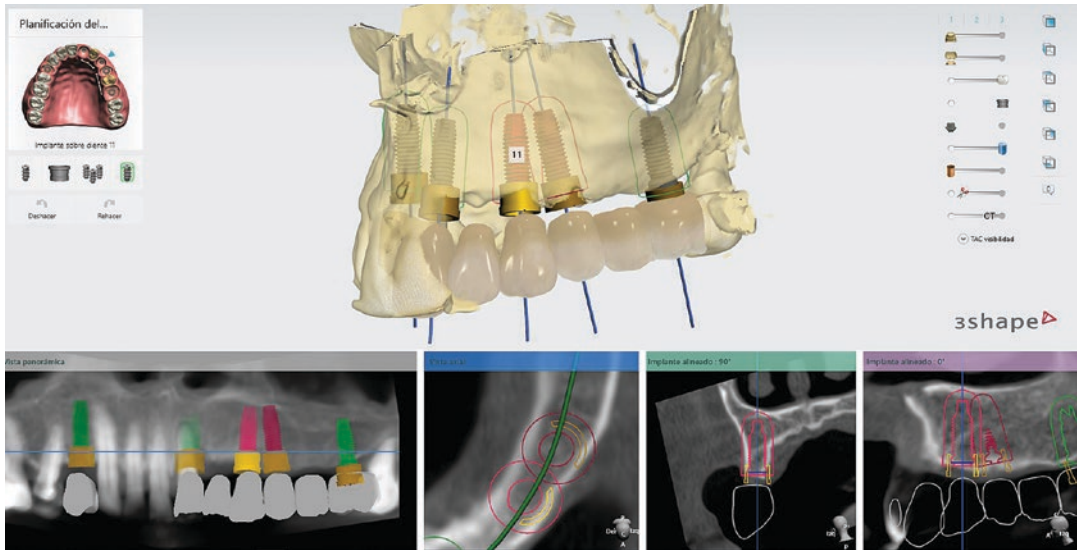

Fig. 2.7 Implant proximity alert is clearly visualized (red) while proper distance is approved (green). Default distance parameters can be customized for each clinical case
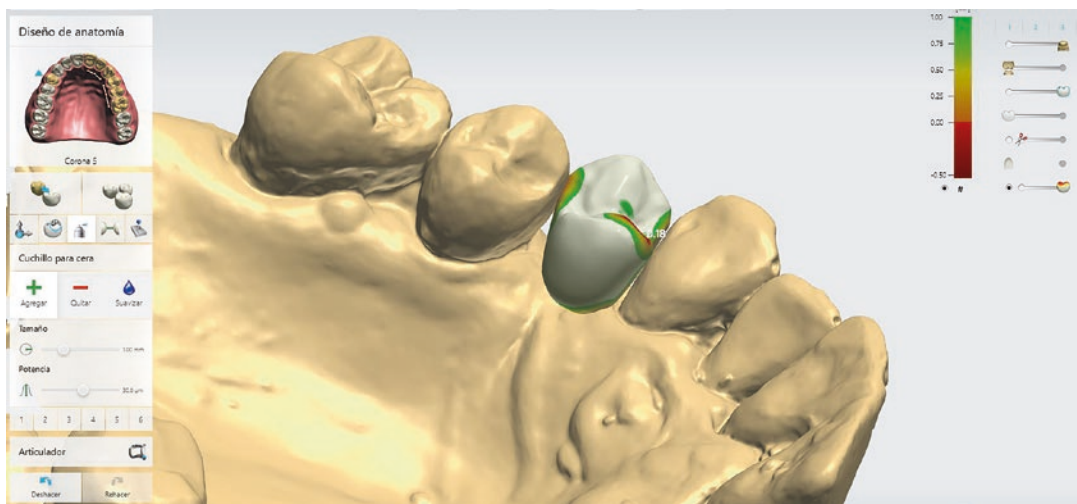

Fig. 2.8 Virtual wax-up, adjacent tooth and antagonist proximity, cusp heights and occlusal surface can be easily assessed

designing process is usually straightforward, few customizations can be accomplished in some of these software. In summary, they offer high quality image and a friendly interface to minimize potential errors and deliver a controlled outcome, but some of them do not permit modifications to the implant planning protocol; i.e., an implant osteotomy cannot be performed with a customized or different drilling system; nor can the tomography be segmented to create bone stereolithographic models. In this category, you can find programs like: Implant Studio® from 3Shape®; CoDiagnostix® from Dental Wings®; Exoplan® from GmBh®.

2.2.2 Interactions Between Software Programs

As described previously, communication between software depends exclusively on the usage of the same language. It is important to understand that, even though there is a universal language sup-
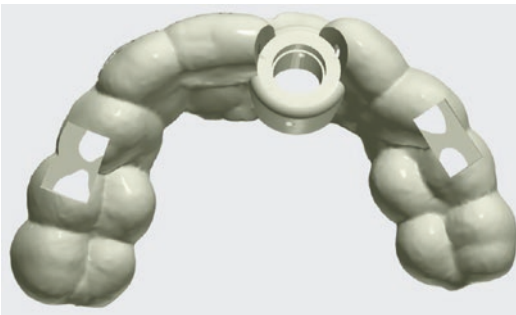

Fig. 2.9 STL file exported from the software to fabricate the surgical template

ported by all software (standard tessellation language or STL), each program can use its own language; i.e., 3Shape software uses DCM files. This provokes that both files are supported and so, can be uploaded to plan the surgery (Fig. 2.10). However, after implant planning is completed, the software delivers an STL file containing the template to be manufactured, but preserves all planning information (surface scan with the virtual wax-up and implant position) in its own specific language. Although this semi-open system allows communication between programs, some information is lost in each communication. The same inconvenience can be seen between implant and prosthetic software.

To give an example, if using a 3Shape Implant Studio® software, the surface scan can be uploaded either with a STL file or with a DCM file (taken from a Trios Scanner from 3Shape). DCM will carry additional information such as color and STL file will lose all additional information other than the surface topography (Fig. 2.11). After finalizing the design, a template will be exported in a universal language (STL). Moreover, the file that represents the modified surface scan (jaw and implant) will be exported in DCM format. This means that, in order to proceed with a full digital prosthetic treatment, like fabricating a provisional crown for immediate implant loading, you will need a prosthetic CAD software from the same brand (3Shape) or anyone else that supports DCM files. The modified surface scan file contains the implant in its position and the virtual wax-up of the prosthetic plan, both necessary to continue with the digital workflow to obtain a restoration.
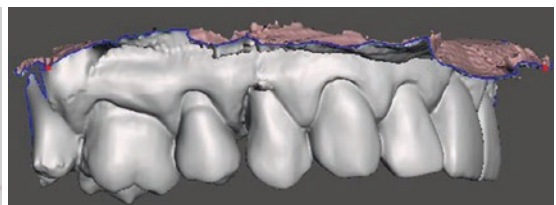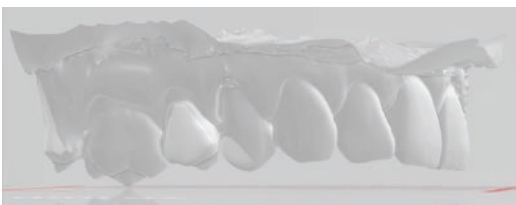

Fig. 2.10 Same object digitally stored in different extension files. PLY file (left) obtained with Emerald® scanner from Planmeca and STL file (right) compatibility. Both files are exported from the scanner. Only STL file can be uploaded in a 3Shape software as it only supports STL (universal language) and DCM (its own language)
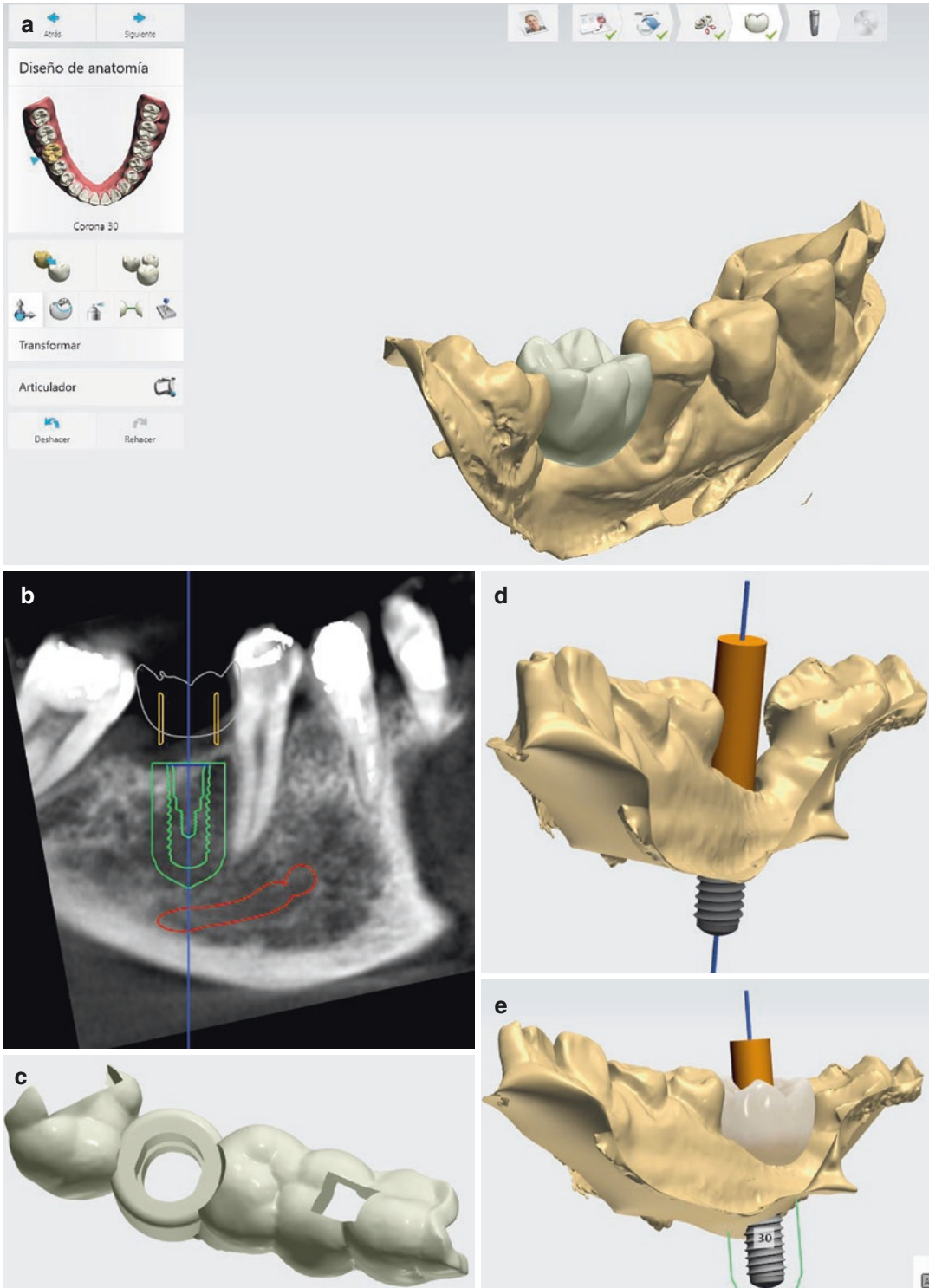
Fig. 2.11 Same clinical case as Fig. 2.10 is uploaded using a compatible format (STL). Virtual wax-up (**a**) and implant planning (**b**) are performed. Template is exported into an STL file to be printed or milled (**c**) and information of implant position (**d**) and crown wax-up used to fabri-cate a restoration (**e**) are only exported in DCM files. Thus, complete brand software package (both surgical and prosthetic programs) is needed to generate a dynamic workflow

The same example can be given backwards, when using for instance, Exocad software (most common CAD software used in dental labs nowadays) to design a crown/bridge/denture to be supported by implants. The design can be then exported to the surgical planning software of the same brand (Exoplan®) to allow implant placement and simultaneous prosthetic modifications in a synergic way. On the contrary, if wanting to use another surgical planning software, such as DDS Pro®, a new STL file should be exported from Exocad, containing the restorations. Therefore, initial surface scan would be replaced by this new model. Clinician should keep in mind that this new model has to provide enough information to merge with the CBCT image (Fig. 2.12). Although possible, this technique demands more experience on software management and creates obstacles in a digital pathway that should be smooth.

2.2.3 CAD Workflow

Although every CAD program has its own characteristics, all systems offer the user a similar workflow [3]. Once understood the path needed, clinicians can easily use any software. Overall steps include:

– *Job definition*: This can seem an insignificant task but has all to do with path selection. Site specifications regarding crown/bridge virtual design, implant distribution and guided or non-guided surgery are usually the available options among the software. Incorrect job definition usually leads to an unwanted pathway, i.e.: defining a non-guided implant placement without virtual wax-up, will make the software avoid the STL file uploading step; as this file will only be demanded whenever template design or virutal wax-up is indicated (Fig. 2.13).
– *File uploading*: Depending on job definition, the program will ask the user to upload a CBCT image and/or a surface scan. As said before, if a virtual wax-up or a guide fabrication is not necessary, an STL file will not be demanded. Nevertheless, additional files can be uploaded to have more patient information (Fig. 2.14).
– *File cropping*: This step reduces volume information, especially in extended DICOM images, helping the clinician focus on site evaluation and also reducing memory used to navigate and store the project. Special attention should be kept on leaving enough dental structures in the cropped DICOM file to merge with the STL (Fig. 2.15).
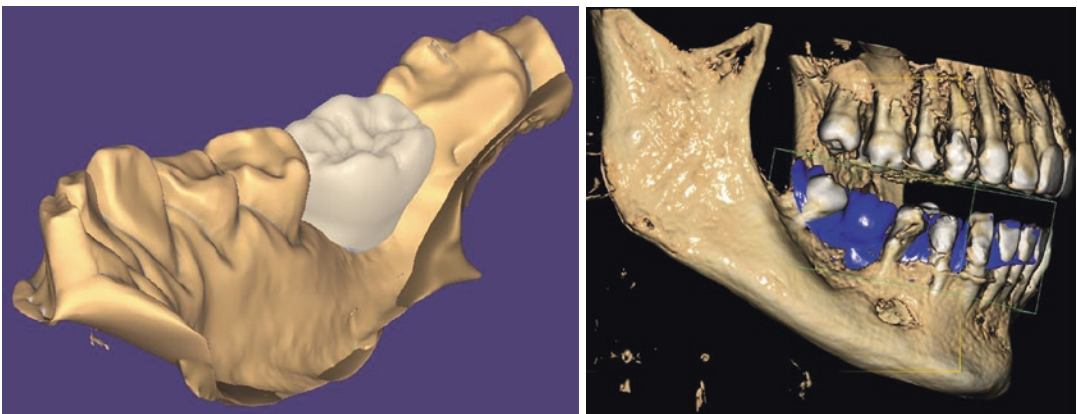

Fig. 2.12 Same clinical case is used to explain a different software interaction. First, the surface scan is uploaded in a CAD software (Exocad®) and a crown is waxed up (left). Second, a new file is exported (model and crown design) in STL format. Finally, this latest file is imported into a surgical planning software (DDS Pro®) and adjacent teeth are used to merge the CBCT and the new surface scan (right). Note that the waxed-up tooth is not present in the DICOM file. Multiple reference points are present in this case, so software interaction is possible

Fig. 2.13 Job definition. In this case, tooth #14 indication is stablished. Wax-up function is selected (will require upper jaw surface scan and antagonist) for single implant virtual placement (will require patient CBCT) and template fabrication for static guided surgery (will require upper jaw surface scan)
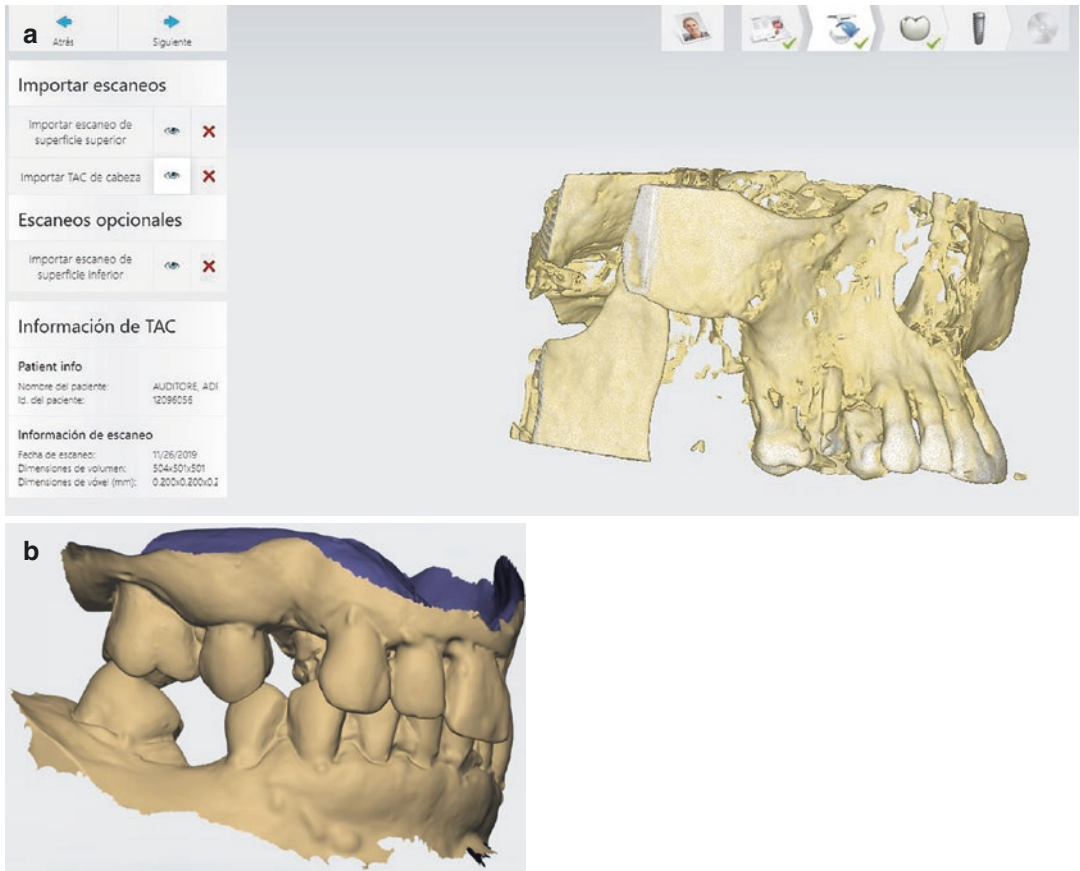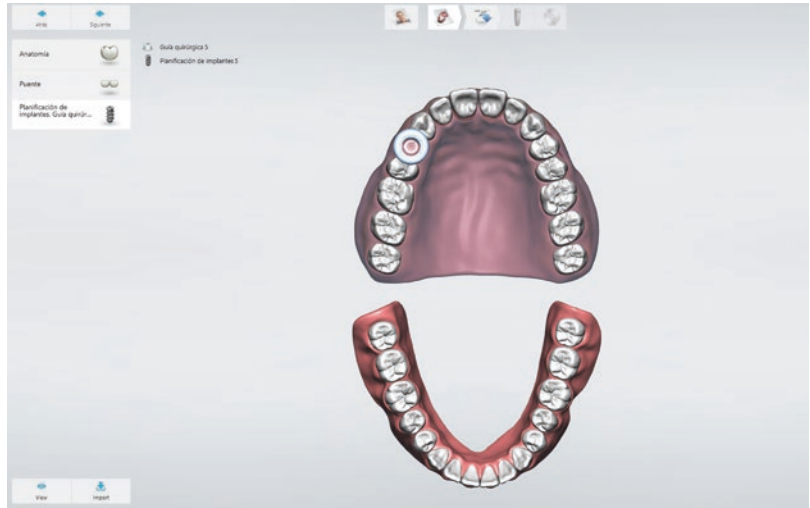

Fig. 2.14 CBCT (**a**) and both jaw scans (**b**) are uploaded according to job definition
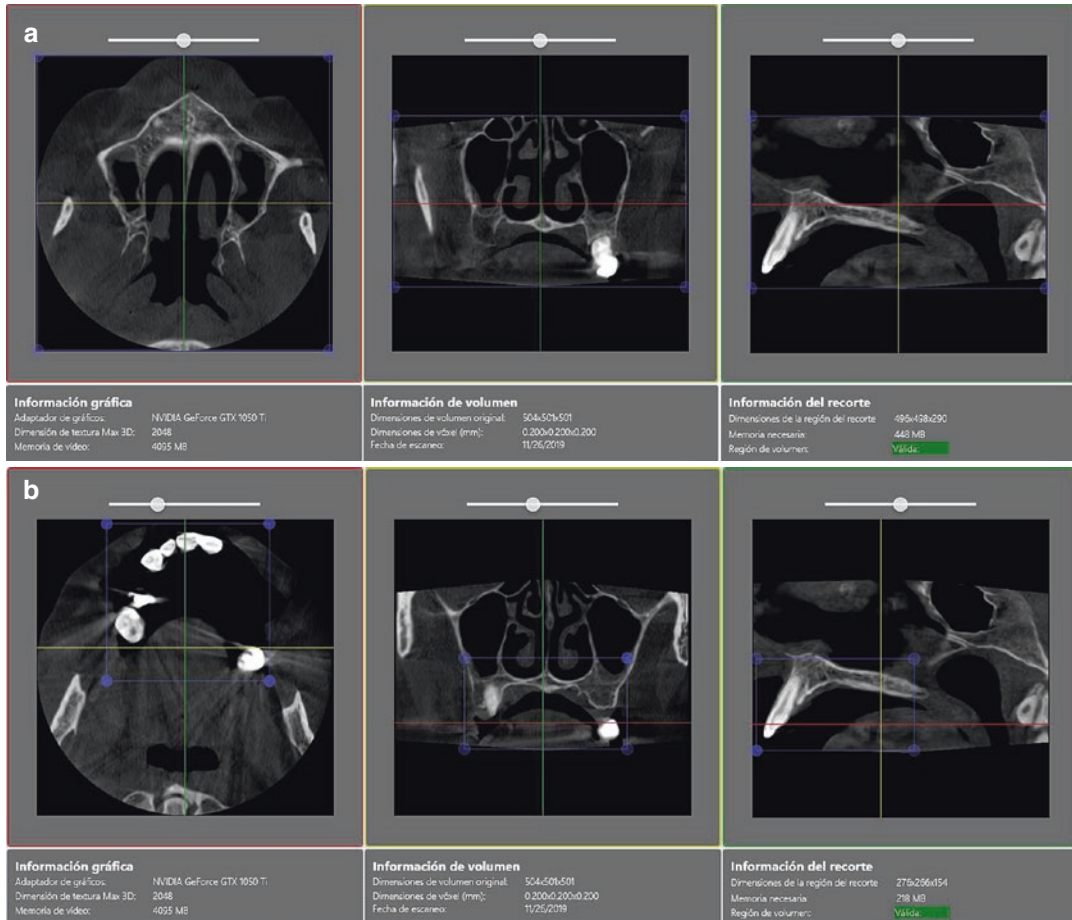
Fig. 2.15 CBCT cropping. Computer memory needed (highlighted in green) will vary as file volume is reduced (**a**, **b**)

– *Panoramic curve definition*: when examining a CBCT, a panoramic curve that goes throw the center of the bone ridge at a crestal level has to be drawn. This serves for determining the axial views where the virtual implant will be placed (Fig. 2.16).
– *Mental nerve definition*: Whenever planning an implant in the mandible, this is a necessary step to verify implant security distance during its placement.
– *Virtual Wax-Up*: Positioning a tooth provided by the library and adapting it to the desired clinical situation comes prior to implant placement, as the intention of this protocol is to deliver an implant that is prosthetically driven. This step can appear before or after CBCT

image manipulation (crop, panoramic curve and mental nerve definition) (Fig. 2.17).
– *Image Merging*: While some programs offer automatic matching, this step usually requires identifying anatomical points present in both STL and DICOM files. Correct merging is one of the key steps for achieving a good outcome (Fig. 2.18).
– *Implant Placement*: Implant selection and positioning throughout CBCT axial slices, together with emergence profile assessment towards the future crown demands same expertise as conventional implant placement. Main advantage here is the possibility to change implant brand/model or length/diameter to fit into the clinical situation. Also, a

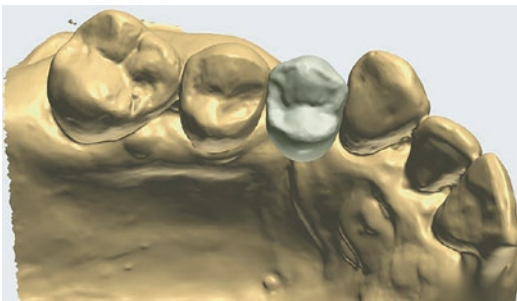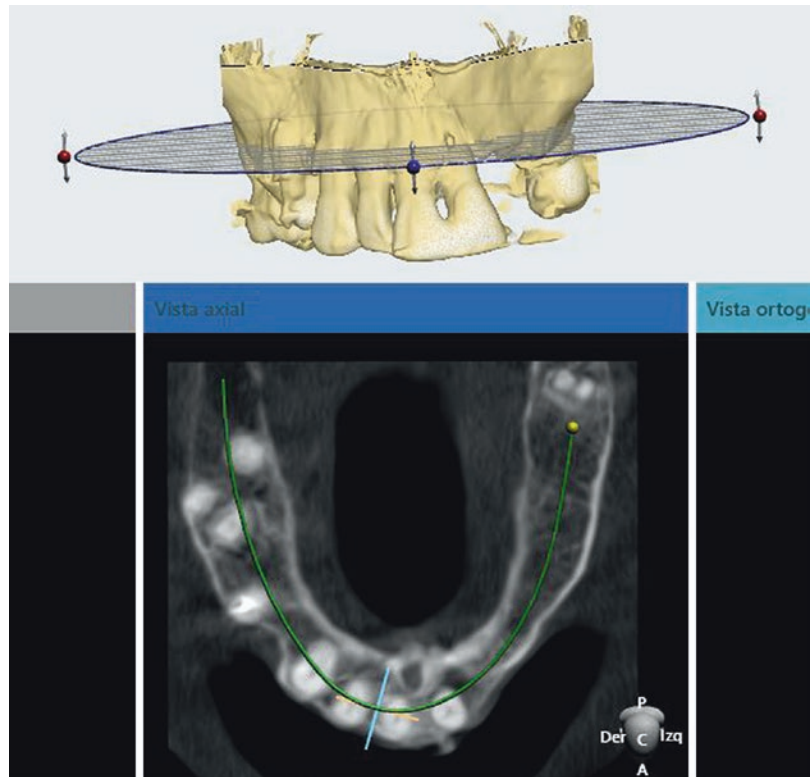**Fig. 2.16** Panoramic curve definition to visualize axial slices

Fig. 2.17 Tooth wax-up

safety perimeter is preset within the software to detect possible proximity to nerves or adjacent implants. These values can be modified to customize the surgical approach (Fig. 2.19).

– *Guide Fabrication*: As with conventional splints, retentive areas should be avoided in order to properly fit the template. So, insertion axis is determined within the software to visualize these areas and draw the contour of the future guide (Fig. 2.20). In this step, some values can be cus-

tomized, such as space between guide and teeth (fit), distance from implant platform to sleeve (offset), material (guide) thickness, manufacturing configurations (DLP, SLA, milling system) and space between guide and sleeve. Also, other items can be added to the template, such as exploring windows to assess correct fitting, bars or reinforcement structures and other written references (i.e.: name of the patient or other relevant information). Every aspect of the template design has to be analyzed in relation to the manufacturing method and material.

– *Confirmation and File Export*: Normally, a surgical report containing the drilling sequence and the virtual planning is delivered to the user (or the surgeon if designed by a third party), to be checked and confirmed (Fig. 2.21). Afterwards, an STL file is exported containing the information necessary for milling or printing the template. For legal motives, some programs do not allow the user to modify the surgical plan after project is confirmed. Additionally, a list of materials needed for the
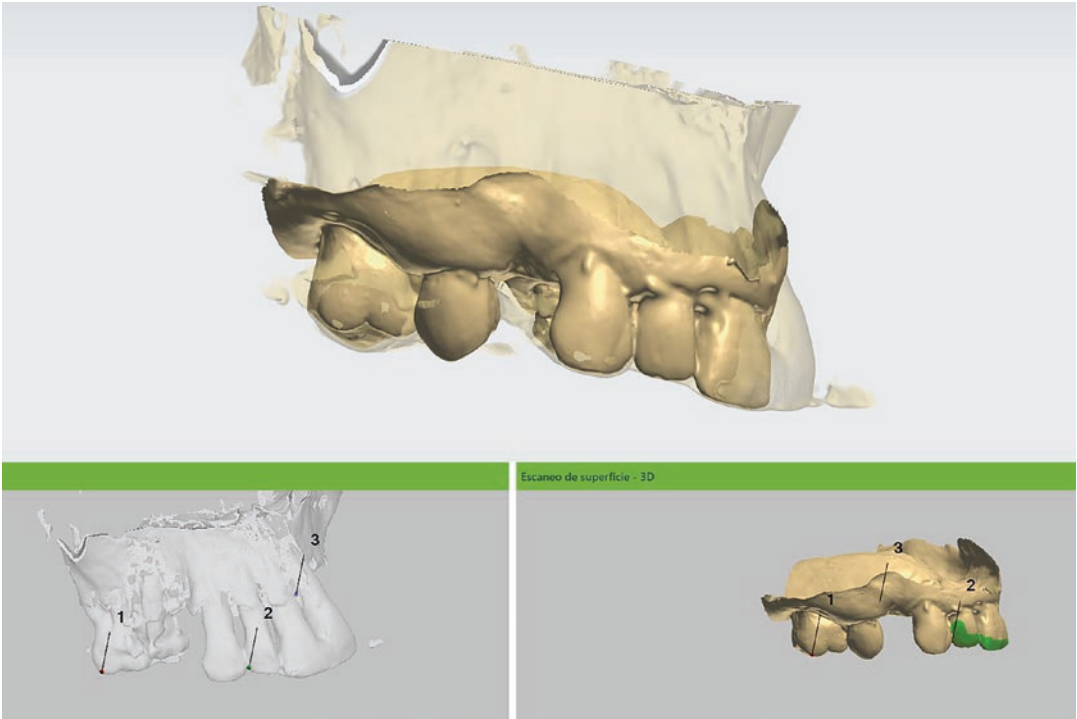
Fig. 2.18 Fusion of the CBCT and the surface scan
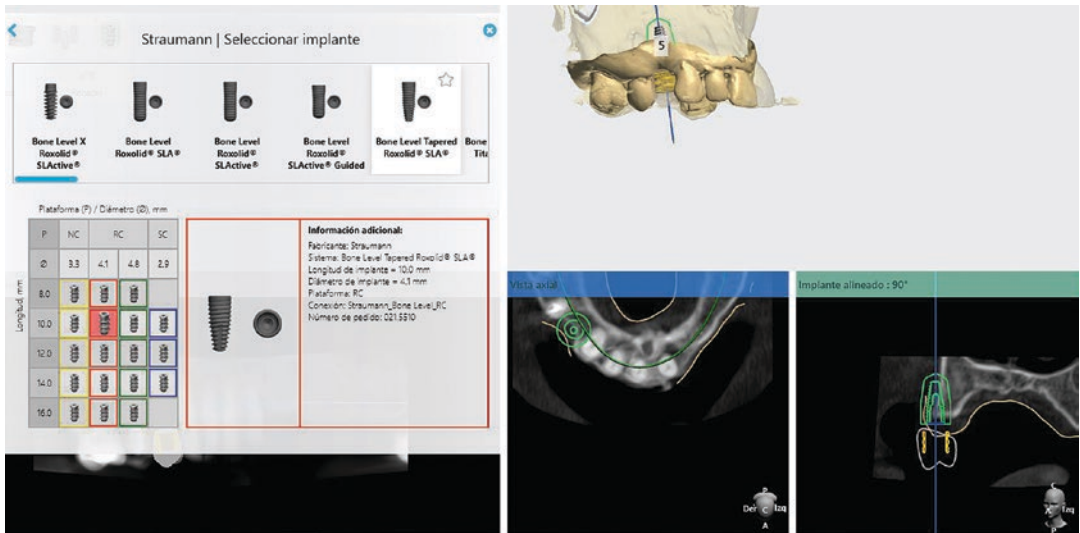

Fig. 2.19 Implant selection and security margin assessment can be done in multiple views to ensure a correct outcome