Digital Dental Implantology

From Treatment Planning to Guided Surgery

Jorge M. Galante
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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

Nicolás A. Rubio

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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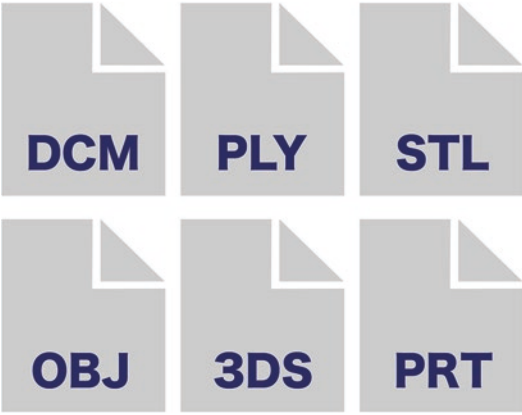

Fig. 1.1 Different file types for 3D objects

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-

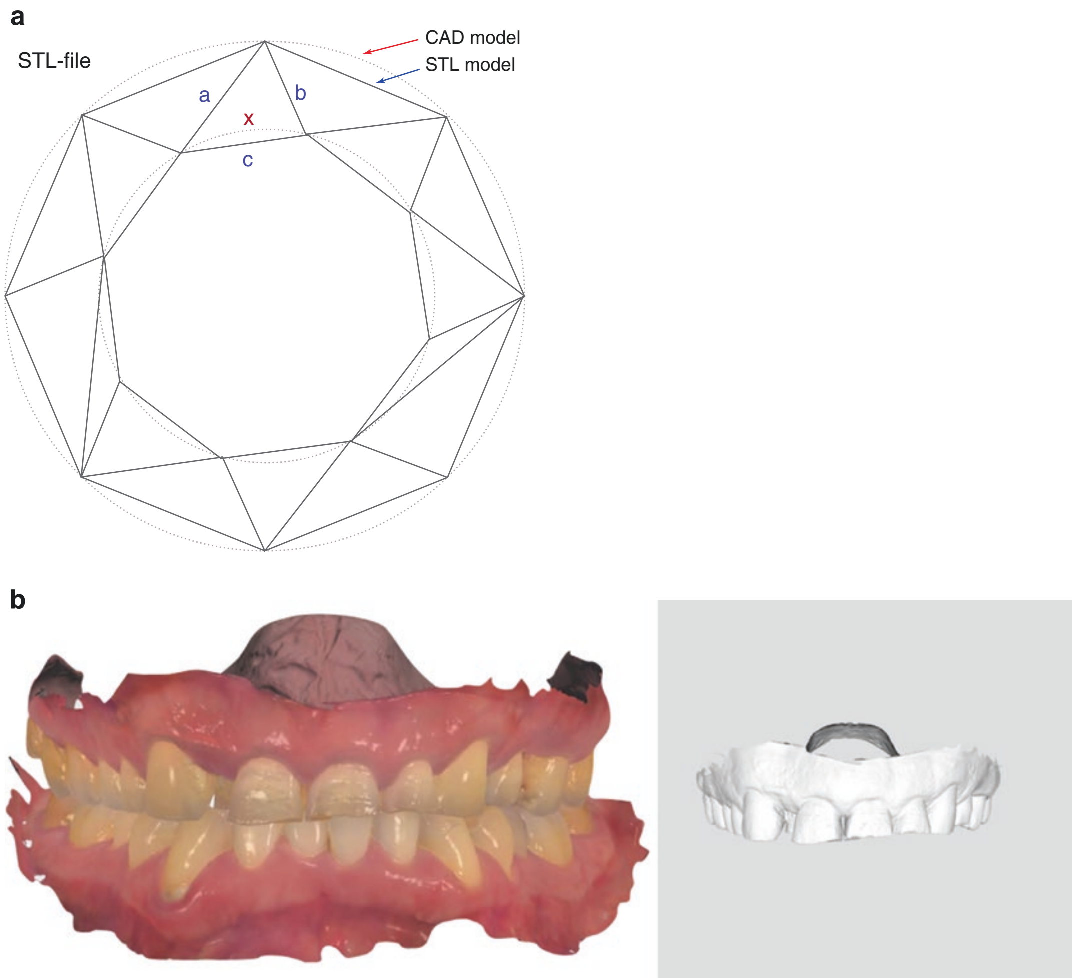

Fig. 1.2 (**a**) Standard Triangle Language (STL) stands for the reconstruction of an object based on triangular forms. (**b**) Surface scan in DCM format (left) and STL format (right). This DCM file is used by 3Shape® to add features such as color. When transforming this file into a plain STL file, 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

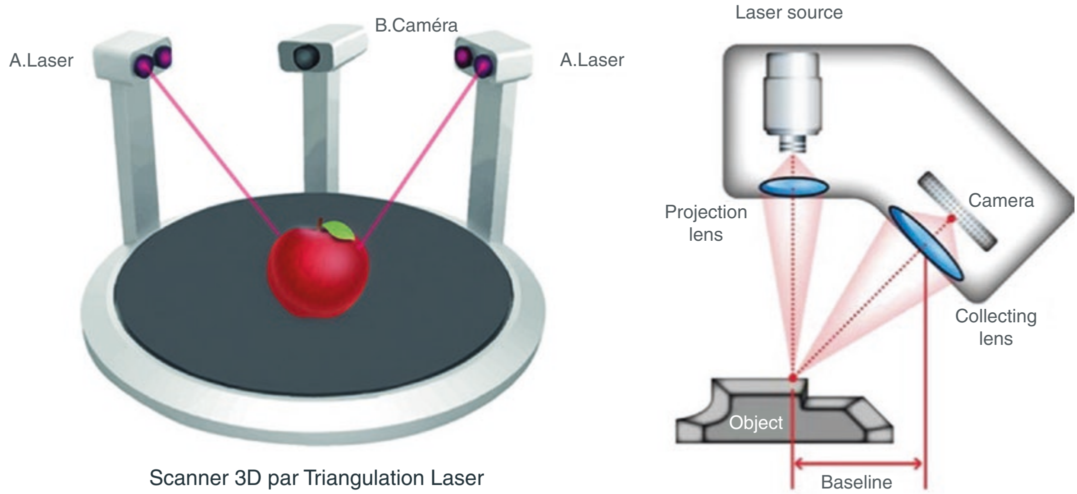

Fig. 1.8 Triangulation principle. A light is projected over an object and the reflection is captured by a camera. The angle of reflection is measured to determine the surface of the scanned object

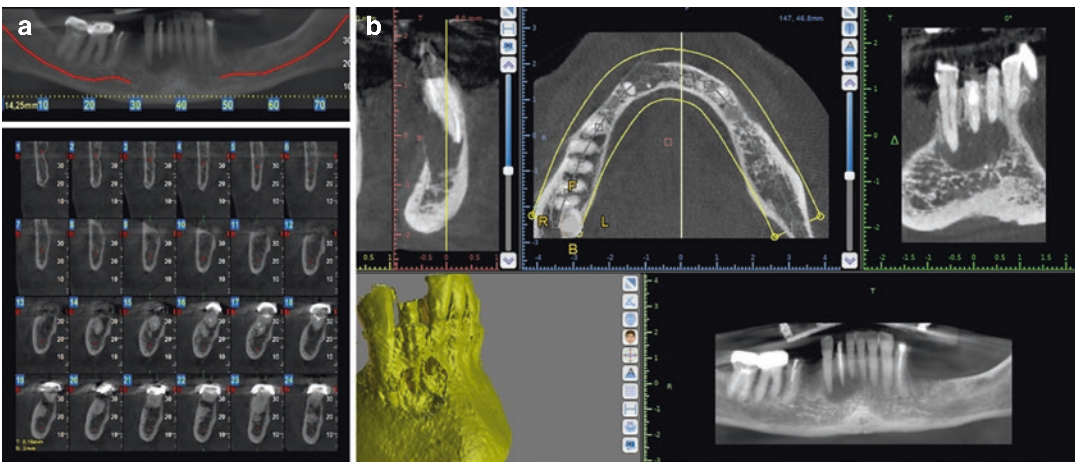

Fig. 1.9 CBCT visualization in conventional JPG file (**a**) and in software viewer (DICOM file manipulation). Panoramic curve, slices and 3D rendering can be customized and the study can be navigated to get as much information as possible (**b**)

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.

Fig. 1.10 Romexis® Viewer from Planmeca. This software comes together with CBCT images whenever a study is made with a Planmeca equipment. Additionaly, full version of this program can be purchased to unlock other features

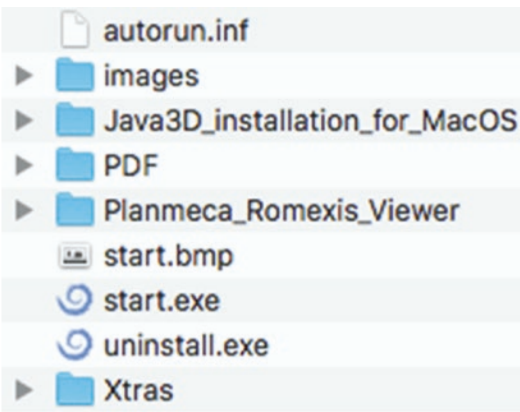

Fig. 1.11 Files contained in the CD that comes with the CBCT. The folder "images" gathers the slices that can be imported into any surgical planning software (DICOM files) while the icon "Start.exe" runs a viewer to visualize the study

DICOM files can be stored in three different formats (Fig. 1.12):

– DICOM (single frame): Every slice scanned by the CBCT equipment is saved in an independent file, resulting in multiple small size files. Software needs to put them all together to reconstruct the tridimensional image. Although apparently less pragmatic, this file exporting method is preferable over the other two as it preserves all relevant data and is supported by most software programs and viewers. However, this storage process increases study size and the parsing overhead as it replicates information in every file saved.
– DICOM (multi frame): This format was created to reduce file size and simplify parsing, storage, and communication, as it combines all slices into a single DICOM file. Nevertheless, some software do not support this format as they have not implemented it yet. Hopefully, this situation will revert to ease the digital workflow and global communication.
– DICOMDIR: It is a special file that serves as directory to a collection of DICOM files. This format is similar to a compressed ZIP/RAR file and can contain several studies from one or more patients, organized in the following way: Patient Level, Study Level, Series Level, Image Level. In hospitals or massive medical environments, DICOM Directory should theoretically shorten time required to find and display information stored when searching DICOM files. Still, this is not the case of our daily practice and not many imaging software support this file. A specific program can be downloaded from internet (often free of charge) to decompress info stored in the directory.

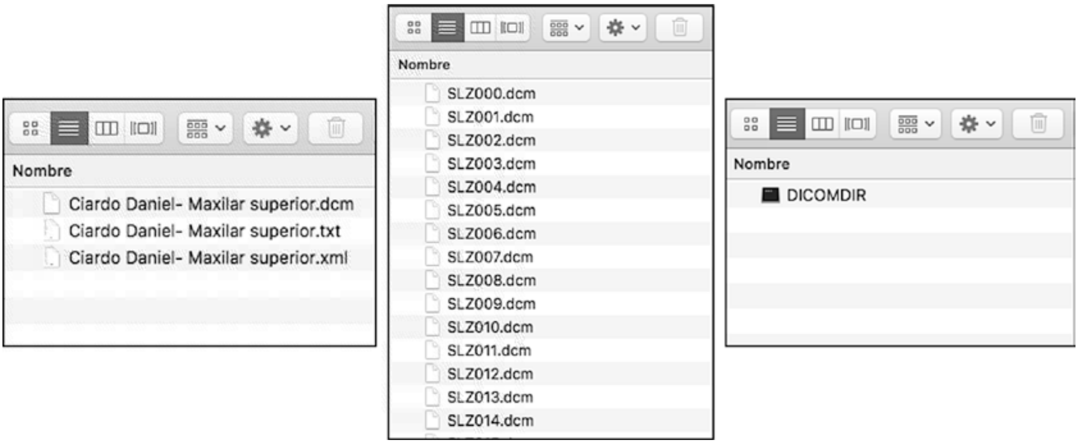

Fig. 1.12 Possible DICOM file storage: multi frame (left), single frame (center) and directory or DICOMDIR (right)

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.

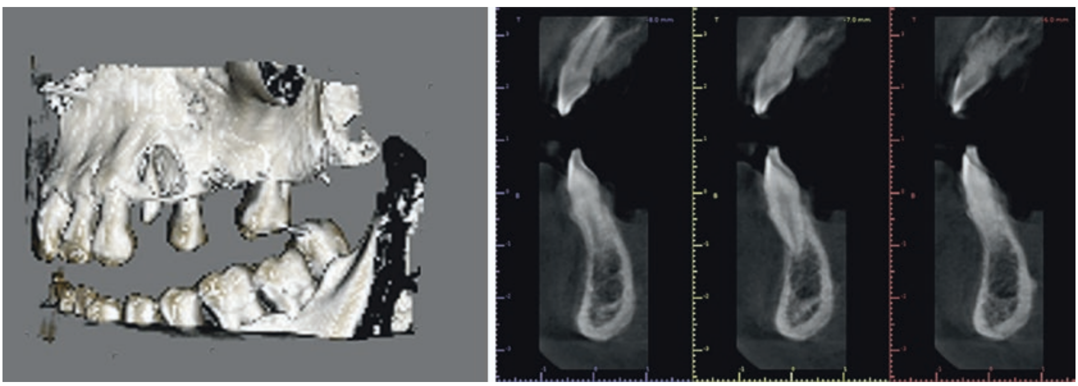

Fig. 1.13 Correct interarch separation allows visualization of the occlusal aspect of the teeth

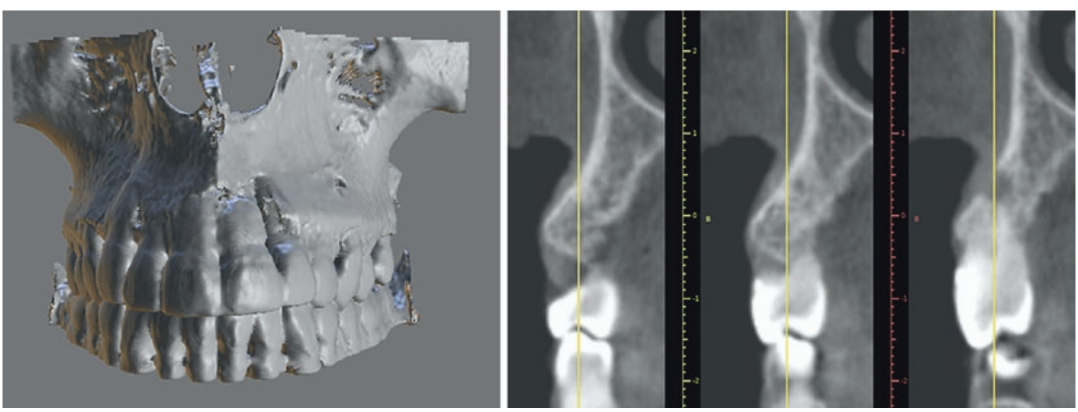

Fig. 1.14 Incorrect interarch separation. Occlusal surfaces are not visible

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 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).

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

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-

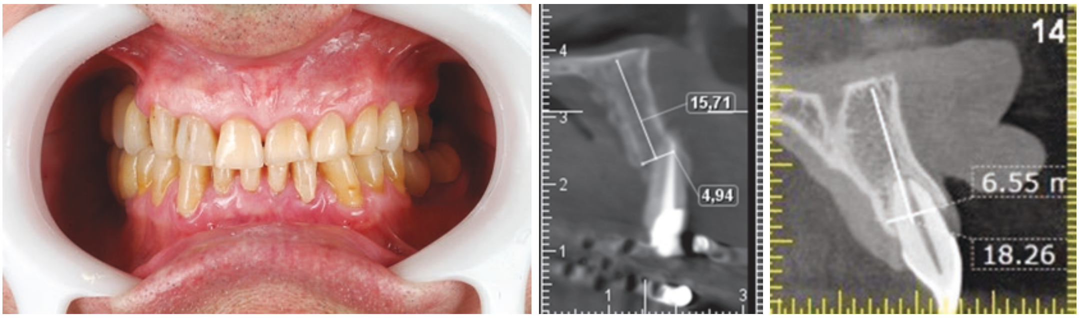

Fig. 1.16 Method published by Januário et al. [14] for soft tissue separation

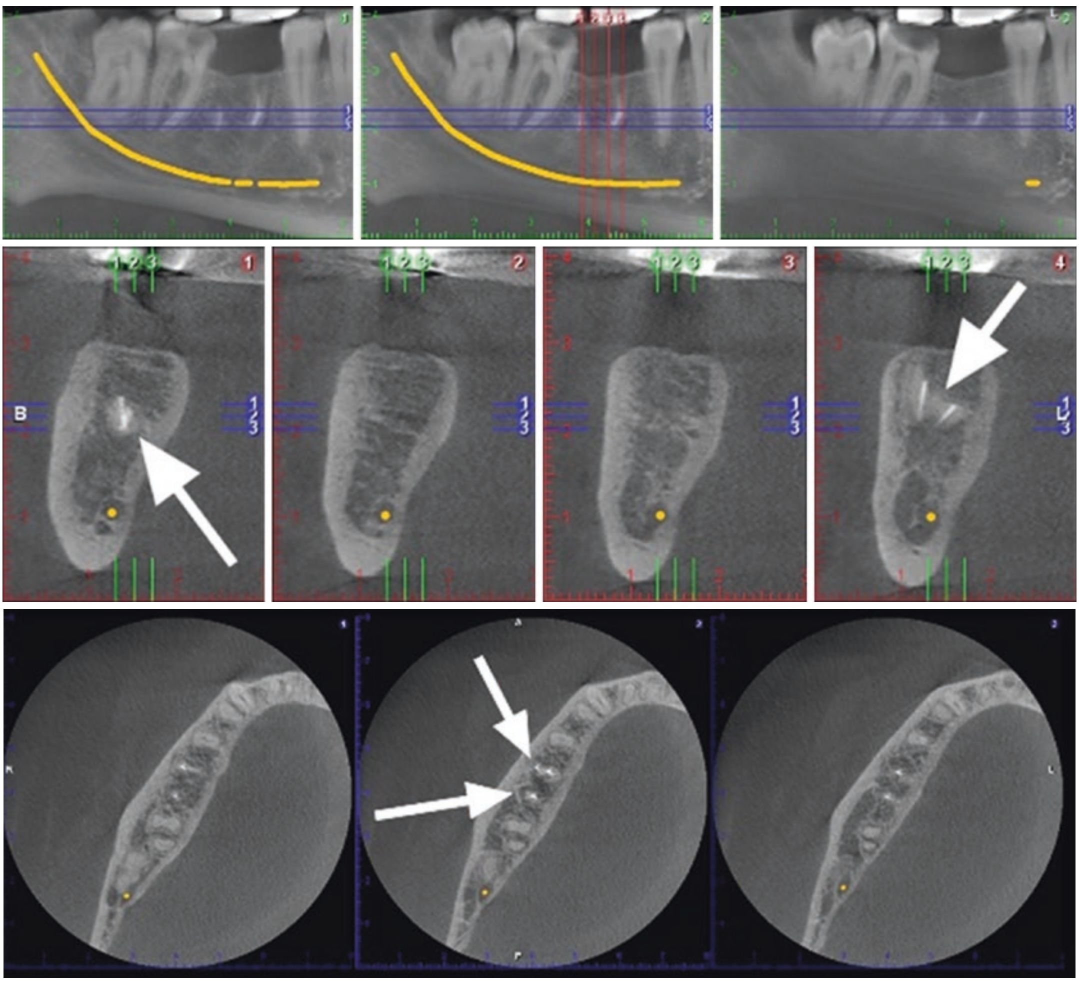

Fig. 1.17 CBCT taken with a small FoV. A small portion of the mandible can be assessed. Thus, image quality is improved and radiation dose is reduced

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 temporomandibular joint alterations. Despite increasing the area of examination, whenever assessing implant placement, a medium FoV shows simi-

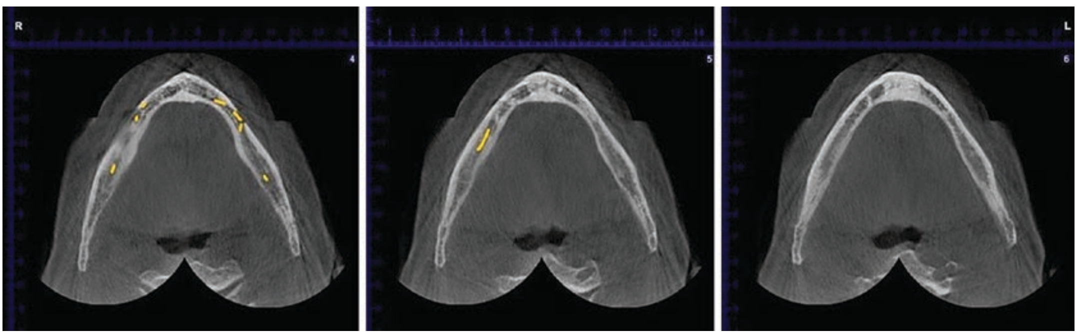

Fig. 1.18 A small FoV is used to get an image of the whole mandible. For that means, 3 separate scans are superimposed. Horizontal view shows three circles (scans) superimposed. Radiation dose is increased and so, a bigger FoV size is recommended in these cases

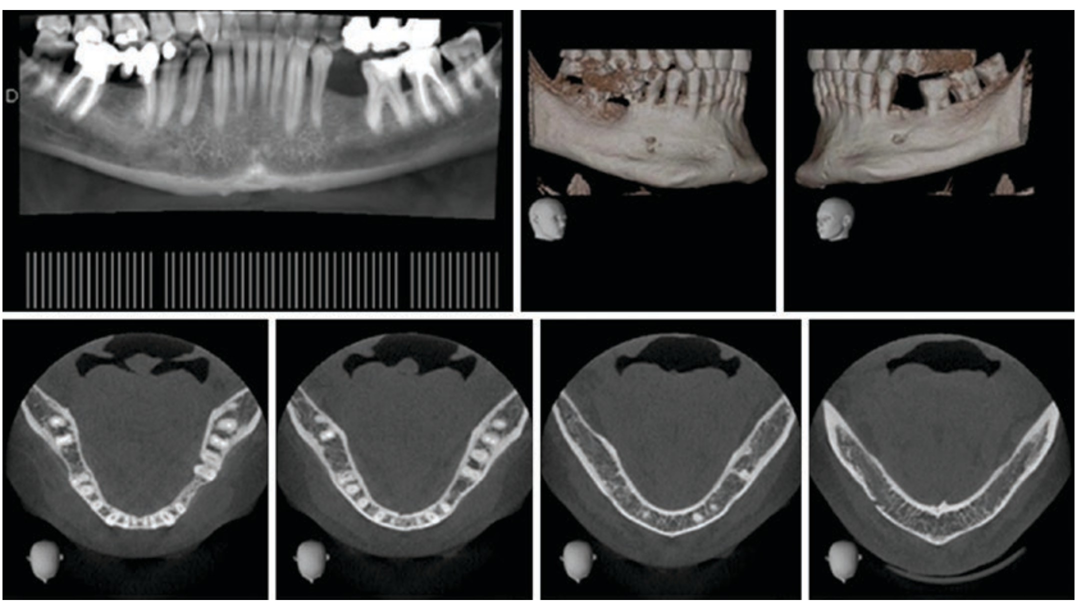

Fig. 1.19 Medium FoV can give an image of the whole jaw or maxilla. If arches are separated, opposing jaw is usually not visible

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 anomalies, 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,

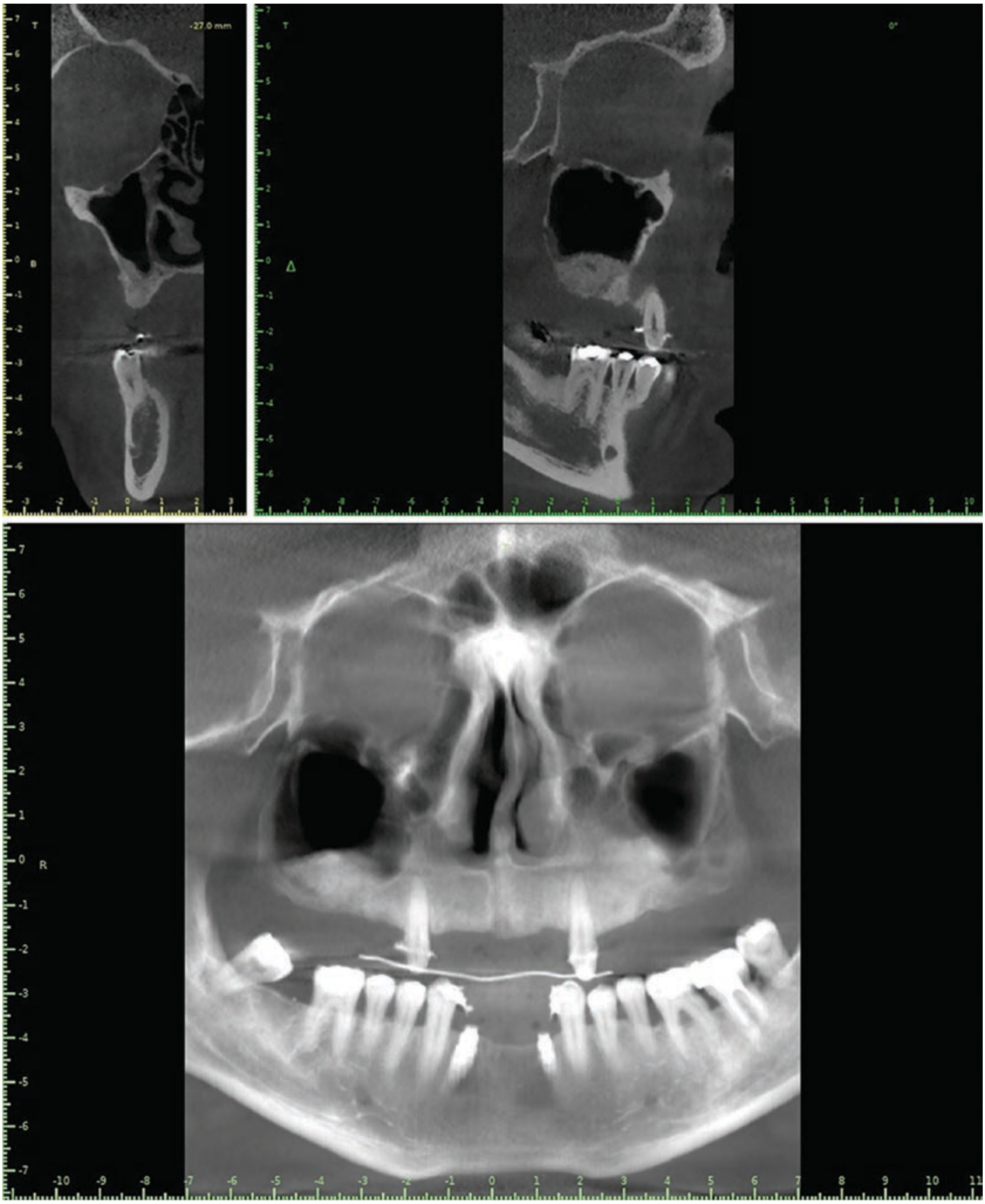

Fig. 1.20 Large FoV is useful to evaluate both arches and contiguous regions. Radiation with these scans is high, so cost-effect ratio should be analyzed carefully