

Practical Guide to 3D Printing and Planning in Orthopedics and Traumatology

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ABSTRACT

Access to 3D planning and printing technology is destined to have a disruptive impact on the surgical practice of Orthopedics. Its advantages include a better understanding of the injuries, greater technical precision, shortened surgical times, decreased blood loss, and less exposure to X-rays. The aim of this publication is to provide a practical step-by-step guide using the treatment of a displaced middle-third clavicle fracture as an example.

Key words: 3D preoperative planning; 3D printing; personalized intraoperative guides; clavicle fracture.

Level of Evidence: V

Guía práctica de planificación e impresión 3D en Ortopedia y Traumatología

RESUMEN

El acceso a la tecnología de planificación e impresión 3D está destinado a tener un impacto disruptivo en la práctica quirúrgica de la Ortopedia y Traumatología. Sus ventajas incluyen una mejor comprensión de las lesiones por tratar, mayor precisión técnica, acortamiento de los tiempos quirúrgicos, disminución de la pérdida sanguínea y menor exposición a los rayos. El objetivo de esta publicación es ofrecer una guía práctica paso a paso tomando como ejemplo el tratamiento de una fractura desplazada del tercio medio de la clavícula.

Palabras clave: Planificación preoperatoria 3D; impresión 3D; guías intraoperatorias personalizadas; fractura de clavícula.

Nivel de Evidencia: V

INTRODUCTION

Three-dimensional printing includes a group of technologies through which it is possible to generate three-dimensional (3D) objects from two-dimensional information.

In the field of medicine, the option of replicating the anatomy in 3D form in electronic devices and then being able to print them offers an enormous possibility to understand the injuries to be treated and plan the procedures.^{1,2}

The applications of this technique in the field of Orthopedics and Traumatology include diagnosis, surgical planning, creation of intraoperative guides, creation of personalized implants, surgical training, printing of orthoses and prostheses, and bioprinting.¹⁻⁴

The purpose of this publication is to provide a step-by-step guide to preoperative planning and printing of the model and custom guides. We will use a clavicle fracture osteosynthesis procedure as an example. Some recent publications report on the usefulness of this technique in the treatment of displaced clavicle fractures and their sequelae.⁵⁻⁹

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FROM IMAGING TO 3D PRINTING

The process that ends in the creation of a 3D model has several stages (Figure 1).

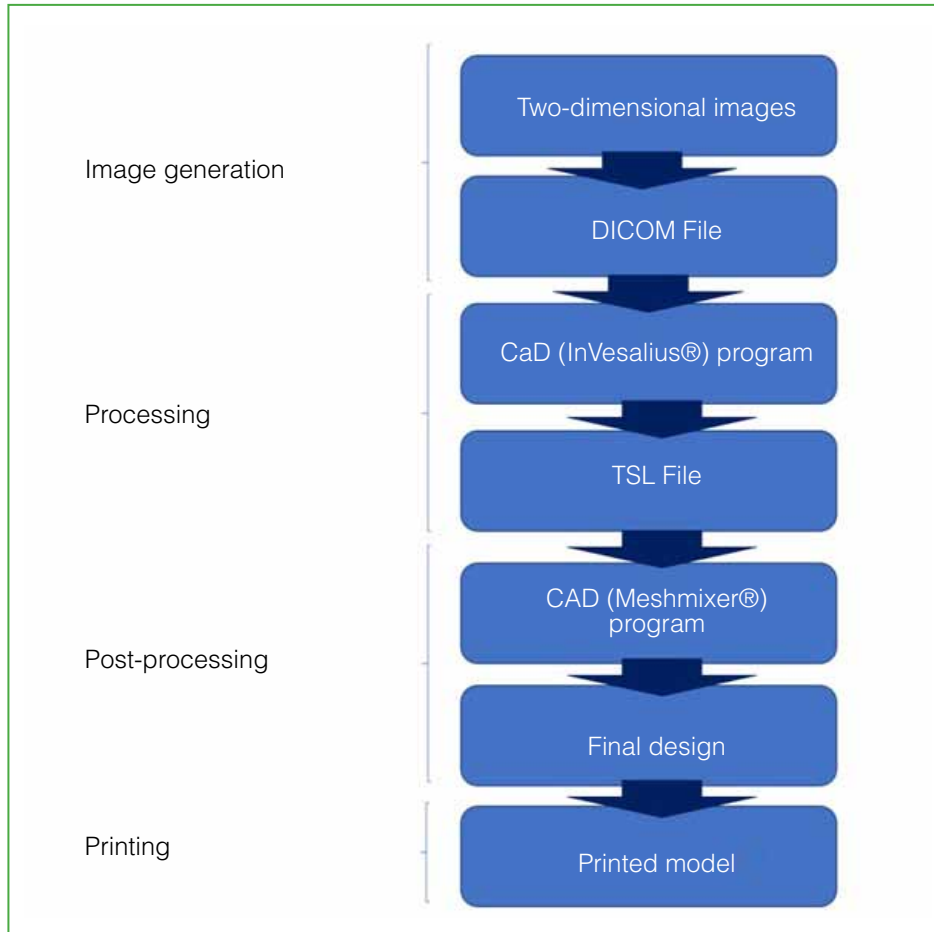


Figure 1. Stages from the generation of images to the finished printed model.

Image generation

The first step is the acquisition of the images. These must meet minimum requirements for resolution, overlap, and thickness of the slices in order to be processed. In the field of Orthopedics and Traumatology, computed tomography (CT) studies are usually used, although ultrasound and magnetic resonance imaging could also be used.² In the latter, the resonator must be configured appropriately so as not to lose resolution.

The information generated by the CT is transferred to our computer using a DICOM file. This is a standardized communication protocol between information systems and, at the same time, a medical image storage format developed by the American College of Radiology in association with the National Electrical Manufacturers Association of the United States.

This DICOM communication language standardizes the format of images from different equipment (CT, MRI, ultrasound) making it compatible with other devices.

Processing: how to convert DICOM files into 3D images?

The transformation and design of the images are performed with programs for the reconstruction of CT and MRI images. These are known as CAD (Computer-Aided Design) programs. They allow the transformation of the original DICOM file into an STL file. A good example of this type of software that is responsible for stacking the image slices is the InVesalius® program. It can be downloaded free of charge from the web¹⁰ and used with both Mac® and Windows®. Another option is the Horos® program, but in this case, it is specific to Mac®. It can be downloaded for free from the web.¹¹ Another very popular option is the 3DSlicer® program, also free of charge.¹²

A paid option is the Mimics® program,¹³ which is very versatile, it is approved by the Food and Drug Administration and has the CE mark (European Community).

With these programs, two-dimensional CT images can be transformed into a virtual 3D model. The resulting STL file is a triangle mesh that allows us to define the surface and shape of an object. The smaller the triangles or tiles of that mesh, the higher the resolution of the object and the greater the weight of the file. The acronym STL stands for Surface Tessellation Language or also Standard Triangle Language.

The main steps of this stage are:

a) Importing the images: The first step is to import the DICOM files into the processing program. These files are usually delivered by imaging centers on a compact disc or sent electronically. In the case we have taken as an example, we are able to see the usual CT images through the InVesalius® processing program (Figure 2A).

To process the CT images, the images of the axial slices are selected. There are usually two files, the “soft tissue window” and the “bone window”. The first one, that is, the “soft tissue window”, must be selected (Figure 2B) and imported.

b) Selection of areas of interest (Segmentation): In this step, the bone sectors will be selected to be able to adequately visualize the clavicle and the soft tissue will be discarded. Through a scroll control located on the left of the screen (Figure 2C), the program allows us to limit the selection to bone structures. The selection will be seen in green (Figure 2D).

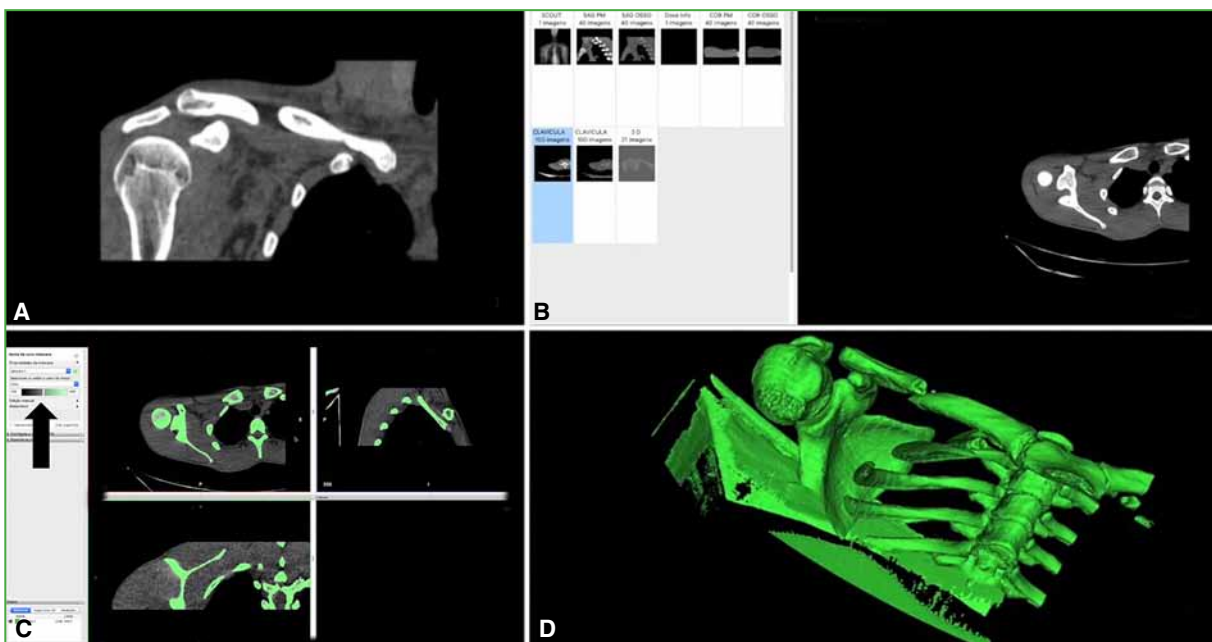


Figure 2. A. Computed tomography image. B. Soft tissue window selection. C. Selection of bone structures (black arrow). D. Selected structures.

It is usually between the 170 to 200-pixel values of the selection window. In this way, all the CT slices will be selected creating a 3D model. The result is a digital 3D model that can be manipulated and oriented in different positions in space (Figure 3).

c) Exporting the 3D model: The final step of the processing stage is to save the file in STL format.

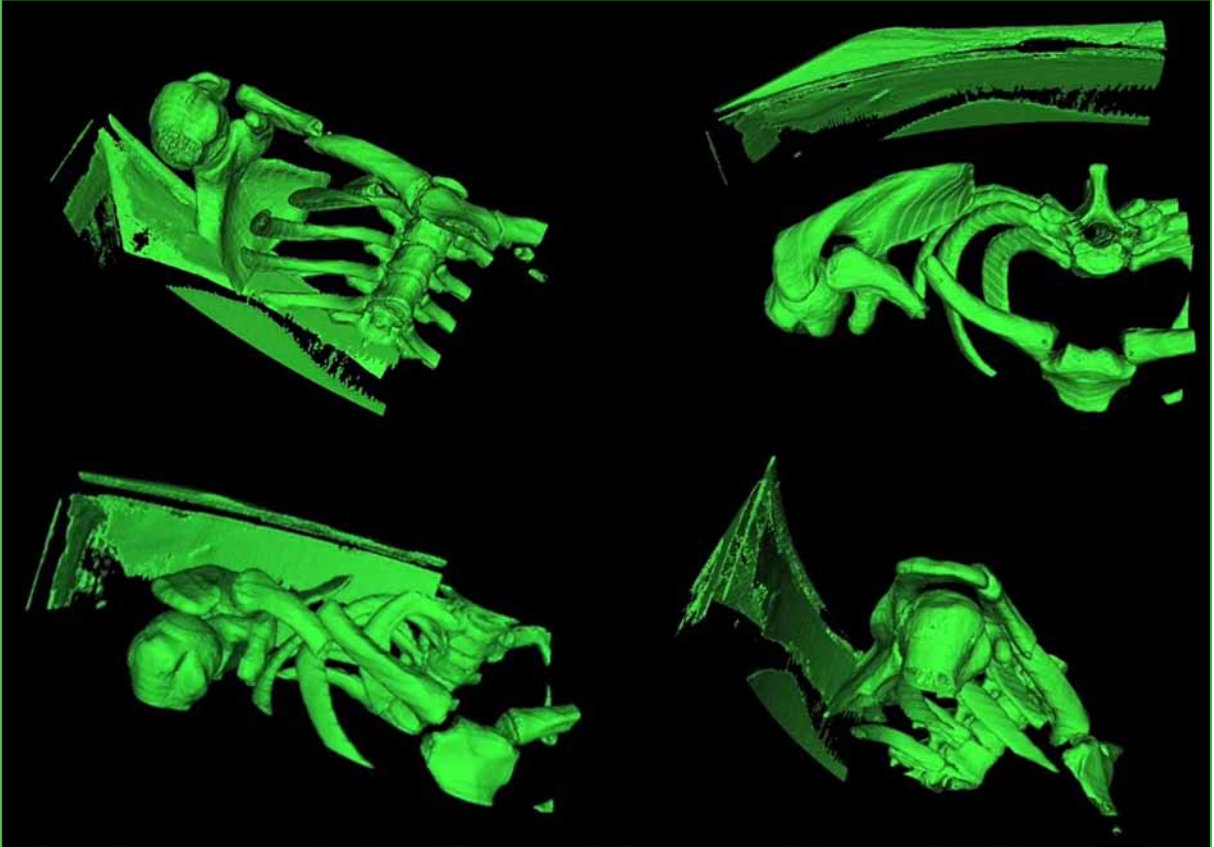


Figure 3. Malleable model in all planes of virtual space.

Post-processing: preparing the model for planning and printing

The STL format defines the geometry of objects, but unlike other file types, it does not include details of color, texture, or physical properties. It is a suitable format for rapid prototyping, which is defined as the group of techniques that allow a scale model to be manufactured. If the goal is to evaluate the images in 3D form on the computer, it is sufficient; but if the 3D model is to be printed or used in a finite element simulation, an additional step called “post-processing” will be necessary. In this step, adjustments are made to improve the quality of the model, its measurements and surgical simulations, and make it ready to be printed.

A good alternative for this stage of the process is the Meshmixer® program, which can also be downloaded free of charge from the web.¹⁴ It has been described as a Swiss penknife that contains a series of tools that allow the finishing of the model.¹⁵ These functions include editing, repairing, and even print feasibility analysis. It can be used with both Mac® and Windows®.

The steps included in this stage are:

- a) Import of the STL file: as in the previous stage, the first step is to import the 3D file.
- b) Selection of the area of interest: in our case, the clavicle.

c) Choice of texture: the program offers the option of choosing between different textures for the surface of the model.

d) Separation of the fragments: each of the fragments must be selected and saved independently to be able to manipulate them freely and to eventually print them (Figure 4). This is a necessary step to print the fragments. To carry out this action, each fragment must be selected sequentially. Use the “Separate” tool from the menu and save them separately.

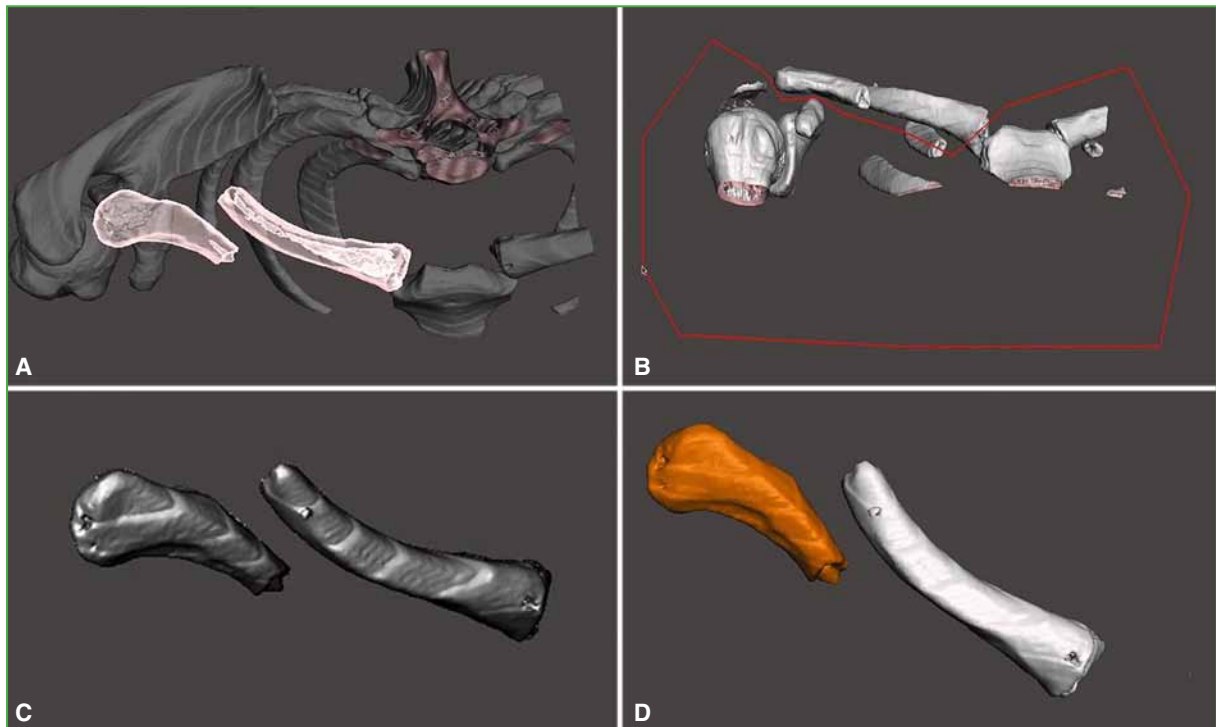


Figure 4. **A.** Selection of the clavicle. **B.** Selection of the area to delete. **C.** Segmentation result. **D.** Selection of the distal fragment.

e) Manipulating the fragments: the “Transform” tool allows you to move one of the fragments (previously selected) in different directions.

f) Reduction of the fracture: the selection of the fragments and the possibility of manipulating them will allow the reduction of the fracture to be carried out. One option in a clavicle fracture is to select the medial fragment and bring it towards distal. The medial fragment is selected and, with the “Transform” tool, the fragment can be manipulated in three dimensions. We can start in the coronal plane and, once a good reduction has been obtained, control the reduction in the axial plane (Figure 5).

g) Simulation of osteosynthesis: to simulate osteosynthesis, it is necessary to start by importing the implant. This can be drawn with a CAD program or obtained from an image database. The osteosynthesis plate is then selected and, with the “Transform” editing tool, it is manipulated in space until it is positioned in the preferred place in relation to the already reduced fractured clavicle. The plate assembly can be rotated on the clavicle and viewed in all planes until proper positioning is achieved (Figure 6). Each of the screws can also be measured (Figure 7).

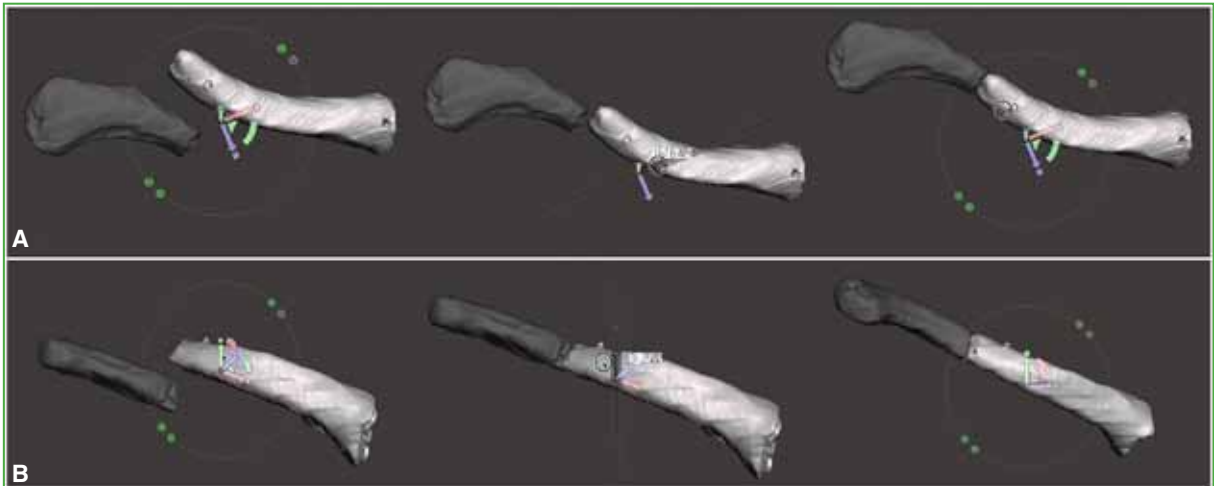


Figure 5. A. Reduction in the coronal plane. B. Reduction in the axial plane.

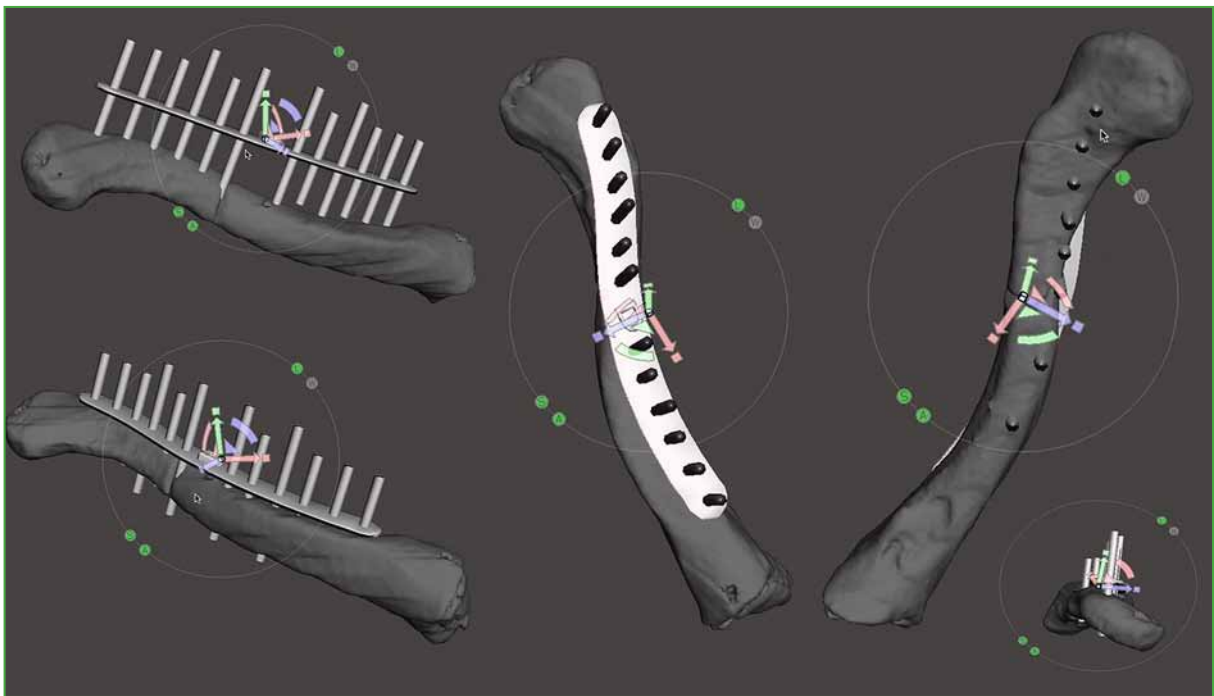


Figure 6. Verification of the positioning of the plate and the screws in different spatial planes.

h) Generation of personalized guides: 3D printing allows the production of specific guides for specific cases. Once the position of the plate and the screws has been defined, the most important thing to generate the guide is the direction of the latter. Therefore, the osteosynthesis plate is selected and erased, revealing the image of the bone fragments and the screws. The images of the medial fragment and the lateral fragment with the corresponding screws are then selected and saved separately, in order to work more comfortably. Once one of the fragments has been selected, we can go to the “Meshmix” tool and select “Primitives”, this section gives the possibility to select between different object shapes; in our case, the most useful is a cube that will be used to build the guide for the screws.

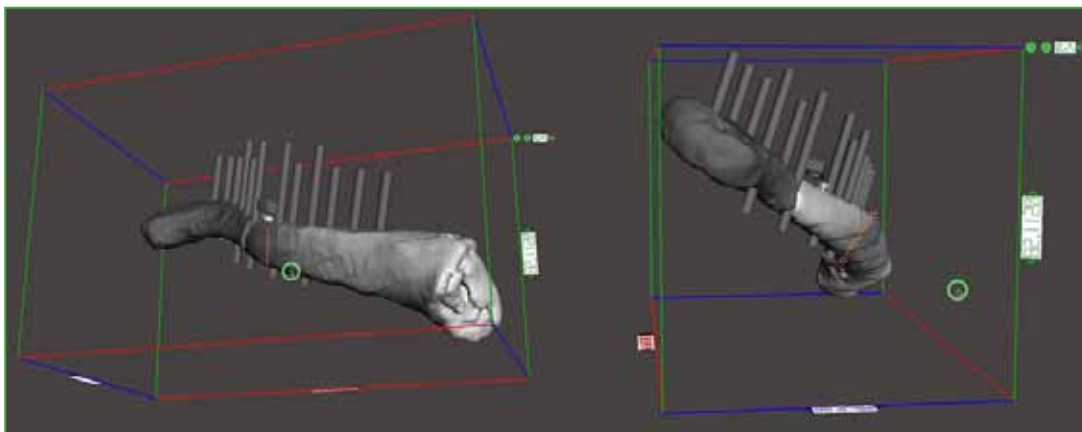


Figure 7. Measurement of the length of the screws.

Once selected, the cube is positioned on the clavicle including the screws whose guide we are interested in making (Figure 8A) and “Create new object” is selected. Then “Edit” and “Transform” are selected to be able to give the desired shape to the guide. This way we can define the exact position and direction of the selected screws. In the case of the example, two screws close to the fracture site are selected, considering that, by having their exact position with respect to the plate, the positioning of the rest of the screws is guaranteed (Figure 8B).

The next step is to select and delete the image of the clavicle using the “boolean difference” tool. In this way, the image of the guide with the screws will be isolated (Figure 8C). The next step is to remove the image of the screws with the same “boolean difference” tool and the guide will be finished (Figure 8D).

The Meshmixer® program offers this simple alternative to making a guide, but there are much more complex and detailed options.

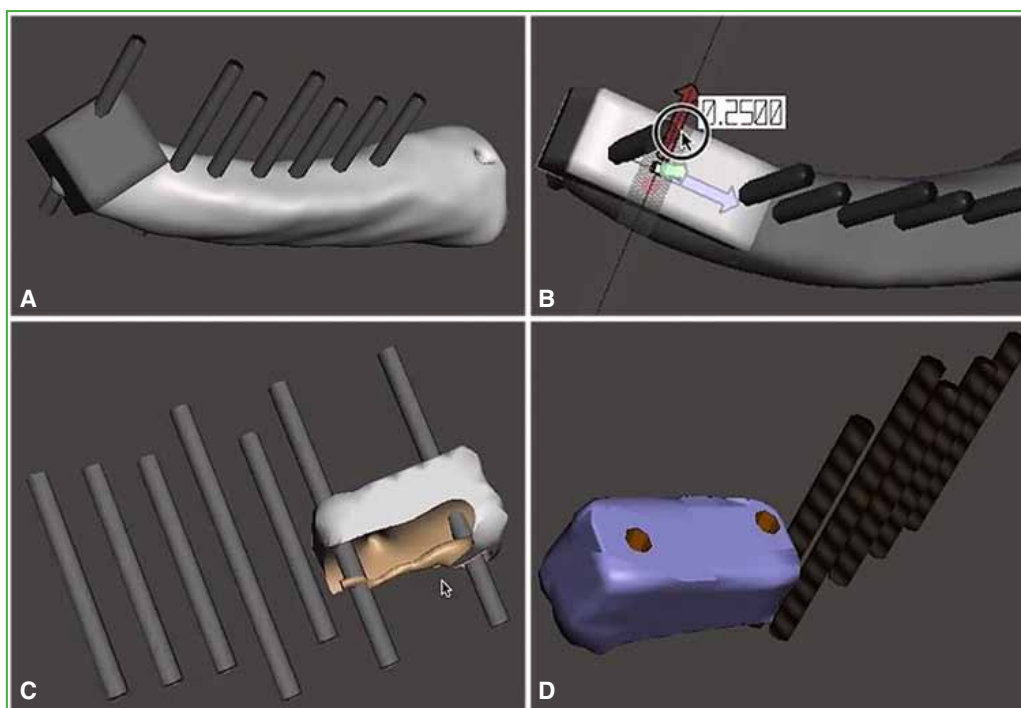


Figure 8. Custom guide design. **A.** Basic geometric figure. **B and C.** Guide design including two screws. **D.** Final image of the guide.

Printing

When necessary, the final step will be the printing of the model. In this case, there will be a clearer 3D vision and the tactile sensation will be added. In addition, having the printed model has great educational utility in the transmission of information to patients.

If the model or the guides are going to be sterilized for intraoperative use, special attention must be paid to the type of material that will be used and if it has a health registration for its use in surgery. Sterilization can alter the properties of models by changing the size of a printed cutting guide and influencing the position of a computer-calculated osteotomy. These factors must be considered and anticipated.

To print the 3D model, it will be necessary to use a slicer program where we will determine the printing parameters, such as layer height, temperature, infill density, speed, among others. Popular slicing software includes Ultimaker Cura®¹⁶ and Slic3r®¹⁷, both of which are free and compatible with Windows®, Mac®, and Linux®.

The 3D printer interprets the digitally provided coordinates in the STL file and converts them into a file called G-Code. It divides the STL file into a sequence of horizontal cross-sections in two dimensions from 25 to 100 µm, depending on the technique used. The object will be printed in consecutive layers starting at the base that reconstruct it from a series of two-dimensional layers. In this way, an exact replica of the original object is printed.¹⁷

The quality of the program and the printer will influence the characteristics of the final product. Another variable to consider is the printing time. This will vary depending on the volume and orientation of the model, as well as the resolution of the printer.² The volume varies depending on the infill that is defined for the object to be printed.

Types of 3D printers

There are two types of technologies to create an object: subtractive and additive. In the first case, the unnecessary material is removed by the printer mimicking the work of a sculptor who works on a block of stone until the final sculpture is obtained. Additive technology, on the other hand, is characterized by adding layer upon layer. The most frequently used mechanism in surgical planning is the additive one because it is cheaper and faster.

There are three major operating mechanisms of additive printers:

- Stereolithography (SLA): The first method created. Ultraviolet light is applied to a container with resin. The light is controlled by a computer and polymerizes the surface of the resin in the container, giving shape to the object. With a descending piston, more resin is exposed to light and the different successive layers are created.

- Selective laser sintering (SLS): Sintering involves making objects by pressing powders or other materials that have previously been heated without reaching fusion. Ultraviolet light is also applied, but in this case, it acts on a powder, instead of on a liquid resin. A layered addition occurs, solidifying the material.

- Fused Deposition Modeling (FDM): In this case, the material used is a plastic filament that passes through a resistance in a nozzle that heats it above 200 °C and melts it to deposit it on a mobile platform. This technology is simpler and more accessible. Its way of working is similar to a piping bag in which the material is expelled by the pressure of the operator's hands and its movement generates the shapes. In this case, the 3D printer has an extruder and engines that determine its mobility and the mobility of the surface on which the material falls, causing the deposition of the material to generate the desired shape in each layer.

FINAL CONSIDERATIONS

The effect that 3D planning and printing will have in medicine has been compared to the advent of radiology.¹ The use of this technology will surely, over time, find its precise role in our practice. We consider it of fundamental importance that the surgeon gets involved in the use and development of these new tools that will be of habitual use in the operating room of the future.

Conflict of interests: The authors declare they do not have any conflict of interests.

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