Use of 3D Printing Models in Orthopedics and Traumatology: Case Series

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ABSTRACT

Introduction: Understanding and treating deformities, defects and complex fractures remains a challenge in the area of orthopedics and traumatology. 3D printing models are used for diagnostics, surgical planning, the manufacturing of intraoperative guides and implants, and surgical training. The objective of our work was to report on a series of cases where 3D printing was implemented in our service and to carry out a narrative review. The case series includes two acetabular fractures, two idiopathic scoliosis, a complex tibial pilon fracture, and a talar fracture. 3D printing models were used for surgery planning, which benefited both the patient and the surgical team. **Conclusions:** With the rise of 3D printing in orthopedics and traumatology, we are able to better understand fractures and complex deformities, as well as improve preoperative planning. The model's production timelines may be delayed, limiting its usefulness in an emergency. There are yet insufficient studies that report substantial benefits to the patient and medical team, such as reduced surgical time, intraoperative blood loss, and radiation exposure.

Keywords: 3D printing; surgical planning; deformities.
Level of Evidence: IV

Uso de modelos de impresión 3D en Ortopedia y Traumatología: Serie de casos

RESUMEN

Introducción: Comprender y tratar deformidades, defectos y fracturas complejas sigue siendo un desafío en el área de la Ortopedia y Traumatología. La aplicación de modelos de impresión 3D incluye el diagnóstico, la planificación quirúrgica, la creación de guías intraoperatorias e implantes y el entrenamiento quirúrgico. Las deformidades y fracturas articulares complejas representan un reto en el tratamiento quirúrgico debido a la complejidad tridimensional. La tecnología de impresión 3D permite simular la anatomía, la reducción de trazos fracturarios, osteotomías, y la dirección y longitud de tornillos. El objetivo de este artículo es comunicar una serie de casos en los que se implementó la impresión 3D y presentar una revisión narrativa. Se describen dos casos de fractura de acetábulo, dos de escoliosis idiopática, una fractura del pilón tibial compleja y una fractura de astrágalo en los que se crearon modelos de impresión 3D para la planificación quirúrgica que resultaron beneficiosos tanto para el paciente como para el equipo quirúrgico. **Conclusiones:** Con el auge de la impresión 3D en el área de la Ortopedia y Traumatología, podremos facilitar el entendimiento de fracturas y deformidades complejas y mejorar las planificaciones prequirúrgicas. El tiempo de producción del modelo puede demorarse y ser una limitación para su uso en urgencias. Aún faltan estudios para evaluar los beneficios significativos para el paciente y el equipo médico, como la reducción del tiempo operatorio, la pérdida de sangre intraoperatoria y la exposición a la radiación.

Palabras clave: Impresión 3D; planificación quirúrgica; deformidades.
Nivel de Evidencia: IV

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INTRODUCTION

Understanding and treating complex deformities, defects and fractures, particularly joint fractures, continues to be a challenge in the field of Orthopedics and Traumatology. It has been demonstrated that 3D models improve anatomical visualization and surgical planning. However, it is unclear how to best apply the technique and whether it results in superior intraoperative and postoperative outcomes.[1]

This article aims to present a series of cases in which 3D printing was implemented in our Department and a narrative review of its use in the area of Orthopedics and Traumatology.

History and characteristics of 3D printing

The origin of 3D printing dates back to 1859, when François Willème developed the first 3D scanning technology in France, which he called “photo sculpture”. Using photographs taken at 360° and with the help of a pantograph, the outlines of the model were drawn to the desired scale, then profiles were cut out and added together to form the three-dimensional sculpture. In 1892 in the United States, Joseph Blanther patented a technology that produced 3D topographic maps using a layering method similar to today’s printers.[2] Finally, in 1984, Charles Hall filed the first patent for a 3D printer entitled “Apparatus for production of 3D objects by stereolithography”, which was the world’s first 3D printer.[3] The first reported use in Orthopedics was in 1999 as a preoperative planning aid for complex spinal surgery.[4]

To use the 3D printer, a high-resolution CT scan of the deformity, fracture or defect is required. The computer-aided design program creates a digitized representation of an object that is then converted into a stereolithography (STL) file. STL files “cut out” the digitized model created by the design program, which allows the 3D printer to print the object layer by layer. The most commonly used 3D printing materials are titanium, acrylonitrile butadiene styrene, and polylactic acid.

Three types of printing methods have been described:

1. Stereolithography: the first method to be created. Ultraviolet light is applied to a cuvette containing resin. The light is controlled by a computer and polymerizes the surface of the resin in the cuvette giving shape to the object. Using a descending piston, more resin is exposed to the light and successive layers are created.

2. Selective laser sintering: it produces objects by pressing powders or other materials that have been previously heated without melting. Ultraviolet light is used as well, however, this time it acts on a powder instead of a liquid resin. Solidifying the material results in a layered addition.

3. Fused deposition modeling: in this case, the material used is a plastic filament that passes through a resistor in a nozzle that heats it to over 200 °C and melts it to deposit it on a moving platform. This technology is simpler and more accessible.

Orthopedics and Traumatology Applications

The application of 3D printing in the medical field includes diagnostics, surgical planning, creation of intraoperative guides and implants, and surgical training.

Regions of the body with complex anatomy, such as the pelvis or spine, are better understood with 3D printing and its use can significantly improve learning.[5] It is useful, for example, for planning osteotomies in cases of severe spinal deformities, as well as for determining the trajectory of pedicle screws.[6] In complex fractures, surgeons can use the fractured 3D model to simulate the reduction technique and use the uninjured 3D model to optimize plate selection.[7]

Case reports indicate that surgical planning can reduce surgery duration, leading to less blood loss and radiation exposure, ultimately improving patient and surgical team safety.

In addition, 3D models were found to improve the patient’s understanding of the fracture and communication with the physician, resulting in better compliance with postoperative rehabilitation.[8]

The following is a description of a series of cases from our Service in which 3D printing technology was implemented.

CLINICAL CASE 1

A 20-year-old male was admitted to the Emergency Department after suffering a motorcycle accident. He had a fracture of the left acetabulum in both columns, with a simple line in the posterior column and an iliac line in the anterior (AO classification 6.2-C1.2) (Figure 1A).

Reduction and osteosynthesis was performed with two 3.5-mm reconstruction plates, a 6.5-mm cannulated screw and a one-third tubular plate. The 3D-printed model was designed for surgical planning, and surgery was performed four days after the fracture (Figures 1B and C).

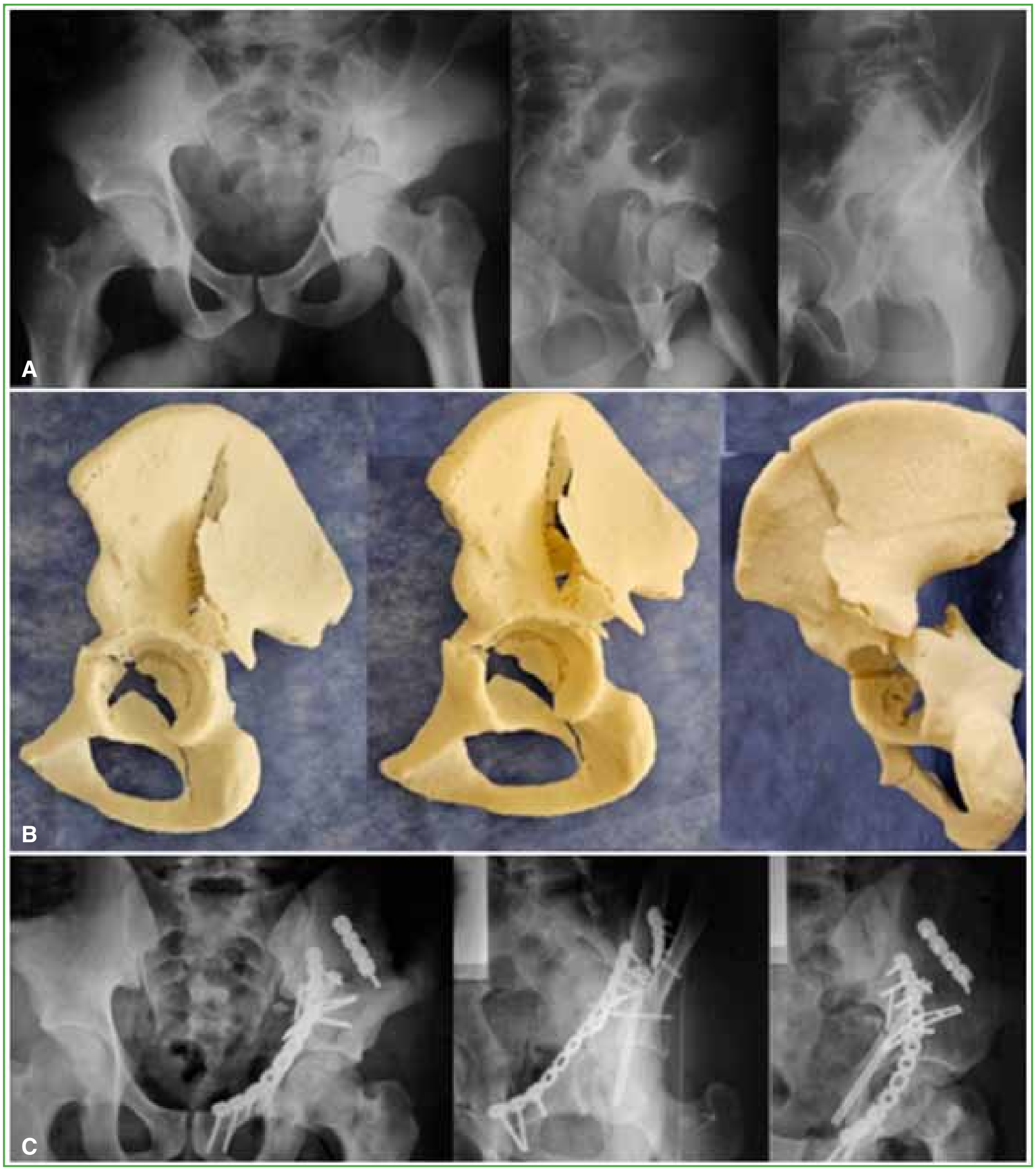

Figure 1. Clinical case 1. **A.** Radiograph. Fracture of the right acetabulum with involvement of both columns. **B.** 3D printed model. **C.** Control radiographic study in the immediate postoperative period.

The replica of the fractured acetabulum provided an accurate representation of the volume, size and orientation of the bone fragments of the compromised columns, and it was used to measure the length of the plates and their respective screws. The surgical team reported that surgical time was optimized and that there were no complications in the placement of the implants.

CLINICAL CASE 2

A 16-year-old male was admitted to the Emergency Department after a motorcycle accident. He had a juxtatectal transverse fracture of the right acetabulum with a high T-shaped line in the anterior column (AO classification 6.2-B.2) (Figure 2A). Reduction and osteosynthesis was performed with a 3.5-mm reconstruction plate and a 6.5-mm cannulated screw, and the 3D printing model was designed for surgical planning. Surgery was performed nine days after the fracture (Figures 2B and C).

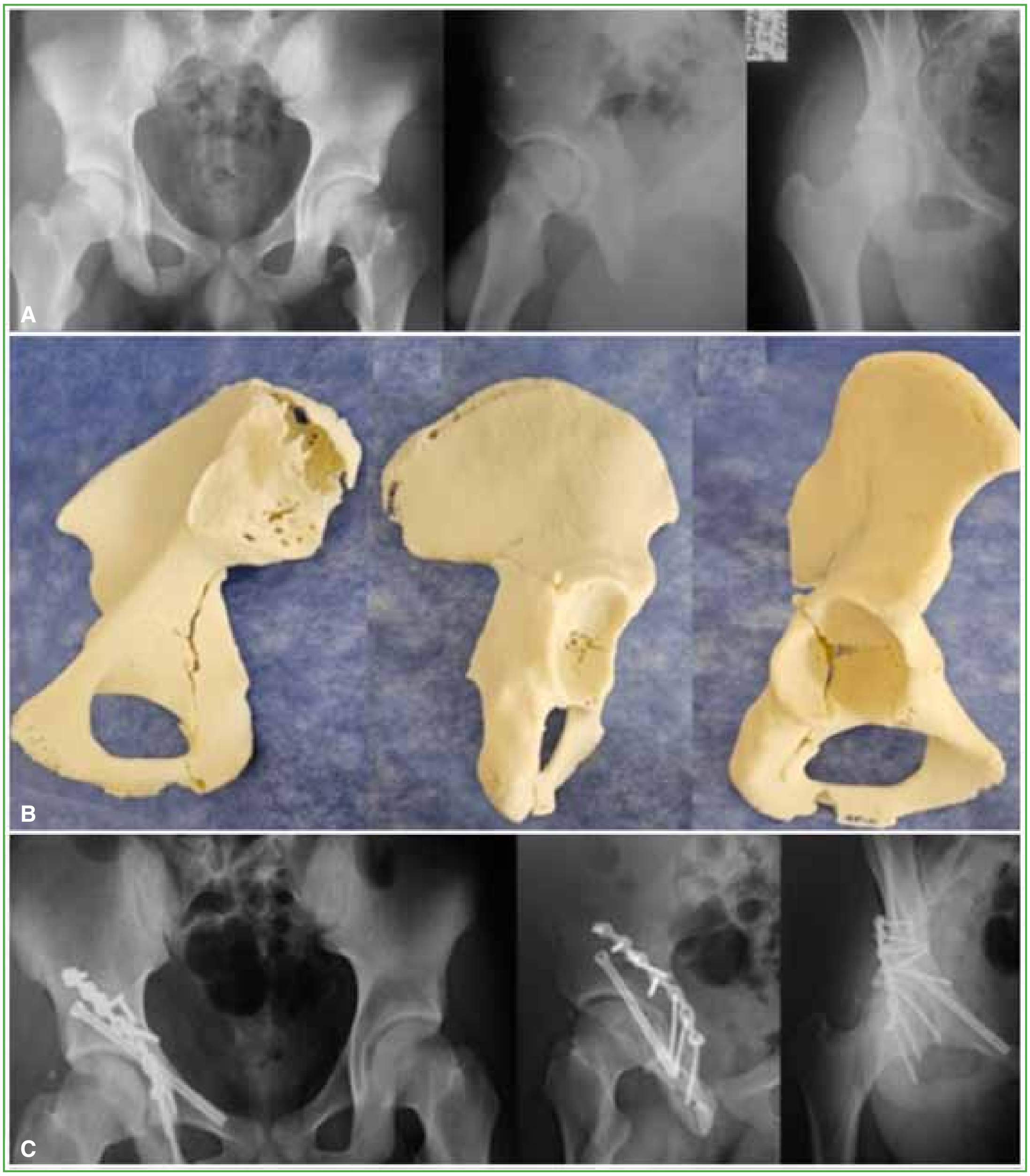

Figure 2. Clinical case 2. **A.** Radiographic study. The T-shaped fracture line in the right acetabulum can be seen. **B.** 3D printed model. **C.** Control radiographic study in the immediate postoperative period.

Surgical planning with the 3D model allowed accurate assessment of the fracture anatomy and planning of the reduction. During the operation, it assisted the surgical team in following the fracture anatomy and placing the implants correctly.

CLINICAL CASE 3

A 39-year-old woman was admitted to the Emergency Department after a fall from height (2 meters). She had a right tibial plafond fracture with a complete intra-articular, complex metaphyseal-complex epiphyseal line (AO classification 4.3-C3) (Figures 3A and B).

In the Emergency Department, reduction and fixation with an external fixator were performed, and reduction and osteosynthesis with two anatomical plates for the distal end of the tibia were proposed as the definitive treatment. Due to the evolution of the soft tissues, this surgery was performed two weeks after the fracture, with previous planning in a 3D model (Figures 3C and D).

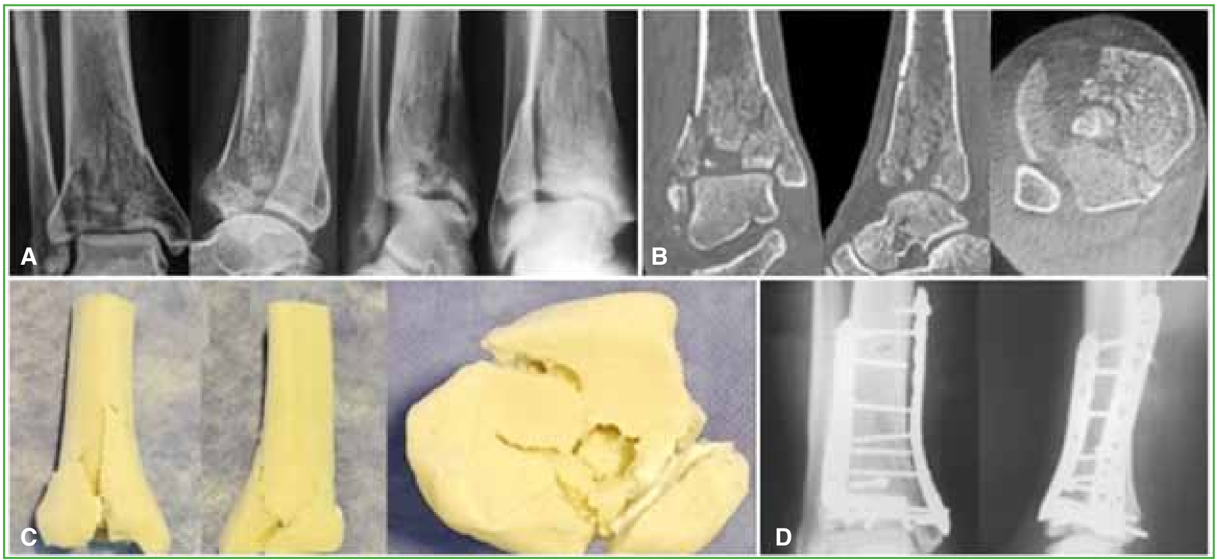

Figure 3. Clinical case 3. Radiographic and tomographic studies. The fracture of the right tibial plafond, with a complex epiphyseal-complex metaphyseal line, can be seen. **C.** 3D printed model. **D.** Radiographic images in the immediate postoperative period.

The use of the 3D model made it possible to examine the fracture lines in three dimensions and plan the reduction; to see the articular subsidence with greater precision, and to contemplate the use of a bone graft, thus optimizing surgical time frames. On the other hand, it was useful for discussing the condition and surgical procedure with the patient.

CLINICAL CASE 4

A 26-year-old woman was admitted to the outpatient clinic for idiopathic scoliosis, with a structural main thoracic curve at T3-L1 of 54° and a 30° secondary lumbar curve (Lenke IA+ classification) (Figures 4A and B).

Reduction and selective arthrodesis of the main curve was indicated. A 3D impression model was created for surgical planning (Figures 4C-E). The 3D model allowed us to better understand the deformity in three dimensions and to explain the surgery to the patient and family members. The intraoperative use allowed us to visualize the screws' entry point and orientation more clearly. There were no complications during surgery, nor loss of evoked potentials.

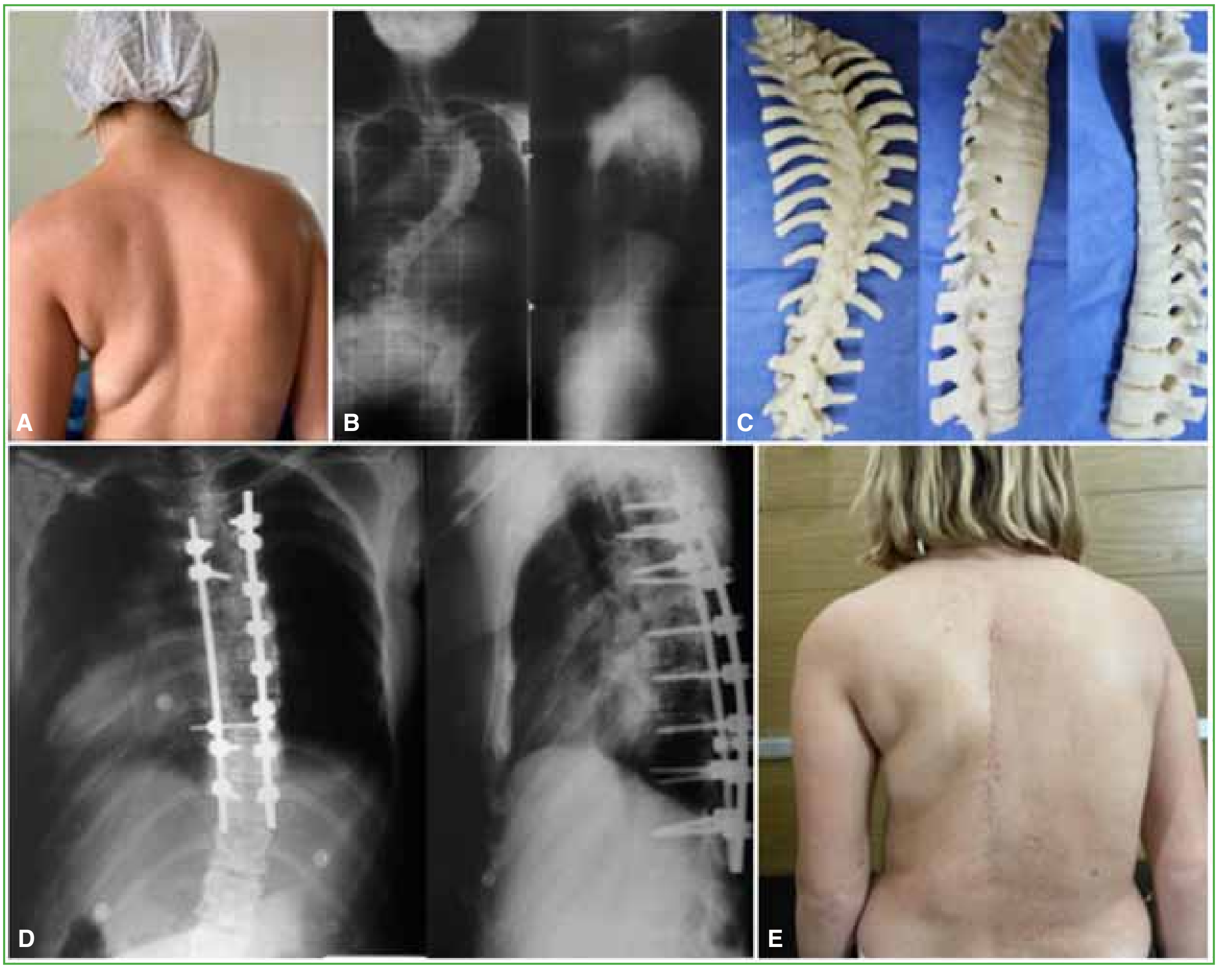

Figure 4. Clinical case 4. **A.** Clinical image of the patient with idiopathic scoliosis. **B.** AP and lateral radiographs of the spine. **C.** 3D printed model. **D.** Radiographic control in the immediate postoperative period. **E.** Clinical image 21 days after surgery.

CLINICAL CASE 5

A 19-year-old female with idiopathic scoliosis, with a main thoracic curve of 61° at T6-L1 and a secondary lumbar curve of 40° at L2-L5 (Lenke classification 1B+) (Figures 5A and B). Selective arthrodesis of the main curve was indicated and a 3D impression model was created (Figures 5C-E).

We used the model to illustrate the spinal defomity to the patient and her family, as well as explain the surgical procedure and its complications. At the same time, we used the design tool to identify the entry points and trajectories of the pedicle screws, as well as create a smaller printed model with holes for pin placement to aid us throughout the surgery. The surgical procedure has not yet been performed.

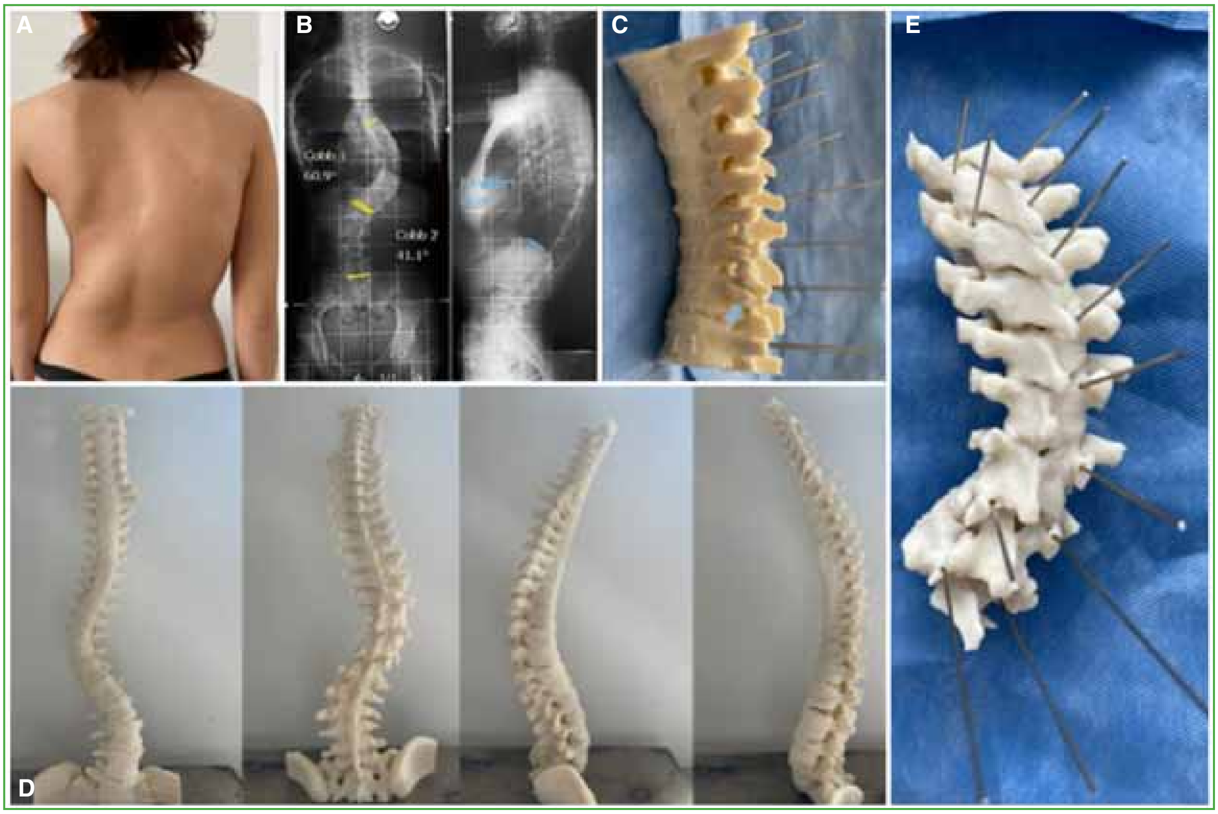

Figure 5. Clinical case 5. **A.** Clinical image of the woman with idiopathic scoliosis. **B.** AP and lateral radiographs of the spine. **C-E.** 3D printed models showing the spinal deformity in the three planes and the simulation of the screw trajectory.

CLINICAL CASE 6

A 22-year-old woman was admitted to the emergency department after an equestrian accident. An open fracture-dislocation of the right talus was found and mechanical-surgical debridement was performed, followed by reduction and immobilization with a short leg splint. Radiographs and a CT scan revealed a fracture of the right talus with a complex line involving the neck, compatible with type III of the Hawkins classification (Figures 6A and B).

Initially, reduction and osteosynthesis with a mini fragment plate were proposed because complementary studies revealed comminution in the lateral and posterior walls. However, when the 3D printed model was available and the surgical steps were planned, it was discovered that the fracture line in the posterior wall was not comminuted; therefore, the approach was adjusted to use two 3-mm and two 4-mm cannulated screws (Figures 6C and D).

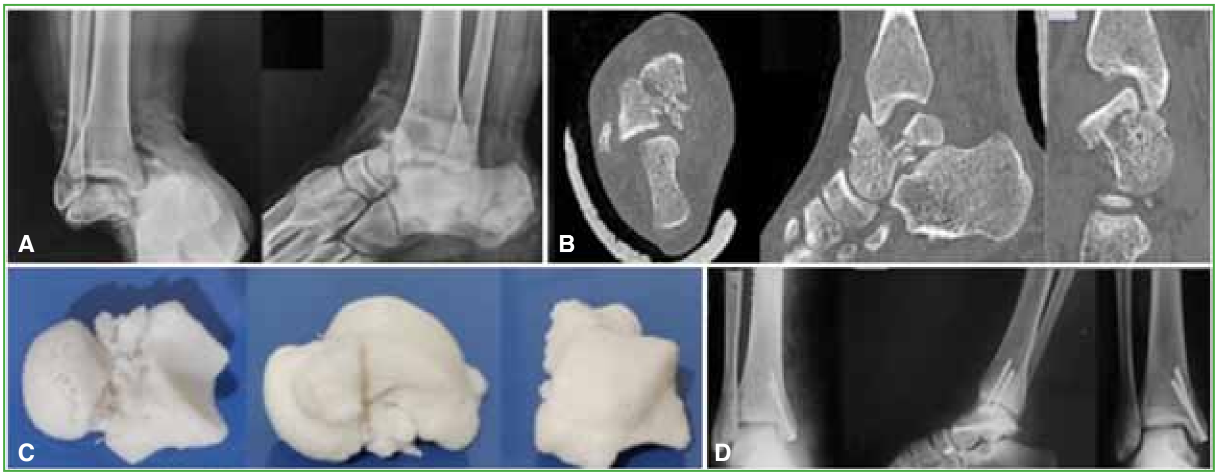

Figure 6. Clinical case 6. Radiographic and tomographic studies. Subtalar fracture-dislocation of the right foot with a neck line compatible with type III of the Hawkins classification. **C.** 3D printed model. **D.** Radiographic control in the immediate postoperative period.

DISCUSSION

Scoliosis deformities and complex articular fractures, such as those of the tibial plafond and acetabulum described in this article, pose a surgical challenge due to their three-dimensional structural complexity. 3D printing technology allowed us to perform an accurate simulation of the anatomical changes in real size, which facilitated planning with a degree of precision that is not possible with conventional instruments, in addition to deepening anatomical knowledge. The reduction achieved was more precise because we had a three-dimensional replica of the affected region.[9]

It is clear that using 3D models reduces surgical times, but image processing and printing require several hours. The time necessary to create it ranges between 5 to 72 hours, which may limit its application in an acute trauma scenario, in addition to requiring economic, human, and technological resources.

Currently, there are few prospective and comparative scientific studies examining the relationship between the use of 3D printing and the considerable benefits for the patient and surgical team, such as shorter surgery times or fewer intra-operative complications. However, we believe that the application of 3D printing in Orthopedics and Traumatology will result in significant advancements in the field.

CONCLUSION

As our experience illustrates, the rise of 3D printing in Orthopedics and Traumatology allow us to better understand complex fractures and deformities, as well as improve pre-surgical planning. There are yet insufficient studies evaluating the significant benefits of this tool for both the patient and the medical team, such as reduced surgical times, intraoperative blood loss, and radiation exposure.

Conflict of interests: The authors declare no conflicts of interest.

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