

# THE USE OF 3D PRINTED MODELS FOR KNEE REVISION SURGERY

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## SUMMARY

**Background:** Preoperative planning for complex primary and revision knee arthroplasty requires precise anatomical understanding, particularly in cases involving significant bone loss, osteolysis, or tumor pathology. While two-dimensional imaging and three-dimensional (3D) virtual reconstructions provide essential kinematic-geometric data, they may not fully translate into surgical execution for severe deformities or pelvic discontinuity.

**Objective:** This article evaluates the application of 3D-printed anatomical models in preoperative planning for complex knee revision surgery to improve component sizing accuracy and intraoperative efficiency.

**Key Points:** Utilizing high-resolution CT scans and DICOM data, 1:1 scale polylactic acid models are produced via fused deposition modeling. These models allow surgeons to perform "dry run" simulations using actual instrumentation to preselect implant sizes, stem lengths, offsets, and the necessity of augments, such as cones or sleeves. Clinical cases demonstrate that these models accurately replicate bony landmarks and defects, facilitating the identification of potential intraoperative complications, such as iatrogenic fractures during cone placement. Although the models lack soft tissue representation and possess different thermal properties than human bone, they facilitate a reduction in the number of required surgical instrument trays and optimize the surgical workflow.

**Conclusion:** Integrating 3D-printed models into revision knee surgery planning enhances surgical precision and confidence. By allowing for the pre-assembly of components and the elimination of unnecessary instrumentation, this technology offers significant potential for reducing operative time and perioperative costs while serving as a valuable educational tool for surgical training.

## KEYWORDS

Arthroplasty, Replacement, Knee; Reoperation; Printing, Three-Dimensional; Surgery, Computer-Assisted; Models, Anatomic

## INTRODUCTION

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Preoperative planning is a key issue in orthopaedic surgery as it requires precise and specific knowledge of each patient's anatomy, especially for complex primary cases and revision arthroplasty. Two-dimensional (2D) images often cannot provide a comprehensive understanding of severe deformities and it can be difficult to plan details in advance, especially in cases of significant bone loss due to osteolysis or bone tumour pathology. Recently, orthopaedic surgeons have found that having a 3D printed model of the patient's anatomy can be useful in predicting certain steps in surgical treatment.

## VIRTUAL 3D MODELS

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Currently, 3D virtual reconstructions of the knee are used for computer-assisted surgery (CAS) in total knee arthroplasty (TKA), where the systems provide kinematic-geometric data of each patient for the pre-operative and intraoperative periods. Then, after the treatment time, surgeons can benefit from the information collected thanks to a communication system between the sensors positioned on the patient and the navigation system, which consists of an infrared camera coupled with transmitters [1-2]. The navigation systems are developed to achieve optimal accuracy in the positioning of prosthetic components and to increase the reproducibility of the surgery. Similarly, virtual 3D reconstructions of the knee are used in robotic surgery for knee arthroplasty [3-5]. Computer-aided systems can improve the accuracy of defining anatomical landmarks and the precise location and orientation of bone cuts [6].

## 3D PRINTED MODELS

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The use of 3D printed models is gaining popularity in medicine and surgery. 3D printing is a type of manufacturing process in which a 3D object is created from a digital model [7]. In orthopaedic surgery, the 3D printing technique can help to understand complex anatomy, anatomical defects but also to produce custom-made implants that are perfectly adapted to a specific patient and can provide support during procedures [8]. Today, the most common use of 3D printing technology is patient-specific instrumentation (PSI), which was designed to improve the accuracy of preoperative planning and intraoperative implant positioning in total knee arthroplasty (TKA) [9-11]. Although still under debate, it may have a role in supporting operations, particularly in complex cases [12, 13].

Outside of PSI, applications of a real 3D printed model are limited to data collection and study of knee morphology and kinematics, such as variations in internal/external rotation angle during walking or monitoring of patellar tracking during kneeling [14, 15]. In other cases, 3D technology has been suggested for the implementation of 3D printed instrumentation for routine use in total knee arthroplasty [16], based on a virtual reconstruction of the knee. The ability to predict the precise sizing of implant components for total knee arthroplasty can have several advantages in the operating room, in terms of simplifying surgical steps and reducing the number of instrument trays needed [17]. Finally, the application of 3D printed models has been suggested for complex cases, such as periprosthetic femoral fractures (FFP) around a tumour prosthesis or multiaxial osteotomies [18].

## 3D MODELS FOR REVISION SURGERY

The development of three-dimensional (3D) printing technology is proposed for better planning of complex revision surgery. Regarding preoperative revision planning, conventional radiographs often underestimate the degree of bone loss, while computed tomography (CT) can provide additional details, but the surgeon is limited in his or her ability to clinically translate this information into surgical execution (Fig. 1).

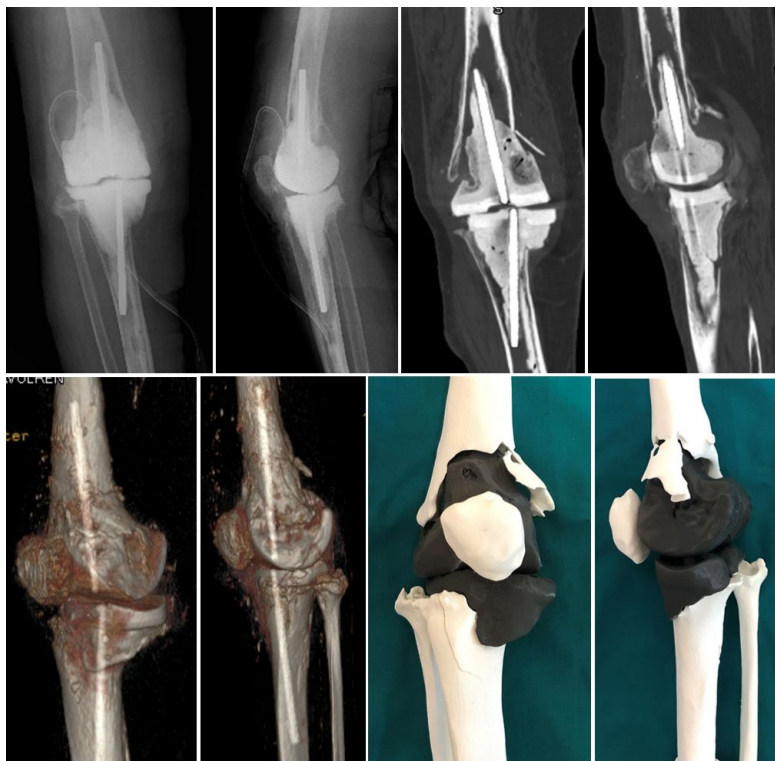


Figure 1: Starting from conventional knee X-rays, through CT scans and virtual 3D scans, the 3D printed model helps the surgeon to get a concrete idea of the anatomy and bone stock.

3D technology has already been used for complex hip revisions in our department for many years. In a recent published study we compared the diagnostic accuracy between 3D printed model with 3D CT reconstruction for pelvic discontinuity [19] (Fig. 2). For knee revision surgery based on a preoperative CT scan, a 1:1 3D plastic knee model is made, including the cement spacer or implant to be removed in a different colour and separated from the virtual bone (Fig. 3).

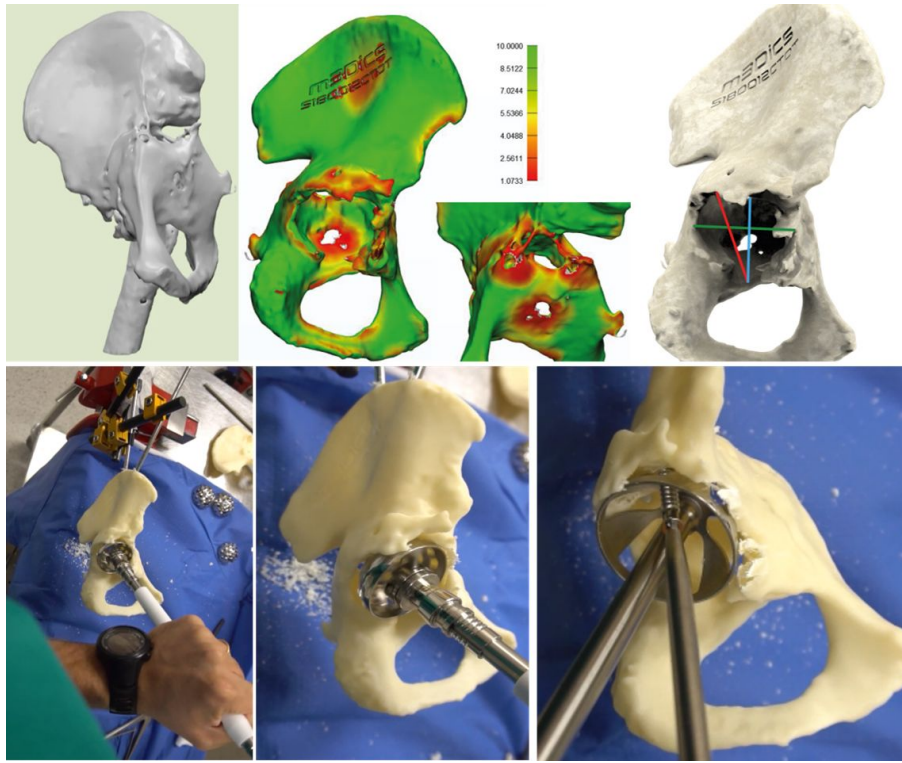


Figure 2: The 3D printed model used for revision hip arthroplasty [19].



Figure 3: Examples of different 3D models for knee revision surgery.

Images in DICOM format (Fig. 4) were processed by using M3DICS medical grade software ([www.medics3d.com](http://www.medics3d.com)).



Figure 4: Images in DICOM format.

The first step is the image processing that provides a 3D virtual model (HA3D™ reconstruction) of the knee, based on high resolution CT scans. It focuses on the reconstruction of bone structures outside the spacer and/or implants. The next step is the printing of the HA3D™ mathematical model into the correlated interactive 3D PDF allowing navigation (Fig. 5).

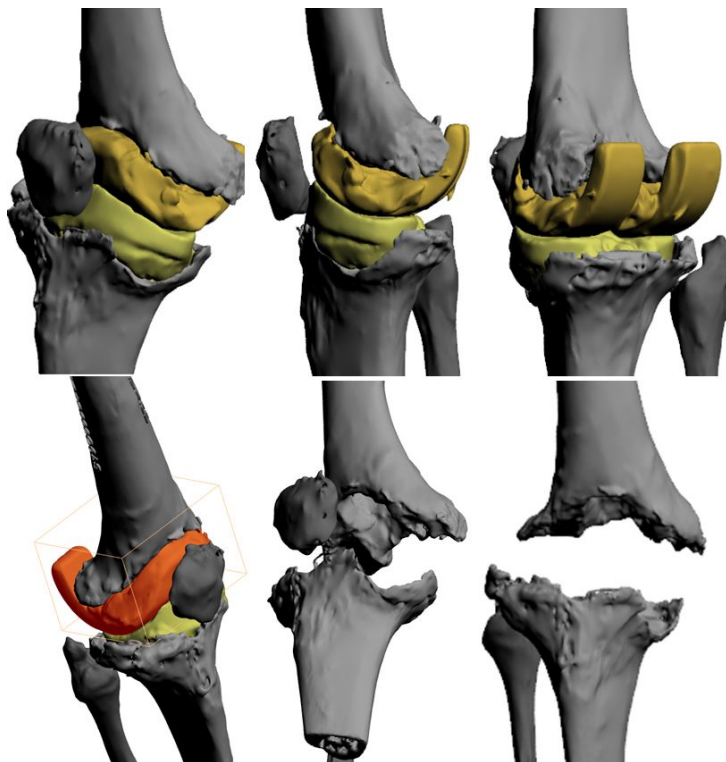


Figure 5: Interactive 3D-PDF for navigation and planning. Metal and cement parts can be removed.

With the HA3D™ model, a complete case report with all relevant measurements is provided. After the validation of the printed project, the model is produced with additive manufacturing technology, in particular FDM (Fused Deposition Modeling) technology. PLA (Polylactic Acid) material is the most commonly used for 3D models (Fig. 6-8).



Figure 6: The 3D model produced with FDM technology and taken to the dry lab for surgical testing.

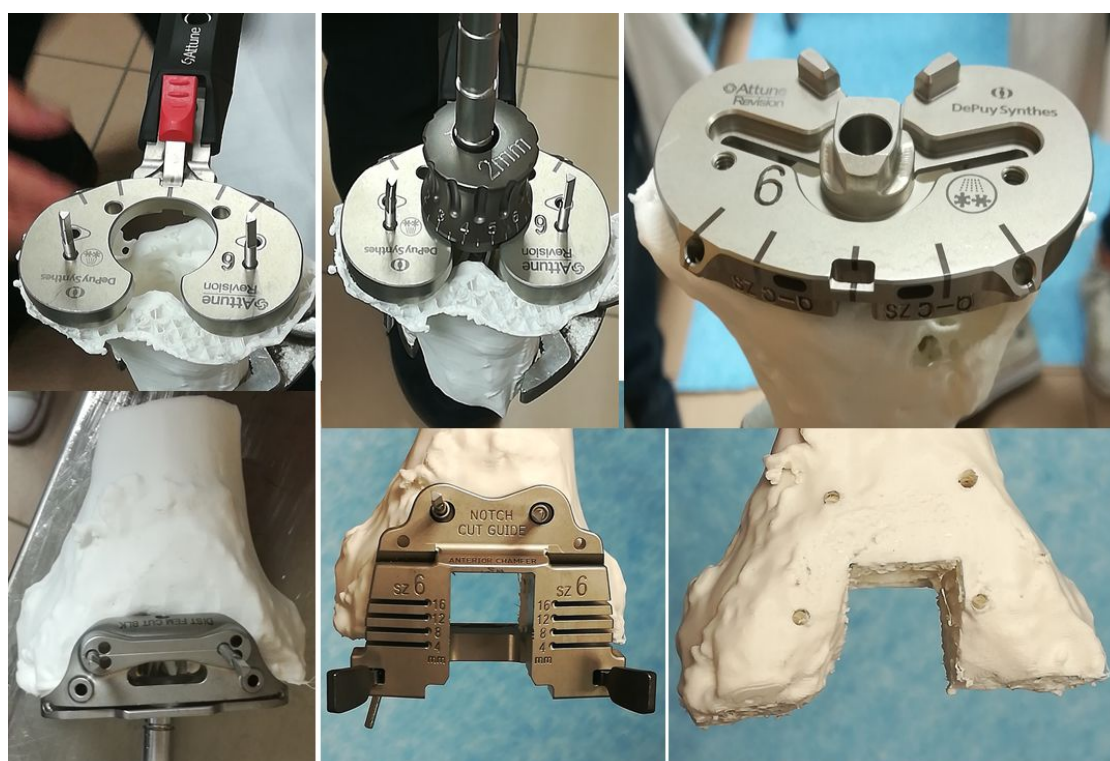


Figure 7: Shows how real surgical instruments can be used on the 3D model for cutting and positioning tests.



Figure 8: Preparation of the tibia. The alignment can also be checked as the model represents the entire shaft.

A few days before surgery, the surgeon and nurse can "implant" the real prosthesis and perform the upcoming procedure (fig. 6-8) using real instrumentation on the newly produced 3D model to determine the size of the components (fig. 9) and the need for wedges or cones, if necessary, to restore the correct position and rotation of the joint axis.

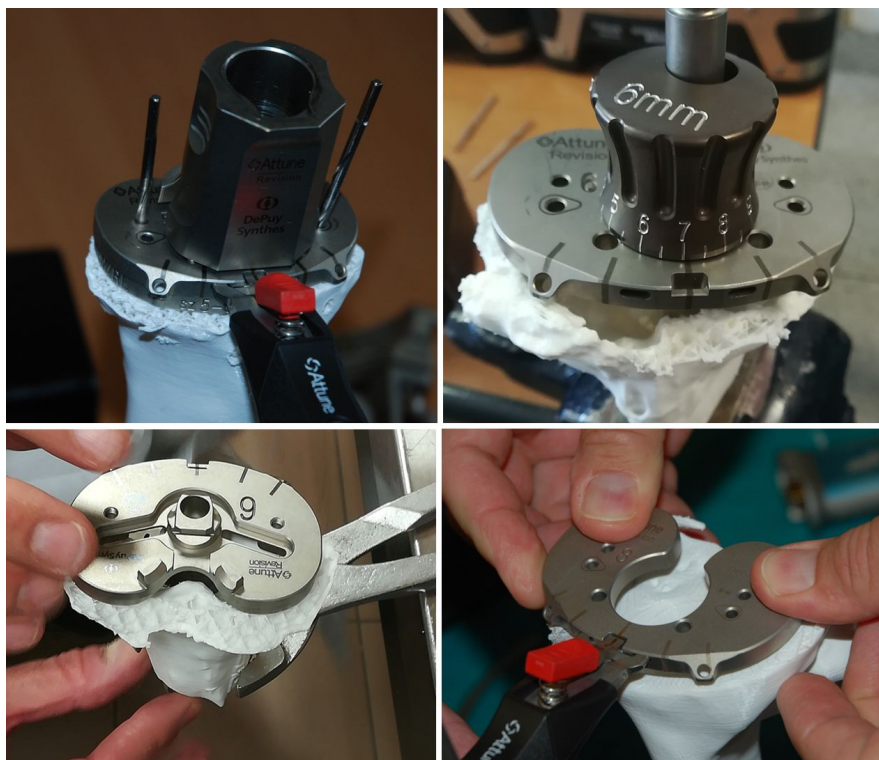


Figure 9: Detail of several tibial preparations: the tibial tray is useful for trimming, offset and rotation.

During implantation all the different options for stem length and offset, spacers, blocks and sizes can be preselected and every feature of the implant is already known and can be assembled. In many cases the preop plan fits very well with the final intraoperative solution (fig. 10-12).

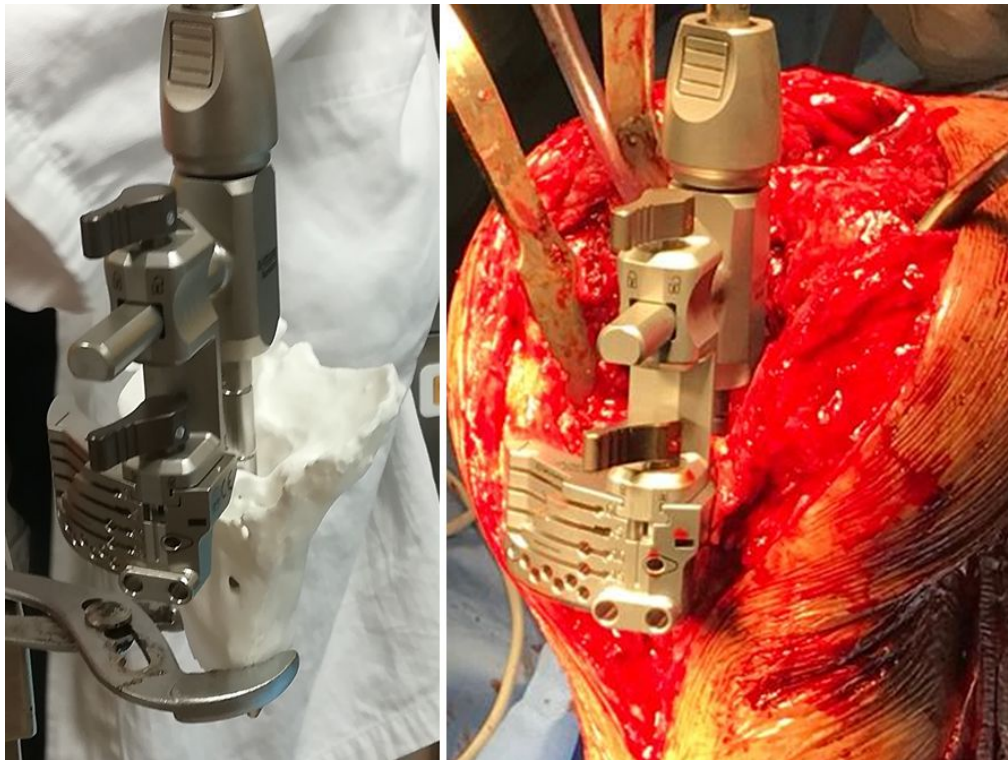


Figure 10: Correspondence between the tibia trial and the actual surgery

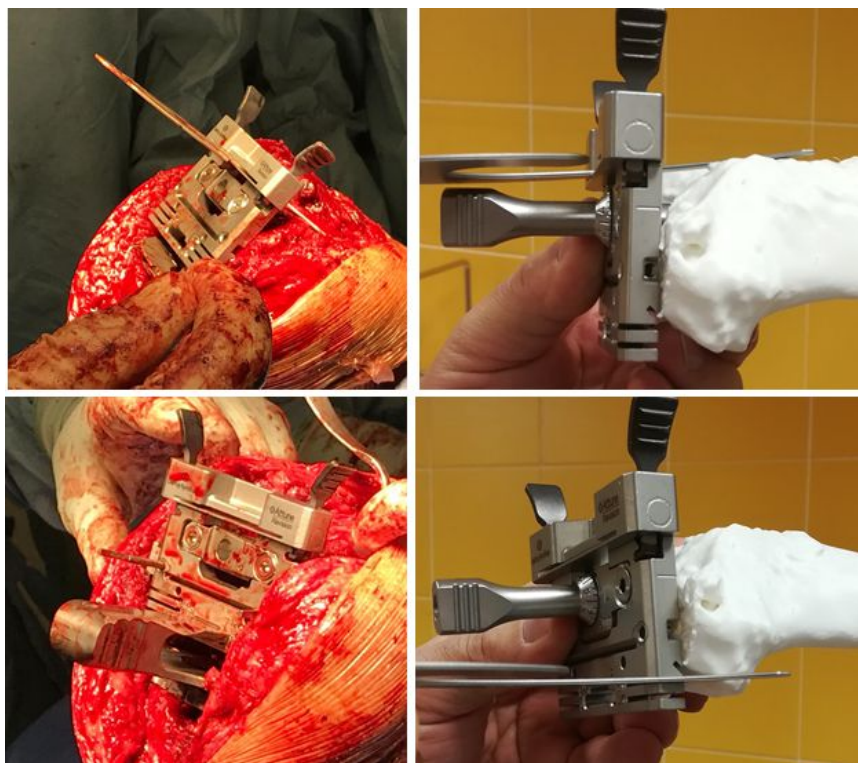


Figure 11: Correspondence between the femur trial and the actual surgery.

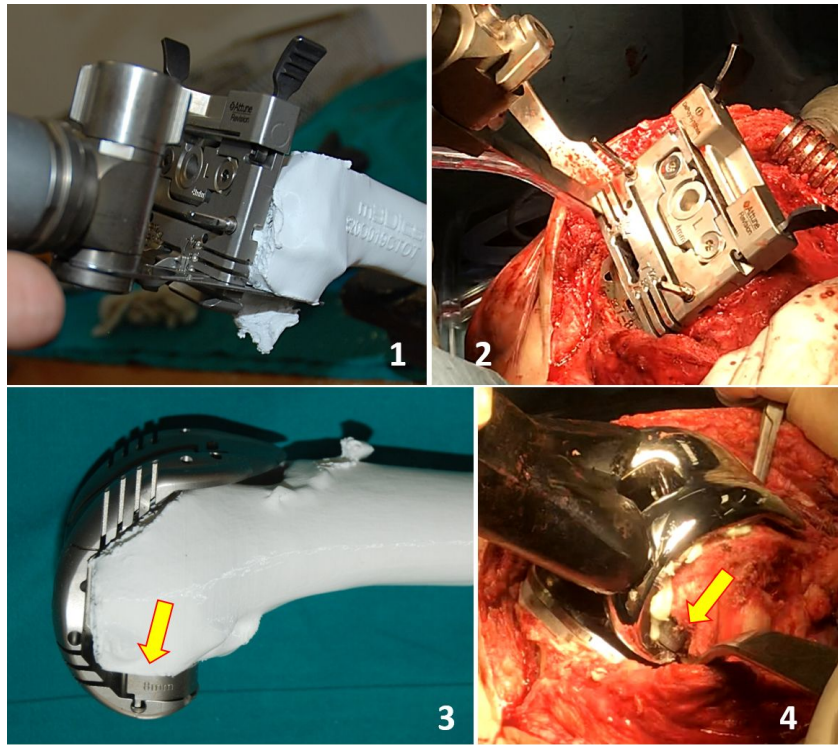


Figure 12: On the femoral side, the major advantages are the offset planning, the position to avoid notching, the rotation and the amount of posterior cuts and osteophytes. The arrows highlight the posterior wedges where the actual surgery exactly replicated the dry run.

The 3D model accurately reproduces all the bony landmarks that will be used for surgery and can be cut and manipulated with the surgical instruments. The model can then be sterilised, marked and taken into the operating room to help orient the surgeon and placing the components. The advantage of 3D printed models is demonstrated by bone loss after infection with Case 1 (Figs. 13 and 14) and after aseptic loosening with Case 2 (Figs 15 and 16).

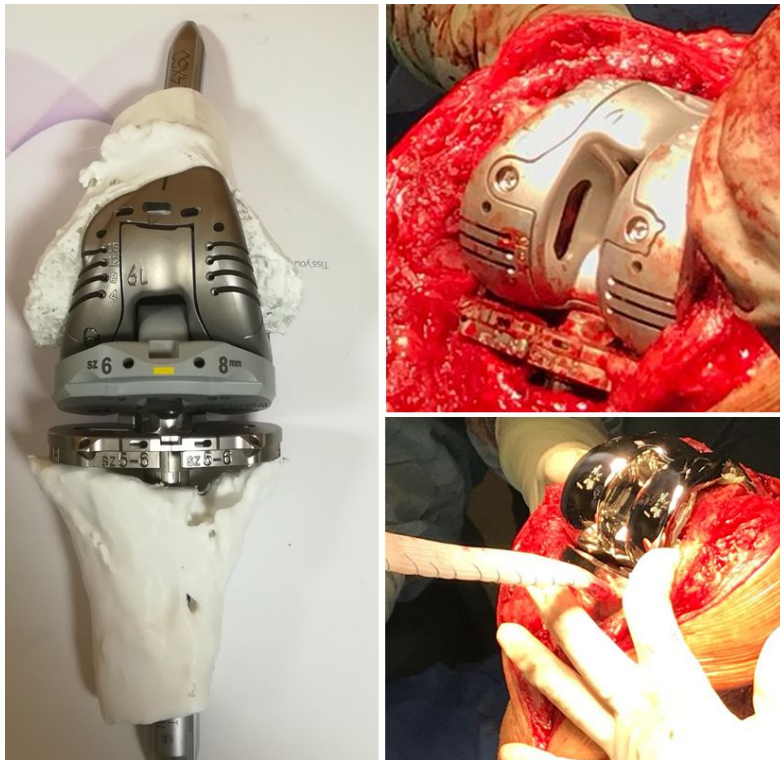


Figure 13: Case 1. Male, 58 years old, massive knee infection after anterior cruciate ligament reconstruction, failure of salvage arthroscopic procedure, treated with two times AB cement spacer at four and six months respectively (see Fig. 4 and Fig. 5). The patient came for a knee replacement with severe bone loss and patellar tendon rupture. Fig. 10 shows the perfect match between the dry run and the intraoperative situation. A mesh was used for the patellar tendon



Figure 14: Two-year radiological follow-up of case 1

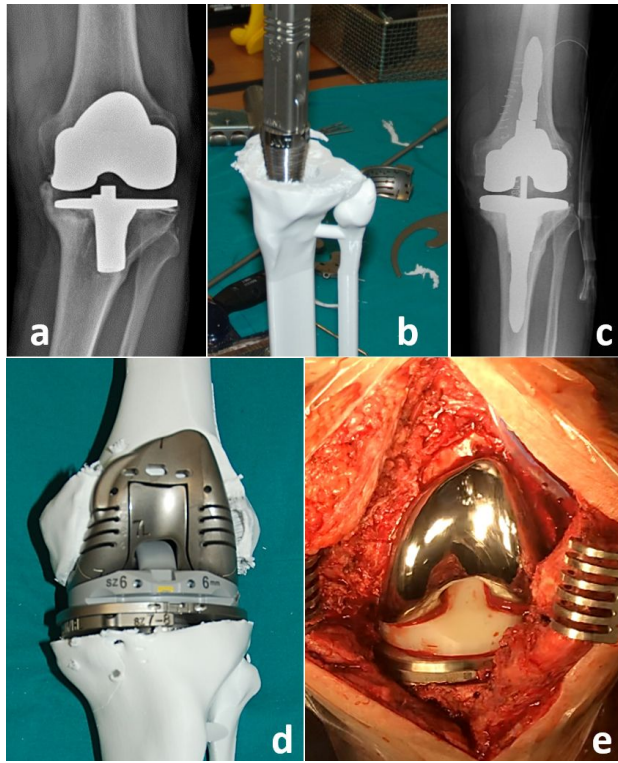


Figure 15: Case 2. Male, 68 years old. Aseptic tibial loosening with bone loss on the tibial side. The trials allowed a plan to be made for the tibia to know in advance the exact type of implants in terms of stem, sleeve and size.

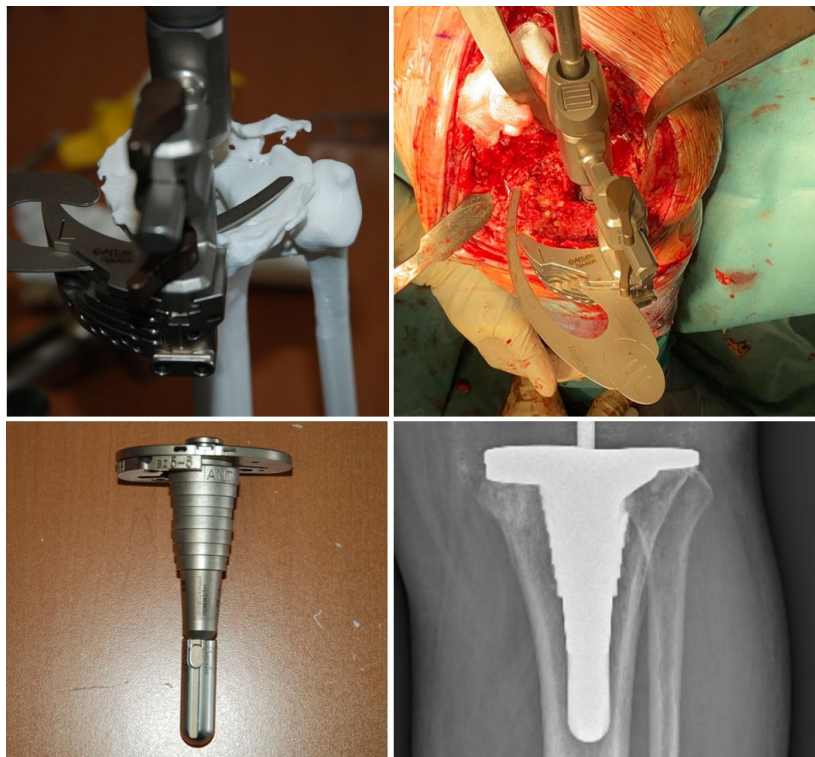


Figure 16: Further details for the tibia planning and solution of case 2

## DISCUSSION

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The preoperative use of the 3D model (Fig. 17) allows the surgeon to plan the operation, to study anatomy and bone loss and to identify the best option for reconstruction, with the possibility to switch from one solution to another (e.g. rods or cones, offset..., Figs. 18-20) and to choose the most appropriate one in order to save time and reduce unnecessary manoeuvres during the operation.

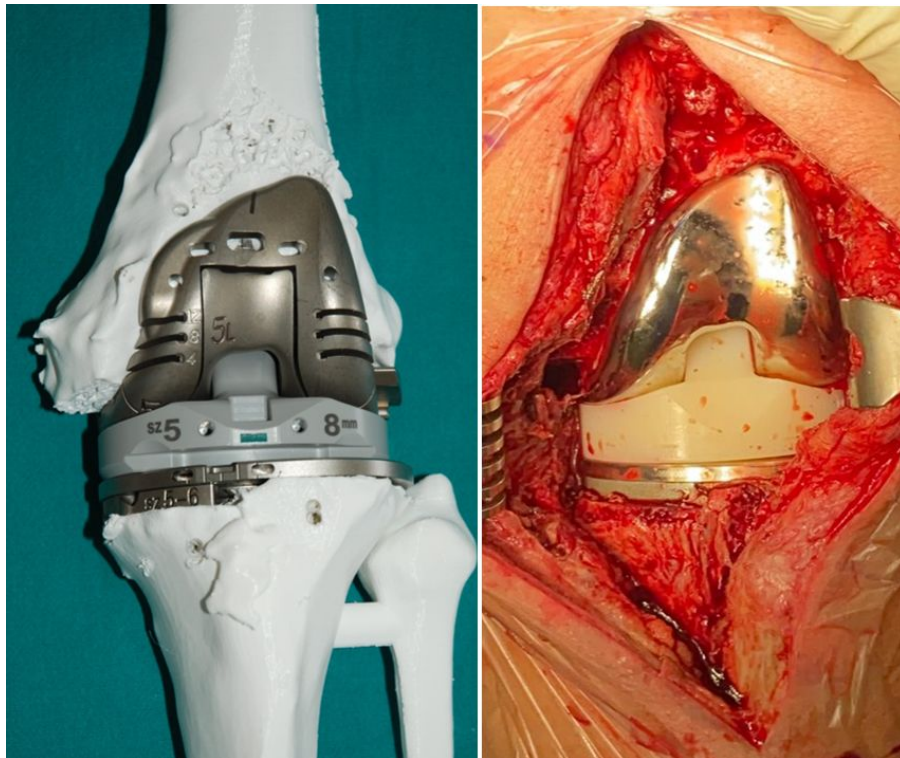


Figure 17: Dry run (left) and definitive implant (right) for case 2. Studying the anatomy and the type of bone loss and finding the best options for reconstruction in advance improves surgeon confidence and saves time.

Case 3 further demonstrates the advantages of 3D models for a 77 years old woman after two stage revision for septic loosening of a cemented primary implant 12 years ago. After reinfection and several AB spacers, bone stock on both femoral and tibial sides was compromised (see also fig. 1). Re-Revision surgery was planned with RHK using cones for both the tibia and femur (Figs 18 and 20).

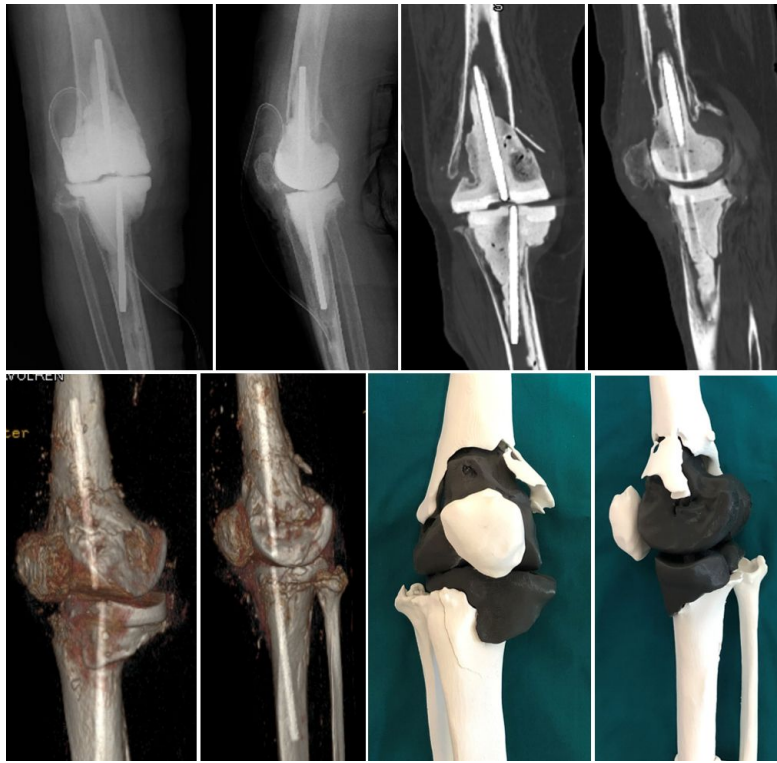


Figure 1: Starting from conventional knee X-rays, through CT scans and virtual 3D scans, the 3D printed model helps the surgeon to get a concrete idea of the anatomy and bone stock.

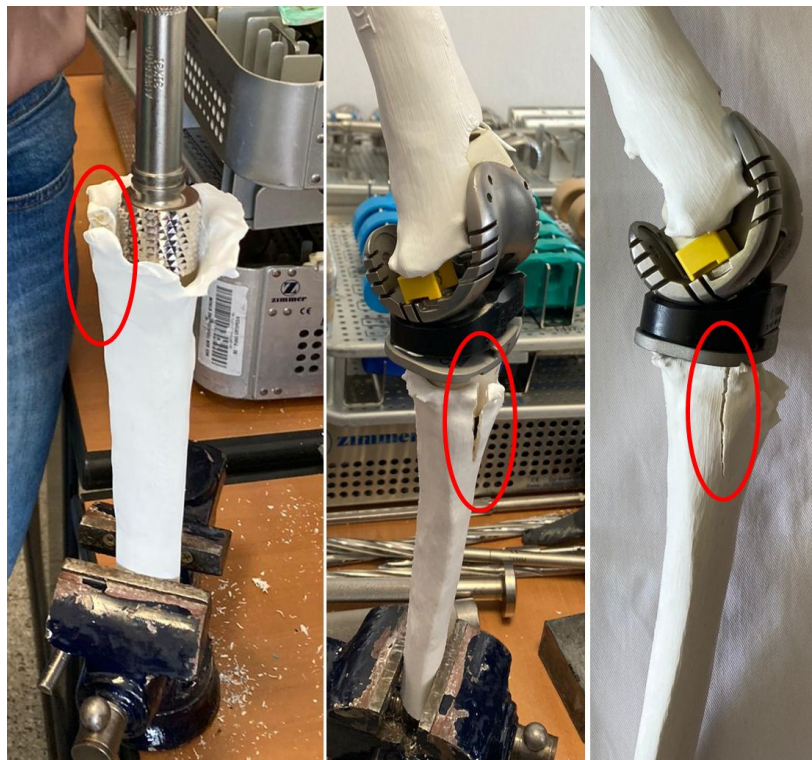


Figure 18: Case 3.. During the dry run, the cone caused a fracture on the meta-epiphyseal bone of the tibia (red circles), and the smaller cone did not fit to the bony defect. A different strategy without the cone using cement filling only was therefore considered. During the operation, the impossibility of using the cone was confirmed.

It was easy to switch to the alternative solution without cone, which had already been tested during the dry run.

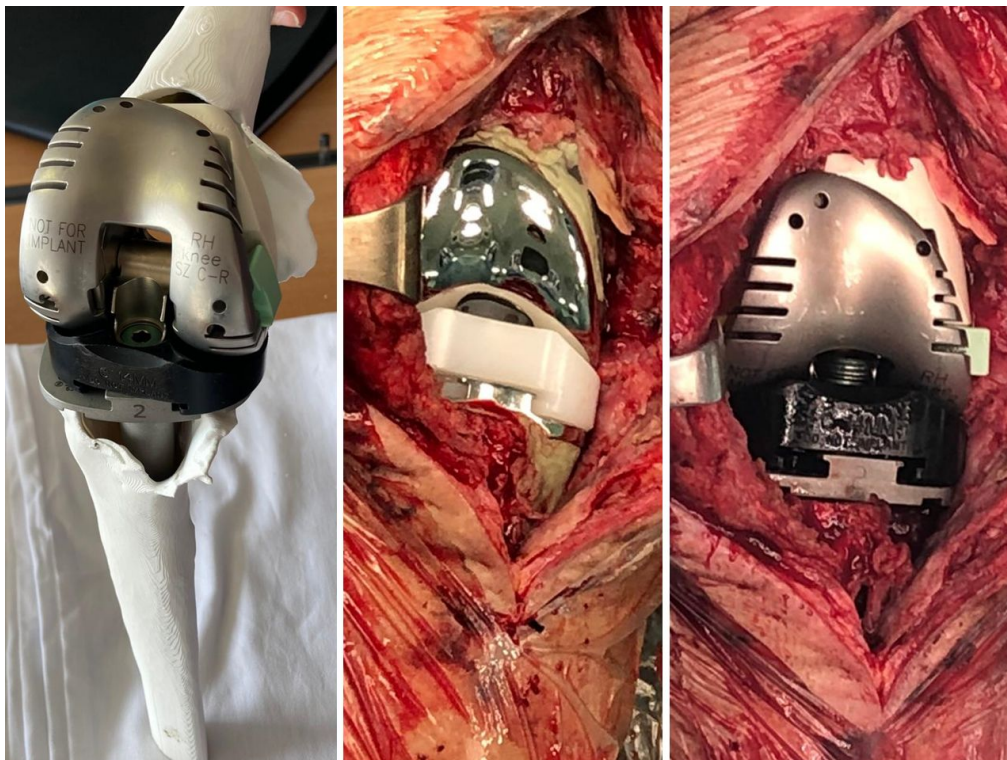


Figure 19: Among the difficulties related to bone loss and instability, it was a great help to know in advance the measurements and sizes of the double cones, augments and wedges for the femur which were already tested in the dry run (left of the figure). The picture shows the choice without cone on the tibial side.

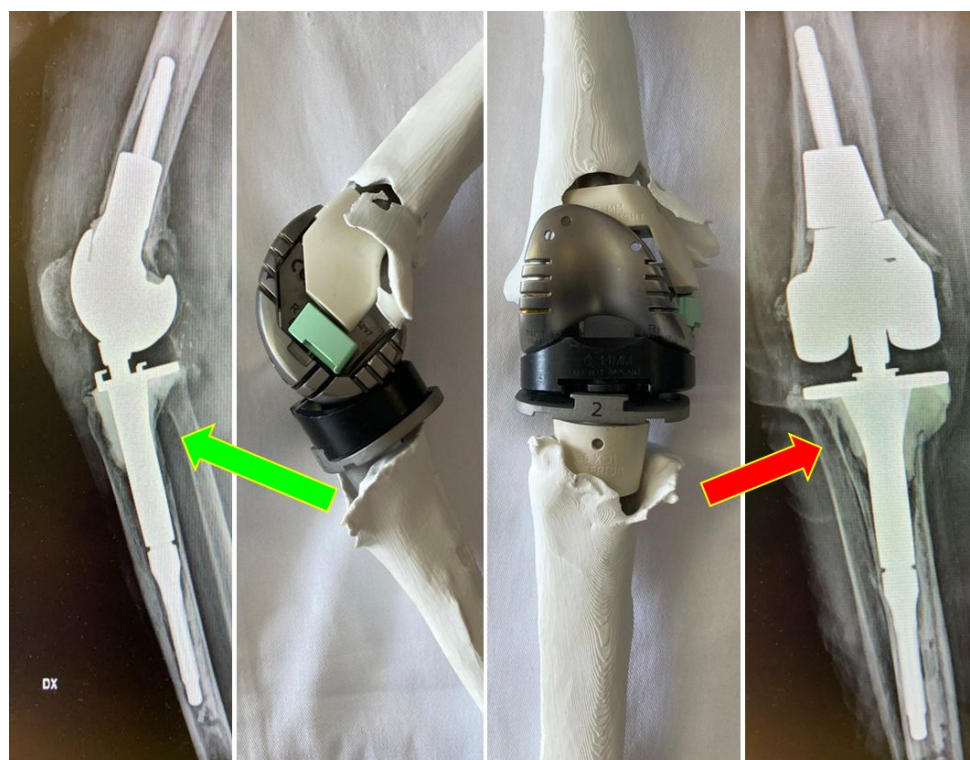


Figure 20: The image highlights that the use of the cone was not possible for the tibia (third image) There is a discrepancy between the dry test and the implant (red arrow), whereas the solution without the cone was appropriate and therefore chosen (left side of the image) with a match between the dry test and the implant (green arrow).

Once the model is assembled, the surgeon can go to the operating room with peace of mind, knowing that only minimal modifications will be required. Nevertheless, this type of preoperative planning allows for a significant reduction in the instruments and materials used during surgery. The lack of capsular and ligament components is a limitation of this technique and therefore a way to implement this in the model needs to be investigated, for example by using varus-valgus stress radiographs to reproduce the same amount of laxity in the model (Fig. 21).

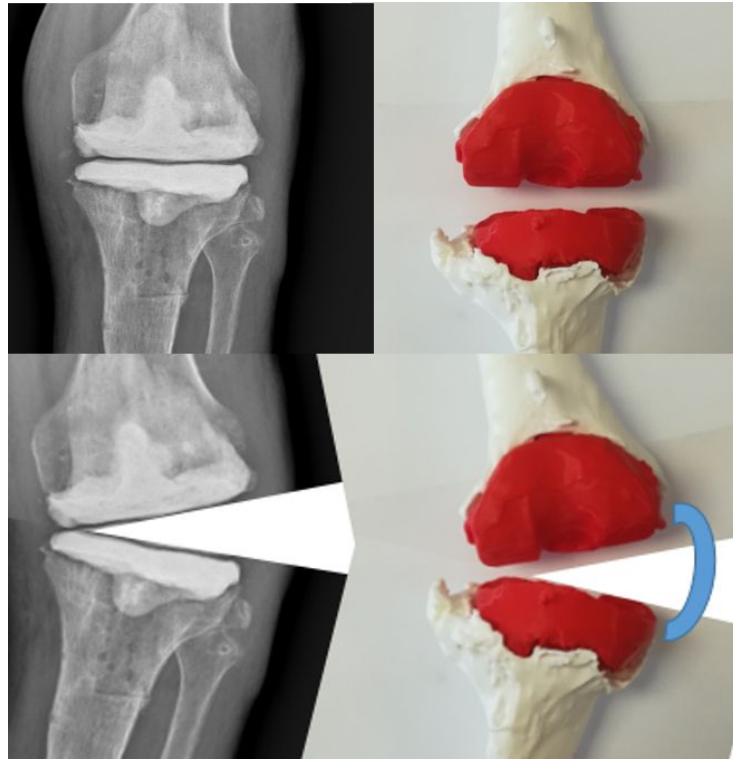


Figure 21: A hypothesis on how to introduce the ligament component.

Another limitation of the technique is that the plastic material does not mimic the behaviour or consistency of human tissue and can be heated and sometimes melted by the friction of the saws. Nevertheless, the primary learning objectives of this technique are to improve surgeon confidence and save time.

The economic aspect must also be taken into account. The 3D model costs about 500 euros, which can be reduced by intensive use, but saves time and other costs. Once the reproducibility of the system is proven (Fig. 22), it will be possible to eliminate all unnecessary materials and instruments from the operating theatre, thus saving costs for storage, sterilisation, transport and operating time.

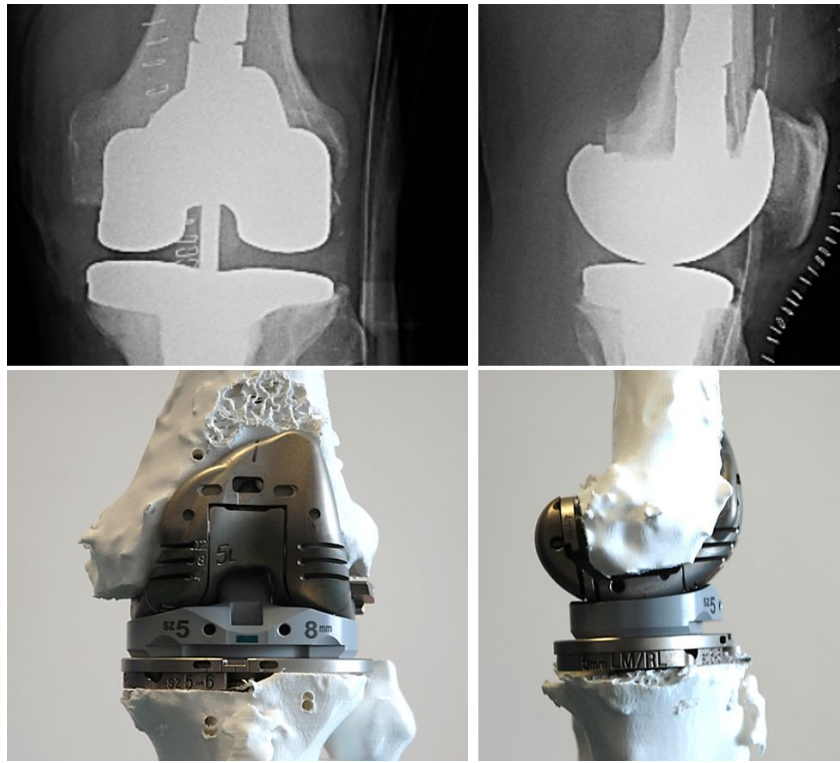


Figure 22: Once the reproducibility of the system is proven, the quantity of instruments and parts will be considerably reduced, with advantages in terms of storage, sterilisation, transport and therefore costs.

Another interesting aspect is education (Fig. 23). This 3D technology allows to reproduce exactly the real surgery, with the real instruments. It is therefore a learning tool for less skilled surgeons, low-volume surgeons or residents, as well as for nurses or ward assistants.



Figure 23: Education is important, and fun.

Finally, in the near future, the use of 3D models may be extended to other procedures such as periprosthetic knee fractures, tumours and corrective osteotomies. How can healthcare professionals benefit from 3D technology? Expert surgeons may be able to pre-assemble the implant, significantly reducing the time for revision surgeries. Other surgeons will become familiar with the instruments and the condition of the bone before operating, which will give them more confidence at the time of surgery. Residents have the opportunity to practice with the revision instruments on a 3D model instead of a patient. Nurses and ward assistants, who in many hospitals are not exclusively dedicated to revision surgery, can learn the technique and instruments.

## CONCLUSION ---

Although the costs associated with this technology are low, significant efficiency benefits can be achieved. Primarily by reducing the number of instrument trays required for each procedure and the overall time savings associated with unplanned intraoperative findings. Cost savings can also be achieved by reducing the volume of sterilisation, transport and storage costs. Finally, this technology can help less experienced revision surgeons to reduce anxiety and improve confidence, knowing that they can now focus on performing a planned surgery in advance.

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