# Improved Ureteroscopies Care Through the Use of 3D Printing Techniques

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***Abstract*—Simulation is widely used in medical schools, nursing programs, and other healthcare training institutions. This training method is nowadays essential and aims to reduce and limit the frequency of medical errors. Flexible ureteroscopy will allow the diagnosis and treatment of kidney stones located at the top of the urinary tract. This technique, which is efficient, reproducible, and not very traumatic, is very frequently used to treat nephrolithiasis often caused by poor hydration and/or nutrition. Complications of this surgical technique remain rare but the use of a simulator before the operation allows to initiate and prepare doctors in order to acquire good gestural techniques. From this perspective, this paper will deal with the creation and 3D printing of a urinary tract simulator named "UreteroSim-Abulcasis". For this purpose, uro-scans provided by the Cheikh Zaid International Hospital in Rabat (Morocco) were used to obtain a 3D reconstruction of the urinary tract. A list of modeling and 3D reconstruction simulators was first established to determine the one that would be the most suitable, and then a prototype was created using a 3D fused deposition modeling printer.**

***Index Terms*—Medical Simulation, Ureteroscopy, 3D Reconstruction, 3D modeling, 3D Printing, Nephroloathiasis, Kidney Stones, UreteroSim-Abulcasis, CT Images**



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## I. Introduction

Urinary lithiasis is a frequent, recurrent, and increasing condition; its prevalence is 9.8% [1] among people over the age of 45. The natural evolution of this disease is most often towards the spontaneous expulsion of the calculus. Nevertheless, a urological intervention may sometimes be mandatory. Indications for surgery are related to the calculus size, its growth observed during follow-up, and the presence of symptoms such as infection, pain, hematuria, and signs of obstruction, but also depends on comorbidities, the risk of recurrence, and the patient's social or professional situation. Thus, three techniques are used: Shock Wave Extracorporeal Lithotracy

(LEC) for proximal ureteral stones smaller than 10 mm and settling in the ureter, Percutaneous Nephrolotomy (NLPC) for kidney stones bigger than 20 mm, and Ureteroscopy (URS) which is an invasive procedure used for proximal ureteral stones bigger than 10 mm, distal ureteral stones and renal stones smaller than 20 mm [2]. Ureteroscopy has become the main first-line treatment of urinary lithiasis. This surgical technique is carried out by natural means, and the recall of the selection criteria of the appropriate intervention can help to improve proactive professional practices [3]. Moreover, we distinguish two types of ureteroscopes. First rigid ureteroscopes, that process urethral calculations ranging in size from 7.5 to 12.5 Charrière (CH). Then soft ureteroscopes, known by a finer caliber, are mainly useful for the treatment of renal lithiasis and renal cavities exploration in the case of cavity tumors (i.e., biopsies). Furthermore, the Contact Lithotritis Fragmentation System can use either ballistic waves generally known as lithoclasts, ultrasounds for fragmentation of friable stones and their suction (i.e., sonotrode), or Holmium YAG laser, which allows good fragmentation of calculations even the most resistant ones. Nevertheless, complications of ureteroscopy are variable: perforation, stenosis, ureteral disinsertion, pyelonephritis, or ureteral stenosis. In order to avoid these complications, especially those due to bad handling, it would be wise to implement practical learning techniques. A possible solution would be to use simulation learning technologies. In this context, simulation is the imitation of the functioning of a real-world process or system over time. It refers to the process of creating a virtual or physical representation of a system in order to investigate its behavior and analyze its performance [4]. Simulation-based training (SBT) has been recognized to improve quality and safety in different industries, including the armed forces, aeronautics, and healthcare. In the specific case of the healthcare field, simulation is an alternative approach to education, where students can experience low-frequency or high-risk scenarios and acquire cognitive, emotional, and psychomotor skills in a safe practice environment with Standardized patients or realistic equipment such as manikin, a procedural simulator, Virtual Reality or software that mimics real clinical practice contexts [5]. Furthermore, simulation can also be used as an alternative to issues such as students' lack of confidence in providing real-world patient care [6]. In 1759, Angélique du Coudray's delivery manikin was created in order to train many midwives and doctors [7]. Resusci Annie was born in 1960. This Laerdal product was designed in order to encourage the practice of rescue techniques. Thus, it was originally conceived for the practice of cardiopulmonary resuscitation, chest compressions, and mouth-to-mouth breathing. Her face was designed based on the death mask of a French drowning victim from the River Seine. In 1968, Dr.Harvey designed the first model that uses the modern concept of a task simulator, thereby cardiac auscultation and blood pressure, to determine heart disorders [8]. At the same time, Doctors Judson Denson and Stephen Abrahamson developed a computer-controlled manikin, the Sim One [9]. In 1987, Dr. David Gaba used computer software to develop the first immersive operating room, dedicated first to Continuing Medical Education and then to Initial Medical Training in 1992 [10]. Since the end of the 1990s, and thanks to the development of computing and video games, the offer of medical simulation training has been enhanced with the emergence of task simulators, 3D printing, and the creation of virtual environments [11]. Thus, the use of 3D technology to create a high-fidelity simulator of ureteroscopy will not only enable better training and a mastery of the manipulation but will also help reducing the surgery duration and thus protect patients from infections [12]. The rest of the paper is organized as follows. Section II depicts materials and methods used to develop the proposed "UreteroSim-Abulcasis" simulator. Section III is devoted to the results, section IV depicts the discussion. Finally, conclusions are mentioned in Section V.

## II. Materials and Methods

In this section, an overview of the urinary tract anatomy is introduced. Then, 3D design software are compared to select the best ones in terms of documentation, price, operating system, export/import format, and rating. Finally, the 3D printer used for urinary tract printing is presented.

### A. *The Anatomy of the Urinary tract*

The urinary system consists of different organs, ducts, and orifices, including the kidneys, ureters, bladder, urethra, and urethral meatus. The kidneys filter the blood and secrete urine. The human anatomy places the kidneys under the ribs, on either side of the spine. They are connected to the renal artery, through which the blood arrives to be filtered. The adrenal glands, which are located in each kidney, secrete hormones. As shown in Figure 1, the ureters are tubes that extend from the kidneys and carry urine from the kidneys to the bladder, they are about 20 to 30 centimeters long.

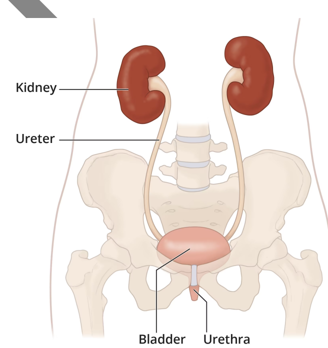



Fig. 1. The urinary tract. From: www.niddk.nih.gov

Urolithiasis is a common disease with an estimated global prevalence of up to 15% and a recurrence rate of up to 50% [13]. It occurs when the presence of high concentrations of crystals that make up the stone saturates the urine, accumulates in the kidney parenchyma, and begins to crystallize, thereby forming kidney stones. Crystals continue to aggregate and enlarge with the potential to migrate to the ureters and become symptomatic. Hydronephrosis can occur as a result of upstream dilation of the ureters and renal pelvis when stones cause obstruction and impede the flow of urine through the ureters. The most common site of stone obstruction is near the ureteropelvic junction (UPJ). This is because the diameter of the ureter is very narrow in this area. Ureteral stones are painful because of the increased luminal tone as they pass through the ureter and hydronephrosis, which releases prostaglandins and causes colic associated with the stone [14]. Urolithiasis is becoming more common and carries a high economic burden. The modern mainstay of definitive management of upper urolithiasis is surgical intervention (Shock Wave Extracorporeal Lithotracy (LEC) for proximal ureteral stones smaller than 10 mm and settling in the ureter, Percutaneous Nephrolotomy (NLPC) for kidney stones bigger than 20 mm and Ureteroscopy (URS)), and open surgery is becoming relatively rare also the use of laparoscopic/robotic surgery for stone removal. However, Ureteroscopy is still an effective method for the treatment of renal and ureteral lithiasis, its low morbidity has expanded its indications including biopsy samples to diagnose renal and ureteral tumors. Furthermore, It can also be used in case of ureter abnormalities (i.e., stenosis and junction abnormality) [15].

### B. 3D Design Software

*1) 3D Slicer Software:* 3D Slicer is a free open-source software that is a flexible and modular platform to analyze and visualize medical images. The software has a complete interface with a broad range of functions, as well as free online videos and documentation. It is used to display information related to DICOM files in addition to changing image settings. This software offers advantages such as performing 3D reconstructions from 2D images taken by different modalities of medical imaging, as well as segmenting images using different tools. Furthermore, it allows comparing multiple views at the same time and measuring distances. The source code of this software is accessible in such a way that it is possible to complete it with many missing features if necessary [16].

*2) Meshmixer Software:* Meshmixer is a free 3D modeling software developed by Autodesk that enables users to create and manipulate 3D meshes. It provides a large range of features for editing, repairing, and optimizing 3D models for 3D printing or other applications. Meshmixer enables users to both import and export different file formats, such as OBJ, PLY, and STL, and mix multiple templates to generate complex designs. It features tools to sculpt, modify and merge 3D meshes, as well as to add textures, colors, and patterns.

*3) Creo Parametric Software:* Creo Parametric is software used for modeling complex mechanical components and products, performing virtual simulations, testing designs, and generating 2D drawings for manufacturing. It is developed and maintained by PTC (Parametric Technology Corporation). It supports various manufacturing processes such as CNC machining, injection molding, and sheet metal fabrication and is widely used in the automotive, aerospace, consumer products, and industrial machinery sectors.

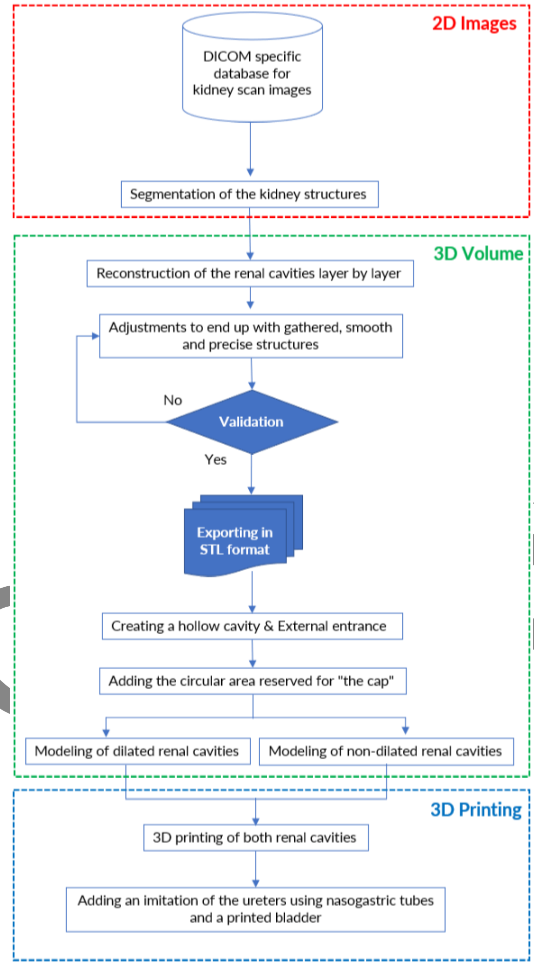



Fig. 2. Overview of the creation steps of "UreteroSim-Abulcasis" simulator

*4) 3D Printer:* In order to print the patient's kidneys and bladder in 3D, Volumic Stream 30 Ultra 3D printer was used. It is a fused deposition modeling (FDM) printer that uses a filament of 1.75 mm. It prints with a Precision X/Y of 15µ and a precision Z of 1µ and a print resolution: from 1 micron to 275 microns. It has a Large print volume of $295 \times 200 \times 300mm$ and it supports different materials such as PLA, ABS, NINJAFLEX, NYLON, PETG, etc. PLA had been used to print both kidneys.

## III. Experiments and Results

### A. "UreteroSim-Abulcasis" Simulator Presentation

Many 3D-printed models and simulators have been proposed to improve patient care in the treatment, diagnosis, and surgical planning of renal disorders [17]. 3D printing technology has made significant inroads in the field of healthcare, revolutionizing the way medical professionals approach patient care, medical research, and medical device manufacturing. Patient-specific models of kidneys and renal structures can be utilized to enhance surgical results and lower risks. Also, it can effectively cure kidney disorders such as kidney cancer, renal cysts, and renal artery stenosis. Bernhard et al. [18] used

3D printing of renal tumors to help patients in understanding their conditions and treatments. Weng et al. [19] employed a 3-dimensional printer to manufacture a replicated heart, kidneys, and liver to cover the voids left by the removal of the patient's organs. The new clinical use of 3-dimensional printed items during transplant surgery is being introduced in this case report for the first time. In light of this, the authors come to the conclusion that the use of a 3D printer to build simulated organs to replace the voids left behind after organ removal can imitate organ integrity, which may have psychological advantages for the family and caregivers. More recently, Guzmán et al. [20] developed a 3D-printed plastic model for teaching, training, and education in flexible ureteroscopy. The authors utilized a CT scan from a real-life patient's upper urinary tract. Also, they used Horos™ and FDM-Ultimaker software for segmentation and 3D printing, respectively. Figure 2 summarizes the creation steps of the proposed "UreteroSim-Abulcasis" simulator which is based on three major steps: segmentation, reconstruction/modeling, and printing.

### *B. 3D slicer Software*

In order to generate a real Cheikh Zaïd international hospital patient's kidney 3D volume on 3D slicer software, DICOM (Digital imaging and communications in medicine), images taken by uro-scan modality were used. Using the Segment editor tool functions kidney structures were highlighted in green and segmented. A 3D volume of the segmented structures was created using the "Volume rendering tool" as shown in Figure 3.

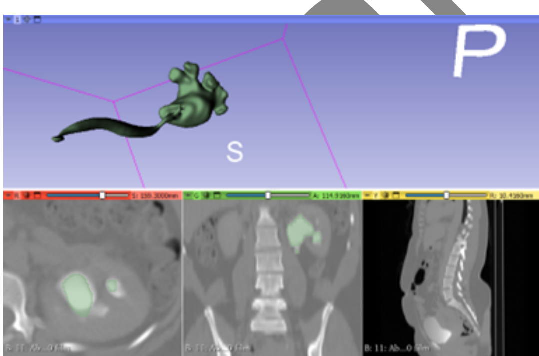



Fig. 3. Kidney structures segmentation on 3D Slicer

The 3D volume was then exported under STL format to make it compatible with the Volumic Stream 30 Ultra 3D printer, used by the medical simulation center of the Chaikh Zaïd Foundation team, as well as other 3D modeling software.

### *C. Meshmixer Software*

The 3D Volume created using a 3D slicer was filled inside. In order to reproduce the hollow aspect of the kidney structure, Meshmixer Software was used following two main steps. The first was to make the hollow part using functions such as offset and shell to have, in addition to a dug part, a thickness of 1 or 2mm with some Boolean differences. Then, as a second step, a circular area was created to form an external opening cap. Its purpose is to close the hole once the supervisor has positioned the kidney stones. As shown in Figure 4, case 1 represents a real patient dilated renal cavities modeling. Whereas, case 2 depicts real patient non-dilated renal cavities modeling with elongated calyxes and greater angular inclination.

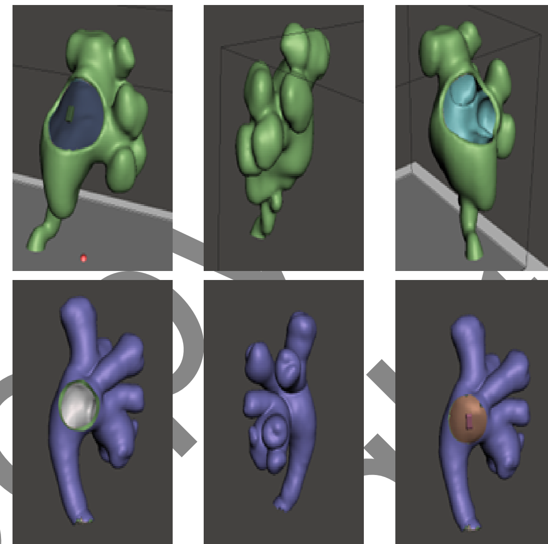


Fig. 4. Kidney structures segmentation on 3D Slicer. Green color represents case 1. Purple color represents case 2.

A bladder was modeled in 3D using Creo Parametric software in order to simulate a whole urinary tract as shown in Figure 5.

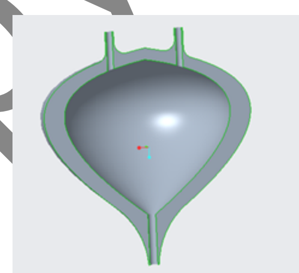


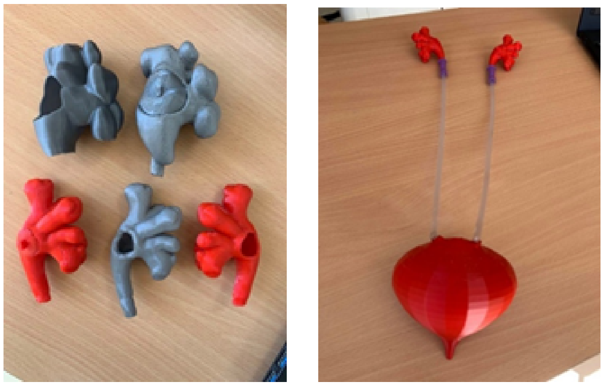
Fig. 5. 3D volume of a real patient bladder on Creo parametric software

### *D. 3D Printing*

Both real patients' dilated renal cavities and non-dilated renal cavities with elongated calyxes and greater angular inclination were printed using PLA plastic material as shown in Figure 6 (a). The same plastic material was used to print the patient's bladder. To have a complete simulator, we managed to find an imitation of the ureters using nasogastric probes were used and we printed a bladder in PLA, modeled with the Creo Parametric software. Figure 6 (b) depicts the proposed simulator named "UreteroSim-Abulcasis".

## IV. Discussion

The proposed ureteroscopy simulator named "UreteroSim-Abulcasis" was tested in the operating room of Cheikh Zaïd



(a) (b)

Fig. 6. (a) Printed renal cavities with caps. (b) ”UreteroSim-Abulcasis” simulator

International Hospital by an expert professor and his resident doctors (Figure 6). They found the use of this simulator quite realistic and the diameter of the cavities matched the ureteroscope. Thus, this simulator can be used to perform pre-operative training on real patients' 3D printed urinary tract, and therefore prepare for any accidental discovery mainly of tumors requiring a biopsy sample to analyze its nature. Moreover, this will allow doctors to train on kidneys of particular anatomy or with ureter abnormalities such as stenosis or junction abnormality. In addition, better pre-operative training on the proposed simulator will reduce the surgery duration by enabling doctors to both master ureteroscopy manipulation and to better manage their time. Consequently, this will protect the patients from hospital-acquired infections by shortening the anesthesia duration.

## V. Conclusion

The development of 3D printing technology has opened up new avenues for medical professionals to enhance patient care. One such application is the printing of a patient-specific urinary tract for use in simulating ureteroscopy lithiasis procedures. In this paper, the ”UreteroSim-Abulcasis” simulator is proposed using Meshmixer, 3D Slicer, and Creo Parametric. This set of software permits doctors and engineers to design a 3D model of the urinary tract based on a patient's medical imaging data. This model is then refined and optimized for printing using a variety of techniques. Once printed, the model is used to simulate different aspects of a ureteroscopy procedure, including insertion of the scope and extraction of stones, allowing medical professionals to practice and refine their skills before performing the actual procedure on a patient. The proposed ”UreteroSim-Abulcasis” has the potential to greatly improve patient outcomes by reducing the risk of complications and increasing the success rates of these procedures.

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