

Chapter 13

Three-Dimensional Medical Printing in Urology



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13.1 Introduction

Three-dimensional (3D) printers are devices that make 3D designs prepared in computer-aided design (CAD) programs into real 3D objects using various materials. Additive manufacturing (AM) is another name frequently used in the literature for 3D printer technology. It was the first known step in 3D printers to polymerize a photosensitive resin by ultraviolet light for the first time in 1986 by Charles W. Hull [1]. In their early years, they used it widely in architecture, automotive, and aerospace industries. It created a technological revolution by giving engineers, architects, and designers a chance to transform a model they designed in a fully virtual environment into a real three-dimensional object. Although the photosensitive resin was originally used for production; many new materials, from ceramics to various polymers, from metal types to wax and even human cells, can be used in production with new technological developments [2]. Today, 3D printers have become an accessible technological product with the developing technological infrastructure, where individual users can make their own installations and create their own 3D models and products.

In the absence of medical imaging techniques, information about the patient's body was limited only by physical examination. The anatomical conditions of the sick organs were an enigma, and perhaps their real condition had a chance to be detected only intraoperatively. When German physicist Wilhelm Conrad Roentgen announced that he discovered X-rays with his article "Ober eine neue Art von Strahlen" on December 28, 1895; one of the first big steps was taken for medical imaging [3]. Following this big step, X-ray radiographs became the most important

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imaging method in the field of medicine used for a long time. With the advancing technology, new imaging techniques such as computed tomography (CT), Ultrasonography (US) and magnetic resonance imaging (MRI) have led to revolutionary results in diagnostic algorithms. The ability of clinicians to use cross-sectional imaging when trying to diagnose patients has enabled the organs to be evaluated in detail, thereby making it easier to diagnose correctly. Although the cross-sectional imaging methods provide much more anatomical details than classical radiographs, it may be inadequate to enable us to understand the interrelationships of organs and tissues that are making important neighborhoods with each other in a 3D space. The unique contribution of 3D modeling in the field of medical imaging helps exactly to illuminate this “blind spot”.

Awareness of the use of 3D printers in the medical field has been on the agenda in the last few decades [4]. In general, it is noticed that this new technology, which has led to groundbreaking results in the sectors it has been used to date, can be used in many fields of medicine. For each patient, 3D models can be created for surgical planning, and these 3D models can be used both to inform the patient and to understand the treatment process. At the same time, using these models, education can be given in the field of medicine, or research assistants who are undergoing surgical training can be given the chance to undergo surgical training without the risk of harming the patient. With this novel technology, customized medical equipment and prosthesis can be produced for the patient.

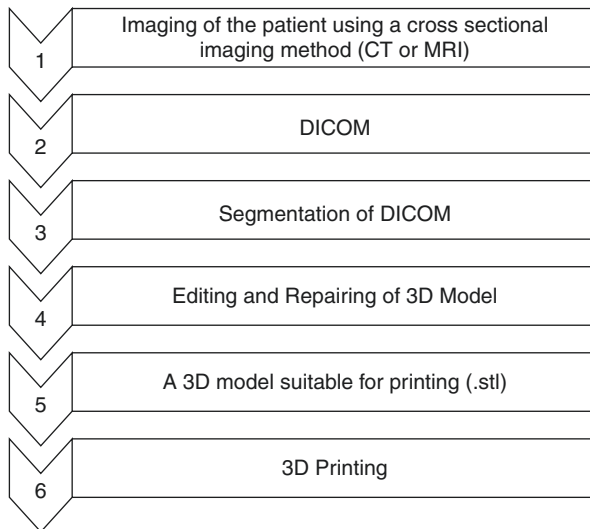
In this book section, it is aimed to review the applications of 3D printer technology in the field of urology, to evaluate its potential benefits and limitations, and to evaluate our future expectations.

13.2 How 3D Printing Is Work?

13.2.1 Creation of 3D Models

In order to print in 3D printers, a 3D model ready to be printed must be prepared first. Although the 3D modeling process is described in detail in a separate chapter in this textbook; it is deemed necessary to give a brief information about the process in this chapter. With an overall perspective, the production of organs from a real patient or a cadaver as a 3D model involves a process consisting of multiple stages (Fig. 13.1). The cross-sectional views of the patient, which is obtained in DICOM format in 2D, are converted to 3D with the help of CAD programs. The artifacts that occur when converting to 3D are taken to an edit and repair process to obtain a more realistic model. At the end of all these processes, a 3D model is created in “.stl” format suitable for printing on a 3D printer. The format called “the Standard Tessellation Language” or “Standard Triangle Language” abbreviated as STL is the standard software format used by CAD programs. Only the surface anatomy is defined to consist of small triangles, with no color or pattern in the STL format.

Fig. 13.1 Production steps of a 3D printing model



Unlike other common formats, OBJ contains color or pattern information different from STL format, while PLY format can contain additional data such as transparency [5]. After the 3D models are ready to be printed, the printing phase can be started by selecting the appropriate 3D printer, which differs according to the intended use and the type of material desired to be printed.

13.2.2 3D Printing Technology

In the introduction part of this chapter, we have stated that there are many different 3D printer technologies and many materials from resin to various metals can be used as printing material. A brief summary of 3D printing technologies is important to higher perceive the present and potential applications of 3D printing technologies in the medical field. Although the technological options we have are very diverse, four basic 3D printing technologies are used more. These can be listed as fused deposition modeling (FDM), inkjet printing, powder-based printing, and stereolithography (SLA) [6].

13.2.2.1 Fused Deposition Modeling

FDM technology is the most widely used and low-cost 3D printing technology today [7]. The FDM method is one of the subtypes of extrusion-based printing technology. It works on the principle of heating and melting a thermoplastic filament to form three-dimensional layers [8]. Overlapping layers create a 3D model when the writing phase is complete. An important limitation of FDM technology is that it can

be printed using only one color, except for models that allow double filament to be used. Also, when the printing phase is completed, the layer marks forming the model can be selected with the naked eye when viewed from the outer surface of the model.

13.2.2.2 Inkjet Printing (Material Jetting)

Inkjet-based (or droplet-based) printing technology occurs by placing the droplets on top of each other in a form that creates a 3D model [7]. An interesting and prominent feature in these printing technologies is the ability to print by combining scaffolds with live cells or using bioinks containing living cells. Inkjet-based technologies are the common names for subgroups such as multijet modeling (MJM), wax deposition modeling (WDM), binder jetting (BJ), and laser-induced forward transfer (LIFT) [9–11].

In MMJ, liquid acrylic polymers are layered on a building platform using a print head with one or more nozzles. Cured by exposure to UV lamps after layering. Melted wax is also used to provide a support structure with acrylic polymer to ensure structural durability during the process. The wax around the 3D model is cleaned with the melting process after printing [7].

In WDM technology, wax is first melted and deposited on a building platform layer by layer through a print head. The melted wax cools down on this platform to become solid and takes its final shape [7].

In the technology called BJ, a 3D model is created by connecting an adhesive substance sprayed from the print head and various powder materials such as ceramics, metals and polymers. Therefore, BJ technology can be considered as a kind of powder based technology [12].

Since laser light is used in LIFT technology, it does not require a printhead [13]. After the laser absorbent layer is covered with ink material, the laser light focuses on this layer and turns the metal into gas-plasma state. The vapor pocket formed at this time, extracts a droplet from the ink material. This technology, which was used only for metals when it was first used, has recently been used for cell-laden hydrogels.

13.2.2.3 Powder-Based Printing

Although the source of energy used and the types of powder materials differ, the logic in all of the powder-based 3D printer technologies relies on heating to ensure the integrity of the powder materials. Selective laser sintering (SLS), direct metal laser sintering (DMLS), selective laser melting (SLM) and electron beam melting (EBM) can be classified under the heading of powder based printing technologies [14].

Although there are technological similarities between the sintering process and the melting process, there are some important differences in terms of the resulting

product. In the sintering process, the resulting material has a porous internal structure and a rough surface, since the powders are not completely melted. In the melting process, the powders are completely melted and combined so that a higher density and more solid 3D printing can be obtained [15].

In SLS, SLM and DMLS methods, laser beams directed with the help of mirrors are used for heating. Although SLS and DMLS methods are roughly similar technologies, a wide variety of materials can be used for printing in the SLS method, while only metal material can be used in DMSL.

In EBM technology, high energy electron beam is used through electromagnetic coils. For this system to work, a vacuumed working environment is required, and the cost increases compared to other powder-based printers.

13.2.2.4 Vat Polymerization-Based Printing

In the technology called vat photopolymerization printing, light waves focus on a vat which is filled with a UV-sensitive resin material. The focused ultraviolet light hardens one layer at a time, forming layers in a row [7]. Vat Polymerization-based Printing technology includes stereolithography (SLA), direct or digital light processing (DLP) and continuous directlight processing/continuous liquid interface production (CDLP/CLIP).

The first 3D printer technique found by Charles W. Hull in 1986 was a SLA method [1]. In SLA technique, an ultraviolet (UV) light sensitive resin is polymerized with UV and converted into a solid state. It is the most commonly used 3D printer technology in the surgical planning stage today because it gives very close results to the reality [16].

The DLP method is very similar to the SLA, but uses a shallower resin container. It provides the opportunity to print faster because it uses a digital light projector that is under the resin container and cures the entire layer at once [17].

In addition to DLP method in CDLP (or CLIP) method, the build plate moves in the Z-direction continuously [7]. This additional feature allows the printing time to be shortened thoroughly.

13.3 Using of 3D Medical Printing in Urology

13.3.1 Pre- and Intraoperative Surgical Planning

An important issue in which three-dimensional medical technologies can be beneficial is the pre-surgical planning stage. The data obtained by the patient's imaging methods can be made three-dimensional in the virtual environment, and the neighborhoods of the tissues and organs and the anatomical location of the structure to be intervened can be evaluated in detail before surgery, and a more realistic assessment opportunity can be obtained while planning in the preoperative period.

Surgical treatment of kidney stone diseases is one of the urological study areas where technology is developing rapidly. In addition to the developed laser systems, ultrasonic lithotripters and flexible instruments, the use of 3D technologies seems to increase this development rate.

In 2017 Ghazi et al. kidney including the pelvicaliceal system and relevant adjacent structure models were created using polyvinyl alcohol hydrogels and three-dimensional-printed injection molds [18]. All steps of a percutaneous nephrolithotomy (PCNL) were simulated including percutaneous renal access, nephroscopy, and lithotripsy steps. Five experts with >100 caseload and 10 novices with a previous <20 caseload from both urology (performing the full procedure) and interventional radiology (performing access only) departments completed the simulation. Face and content validity were calculated using model ratings for similarity to the real procedure and usefulness as a training tool. The similarity and conformity of the prepared models to the real procedure were evaluated by the participants as very successful.

Atalay et al. used 3D replicated models which has been previously created with usage of preoperative images of five patients during pre-operative training [19]. The trainees had progression with a range of 60–88% in understanding of calyceal localizations and determination of access side. More, the same authors informed the patients preoperatively with their pre-printed models [20]. Surveys were fulfilled by patients and the results relieved that there an increase of patient knowledge of stone localization, kidney anatomy and possible complications during the procedures by aid of informative printed models.

Models obtained with 3D printer technology can be used by offering in vitro work environment for different studies besides preoperative planning, medical education and patient information. Antonelli et al. described usage of a polythene sac “The PercSac” in order to prevent migration of stone fragments during the PCNL procedure performed on 3D printed kidney models [21].

In 2019, Xu et al. evaluated the effectiveness of usage of 3D printed models for optimal calyx selection and stone free rate among staghorn stones [22]. According to their results, 3D printed models may be used to achieve better stone free rates with most suitable access side selection during PCNL procedures among patients with staghorn stones [22]. Similarly at same year Bianchi et al. evaluated the improvement of access sides during PCNL with aid of 3D kidney models [23]. According to their evaluation of 3D-guided approach on PCNL of a 25 × 15 mm left kidney stone, the preoperative planning of the puncture with better knowledge of the renal anatomy and may be helpful to reduce operative time and improve the learning curve [23]. Canat et al. also declared that stone volume calculation using CT based 3D-reconstructed algorithm improves the accuracy of stone volume estimation and this measurement is superior to ellipsoid formula [24].

Besides from PCNL as considering the ureteroscopic lithotripsy Kuroda et al. demonstrated a case of allograft ureteral stone which has been treated with ante-grade approach with usage of a 3D printed model to determine the ideal approach [25]. Due to the anatomical difficulty regarding the patients allograft kidney, they had prepared a 3D image and model for selecting the best percutaneous approach [25].

The “partial nephrectomy” procedure, also called nephron-sparing surgery, is the primary treatment for small kidney masses with suspected renal cancer. Factors such as the location of the mass on the kidney, the depth of invasion closely affect the parameters such as the duration of surgery, the amount of bleeding, the possibility of complications. One of the most common uses of 3D modeling in the field of urology is the preoperative planning of the surgeries of the masses detected on the kidney. In a study carried out by Smektala et al. in Poland, patient images were processed, mold modeling was made, casting molds were created, and silicone replicas were produced through these molds, in which five cases planned to undergo laparoscopic partial nephrectomy surgery with suspicion of renal carcinoma [26]. The models obtained in this low cost study were first used for surgical planning before partial nephrectomy, and in the later period, they were used in laparoscopic surgery training.

Wake et al. created personalized replicated kidneys through 3D printers in the preoperative period, by processing the MRI of a series of 10 cases with a nephrometry score between 6 and 10 [27]. Three surgeons whom have been experienced in the field of urooncology completed a questionnaire about their surgical approach plans without replica models first and then with replica models [27]. It was interesting in the results of the research is that the transperitoneal or retroperitoneal surgical approach plans made without seeing the model change at a rate of 30–50% after the model is seen [27]. 3D replicas of the mass to be surgically caused serious changes in the decision of the surgeons making plans by looking at MRI.

Westerman et al; In a study comparing the use of 3D printer material replicated kidneys when performing surgical planning with the use of CAD programs for surgical planning in cases of challenging nephron-sparing surgery, they obtained data indicating that models produced using a 3D printer provide more successful surgical planning [28].

Golab et al. performed preoperative planning with cardiovascular surgery via a 3D model of a renal cancer case with a thrombus extending to the right atrium where multidisciplinary approach is required during surgery [29]. So, the 3D models produced specifically for the patient can facilitate joint preoperative planning in complex cases where teams with different specialties will enter together.

An interesting study was performed considering the 3D printing assisted laparoscopic cryoablation of small renal tumors [30]. The 3D reconstruction was used to mimic cryoablation procedure. The results showed that the 3D printing technology assisted laparoscopic cryoablation is a feasible method to treat renal tumors, which maybe a better way to preserve nephrons, especially for those elderly and/or comorbid patients [30].

There also exists different interesting cases of renal tumors which has been successfully treated surgically with help of 3D printing technology. As an example, Mercader et al. reported the aid of 3D printed modelling during the surgical planning of a patient with horseshoe kidney [31].

According to a study that evaluating the 3D printed modelling on laparoscopic partial nephrectomy(LPN), 3D models supplied a shorter ischemia time but longer surgery waiting time [32]. The patients with RENAL score ≥ 8 , the 3D-LPN group

had significantly shorter warm ischemic time and less intraoperative blood loss than the traditional LPN group. Intra- and postoperative hospital complication rates were similar for 3D-LPN and traditional LPN groups (8.7% vs. 13.7%) [32]. Similarly, Kyung et al. also evaluated the application of 3D printed kidney models during partial nephrectomy to predict surgical outcomes [33]. The translation of 2D images of CT or MRI data to a 3D model helps surgeons improvements regarding tumor localization [34].

Moreover, recent studies also investigated 3D printed models among bladder, prostate and retroperitoneal tumors in urology [35–37]. Laparoscopic radical cystectomy with an introcorporeal neobladder is one of challenging cases in urooncology. Bejrananda et al. described the patients Y pouch neobladder in a 3D printed model during the follow-up in order to help the patient to understand the morphology and neobladder capacity after the initial surgery [35]. In order to improve the validation considering the prostate cancer diagnosis and treatment plan, Rutkowski et al. suggested a MRI-based cancer lesion analysis with 3D printed patient specific prostate cutting guides [36]. According to their study 10 patients with prostate cancer were evaluated with Prostate Specific Membrane Antigen (PSMA) Positron Emission Tomography (PET)/MRI both before and after chemohormonal treatment. Post-treatment images were used to design patient-specific prostate cutting guides that were used to create uniform thickness sections of surgically removed prostates. So that The prostate cutting guides were used to successfully section the prostate for histopathological evaluation and slice-by-slice MRI comparison [36]. Effectiveness of 3D printing modelling to plan a retroperitoneal tumor was investigated among 24 surgeons [37]. Regarding a single case all the surgeons were asked to compare the CT and 3D models. Especially junior surgeons declared that the 3D models provide greater help for preoperative planning and confidence building than using CT in resection of retroperitoneal tumor [37].

Besides urooncology and endourology there are special subgroups of urological interventions where 3D printing models may also take place. Renal transplantation is one of the urological study areas where the use of 3D printers is applied. In a study conducted in 2015, the donor kidney and the pelvic cavity of the recipient patient were rendered in 3D by imaging the patients before the renal transplantation, and printed as replica models [38]. During the study, it was aimed to decrease the vascular clamp time and bleeding amount in the intraoperative period by evaluating the pelvic vascular structures and their neighbors, the pelvic location and location of the kidney to be transplanted, and the vascular lengths required for anastomosis [38]. Urethral injury is an important problem among patients with pelvic fractures. Posterior urethral anastomosis during urethroplasty may be a challenging intervention. Joshi et al. conducted a study consisted of 3D printed models composed of pelvic fracture patients with urethral injuries [39]. A total of 10 models were printed which were obtained by 3D CT images. According to their results 3D printing can be applied to pelvic fracture urethral injury to understand the anatomy of the posterior urethra and its relations with peri neighbouring important anatomical structures [39]. Even, individualized 3D printed extravascular titanium stents have been shown to be used as a minimally invasive treatment option among patients with nutcracker syndrome [40].

13.3.2 Education and Training

The “*primum non nocere*”, namely the “do not harm first” principle of the Ionian Physician Hippocrates, who is known as the founding father of medicine, is a basic principle that is taught to every physician candidate who is preparing to embark on his career. The methodology used in classical medicine education is based on the “see, do, teach” algorithm of William Stewart Halsted, who is accepted as the founder of modern surgery. In an education system based on Halsted methodology, it will run parallel with the number of patients with access to education and experience that the person can obtain. It is also obvious that using the human body, which is the main object of the medical education process, as training material in processes with potential for harm, will create ethical, moral and legal problems due to the indispensable and indisputable importance of human life. Cadavers have been used as the most important educational tools of medical education for many years in order to overcome various problems caused by the trainings given on the patient’s body. However, difficulties in cadaver supply, limitations such as not being able to observe physiological changes in a living organism and religious prejudices brought new searches [41]. Although various animal models used in medical education make important contributions to education, education remains far from the targeted quality due to the physiological and anatomical differences between the living body used as educational material and the human body. All these limitations and difficulties in medical education require the use of applications such as simulation, augmented reality and virtual reality in the medical education process.

In 2019, Tatar et al. published an important review considering the importance and validity of 3D medical printing and virtual reality on urology training with ‘MedTRain3DModsim’ Erasmus + European Union Project [42]. At the same year Guliev et al. evaluated the use of a 3D printed segmented collapsible model of pelvicalyceal system during urology training [43]. According to their study the determination of the anterior and posterior calyces of the upper group was improved by 61% and 69%, the difference in the determination of the calyces of the middle group was 60% and 51%, and the answers regarding the number of the anterior and posterior calyces of the lower group became better by 67% and 74%, respectively ($p < 0.001$). The ability to select the optimal calyx for the primary and the second access became better by 60% and 55%, respectively ($p < 0.001$) [43].

There exists an increase in the usage of ultrasound guidance during recent years on both endoscopic and percutaneous interventions. Aro et al. developed 3D printed kidney models especially ultrasound-compatible ones in order to be used during training [44]. Day by day there is an increasing interest and studies go on. Recently, Melynk et al. published a technical report that indicates the usage of perfused hydrogel kidney model created using 3D printed injection moldings for RAPN simulation and training [45]. Anatomically correct, tumor-laden kidney models were created from 3D-printed casts designed from a patient’s CT scan and injected with poly-vinyl alcohol (PVA). A variety of testing methods quantified Young’s modulus in addition to comparing the functional effects of bleeding and suturing

among fresh porcine kidneys and various formulations of PVA kidneys. It was the first study that utilize extensive material testing analyses to determine the mechanical and functional properties of a perfused, inanimate simulation platform for RAPN, fabricated using a combination of image segmentation, 3D printing and PVA casting [45].

The predominant use of 3D printers in the area of prostate diseases is the diagnosis and treatment of prostate cancer. There are studies in the literature that support the combination of multiparametric prostate MRI (mpMRG) and 3D prostate model to increase the success rates in the diagnosis of prostate adenocarcinoma. In a study conducted by Wang et al. Published in 2015, all of the 16 patients with suspected prostate cancer had 3.0 Tesla mpMRG, and STL files obtained from the processed images were created in 3D with prostate models. Cognitive fusion prostate biopsy was performed on patients by evaluating mpMRG and 3D prostate models together. When evaluating the results, the researchers stated that they performed higher rates of prostate cancer detection compared to cognitive fusion biopsies in the current literature and argued that the combination of mpMRG and 3D model will increase the diagnostic value of prostate biopsy [46].

If the dorsolateral neurovascular bundles cannot be distinguished and preserved during radical prostatectomy, which is the gold standard treatment of non-metastatic prostate adenocarcinoma, erectile dysfunction may develop permanently in the postoperative period [47]. Intraoperative discrimination of dorsolateral neurovascular bundles is a problem that forces surgeons. In a study conducted by Jomoto et al. In a combination of magnetic resonance angiography and patient-specific 3D prostate models, the use of the 3D prostate model made it easier to find neurovascular bundles intraoperatively, thus facilitating radical prostatectomy with a nerve-sparing technique [48].

Apart from urological surgery, there are several studies in the literature that demonstrate the advantages of custom made 3D prostate models during the application of different treatment modalities such as cryotherapy, HIFU (High Intensity Focused Ultrasound) and brachytherapy used in the treatment of prostate cancer [49, 50].

As we take a look to very recent studies, Choi et al. described a phantom model for simulation and quantitative evaluation of transurethral resection of the prostate [51]. The phantom mirrors the anatomy and haptic properties of the gland and permits quantitative evaluation of important surgical performance indicators. Mixtures of soft materials are engineered to mimic the physical properties of the human tissue, including the mechanical strength, the electrical and thermal conductivity, and the appearance under an endoscope. Electrocautery resection of the phantom closely resembles the procedure on human tissue. Quantitative criteria for performance assessment are established and evaluated by automated image analysis. According to their results surgery on the phantom was accepted to be useful for medical training [51].

Witthaus et al. incorporated and validated the clinically relevant performance metrics of simulation (CRPMS) in to a novel full-immersion simulation platform

for nerve-sparing robot-assisted radical prostatectomy (NS-RARP) utilizing 3D printing and hydrogel technology [52]. Anatomically accurate models of the human pelvis, bladder, prostate, urethra, neurovascular bundle (NVB) and relevant adjacent structures were created from patient MRI by injecting polyvinyl alcohol (PVA) hydrogels into three-dimensionally printed injection molds. The steps of NS-RARP were simulated: bladder neck dissection; seminal vesicle mobilization; NVB dissection; and urethrovesical anastomosis (UVA). Five experts (caseload >500) and nine novices (caseload <50) completed the simulation. Force applied to the NVB during the dissection was quantified by a novel tension wire sensor system fabricated into the NVB. Post-simulation margin status (assessed by induction of chemiluminescent reaction with fluorescent dye mixed into the prostate PVA) and UVA weather tightness (via a standard 180-mL leak test) were also assessed. Objective scoring, using Global Evaluative Assessment of Robotic Skills (GEARS) and Robotic Anastomosis Competency Evaluation (RACE), was performed by two blinded surgeons. GEARS scores were correlated with forces applied to the NVB, and RACE scores were correlated with UVA leak rates. The correlation of validated objective metrics (GEARS and RACE) with our CRPMS suggests their application as a novel method for real-time assessment and feedback during robotic surgery training [52].

In another study, in a patient who tried to preserve the functions of adrenal hormone secretion in the long term by performing partial adrenalectomy on one side and partial adrenalectomy on the other side, a case presentation was performed preoperatively, the 3D adrenal gland model was produced, and the adrenal gland volume to be used in the patient was calculated and used as a guide during surgery [53]. In a study conducted by Cheung et al. In 2014, a simulator for pediatric pyeloplasty surgery was created with a 3D model produced using silicone material from a model created by processing images of a pediatric patient with ureteropelvic junction stenosis with CAD programs [54].

As considered for andrology training Pinto et al. described an artificial model composed of two vas deferens made with silicone tubes, covered by a White resin, measuring 10 cm in length and internal and external diameters of 0.5 and 1.5 mm, respectively [55]. The holder of the ducts is made by a small box developed with polylactic acid, using a 3D print [55].

13.3.3 Patient Counseling

Today, with the developing technology, patients can easily access most information about their diseases. However, many patients do not have the level of knowledge to understand the current state of the disease, to evaluate different treatment methods that can be applied together with their physician and to decide what is appropriate for their condition. Materials embedded thanks to 3D printer technology can also help clinicians inform patients.

13.3.4 Other 3D Printers Applications in Urology

Del Junco and colleagues made flow dynamics measurements using double j stents (DJS) produced using a 3D printer and a saline solution in a pig model [56]. In another study conducted in 2015, Park and his friends made pressure measurements with DJS produced with a 3D printer that showed anti-reflux feature thanks to the polymeric valves [57]. More, Russo et al. described the new perspectives of 3D printing in andrology [58].

13.4 Future Aspects of 3D Medical Printing in Urology

The area where 3D printer technology is expected to cause the biggest changes in medicine may be the field of tissue engineering. The rabbit urethra, produced by Zhang et al. using organic materials and living cells, can be considered as a step closer to the point that human beings dream of producing living tissues and organs in the laboratory environment and transplanting them to patients [59].

Kim et al. published a very important study that considering the structure establishment of 3D cell culture printing model for bladder cancer [60]. They constructed a 3D cell scaffold using gelatin methacryloyl (GelMA) and compared cell survival in 3D and 2D cell cultures. 3D cell cultures showed higher cancer cell proliferation rates than 2D cell cultures, and the 3D cell culture environment showed higher cell-to-cell interactions through the secretion of E-cadherin and N-cadherin. The effects of drugs for bladder cancer such as rapamycin and BCG showed that the effect in the 2D cell culture environment was more exaggerated than that in the 3D cell culture environment. They fabricated 3D scaffolds with bladder cancer cells using a 3D bio printer, and the 3D scaffolds were similar to bladder cancer tissue [60]. So the technique can be used to create a cancer cell-like environment for a drug screening platform.

13.5 Conclusions

When the current technology is evaluated, it is an indisputable fact that training with models obtained with 3D printers cannot replace the clinical training given on a real case. However, the use of this new technological application in the education of less experienced people, especially at the beginning of the training curve; Reducing the possible complications that may be encountered due to inexperience at the beginning of the training process may be beneficial in terms of increasing patient safety. The use of 3D printed models produced with the help of 3D technologies during preoperative evaluation in many diseases provides a better evaluation of anatomical structures, increases surgical success rates and, reduces complication rates. 3D

printing models are among the most powerful assistants who strengthen the hand of physicians in informing patients and their relatives about the disease and treatment processes. In the future, it is thought that 3D printer technologies will be used more widely in the field of medicine with decreasing costs and increasing prevalence.

References

1. Hull CW. Apparatus for production of three-dimensional objects by stereolithography. Google Patents; 1986.
2. Schubert C, van Langeveld MC, Donoso LA. Innovations in 3D printing: a 3D overview from optics to organs. *Br J Ophthalmol*. 2014;98(2):159–61.
3. Babic RR, Stankovic Babic G, Babic SR, Babic NR. 120 YEARS SINCE THE DISCOVERY OF X-RAYS. *Med Pregl*. 2016;69(9–10):323–30.
4. Cacciamani GE, Okhunov Z, Meneses AD, Rodriguez-Socarras ME, Rivas JG, Porpiglia F, et al. Impact of three-dimensional printing in urology: state of the art and future perspectives. A systematic review by ESUT-YAUWP Group. *Eur Urol*. 2019;76(2):209–21.
5. Parikh N, Sharma P. Three-dimensional printing in urology: history, current applications, and future directions. *Urology*. 2018;121:3–10.
6. Chen MY, Skewes J, Desselle M, Wong C, Woodruff MA, Dasgupta P, et al. Current applications of three-dimensional printing in urology. *BJU Int*. 2020;125(1):17–27.
7. Liaw CY, Guvendiren M. Current and emerging applications of 3D printing in medicine. *Biofabrication*. 2017;9(2):024102.
8. Wong KV, Hernandez A. A review of additive manufacturing. *Int Scholarly Res Notices*. 2012;2012
9. Upcraft S, Fletcher R. The rapid prototyping technologies. *Assem Autom*. 2003;23(4):318–30.
10. Do A-V, Khorsand B, Geary SM, Salem AK. 3D printing of scaffolds for tissue regeneration applications. *Adv Healthcare Mater*. 2015;4(12):1742–62.
11. Ozbolat IT. Scaffold-based or scaffold-free bioprinting: competing or complementing approaches? *J Nanotechnol Eng Med*. 2015;6(2).
12. Sachs EM, Haggerty JS, Cima MJ, Williams PA. Three-dimensional printing techniques. Google Patents; 1994.
13. Malda J, Visser J, Melchels FP, Jüngst T, Hennink WE, Dhert WJ, et al. 25th anniversary article: engineering hydrogels for biofabrication. *Adv Mater (Deerfield Beach, FL)*. 2013;25(36):5011–28.
14. Shirazi SFS, Gharekhani S, Mehrali M, Yarmand H, Metselaar HSC, Adib Kadri N, et al. A review on powder-based additive manufacturing for tissue engineering: selective laser sintering and inkjet 3D printing. *Sci Technol Adv Mater*. 2015;16(3):033502.
15. Kruth J-P, Mercelis P, Van Vaerenbergh J, Froyen L, Rombouts M. Binding mechanisms in selective laser sintering and selective laser melting. *Rapid Prototyp J*. 2005;11(1):26–36.
16. Kim GB, Lee S, Kim H, Yang DH, Kim Y-H, Kyung YS, et al. Three-dimensional printing: basic principles and applications in medicine and radiology. *Korean J Radiol*. 2016;17(2):182–97.
17. Billiet T, Vandenhoute M, Schelfhout J, Van Vlierberghe S, Dubruel P. A review of trends and limitations in hydrogel-rapid prototyping for tissue engineering. *Biomaterials*. 2012;33(26):6020–41.
18. Ghazi A, Campbell T, Melnyk R, Feng C, Andrusco A, Stone J, et al. Validation of a full-immersion simulation platform for percutaneous nephrolithotomy using three-dimensional printing technology. *J Endourol*. 2017;31(12):1314–20.
19. Atalay HA, Ulker V, Alkan I, Canat HL, Ozkuvanci U, Altunrende F. Impact of three-dimensional printed pelviciceal system models on residents' understanding of pelviciceal

- system anatomy before percutaneous nephrolithotripsy surgery: a pilot study. *J Endourol.* 2016;30(10):1132–7.
20. Atalay HA, Canat HL, Ulker V, Alkan I, Ozkuvanci U, Altunrende F. Impact of personalized three-dimensional – 3D-printed pelvicalyceal system models on patient information in percutaneous nephrolithotripsy surgery: a pilot study. *Int Braz J Urol.* 2017;43(3):470–5.
 21. Antonelli JA, Beardsley H, Faddegon S, Morgan MS, Gahan JC, Pearle MS, et al. A novel device to prevent stone fragment migration during percutaneous lithotripsy: results from an in vitro kidney model. *J Endourol.* 2016;30(11):1239–43.
 22. Xu Y, Yuan Y, Cai Y, Li X, Wan S, Xu G. Use 3D printing technology to enhance stone free rate in single tract percutaneous nephrolithotomy for the treatment of staghorn stones. *Urolithiasis.* 2019;
 23. Bianchi L, Schiavina R, Barbaresi U, Angiolini A, Pultrone CV, Manferrari F, et al. 3D Reconstruction and physical renal model to improve percutaneous puncture during PNL. *Int Braz J Urol.* 2019;45(6):1281–2.
 24. Canat L, Atalay HA, Degirmençtepe RB, Bayraktarlı R, Aykan S, Cakir SS, et al. Stone volume measuring methods: should the CT based three-dimensional-reconstructed algorithm be proposed as the gold standard? What did the three-dimensional printed models show us? *Arch Esp Urol.* 2019;72(6):596–601.
 25. Kuroda S, Kawahara T, Teranishi J, Mochizuki T, Ito H, Uemura H. A case of allograft ureteral stone successfully treated with antegrade ureteroscopic lithotripsy: use of a 3D-printed model to determine the ideal approach. *Urolithiasis.* 2019;47(5):467–71.
 26. Smektala T, Golab A, Krolikowski M, Słojewski M. Low cost silicone renal replicas for surgical training – technical note. *Arch Esp Urol.* 2016;69(7):434–6.
 27. Wake N, Rude T, Kang SK, Stifelman MD, Borin JF, Sodickson DK, et al. 3D printed renal cancer models derived from MRI data: application in pre-surgical planning. *Abdominal Radiol (New York).* 2017;42(5):1501–9.
 28. Westerman ME, Matsumoto JM, Morris JM, Leibovich BC. Three-dimensional printing for renal cancer and surgical planning. *Eur Urol Focus.* 2016;2(6):574–6.
 29. Golab A, Słojewski M, Brykczynski M, Lukowiak M, Boehlke M, Matias D, et al. Three-dimensional printing as an interdisciplinary communication tool: preparing for removal of a giant renal tumor and atrium neoplastic mass. *Heart Surg Forum.* 2016;19(4):E185–6.
 30. Jian C, Shuai Z, Mingji Y, Kan L, Zhizhong L, Weiqing H, et al. Evaluation of three-dimensional printing assisted laparoscopic cryoablation of small renal tumors: a preliminary report. *Urol J.* 2020;
 31. Mercader C, Vilaseca A, Moreno JL, Lopez A, Sebastia MC, Nicolau C, et al. Role of the three-dimensional printing technology in complex laparoscopic renal surgery: a renal tumor in a horseshoe kidney. *Int Braz J Urol.* 2019;45(6):1129–35.
 32. Fan Y, Wong RHL, Lee AP. Three-dimensional printing in structural heart disease and intervention. *Ann Transl Med.* 2019;7(20):579.
 33. Kyung YS, Kim N, Jeong IG, Hong JH, Kim CS. Application of 3-D printed kidney model in partial nephrectomy for predicting surgical outcomes: a feasibility study. *Clin Genitourin Cancer.* 2019;17(5):e878–e84.
 34. Wake N, Wysock JS, Bjurlin MA, Chandarana H, Huang WC. “Pin the tumor on the kidney”: an evaluation of how surgeons translate CT and MRI data to 3D models. *Urology.* 2019;131:255–61.
 35. Bejrananda T, Liawrungrueang W. Successful transitional cell carcinoma of bladder underwent laparoscopic radical cystectomy with orthotopic intracorporeal Y pouch neobladder using a 3D digital printing model for surgical post op pouch evaluation. *Urol Case Rep.* 2020;31:101190.
 36. Rutkowski DR, Wells SA, Johnson B, Huang W, Jarrard DF, Lang JM, et al. Mri-based cancer lesion analysis with 3d printed patient specific prostate cutting guides. *Am J Clin Exp Urol.* 2019;7(4):215–22.
 37. Sun G, Ding B, Yu G, Chen L, Wang Z, Wang S, et al. Three-dimensional printing – assisted planning for complete and safe resection of retroperitoneal tumor. *J Xray Sci Technol.* 2020;28(3):471–80.

38. Kusaka M, Sugimoto M, Fukami N, Sasaki H, Takenaka M, Anraku T, et al. Initial experience with a tailor-made simulation and navigation program using a 3-D printer model of kidney transplantation surgery. *Transplant Proc.* 2015;47(3):596–9.
39. Joshi PM, Kulkarni SB. 3D printing of pelvic fracture urethral injuries-fusion of technology and urethroplasty. *Turk J Urol.* 2020;46(1):76–9.
40. Wang H, Guo YT, Jiao Y, He DL, Wu B, Yuan LJ, et al. A minimally invasive alternative for the treatment of nutcracker syndrome using individualized three-dimensional printed extravascular titanium stents. *Chin Med J.* 2019;132(12):1454–60.
41. Hasan T. Is dissection humane? *J Med Ethics Hist Med.* 2011;4:4.
42. Tatar I, Huri E, Selcuk I, Moon YL, Paoluzzi A, Skolarikos A. Review of the effect of 3D medical printing and virtual reality on urology training with ‘MedTRain3DModsim’ Erasmus + European Union Project. *Turk J Med Sci.* 2019;49(5):1257–70.
43. Guliev B, Komyakov B, Talyshinskii A. The use of the three-dimensional printed segmented collapsible model of the pelvicalyceal system to improve residents’ learning curve. *Turk J Urol.* 2020;46(3):226–30.
44. Aro T, Lim S, Petrisor D, Koo K, Matlaga B, Stoianovici D. Personalized renal collecting system mockup for procedural training under ultrasound guidance. *J Endourol.* 2020;34(5):619–23.
45. Melnyk R, Ezzat B, Belfast E, Saba P, Farooq S, Campbell T, et al. Mechanical and functional validation of a perfused, robot-assisted partial nephrectomy simulation platform using a combination of 3D printing and hydrogel casting. *World J Urol.* 2020;38(7):1631–41.
46. Wang Y, Gao X, Yang Q, Wang H, Shi T, Chang Y, et al. Three-dimensional printing technique assisted cognitive fusion in targeted prostate biopsy. *Asian J Urol.* 2015;2(4):214–9.
47. Nguyen LN, Head L, Witiuk K, Punjani N, Mallick R, Cnossen S, et al. The risks and benefits of cavernous neurovascular bundle sparing during radical prostatectomy: a systematic review and meta-analysis. *J Urol.* 2017;198(4):760–9.
48. Jomoto W, Tanooka M, Doi H, Kikuci K, Mitsue C, Yamada Y, et al. Development of a three-dimensional surgical navigation system with magnetic resonance angiography and a three-dimensional printer for robot-assisted radical prostatectomy. *Cureus.* 2018;10(1):e2018-e.
49. Wendler JJ, Klink F, Seifert S, Fischbach F, Jandrig B, Porsch M, et al. Irreversible electroporation of prostate cancer: patient-specific pretreatment simulation by electric field measurement in a 3D bioprinted textured prostate cancer model to achieve optimal electroporation parameters for image-guided focal ablation. *Cardiovasc Intervent Radiol.* 2016;39(11):1668–71.
50. Wang J, Zhang F, Guo J, Chai S, Zheng G, Zhang K, et al. Expert consensus workshop report: Guideline for three-dimensional printing template-assisted computed tomography-guided 125I seeds interstitial implantation brachytherapy. *J Cancer Res Ther.* 2017;13(4):607.
51. Choi E, Adams F, Palagi S, Gengenbacher A, Schlager D, Muller PF, et al. A high-fidelity phantom for the simulation and quantitative evaluation of transurethral resection of the prostate. *Ann Biomed Eng.* 2020;48(1):437–46.
52. Witthaus MW, Farooq S, Melnyk R, Campbell T, Saba P, Mathews E, et al. Incorporation and validation of clinically relevant performance metrics of simulation (CRPMS) into a novel full-immersion simulation platform for nerve-sparing robot-assisted radical prostatectomy (NS-RARP) utilizing three-dimensional printing and hydrogel casting technology. *BJU Int.* 2020;125(2):322–32.
53. Srougi V, Rocha BA, Tanno FY, Almeida MQ, Baroni RH, Mendonca BB, et al. The use of three-dimensional printers for partial adrenalectomy: estimating the resection limits. *Urology.* 2016;90:217–20.
54. Cheung CL, Looi T, Lendvay TS, Drake JM, Farhat WA. Use of 3-dimensional printing technology and silicone modeling in surgical simulation: development and face validation in pediatric laparoscopic pyeloplasty. *J Surgic Educ.* 2014;71(5):762–7.
55. Pinto L, de Barros CAV, de Lima AB, Dos Santos DR, de Bacelar HPH. Portable model for vascotomy reversal training. *Int Braz J Urol.* 2019;45(5):1013–9.
56. del Junco M, Yoon R, Okhunov Z, Abedi G, Hwang C, Dolan B, et al. Comparison of flow characteristics of novel three-dimensional printed ureteral stents versus standard ureteral stents in a porcine model. *J Endourol.* 2015;29(9):1065–9.

57. Chang-Ju P, Hyeon-Woo K, Sangdo J, Seungwan S, Yangkyu P, Sang MH, et al. Anti-reflux ureteral stent with polymeric flap valve using three-dimensional printing: an in vitro study. *J Endourol.* 2015;29(8):933–8.
58. Russo GI, Di Mauro M, Cimino S. Use of 3D printing in andrological surgery: what are the new perspectives. *Int J Impot Res.* 2019;
59. Zhang K, Fu Q, Yoo J, Chen X, Chandra P, Mo X, et al. 3D bioprinting of urethra with PCL/PLCL blend and dual autologous cells in fibrin hydrogel: an in vitro evaluation of biomimetic mechanical property and cell growth environment. *Acta Biomater.* 2017;50:154–64.
60. Kim MJ, Chi BH, Yoo JJ, Ju YM, Whang YM, Chang IH. Structure establishment of three-dimensional (3D) cell culture printing model for bladder cancer. *PLoS One.* 2019;14(10):e0223689.