Innovations in Urology: Focus on 3D Printing

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Overview

The world of medicine has witness numerous innovations over last few decades, and the trend is likely to continue in near future with emergence of novel modalities having applications in diagnostics, therapeutics and related domains. One such enticing innovation that seems to have gained increased attention among the clinical researchers and practitioners is the rise of three-dimensional (3D) printing, which allows three-dimensional renderings to be realized as physical objects with the use of a printer. The technique has revolutionized prototyping and found applications in many nonmedical fields, while in medicine, it could have applications in various surgical and other disciplines.[1] This mini-review discuses about the potential applications of this interesting technical in the field of urology.

Three-dimensional (3D) printing has several potential applications in surgical practice and research, with a constantly improving quality contributing to its increased use on patients' related outcomes. Especially, the need for improved visualization and surgical outcomes has given rise to 3D-printed anatomical models, patient-specific guides, and 3D-printed prosthetics. As such, some typical applications vary from anatomical models mainly intended for surgical planning to surgical guides and implants; though 3D-printed objects can also be used to study complex cases, to practice procedures, and to teach students and patients.[2]

Three-dimensional printing thus has the potential to enhance patient-specificity of pre-operative counselling, surgical simulation, implantable prostheses and even transplant organs. It could allow customizable surgical instruments to be shared digitally, adjusted to preference and then produced as required. Nevertheless, as the technique is still in its nascent stage, high cost related to this novelty appears a major limitation at least currently; with 3D-printers used in surgical research ranging in price from $2000 to $900,000 this resource requires investment. Besides, maintenance, cartridge consumables, specialist software for converting medical imaging into printable format and the computer hardware further add to the setup costs, making these printers beyond the budget of most urologic practices.[2,3] Table 1 enlists some of the benefits and limitations of 3D printing in urology/nephrology.[4] Figures 1 and 2 Illustrate some products of 3D printing and a range of 3D printers.[2]

Generally, plastics are the most widely used materials in 3D printing; however, 3D printers are not limited to using plastics only, and other metals and materials like steel, titanium, gold, silver, nylon, glass-filled polyamide, epoxy resins, wax, and photopolymers can also be applied.[3]

Table 1: Benefits and challenges of 3D Printing within the field of urology/nephrology

Benefits	Challenges
• More relevant models and less dependency on animal testing • Improved survival rates and quality of life • Reduction or elimination of organ waiting lists • Elimination of organ rejection • Reductions in the illegal trade of organs	• Complexity of printing process • Complexity of design software • Mimicking organ functions • Potential (behavioral) trivialization • Technological limitations

Source: Neu R. 3D Printing: A Revolutionary Advance for the Field of Urology? *Technology Innovation Management Review.* 2014;19-24.

Figure 1: Some models made via 3D printing or 3D printed molds including a renal tumor model (left), liver (center), femoral head (right), and skin (right)

Source: Mathews DAP, Baird A, Lucky M. Innovation in Urology: Three Dimensional Printing and Its Clinical Application. *Front Surg.* 2020;7:29.

Figure 2: Some 3D printers in use at 3D LifePrints hub at Alder Hey Children's Hospital, Liverpool

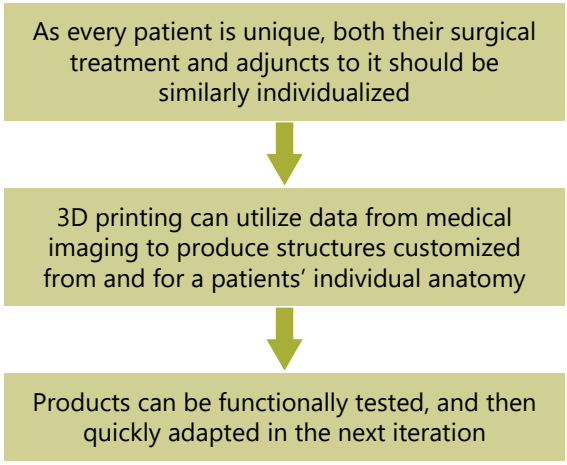
Source: Mathews DAP, Baird A, Lucky M. Innovation in Urology: Three Dimensional Printing and Its Clinical Application. *Front Surg.* 2020;7:29.

Application of 3D Printing to the Field of Urology

Patient-Specific Prostheses & Bioprinting

With continuing advancements, the scope of research and development, design, marketing, and consumerism of the 3D-printing industry is likely to expand and evolve. At present, though in early stages, 3D printing has found applications within the field of urology with the promise of organ generation. And this could be particularly promising given the continuously increasing need of organ donors as the number of patients with chronic renal failure rises.[3] A typical characteristics of 3D printing that could help in this endeavour is that it allows rapid prototyping of novel equipment and the translation of medical imaging into tangible replicas of patient-specific anatomy (Figure 3).[2] In fact, researchers have demonstrated how organs with complicated vascular systems could be replicated with sophisticated 3D-imaging technologies, thereby allowing creation of an accurate representation of the organ's intricate, detailed, internal characteristics.[3] A biological blueprint can be formulated, and a new organ can then be printed using patient's own harvested cells. Like this, many urologic problems might be solved with the innovation of 3D printing: for instance, replacing damaged sphincters, either urethral or ureteric, with biofabricated ones; replacing a damaged ureter with a biofabricated ureter in place of ureteric stents or taking part of the ileum to fashion a ureter; or to create a urethra in order to treat patients with long urethral strictures.

Figure 3: Primary rationale for 3D printings' increasing utilization within urology

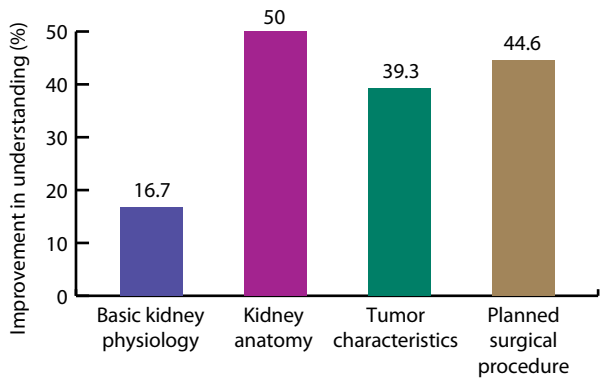


Source: Mathews DAP, Baird A, Lucky M. Innovation in Urology: Three Dimensional Printing and Its Clinical Application. *Front Surg.* 2020;7:29.

Patient Education

Three-dimensional modules, which allow accurate modelling of individual patients' anatomy, could play a major and significant role in patient education also. Considering related application in urology, it has been observed that 3D-created kidney models with transparent resin for renal parenchyma showing tumor, vasculature, and collecting system in patients awaiting partial nephrectomy can improve the patients' understanding of the kidney anatomy and patho-physiology. In a prospective pilot

Figure 4: Improvement in patients' understanding of renal characteristics after viewing their personal 3D kidney model



Source: Bernhard JC, Isotani S, Matsugasumi T, *et al.* Personalized 3D printed model of kidney and tumor anatomy: a useful tool for patient education. *World J Urol.* 2016;34(3):337-45.

study designed to present initial clinical experience with 3D printing to facilitate patients' pre-surgical understanding of their kidney tumor and surgery, seven patients with a primary diagnosis of kidney tumor who were being considered for partial nephrectomy were included. The results showed that after viewing their personal 3D kidney model, patients demonstrated an improvement in understanding of basic kidney physiology by 16.7%, kidney anatomy by 50%, and tumor characteristics by 39.3% and the planned surgical procedure by 44.6% (Figure 4).[5] In another study investigating the impact of personalized 3D printed pelvicalyceal system models on patient information before percutaneous nephrolithotripsy surgery, patients demonstrated an improvement in their understanding of basic kidney anatomy by 60%, kidney stone position by 50%, the planned surgical procedure by 60%, and understanding the complications related to the surgery by 64%. In addition, overall satisfaction of conservation improvement was 50%.[6] The approach could therefore be employed for various urologic surgeries, given the fact that understandings of the disease and the surgical procedure from patients were well appreciated with this novel technology.[2]

Surgical Planning

While at one end, 3D models could increase patients' awareness and knowledge about their organs' structure; these models could in fact be useful even for experienced healthcare professionals. In fact, it has been observed that 3D models could (i) change experienced urologist's planned surgical approach for treatment of a renal tumor when compared to that with imaging alone, and (ii) the planned approach based on a 3D-printed model was more likely to be followed than one based on 2D imaging.[2,7] More importantly, the 3D printed models could help to increase the urologist's confidence regarding the chosen operative procedure. In a study, patient-specific 3D models of kidney units with suspected malignancies were developed to allow pre-operative surgical simulation, and partial nephrectomy and renorrhaphy were performed on each of the replicas. Subsequently, patients successfully underwent robotic partial nephrectomy. A comparison was made between the cases and the a prospectively maintained robotic partial nephrectomy database. The results of the comparison showed that patients with surgical models demonstrated fewer positive surgical margins, lower estimated blood loss, shorter hospitalization, and fewer post-operative complications.[8]

Surgical Training

Surgical training is another potential area where 3D printing could have immense application. As mentioned earlier, it is established that 3D models provide better and improved visualization of the organ and surgical pathology, adds to the surgical planning decision and also the confidence of the operating surgeons. This confidence could possibly be the outcome of experiences that uro-surgeons would gain by working on these realistic patient-centric 3D models. In a recently conducted comparative analysis of cloaca imaging in advancing the surgeon's understanding of complex anatomy, authors noted that with novel surgical education resources of a 3-D cloacagram, a more quickly advancing skill is possible amongst surgeons who otherwise have a steep learning capacity to understand 2-D images provided by conventional cloacagrams.[9] Such a simulation utilizing 3D-printing has been described for a myriad of urology procedures, such as partial nephrectomy, pyeloplasty, robot-assisted prostatectomy, robot-assisted kidney transplant, vasectomy reversal, and transurethral resection of the prostate (TURP). Furthermore, simulation seems to present a reproducible and uniform means to assess the trainee performance both subjectively and with quantitative metrics.[2] Recently, Choi and colleagues developed a high-fidelity phantom for the simulation and quantitative evaluation of TURP, using mixtures of soft materials engineered to mimic the physical properties of the human tissue; and demonstrated that surgery on the phantom is useful for training.[10]

Future Directions

A rise in interest on the use of 3D-printing is clearly evident in both the industry and the academia. While continuing

advancements are being made in the technology, there is also a rapid increase in the published research on this novel method. As follows, both the proposed and potential applications of 3D printing, not only in urology but many other medical specialities, seems to be expanding. Within urology, the scope of novel developments typically showcases the freedom to innovate and rapidly prototype afforded by 3D printing.[2] At present, the major focus of 3D printing in urology appears to be on the tangible models of patient anatomy to enhance patient understanding, surgical planning and simulation training. Nevertheless, as this bioprinting promises major potential advances in patient-specific grafts in the future, it is believed that rapid prototyping together with network sharing and development of ideas would prove pivotal in ongoing surgical innovation.

Conclusion

Three-dimensional printing is novel technology with immense advantages and capabilities, ranging from patient education, clinical decision making to the training of the surgeons. Although these explorations of its urological applications remain nascent currently, the seemingly limitless scope for innovation afforded by the technology presents undeniable value as a useful resource with several applications. At present, since the technology is in its initial stages, a major interest is to determine whether the increased intervention costs can be balanced with its observable advantages. Nevertheless, with time, it is believed that this gap might be filled as the technology gains more widespread acceptance in the real-world. Till then, distinguishing potential from proven advantage seems the key to guiding research and future practice of 3D printing in urology.

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