3D Printing and Its Urologic Applications

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3D printing is the development of 3D objects via an additive process in which successive layers of material are applied under computer control. This article discusses 3D printing, with an emphasis on its historical context and its potential use in the field of urology.

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KEY WORDS

3D printing • Medical applications of 3D printing • Urologic applications of 3D printing • Biofabrication

A 3D printer is unlike the printers most commonly used in a urology office. 3D printing is also known as desktop fabrication or additive manufacturing. It is a prototyping process whereby a real object is created from a 3D computer-created design. The digital 3D model file is sent to the 3D printer, which prints the design one layer at a time, forming a 3D object.[1]

The smallest 3D printer weighs 1.5 kg and costs approximately $1600. The biggest drawback for the individual small practice user is the relatively high cost of the printer.[2] In addition to the cost of the hardware, the professional 3D software and 3D model design are likewise expensive[3] and is beyond the budget of most urologic practices. A list of commercial 3D printers currently available is shown in Table 1.

Methods

A review of the medical literature was conducted to examine the application of 3D printing to medicine in general and urology in particular.

Materials Used in 3D Printing

Currently, plastics are the most widely used materials in 3D printing; however, 3D printers are not limited to using plastics. Metals used in 3D printing include steel, stainless steel, titanium, gold, and silver. Other manufacturing materials that can be used for 3D printing include nylon, glass-filled polyamide, epoxy resins, wax, and photopolymers.[1,4] There are 3D printers that can make use of several materials at the same time. These multijet 3D printers can create models offering a range of textures, colors, strength, and malleability.

TABLE 1

3D Printer Manufacturers

Industrial 3D-Printer Manufacturers	
	Stratasys (Eden Prairie, MN)
	3D-Systems (Rock Hill, SC)
Personal 3D-Printer Manufacturers	
	Reprap.org (Bath, United Kingdom)
	Makerbot Industries (New York, NY)
	Ultimaker (Geldermalsen, Netherlands)
	Fab@Home (Cornell University; Ithaca, NY)

3D-Printing Software

There are a number of unique 3D printing programs that are free, open-source content, which means that anyone can access the software and create 3D print templates. *SketchUp* (Trimble Navigation, Sunnyvale, CA) is one of several user-friendly software programs. The program has a short learning curve; for example, with the *SketchUp* "Push/Pull" tool, you can extrude any flat surface into a 3D form.

With 3D printing, it may soon be possible to make a body part from inert materials in just a few hours.

Medical Applications of 3D Printing

3D printing has existed for over a decade in the medical field, but, until recently, its use was limited mostly to dentistry and orthopedics. However, as printers and software become more widely available, there is a rapid increase in the use of 3D printing in medicine.

The applications of 3D technology in the medical arena are unlimited. It is possible for surgeons to produce facsimiles of their patients' body parts that need to be removed or replaced. With 3D printing, it may soon be possible to make a body part from inert materials in just a few hours. The technology enables developers and designers to transform objects from a projection on a monitor to a 3D-printed organ or tissue.

A study published in *Urology* describes how accurate models of patients' kidneys, including their malignancies, have been constructed using 3D printing technology. This helps doctors explain pathology to their patients and will help students, residents, and fellows enhance their surgical skills.[5]

Additionally, 3D printing has been clinically used to print patient-specific implants and devices.[6] Successful operations include an implant of a titanium pelvis, the implantation of a titanium lower jaw, and a plastic tracheal splint implanted in an infant. The hearing aid and dental industries are expected to be strong areas of future development using custom 3D printing technology. In March 2014, surgeons in Swansea, Wales, used 3D-printed parts to rebuild the face of a motorcyclist who had been seriously injured in an accident. Moreover, research is being conducted on methods to bioprint replacements for tissue lost due to arthritis and cancer.[7] Biomaterials have been used to replace damaged human tissue by printing a cellular "scaffold" to enable the cells in the organ to bridge the gap of missing tissue.[8]

3D printing has been successfully used in orthopedics for casts that fit snugly to the patient's extremity, providing lightweight, strong support to protect the fracture site. These casts are washable, eco-friendly, and shower friendly.

Moreover, 3D-printed prosthetics have been used in veterinary medicine for rehabilitation of injured animals. In 2013, a 3D-printed foot allowed an injured duckling to walk again. In 2014, a Chihuahua born without front legs was fitted with a harness and wheels created with a 3D printer.[9]

In addition to the aforementioned uses, 3D printing has been studied by biotechnology firms and academia for possible use in tissue-engineering applications for building organs and body parts using inkjet techniques. In this process, layers of living cells are deposited onto a gel medium or sugar matrix and slowly layered to form 3D structures, including the vascular supply to the organ. The first production system for 3D tissue printing was delivered in 2009, based on NovoGen (Hornsby, NSW, Australia) printing technology, which allows scientists to assemble living tissue cells into a desired pattern. When combined with an extracellular matrix, the cells can be arranged into complex structures, such as human organs. Designed by Organovo (San Diego, CA),[10] the NovoGen technology has been successfully integrated with a production printer that is intended to develop processes for tissue repair and organ development.[11]

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China has committed a value of $500 million toward the establishment of 10 national 3D-printing development institutes focusing on medical applications of 3D printing. In 2013, scientists in China began printing ears, livers, and kidneys, using specialized 3D bioprinters that use living cells.[12,13] These printers take less than 1 hour to produce a small liver or ear cartilage.

The use of 3D printing within the medical field, such as in the synthesis of replacement organs, could have the potential to affect significant social change.[14,15] Because 3D printing produces products customized for each patient, subsequent alteration of the product will not require significant retooling, but only involves small changes of code in a design file.[16] This new approach holds significant benefits, including customized prosthetic limbs, the generation of ceramic scaffold use in bone replacement therapies,[14,17] and applications in organ biofabrication.[18]

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Urologic Applications of 3D Printing

What started as the replication of simple objects has progressed into a sophisticated industry for the fabrication of detailed products. As a result, conventional forms of manufacturing will become obsolete, and the scope of research and development, design, marketing, and consumerism of the 3D-printing industry will certainly change.

Recently, 3D printing has found applications within urology with the promise of organ generation.[18] The increase of aging populations in developed countries has accelerated the need for replacement organs. Unfortunately, the number of organ donors has remained static. Specifically, in the fields of urology and nephrology, the need for organ donors is continuously increasing as the number of patients with chronic renal failure rises.[16]

Researchers have demonstrated how organs with complicated vascular systems, such as the kidney and liver, could be replicated with sophisticated 3D-imaging technologies, allowing physicians to create an accurate representation of the organ's intricate, detailed, internal characteristics. A biological blueprint can then be formulated, and a new organ can be printed, using the patient's own harvested cells.[7]

The process of biofabrication involves the deposition of living cells and other biological materials to be developed into new human organs.[19] Bioprinting must be flexible and accommodate a broad variety of materials, including organ-specific cells, blood vessels, smooth muscle, and endothelial cells.[20] This technology could ultimately revolutionize the fields of urology, nephrology, and transplant surgery, reducing or eliminating the need for organ donors. This, in turn, would eliminate complications arising from immunosuppression and transplant rejection because the technology uses the patient's own cells, which are compatible and not challenged by the patient's immune system. In the United States, a kidney transplant costs $80,000, followed by $13,000 annual costs for antirejection medication, with a total cost of approximately $260,000 for each patient requiring transplantation.[21] As 3D-printing technology becomes more refined, creating a functioning kidney would be more cost effective than the current standard of care.

It is not sufficient to produce only a structural replication of an organ; the new organ must be able to perform all of its clinical functions before being transplanted into a patient. For example, if a bioprinted kidney is incapable of secreting erythropoietin, then the organ is not fully functional to the patient. For the printed organ to fully replace the original organ, complex structures containing cells of different types must be printed.[22]

Another technology that has been used in urology involves bladder replacement. This process takes a very small postage stamp-sized piece of the patient's bladder. The transitional and smooth muscle cells proliferate outside the body. A bladder scaffold is covered with the patient's own cells. Within a few weeks, the engineered organ can be implanted into the patient. For patients with severely damaged bladders, the urologist sutures this functioning 3D bladder to the patient's ureters and to the urethra.[22,23]

This technology could ultimately revolutionize the fields of urology, nephrology, and transplant surgery, reducing or eliminating the need for organ donors.

Many other urologic problems might be solved with the innovation of 3D printing. Damaged sphincters, either urethral or ureteric, could be replaced with biofabricated ones. This may solve the problem for patients who receive treatment for a damaged sphinter with little progress which results in a decreased quality of life. A damaged ureter can be replaced with a biofabricated ureter in place of ureteric stents or taking part of the ileum to fashion a ureter. The same process could be possible to create a urethra in order to treat patients with long urethral strictures.

Discussion

As with any new technology, there is likely to be some degree of resistance, which may impede the adoption of the technology. Support from all levels of management and the identification of champions for the technology are key ingredients for encouraging adoption. There will need to be cooperation in academia in order to expose the health care industry to this new technology.[15,16]

To make this technology and organ creation more applicable to clinical medicine, it will require progress in software design and standardization of kidney bioprinting techniques. Such software can be complex,[15,16] as the printing needs to consider the body's intricate vascular system. For development of this technology, financial resources will need to be obtained, perhaps through a national project that includes health care systems, software developers, industry, and training programs. Finally, medical education will need to include training on the use of 3D printing, as this will become an integral part of the future of medicine.

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Conclusions

Urology has seen tsunamic forces challenge the current treatment status quo. Examples from the past few decades include extracorporeal shockwave lithotripsy, laparoscopic surgery, robotic surgery, phosphodiesterase inhibitors, and new techniques for imaging. 3D printing is going to create monumental changes in health care, and in urology in particular. With 3D printing we are witnessing an exciting new technology that will make a difference to medicine, to urologists, and to our patients. ■

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MAIN POINTS

- 3D printing (also known as desktop fabrication or additive manufacturing) is a prototyping process whereby a real object is created from a 3D computer-created design.
- Plastics are currently the most widely used materials in 3D printing; however, 3D printers are also capable of using stainless steel, titanium, gold, and silver. Other manufacturing materials that can be used for 3D printing include nylon, glass-filled polyamide, epoxy resins, wax, and photopolymers.
- Previously limited to primarily dentistry and orthopedics, there has been a recent increase in the use of 3D printing in other fields of medicine. For example, it is possible for surgeons to produce facsimiles of their patients' body parts that need to be removed or replaced. With 3D printing, it may soon be possible to make a body part from inert materials in several hours.
- 3D printing has also been studied by biotechnology firms and academia for possible use in tissue-engineering applications for building organs and body parts using inkjet techniques. In this process, layers of living cells are deposited onto a gel medium or sugar matrix and slowly layered to form 3D structures.
- Making technology more applicable to clinical medicine will require software design progress and standardization of organ-bioprinting techniques. Medical education will need to include training on the use of 3D printing if it is to become an integral part of medicine in the future.

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