Narrative review of 3D imaging for preoperative planning in urology

Fabrizio Gallo[1], Alberto Caviglia[2], Martina Beverini[2], André Van der Merwe[3], Heidi Van Deventer[3], Maurizio Schenone[1], Carlo Terrone[2], Guglielmo Mantica[2,3]

[1]Department of Urology, San Paolo Hospital, Savona, Italy; [2]Department of Urology, Policlinico San Martino Hospital, University of Genova, Genova, Italy; [3]Department of Urology, Stellenbosch University and Tygerberg Hospital, Cape Town, South Africa

Contributions: (I) Conception and design: F Gallo, A Caviglia; (II) Administrative support: All authors; (III) Provision of study materials or patients: All authors; (IV) Collection and assembly of data: M Beverini, A Caviglia, F Gallo; (V) Data analysis and interpretation: All authors; (VI) Manuscript writing: All authors; (VII) Final approval of manuscript: All authors.

Correspondence to: Guglielmo Mantica. Department of Urology, Ospedale Policlinico San Martino, University of Genoa, Genoa, Italy. Email: guglielmo.mantica@gmail.com.

Abstract: In the current era, the implementation of robotic-assisted or standard laparoscopic surgery has resulted a minimally-invasive approach for the treatment of most genitourinary malignancies. The aim of minimally invasive approaches and related tools is to highlight the precision of surgery and improving outcomes. During the last years 3D modeling has emerged as a novel, exciting, and effective tool in the hands of patients, trainees, naive and experienced surgeons, especially in the field of urology. In particular, patient-specific 3D models have been introduced as tools for providing accurate anatomical details of the patient organs for preoperative planning. The aim is to reduce intraoperative complications and the operative time and to improve patient safety. This technology has been finding fertile ground in the field of focal surgery, where the correct identification of the area to be removed is of fundamental importance for the success of the operation and the achievement of excellent outcomes. In general, these 3D models can be virtual, printed or augmented-reality (AR) and are based on high resolution imaging such as multiparametric magnetic resonance (mp MRI) imaging or computed tomography scans (CT scan). The aim of this narrative review is to provide an overview of the current use of these 3D models for preoperative planning in urological surgery.

Keywords: 3D models; virtual 3D models; 3D urology; augmented-reality (AR)

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Introduction

In the current era, the implementation of robotic-assisted or standard laparoscopic surgery has resulted a minimally-invasive approach for the treatment of most genitourinary malignancies (1-3). The aim of minimally invasive approaches and related tools is to highlight the precision of surgery and improving outcomes.

Over the last years, patient-specific 3D models have been introduced as tools for providing accurate anatomical details of the patient organs for preoperative planning. The aim is to reduce intraoperative complications and the operative time and to improve patient safety (4).

In general, these 3D models can be virtual, printed or augmented-reality (AR) (*Table 1*).

The virtual models are firstly modeled using 3D modelling tools to create the organs 3D geometries and subsequently rendered using computer graphics techniques. 3D printing is process of making three dimensional solid organs from the digital file, in order to create model easily handled by surgeons and patients. The AR is a mixture of reality and virtuality that allows anatomy and organs to be augmented with additional information (5-7). The expression AR refers to the

Table 1 Types and characteristics of 3D models for preoperative planning

Type	Characteristic
Virtual	3D models created using rendering technologies and available on devices as virtual images
Printed	3D printed solid model that can be easily handled by surgeons
Augmented-reality	Mixture of reality and virtuality that allows anatomy and organs to be augmented with additional information

superimposition of images, obtained preoperatively, to the real-time image of the intervention. The image must be aligned with the surgical instruments, but also with the organ and surrounding tissues, which will be manipulated during the surgery.

Usually, these models are based on high resolution imaging such as multiparametric magnetic resonance (mp MRI) imaging or computed tomography scans (CT scan). This technology, available to the surgeon in the preoperative setting, is leading to a further evolution of minimally invasive surgery and in urology as we know it.

The aim of this narrative review is to provide an overview of the current use of these 3D models for preoperative planning in urological surgery. We present the following article in accordance with the Narrative Review reporting checklist (available at https://amj.amegroups.com/article/view/10.21037/amj-20-175/rc).

Methods

A non-systematic literature search of PubMed and EMBASE databases was carried out in August 2020 in order to select relevant papers published between 1990 and 2020, providing data on the use of 3D imaging for preoperative planning in urology. The inclusion criteria were studies published in English language and studies reporting results, type of model and outcomes.

Discussion

In the field of medicine, and especially surgery, urology is one of the branches that first saw the spread of 3D models as tools for both training and preoperative planning of particularly complex surgical interventions. In particular, in recent years it has been finding fertile ground in the field of focal surgery, where the correct identification of the area to be removed is of fundamental importance for the success of the operation and the achievement of excellent outcomes.

Prostate surgery

Virtual and printed models

Currently there are few studies about 3D models applied to the prostate surgery. Nevertheless, the first studies published on this topic focused on the evaluation of the usefulness of such technology in order to perform "cognitive" procedures.

One of the areas where this technology could be of most help is in the knowledge of the location of the prostate cancer nodule and its relationships with neurovascular bundles (NVBs) and the prostate capsule. Having more detailed information through 3D images could allow the surgeon to approach better the NVBs and modulate the surgery (8).

Chandak *et al*. reported that tactile interaction with a printed model during robot-assisted radical prostatectomy (RARP) allowed the surgeon to perform incremental nerve spare or wider excision of the NVBs around the palpable tumours (9).

A survey of the 2018 by Porpiglia *et al*. revealed, about the role of the 3D printed models, that this technology can improve both oncological outcomes and the preoperative planning (10).

AR

At the moment, all the available and tested tools are based on rigid prostate models and these lead to a static view which do not simulate the necessary biological tissue deformation and do not create dynamic overlapping, which can be used during, for example the nerve-sparing phase, in which the prostate shape is deformed by the traction exerted by the robotic arms (4).

A first experiment in prostate cancer surgery was made, in 2013 by Thompson *et al*. who evaluated an image-guided system for robotic radical prostatectomy overlaying MRI scans over the prostate anatomy during surgery (8).

In the 2018, Porpiglia *et al*. published a work on the use of AR during RARP and they recently updated their results where the final pathology examination confirmed the location of the index lesion as indicated by 3D reconstruction in 100% of cases. The authors concluded find out that the index lesion was located in the same area of the prostate as it was seen at the preoperative images. Furthermore, The mean (SD) prostate volume of the 3D model based on mpMRI was 44.5 (13.8) mL, whilst the mean (SD) volume of the 3D reconstruction based on prostate specimens scan was 43.2 (16.1) mL, without a significant difference between the two (P>0.05). The AR-guided surgery confirmed the extracapsular involvement in the 79% of the patients and the mismatch between the 3D reconstruction and scanning was <3 mm in the 85% of the prostate surface. Positive surgical margins were positive in 23.3% of cases. So, they conclude that, when tested by expert prostate surgeons, it can be helpful, especially in the key steps of the intervention (11,12).

Kidney surgery

Virtual models and printed models

At the moment most of the studies concern the nephron-sparing surgery.

Concerning that the use of three-dimensional technology would seem to be able to bring a better preoperative planning, especially in the case of complex tumors, in which the traditional imaging, then two-dimensional, may be insufficient. Furthermore, it would appear to be an important tool as regards the surgical indication itself (4,13).

von Rundstedt *et al*., succeeded in demonstrating that there is a correlation between the three-dimensional model of the tumor and its characteristics in terms of morphology and volume on pathological examination. In particular, there was no significant difference in volumes between the original 3D reconstruction from the CT scan, the resected pre-surgical model, and the resected tumor specimen. Furthermore, one of 10 patients had a positive margin on final pathology, with tumor only focally present at the resection margin. In preoperative evaluation, it is shown that 3D models can influence surgical indications (14).

Similarly, Wake *et al*. find out that with a 3D printed models of the kidneys and of the tumor mass, 30–50% of surgeons decided to change the surgical approach from what they had previously planned (15-17).

Sun *et al*. performed a systematic review in 2018 including fifteen studies focusing on 3D printed models the replicate renal anatomy and tumor and the precision of the measure between the tridimensional models, the original images and the surgical findings. They find out an improved patient understanding of the surgery, an improving of the understanding about kidney malignancies, anatomy and surgery by medical students and, most important, a significant reduction of intraoperative complications and surgery time (18).

AR

As for the printed models, most of the studies evaluated the usefulness of the AR mostly about partial nephrectomy.

In 2009, Su *et al*. tested a real-time image overlay system with preoperative CT images and found a discrepancy of only 1mm between the superimposed images and the operative field (19).

Wake *et al*., in the 2018, published a video article about the AR for kidney models to be used during robotic nephron-sparing surgery. They use the AR to assist the surgeon both pre-, for the planning, and intraoperatively. The authors concluded that the use of 3D AR models resulted in being safe and feasible (17).

Endourology

To date, the standard approach for the treatment of a kidney stone >2 cm or for multiple or lower calyx stones remains percutaneous nephrolithotomy (PCNL). Difficulties are usually encountered in obtaining adequate access and obtaining a high stone-free rate, as well as a low complication rate. For all reasons, among all endourological procedures, PCNL requires careful preoperative planning and that is why numerous three-dimensional models are being developed (20).

At the moment, for the PCNL are described only printed 3D models. Surely, virtual models are performed to create the printed one, but their use in preoperative and intraoperative assessment has not yet entered surgical practice, such as the AR that we described before for kidney and prostate surgery.

The kidney has a complex structure with a high variability of both the calicopyelic system and the shape and shape and size of the pelvis. Therefore, it becomes fundamentally to produce an anatomically correct and manipulable three-dimensional organ for simulations and for preoperative planning.

Most of the scientific evidence has shown that patient-specific preoperative planning based on 3D technology can lead to an improvement in operating times, the stone-free rate, a reduction in both the fluoroscopy time and the percutaneous access attempts (21,22).

Antonelli *et al*. studied a simplified pelvicalyceal system (PercSac) and demonstrated its advantages in preventing stone migration during the lithotripsy phase. In particular, they found a median time for stone fragmentation to be significantly shorter in the PercSac group compared with the control group [217 s (IQR, 169–255 s) *vs.* 340 s (IQR, 310–356 s); P=0.028]. Likewise, the total time for complete stone clearance from the kidney was significantly shorter for the PercSac group [293 s (IQR, 244–347 s) *vs.* 376 s (IQR, 375–480 s); P=0.047] (23).

The use of CT images for the three-dimensional reconstruction of the pelvicalyceal system and stones can lead to an improvement both in the preoperative setting and when it comes to patient selection.

In addition, a 3D system simplifies the study of the renal hilum and the vascular system of the kidney in question in order to reduce the risk of vascular lesions (24).

An accurate three-dimensional model can allow a better visualization of the dilation of the renal calyxes and their conformation, or it can highlight the number of stones or the conformation of a staghorn stone.

Finally, it allows us to deepen the relationship between the kidney and the surrounding anatomical structures such as, for example, lungs, liver, colon or spleen (20,24).

Reconstructive surgery

At the moment there are no studies about the usefulness of the 3D imaging in the reconstructive surgery in the preoperative study, for example in case of complex urethral strictures.

Instead there are some *in vitro* and *in vivo* studies that highlight the use of 3D technology to create grafts for urethroplasties.

For example, Zhang *et al.* (2017), studied, on an animal model, the use of a 3D bioprinting technology for the creation, in vitro, of an urethra using polymers on which they made urothelial and smooth muscle cells grow. The result would appear promising and the reconstructed urethra seems to maintain the elasticity and dynamism characteristics of the native urethra (25).

Critical overview

During the last years 3D modeling has emerged as a novel, exciting, and effective tool in the hands of patients, trainees, naive and experienced surgeons, especially in the field of urology.

As an educational vehicle, it has received a long-awaited welcome from patients and students as a modality that can significantly improvement their comprehension of the anatomy, complexities of surgical conditions, and the procedures being offered. This technology provided a particular value for augmenting and improving the training of novice surgeons in a safe environment. In a world where urologists in training are offered several different tools, in the name of unstandardized surgical training, 3D printing is today representing a possible pathway of feasible standardization. Furthermore, its value as a pre-operative planning tool has been especially impactful in partial nephrectomies and radical prostatectomies, refining the approach, saving valuable operative time, and increasing the surgeon confidence (1,4,7,11). The impact of surgical planning with 3D models may impact patient outcomes, leading us to a better understanding of the anatomy, reducing learning curves and possibly reducing complications.

The limitations existing in the current literature are similar to other novel applications, generally small sample sizes with short term follow-up and a lack of high-level evidence. Furthermore, the lack of technical standardization, absence of control groups, and varying cost estimates limits the power of the available studies. Despite these limitations, the technology remains widely accepted with some surgeons even reporting a cognitive benefit for their daily surgical activities (1,4,13,17).

One of the concerns remains the cost, which is driven by the choice of materials and technique, availability of modeling software, and access to a 3D printer. As with any new technology, the initial highly variable costs remain not affordable for all urology units, but with increased availability of low-cost 3D printers and open source modeling software this technology is becoming an established standard at many academic centers (26,27). However, the tradeoff between costs and benefits necessitates a close inspection of the true value gained. Current estimates have proven the notion that the cost of the model may easily be offset by the added benefit of reduced operative times alone. Komai *et al.*, reported that using the 3D printed kidney significantly shortened the duration of intraoperative ultrasound (mean 3.3 min) compared to a retrospective matched cohort without the 3D model (6.3 min, P=0.021) (27). Furthermore, Childers *et al.* showed that the costs savings from this minor step alone would cover almost half the costs of the 3D model (28).

A further concern is the challenge and lack of expertise in converting radiological imaging (from CT scan and MRI) into a 3D virtual, printed or AR model. In most of cases the surgeon is assisted by an engineer by converting digital imaging and communications in medicine (DICOM) data to stereolithography (STL) format. However, most of published papers lack in the accurate description of this process and difficulties (29).

Other remaining challenges include issues of biocompatibility between 3D printing materials, and lack of regulatory policies. Some regulatory bodies are currently under consultation for frameworks regarding the implications for the use of 3D printing in healthcare. A recently announced FDA document has been published as the first to provide such a comprehensive regulatory framework (30). However, with continued research and development, increased funding, and greater popularity, the process will become quicker, cheaper, and more accessible.

Conclusions

3D imaging showed revolutionary potentials for education, patient counseling, pre- and intraoperative surgical planning, especially in urology (31,32). Although costs remain the major concern, this kind of technology represents a step forward to meet patients' and surgeons' expectations.

It seems that the opportunities for innovation in surgery with 3D printing technology are boundless, and we are currently in the middle of a dynamic, paradigm-shifting era.

Randomized prospective studies are required to truly evaluate the tangible benefits of this technology and to quantify the added value.

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