World Journal of Urology (2022) 40:617–619
https://doi.org/10.1007/s00345-022-03977-6

EDITORIAL

Patient specific simulation in urology: where are we now and what does the future look like?

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Published online: 7 March 2022

Technological innovations of the twentieth century have provided medicine and surgery with new tools for education and therapy. Modern medical imaging provides essential preoperative knowledge of patient anatomy and pathologies. However, the patient is represented on a set of two-dimensional (2D) images, and their radiologic interpretation often remains a difficult task [1]. By combining software that enables segmentation of medical imaging with emerging technologies including; 3D printing, virtual reality applications and augmented reality platforms various types of patient-specific applications providing preoperative surgical simulation have now become easily accessible [2]. Patient-specific simulation (PSS) as a strategy marks a distinct shift in the use of simulation from a platform that allows practice of a specific skill (i.e., training) to one that allows cognitive and/or physical rehearsal of a specific event (i.e., a patient's operation) [3]. PSS in any form allow surgeons to cognitively or physically practice, plan, and address potential problems related to a specific patient's case, thus optimizing the real intervention [2]. However, its benefits are limited by uncertainty in accurately defining the anatomical/pathologic patient variability, feasibility of translating them into clinical applications, and effectiveness in improving surgical outcomes.

In this special issue of *Patient-Specific Simulation—A New Era in Surgical Innovation* we explore recent advances, address various shortcomings, and provide evidence of successful skill transfer using patient specific simulations. Several papers in this issue focus on patient specific applications for percutaneous nephrolithotomy (PCNL) in the treatment of complex renal stones. Melnyk et al. [4] in 'How specific are patient-specific simulations? Analyzing the accuracy of 3D-printing and modeling to create patient-specific rehearsals for complex urological procedures', presented a new quality control measure by confirming anatomical accuracy for patient specific hydrogel models prior to their use for patient care. Authors explored the anatomical accuracy of hydrogel models, developed using 3D printing and molding for pre-operative surgical rehearsals, of robotic-assisted partial nephrectomy (RAPN) and PCNL. Using three different methods surface geometry, alignment, and volumetric overlap were analyzed comparing sets of virtual computer-aided designs (CADs) created through segmentation of patient CT scan images versus patient-specific RAPN and PCNL hydrogel models that were CT scanned and segmented to create a corresponding model CAD. The authors found geometries of the RAPN parenchyma, tumor, artery, vein, and pelvicalyceal system (PCS) to lay within an average deviation of 2.5 mm of the original patient geometry. Similarly, geometries of the PCNL PCS and stone lay within 2.5 mm in alignment. The authors utilized this process for further refinement of their modeling process to fabricate anatomically accurate RAPN and PCNL patient-specific rehearsal platforms prior to live surgery. Ghazi et al. [5] took the process a step further evaluating the utility of these anatomically accurate high-fidelity patient-specific PCNL hydrogel simulations on surgical and patient outcomes. 20 consecutive PCNL procedures were split between 10 patients where only standard review of patient imaging was completed versus 10 patients where a full procedural rehearsal was completed 24–48 h before the real case utilizing patient- specific hydrogel models fabricated from patient imaging. The rehearsal group showed significant improvements in mean fluoroscopy time, percutaneous needle access attempts, complications and additional procedures. This study demonstrated rare clinical evidence that PSS rehearsals are effective in improving surgical performance and patient outcomes for a complex endourological procedure. Checcucci et al. [6], presented a comprehensive overview of the most recent evidence on current applications of virtual imaging guidance for PCNL. The authors provided a brief overview of the various platforms

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where 3D virtual navigation technology for PCNL was used with the purpose of surgical training and planning as well as in the field of surgical navigation ranging from cognitive to augmented reality to mixed reality applications. The authors also reported on preliminary experiences that explored the application of artificial intelligence guidance for percutaneous puncture, presenting a new frontier for autonomous PCNL access.

Several papers in this issue focus on patient specific applications for minimal invasive partial nephrectomy in the treatment of renal malignancies. Melnyk et al. [7] in the publication 'Utilizing head mounted eye trackers to analyze patterns and decision-making strategies of 3D virtual modelling platform (IRIS) during preoperative planning for renal cancer surgeries' presents a unique insight into the use of 3D virtual models for preoperative planning of RAPN. Utilizing head mounted eye trackers the authors analyzed how eye tracking metrics and utilization patterns differ between preoperative surgical planning using a 3D virtual modelling platform developed by intuitive surgical (IRIS) and standard axial CT scans. Urologists wearing eye trackers randomly reviewed IRIS and CT images of patients with renal masses of varying complexity after which they answered a series of questions regarding surgical plan. Eye tracking metrics of cognition were collected. Using IRIS urologists spent significantly less time interpreting data from IRIS than CT scans (− 67.1 s, $p<0.01$) and had higher inter-rater agreement of surgical approach ($\alpha=0.16$–0.34). The planned surgical approach changed in 22/59 of the cases after viewing IRIS with surgical plans demonstrating a greater tendency towards a more selective ischemia approaches which positively correlated with improved identification of vascular anatomy. Compared to viewing the CT scan, eye tracking metrics were significantly lower when using IRIS, indicating interpreting information from IRIS required less mental effort. The authors concluded that urologists extrapolated more detailed information in less time with less mental effort using IRIS than CT scans and proposed surgical approaches with potential to enhance surgical outcomes. Amparore et al. [8], presents a synthesis of current applications of 3D virtual models for RAPN. They demonstrated the use of 3D virtual models in various settings, including surgical planning, intraoperative guidance, and surgical training. The authors present several studies on the application of this technology for surgical planning, demonstrating impact on clinical outcomes such as renal function recovery. The intraoperative use of these technologies depended mainly on cognitive alignment of the patient specific virtual models with the intraoperative findings, whilst experiences with genuine intraoperative navigation remain experimental. One of the latest innovations is the development of dedicated software capable of automatically overlapping the 3D virtual models to the real anatomy. The authors concluded the crucial role of 3D-virtual reconstructions during RAPN but efforts to optimize overlay of 3D virtual models onto the surgical scene is key to further improve the efficiency and widespread adoption of this technology for intraoperative navigation in RAPN. To that point, Nimmagadda et al. [9], in the manuscript titled "Patient-Specific, Touch-Based Registration during Robotic, Image-Guided Partial Nephrectomy." summarized the Vanderbilt Institute for Surgery and Engineering (VISE) work towards 3D augmented reality overlay in RAPN using an alternative novel registration approach that leverages existing hardware and kinematic data in the DaVinci robotic system. The software utilized patient pre-operative axial imaging to output and register a 3-dimensional simulation of the renal anatomy in the da Vinci console onto the surgical scene. This is the first overview involving touch-based registration and presents a leap in the field of augmented reality approaches where the 3D virtual model can be utilized as an intraoperative guide during robot assisted renal surgery. Two systemic reviews focused on PSS in a broader sense where a novel application is applied to various urological diseases. Doyle et al. [10], explored machine learning applications for patient specific urologic surgical care and Fujihara et al. [11], investigated the impact of virtual reality technologies on urological surgeries, specifically in the management of prostate cancer and renal cancer.

This issue provides insights into the current status of patient-specific simulation in Urology and advancements from technical and research perspectives. However, for patient-specific simulation to become a standard approach, future research should focus on better characterizing the link between the use of platforms that incorporate patient-specific anatomy/pathology and overall surgical outcomes.

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