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Short Commentary

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3D virtual clipping: A personalized planning and rehearsal tool for off-clamp partial nephrectomy

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Abstract

Kidney cancer treatments result in a loss of nephron mass. Nephron sparing surgery can reduce such loss through application of on- and off-clamp techniques. The on-clamp technique is widely used but resulting warm ischemia has a negative impact on long-term patient outcomes. The alternative off-clamp technique mitigates negative effects on renal function but is often considered a technique for expert hands in select cases only.

A growing interest for 3D model imaging and 3D model printing is demonstrated in the organ sparing surgical literature. Leveraging their respective long experience in Minimally Invasive Surgery (MIS) planning and off-clamp technique, the authors argue that 3D virtual clipping could increase the utilization of the off-clamp technique and ultimately benefit more patients.

The argument is illustrated with a case of left renal mass, where virtual clipping allows for evaluation of the functional volume of kidney exposed to ischemia for both on- and off-clamp techniques. The planning of selective arterial control limited to vessels feeding the tumor is discussed, and a related digital and mental imagery is proposed to rehearse in preparation for the next day procedure.

Shifting from a traditional “on-clamp fits all partial nephrectomies” model to a novel concept of patient centered digital and mental rehearsal could be a first step towards more personalized surgery

Keywords: 3D imaging; CT; MRI; DICOM data; Virtual clipping tool; Personalized surgery; Mental imagery; Rehearsal.

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Introduction

Shifting from open Partial Nephrectomy (PN) to laparoscopy or robotically assisted laparoscopy, most urologists had abandoned the benefit of cooling the kidney with ice sludge. The glomerular protection provided by cooling the renal cortex allowed for completion of tumor resection, closure of the collecting system and hemostasis without being under time pressure. The adoption of minimally invasive approaches has resulted in exposing fragile nephrons to warm ischemia and setting for the surgeon a stressful limit of 20 minutes for acceptable Warm Ischemia Time (WIT); 36% of the cases are not completed within the acceptable WIT [1]. In this perspective paper, we explore the potential role of intelligent digital technology in mitigating warm ischemia. Here, Visible PatientTM medical device software (Visible Patient S.A.S., Strasbourg, France), is used to create a 3D model from DICOM data of a left kidney CT-urogram. For planning an off-clamp partial nephrectomy, the software enables selective arterial control to the tumor, limiting WIT.

Description

Here we show images and 3D reconstructions to demonstrate the additional clinically relevant information added by digital technology.

In Figure 1, we show images and 3D reconstructions from a single patient who presents with cysts and a solid mass in the left kidney. Starting from a conventional biplanar grey scale axial display (Figure 1a), an AI powered functionality differentiates and colors organs in an anatomical atlas style (Figure 1b). More than a "nice to have" feature, this enhancing function supports clinicians in locating and identifying renal masses and differentiating densities of a solid mass, colored here in apple-green, from cysts in olive-green. Orienting the 3D reconstruction in the surgical lateral position displays a realistic representation of the expected 3D surgical anatomy view (Figure 1c). By removing organs using a simple drop-down list and adjusting opacity we obtain an ad-hoc volume rendering of the kidney and surface rendering of the arterial vasculature of the patient: one upper pole artery, one lower pole artery and a mid-artery presenting with an early division into anterior and posterior branches (Figure1d).

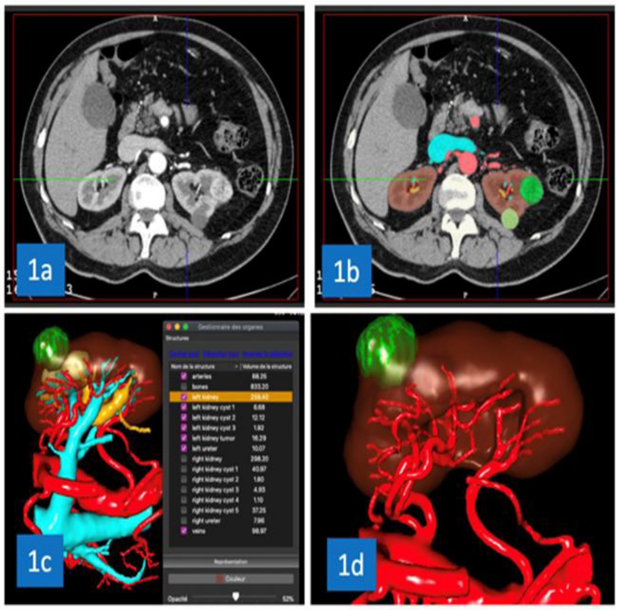

Figure 1: 1a) Original image, 1b) 2D color atlas, 1c) 3D volume and surface rendering in the surgical lateral position identifying a left renal mass, 1d) patient specific clean arterial vasculature after removal or organs from the drop list.

In Figure 2, the 3D reconstruction can inform surgical approach and clamping strategy. After rotating the model to gain an upper pole view, the tumor shows its anterior location, supporting informed decision making in favor of an anterior transperitoneal approach over a posterior extraperitoneal route (Figure 2a). The application of a virtual clip at different levels on the upper and lower arteries highlights the volumes of distribution, which are away from the renal mass and quantifies those volume at respectively 7% and 13 % from the total volume of the left kidney (Figure 2b and 2c). Clamping both anterior and posterior branches of the mid-artery results in an ischemic volume of 78%. (Figure 2c), which predicts the related territories that will be exposed to warm ischemia if a standard on-clamp Laparoscopic PN (LPN) technique is chosen.

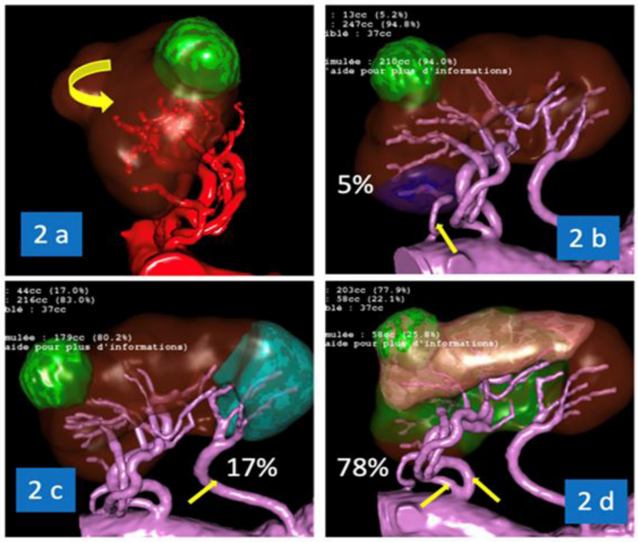

Figure 2: 2a) 3D upper view informing decision making on the approach, 2b) virtual clip on the upper artery, 2c) clipping the lower artery, 2d) simulation of the on-clamp method exposing 78% of the kidney to warm ischemia.

In Figure 3 we show how digital technology using a virtual clipping tool could help surgeons build a mental operative imagery for personalized rehearsal of selective control and support readiness for "what if" operative events, such as bleeding. The virtual clip tool allows for prompt identification of a small branch accessible at the renal sinus level. This vessel feeds most of the tumor. Its temporary or permanent control would result in ischemia limited to 13% of the renal volume (Figure 3a). Should the intra-operative need occur, two easily accessible adjacent arteries could benefit from a temporary control, adding 14% to the ischemic volume (Figure 3b). Finally, the ability to combine and adjust surface rendering (here vessels and ureter) and the transparency of volume rendering of the kidney gives clear anatomical landmarks of interest to anticipate a selective or emergency access to specific branches.

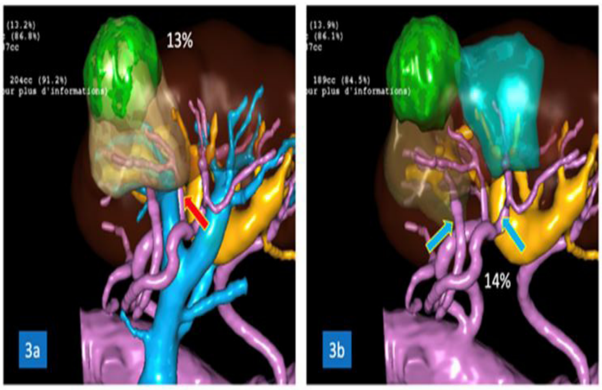

Figure 3: 3a) building an operative mental imagery as personalized rehearsal for selective control of the feeding artery and identifying adjacent anatomic landmarks. 3b) "what if" digital and mental readiness for ad-hoc clamping of adjacent territories, here in case of intra-operative bleeding, without having to clamp the entire pedicle.

Discussion

Five decades of nephron sparing surgery have seen continuous improvement in technique and surgical approach. Before and through the 1980's, open PN was the standard of care to preserve the renal function while excising tumors on solitary kidneys or for bilateral disease. In the 90's PN had demonstrated its non-inferiority to radical surgery oncologic outcomes and improved renal function outcomes. From the turn of the century, the laparoscopic approach has established itself as standard of care along with the open technique. Over the last decade, the robotic on-clamp technique has taken off and seen a steady adoption across all regions of the world [2]. We expect in the current decade to witness a further reduction of invasiveness with a growing adoption of focal ablation, and the emergence of digital technologies facilitating off-clamp surgery and/or possibly a hybrid combination of both.

To mitigate the detrimental effects of WIT, reputed authors have proposed adjusting the cooling principles to the MIS context. Although successful, their proposed methods have unfortunately not taken roots within the urological community [3-5]. Carrying out a PN off-clamp is an alternative answer to warm ischemia. Off-clamp techniques were already proposed two decades ago [6,7]. Off-clamp PN requires careful and time consuming pre-operative anatomical planning, as well as excellent suturing skills for readiness in case of sudden bleeding. Surgeons and radiologists would not always find time together to obtain images optimized for surgical planning. As a result, off-clamp PN has been long perceived as a tour de force, until it gained a new popularity brought by the zero-ischemia novel concept [8].

Beyond technical feasibility, a robust quantity of evidence comes in support of off-clamp LPN in the form of a meta-analysis. The warm ischemia from the on-clamp technique is correlated to a higher risk of chronic kidney disease and related long-term cardio-vascular events than off-clamp techniques [9]. In parallel, the use of printed or digital 3D models has contributed to a significant reduction in the mean WIT on a small comparative series of on-clamp procedures and, most importantly, has helped to limit warm ischemia to the recommended 20-minute threshold [10]. The facilitating role of 3D printing for zero-ischemia partial nephrectomy has been recently highlighted in pediatric surgery [11]. Selective clamping based on 3D reconstruction can avoids ischemia [12]; and alter surgical plan [13]. The presentation of 3D rendering and virtual clipping tool as the urology scientific community, who has awarded it a prize [14], has welcomed a concept for PN. We therefore expect that 3D pre-operative planning, identifying patient specific vasculature, simulating the surgical position, and virtual clip application will facilitate off-clamp techniques and enable more efficient vascular planning. Digital technology could ultimately enable off-clamp PN technique to benefit to more patients.

Advanced imaging, as shown here, could simplify the pre-operative construction of a precise kidney vasculature, which requires time and effort at the radiologist console, on a drawing board, or building a mental image. It could also confirm the planned representation intra-operatively and consistently help in locating the feeding vessel(s) more efficiently than with a laparoscopic ultrasound with Doppler function, which is not always available at the right time in all facilities.

There are some limitations to this perspective. Digital imaging technologies cannot overcome all technical difficulties related to off-clamp technique. Firstly, the intra-hilar dissection of vessels in view of selective control at the renal sinus level requires more time and patience than a direct approach to the main pedicle at its origin. It might under some circumstances not be possible. The authors' off-clamp technique was initially developed in laparoscopy using straight stick harmonic-based energy instrument preventing bleeding from the cortex, dispensing with slipknot compression sutures. Since harmonic instrumentation is not yet available with freedom of motions on robotic platforms, compression sutures might still be needed at the end of the procedure, causing additional ischemic margins and infringing the territory of the adjacent vessels shown in picture Figure 3b.

Finally, there could be a parallel and a synergy between rehearsal using 3D digital imaging and Mental Training (MT), which uses also mental imagery. MT has longstanding proven records in other professions such as aviation and sport and has also demonstrated its potential in surgery [15]. We believe that digital simulation can support surgeons building mental imagery and a step-by-step strategy that could transform the off-clamp PN procedure from tour de force to routine.

Conclusion

We have explored a 3D virtual clipping tool applied to partial nephrectomy and discussed its possible role in off-clamp procedures. As a first digital step towards personalized surgery, the application of a virtual clip on a 3D model could augment and refine decision making in partial nephrectomy and protect kidney and patient from the risk of overriding the stressful 20 minute warm ischemia countdown. Selective vessel control could reduce the risk of sudden bleeding arising from the depth of the resection bed. Mental imagery and virtual simulation used in other skilled professions to reduce cognitive load have been demonstrated effective in surgery. We anticipate 3D imaging reconstruction can help building the adequate mental imagery and invite further exploration in future clinical research.

Declarations

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