Track-Guided Ultrasound Scanning for Tumour Margins Outlining in Robot-Assisted Partial Nephrectomy

Agostino Stilli [1], Manios Dimitrakakis[2], Maxine Tran[3], Danail Stoyanov[1]

[1]*University College London, Department of Computer Science, Surgical Robot Vision Group*
a.stilli@ucl.ac.uk, danail.stoyanov@ucl.ac.uk
[2]*University of Patras, Department of Electrical and Computer Engineering, Laboratory of Automation and Robotics*
[3]*University College London, Department of Nanotechnology, Div. of Surgery & Interventional Science*

INTRODUCTION

Robot-Assisted Partial Nephrectomy (RAPN) is a medical procedure in which part of a kidney is removed, typically because of the presence of a tumour. RAPN is the second most diffused robotically assisted surgical procedure worldwide after prostatectomy [1]. The advantages of this robot-assisted procedure are detailed in [2], and in [3] it is argued that RAPN can be used in place of open surgery or total nephrectomy in some complex renal tumour cases. The RAPN procedure is thoroughly described in [4]. Methods used for the identification of the tumour include pre-operative Computer Tomography (CT) scans, Magnetic Resonance (MR) imaging and intraoperative Ultrasound (US) scans. The use of drop-in US probes for RAPN procedures is widely recognized as the golden standard for the intra-operative detection and margins outlining of the mass targeted. In [5] the authors show that the use of US drop-in probes guided by robotic laparoscopic tools rather than standard laparoscopic tool is beneficial for the surgeon as it significantly increases the dexterity, hence, the field of view of the system. Typically, the probe is inserted through a standard trocar port and the surgeon grasps it with a gripper, picking up the probe from a dedicated slot. The slot is generally designed to match the EndoWrist® Prograsp™ Forceps gripper of the daVinci Surgical System, (Intuitive Surgical Inc., Sunnyvale, CA, US). Once the probe is paired with the gripper, the surgeon can navigate to the target organ to perform the scan: multiple swipes with the US probe are performed on the kidney surface in order to localise the tumour. Section by section the resection area is outlined and marked with an electrocautery tool. The additional degrees of freedom provided by the dexterous wrist of the robot-assisted laparoscopic tool navigating the probe in comparison with the standard laparoscopic scenario ease the swiping process, nonetheless, this procedure is still challenging. The US probe often requires repositioning because of slippage from the target organ surface. Furthermore, the localisation can be inaccurate when tumours are in locations particularly hard to reach, e.g. in the back part of the kidney. In such cases, kidney repositioning could be required. A highly skilled surgeon is typically required to successfully perform this pre-operatory procedure. Similar problems exist in many other medical procedures involving the use of drop-in US probes, e.g. prostatectomy. In this paper we propose a novel approach for the navigation of US probes: the use of pneumatically attachable flexible rails to enable swift, effortless and accurate track-guided scanning of the kidney. The proposed device, shown in Fig.1 (a, section view in b), is attached on the kidney side surface with the use of a series of bio-inspired vacuum suckers and it is used as a guide on which the surgeon attaches and slides the drop-in US probe. The use of vacuum pressure in surgical applications has been previously investigated to enable the navigation of micro-robotic systems [6], the stabilisation of a beating heart [7], as well as the anchoring of medical devices [8]. Nonetheless, the concept of pneumatically attachable rails, as well as the concept of rail-like systems for track-based navigation of surgical instruments and sensing probes, has never been proposed to date. Given the novelty of the proposed system, a patent application has been filed (United Kingdom Patent Application No. 1808728.8).

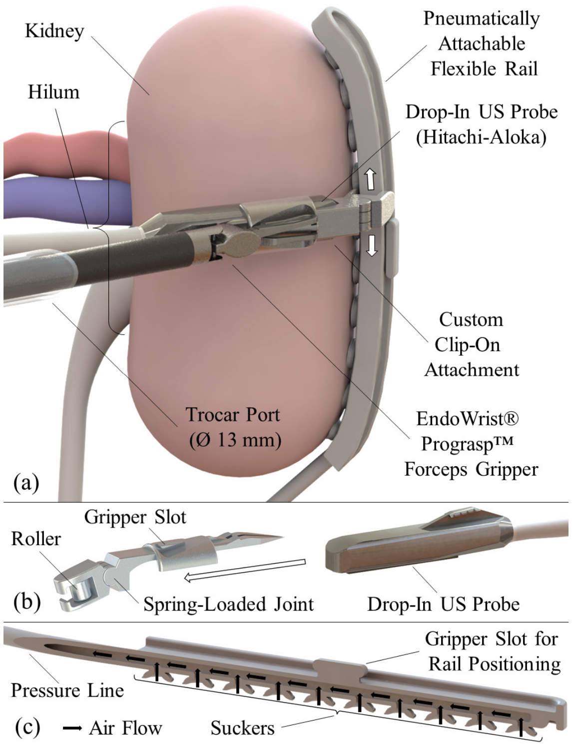

Figure 1 – Pneumatically attachable flexible rails: (a) overview of the system when used to guide a drop-in US probe for tumour margins outlining in RAPN, (b) custom add-on (left) for the drop-in US probe (Hitachi-Aloka pictured on the right) to allow the connection between the probe and the rail; (c) section view of the proposed system , components and air flow.

MATERIALS AND METHODS

The proposed system is shown in the CAD drawings in Fig.1 (a) and (c). A flexible pressure line supplies the vacuum pressure to the proximal end of the proposed system. This line connects with a cavity that runs through the entire length of the system: suckers are arranged on a protruding line and connected such cavity by a series of openings, as shown in Fig.1 (c). The distal end of the cavity is sealed. Once vacuum pressure is applied, all the suckers are depressurized. As a result, the suckers, hence, the whole system, firmly connects with any adjacent body surface or organ. As shown in Fig.1 (a), along the whole perimeter of the system, excluding the proximal end, a continuous T-section rail is embedded. A customized slot is also embedded to match the shape of a EndoWrist® Prograsp™ Forceps gripper to facilitate the system positioning during the deployment (Fig.1 (c)).

The deployment process can be summarized as follows:

1. The system is passed through a standard trocar port and grasped by the gripper slot with the EndoWrist® Prograsp™ Forceps gripper.
2. The mid-point of the sucker line is placed in contact with the mid-point of the lateral surface of the kidney, opposed to the hilum, as shown in Fig.1 (a).
3. Vacuum pressure is applied to the sucker line, making the system adhere to the kidney surface in its whole length. Any other robot-assisted tool can be used to apply a small force on those parts of the system not in suction to allow the pneumatic connection.
4. The system is now firmly connected to the kidney and it is released from the gripper.
5. The drop-in US-probe (Hitachi-Aloka pictured in Fig.1 (a) and (b)) with the customized connector (Fig.1 (b) left) already assembled onto it is passed through the same trocar port fitting the pressure line, grasped with EndoWrist® Prograsp™ Forceps gripper by the dedicated slot and attached to the rail.
6. The drop-in US-probe is moved along the rail to perform the scan, outlining the tumour, hence, the margin of resection.

Inherently in its design, the proposed system is flexible enough to match the surfaces of the internal organs and cavity walls, but at the same time stiff enough to provide a rail-like structure for robust coupling with any probe/tool sliding along it. To achieve such characteristics, rubber-like materials with low Shore hardness have been used to provide the required compliance to the suckers. Contextually, materials of higher Shore hardness have been used to build the walls of the pressure line, in order to prevent it from collapsing once vacuumized. Thus, the use of rubber-like materials of different Shore hardness in the same body element is of paramount importance for the correct functionality of the proposed system.

At the current stage we have designed and prototyped the proposed system using multi-material multi-hardness soft 3D-printing (Model: Objet260 Connex, Stratasys, Eden Prairie, MN, USA). The digital material FLX9985-DM (TangoBlackPlus + VeroClear, Shore Hardness 85A) has been used for the walls of the internal cavity and the rail. TangoBlackPlus FLX930 material (Shore Hardness 28A) instead has been used for the suckers.

RESULTS

Preliminary tests have been performed on animal tissue (chicken breasts), showing that it is possible to: 1 – firmly anchor the proposed system to the tissue when a vacuum pressure of 0.092 MPa ($P_a = 9.325\ Pa$) is applied, 2 – connect a US-probe paired with the custom attachment and 3 – slide it along the whole length of the rail, without causing the system to detach or damaging the underlying surface of the tissue. Detailed results related to this investigation will be presented in a separate paper.

CONCLUSION AND DISCUSSION

In this work, the concept of pneumatically attachable flexible rails for MIS surgical applications has been introduced for the first time. The proposed system on top of its main function, i.e. to provide a rail-like structure to guide probes along its length, can be used also to:

- actively constrain the shape of the organ/tissue to which it is attached;
- provide a visual reference of known shape and size in the field of view of the endoscope, thus allowing more accurate super-imposition of US-reconstructed 3D images of the tumour in augmented reality (AR).
- create a scaffold to be used to mobilise or retract organs as well as mini- and micro-robotic systems.

The system here presented has been developed for use in RAPN, as this common procedure is among those which can benefit the most of this novel approach, nonetheless its use can be extended to several other procedures (e.g. prostatectomy, partial hepatectomy) and sensing probes (e.g. γ-/β-imaging). Not only the abdominal, but also the pelvic and the thoracic cavities and the organs therein can be targeted. Furthermore, the design of the proposed system allows for ease of customization according to the size of the organ or internal body wall targeted. Future work will investigate on the use of the proposed system with peri-operative surgical imaging probes and the coupling with the da Vinci surgical robot system.

REFERENCES

[1] H. J. Marcus *et al.*, "Trends in the diffusion of robotic surgery: A retrospective observational study," *Int. J. Med. Robot. Comput. Assist. Surg.*, vol. 13, no. 4, 2017.

[2] S. Kaul *et al.*, "da Vinci-assisted robotic partial nephrectomy: technique and results at a mean of 15 months of follow-up," *Eur. Urol.*, vol. 51, no. 1, pp. 186–192, 2007.

[3] C. G. Rogers, A. Singh, A. M. Blatt, W. M. Linehan, and P. A. Pinto, "Robotic partial nephrectomy for complex renal tumors: surgical technique," *Eur. Urol.*, vol. 53, no. 3, pp. 514–523, 2008.

[4] S. B. Bhayani, "da Vinci robotic partial nephrectomy for renal cell carcinoma: an atlas of the four-arm technique," *J. Robot. Surg.*, vol. 1, no. 4, pp. 279–285, 2008.

[5] B. F. Kaczmarek *et al.*, "Comparison of robotic and laparoscopic ultrasound probes for robotic partial nephrectomy," *J. Endourol.*, vol. 27, no. 9, pp. 1137–1140, 2013.

[6] S. Ohno, C. Hiroki, and W. Yu, "Design and manipulation of a suction-based micro robot for moving in the abdominal cavity," *Adv. Robot.*, vol. 24, no. 12, pp. 1741–1761, 2010.

[7] G. Knight, W. D. Fox, and D. R. Schulze, "Cardiac stabilizer device having multiplexed vacuum ports and method of stabilizing a beating heart." Google Patents, 08-Jul-2003.

[8] B. Schena, "Extendable suction surface for bracing medial devices during robotically assisted medical procedures." Google Patents, 19-Feb-2013.