Autonomous robotic surgery makes light work of anastomosis

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An autonomous robotic laparoscopic surgical technique is capable of tracking tissue motion and offers consistency in suturing for the anastomosis of the small bowel.

Robotic surgery with minimally invasive approaches have been shown to improve clinical outcomes such as patient recovery time and also decrease the chances of complications during the intervention [1]. They have also been shown to improve surgeon dexterity and precision when compared to conventional laparoscopic surgery [2]. Buoyed by advances in artificial intelligence, recent research efforts have been directed towards increasing the level of autonomy of the robotic system in surgery. For example, tasks such as ablation of tumors or the control of endoscopy instruments in unstructured environments have been automated with the aid of machine learning [2, 3]. Increasing the level of autonomy in robotic surgical systems has the potential to standardize surgical procedures that are independent of surgeons' training and experience. This will inevitably improve the consistency in these procedures whilst reducing the surgeon's operating workload, and at the same time harnessing their supervisory role to guarantee the safety of the overall surgery. Prior work (*4*) has presented a classification of different levels of autonomy, including enabling technologies and possible applications. However, it should be noted that full autonomy is yet to be realized and high autonomy has yet to reach clinical translation.

Writing in *Science Robotics*, Saeidi *et al.* present an autonomous strategy for laparoscopic soft tissue surgery in the anastomosis of the small bowel (*5*). Autonomous soft tissue surgery in unstructured environments requires accurate and reliable imaging systems for detecting and tracking the target tissue. Moreover, it is also necessary for these autonomous approaches to enable complex task planning that take tissue deformation into consideration, with the potential to precisely execute plans using dexterous robotic tools and control algorithms that are adaptable to dynamic surgical situations. In such highly variable environments, preoperative surgical planning such as in rigid tissues is not a viable solution. In the case of laparoscopic surgeries, the difficulty further increases due to limited access and visibility of the target tissue and the disturbances from respiratory motion artifacts.

Saeidi and colleagues achieved the autonomy necessary to perform robotic laparoscopic anastomosis in small bowel using a Smart Tissue Autonomous Robot (STAR). This was done by developing several autonomous features for their system including tissue tracking, detection of the motion in tissue generated from breathing and its deformation, robot tool failure detection, camera motion control, suture planning and synchronization of the robot tool with breathing motions of the tissue and under a Remote Center of Motion. The operator is capable of selecting among autonomously suggested suture plans and can also approve a re-planning step for the repetition of a stitch as needed. Saeidi and colleagues integrated the autonomous strategy into a surgical procedure for the anastomosis of the small bowel and this was tested in a series of in vivo studies on porcine models with a one-week survival period. The STAR system proposed by Saeidi and colleagues comprises of medical robotic arms for robotic suturing (6) and for the actuation of surgical tools (**Figure 1**). It also has a dual-channel Near Infrared (NIR) and 3D structured light endoscopic imaging system (7). The imaging system was utilised for autonomously tracking biocompatible NIR markers that are placed on the tissue (*8*). In turn, these data are used to reconstruct the 3D surface of the tissue.

To track the motion of the tissue due to breathing and other tissue motion during laparoscopic surgery, Saeidi and colleagues developed a machine learning algorithm based on Convolutional Neural Networks (*9*) and the feedback from the NIR camera. The estimated positions are utilized in the suture planning algorithm to generate suture plan options which are presented to the operator. The path planning algorithm, developed in their previous work (*10*) generates multiple suture plan options on the 3D point cloud of the tissue which can be selected by the operator from a Graphical User Interface. This method also projects the robottool on each planned suture point and predicts the chances of tool collision with the tissue, and autonomously generates a new suture plan if the original image is noisy. These stepwise target positions are then sent to the low-level control block to guarantee that the desired position andorientation is followed. Low-level motion control also guarantees that these motion primitives are executed via smooth task-space trajectories which are converted to joint space trajectories and are tracked via the robot drivers to complete the surgical task.

Experiments for end-to-end anastomosis were initially conducted by Saeidi and colleagues using phantom bowel tissue. The study groups included autonomous robotic anastomosis with the STAR system, a Manual Laparoscopic (LAP) method, and a da Vinci SI based Robot-Assisted Surgery (RAS) method. The system developed by Saeidi and co-workers outperformed surgeons using LAP and RAS surgical techniques in metrics including the consistency of suture spacing and bite depth as well as the number of suture hesitancy events which directly affect the quality of a leak-free end-to-end anastomosis.

Laparoscopic autonomous surgery was also performed in vivo on porcine small bowel tissue using STAR. After surgery, the animals were monitored for a one-week survival period, and subjected to limited necropsy to compare the healed anastomosis to a control group using LAP. The survival study indicated that the STAR system could match the performance of expert surgeons in metrics including leak-free anastomosis and lumen patency whilst also exhibiting an elevated level of consistency.

Despite these achievements, there are some limitations in the work by Saeidi and colleagues. Currently, successful implementations of the robot control algorithms depend on the reachability and correct staging of the tissue in a certain working region. Another limitation of this study was that the comparison between the STAR system, manual laparoscopic surgery, and tele-operated da Vinci was performed on phantom tissue. Additionally, due to ethical reasons to limit the number of animals in the study, limited comparisons were done with one manual laparoscopic surgery and instead an extensive, more controlled comparison study in phantom tissue was carried out. However, considering all these factors, Saeidi and co-workers demonstrated laparoscopic autonomous robotic surgery for soft tissue bowel in unstructured and dynamic environments under motion and visual constraints. The group developed advanced imaging systems, machine vision and machine learning techniques,with real-time control strategies to track tissue position and deformation. Their approach enabled them to perform complex surgical planning, interact with the human user, and adaptively execute the surgical plans. The STAR system encapsulates the autonomous control functionality and reduces the manual involvement of the human operator.

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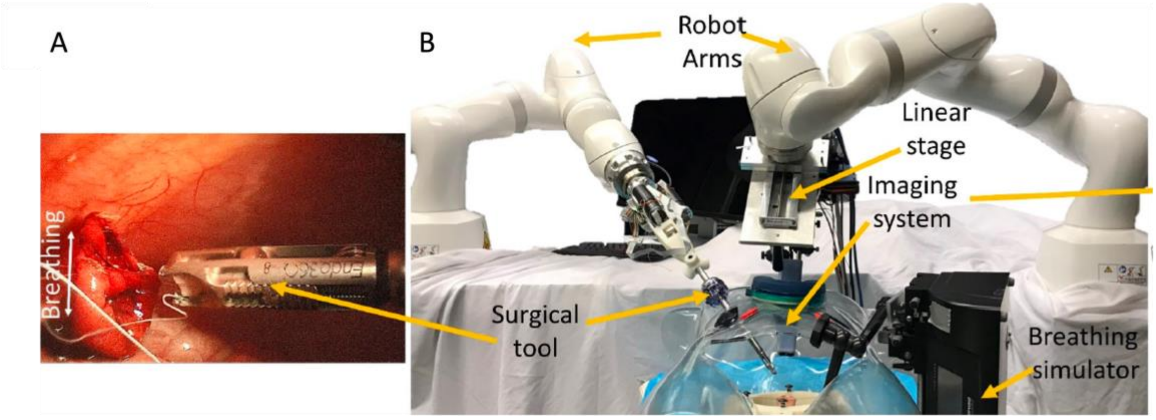

Figure 1: Enhanced autonomous laparoscopic soft tissue surgery. (A) The surgical tool for the STAR laparoscopic autonomous system for in vivo small bowel surgery is capable of tracking breathing motion. (B) The STAR system is composed of robotic arms and actuated surgical tools. It also contains a dual-channel NIR and 3D light endoscopic imaging system. Two KUKA LBR Med robotic arms are independently utilised for robotic suturing and for theimaging system. Reproduced from Saeidi *et al.* [2].