Journal of Robotic Surgery
https://doi.org/10.1007/s11701-019-00971-w

BRIEF COMMUNICATION

Wearable haptic interfaces for applications in gynecologic robotic surgery: a proof of concept in robotic myomectomy

Andrea Giannini[1] · Matteo Bianchi[2,4] · Davide Doria[2] · Simone Fani[2,3] · Marta Caretto[1] · Antonio Bicchi[2,4] · Tommaso Simoncini[1]

Received: 25 April 2019 / Accepted: 1 May 2019

Abstract

Uterine fibromatosis is common in women, with an estimated prevalence of up to 15–50% after 35 years. About 80% of women affected by fibromatosis have symptoms and require medical or surgical treatment. Nowadays, the gold standard for the surgical treatment of uterine fibromatosis is the use of minimally invasive surgery. The surgical skills and improvements offered by robotic approach can be relevant in reproductive surgery, in particular in minimally invasive myomectomy. However, the lack of tactile feedback of robotic platform is an important technical drawback that can reduce the accuracy of surgical procedures. Here, we present the design and the preliminary test of the wearable fabric, yielding display wearable haptic interfaces able to generate a real-time tactile feedback in terms of stiffness for applications in gynecologic robotic surgery. We preliminarily tested the device in the simulation of a real scenario of conservative myomectomy with the final purpose of increasing the accuracy and precision during surgery. The future goal is the integration of a haptic device with the commercially available robotic surgical systems with the purpose of improving the precision and accuracy of the surgical operation, thus allowing a better understanding concerning the anatomical relationship of the target structures. This in turn could determine a change in the surgical strategy in some cases, letting some patients selected for a demolitive approach retaining their uterus. This could improve surgical outcomes in fertile women enrolled for minimally invasive surgery for uterine fibroids and may be a facilitation for young gynecological surgeons or during residency teaching plans and learning programs.

Keywords Robotic surgery · Myomectomy · Haptic feedback · Fertility preservation · MIS

Uterine fibromatosis is common in women, with an estimated prevalence of up to 15–50% after 35 years. About 80% of women affected by fibromatosis have symptoms including bleeding, menstrual and pelvic pain and infertility and require medical or surgical treatment. Surgical procedures for patients with myomas include hysterectomy or myomectomy [1, 2].

Nowadays, the gold standard for the surgical treatment of uterine fibromatosis is the use of minimally invasive surgery (MIS), which can be performed using both traditional laparoscopy and robotic platform. Both procedures may be challenging for multiple reasons. Hysterectomies are the most commonly performed gynecologic procedure with over 90% done for benign conditions. Minimally invasive hysterectomies have become increasingly popular since the first laparoscopic hysterectomy was performed in 1988. The laparoscope offers superior visualization and global views of the abdominal and pelvic cavities. Several prospective studies suggested that MIS approaches to hysterectomy for gynecologic conditions may confer improved surgical and disease-related outcomes compared to laparotomy [3]. Among the reported benefits of MIS are the ability to offer excellent dissection, decrease blood loss, reduce post-operative pain,

✉ Tommaso Simoncini
tommaso.simoncini@med.unipi.it

1 Division of Obstetrics and Gynecology, Department of Clinical and Experimental Medicine, University of Pisa, Via Roma, 67, 56126 Pisa, Italy

2 Research Center "Enrico Piaggio", University of Pisa, Pisa, Italy

3 Department of Advanced Robotics, Istituto Italiano di Tecnologia, Genova, Italy

4 Department of Information Engineering, University of Pisa, Pisa, Italy

Published online: 06 May 2019

shorten the duration of hospital stay and accelerate the patient's return to normal activities [4].

Bulky myomas present relevant challenges also for skilled surgeons, and often limit the possibility of achieving hysterectomy in a mini-invasive fashion [5]. Myomectomy can be even more challenging, since extensive ablation of myomas needs to be obtained, while preserving the function of the uterus. Location, number and accessibility of myomas represent the main technical issues. Laparoscopic myomectomy is a difficult procedure because of the long learning curve, limited degree of freedom of the instruments and the difficulty in performing sutures in narrow spaces [6]. The robotic technology is more intuitive than standard laparoscopy, as the system mimics the surgeon's maneuvers at the console. The increased magnification with three-dimensional vision, the seven degrees of freedom of the instruments, and the physiologic tremor filtering are the main key features of robotic technology. These features provide pelvic surgeons with an enhanced ergonomic setting, simplifying complex laparoscopic tasks such as suturing or performing deep pelvic dissection with safety and efficiency as primary factors (Fig. 1).

The surgical skills and improvements offered by robotic approach can be relevant in reproductive surgery, in particular in minimally invasive myomectomy; however, the lack of tactile feedback in robotic platform is an important technical limitation that can reduce the accuracy of surgical procedures [7]. Currently, gynecologists use ultrasound techniques to map uterine leiomyomas during the preoperative workup. In expert hands, 2D ultrasonography identifies with a high sensibility and specificity the number and the localization of leiomyomas [8].

However, also in this case, the intraoperative absence of tactile feedback during minimally invasive myomectomy may result in long operation times required to identify intramural myomas (which may be not visible from the uterine surface) and more number or greater uterine incisions, hence leading to a significant demolitive procedure. However, sizes and location of myomas contribute to tailored procedures for each individual anatomical patient characteristics.

In our opinion, tailoring anatomical models and increasing the accuracy of surgical steps may result in change of surgical planning, increasing minimally invasive techniques and favoring conservative approach to uterus even in the most complicated conditions, and thus preserving reproductive function. Therefore, here we present the design and the preliminary test of the wearable fabric yielding display (W-FYD), wearable haptic interfaces for applications in gynecologic robotic surgery, specifically, in the simulation of robotic myomectomy. This communication aims to explain the rationale, the design, analysis and control of the haptic system that is able to generate a real-time tactile feedback in terms of stiffness.

We use the W-FYD, a wearable fabric-based device as the main haptic interface with the user. It enables to convey controllable softness information to the user's finger pad, allowing both active and passive haptic exploration by regulating the stretching state of a fabric band through two DC motors. The device is placed over the user's finger and fixed to it with an elastic clip that prevents rotation and ensures stability.

In the active mode, the only movement the user can perform is the flexion of the distal phalanx, which provokes the indentation of the fabric. In the passive mode, an additional vertical degree of freedom is implemented through a lifting mechanism, in that pressing the fabric against the user's finger pad conveys only tactile cues to the user's skin. The W-FYD system was successfully integrated in the AR simulator for surgical training, showing promising results for a tactile augmented framework relying on wearable haptics. It was used to reproduce arterial pulse in the AR simulator for laparoscopic cholecystectomy [9]. In a previous work, the following has been accurately described from an engineering point of view: the technical steps to design a system with a master–slave architecture, able to simulate a bilateral tele-operation scenario with a surgical system, where the W-FYD system is used as the haptic interface for real-time softness stimuli generation on the user's finger pad. The device W-FYD, developed at the Research Center "E. Piaggio" of the University of Pisa, is a mechatronic system that can be worn on the user's finger pad [10, 11].

W-FYD can convey controllable stiffness information by regulating the stretching state of a fabric through the control of two motors to which the fabric is connected. The system allows both active and passive haptic exploration. In the active mode, the only movement the user can perform is the flexion of the distal phalanx, which provokes an indentation of the fabric that is measured through an infrared sensor. Based on this measurement and on an off-line characterization performed for different motor positions, the actual position of the motors is regulated to reproduce a given stiffness profile. In the passive mode, the stiffness of the fabric is varied in the same way as in the active mode, but the finger of the user is still, while a lifting mechanism puts the fabric in contact with the finger pad. W-FYD was successfully used in applications for augmented reality and surgical training [10]. In preliminary tests, we performed a feasibility study to demonstrate that the device was able to reproduce the stiffness of myomas in ex vivo uteri. We analyzed myomas with different dimensions and at different depth levels in the biological tissues. Results showed that W-FYD is capable of mimicking the stiffness of such myomas. Furthermore, we also used W-FYD as an input device in a master–slave architecture. More specifically, the indentation provoked by the user's finger on the fabric was used to command the position of a remote probe, which was able to acquire both

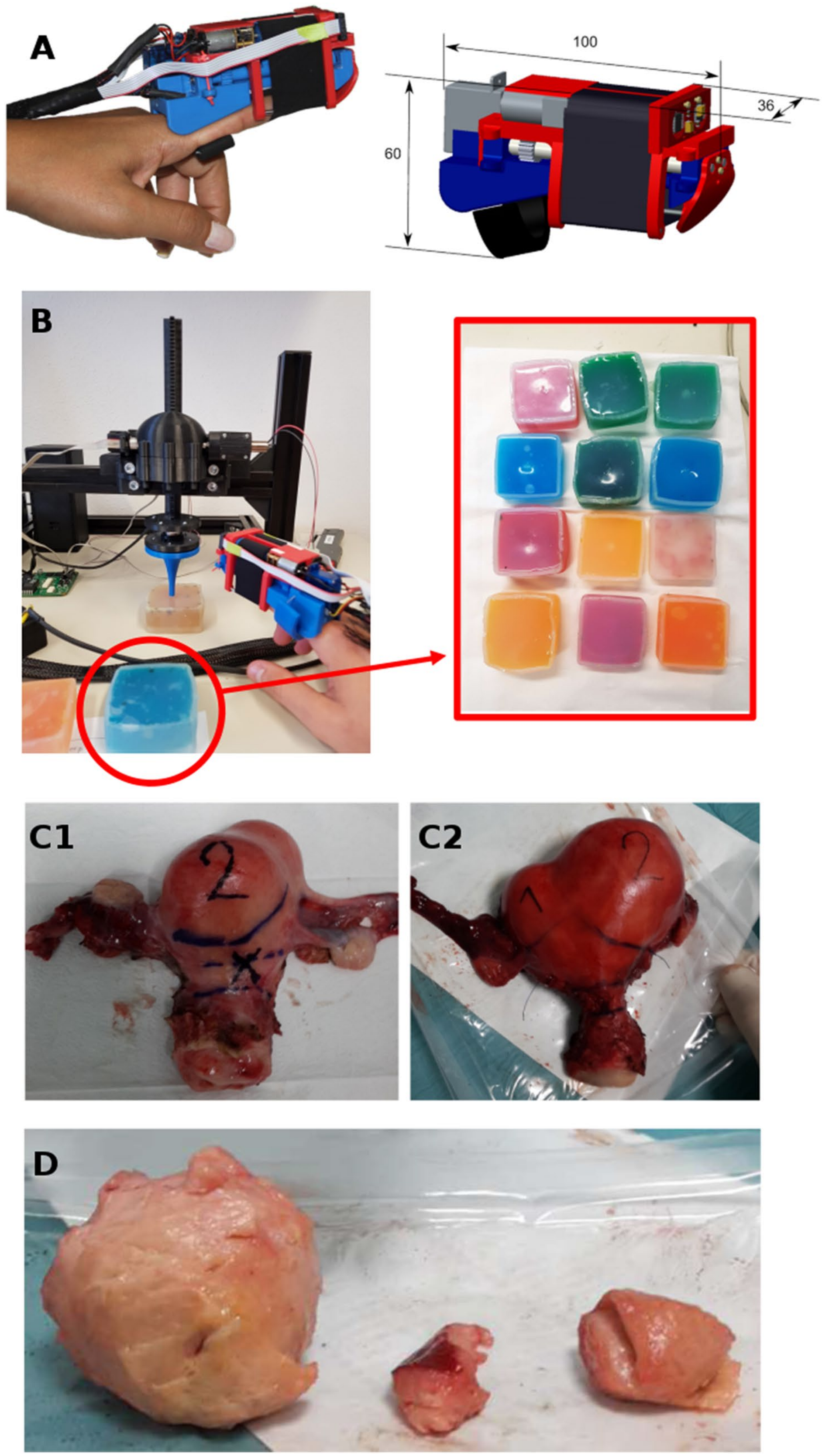

Fig. 1 Schematic description of the development of the wearable fabric yielding display (W-FYD) and its preliminary laboratory testing and subsequent tests on real specimens. **a** W-FYD CAD design. Dimensions are in millimeters and the total mass is 100 g. **b** Experimental setup condition. The right-hand index finger wore the W-FYD system in active mode, to control the indenter of the master–slave architecture to simulate a bilateral tele-operation scenario using different synthetic samples. **c** (**1**) First uterus tested. It presents two subserous myomas on the body and one intramural myoma between the body and the isthmus. (**2**) Second uterus tested. It presents two subserous myomas on the body. **d** Samples extracted from the second uterus. At the center is shown a cubic-shaped piece of uterine tissue with size 15 mm. At the left is shown a spherical-shaped myoma with a diameter of 60 mm. At the right is shown an elliptic-shaped myoma with dimension of 30 × 20 mm

the force and the displacement on a silicone specimen that reproduced the biomechanical characteristics of the uterus with embedded myomas. When the probe was commanded to press against the sample, the stiffness of the sample was computed from the measured values and real time reproduced on the W-FYD. The objective was to enable a remote palpation as it is the case in robot-mediated surgery for the recognition of the fibroids in the tissue, based on stiffness information. Such an information depends on the presence of the myomas (which are stiffer than the physiological tissues) and their depth (the less the depth in the tissue, the stiffer is the explored surface). Experiments with artificial specimens showed that the W-FYD allowed to perceive the presence of the irregularities (i.e., fibroids or myomas) inside the sample under exploration. Based on these encouraging results, we believe that the integration of the W-FYD with a surgical robot can lead to a better and more precise identification of myomas during intraoperative procedures, thus enabling a less invasive and more located surgical intervention. Thanks to the deformability of the fabric, the sensation elicited in users is more natural and closer to the one that the surgeon would have during manual palpation. In the project, we propose using the W-FYD to reproduce the stiffness of the biological tissue, relying on the information on the force and indentation exerted on it, which can be acquired through the sensorized probe of the end effector of a surgical robot.

These improvements are specifically useful for reproductive surgery, since they facilitate or make more effective the critical steps of the procedure such as anatomical identification, dissection and suturing. Pre-surgical 3D reconstruction of patient-specific uterine fibroids superimposed on video stream from the medical robot during intraoperative guide through augmented reality could be a safe method to detect critical anatomical relations between the uterine cavity and myomas, thus allowing safer and tailored approaches to myomectomy during minimally invasive robotic reproductive surgery. The future goal is the integration of a haptic device with the commercially available robotic surgical systems with the purpose of improving precision and accuracy of the surgical operation, thus allowing better understanding concerning the anatomical relationship of the target structures. This in turn brought a change in the surgical strategy in some cases, letting some patients selected for a demolitive approach preserving their uterus. This could improve the surgical outcomes in fertile women enrolled for minimally invasive surgery for uterine fibroids and may be a facilitation for young gynecological surgeons or during residency teaching plans and learning programs.

Compliance with ethical standards

Conflict of interest Andrea Giannini, Matteo Bianchi, Davide Doria, Simone Fani, Marta Caretto, Antonio Bicchi, and Tommaso Simoncini have no conflicts of interest or financial ties to disclose.

References

1. Frishman GN, Jurema MW (2005) Myomas and myomectomy. J Minim Invasive Gynecol 12:443–456
2. Falcone T, Parker WH (2013) Surgical management of leiomyomas for fertility or uterine preservation. Obstet Gynecol 121(4):856–868
3. Nieboer TE, Johnson N, Lethaby A, Tavender E, Curr E, Garry R et al (2009) Surgical approach to hysterectomy for benign gynaecological disease. Cochrane Database Syst Rev 3:CD003677
4. Gynecologists, A. C. o. O. a. (2009) ACOG Committee Opinion No. 444. Choosing the route of hysterectomy for benign disease. Obstet Gynecol 114:1156–1158
5. Bhave Chittawar P, Franik S, Pouwer AW, Farquhar C (2014) Minimally invasive surgical techniques versus open myomectomy for uterine fibroids. Cochrane Database Syst Rev 10:CD004638
6. Sizzi O, Rossetti A, Malzoni M et al (2007) Italian multicenter study on complications of laparoscopic myomectomy. J Minim Invasive Gynecol 14(4):453–462
7. Gingold JA, Gueye NA, Falcone T (2018) Minimally invasive approaches to myoma management. J Minim Invasive Gynecol 25(2):237–250. https://doi.org/10.1016/j.jmig.2017.07.007
8. Levine DJ, Berman JM, Harris M, Chudnoff SG, Whaley FS, Palmer SL (2013) Sensitivity of myoma imaging using laparoscopic ultrasound compared with magnetic resonance imaging and transvaginal ultrasound. J Minim Invasive Gynecol 20(6):770–774
9. Condino S, Viglialoro RM, Fani S, Bianchi M, Morelli L, Ferrari M, Bicchi A, Ferrari V (2016) Tactile augmented reality for arteries palpation in open surgery training. In: International conference on medical imaging and virtual reality, pp 186–197
10. Fani S, Ciotti S, Battaglia E, Moscatelli A, Bianchi M (2017) W-FYD: a wearable fabric-based display for haptic multi-cue delivery and tactile augmented reality. In: IEEE transactions on haptics, p 1
11. Bianchi M, Battaglia E, Poggiani S, Ciotti S, Bicchi A (2016) A wearable fabric-based display for haptic multi-cue delivery. In: 2016 IEEE haptics symposium (HAPTICS), pp 277–283