Use of augmented reality in Gynecologic surgery to visualize adenomyomas

Running title: Augmented reality for adenomyomectomy

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Précis: Use of an Augmented Reality system specifically designed for gynecologic surgery leads to improved, laparoscopic adenomyomectomy, adenomyoma localization and surgical safety.

Abstract

Augmented Reality (AR) is a surgical guidance technology that allows key hidden subsurface structures to be visualized by endoscopic imaging. We report here two cases of patients with adenomyoma and selected for Augmented Reality technique.

The adenomyomas were localized using AR during laparoscopy. Three-dimensional (3D) models of the uterus, uterine cavity and adenomyoma were constructed before surgery from T2-weighted magnetic resonance imaging, allowing an intraoperative 3D shape of the uterus to be obtained. These models were automatically aligned and ‘‘fused’’ with the laparoscopic

video in real time, giving the uterus a semi-transparent appearance and allowing the surgeon in real time to both locate the position of the adenomyoma and uterine cavity, and rapidly decide how best to access the adenomyoma.

In conclusion, the use of our AR system designed for gynecologic surgery leads to improvements in laparoscopic adenomyomectomy, and surgical safety.

Keywords: Augmented reality, Gynecologic surgery, laparoscopy, adenomyomectomy, MRI

Introduction

Adenomyomectomy may be required in cases of deep uterine pain, abnormal uterine bleeding without any other causes, or infertility; however adenomyomas which are small in size have little impact on the outer shape of the uterus and are difficult to localize. The procedure is further hampered by the use of 2D image flat screens which can limit viewing angles and haptic feedback (1), thus impeding perception of depth.

Augmented reality (AR) provides a means for a surgeon to see sub-surface structures in an endoscopic video (1–3), allowing information from pre-operative imaging, such as MRI, to be overlaid and fused in real time with endoscopic imagery (1,3). AR guidance systems have been successfully developed to assist surgical procedures including gynecological procedures (myomectomy (4)) and those of other specialties (adrenalectomy (3), prostatectomy (5), liver resection and neurosurgery (6)).

Despite these advances, automatic real-time AR presents technical challenges, notably when used with mobile organs such as the uterus; an issue which this new approach addresses. The use of AR has been previously reported in localizing myomas in a synthetic uterine model (7), for surgical resection accuracy in a tumor resection animal model (8), and concerning its feasibility in laparoscopic myomectomy in clinical practice (4).

We here report its use in laparoscopic deep adenomyoma localization. In cases such as these AR provides essential information, necessary for precisely locating out-of-view subsurface structures.

Materials & Methods

Two patients underwent a laparoscopic surgery for adenomyomas. Patients provided signed consent which included a clause for no modification to surgery; in accordance with local Institutional Review Board approval. Before surgery, MRI were realized, with classical MRI sequences.T1 and T2-weighted MRI, along the three planes (axial, coronal, and sagittal). We adjusted MRI settings to have a 1mm resolution, with a slice thickness of 3 mm. Prior to surgery, the contours of the uterus, uterine cavity, and adenomyoma were established in conjunction with preoperative T2-weighted MRI (**Figure 1**). This segmentation phase was made possible by use of an interactive segmentation software (Medical Imaging Interaction Toolkit; German Cancer Research Center (9)).

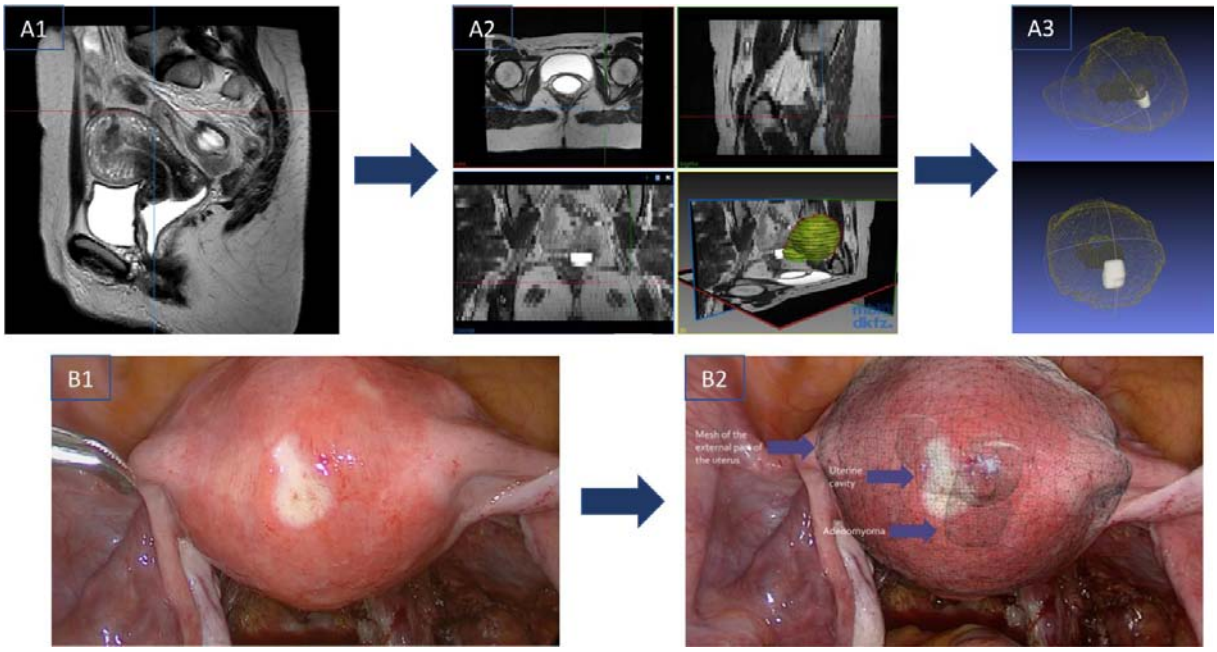

Figure 1. (**A1**): Construction of the pre-operative 3D mesh-model, with the use of (**A2**) T2-weighted magnetic resonance imaging (MRI), segmentation (**A3**) and creation of meshed 3D models. (**B**) Intraoperative view, without (**B1**) and with the Augmented Reality system (**B2**).

A standard laparoscopic technique and laparoscopic set were used with a 0° laparoscope (Spies; Karl Storz). The surgical procedure began by treatment of endometriotic lesions followed by activation of the real-time AR software (>10 frames per second), to visualize the uterine cavity and adenomyoma. The latter comprises three stages (10,11) the first using a ‘‘dense structure-from-motion’’ process i.e. capturing a small number of images of the uterus (simple pictures taken with the laparoscopic camera) taken from various angles and automatically reconstructing a 3D intraoperative mesh model of the shape of the uterus. In the second stage, the preoperative uterus model was aligned to the intraoperative 3D model by a semi-automatic registration process (11): the 3D model is registered to the live laparoscopic video using a novel wide-baseline approach that uses many texturemaps to capture the real changes in appearance of the uterus. This requires a small amount of manual input to mark the limits of the organ, in both the preoperative and the intraoperative model.

The third stage called ‘tracking and fusion’, functions in real-time and aligns preoperative models with the live laparoscopic video. For the tracking stage, we used an existing method based on ‘feature-matching’ proposed in our group. This method is called Wide-Baseline Multi-Texturemap Registration, and do not use classical anatomical landmarks as usual but “teach” the computer to recognize the organ of interest with a few landmarks like organ shape, texture, and biomechanical properties.

Results

Case 1: A 28-year-old patient with dysmenorrhea and recurrent miscarriage, for whom an MRI revealed an adenomyoma (29 x 33 x 24mm) and an endometriotic lesion of the utero-sacral ligament, underwent laparoscopic surgery.

Case 2: A 39-year-old woman with dyspareunia and dysmenorrhea due to endometriotic lesions of the utero-sacral ligament and small deep adenomyoma (11mm x 15mm), underwent also laparoscopic surgery.

The alignment of the models blended with each video frame renders the uterus semi-transparent, thus enabling the surgeon to locate the adenomyoma and uterine cavity with precision (**Figure 1, Video**). AR system was feasible in both cases and it allowed the surgeon to localize the adenomyoma, and to establish the incision point and the extension of the incision. Furthermore, in the first case, this allowed the surgeon greater accuracy concerning the depth of dissection. In the second case the AR system was essential for the localization of the 2cm sized adenomyoma, allowing the surgeon with precision, to establish the initial incision point and the extent of the incision. In both cases an adenomyomectomy was subsequently performed using a classic laparoscopic technique, with increased accuracy made possible due to the available images of the uterine cavity (**Video**).

The post-operative phase was uneventful for both patients who were discharged at post-operative day 1. Pathological analysis confirmed complete excision of both adenomyomas.

Discussion

The present study demonstrated that the AR system is feasible in patients with adenomyomas, and the system can support the surgeon during laparoscopic adenomyomectomy. We aim to use AR to improve surgery involving small adenomyomas that cannot be easily localized during laparoscopy, using fusion of laparoscopic images with preoperative MRI.

Localization of adenomyomas during laparoscopy often presents challenges, and adenomyomas present a surgical challenge during excision, compared with fibroids which are easier to remove. As adenomyomas are generally soft and positioned deep in the uterine muscle, so that tactile feedback is lessened for the surgeon. The boundary between the lesion and normal tissue can only be felt by palpation, frequently requiring open surgery. This lack of tactile feedback provides a likely explanation for why small adenomyomas are often left in place after laparoscopy, with reported recurrence of pelvic pain, abnormal bleeding and/or dyspareunia after surgery.

Laparoscopic management of adenomyomas appears to be safe, feasible and accompanied by good follow-up results and limited recurrence rates (12,13). Authors such as Saremi et al.

have reported a significant reduction in dysmenorrhoea and in hypermenorrhoea (n=103), and cases of spontaneous pregnancy (16). Adenomyomectomy appears to offer a conservative and effective option in the treatment of adenomyosis with preservation of the uterus. Other authors refer to the usefulness of ultrasonic guidance when faced with difficulties involving intraoperative recognition of the adenomatous lesion (12,14)

The present AR system appears to offer a possibility to solve these difficulties. The technical challenges involved due to the mobile nature of the uterus and ovaries may explain the lack of similar reported findings.

In contrast to AR systems previously reported in the literature, our AR system requires no additional laparoscopic hardware, requiring a classic laparoscope only. The software runs on a standard PC (Intel i7 desktop PC) (11). It does not require artificial boundary marking, and unlike other systems (3,17) does not fail with motion blur or when the laparoscope is removed (e.g. for cleaning) and then reinserted. The system provides a solution to the most challenging stage, the tracking and fusion phase, in real time (7).

We previously reported greater accuracy in the localization of small myomas when using AR in a uterine model (7) and in a laparoscopic tumor resection model (8), in addition to the feasibility of the system in the Operative Room (4). Our AR system has some limitations: The most time-consuming aspect of the system centers around the preoperative stage of MRI segmentation, but this should be resolved by the future automation of this phase (18). The intraoperative phase (construction of the 3D intraoperative model and the registration phase) is a quick procedure, taking less than 5 minutes.

The cost-effectiveness of MRI (compared with ultrasound) remains to be demonstrated. MRI provides however the most sensitive means for identification of adenomyomas (particularly those small in size) and for distinguishing myomas from adenomyomas, and adenomyosis, while being less operator dependent (19).

AR could also bring improvements to surgery planning. This system allows visualization during surgery of a preoperative optimized incision plan (vascularization, access to myomas and

adenomyomas, tool ports, uterine cavity localization, tube insertion…). In other indications (endometriosis, oncologic procedures, uterine scar niche...) AR may facilitate localization of the pathology, in addition to anatomic markers and surrounding organs (ureter, main vessels, and rectum).

Conclusion

This study demonstrated that the use of our AR system is feasible in patients with adenomyomas. The software takes into account the mobility of the uterus and thus differs markedly from non-gynecological uses of AR, opening the way to making laparoscopic adenomyomectomy easier, safer and faster. With just small modifications this technique may be used for the majority of gynecological surgeries and so facilitate the localization of anatomic markers (20).

References

1. Pessaux P, Diana M, Soler L, Piardi T, Mutter D, Marescaux J. Robotic duodenopancreatectomy assisted with augmented reality and real-time fluorescence guidance. Surg Endosc. 2014 Aug;28(8):2493–8.

2. Pessaux P, Diana M, Soler L, Piardi T, Mutter D, Marescaux J. Towards cybernetic surgery: robotic and augmented reality-assisted liver segmentectomy. Langenbecks Arch Surg Dtsch Ges Für Chir. 2015 Apr;400(3):381–5.

3. Marescaux J, Rubino F, Arenas M, Mutter D, Soler L. Augmented-reality-assisted laparoscopic adrenalectomy. JAMA. 2004 Nov 10;292(18):2214–5.

4. Bourdel N, Collins T, Pizarro D, Debize C, Grémeau A, Bartoli A, et al. Use of augmented reality in laparoscopic gynecology to visualize myomas. Fertil Steril. 2017 Mar;107(3):737–9.

5. Simpfendörfer T, Baumhauer M, Müller M, Gutt CN, Meinzer H-P, Rassweiler JJ, et al. Augmented reality visualization during laparoscopic radical prostatectomy. J Endourol Endourol Soc. 2011 Dec;25(12):1841–5.

6. Grimson WL, Ettinger GJ, White SJ, Lozano-Perez T, Wells WM, Kikinis R. An automatic registration method for frameless stereotaxy, image guided surgery, and enhanced reality visualization. IEEE Trans Med Imaging. 1996;15(2):129–40.

7. Bourdel N, Collins T, Pizarro D, Bartoli A, Da Ines D, Perreira B, et al. Augmented reality in gynecologic surgery: evaluation of potential benefits for myomectomy in an experimental uterine model. Surg Endosc. 2016 Apr 29;

8. Chauvet P, Collins T, Debize C, Novais-Gameiro L, Pereira B, Bartoli A, et al. Augmented reality in a tumor resection model. Surg Endosc [Internet]. 2017 Aug 15 [cited 2017 Oct 9]; Available from: http://link.springer.com/10.1007/s00464-017-5791-7

9. Wolf I, Vetter M, Wegner I, Böttger T, Nolden M, Schöbinger M, et al. The medical imaging interaction toolkit. Med Image Anal. 2005 Dec;9(6):594–604.

10. Collins T, Pizarro D, Bartoli A, Canis M, Bourdel N. Computer-Assisted Laparoscopic myomectomy by augmenting the uterus with pre-operative MRI data. IEEE International Symposium on Mixed and Augmented Reality (ISMAR); 2014.

11. Collins T, Pizarro D, Bartoli A, Canis M, Bourdel N. Realtime Wide-Baseline Registration of the Uterus in Laparoscopic Videos Using Multiple Texture Maps. In: Liao H, Linte CA, Masamune K, Peters TM, Zheng G, editors. Augmented Reality Environments for Medical Imaging and Computer-Assisted Interventions [Internet]. Springer Berlin Heidelberg; 2013 [cited 2015 Oct 10]. p. 162–71. (Lecture Notes in Computer Science). Available from: http://link.springer.com/chapter/10.1007/978-3-642-40843-4_18

12. Nabeshima H, Murakami T, Nishimoto M, Sugawara N, Sato N. Successful Total

Laparoscopic Cystic Adenomyomectomy After Unsuccessful Open Surgery Using Transtrocar Ultrasonographic Guiding. J Minim Invasive Gynecol. 2008 Mar;15(2):227–30.
13. Osada H. Uterine adenomyosis and adenomyoma: the surgical approach. Fertil Steril. 2018 Mar;109(3):406–17.
14. Grimbizis GF, Mikos T, Zepiridis L, Theodoridis T, Miliaras D, Tarlatzis BC, et al. Laparoscopic excision of uterine adenomyomas. Fertil Steril. 2008 Apr;89(4):953–61.
15. Horng H-C, Chen C-H, Chen C-Y, Tsui K-H, Liu W-M, Wang P-H, et al. Uterine-sparing surgery for adenomyosis and/or adenomyoma. Taiwan J Obstet Gynecol. 2014 Mar;53(1):3–7.
16. Saremi A, Bahrami H, Salehian P, Hakak N, Pooladi A. Treatment of adenomyomectomy in women with severe uterine adenomyosis using a novel technique. Reprod Biomed Online. 2014 Jun;28(6):753–60.
17. Nakamoto M, Nakada K, Sato Y, Konishi K, Hashizume M, Tamura S. Intraoperative magnetic tracker calibration using a magneto-optic hybrid tracker for 3-D ultrasound-based navigation in laparoscopic surgery. IEEE Trans Med Imaging. 2008 Feb;27(2):255–70.
18. De Leener B, Kadoury S, Cohen-Adad J. Robust, accurate and fast automatic segmentation of the spinal cord. NeuroImage. 2014 Sep;98:528–36.
19. Canis M, Gremeau AS, Bourdel N. Elusive adenomyosis: a plea for an international classification system to allow artificial intelligence approaches to reset our clinical management. Fertil Steril. 2018 Nov;110(6):1039–40.
20. Bartoli A, Collins T, Bourdel N, Canis M. Computer assisted minimally invasive surgery: is medical computer vision the answer to improving laparosurgery? Med Hypotheses. 2012 Dec;79(6):858–63.

Video legend

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