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1 **Title: Use of augmented reality in Gynecologic surgery to visualize adenomyomas**

2

3 **Running title:** Augmented reality for adenomyomectomy

4

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20 Declarations of interest: none

21

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

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31 **Abstract**

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

36 The adenomyomas were localized using AR during laparoscopy. Three-dimensional (3D)
37 models of the uterus, uterine cavity and adenomyoma were constructed before surgery from
38 T2-weighted magnetic resonance imaging, allowing an intraoperative 3D shape of the uterus
39 to be obtained. These models were automatically aligned and “fused” with the laparoscopic
40 video in real time, giving the uterus a semi-transparent appearance and allowing the
41 surgeon in real time to both locate the position of the adenomyoma and uterine cavity, and
42 rapidly decide how best to access the adenomyoma.

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

45

46

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

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51 **Introduction**

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

57 Augmented reality (AR) provides a means for a surgeon to see sub-surface structures in an
58 endoscopic video (1–3), allowing information from pre-operative imaging, such as MRI, to be

59 overlaid and fused in real time with endoscopic imagery (1,3). AR guidance systems have
60 been successfully developed to assist surgical procedures including gynecological
61 procedures (myomectomy (4)) and those of other specialities (adrenalectomy (3),
62 prostatectomy (5), liver resection and neurosurgery (6)).

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

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

71

72 **Materials & Methods**

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

82 A standard laparoscopic technique and laparoscopic set were used with a 0° laparoscope
83 (Spies; Karl Storz). The surgical procedure began by treatment of endometriotic lesions
84 followed by activation of the real-time AR software (>10 frames per second), to visualize the
85 uterine cavity and adenomyoma. The latter comprises three stages (10,11) the first using a

86 “dense structure-from-motion” process i.e. capturing a small number of images of the uterus
87 (simple pictures taken with the laparoscopic camera) taken from various angles and
88 automatically reconstructing a 3D intraoperative mesh model of the shape of the uterus. In
89 the second stage, the preoperative uterus model was aligned to the intraoperative 3D model
90 by a semi-automatic registration process (11): the 3D model is registered to the live
91 laparoscopic video using a novel wide-baseline approach that uses many texturemaps to
92 capture the real changes in appearance of the uterus. This requires a small amount of
93 manual input to mark the limits of the organ, in both the preoperative and the intraoperative
94 model.

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

101

102 **Results**

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

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

109 The alignment of the models blended with each video frame renders the uterus semi-
110 transparent, thus enabling the surgeon to locate the adenomyoma and uterine cavity with
111 precision (**Figure 1, Video**). AR system was feasible in both cases and it allowed the
112 surgeon to localize the adenomyoma, and to establish the incision point and the extension of

113 the incision. Furthermore, in the first case, this allowed the surgeon greater accuracy
114 concerning the depth of dissection. In the second case the AR system was essential for the
115 localization of the 2cm sized adenomyoma, allowing the surgeon with precision, to establish
116 the initial incision point and the extent of the incision. In both cases an adenomyectomy was
117 subsequently performed using a classic laparoscopic technique, with increased accuracy
118 made possible due to the available images of the uterine cavity (**Video**).

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

121

122 **Discussion**

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

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

136 Laparoscopic management of adenomyomas appears to be safe, feasible and accompanied
137 by good follow-up results and limited recurrence rates (12,13). Authors such as Saremi et al.
138 have reported a significant reduction in dysmenorrhoea and in hypermenorrhoea (n=103),
139 and cases of spontaneous pregnancy (16). Adenomyectomy appears to offer a
140 conservative and effective option in the treatment of adenomyosis with preservation of the

141 uterus. Other authors refer to the usefulness of ultrasonic guidance when faced with
142 difficulties involving intraoperative recognition of the adenomatous lesion (12,14)

143

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

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

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

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

164 AR could also bring improvements to surgery planning. This system allows visualization
165 during surgery of a preoperative optimized incision plan (vascularization, access to myomas
166 and adenomyomas, tool ports, uterine cavity localization, tube insertion...). In other
167 indications (endometriosis, oncologic procedures, uterine scar niche...) AR may facilitate

168 localization of the pathology, in addition to anatomic markers and surrounding organs (ureter,
169 main vessels, rectum).

170

171 **Conclusion**

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

178

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243

244 **Figure Legend**

245 **Figure 1**

246 **(A)**: Construction of the pre-operative 3D mesh-model, with the use of **(A1)** T2-weighted
247 magnetic resonance imaging (MRI), segmentation **(A2)** and creation of meshes.

248 **(B)** Intraoperative view, without **(B1)** and with the Augmented Reality system **(B2)**.

249

250 **Video legend**

251 Use of augmented reality in to visualize adenomyomas

252

