# Augmented Reality with Diffusion Tensor Imaging (DTI) and Tractography during Laparoscopic Myomectomies

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**Précis:** Augmented Reality with DTI can help a surgeon to visualise and decide the starting incision point in laparoscopic myomectomy.


## Abstract

Augmented Reality (AR) is a technology that allows a surgeon to see key hidden subsurface structures in an endoscopic video in real time. This works by overlaying information obtained from pre-operative imaging, and fusing it in real time with the endoscopic image. MR-DTI and fiber tractography are known to provide additional information to standard structural MRI. Here we report the first two cases of real-time AR during laparoscopic myomectomies with visualization of uterine muscle fibers after MR-DTI tractography, to help the surgeon decide the starting point incision.

First case: A 31 year-old patient underwent a laparoscopic surgery for a 6cm FIGO 5 myoma. Second case: a 38 year-old patient also underwent a laparoscopic myomectomy, for a unique 6cm myoma FIGO 6. Signed consents were obtained for all the patients, which included clauses of no modification of the surgery. Before surgery, MRI were realized. The external surface of the uterus, the uterine cavity, and the surface of the myomas were delimited according to the preoperative MRI. A fiber tracking algorithm was used to extrapolate the uterine muscle fibers architecture.

The aligned models were blended with each video frame to give the feeling that the uterus is almost transparent, and so the surgeon can localize exactly the myomas, and the uterine cavity. We displayed also the uterine muscle fibers, and the visualization of them helped us to decide the starting incision point for the myomectomies. Then, the myomectomies were performed using a classic laparoscopic technique.

Those case-reports shows that AR and DTI fiber tracking in fibroid uterus is possible, providing fiber direction, helping the surgeon to visualize and decide the starting incision point, for laparoscopic myomectomy. Respecting the fibers orientation could improve the quality of the scar, and decrease the architectural disorganization of the uterus.


# 1 Introduction

Augmented Reality (AR) is a technique that can overlay information obtained from preoperative imaging, such as MRI, by fusing it in real time with the endoscopic images (1,2). This technology allow a surgeon to see key hidden subsurface structures in an endoscopic video in real time (1–3).

AR guidance systems have been developed to assist surgical procedures including gynecological procedures with our AR system (myomectomy (4), adenomyomectomy (5)) and other specificities (adrenalectomy (2), prostatectomy (6), neurosurgery (7)).

Despite progress, automatic real-time AR is still technically challenging for mobile organs like the uterus. In our team, we've developed a new approach that can handle mobile organs, and we reported recently the usefulness of AR for localizing myomas in a synthetic model (8), for the accuracy of surgical resection (9), and the feasibility of using AR for laparoscopic myomectomy (4), and adenomyomectomy (5).

MR diffusion tensor imaging (MR-DTI) is an emerging non-invasive method that can improve tissue characterization. Another recent advance is in addition the use of MR-DTI and fiber tractography, that allow one to obtain the fibers direction in a 3D-image (10), like the muscle fibers of the uterus. MR-DTI and fiber tractography are known to provide additional information to standard structural MRI.

## Materials and Methods

Here we report the first two cases of real-time augmented reality during laparoscopic myomectomies with visualization of uterine muscle fibers after DTI tractography-MRI, to help the surgeon to decide the starting point incision.

### The patients

A 31 years-old patient underwent a laparoscopic surgery for a type 6cm FIGO 5 myoma. She's been in consultation for abnormal uterine bleeding, and chronic pelvic

pain. The ultra-sound evaluation and MRI revealed one unique 6cm FIGO 5 myoma, in contact with the uterine cavity.

The second patient: a 38 age-old patient, with a 6cm FIGO 6 myoma underwent also a laparoscopic myomectomy. She was operated because of dysmenorrhea, and infertility, and the ultra-sound evaluation and MRI revealed one unique 6cm FIGO 6 myoma, associated with deep infiltrating endometriosis of both utero-sacral ligaments. We decided to do a complete surgical procedure, but we will focus here of the part of the surgery dedicated to the myomectomy.

Signed consents were obtained for both patients, which included clauses of no modification of the surgery.

**The MRI**

**Image acquisition:**

Before surgery, MRI were realized, with classical MRI sequences. For the DTI, Diffusion weighted single shot echoplanar imaging (SSh-EPI) was acquired with spectral fat saturation and half Fourier sampling along 32 directions to obtain DTI. Diffusion weighted SSh EPI was performed on the axial plane with the following parameters: TE 66 ms, TR 3000 ms, FOV 34 x34 cm, matrix 96x96, thickness 4 mm, EPI factor 134, b 800 $s.mm^{-2}$.

**Segmentation:**

The outer surface of the uterus, uterine cavity, and myomas were delimited according to the preoperative T2-weighted MRI. This segmentation phase was performed with the use of an interactive segmentation software (Medical Imaging Interaction Toolkit; German Cancer Research Center (11)).

## DTI: how it works?

MR diffusion tensor imaging (MR-DTI) is a new method to determine the amount of random diffusion (Brownian motion) of water molecules in tissues, supplying physiological information about the water mobility, that enhance tissue characterization. The Fiber tractography can be add to the MR-DTI, to allow the visualization of the direction of fibers in a three-dimensional image (10).

A prerequisite to visualize DTI data is fiber *reconstruction* and *tracking*.

Fiber tracking is performed using dedicated software starting from a region of interest (ROI). The former reconstructs raw images to diffusion tensors and a few other maps including the Apparent Diffusion Coefficient (ADC) and the Fractional Anisotropy (FA). Tracking is continued until the stop criteria are satisfied. To help fiber visualization in the final fiber tracking, a minimal FA of 0.18 with a pitch of 160 mm were used. The latter computes a 3D model of the fibers from the diffusion tensors. We performed reconstruction and tracking using the computer software TrackViz (12).

## The AR software

The technical solution allowing one to display the obtained fibers onto the surgeon's laparoscopy monitor relies on the augmented reality software Laparaug (13). It has four main parts: (i) the preoperative 3D model of the uterus is segmented using the MITK software (11) and the fibers are expressed in the same coordinate system using the DICOM metadata ; (ii) the fibers located outside the uterus volume are discarded by means of mesh voxelization (14); (iii) the fibers are deformed according to the uterus' external surface deformation undergone between the MRI acquisition and the

surgery and (iv) the uterus is tracked across the laparoscopic live video stream and the fibers location updated in the image.

### The surgical equipment

A standard laparoscopic technique and a standard laparoscopic set were used with a 0° laparoscope (Spies; Karl Storz). Classical laparoscopic instruments were used.

## Results (Figure + video)

The aligned models are blended with each video frame to give the impression that the uterus is semitransparent, and the surgeon can see the exact location of the myomas, and the uterine cavity. We displayed also the uterine muscle fibers, and the visualization of them helped us to decide the starting incision point for the myomectomy. Indeed, the surgeon decided to do the surgical incision following the uterine muscle fibers. Then, the myomectomy was performed with the use of a classic laparoscopic technique.

The post-operative course was uneventful for both patients, and they were discharged home at post-operative day 1.

## Discussion

This work is the first to report laparoscopic myomectomies with in vivo AR DTI fiber tracking in a fibroid uterus. Those two cases show the feasibility of fiber tractography with DTI, in MRI for pelvic lesion in clinical practice, in its possible use during laparoscopic surgery with AR.

MR-DTI and fiber tractography are known to provide additional information to standard structural MRI, showing the uterine muscle fiber direction, with a good correlation to the histological analysis (15).

Diffusion is a multi-dimensional process, which occurs in different values in different directions depending on the microstructure of the tissues. DTI can provide information about the anisotropy of water diffusion in tissues (7). The technique depends on supposing that water molecules will diffuse in the same direction as the general orientation of the fibers rather than perpendicular to them. Indeed, uterine myometrium is composed of smooth muscle bundles and connective tissue diffusion reflects anisotropic characteristics.

It can be used to detect water diffusion directionality which shows then the microstructural architecture of normal and abnormal tissue.

At the beginning, DTI has been used to evaluate and show the integrity of white matter tracts in neuroradiology (16). With the upturn of the MRI hardware and software, DTI was added to abdominal imaging for some of the abdominal organs like uterus. Indeed, in gynecology, the orientation of the muscular fibers of the uterus have been studied, even if the use of DTI on the uterus is quite recent. The initial studies have been published regarding DTI of the uterus specimens of the patients to whom hysterectomy was performed, for various medical reasons (15,17,18) and then in vivo on the uterus of the patients (10).

Quantitative DTI measures on the uterus have already been conducted to analyze the differences in the 3 uterine layers (19), and the menstrual cycle changes (20).

However, few studies performed tractography. Fiber tractography is a novel software application that evaluate the direction of fibers in a three-dimensional image, by estimating the tensor value of each voxel. It works by depicting the intervoxel connectivity based on the anisotropic diffusion of water to give quantitative information on the dominant direction of the water in a well-organized tissue (10).

Thrippelton et al. (15) performed tractography on ex vivo fibroid uterus, with good histological correlation (the water diffusion parameters measured by DT-MRI in the uterus seems to be sensitive to different tissue type and myxoid degeneration) and furthermore, the ex vivo tractography seems to correspond qualitatively to the uterine muscle fiber direction. In the same way, Weiss et al (18) confirm the existence of directional structures in the complex fiber architecture of the uterus. with a correlation with the pathological examination. Fiocchi et al. (10) also performed DTI and tractography in vivo, showing preferential fiber directions in the uterus, and also local changes next to caesarian scars, confirming the sensitivity of the DTI for different tissue type. But conversely to our study, the patients with myomas were excluded in Fiocchi et al's study.

That was the starting point of our reflection, to see if the visualization of uterine muscle fibers after DTI tractography-MRI can help the surgeon to decide the starting point incision, and improve the quality of the surgery.

About the risk of uterine rupture after a myomectomy, it is reported in literature to be around 0.7-1% (21). Many possible risk factors have been investigated in the literature, such as surgical approach, characteristics of myomas removed, type of hemostasis, suture techniques, but none of them seems to be able to predict the event of uterine rupture. Anyway, for us the incision of the uterine wall should follow the orientation of the muscle fibers of the uterus, leading to a potential improvement of the scar quality.

This decrease of the architectural disorganization of the uterus could theoretically reduce the risk of uterine rupture after a myomectomy, even if this event remains a complication that is difficult to predict.

The cost-effectiveness if the use of our software is an important question. First of all, in our experience the intraoperative phase (construction of the 3D intraoperative model and the registration phase) is a quick procedure, taking less than 5 minutes. We have already shown the feasibility of the system in the Operative Room. The cost of a system may also be a weakness. However, our system runs on a standard Intel i7 desktop PC at a cost of less than 1000 Euros (which is dropping each year for the same level of hardware) and does not need any other device. Finally, we have recently started a clinical evaluation of the use of the system in real condition in the OR, with the analysis of the addition time during the surgical procedure, due to the use of the software. We will also complete a cost-effective analysis about the surgical complications, and potential additional morbidity, and the satisfaction of the surgeon after the use of the AR software.

## CONCLUSION

Those two case-reports show that Augmented Reality and DTI fiber tracking in fibroid uterus is possible, providing fiber direction on the surface of the myoma and the uterus, helping the surgeon to visualize and decide the starting incision point, for laparoscopic myomectomies.

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**Figure Legend**

**This figure refers to the second case of the video.**

(A): Construction of the pre-operative 3D mesh-model, with the use of T2-weighted magnetic resonance imaging (MRI): segmentation and creation of meshes, with the visualization of the uterine muscle fibers

(B) Laparoscopic Intraoperative view,

(C) Laparoscopic Intraoperative view with the Augmented Reality system, which shows the uterine muscle fibers and the ideal incision point to start the myomectomy.

**Video legend**

Use of augmented reality with Diffusion Tensor Imaging (DTI) and Tractography during laparoscopic myomectomies.