White Paper

Virtual Navigator in endometriosis

FUSION imaging in deep infiltrating endometriosis

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Introduction

Ultrasonography is widely recognized as the first-choice imaging technique for the study of the female pelvis[1].
Ultrasound (US) provides real-time images, highly appreciated in terms of image quality and tissue information, but above all for its low execution time, non-invasiveness for the patient and low cost for the hospital. Magnetic Resonance (MR), on the other hand, is unequivocally recognized as an imaging technique at high spatial resolution, with the widest field of view, although it is much more expensive and less comfortable for the patient.
Therefore, the combination of these two modalities makes it possible to combine their advantages and overcome their limitations with the aim of providing patients with the best care (Fig. 1).

US

- ✓ Real-time
- ✓ Low-cost examination
- ✓ No patient irradiation
- ✗ Operator-dependent
- ✗ Low accuracy for upper localizations (ileal, recto-sigmoidal, and round-ligament lesions)

MRI

- ✓ High resolution
- ✓ Extended field of view
- ✗ Low accuracy for lower localizations (rectal lesions)
- ✗ Cost & discomfort

Fig. 1: Advantages and limitations of US and MR imaging modalities in DIE assessment.

A cross-modality Imaging approach opens new horizons in gynaecological imaging, from everyday clinical practice to interventional procedures, research and education.

Background

Endometriosis is an inflammatory disease characterized by the presence of endometriotic glands outside the uterus, which affects more than 176 million women worldwide[2].

Although classification of endometriosis is rather controversial, three forms have been defined: peritoneal endometriosis, ovarian endometriosis, and deep infiltrating endometriosis (DIE), where the endometriotic glands invade further than 5 mm into the underlying tissue[3].

DIE, the most aggressive of the three phenotypes that constitute endometriosis, is associated with pelvic pain, dysmenorrhea, dyspareunia, dyschezia and urinary tract symptoms depending on the anatomical location[4].

Although the choice of the best therapeutic approach for women with DIE is often challenging, an accurate diagnosis of this pathology is essential to help the patient make a choice regarding treatment options: medical, surgical and/or to plan fertility treatment[5].

MRI and US both have their benefits and drawbacks in the study of this pathology. Although transvaginal ultrasound (TVUS) is better at detecting rectal nodules (TVUS accuracy of 95.8% vs. 94.9% for MRI), the extent of pelvic endometriosis can be evaluated by MRI with an accuracy of 90.8%[6].

Therefore, MR and US scanning complement each other in screening and diagnosis of endometriosis[7].

The aim of this paper is to show the potential of the fusion imaging technique to locate and assess the main anatomical sites involved in endometriotic lesions, in particular in DIE.

Findings & details of procedure

Esaote Virtual Navigator Technology

Virtual Navigator (VNav) is the Esaote technology for fusion imaging that enables US examiners to combine real-time ultrasound with datasets from second modalities, such as MRI, CT and PET-CT.
In order to perform image fusion, the hardware of the ultrasound system requires a magnetic field generator and a position sensor - known as antenna - for the ultrasound transducer. The antenna makes it possible to detect the position of the transducer in a three-dimensional field, created by the electromagnetic transmitter. The Virtual Navigator software then enables the simultaneous registration of the datasets from a Digital Imaging and Communication in Medicine (DICOM) second modality and from real-time ultrasound (Fig. 2).

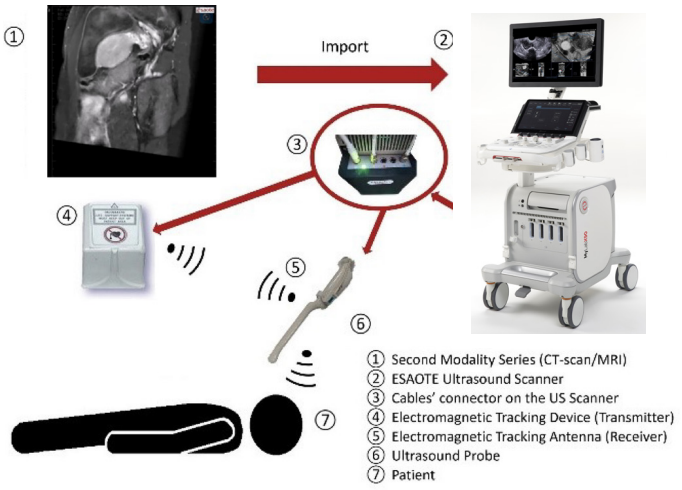

Fig. 2: Tracking solution on Esaote ultrasound system.

The fusion imaging procedure relies on three steps:

1. Preparation phase
The operator imports into the ultrasound device one or more DICOM second modalities, such as MRI, CT, and PET CT directly from the PACS or from external media, such as a CD or USB stick.
Inside the VNav environment, if there is more than one sequence, the operator can use the automatic alignment function to align the series. Then, the physician will identify the target and place it inside the relevant volume by selecting "Ball target" on the touchscreen of the Virtual Navigator menu.

2. Co-registration of ultrasound and second-modality datasets
Once the preparation phase has been completed, the system is ready to start the fusion procedure between MRI and real-time US data. The most straightforward method is to perform single-plane registration by selecting the same plane in sagittal view both on the US scan and on the MRI/CT dataset. After confirmation that the system has registered the two modalities, the system will compute a reformatted slice image of the 3D dataset according to the movements of the US transducer.
Some adjustments can be performed, to optimize the simultaneous registration in closer proximity to the target area and therefore to increase the accuracy of the alignment.
VNav offers different possibilities, such as: one-point alignment, fine-tuning and, to increase accuracy even further, internal marker alignment.

3. Navigation phase
The system is ready to navigate through the two modalities (Fig. 3). If more than one second modality dataset has been uploaded, the operator can switch between them at any time as the current modality. Different display layouts are available.

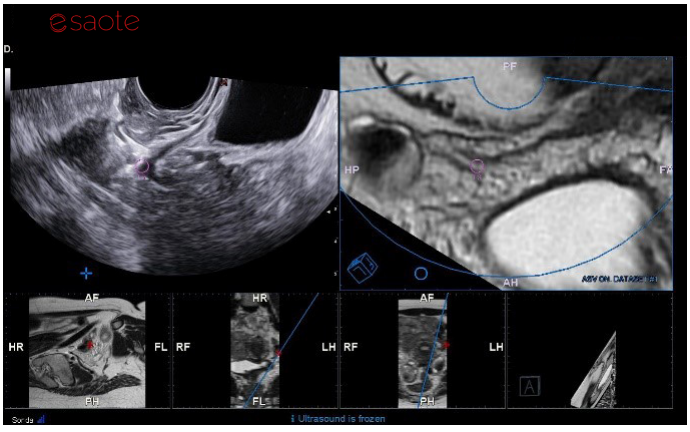

Fig. 3: In the navigation phase the device is ready to navigate through real-time US and MRI.

Methods

This study was conducted over a period of six months. Patients underwent an ultrasound assessment of endometriosis performed by a trained sonographer.
Fusion imaging was offered to all patients who had had a pelvic MRI examination within the previous six months. All MRI examinations were performed on a 1.5-T MRI machine equipped with a phased-array body coil.
The MR volumes acquired at the time of the MRI examination were loaded into the ultrasound device for the fusion imaging procedure. The second MR modality images were then registered, using one plane and two anatomical reference points.
Virtual Navigator's ability to identify and assess the main anatomical structures of pelvic endometriosis (uterosacral ligaments, posterior vaginal fornix, rectum, ureters, bladder) was evaluated.

Results

Over the study period, 500 patients were referred for ultrasound examination as a result of endometriosis. Of these, 15 patients with a median age of 35 years (range: 27-49) had undergone MRI examination within the past year, with a median time interval between MRI and US examination of 87 (range: 1-180) days. All 15 women agreed to an additional evaluation using fusion imaging technology.
The entire procedure (preparation, registration, and navigation) was completed in 30 minutes, in all 15 cases.
The DIE lesions were successfully identified in all 15 patients and correlated with anatomical landmarks.

Case 1 – DIE in the uterosacral ligaments (USLs):

USLs are affected by DIE when hypoechoic thickening, with regular or irregular margins, is seen within the peritoneal fat surrounding the USLs. The lesion may be isolated or may form part of a larger nodule extending into the vagina or into other surrounding structures[8].

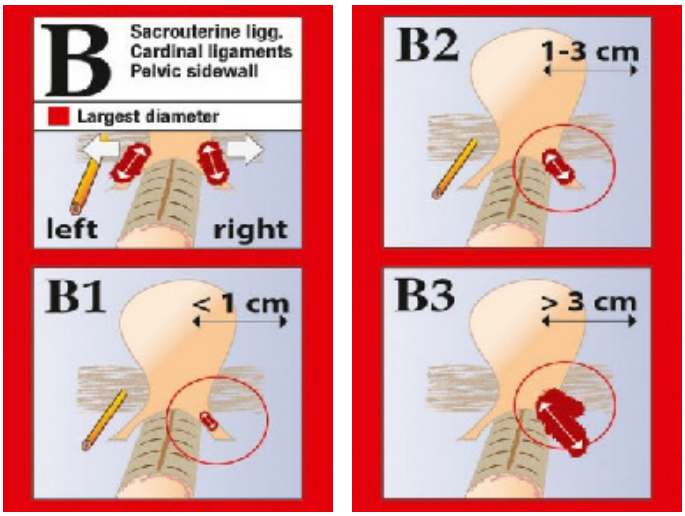

Fig. 4: The #Enzian classification[9] is a non-invasive and surgical description system for endometriosis, with a specific session for deep endometriosis. Compartment B refers to uterosacral ligaments (USLs), cardinal ligaments and pelvic sidewall.

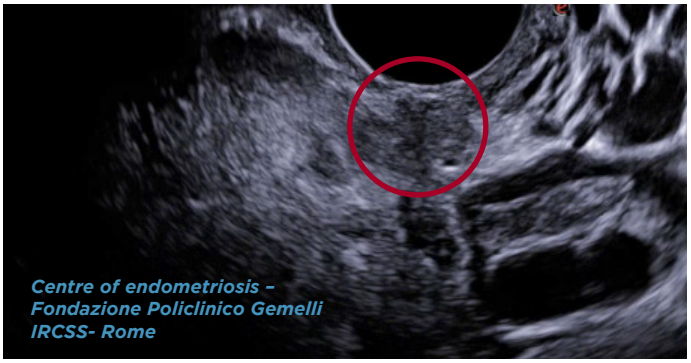

Fig. 5: US - Mid-sagittal view of the uterus - DIE lesions in the USLs appear as hypoechoic structures (red circle).

At the start of the examination, after the first two phases have been successfully completed, a blue spherical target is placed on the US image, corresponding with the endometriotic lesion, to facilitate its identification in the relevant MRI plane.
An endometriotic nodule involving the USL is clearly visible in both the US (left) and MR image (right). US shows the lesion very accurately, along with the physical bond between lesion and vagina. Conversely, the MRI provides a overview, simultaneously displaying the lesion, ovary and uterus in a single image.
Fusion imaging improved the identification and localization of the lesion, as well as showed how the surrounding structures (bowel, vagina, uterus, and ovary) interface with the nodule.

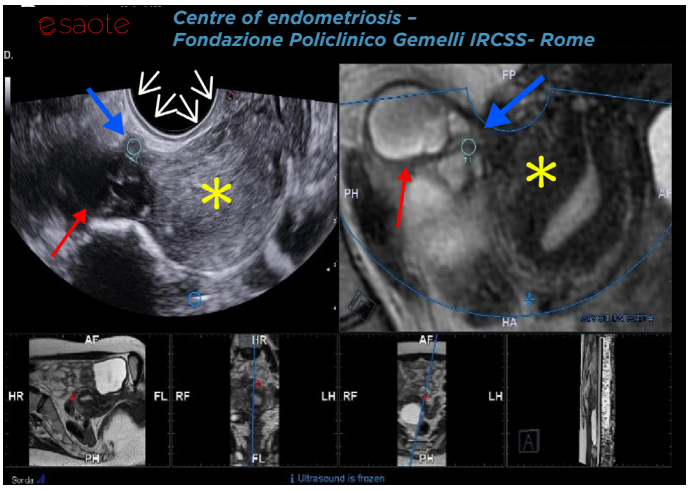

Fig. 6: Fusion imaging between US (left) and MRI (right) in the sagittal plane. The blue arrow shows the USL endometriotic lesion, while the red one represent the ovary. White arrows highlight the vagine when the uterus is indicated by the yellow asterisk.

After MRI-US examination, the patient underwent laparoscopy, which confirmed the diagnosis made by fusion imaging.

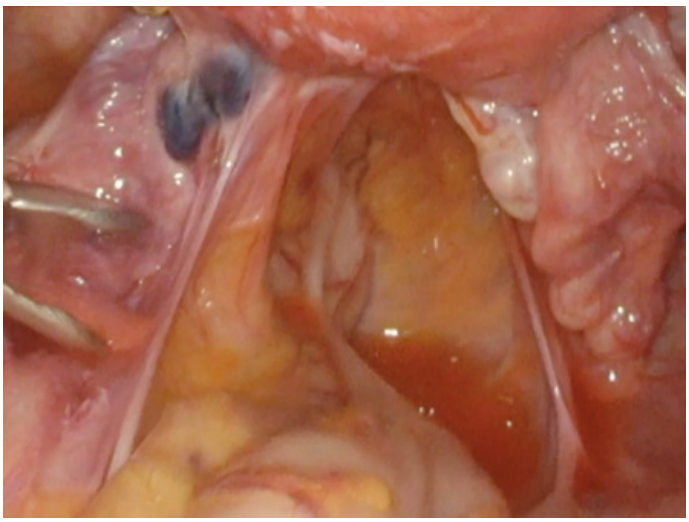

Fig. 7: The USL lesion identified by fusion imaging is clearly visible on the laparoscopic image.

Scan the QR code below to see Virtual Navigator in navigation environment. Here, the spherical target appearance or disappearance is contingent upon the visualization of the USL lesion.

Case 2 – Bowel affected by DIE:

Bowel DIE classically involves the anterior rectum, rectosigmoid junction and/or sigmoid colon, all of which can be visualized using TVS[8].

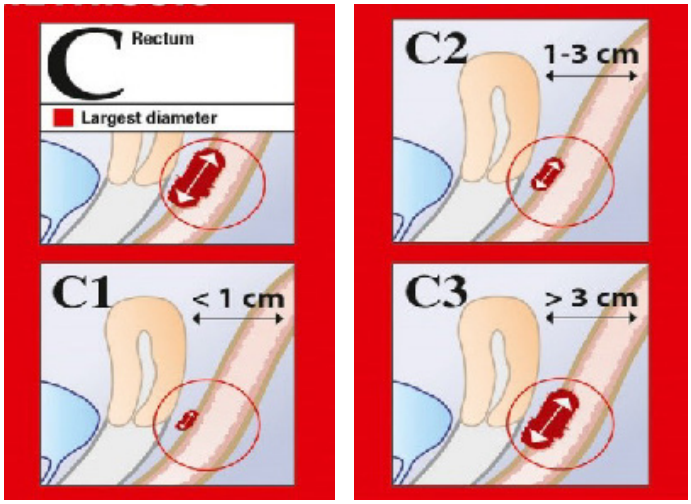

Fig. 8: In the #Enzian classification[9] compartment C is used to assess the length of the lesion in the anterior wall of the rectum. Severity grade is determined by the maximal diameter of the lesion measured in the sagittal section along the axis of the rectum as follows: C1 if the maximal diameter is =< 1 cm, C2=1-3 cm, C3 = >3 cm.

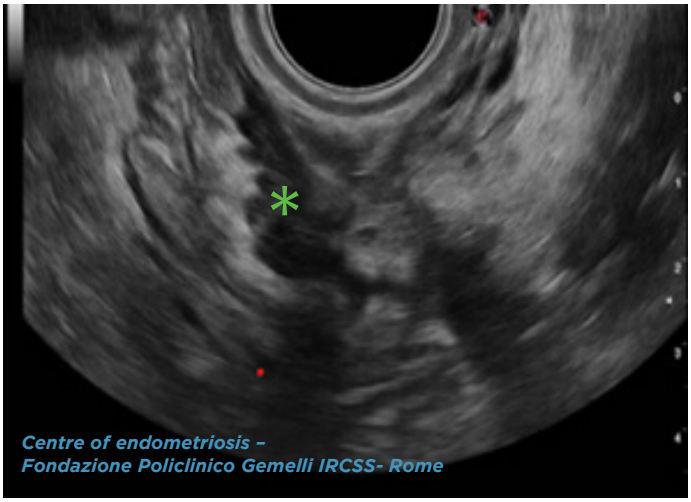

Fig. 9: US - Sagittal view of the uterus - DIE lesions in the rectum appear as hypoechoic structures (green asterisk).

In this case, the endometriotic lesion involves the anterior wall of the rectum and is shown both in the ultrasound (left) and in the MR image (right). TVUS is particularly excellent for identifying the lesion with a specific focus on the retro-cervical area. Conversely, MR volumes display the entire intestine in one view, helping to visualize the multifocality of the lesion. Once again in this study, fusion imaging technology has proved to be highly effective, showing perfect synchronization between US and MRI and resulting in faster and more comprehensive identification of the lesions.

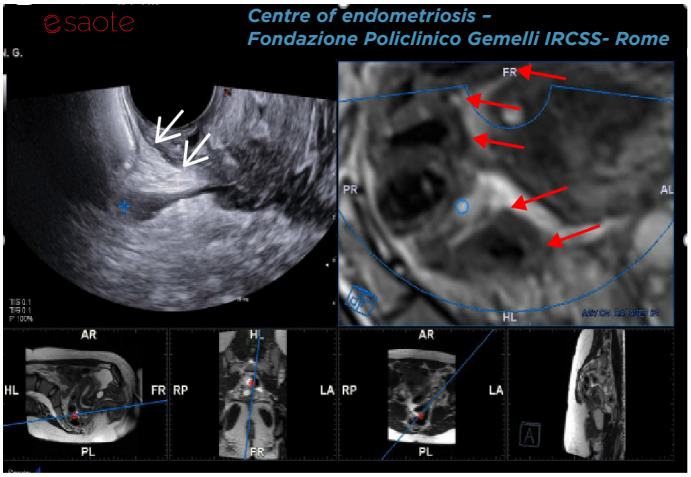

Fig. 10: Fusion imaging between US (left) and MRI (right) in the sagittal plane. The white arrows show the retro-cervical area, while the red ones indicate the intestine. + and o represent the endometriotic rectal lesion in US and MRI, respectively.

The findings of the laparoscopy performed using fusion imaging were consistent with previous results.

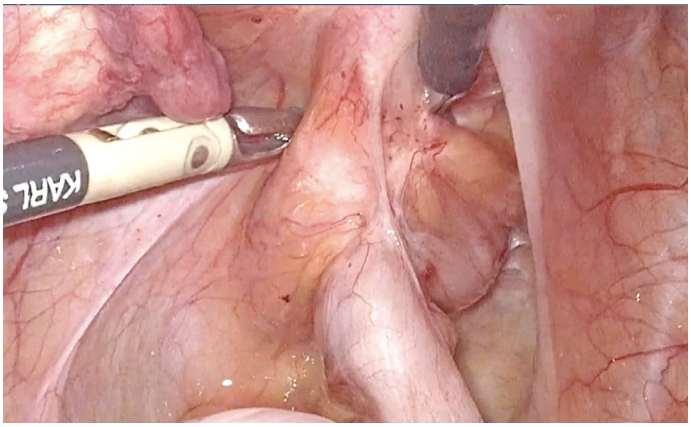

Fig. 11: The rectal lesion identified using fusion imaging is clearly visible on the laparoscopic image.

The video accessible via QR code gives the opportunity to witness Virtual Navigator's potential: the panoramic MRI view, combined with the highest ultrasound resolution, facilitates the eventual detection of multifocal intestinal lesions.

Case 3 – Ureteric involvement in endometriotic patients:

In US examination, the ureter is identified as a fusiform, fluid-filled anechoic tubular structure, displaying intermittent peristalsis in continuity with the urinary bladder. Pelvic ureter can be divided into two tracts: the vesicovaginal tract, from the intersection with the uterine artery to the entry into the bladder, and the parametrial tract from the point it crosses the iliac vessel to the one it crosses the uterine artery[10].

Usually, when the ureteral diameter is ≥ 6 mm in US examination, ureteral obstruction is causing congestion[10]. However, it should be noted that the early stages of ureteral dilation may not be accompanied by hydronephrosis as in the case of this patient where no blood flow is detectable with Doppler technology (see Fig. 13).

Fig. 12: In the #Enzian classification[9] extrinsic and/or intrinsic ureteric involvement with signs of obstruction are classified as "FU".

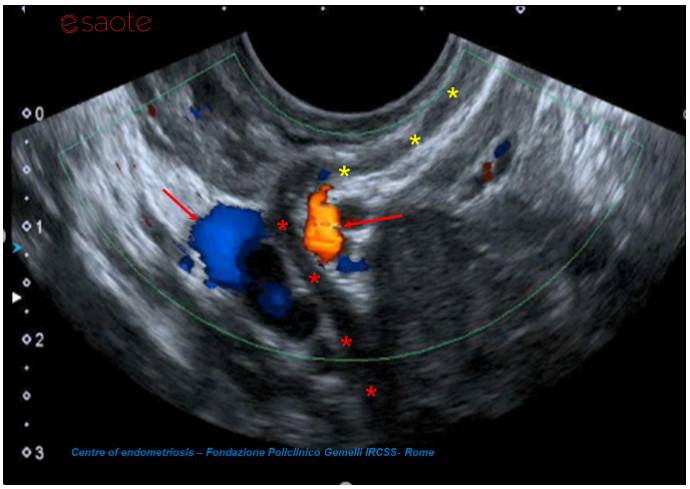

Fig. 13: Pelvic ureter during US examination. The (*) delineate the vesicovaginal tract, while the (*) the parametrial one. The red arrows show the uterine artery.

DIE lesions can, in severe cases, extend to the ureter, as visible in both the modalities (US and MRI), shown in Fig. 14. As proper examination of the ureter requires a broad field of view, in order to reach the intersection with the common iliac vessels, an MR examination is essential. Indeed, MR images show the intestine, all in one image, enabling the identification of ureter stenosis in cases of posterior compartment endometriosis.

In this case, real-time US with its Power Doppler technology, has been useful for a more accurate assessment of the ureter itself.

Therefore, the advanced ultrasound technique of Virtual Navigator has proved to be suitable for many cases of endometriosis, including the ureteric ones.

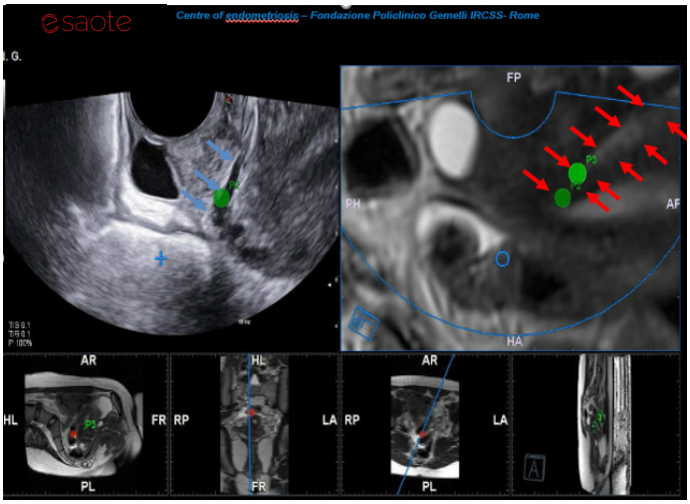

Fig. 14: Fusion imaging between US (left) and MRI (right) in the sagittal plane. The blue arrows depict the ureter on ultrasound, while the red ones are the ureter on MRI. The blue marks (+/o) underline the synchronization between the two modalities. The green dots, P2 and P3, are located in correspondance of the dilated ureter.

Laparoscopic examination has highlighted a dilated ureter, serving as proof that fusion imaging diagnosis was correct.

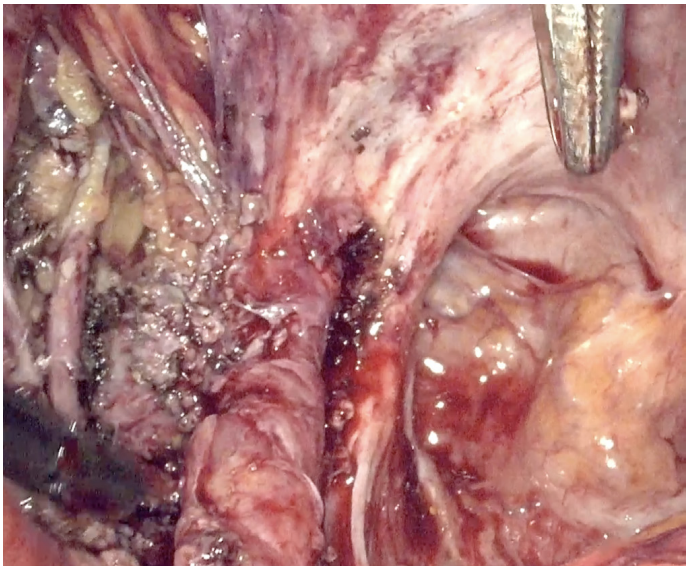

Fig 15. The medialized and dilated ureter identified by fusion imaging are clearly visible on the laparoscopic image.

In the video linked to this QR code, Virtual Navigator in action is observable. This technology enables to leverage the panoramic view from the MRI, in conjunction with improved ultrasound resolution, to effectively locate the ureter and conduct a more precise examination of the organs affected by endometriosis. At the beginning of the ultrasound scan, a green spherical target was positioned, facilitating instant identification of the ureter within the corresponding MRI plane (P2 and P3). The video also illustrates how these spherical targets come into view or vanish based on the visualization of the dilated ureter.

At the start of the examination, green spherical targets were placed on the ultrasound image, resulting in immediate identification of the ureter (P2 and P3) in the corresponding MRI plane. In the video, we can also see how the spherical targets appear or disappear depending on the view of the dilated ureter.

Case 4 – DIE in the bladder nodule:

On two-dimensional (2D) ultrasound the appearance of DIE in the bladder can be: an hypoechoic or a spherical lesion; with or without regular margins; involving the bladder's muscularis (most common) or (sub)mucosa (less often). DIE in the bladder is diagnosed only if the muscularis of the wall bladder is affected, if only serosa is involved, the disease is consider as a superficial one.

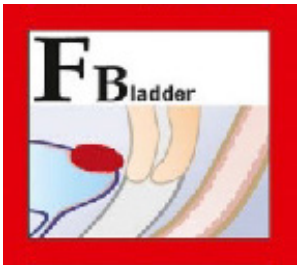

Fig. 16: In the #Enzian classification[9] deep lesions of the urinary bladder with involvement of the muscular layer are classified as "FB".

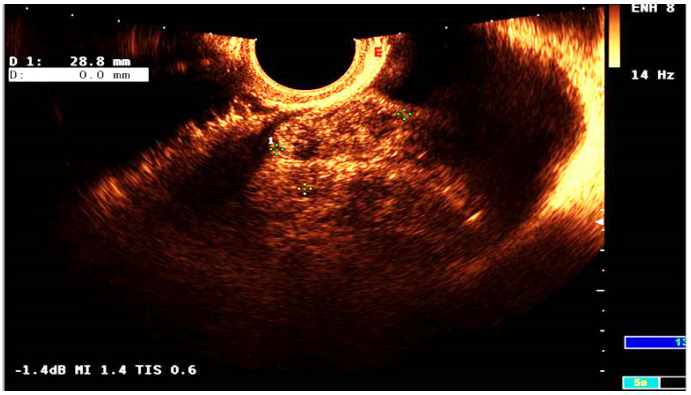

Fig. 17: DIE appearance in the bladder on 2D ultrasound.

From both the ultrasound (left) and the MRI (right), it is clear that the bladder is strongly involved in the endometriotic lesion. US examination emphasized the main exophytic lesion, whereas MRI has enabled the visualization of the physical link between the lesion and the vaginal wall. Therefore, fusion imaging identified not only the endometriotic lesion and established it in detail, but also the adjacent structures, the vagina and the vesicovaginal tract of the ureter, themselves involved in the phenomenon of endometriosis.

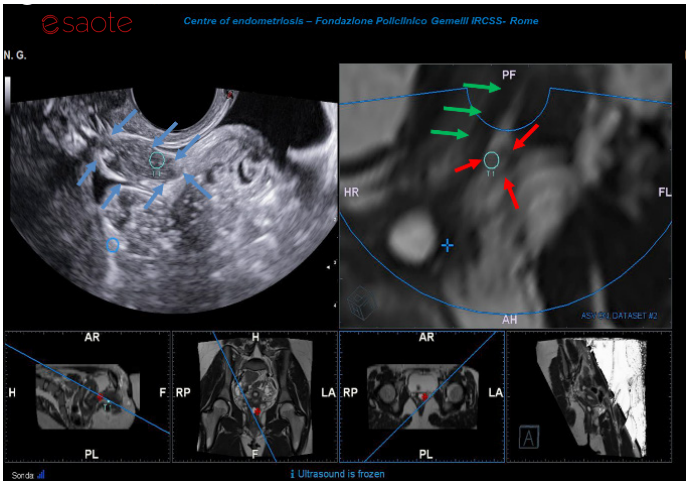

Fig. 18: Fusion imaging between US (left) and MRI (right) in the sagittal plane. The blue mark represent the bladder lesion. Blue arrows: exophylic lesion; red arrows: vagina; green arrows: ureter.

Laparoscopic examination, performed after fusion imaging, has confirmed the bladder excision of the endometriotic nodule previously diagnosed.

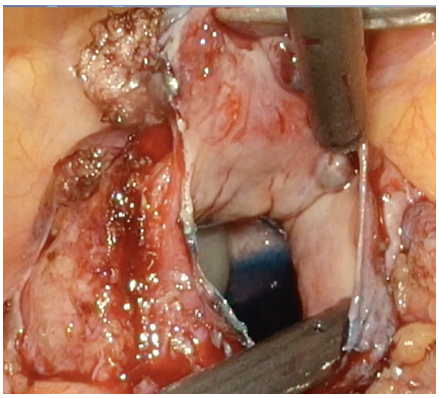

Fig. 19: The bladder excision of the endometriotic nodule identified by fusion imaging are clearly visible on the laparoscopic image.

In the video provided through the QR code below, Virtual Navigator's strength is once again emphasized. A blue spherical target was initially positioned on the ultrasound image, enabling the swift identification of the bladder lesion in the corresponding MRI plane. The video also demonstrates how these spherical targets can either materialize or vanish, contingent upon the viewpoint of the bladder lesion.

Conclusion

Virtual Navigator is a complete and effective technology which, by combining the information from both MRI and real-time US datasets, could support clinicians in the diagnosis of DIE, especially in the case of women who are possible candidates for surgery. Indeed, the combination of US and MRI techniques provides a high level of information by optimizing the spatial, contrast, and temporal resolution from each of these modalities. Furthermore, it could be of assistance to clinicians in US navigation inside the female pelvis, by providing a broader view of the anatomical structures involved in the injuries. Fusion imaging technology may therefore improve evaluation of the anterior, lateral, and posterior compartments of the pelvis.

Additional tools such as microV, the latest Esaote technology in microvascularization visualization, QElaXto 2D, the Esaote 2D shear-wave technique for stiffness evaluation, and CnTI™, the Esaote software for Contrast Enhancement Ultrasound (CEUS) can be embedded in the VNav environment. All these techniques, available in real-time during a fusion procedure, may increase the accuracy of the physician's diagnosis, by enhancing the quantity and quality of the information available.

In conclusion, endometriosis is a complex multifocal disease, which is very difficult to detect. Increasing the capabilities for the US diagnosis of this pathology is therefore fundamental to improve the care for patients suffering from this condition. Esaote's Virtual Navigator fusion imaging technology, with its multidisciplinary approach, appears to add genuine value in the diagnosis of DIE.

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Notes

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