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Introduction

The development of many imaging methods has revolutionized the approach to medicine by multiplying the diagnostic possibilities in a non-invasive way. The storage and use of digital data in computer databases allow the immediate review and use of this information. The coupling of techniques has developed considerably through image fusion methods. These combine the advantages of each imaging method by superimposing their specific diagnostic information (ultrasound, Computed Tomography (CT) scan, Magnetic Resonance Imaging (MRI), Positron Emission Tomography (PET)-Fluorodeoxyglucose (^{19}FDG)).

The fusion of MRI and ultrasound data has grown significantly, in particular in digestive and prostate imaging [1, 2]. In addition to the diagnostic contribution, this technique of fusion allows an optimization of samples by targeted biopsies [3, 4]. The MRI-ultrasound fusion technique is currently underdeveloped in obstetrics and gynaecology. Preliminary studies have suggested its potential interest in looking for deep pelvic endometriosis and scars from caesarean sections [5, 6]. More recent studies underlined the potential value of fusion of CT or PET-^{19}FDG and ultrasound in the evaluation of gynaecological cancers [7-10].

The MRI-ultrasound fusion technique corresponds to a coupling of the images carried out by means of an electromagnetic support and sensors placed on the probe. The sensors allow the position of the probe to be identified in space, allowing the consequent or associated analysis of MRI acquisitions previously loaded into the ultrasound system. Automatic or manual synchronization of MRI and ultrasound images is necessary beforehand so that a given point visualized on ultrasound corresponds to the same point visualized in MRI.

In order to determine the potential contribution of this technique, since 2019, we have undertaken to apply it to 160 selected patients to benefit from joint investigation of MRI and transvaginal ultrasound probe inserted into the vagina in cases of suspected endometriosis.

In order to optimize the MRI-ultrasound fusion technique a number of technical considerations need to be determined concerning the conventional MRI and ultrasound imaging protocol, MRI and ultrasound fusion imaging technique, indications for fusion technique in gynaecological imaging, and limitations of ultrasound and MRI.

1. Conventional ultrasound and MRI imaging protocol

Transvaginal ultrasound is the first-line technique examination for any gynaecological pathology globally. Despite its universal distribution, transvaginal ultrasound does not benefit from any international consensus on the image orientation reference analysis plan [11]. The sagittal analysis of a female pelvis can thus be performed by the sonographer according to two potential analysis plans: the top-down ("Gynaecology plane") and the bottom-up ("Radiology plane"). Hence, gynaecologists and radiologists often work with "inverted" images. For both specialties, on a median sagittal view, the bladder is located on the left and the rectum on the right looking at the acquisition screen, the ultrasound sector being placed at the top in gynaecology (top-down) while it is at the bottom in radiology (bottom-up) (Figure 1). In a recent study, Taksøe-Vester et al demonstrated that bottom-up image orientation led to steeper learning curves with fewer attempts and less time needed to reach expert levels of performance [12].

Using MR imaging, the analysis plans are perfectly defined, a median sagittal acquisition visualizes anatomically from left to right the pubic symphysis, the bladder and urethra, the uterus and vagina, the rectum and anal canal and finally the sacrum and coccyx. The same elements are visualized in an almost similar way during a "bottom-up" sagittal transvaginal ultrasound analysis, only the bone structures being less well visualized. It would therefore appear desirable to adopt this common orientation to perform all transvaginal ultrasounds, in particular those intended for an ultrasound-MRI fusion (Figure 1).

2. MRI and ultrasound fusion imaging

a. Registration and acquisition of data

Due to the limited number of published works there is no consensus on the optimal requirements and therefore some recommendations can be discussed here. The MRI-ultrasound fusion is probably best achieved with acquisition of both modalities on the same day, optimizing synchronization of pelvic organs. This technique should be optimally performed and interpreted by the same examiner or can be analysed by two different examiners. The MRI should always be done first in order to allow an imaging transfer from Picture Archiving Communication System (PACS), or failing that, by using a CD Rom on the ultrasound machine. In our practice, MR and ultrasound images are respectively acquired at 1.5T (GE HDXT, Milwaukee, USA) or 3T (GE Architect, Milwaukee, USA) and with a Logiq E-10 (GE Healthcare Ultrasound, Milwaukee, WI, USA).

A certain number of prerequisites concerning the MRI protocol have been defined by a recent European consensus conference [13]. Optimizing MRI quality involves the application of simple principles including a relative fast of 3 hours, a digestive / colon preparation by an enema the day before or in the hours prior the study, and an empty bladder before the completion of each imaging modality in order to optimize the registration of these imaging methods. Sub-cutaneous or intravenous injection of an antiperistaltic agent (e.g. Glucagen®) is highly recommended before any MRI examination to limit bowel movement artefacts. After MRI, care must be taken to ensure that there are no episodes of hypoglycaemia (post Glucagen 'injection) that may interfere with performing secondary ultrasound-MRI fusion imaging. The optional techniques with vaginal and rectal opacification by ultrasound gel are not recommended because they modify the natural anatomical relationships.

A conventional MRI protocol uses at least sagittal and axial 2DT2 Fast-Spin-Echo (FSE) / Turbo-Spin-Echo (TSE) MRI sequences, regardless of the suspected pathologies studied (Figure 2). These two sequences were naturally integrated in the imaging studies in gynaecological imaging to carry out the fusion technique. This approach is not optimal due to the technological constraints of ultrasound acquisition. Transvaginal ultrasound provides sagittal and coronal views but is unable to provide a strict axial acquisition view unlike MRI. This technological limit highlights the interest of 3DT2 (Hypercube Hypersense or Space) and 3DT1 Dixon sequences (Figure 2). These T2-weighted and T1-weighted volume acquisitions are isotropic allowing infinite multiplanar studies perfectly suited to perform fusion imaging. In addition to the natural spontaneous contrast resolution of MRI, there is a marked optimization of its spatial resolution, allowing better correlation with ultrasound data.

The use of a 3DT2 acquisition volume allows the sonographer to overcome any limitations in terms of analysis plan (Figure 1, video 1). The addition of a 3DT1 Dixon acquisition allows correlation with T1 contrasts (phase imaging) and with fat-suppression (water imaging), favouring for example the search for small haemorrhagic endometriotic implants (Figure 3). No recommendation can be achieved regarding the use of gadolinium in the evaluation of deep pelvic endometriosis (DPE) in European Society of Urogynaecological Radiology (ESUR) guidelines [13]. Hence, post-contrast 3DT1-weighted MRI cannot be actually recommended for ultrasound-MRI fusion technique. In conclusion, the acquisition and loading of 3DT2 and 3DT1 Dixon sequences should therefore be absolutely preferred.

b. Synchronization of MRI and ultrasound images

The MRI-ultrasound fusion technique relies on the most precise image synchronization possible so that two structures examined by MRI and ultrasound have the same spatial coordinates. This is quite easily obtained when studying a stationary organ with fixed anatomy and small in size such as the prostate [3]. The overall examination of a female pelvis poses more serious problems in terms of image registration, which can be automatic or manual. The placement of three spatial landmarks on the abdominal wall of patients during the acquisition of MRI sequences should allow automatic synchronization with the ultrasound machine. A lack of recognition of benchmarks has so far not allowed this method to be adopted. The synchronisation is therefore carried out manually by placing three successive points on the ultrasound image then the MRI (e.g. uterine fundus, isthmus, exocervix, or urethra orifice) (Figure 1). This essential step represents one of the major current limitations of ultrasound-MRI fusion in gynaecology (Video 2). A recent preliminary study of 10 patients with suspected endometriosis showed a significant lack of synchronization of ultrasound and MRI images [14].

c. Fusion navigation

The term "fusion" is probably used in excess because it is a method of comparative analysis of successive sectional planes. The actual fusion of ultrasound and MRI acquisitions is possible but requires precise adjustment of the two modalities (video 3).

d. The fusion technique can be performed by a radiologist alone or by a gynaecologist ultrasound examiner assisted by a radiologist.

3. Indications for fusion technique in gynecological imaging

There is currently no recognized indication, however, pelvic endometriosis appears to be an interesting field of investigation. Some preliminary studies have demonstrated its feasibility, current limitations and possibilities [5, 14]. Coupling the two imaging modalities could make it possible to optimize the detection of superficial peritoneal (haemorrhagic implants), ovarian (deep implants and differential diagnoses between endometriotic cysts and haemorrhagic luteal) and to reinforce the detection of deep endometriotic lesions (Figure 3). A recent Cochrane review highlighted the specific diagnostic accuracy of ultrasound and MRI for deeper locations [15]. Of these, only rectosigmoid involvement is evaluated identically by the two imaging techniques. For other deep pelvic locations, there are important variations in the diagnostic value of ultrasound and MRI.

The fusion coupling could allow an optimization of the detection of certain frequent deep pelvic localizations, for example at the level of the uterosacral ligaments, in particular distally. The fusion technique should also improve the independent diagnostic relevance of each imaging modality. Thus, the learning curves of each technique should be independently enhanced due to the concurrent information gathered.

A preliminary study has shown that the MRI-ultrasound fusion technique is possible for the detection of adenomyosis, but the absence of a histological gold standard limits the interest of this study [16]. Leiomyomas/fibroids and adenomyosis represent the two most common uterine pathologies frequently associated. The contribution of fusion coupled with a Power Doppler study should make it possible for a differential diagnosis between leiomyoma and adenomyoma.

Recent studies underlined the potential value of fusion imaging for some gynaecological cancers [7, 9, 10, 17]. These studies suggested that fusion of MRI or CT and ultrasound is feasible in patients with locally advanced cervical and ovarian cancers and may increase the diagnostic accuracy of the single imaging methods [10, 17]. Another study showed that the visualization of lymph node architecture by linear array or transvaginal ultrasound probe can be dynamically fused and assessed with images from previous cross-sectional studies and may help to identify the target lymph node, guiding the examiner to perform a core needle biopsy or to inject radiotracer for selective surgical nodal excision, according to radio-guided occult lesion localization technique [7].

4. Limitations of ultrasound

Transvaginal ultrasound is the first-line investigation for exploring the female pelvis. It is a simple, accessible, reproducible, and inexpensive modality characterized by high spatial resolution. Two technological limitations specific to ultrasound deserve to be highlighted, of geometric and mathematical origin. Unlike MRI, ultrasound has limitations in terms of contrast resolution, limiting tissue characterization of the pelvic structures studied. Ultrasound vocabulary has always erroneously referred to sagittal, transverse and oblique reference acquisition planes. This terminology is inaccurate since endovaginal ultrasound provides sagittal, coronal and oblique acquisitions. Only a suprapubic pelvic ultrasound can make strict axial cuts of the female pelvis. The limitations of suprapubic ultrasound in terms of spatial resolution do not compensate for this structural defect in endovaginal analysis. This limitation could possibly be compensated for by the acquisition of 3D ultrasound volume, but currently this is not possible, as the probes dedicated to ultrasound-MRI fusion are not volumetric.

The field /scope of analysis of transvaginal ultrasound is limited by the formatting and power of the ultrasound beam, the nature and depth of the anatomical structures studied, themselves conditioned by the patient's morphotype/morphology. This being inversely proportional to the width of the average frequency band used.

In addition, a major problem might be the presence of locally advanced disease (endometriosis or malignancy) causing distorted anatomy making the use of constant planes during ultrasound imaging not applicable. In order to get better image quality, the probe should be inserted deeply or almost withdrawn from the vagina and rotated in different angles of probe to visualize properly the region of interest (for instance the anterior surface of lower and upper rectum, rectosigmoid and sigmoid colon). Another problem can be the aspect of movements especially in assessment of endometriosis or locally advanced cervical cancer. TVUS probe moves organs out of their position on the MRI scan in order to evaluate a dynamic aspect of ultrasound examination combining sliding sign to assess the mobility of the pelvic organs and tenderness-guided ultrasound in mapping of endometriosis or pelvic adhesions. Similarly, in cervical cancer, to assess the tumour growth in surrounding organs (bladder or rectum) the mobility (or fixity) of organs against each other improves the diagnostic accuracy (in terms of negative predictive value).

5. Limitation of MRI

MRI is the second-line technique /investigation for exploring the female pelvis. It is a moderately accessible and expensive modality characterized by spontaneous high contrast resolution.

Even so 3DT2 MRI acquisition is highly recommended for ultrasound-MRI fusion technique, few studies have reported that overall imaging quality is lower than multiplanar sagittal, axial, and coronal 2D FSE T2-weighted sequences [18-21].

MR imaging provides a better tissue characterization than TVUS but the use of three different contrasts (T2, T1, and T1 with fat-saturation) is required.

6. Conclusion

The MRI/US fusion technique is a new non-invasive diagnostic tool that could be useful in clinical practice. Firstly, this technique may allow to improve TVUS detection of some abnormalities using MRI and vice versa. Secondly, it could be used as a reference method in the diagnosis of pelvic endometriosis in the presence of concordant positive or negative diagnosis for each specific endometriotic location during staging. Thirdly, fusion of ultrasound and MR images may improve the agreement with the surgical findings when compared with the single imaging methods in patients with advanced ovarian cancer. Finally, prospective studies dedicated to specific gynaecologic diseases, mainly pelvic endometriosis, are required. In this setting, the development of automatic based registration and learning curve analysis are required.

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Figure legends

Figure 1: Simultaneous original display of corresponding sagittal planes obtained by transvaginal sonography (TVS, a) and magnetic resonance imaging (MRI, b) with additional reconstructed top-down TVS image (c). This figure emphasizes the main location points (arrowheads) used to synchronize TVS and MRI techniques. Note the variations according to bladder filling (B), uterus (U) and rectum (R) localizations.

Figure 2: Sagittal 2D FSE T2-w, axial 2D FSE T2-w, reformatted sagittal 3DT2-w and 3DT1-weighted MRI sequences in the same patient displaying the different pelvic structures and organs: pubic bone (P), bladder (B), uterus (U), cervix (C) rectosigmoid colon (R), and sacrum (S). Note the presence of endometrial cyst (E), superficial peritoneal implants (I) and external adenomyosis (*i.e.* uterine endometriosis) (A).

Figure 3: Fusion imaging of superficial peritoneal and retrocervical endometriotic lesions. Simultaneous original display of corresponding sagittal planes obtained by transvaginal sonography (TVS, a) and magnetic resonance imaging (MRI, b) with additional reconstructed top-down TVS image (c). This figure displays on both modalities the presence of pelvic fluid in the pouch of Douglas (D) containing cystic haemorrhagic peritoneal lesions (P) and deep retrocervical endometriosis that is echogenic on TVS and hypointense on T2-weighted MRI.

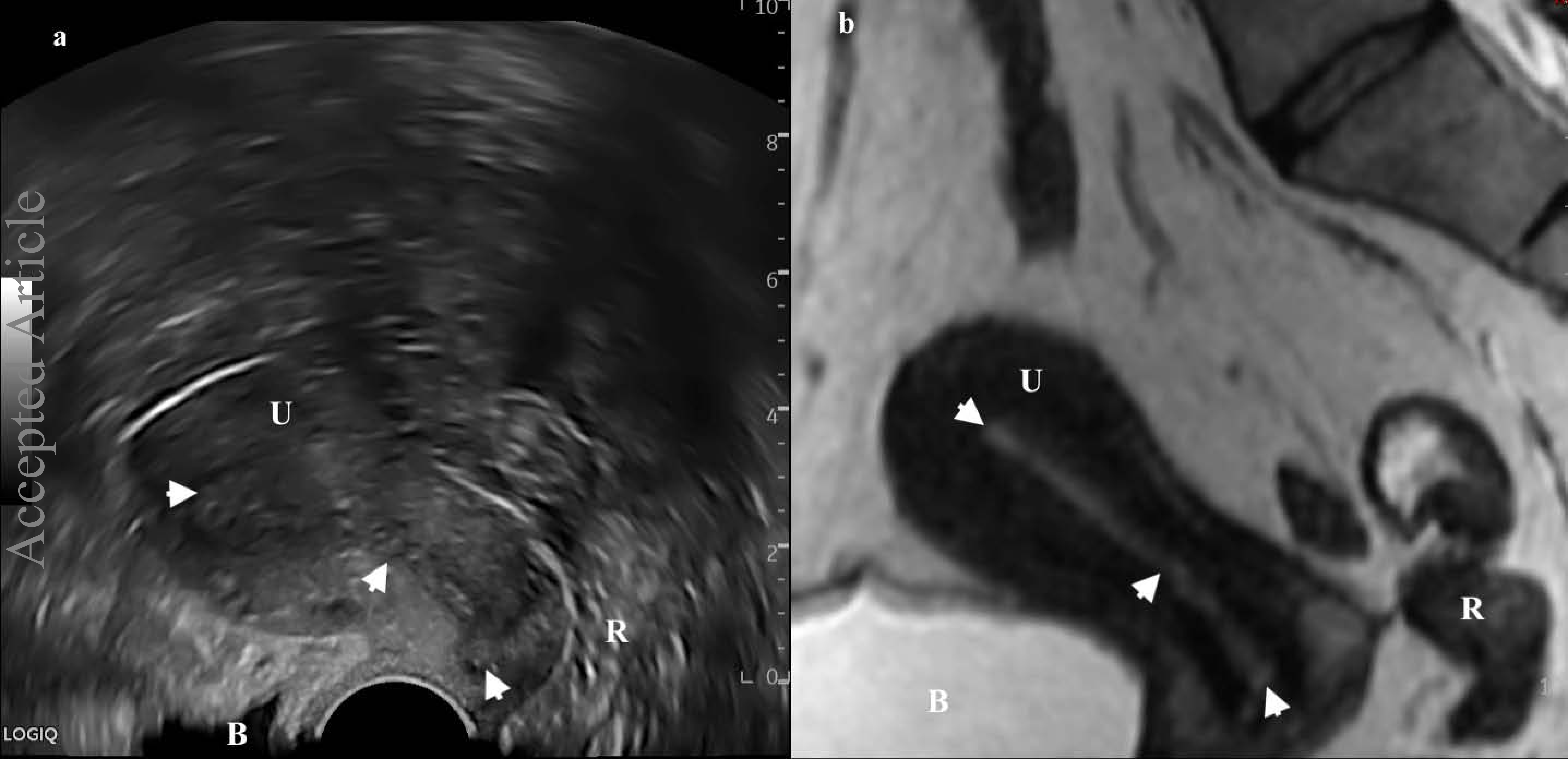
Videos legends

Video 1: This 3DT2-weighted MRI sequence shows multiple anatomical continuous plans (coronal, axial and sagittal) and corresponding aspect of the different normal pelvic organs (bladder, normal ovaries with follicles and rectosigmoid) and abnormalities (superficial uterine adenomyosis with multiple high signal intensity tiny cysts within normal junctional zone on low signal intensity, Nabothian cysts within endocervical canal, and small amount of fluid in the pouch of Douglas).

Video 2: Ultrasound-MRI fusion movie shows the simultaneous display of sagittal and different coronal obliques planes obtained by transvaginal sonography and magnetic resonance imaging.

Note that a perfect match is not obtained for different pelvic structures analysed (e.g. Nabothian cyst, ovaries).

Video 3: Ultrasound-MRI fusion movie using fusion technique mode. In this video, both ultrasound and MRI analysis are mixed together, this technique appearing not optimal for dedicated analysis of pelvic organs and structures.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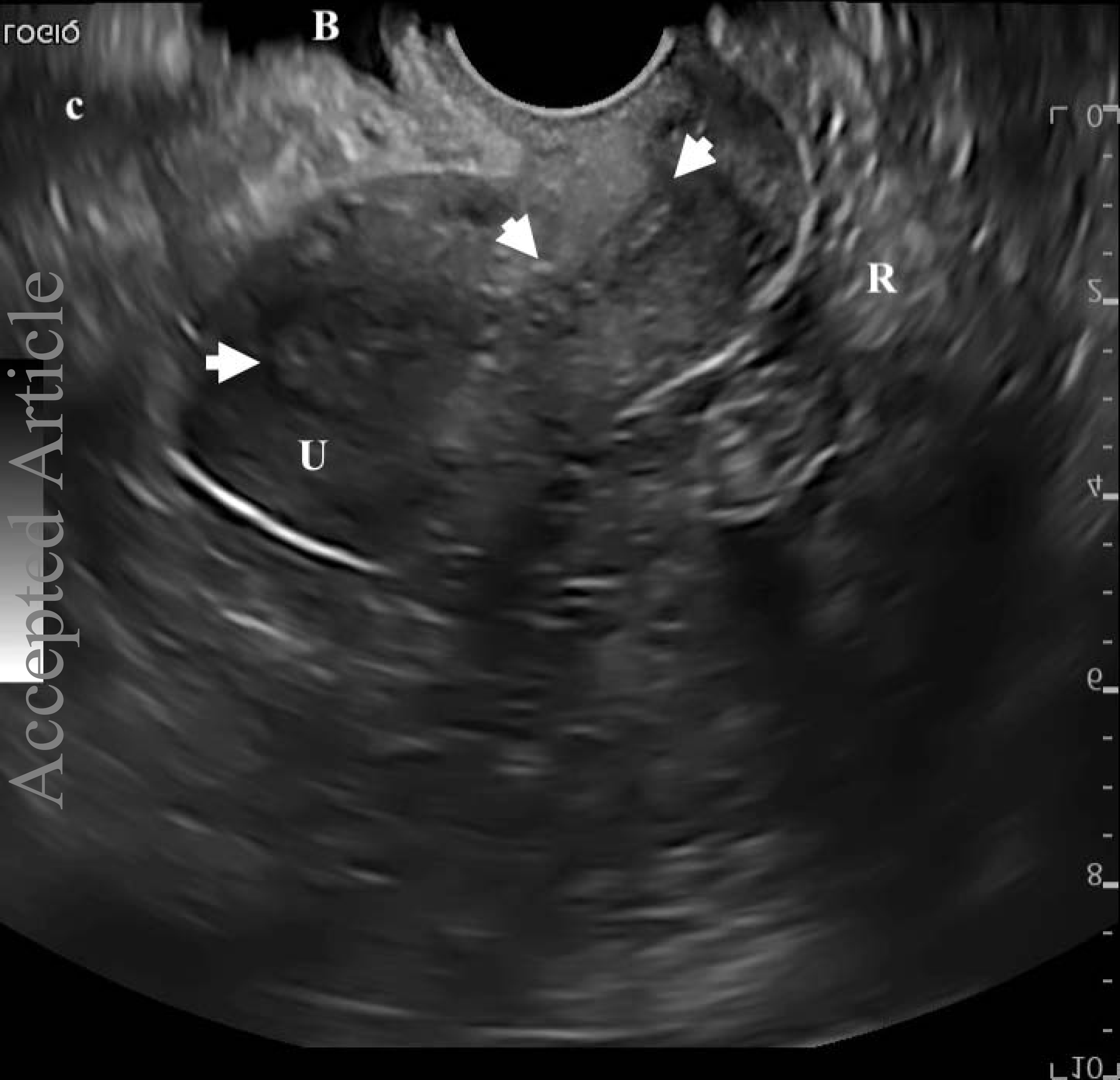
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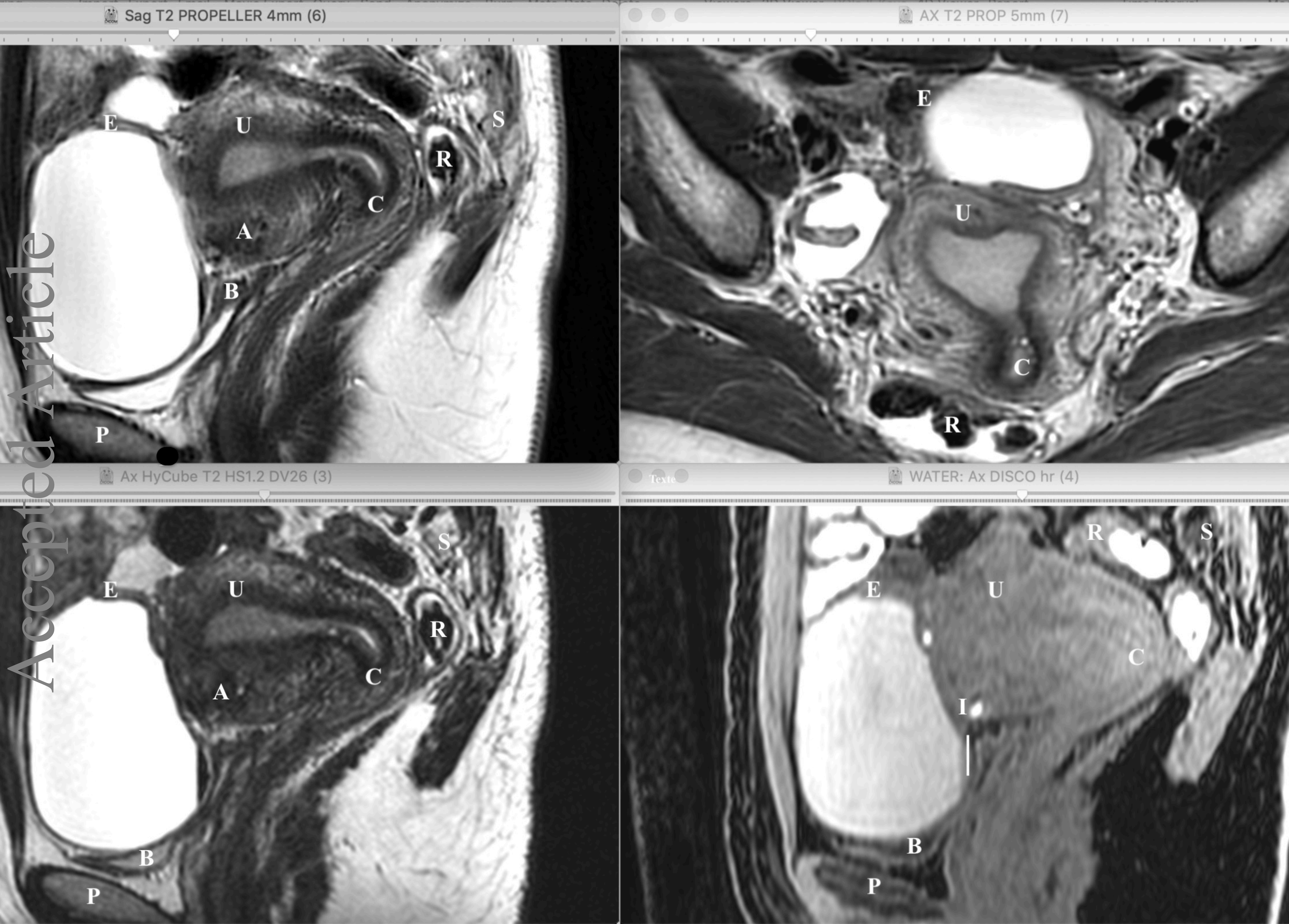
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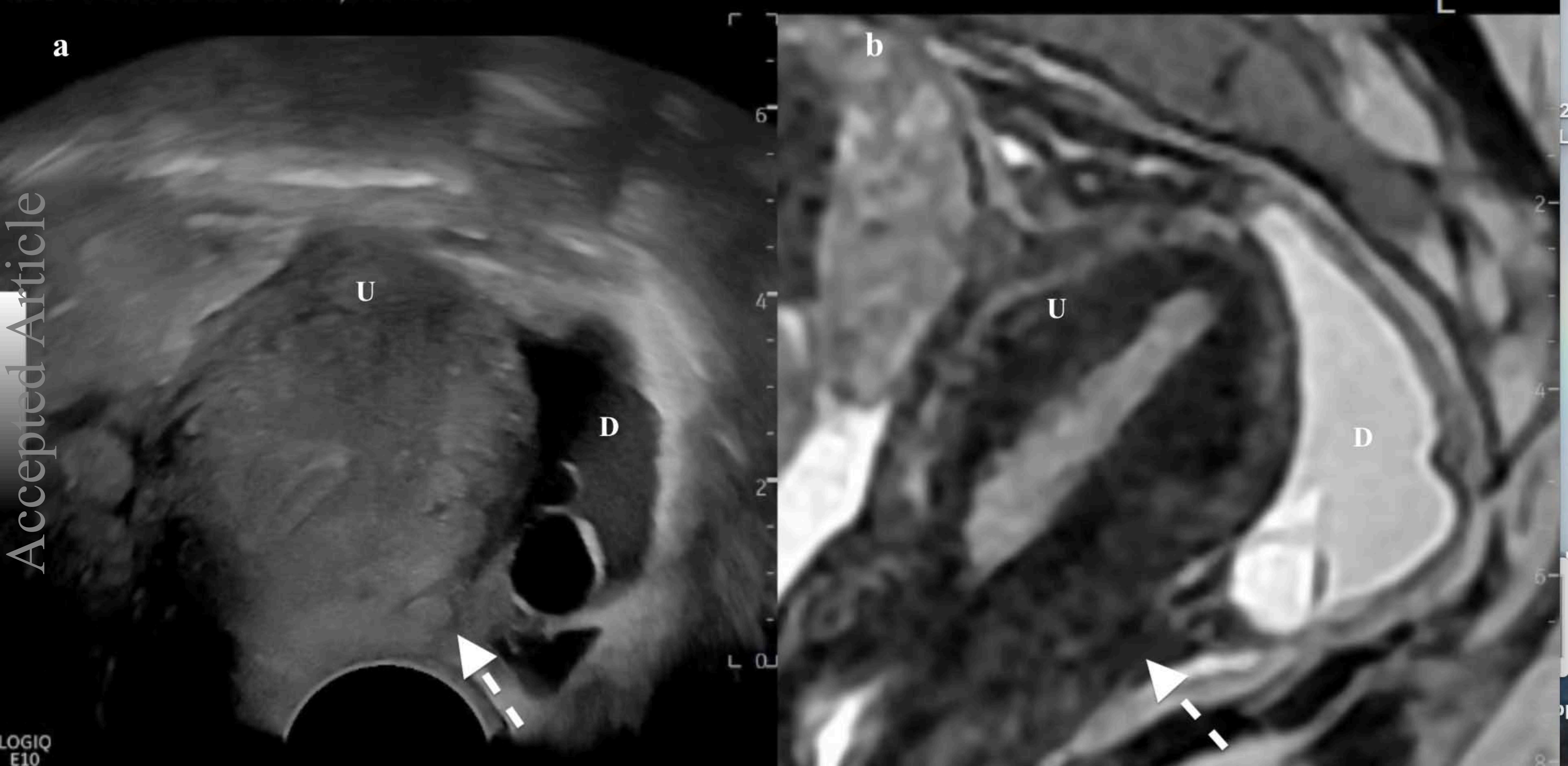
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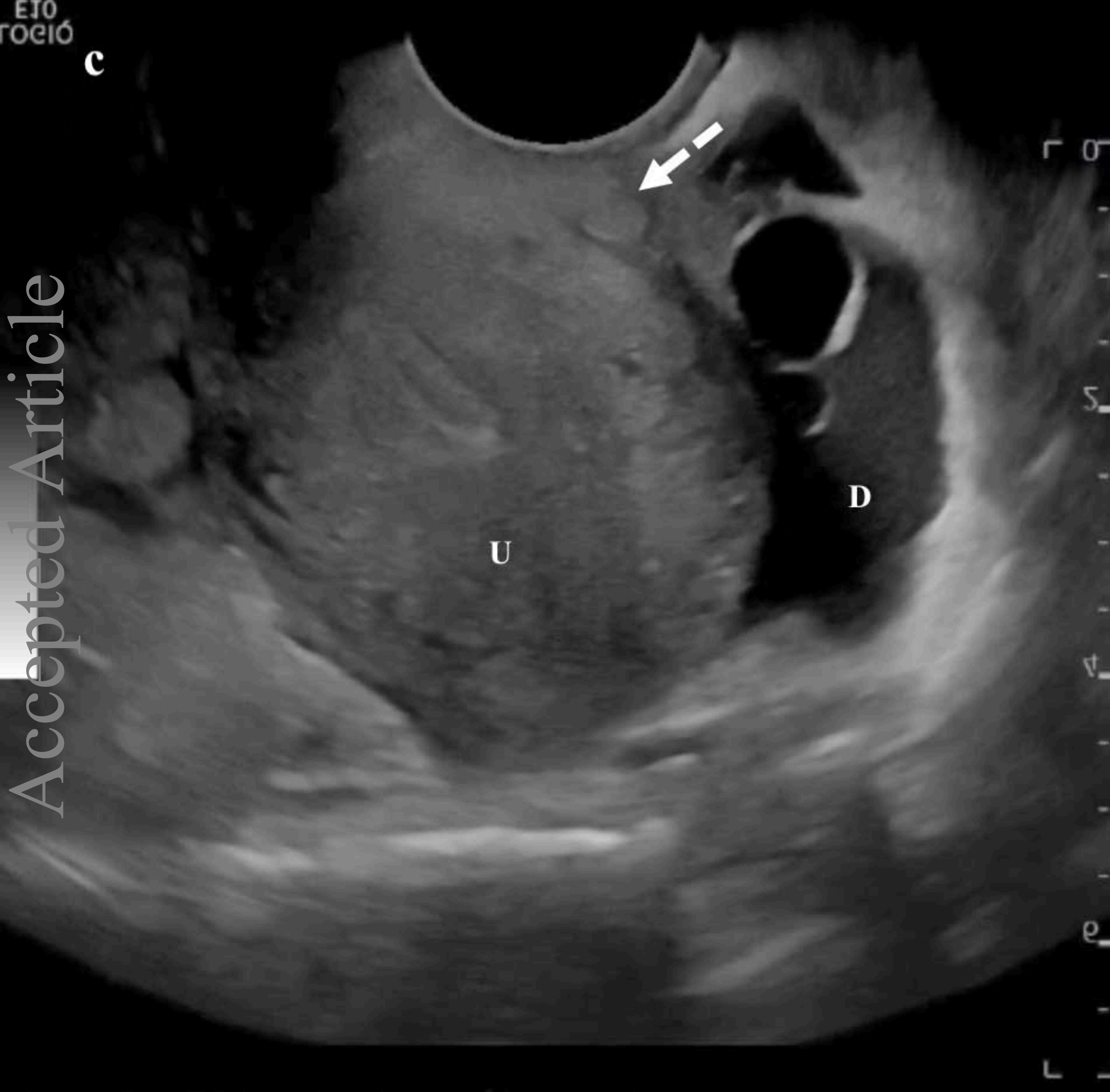
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