Role of novel magnetic resonance imaging sequences in characterization of ovarian masses

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Abstract

Introduction: Differentiating a benign from a malignant adnexal mass would provide a basis for optimal preoperative planning and may also reduce the number of unnecessary laparotomies patients undergoing treatment for benign disease. MRI provides additional information on the composition of soft-tissue masses using differences in MR relaxation properties seen in various types of tissue. More recently developed MRI sequences, like diffusion weighted, susceptibility weighted, and dynamic contrast enhancement sequences provided additional capacities for adnexal lesion tissue characterization.

Aim of the work: The aim of this work was to study the role of MRI including the novel sequences, namely dynamic contrast enhanced MRI (DCE–MRI), diffusion weighted images (DWI) and susceptibility weighted images (SWI) in the characterization of ovarian masses.

Patients and methods: This study included 25 patients having indeterminate adnexal masses at ultrasound. They were subjected to pelvic MRI, including T1, T2, T1 fat sat sequences, as well as the DWI, SWI, and DCE sequences. Final diagnosis was reached through histopathological data, or therapeutic response.

Results: All endometriomas showed blooming on SWI. All malignant lesions showed restricted diffusion and type III DCE curves.

Conclusion: MRI, especially the more recent sequences (DWI, SWI and DCE) allows accurate characterization of ovarian lesions.

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1. Introduction

Determining whether a clinically diagnosed adnexal mass is benign or malignant is frequently not possible until surgical exploration and histologic examination are performed. Consequently, it may not be possible to decide preoperatively
whether conservative or radical surgery is appropriate. A reliable method with which to differentiate a benign from a malignant adnexal mass would provide a basis for optimal preoperative planning and may also reduce the number of unnecessary laparotomies patients undergoing treatment for benign disease (1).

Sonography is the initial imaging study of choice in the evaluation of women with suspected adnexal masses because of its widespread availability, relatively low cost, and high sensitivity in the detection of masses. However, sonography is limited by its decreased specificity for the diagnosis of benignity, which can vary from 60% to 95% and result in as many as 20% of adnexal masses being classified as indeterminate (2).

CT has been used primarily in patients with ovarian malignancies, either to assess disease extent prior to surgery or as a substitute for second-look laparotomy. CT has a limited value in the diagnosis of adnexal masses (3).

MRI provides additional information on the composition of soft-tissue masses using differences in MR relaxation properties seen in various types of tissue. This information is invaluable in determining the character of soft-tissue masses. In the pelvis, MRI has been shown to have a 91–93% overall accuracy for differentiating benign from malignant adnexal tumors particularly when gadolinium-enhanced techniques are used (4).

Diffusion-weighted imaging exploits the random motion of water molecules, because water movement in highly cellular tissues is restricted, the water molecules within such tissue retain their signal even at high b values (500–1000 s/mm²). This explains why highly cellular tissues such as tumors appear persistently bright on diffusion-weighted images, even at high b values (5). An ovarian adnexal mass with a solid component that exhibits a low signal on T2-weighted images and a low signal on b1000 diffusion-weighted images is always benign (6).

Quantitative dynamic contrast enhanced MRI (DCE-MRI) provides an accurate method for the prediction of malignancy, particularly in preoperative indeterminate cases (7). The early enhancement patterns of ovarian epithelial tumors on DCE-MR images can help distinguish between benign, borderline, and invasive epithelial tumors (8).

Susceptibility-weighted MRI is a relatively new MRI technique that maximizes sensitivity to susceptibility effects and thus provides an additional method to evaluate the nature of soft-tissue tumors.

### Table 1 Parameters of MR sequences.

<table>
<thead>
<tr>
<th>Sequence Type</th>
<th>Sagittal T2</th>
<th>Axial T2</th>
<th>Coronal T2</th>
<th>Axial T1</th>
<th>Axial T1 fat sat</th>
<th>SWI</th>
<th>DCE</th>
</tr>
</thead>
<tbody>
<tr>
<td>TR/TE</td>
<td>4510/96</td>
<td>5210/71</td>
<td>4000/94</td>
<td>2470/10</td>
<td>2470/97</td>
<td>49/40</td>
<td>5.5/2.3</td>
</tr>
<tr>
<td>Echo train length</td>
<td>13</td>
<td>14</td>
<td>13</td>
<td>13</td>
<td>3</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Slice thickness</td>
<td>3.5</td>
<td>5.5</td>
<td>6</td>
<td>5.5</td>
<td>5.5</td>
<td>2</td>
<td>2.5</td>
</tr>
<tr>
<td>Gap</td>
<td>5.4</td>
<td>6</td>
<td>7.2</td>
<td>6</td>
<td>6</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Field of view</td>
<td>280 × 280</td>
<td>360 × 360</td>
<td>350 × 350</td>
<td>360 × 360</td>
<td>360 × 360</td>
<td>350 × 400</td>
<td>300 × 400</td>
</tr>
<tr>
<td>Number of averages</td>
<td>3</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Matrix size</td>
<td>205 × 256</td>
<td>256 × 320</td>
<td>460 × 350</td>
<td>288 × 320</td>
<td>288 × 320</td>
<td>177 × 256</td>
<td>166p × 320</td>
</tr>
<tr>
<td>Flip angle</td>
<td>150</td>
<td>150</td>
<td>150</td>
<td>150</td>
<td>150</td>
<td>15</td>
<td>10</td>
</tr>
<tr>
<td>Sensitivity encoding factor</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>–</td>
<td>2</td>
</tr>
</tbody>
</table>

### Table 2 Distribution of patients according to the final imaging diagnosis.

<table>
<thead>
<tr>
<th>Pathology Type</th>
<th>Number of Patients</th>
<th>Percentage (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ovarian pathology</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Endometriomas</td>
<td>9</td>
<td>36</td>
</tr>
<tr>
<td>Benign neoplasms</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mucinous cystadenoma</td>
<td>2</td>
<td>8</td>
</tr>
<tr>
<td>Ovarian fibroma</td>
<td>2</td>
<td>8</td>
</tr>
<tr>
<td>Serous cystadenoma</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>Mature cystic teratoma</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>Borderline neoplasms</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Borderline serous cystadenocarcinoma</td>
<td>2</td>
<td>8</td>
</tr>
<tr>
<td>Borderline mucinous cystadenocarcinoma</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>Malignant neoplasms</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mucinous cystadenocarcinoma</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>Krukenberg tumor</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>Malignant ovarian neoplasm of unidentifed nature</td>
<td>1</td>
<td>4</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Extraovarian pathology</th>
<th>Number of Patients</th>
<th>Percentage (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pelvic hematoma</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>Cervical subserous fibroid</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>Broad ligament cyst</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>Haematosalpinx</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>Total</td>
<td>25</td>
<td>100</td>
</tr>
</tbody>
</table>

### Table 3 MRI features in patients presenting with endometriomas.

<table>
<thead>
<tr>
<th>MRI feature</th>
<th>Number of Patients</th>
<th>Percentage (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>T1 Hyperintense</td>
<td>9</td>
<td>81.8</td>
</tr>
<tr>
<td>T2 Hyperintense</td>
<td>6</td>
<td>54.5</td>
</tr>
<tr>
<td>T1 fat sat Hyperintense (not suppressed)</td>
<td>11</td>
<td>100</td>
</tr>
<tr>
<td>SWI Blooming</td>
<td>11</td>
<td>100</td>
</tr>
<tr>
<td>DWI Not restricted</td>
<td>6</td>
<td>54.5</td>
</tr>
<tr>
<td>Restricted</td>
<td>1</td>
<td>45.5</td>
</tr>
<tr>
<td>Total</td>
<td>11</td>
<td>100</td>
</tr>
</tbody>
</table>

Contrast was administered to only two of these patients. Both of which showed internal content (blood clots versus internal septations). No enhancement was noted after contrast administration proving the diagnosis of internal blood clots and hence endometriotic cysts of the ovaries.
has exquisite sensitivity to blood products such as hemosiderin and deoxyhemoglobin. This sequence is more sensitive to the susceptibility difference between tissues than is conventional T2*-weighted imaging (9–12). Susceptibility-weighted imaging

Fig. 1 27 year-old patient with endometriotic cyst in the left ovary. (a) US shows indeterminate isoechoic lesion. (b) Axial T2 shows a hyperintense ovarian lesion with hypointense septum. (c) Axial T1 shows a hyperintense lesion. (d) Axial T1 fat sat showed no suppression. (e) SWI showing blooming. (f) T1 fat sat postcontrast showed no enhancement of the septum so diagnosed as a blood clot. (g) DWI and (h) ADC map showing no restriction.
can contribute to the diagnosis of endometrioma by depicting hemosiderin deposition in the cyst wall (12).

The role of these new sequences is only recently discussed in the literature, and therefore, we aimed to shed light on this topic in the current study.

2. Aim of the work

The aim of this work was to study the role of MRI including the novel sequences, namely dynamic contrast enhanced MRI (DCE–MRI), diffusion weighted images (DWI) and susceptibility weighted images (SWI) in the characterization of ovarian masses.

3. Patients and methods

This study included 25 patients having indeterminate adnexal masses at ultrasound examination and presented to the Radiodiagnosis Department, Alexandria Main University Hospital.

All the studied patients were subjected to the following:

1. Full history taking.
2. Thorough clinical examination.
3. The medical ethics were considered: informed patient’s consent was obtained, the patient should be aware of the examination, the economic status of the patient is considered and the patient has to get benefit from the examination. The Institutional Review Board approved the study.
4. Ultrasound examination was done on a Siemens · 300 ultrasound machine (Erlangen, Germany) including a convex probe for the abdominopelvic approach (5.2 MHz) and an endovaginal probe for the transvaginal approach if possible (9.4 MHz).
5. MRI protocol.
6. Abdominopelvic CT was revised in 6 of our patients.
7. The final diagnosis of the 25 patients included in the study was based on biopsy and histopathological verification in 14 patients (56%). The other 11 patients were diagnosed by the characteristic MRI features, and follow up by monitoring clinical response to medical treatment (44%).

- The two patients diagnosed to have ovarian torsion were proved surgically.
- All the patients diagnosed with benign and malignant ovarian neoplasms were pathologically proven.
- Two of the three patients diagnosed as borderline ovarian neoplasms were pathologically proven.
- Only three of the patients diagnosed as endometriomas were pathologically proven.
- All patients with extraovarian pathologies were improving on medical treatment.

3.1. MRI study protocol

MRI sequences were acquired on an Avanto 1.5T closed magnet MRI machine (Siemens, Erlangen, Germany) using phased-array pelvic coils (8 channels).
The patients were placed in the supine position. The urinary bladder was in moderate repletion. All sequences were acquired with saturation bands placed anteriorly and posteriorly to eliminate the high signal from subcutaneous fat. The

Fig. 2 64 year-old patient with left ovarian serous cystadenoma complicated by ovarian torsion. (a) Axial T2 shows a hyperintense cystic lesion. (b) Axial T1 shows a hypointense lesion with no suspicious features. (c) Axial T1 fat sat shows hemorrhagic ascites in douglas pouch. (d) SWI shows no blooming in the ovarian lesion and blooming of the hemorrhagic ascites. (e) DWI and (f) ADC showing no restricted diffusion. (g and h) Coronal T2 W images showing thickening and whirling of the left fallopian tube.
patients fasted for 3 h and did not receive an antispasmodic drug before the MRI exam.

Sagittal T2-weighted fast spin-echo sequence from one femoral head to the other, axial T2-weighted fast spin-echo sequence from the renal hilum to the symphysis pubis, axial T1-weighted spin-echo sequence, Coronal T2 weighted fast spin-echo sequence (if needed) and susceptibility-weighted sequence were systematically added. The acquisition protocols, including sequences and parameters, are given in Table 1.

DW MR images were obtained in the axial plane by using a single-shot echo-planar sequence with the sensitivity encoding technique (sensitivity encoding factor, 2). The $b$ values

![Fig. 3](image-url) 34 year-old patient with right ovarian mature cystic teratoma. Axial T2 (a) and Axial T1 (b) show a heterogeneous hyperintense right ovarian lesion. (c) Axial T1 fat sat shows complete suppression of the signal intensity denoting fatty content. (d) DWI and (e) ADC showing areas of restricted diffusion.
corresponding to the diffusion-sensitizing gradient were 0, 500, and 1000 s/mm². All images were acquired with a section thickness of 5 mm and intersection gaps of 7.5 mm. Motion-probing gradient pulses were placed in the three orthogonal planes. Isotropic DW images were generated by using the three orthogonal axis images.

DCE T1-weighted gradient-echo sequences (two-dimensional [2D] fast low-angle shot [FLASH]) were acquired in a plane allowing to show the solid tissue of the ovarian tumor (i.e., solid portion, papillary projections, or thickened irregular septa) and the normal myometrium in a single image. Gadolinium chelate (DOTAREM; Guerbet, Aulnay, France) was given at a dose of 0.1 mmol/kg via a power injector at a rate of 2 mL/s, followed by 20 mL of normal saline to flush the tubing. 12 dynamic sequences were acquired, each having an acquisition time of 20 s, thus giving a total time of 4 min for the dynamic sequence, and beginning immediately after the bolus injection. Postcontrast axial and sagittal T1-weighted spin-echo sequences with fat saturation were acquired after gadolinium injection.

Fig. 4 37 year-old patient with bilateral mucinous cystadenomas. (a) Axial T1 shows an intermediate signal intensity of the lesion. (b) Axial T2 shows a hyperintense signal with multiple shades in different loculi (stained glass appearance). (c) Sagittal T2 W image. (d) SWI shows no blooming. (e) DWI and (f) ADC showing areas of restricted diffusion.
3.2. Data analysis

Images were transferred to a post-processing workstation (Sono-Go B15). Regions of interest (ROIs) are placed within solid tissue selected on precontrast MR images and on normal outer myometrium to measure signal intensity versus time. Normal myometrium is used as an internal reference tissue. Myometrial time intensity curve has a sigmoid pattern, which is in the same signal intensity range than those of ovarian tumors and thus is useful for tumor characterization. Time-intensity curves (over all frames) are determined for semi quantitative or pharmacokinetic perfusion analysis. Because tumors are often heterogeneous, several ROIs are drawn, and only the maximum enhancement parameters are taken into account for analysis.

Fig. 5 61 year-old patient with right sided fibrotic lesion and adenomyosis. D.D. includes right sided ovarian fibroma versus subserous fibroid. (a and b) Axial T1 and T2 show a hypointense signal intensity of the lesion. (c) DWI showing no areas of restricted diffusion. (d) T1 fat sat postcontrast showing only mild enhancement of the lesion and (e) type 1 dynamic enhancement curve. Dotted line representing the enhancement pattern of the myometrium and the continuous line is that of the lesion. This narrows the D.D to only ovarian fibroma. (subserous fibroid will have a type 2 curve, similar enhancement dynamics as the myometrium).
4. Results

The present work included 25 female patients with indeterminate adnexal lesions on ultrasound examination.

The patients included in the study had a final imaging diagnosis of ovarian lesions in 21 patients (84%) and 4 patients had extraovarian pathologies (16%) (Table 2).

4.1. MRI diagnosis

Nine patients were diagnosed as ovarian endometriomas, two had bilateral disease; they showed the following MRI features (Table 3, Fig. 1).

Six patients were diagnosed as benign ovarian neoplasms, they showed the following MRI features (Table 4, Figs. 2–5).

Three patients were diagnosed as borderline ovarian neoplasms; one of them had bilateral disease. They showed the following MRI features (Table 5, Fig. 6).

Three patients were diagnosed as malignant ovarian neoplasms; they showed the following MRI features (Table 6, Fig. 7).

5. Discussion

5.1. Endometriomas

Since two of the patients had bilateral disease, we increased the total number of endometriomas in the study to 11 and they showed the following MRI features:

Nine out of 11 patients showed hyperintense T1 and only 2 showed hypointense signal. Six showed T2 hyperintense signal and five showed a hypointense signal.

All 11 patients did not suppress in the T1 fat sat sequence, which is matching with what Spencer and Weston stated. They said that the classical MRI features of endometriosis are: (1) high signal on T1 weighted images (methemoglobin), (2) no loss of this signal on fat suppressed T1 weighted images and (3) dark structures on T2 weighted images. These can be rings or nodules (hemosiderin staining) in chronic lesions or from deoxyhemoglobin contained within recent bleeding. A key finding is “shading” in which there is progressive signal loss due to T2* effects in the dependent portion of a lesion due to greater concentrations of blood products. Fluid–fluid levels may be seen (13).

Woodward et al. stated that hemosiderin-laden macrophages combined with the fibrous nature of the cyst wall give it a low signal intensity appearance on both T1- and T2-weighted images (14), which explains the 2 cases showing T1 hypointense signal.

All of our 11 cases showed blooming in the SWI sequence. According to Takeuchi et al. to diagnose endometrioma with MRI, visualization of hemosiderin deposition in the cyst wall may be helpful, especially in the diagnosis of endometriomas that do not exhibit typical MRI findings. Susceptibility-weighted MRI is a relatively new MRI technique that maximizes sensitivity to susceptibility effects and has exquisite sensitivity to blood products such as hemosiderin and deoxyhemoglobin (11). Woodward et al. stated that the most problematic lesions to differentiate are hemorrhagic corpus luteum cysts, whose MR imaging appearance can be similar.
to that of endometriomas. Hemorrhagic cysts are usually unilocal as opposed to endometriomas, which are frequently multilocular and bilateral. In addition, hemorrhagic cysts do not exhibit shading on T2-weighted images and will resolve with time. A follow-up examination (this can be done with US) can confirm the diagnosis. Ovarian carcinoma can occasionally have internal hemorrhage. Visualization of solid components, septations, and a size larger than expected for an endometrioma are features suggestive of malignancy (14).

Five out of our 11 cases showed restriction in the DWI sequence (could be phase dependent) while the others did not restrict.

According to Thomassin-Naggara et al. in a study conducted on 124 women, a low $b_{1000}$ signal intensity within the solid component was more frequent in benign than in malignant masses and that the $b_{1000}$ signal intensity within the cystic component did not differ significantly between malignant and benign adnexal masses. An ovarian adnexal mass with a solid component that exhibits a low signal on T2-weighted images and a low signal on $b_{1000}$ diffusion-weighted images is always benign (6). In another study conducted by Feuerlein et al. on 230 patients who underwent abdominal MRI, including diffusion-weighted imaging had a total of 55 lesions with restricted diffusion. Only 43 lesions were malignant and the remaining 12 were benign lesions in a different abdominal organ, one patient had hemorrhagic ovarian cyst. They concluded that restricted diffusion is generally considered to be associated with malignant tumors because of the high cellularity of these tumors. However, in interpretation of diffusion-weighted images, it should be kept in mind that a number of benign lesions could exhibit restricted diffusion on images with high $b$ values, thus mimicking malignant lesions (15). And in another study conducted by El sorogy et al. which was performed on 20 patients with ovarian masses, it was concluded that the direct visual assessment of DWI of ovarian lesions is not useful in differentiating benign from malignant ovarian lesions; however, DWI plays a complementary role in detecting the solid components of malignant lesions. Determining the threshold of the ADC for diagnosing cystic ovarian tumors is difficult because of their large variance (16).

Contrast was administered in only two of our patients. Both were not confidently diagnosed before contrast administration due to the suspected presence of internal septations and/or mural nodules. After contrast administration, neither enhancing internal soft tissue nodules nor septations were
found and hence the diagnosis of internal blood clots was established.

Woodward et al. also stated that administration of gadolinium-based contrast material is not particularly useful in the evaluation of endometriomas. When used, the cyst wall demonstrates a nonspecific, variable enhancement pattern that does not differentiate it from other benign and malignant processes. In addition, a false-positive diagnosis may be made when normally enhancing parametrium is misinterpreted as endometriotic foci. The use of gadolinium should be reserved for those cases in which there is a concern for ovarian carcinoma (14).

5.2. Benign ovarian neoplasms

- The two mucinous cystadenomas showed complex cystic nature with stained glass appearance. One of them showed areas of restricted diffusion (could be attributed to the viscid contents) while the other did not restrict. Only one of them was given contrast owing to complex nature with multiple internal septations and the absence of internal solid components could not be confirmed in the precontrast sequences.
- The patient with serous cystadenoma had a simple cystic lesion. No contrast was administrated.

Jung et al. reported similar criteria as regards the differentiation between these two pathological entities. It was stated that a tumor that manifests as an unilocular or multilocular cystic mass with homogeneous CT attenuation or MR imaging signal intensity of the locules, a thin regular wall or septum, and no endocystic or exocystic vegetation is considered to be a benign serous cystadenoma.

And a tumor that manifests as a multilocular cystic mass that has a thin regular wall and septa or that contains liquids of different attenuation or signal intensity but has no endocystic or exocystic vegetation is considered to be a benign mucinous cystadenoma and that mucinous cystadenomas tend to be larger than serous cystadenomas at presentation (16).

- The two patients with ovarian fibroma showed solid soft tissue lesions. Both were administered contrast, and showed mild enhancement mounting to a type 1 curve.

According to Shinagare et al. fibromas and fibrothecomas, which are benign ovarian stromal tumors, account for only 4% of all ovarian neoplasms but represent the most common solid primary ovarian tumors in asymptomatic women of all ages. The importance of correct diagnosis of fibromas and fibrothecomas lies in their benign nature. These are relatively common incidental solid ovarian tumors, and the ability to make a diagnosis of this benign tumor on imaging can greatly affect the patient management, especially in terms of avoiding unnecessary surgery, decreasing patient anxiety, and avoiding morbidity associated with invasive surgical procedures. It is also important to differentiate them from broad ligament fibroids (leiomyomata), because of differences in the management of these entities (17).

Despite their characteristic MRI features, it can still be difficult to distinguish fibromas and fibrothecomas from fibroids, usually pedunculated subserosal or broad ligament fibroids.
Fig. 7  55 year-old patient with bilateral mucinous cystadenocarcinoma. (a) Axial T1 shows bilateral heterogeneous hypointense ovarian cystic lesions. (b) Axial T2 cuts showing heterogeneous hyperintense lesions with stained glass appearance. Multiple papillary projections are seen. (c) Coronal T1 fat sat postcontrast showing papillary projections. (d) DWI and (e) ADC showing restricted diffusion. (f) Abdominal scans reveal thickening of the peritoneal reflections and ascites denoting peritoneal carcinomatosis. (g) Type 3 dynamic enhancement curve. Dotted lines representing the enhancement pattern of the lesion and the continuous line is that of the myometrium.
Dynamic contrast-enhanced MRI has been reported to aid in this distinction where the enhancement of fibromas and fibrothecomas was significantly lower than that for myometrium and fibroids at all time points (17) which agrees with our findings where the ovarian fibromas always showed a type 1 curve in PW sequence and a type 2 curve was noted in the case with cervical subserous fibroid although both of them showed similar morphological features making it impossible to suspect their origins without PWI.

- The last patient had mature cystic teratoma and showed heterogeneous hyperintense T1 and T2 signal that suppressed in the fat sat sequence. No contrast was administered.

Similar findings were stated by Park et al. who stated that the diagnosis of uncomplicated teratomas at MR imaging is fairly straightforward because it is very sensitive for detection of intratumoral fat. Intratumoral fat can be diagnosed with the combination of T1-weighted imaging and fat-saturated T1-weighted imaging; intratumoral fat shows high signal intensity on T1-weighted images but signal drop on fat-saturated T1-weighted images. Chemical-selective fat-saturated T1-weighted imaging is mandatory for diagnosis of teratomas because other conditions, such as hemorrhage or a high concentration of protein, can also cause T1 shortening (19).

Two out of the six patients, one of the ovarian fibroma patients and the patient with serous cystadenoma, were complicated by ipsilateral ovarian torsion. Both showed thickening of the ipsilateral fallopian tube, ipsilateral edematous and enlarged ovary and associated ascites, which were hemorrhagic in the patient with fibroma.

According to Chang et al. the most constant finding in ovarian torsion is a large ovary. Common findings that are somewhat nonspecific include an adnexal mass that may be in the midline or rotated toward the contralateral side of the pelvis, deviation of the uterus to the side of the affected ovary, engorged blood vessels on the twisted side, pelvic ascites, and obliteration of fat planes. In cases of hemorrhagic infarct, a few characteristic findings can be seen, including a beaked protrusion at the periphery of the affected ovary – a finding consistent with engorged blood vessels – hematoma, and the absence of enhancement (19).

Thomassin-Naggara et al. stated that the following criteria were considered predictive of benignity: purely cystic lesions, a regular and homogeneous solid component with low signal intensity at T2-weighted imaging, a solid component without high signal intensity on DW images obtained at $b = 1000 \text{ s/mm}^2$, and a solid component with a type 1 time-signal intensity curve on PW images (20).

In the current study, the diagnosis of a benign lesion was based on the same MR criteria.

5.3. Borderline ovarian neoplasms

- The two patients with borderline serous cystadenocarcinomas showed cystic nature with thick enhancing wall and multiple enhancing papillary projections seen after contrast administration. One of the lesions showed a type 2 curve while the other a type 1 curve.

- Doppler examination was done to the patient with type 1 curve and showed evident blood flow within the papillary projections.

- The patient with borderline mucinous cystadenocarcinoma had a complex cystic lesion with stained glass appearance and thick enhancing septations seen after contrast administration that showed a type 2 curve.

Thomassin-Naggara et al. stated that only invasive tumors displayed time intensity curve type 3 (specificity 100%). Enhancement curve types 1 and 2 corresponded to benign and borderline ovarian tumors, respectively, however, with a significant overlap (21).

In a study conducted on 283 women with adnexal masses, Hassen et al. stated that the association of morphologic and vascular ultrasound findings could highly suggest the diagnosis of benign or malignant papillary projection. It was concluded that for papillary projections $\geq 10 \text{ mm}$, color flow was present in all malignant, in 86% of borderline, and absent in all benign tumors (22).

Bouic-Pages et al. stated that the presence of vegetations or papillary excrescences suggests the diagnosis of borderline epithelial tumor and that their number and size are proportionally related to the tumor aggressiveness (23).

5.4. Malignant ovarian neoplasms

- The patient with mucinous cystadenocarcinoma had a complex cystic lesion with stained glass appearance. DWI showed restricted diffusion with ADC value of 0.9. Thick enhancing wall and enhancing papillary projections were seen after contrast administration that showed a type 3 curve.

- This patient had associated peritoneal carcinomatosis and lung deposits.

- The patient with Krukenberg tumor had a solid mass lesion that showed restricted diffusion with ADC value of 0.8. Strong heterogeneous enhancement was seen after contrast administration mounting to a type 3 curve.

This patient had history of gastric carcinoma and right oophorectomy for Krukenberg tumor.

- The last patient had advanced malignant ovarian tumor whose nature could not be further identified. Restricted diffusion was seen with ADC value of 0.7. and strong heterogeneous enhancement after contrast administration mounting to a type 3 curve.

This patient had associated ascites and omental nodules.

According to Thomassin-Naggara et al., the following criteria were considered predictive of malignancy: vegetations, an irregular or heterogeneous solid component with intermediate signal intensity at T2-weighted imaging, a solid component with high signal intensity on DW images obtained at $b$ value of $1000 \text{ s/mm}^2$, a solid component with a type 3 time-signal intensity curve on PW images, or associated abdominal or pelvic ascites or peritoneal implants (20).

To sum up, the special MRI sequences used in our study were useful in characterization of ovarian lesions as follows:
In our study, SWI sequence was done in all of our patients suffering from ovarian pathology and has proved effective in diagnosis of endometrioma. All of our endometrioma patients had evident blooming in the SWI sequence and all the rest did not bloom. Hence SWI was effective in diagnosis of 100% of the cases of endometriomas.

DCE sequence was done in 11 of our patients: two endometrioma patients, three of the patients suffering from benign ovarian pathology, three patients with borderline and three with malignant ovarian neoplasms.

It has proved effective in all of the patients were:

- No enhancement was seen in the endometrioma patients.
- The benign category showed:
  - Enhancement of the thin walls and septations in the mucinous cystadenoma patient.
  - Mild enhancement mounting to a type 1 curve in both ovarian fibroma patients.
- The borderline category showed:
  - Type 2 curve in two of the patients; one of the patients with borderline serous and the patient with mucinous cystadenocarcinoma.
  - A type 1 curve in the other patient with borderline serous cystadenocarcinoma, which was diagnosed as borderline owing to the presence of papillary projections with internal blood flow (seen by Doppler examination).
- The malignant category showed:
  - Intense enhancement with a type 3 curve in all three patients.

Hence DCE sequence is effective in differentiating between benign and malignant lesions, however overlap between the benign and borderline categories may occur which should be differentiated by their different morphologic criteria.

In our study, DWI sequence was done in all of our patients suffering from ovarian pathology. The following was observed:

- Restriction was noted in five out of the 11-endometrioma patients.
- In the benign category: areas of restricted diffusion were seen in two out of the six patients; one mucinous cystadenoma and the mature cystic teratoma patient.
- In the borderline category: no restriction was seen in any of the three patients.

- In the malignant category: all three patients showed restricted diffusion with ADC values of 0.7, 0.8 and 0.9.

In neuroradiology, it is known that according to the stage of the hematoma, DWI is variable where the hematoma is seen restricted in the hyperacute and late subacute stages only while it is not restricted in the other stages (24).

The presence of restriction in some of our endometrioma cases could be attributed to the same principle. However the different morphological changes according to the age of the hematoma are not yet evaluated in gynecological imaging.

Hence, restricted diffusion is seen in all malignant lesions, however some benign lesions may also show restricted diffusion. Given that DWI findings are not considered in isolation, information derived from images obtained with other sequences should greatly reduce the diagnostic dilemma.

Therefore, now that these sequences have acquired wider acceptance among our clinical colleagues, we plan to study these sequences on a larger scale and using extensive statistical analyses.

6. Conclusions

- Sonographically indeterminate adnexal masses of uncertain origin and solid or complex cystic content benefit from further evaluation with MRI, which is highly accurate for identifying the origin of a mass and characterizing its tissue content, obviating surgery in many cases.
- Susceptibility-weighted imaging contributes to the diagnosis of endometrioma by depicting hemosiderin deposition in the cyst wall.
- DCE MR imaging is useful in distinguishing malignant from benign tumors, and for characterizing gynecologic masses. It also helps to distinguish ovarian fibromas from uterine leiomyomas.
- Enhancement curve types 1 and 2 corresponded to benign and borderline ovarian tumors, respectively, however, with a significant overlap. Enhancement curve type 3 always corresponded to malignant ovarian tumors.
- An ovarian lesion with no restricted diffusion is always a benign lesion. All malignant ovarian lesions are always restricted in the DWI with ADC values less than 1. An ovarian lesion with restricted diffusion could also be benign, so information derived from images obtained with other sequences are helpful.

Conflict of interest

We have no conflict of interest to declare.
References