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The role of diffusion-weighted MR imaging in assessment of peritoneal lesions: radiologic-pathologic correlation

Bahaa Eldin Mahmoud[1*], Asmaa Ahmed Abdelzaher[1], Ahmed Abdellatif Mohamed[2] and Lamiaa I. A. Metwally[1]

Abstract

Background: Peritoneal diseases can be caused by a wide spectrum of pathologies including benign, primary, and secondary malignant lesions. Benign peritoneal diseases can mimic malignancies and have overlapping clinical, pathophysiological, and imaging appearances. Biopsy and histological assessment remain the gold standard for characterization of the peritoneal lesions; however, functional MRI techniques like diffusion imaging with quantitative assessment by ADC (apparent diffusion coefficient) measurements can help in the detection and characterization of different peritoneal lesions. The aim of this study was to evaluate the role of diffusion MR imaging in differentiating between benign and malignant peritoneal lesions with correlation to their pathological results.

Results: Forty patients with peritoneal lesions were included in the study. According to histopathological results, 20 of them were of benign nature, and the other 20 were malignant. The mean ADC value of the benign lesions was $1.5 \pm 0.5 \times 10^{-3}$ mm^2/s while that of malignant lesions was $0.9 \pm 0.3 \times 10^{-3}$ mm^2/s with statistically significant difference ($p < 0.00001$), and a cutoff value of 1.15×10^{-3} mm^2/s can be used to differentiate benign and malignant lesions with 85% sensitivity and specificity. In particular, we compared the mean ADC values of the eight cases of peritoneal tuberculosis with that of fourteen cases of peritoneal carcinomatosa, and it was also statistically significant ($p < 0.001$). However, we did not find a statistically significant difference between the mean ADC value of the benign and malignant cystic peritoneal lesions ($p = 0.5$).

Conclusion: Diffusion MR imaging can provide a reliable non-invasive tool that can help in the differentiation between benign and malignant peritoneal lesions using qualitative and quantitative diffusion assessment through ADC measurements with a recommended cutoff value of 1.15×10^{-3} mm^2/s.

Keywords: Peritoneal lesions, Abdominal tuberculosis, Peritoneal carcinomatosis, Ascites, Diffusion MR

Background

The peritoneum is a serosal membrane of mesodermal origin which covers the peritoneal cavity and is formed by two layers, the visceral peritoneum which covers the intra-peritoneal organs and the parietal peritoneum which lines the abdominal walls and the diaphragmatic undersurface [1]. The main functions of the peritoneum are to provide a frictionless surface over which the viscera can move and also serve as a conduit of fluid transport [2].

The mesentery is a double peritoneal layer which encloses the intestine and attaches it to the posterior abdominal wall. Ligaments are double layers of peritoneum between different organs or between an organ and abdominal walls. The omentum is a double peritoneal layer joining the stomach to other adjacent structures [3].

There is a wide spectrum of peritoneal diseases that can be caused by different benign and malignant pathologies. Benign diseases can mimic malignancies with overlapping clinical, pathophysiology, and imaging

* Correspondence: Bahaa.mahmoud@kasralainy.edu.eg
[1]Department of Radiology, Cairo university, Giza, Egypt
Full list of author information is available at the end of the article

appearances. Histopathological examination of the peritoneal lesions whether by true cut biopsy, FNAC (fine needle aspiration cytology), or excisional biopsy is almost always required and considered the gold standard for diagnosis of the nature of peritoneal lesions [1].

Peritoneal carcinomatosis is the most common malignant peritoneal disease and is defined as intra-peritoneal dissemination of any carcinoma which is not originated from the peritoneum itself. The commonest tumors metastasize to the peritoneum are those from the gastrointestinal tract and the ovaries [4, 5]. Pseudomyxoma peritonei is a clinical or radiologic description rather than a pathological diagnosis which describes the presence of thick mucinous material within the peritoneal cavity usually from ruptured mucinous tumors [5].

Granulomatous peritonitis is one of the commonest benign peritoneal lesion encountered in Egypt. The term granulomatous peritonitis is a form of peritoneal inflammation and infection caused by different agents such as tuberculous, histoplasma, or pneumocystis organisms. Tuberculosis may reach the peritoneal cavity as part of a systemic infection (i.e., miliary tuberculosis), direct extension from the bowel, or lymphatic dissemination [6].

Diffusion-weighted MR imaging (DWI) is a functional MRI technique used to detect the movement of water molecules in biological tissues. Recently, diffusion MR imaging is widely used and became a routine part of MR examination of the abdomen and pelvis to detect and characterize different abdominal lesions. DW MR images are very useful for detection of peritoneal lesions by suppressing the background structures and also facilitating the characterization of the nature of the lesions depending on the tissue cellularity and the presence of intact cell membranes; therefore, it can help in differentiation of benign and malignant lesions [2–7].

Although pathological assessment remains the gold standard in diagnosis of peritoneal lesions, diffusion imaging could represent a non-invasive diagnostic tool that may add a diagnostic value and help in characterization of peritoneal lesions especially in high-risk patients and in apparently benign lesions to avoid unnecessary invasive interventions. The aim of this study was to evaluate the role of diffusion MR imaging in differentiating between benign and malignant peritoneal lesions with correlation to their pathological results.

Methods

- A prospective study included 40 patients with peritoneal lesions referred to the radiology department for MRI examination of the abdomen and pelvis in the period between June 2019 and January 2020.
- Written informed consent was signed by all patients before the MRI examination. The study is IRB approved.

Inclusion criteria

- Patients with peritoneal lesion

Exclusion criteria

- Absolute contraindications to MRI or contraindications to contrast media if contrast is to be used

MRI technique

- The MRI was done using 1.5 Tesla Philips MRI scanner (Achieva- Netherlands).
- A circular surface (Sense-XL-Torso body) coil was used to obtain a high signal-to-noise ratio and high spatial resolution.
- Conventional sequences were first obtained including axial T1, T2, and SPAIR. For T1 WIs, the acquisition parameters were TR 250 ms, TE 30 ms, flip angle 15°, FOV 300–350, slice thickness 7, and for T2 WIs were TR 1000 ms, TE 80 ms, flip angle 90°, FOV 300–350, slice thickness 7.
- DW MRI was then performed in the axial plane using a single-shot spin echo echo-planar imaging acquisition. Motion-probing gradient pulses were placed in the three orthogonal planes. Isotropic DWI was generated using three orthogonal-axis images combining the diffusion signal from all three vectors. Fat suppression was used for background suppression using a selective partial inversion recovery. The following acquisition parameters were used TR 1700 ms, TE 76 ms, slice thickness 8 mm, *b* values 0, 500, 1000 mm^2/s.

Interpretation of the MR images

- Post processing was done by three experienced abdominal imaging radiologists using the Phillips workstation (extended MR workspace 2.6.3.5 Netherlands 2011).
- Features of the peritoneal lesion were analyzed including number of lesions, site, size, and signal intensity at T1, T2, and SPAIR images.
- The morphological nature of the lesions was classified into:
- Solid nodules (less than 1 cm in largest diameter)
- Solid mass (more than 1 cm in largest diameter)
- Cystic masses

- Peritoneal thickening (diffuse sheet-like thickening or nodular/mass-like thickening)

Diffusion analysis

- Qualitative assessment of the signal of the lesion in diffusion images correlated to ADC maps.
- If all or part of the lesion is of high signal in DWI and low in ADC map, it is considered as diffusion restriction.
- If all the lesion is of low signal in DWI and high in ADC map, it is considered as facilitated diffusion.
- If the lesion is of high signal in DWI and high in ADC map, it is considered as T2 shine through effect.
- If the lesion is of low signal in DWI and low in ADC map, it is considered as T2 blackout effect.
- Statistical correlation between the mean ADC values of the different lesions was done.
- ADC maps were assessed both qualitatively by recording the signal intensity and quantitatively by measuring ADC values in different areas of the lesion.
- ADC measurement:
- Pixel-based ADC maps were generated on the workstation. ADC was calculated with linear regression analysis of the function $S = S0 \times \exp(-b \times ADC)$, where S is the signal intensity after application of the diffusion gradient, and S0 is the signal intensity at a b value of 0 mm^2/s. The three b values (0, 400, and 800 mm^2/s) were used for ADC calculation.
- Three circular ROI (region of interest) with an area of about 1 cm^2 (27 pixel) was drawn at the different areas of the lesion; the average ADC value of these 3 readings was then calculated.
- If the area of the peritoneal lesion was less than 1 cm^2 (27 pixel), the smallest measurable area of ROI was drawn.

We categorize the patients into two groups

- Benign peritoneal lesion group: if the pathological examination revealed a benign nature of the lesion.
- Malignant peritoneal lesion group: if the pathological examination revealed a malignant nature of the peritoneal lesion.

Standard of reference

The standard of reference was the histopathological investigation which was done through tissue core biopsy or FNAC if the peritoneal lesion was associated with ascites or loculated fluid collection. Otherwise, the tissue core biopsy was considered and taken by (ultrasound or CT guided) percutaneous needle or under the laparoscopic guidance (incisional or excisional biopsy).

Statistical analysis

- Unpaired student t test was used to compare the mean ADC values of the different study groups, and the results are expressed as mean ± standard deviation or number (%). P value ≤ 0.05 was considered as significant, and < 0.01 was considered as highly significant.

Results

- Forty patients with peritoneal lesions were included in this study, 22 females (55%) and 18 males (45%). Their ages ranged between 8 and 64 years, and the mean age was 40.25 years.
- Among the 40 patients included in the study, there were 20 patients with benign peritoneal pathology and 20 patients with malignant pathology. The diagnoses of the peritoneal lesions according to pathological evaluation are discussed in Table 1.
- According to the morphological classification we followed in this study, it was found that:
  - Fifteen lesions (37.5%) presented as solid nodules and masses, 5 of them (33.3%) were benign and 10 of them (66.6%) were malignant. The pathological diagnoses of benign mass/nodule were desmoid tumor (n = 4) (Fig. 1) and leiomyomatosis peritonealis disseminata (n = 1). The malignant cases were malignant mesothelioma (n = 1), PPSC (n = 1), sarcomatosis (n = 1) (Fig. 2), and peritoneal carcinomatosis (n = 7).
  - Eighteen lesions (45%) were in the form of smooth or nodular peritoneal thickening, 10 of them (55.5%) were benign, and 8 of them (44.4%) were malignant. The pathological diagnoses of benign peritoneal thickening were TB (n = 8), non-granulomatous peritonitis (n = 1) (Fig. 3), and encapsulating peritoneal sclerosis (n = 1). The malignant cases were malignant mesothelioma (n = 1) and peritoneal carcinomatosis (n = 7).
  - Seven lesions (17.5%) presented as cystic masses, 5 of them (71.4%) were benign and 2 of them (28.6%) were malignant. The pathological diagnoses of benign cystic lesions were mesenteric cyst (n = 2), peritoneal abscess (n = 1), and multi-cystic mesothelioma (n = 2). The malignant cases were pseudomyxoma peritonei (n = 2) (one from colonic low-grade mucinous

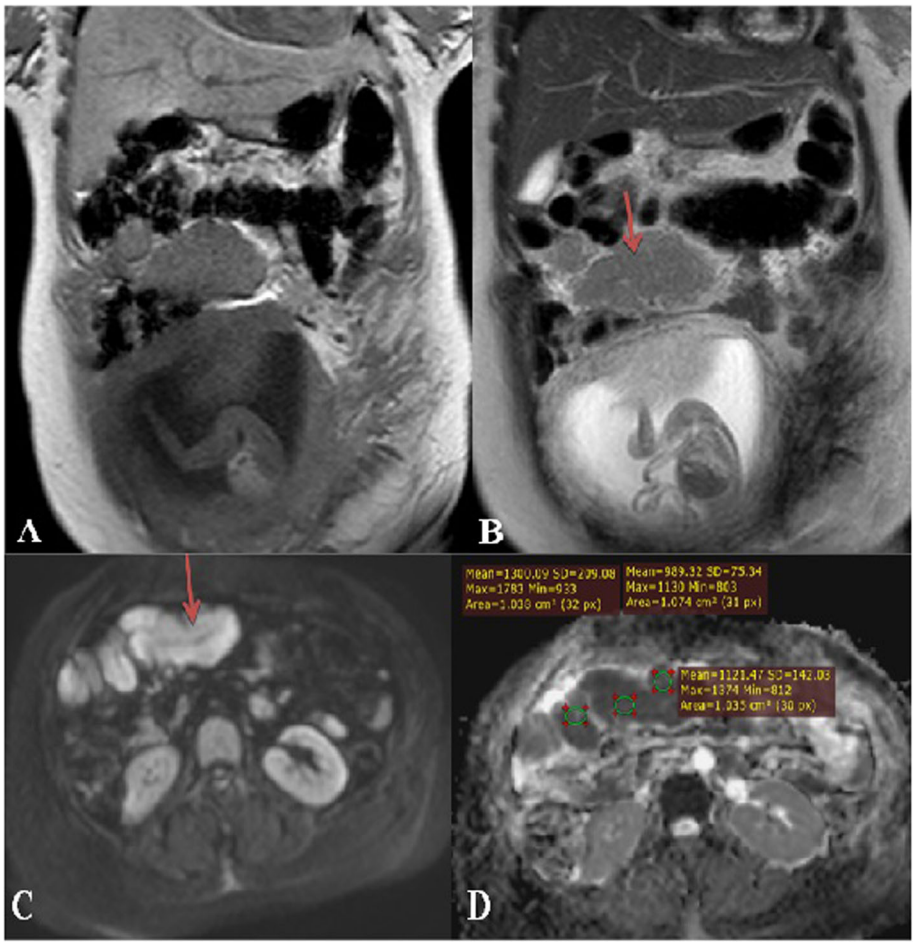

Fig. 1 Forty-two year old male patient with diffuse abdominal pain and fever. **a** DWI at *b* 0. **b** DWI at *b* 500. **c** DWI at *b* 1000. **d** ADC map. Images showed diffuse sheets like pelvic peritoneal thickening (arrow) with high signal in DWI and low in ADC, impressive of restricted diffusion with average ADC value 0.86 ± 0.1 × 10^{-3} mm^2/s. Exploration was done and final diagnosis with peritonitis secondary to acute appendicitis

adenocarcinoma and the another from ovarian low-grade mucinous adenocarcinoma).

- Ascites was found in association with peritoneal lesions in 50% of benign lesions and 100% of the malignant peritoneal lesions.
- Qualitative assessment of ADC and DWI signal were done for all peritoneal lesions in the studied group (Table 2):
  - Restricted diffusion was noted in 33 lesions (77.5%), 14 of them (42.4%) were benign and 19 (57.6%) were malignant.
  - Facilitated diffusion was noted in 4 lesions (10%); all of them were benign.
  - T2 shine-through was noted in 3 lesions (12.5%), 2 of them (66.6%) were benign and 1 (33.3%) was malignant.
- Statistical analysis of the average ADC values of the studied group was done and summarized in Table 3. The lowest ADC value of all peritoneal lesions was found in the peritoneal sarcomatosis (0.5 × 10^{-3} mm^2/s). The highest ADC value in the benign group was noted in multicystic mesothelioma (3 × 10^{-3} mm^2/s), while the highest ADC value in the malignant group was noted in pseudomyxoma peritonei (2 × 10^{-3} mm^2/s).
- Statistical correlation between the ADC values of the different study groups was done and summarized in Table 4.
  - A significant statistical difference ($p < 0.00001$) was found between the benign and malignant peritoneal lesions in general.
  - In particular, we compared the mean ADC values of the tuberculous peritoneal lesions (Fig. 4) and those of metastatic peritoneal deposits (peritoneal carcinomatosis) (Fig. 5). A statistically significant difference was noted ($p < 0.001$).

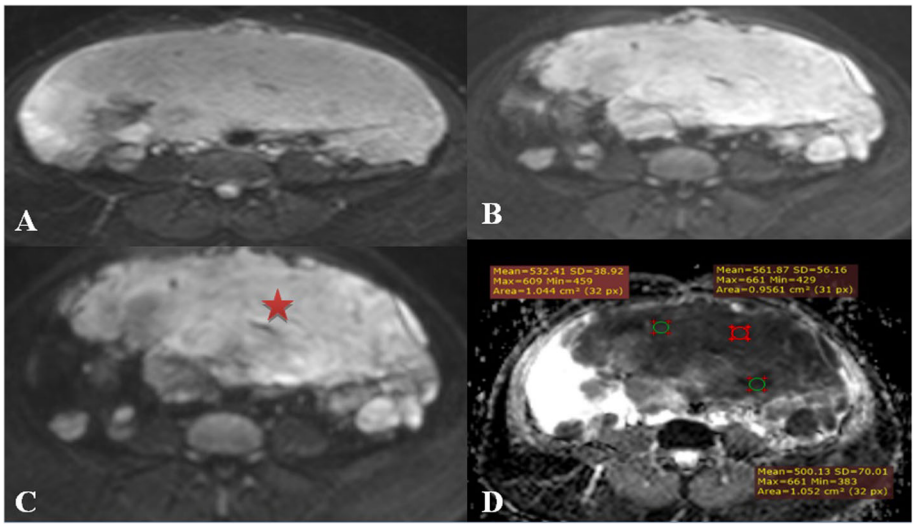

Fig. 2 Thirty-five year old female patient presented with chronic abdominal pain and loss of weight. **a** DWI at *b* 0. **b** DWI at *b* 500. **c** DWI at *b* 1000. **d** ADC map. The images showed sheets of peritoneal thickening (arrow) with high signal in DWI and low in ADC map, impressive of restricted diffusion with average ADC value 1.31 ± 0.08 × 10^{-3} mm^2/s. Final diagnosis after laboratory and pathological examination was tuberculous peritonitis

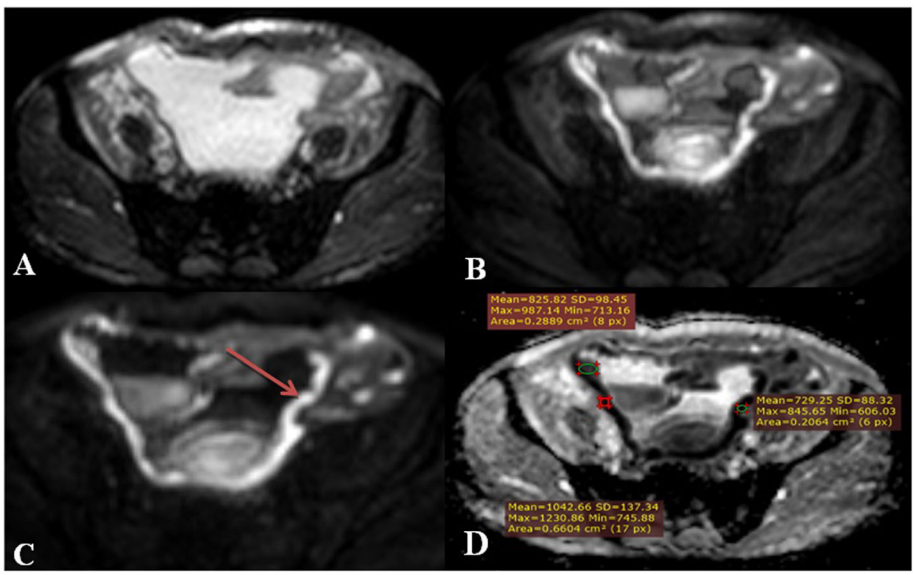

Fig. 3 Fifty-four year old female patient with history of surgically excised ovarian cystadenocarcinoma presented by abdominal pain and distention. **a** DWI at *b* 0. **b** DWI at *b* 500. **c** DWI at *b* 1000. **d** ADC map. The images showed sheets of peritoneal thickening (arrow) with high signal in DWI and low in ADC map, impressive of restricted diffusion with average ADC value 0.83 ± 0.08 × 10^{-3} mm^2/s. Final diagnosis after pathological examination was peritoneal metastatic deposits

Table 2 Characterization of the lesion in the benign and malignant groups in diffusion images using qualitative assessment

	Restricted		Facilitated		T2 shine-through	
	No.	%	No.	%	No.	%
Total	**33**	**77.5**	**4**	**10**	**3**	**12.5**
Benign	**14**	**42.4**	**4**	**100**	**2**	**66.6**
Malignant	**19**	**57.6**	**0**	**0**	**1**	**33.3**

- In cases presented with peritoneal thickening, there was also a significant statistical difference ($p = 0.001$) between the benign and malignant lesions.
- By comparing benign and malignant peritoneal solid masses and nodules, there is a significant statistical difference obtained ($p = 0.0027$).
- No statistically significant difference was noted between the benign and malignant peritoneal cystic lesions ($p = 0.5$).

Receiver operating characteristic (ROC) curve

- ROC curves are commonly used to characterize the sensitivity/specificity tradeoffs for a binary classifier. The area under the curve is viewed as a measure of a forecast's accuracy that donated by AUC.
- In Table 5 and Fig. 6, the AUC of the ADC value of peritoneal lesions was 0.834 with 95% confidence interval range between 0.699 and 0.968 producing a significant *P* value 0.001. We concluded that the ADC value of 1.15 can be used as cutoff value for benign and malignant lesions (significant *P* value 0.001).

Table 3 Mean and standard deviation of average ADC values in different peritoneal pathologies

Pathology	Mean	Standard deviation
Malignant mesothelioma	**0.95**	**0.07**
PPSC	**0.8**	
Carcinomatosis	**0.83**	**0.06**
Pseudomyxoma peritonei	**1.9**	**0.14**
Sarcomatosis	**0.5**	
TB	**1.2838**	**0.08**
Multicystic mesothelioma	**2.95**	**0.07**
DF	**1.19**	**0.07**
Leiomyomatosis peritonealis disseminata	**1.6**	**0.15**
Mesenteric cyst	**1.95**	**0.07**
EPS	**1.9**	
Non granulomatous peritonitis	**0.87**	**0.02**

The peritoneum is a complex serous membrane that forms the lining of the abdominal cavity and divides it into multiple compartments and potential spaces and acts as a conduit for the network of blood vessels, lymphatics, and nerves. Malignant and benign peritoneal disorders can use these conduits to spread throughout the abdomen and pelvis [8].

There is a wide spectrum of benign and malignant peritoneal diseases with overlapping clinical and imaging appearances. Clinical manifestations of peritoneal disorders include abdominal distention, pain and discomfort, gastrointestinal manifestations, and less commonly palpable masses [9].

Pathological assessment remains the cornerstone of diagnosis of the nature of peritoneal lesions; however, non-invasive imaging methods like CT and MRI can aid in differentiation and characterization of the nature of peritoneal pathology. Diffusion MR imaging has been introduced since the 1990s to detect early stroke and other neurologic disorders. Since that time, a growing number of applications for diffusion imaging has emerged in detection and characterization of lesions all over the body [10, 11].

Forty patients presented with peritoneal lesions were included in the current study. According to their pathological diagnosis, 20 lesions were of benign nature, and 20 lesions were malignant. The lesions were classified according to their predominant morphological appearance for simplification and helping in differentiation between different lesions into solid mass/nodule, peritoneal thickening whether smooth or nodular, and finally cystic lesions.

A significant statistical difference ($p < 0.00001$) was found between the benign and malignant peritoneal lesions in general with an ADC cutoff value 1.15×10^{-3} mm^2/s that can be used for differentiation of benign and malignant lesions. To our knowledge, we did not find similar previous studies or recommended cutoff values among our search in literature.

Eighteen cases were manifested predominantly by peritoneal thickening, 10 of them were benign and 8 cases were malignant. Our results showed diffusion restriction of peritoneal tumors and inflammation which is in agreement with study done by Low [2]. Diffusion restriction in peritonitis could be explained by the swelling of cells, infiltration of by inflammatory cells causing increased cellularity, and narrowing of extracellular space.

However, a significant statistical difference was found between the mean ADC value of the benign peritoneal thickening (average ADC value = $1.3 \pm 0.2 \times 10^{-3}$ mm^2/s) and malignant peritoneal thickening (average ADC value = $0.8 \pm 0.1 \times 10^{-3}$ mm^2/s) with *P* value = 0.001. In particular, for its diagnostic importance and owing to the largest number of cases detected in the study, we compared the mean ADC values of TB peritoneal lesions

Table 4 Statistical correlation between the ADC values of the different study groups

	Mean ± SD	*P* value
Benign and malignant lesions in general		
Benign	**1.5 ± 0.5 × 10^{-3} mm^2/s**	**< 0.00001 (Significant)**
Malignant	**0.9 ± 0.3 ×x 10^{-3} mm^2/s**	
TB and peritoneal carcinomatosis		
Peritoneal TB	**1.28 ± 0.08 × 10^{-3} mm^2/s**	**< 0.001 (Significant)**
Peritoneal carcinomatosis	**0.83 ± 0.06 × 10^{-3} mm^2/s**	
Benign and malignant solid nodules and masses		
Benign solid mass/nodule	**1.2 ± 0.1 × 10^{-3} mm^2/s**	**.0027 (Significant)**
Malignant solid mass/nodule	**0.81 ± 0.1 × 10^{-3} mm^2/s**	
Benign and malignant peritoneal thickening		
Benign thickening	**1.3 ± 0.2 × 10^{-3} mm^2/s**	**0.001 (Significant)**
Malignant thickening	**0.8 ± 0.1 × 10^{-3} mm^2/s**	
benign and malignant cystic lesions		
Benign cystic	**1.9 ± 0.8 × 10^{-3} mm^2/s**	**0.5 (Insignificant)**
Malignant cystic	**1.16 ± 0.1 × 10^{-3} mm^2/s**	

and peritoneal carcinomatosis, and also, this revealed a significant statistical difference.

Vicens et al. [8] stated that the most consistent feature in peritonitis is smooth thickening of the peritoneal lining, and this feature contrasts with the nodular thickening seen in peritoneal carcinomatosis.

Low [2] stated that the peritoneal thickening from tumors may be thin and regular, nodular, or mass-like. Peritonitis usually presents as smooth and regular peritoneal thickening without dominant masses or nodules. However, in our study, we found 2 cases of TB peritonitis manifested by nodular peritoneal thickening while one case of peritoneal carcinomatosis and also a case of mesothelioma were manifested by smooth peritoneal thickening.

In our study, we collected 15 cases manifested by predominately solid peritoneal mass or nodule, 5 of them were benign and 10 cases were malignant. A significant statistical difference was found between the benign peritoneal solid lesions (average ADC = 1.2 ± 0.1 × 10^{-3} mm^2/s) and malignant peritoneal solid lesion (average ADC = 0.81 ± 0.1 × 10^{-3} mm^2/s) with *P* value = 0.0027.

Our results showed diffusion restriction in the 4 cases of desmoid which was in agreement with studies done by Herrera et al. and Wang et al. [12, 13]. Vicens et al. [8] reported that the malignant peritoneal mesothelioma is manifested by diffusion restriction which matches with our findings in the two cases of mesothelioma. Previous study demonstrated the importance of diffusion MR imaging in detection and

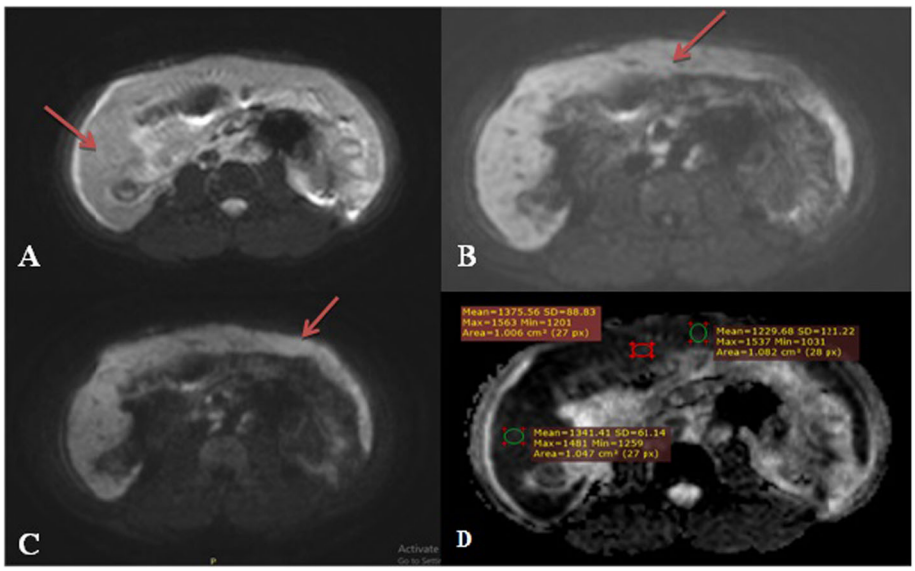

Fig. 4 Twenty-seven year old pregnant female patient with incidentally discovered abdominal mass during routine abdominal ultrasound. **a** Coronal T1 WIs. **b** Coronal T2 WIs. **c** DWI at *b* 1000. **d** ADC map. Note the gravid uterus associated with a solid peritoneal mass showing high signal in DWI and low in ADC map, impressive of restricted diffusion with average ADC value 1.14 ± 0.1 × 10^{-3} mm^2/s. Final diagnosis after pathological examination was desmoid tumor

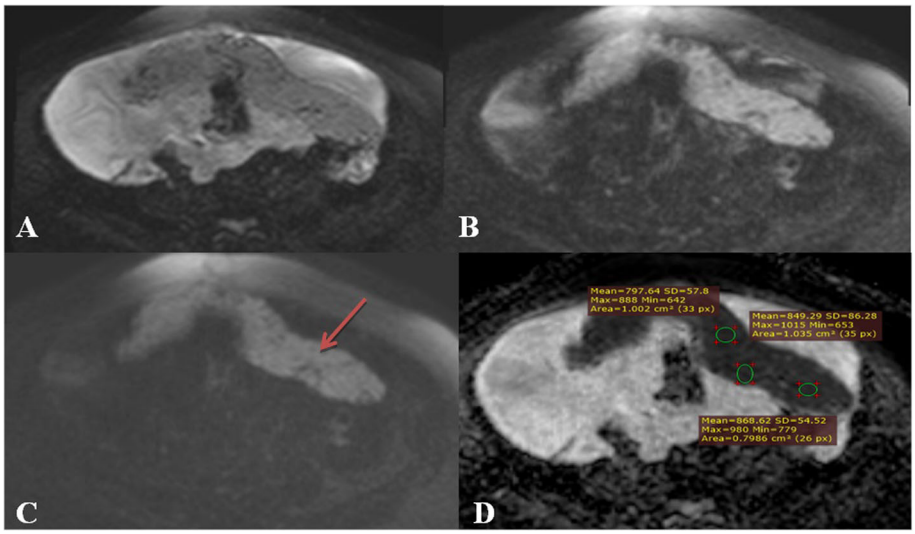

Fig. 5 Forty-nine years old male patient, with abdominal pain and distension, a peritoneal mass was detected during abdominal ultrasound. **a** DWI at *b* 0. **b** DWI at *b* 500. **c** DWI at *b* 1000. **d** ADC map. The images showed a large irregular solid peritoneal mass lesion with high signal in DWI and low in ADC map, impressive of restricted diffusion with average ADC value 0.5 ± 0.02 × 10^{-3} mm^2/s. Final diagnosis after pathological examination was peritoneal sarcomatosis

characterization of peritoneal sarcomatosis which shows marked restricted diffusion [14].

There were 7 cases manifested by predominately cystic lesions, 5 of them were benign and 2 were malignant. Regarding the diffusion analysis of the cystic lesions, T2 shine-through was found in the two cases of mesenteric cyst and restricted diffusion in the two cases of pseudomyxoma peritonei. The DWI and ADC findings in cases with pseudomyxoma peritonei could be explained by the fact that mucinous materials has high fluid contents and less cellularity than non-mucinous carcinoma, so it could be misjudged as benign lesions in DWI [15].

Our study showed a facilitated diffusion in the two cases of multi-cystic mesothelioma and T2 shine-through in mesenteric cysts. There are no studies done before describing the results of DWI and ADC in such pathological entity. Diffusion restriction was found in the case of peritoneal abscess with low ADC value, which is in agreement with the study done by Castrillon et al. [16].

Table 1 Pathological diagnosis of the peritoneal lesions included in the study

Nature	Pathology	Number	Percent
Benign	**TB peritonitis**	**8**	**20**
	Multicystic mesothelioma	**2**	**5**
	Mesenteric cyst	**2**	**5**
	Peritoneal fibromatosis (desmoid)	**4**	**10**
	Non granulomatous infective peritonitis	**2**	**5**
	Leiomyomatosis peritonealis disseminata	**1**	**2.5**
	Encapsulating peritoneal sclerosis	**1**	**2.5**
	Total	**20**	**50**
Malignant	**Peritoneal carcinomatosis**	**14**	**35**
	Pseudomyxoma peritonei	**2**	**5**
	Peritoneal sarcomatosis	**1**	**2.5**
	Malignant peritoneal mesothelioma	**2**	**5**
	Primary peritoneal serous carcinoma	**1**	**2.5**
	Total	**20**	**50**
Total		**40**	**100**

Table 5 AUC and 95% confidence interval

Test results	AUC	Standard error	*P* value	95% confidence interval		Sensitivity	Specificity
				Lower bound	Upper bound		
ADC value of peritoneal lesions	**0.834**	**0.069**	**0.001**	**0.699**	**0.968**	**85%**	**85%**

Our study revealed insignificant statistical difference between the benign peritoneal cystic lesions (average ADC value = 1.9 ± 0.8 × 10^{-3} mm^2/s) and malignant peritoneal cystic lesions (average ADC value = 1.16 ± 0.1 × 10^{-3} mm^2/s) with *P* value = 0.5. However, this result could be attributed to the high fluid contents of the cystic lesions whether benign or malignant, also the small number of lesions could contribute to such result. Further studies with larger number of patients are recommended.

Limitations

- Relatively small sample size with wide pathological spectrum
- There is no overwhelming agreement in the literature concerning optimal ADC techniques and image analysis procedures, including region of interest (ROI) size and placement.
- The ADC value may not fully represent the whole lesion.
- Poor anatomic localization and relatively poor spatial resolution of DWI images. However, we used the conventional sequences like T1 and T2 WIs in addition to b0 diffusion images for better localization of the lesion.

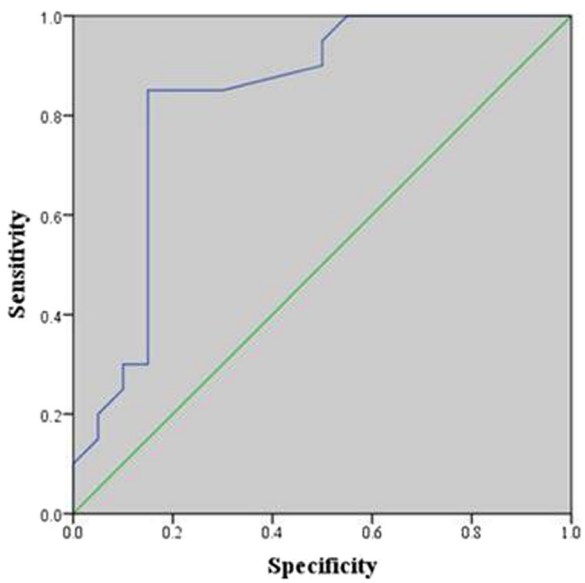

Fig. 6 ROC curve

Conclusion

Diffusion MR imaging can provide a reliable non-invasive tool that can help in the differentiation between benign and malignant peritoneal lesions using qualitative and quantitative diffusion assessment through ADC measurements with a recommended cutoff value of 1.15 × 10^{-3} mm^2/s.

Abbreviations

ADC: Apparent diffusion coefficient; DWI: Diffusion-weighted images; FNAC: Fine needle aspiration cytology; FOV: Field of view; PPSC: Primary peritoneal serous carcinoma; ROI: Region of interest; TB: Tuberculosis

Acknowledgements

Not applicable

Authors' contributions

B.E.M put the idea of the study, participated in the study design, and performed the MRI assessment. A.A.A participated in the study design, MRI assessment, and data collection, and performed the statistical analysis.A.A.M contributed to data collection and clinical assessment of the patients. L.I.A.M participated in the study design, MRI assessment, and the statistical analysis. All authors read and approved the final manuscript.

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Availability of data and materials

All the datasets used and analyzed in this study are available with the corresponding author on reasonable request.

Competing interest

The authors declare that they have no financial or non-financial competing interest.

Ethics approval and consent to participate

Written informed consent was signed by all patients before the MRI examination. The study is approved by the medical committee of the Faculty of Medicine, Cairo University, at June 2019. Reference number not available.

Consent for publication

All patients included in the research signed a written informed consent to publish the data contained within this study. In young patients less than 16 years old, the consent for the publication was given by their parents or legal guardian.

Author details

[1]Department of Radiology, Cairo university, Giza, Egypt. [2]National Cancer Institute, Cairo, Egypt.

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References:

1. Elsayes KM et al (2006) MRI of the peritoneum: spectrum of abnormalities. *American journal of roentgenology* 186(5):1368–1379
2. Low, Russell N. "MRI of the peritoneum." *MRI of the Gastrointestinal Tract*. Springer, Berlin, Heidelberg, (2010). 249-269.
3. Patel R, Beal I, Planche K (2011) Applied peritoneal anatomy-a pictorial review. European Congress of Radiology 2011

4. Singh S et al (2016) Peritoneal carcinomatosis: pictorial review of computed tomography findings. *Int J Adv Res* 4:735–748
5. Levy AD, Shaw JC, Sobin LH (2009) Secondary tumors and tumorlike lesions of the peritoneal cavity: imaging features with pathologic correlation. *Radiographics* 29(2):347–373
6. Bulut Gökten, Dilara, et al. "A case report of peritoneal tuberculosis: a challenging diagnosis." *Case reports in infectious diseases* 2018 (2018).
7. Qayyum A (2009) Diffusion-weighted imaging in the abdomen and pelvis: concepts and applications. *Radiographics* 29(6):1797–1810
8. Vicens RA et al (2015) Multimodality imaging of common and uncommon peritoneal diseases: a review for radiologists. *Abdominal imaging* 40(2):436–456
9. Pannu HK, Oliphant M (2015) The subperitoneal space and peritoneal cavity: basic concepts. *Abdominal imaging* 40(7):2710–2722
10. Malayeri AA et al (2011) Principles and applications of diffusion-weighted imaging in cancer detection, staging, and treatment follow-up. *Radiographics* 31(6):1773–1791
11. Thoeny HC, De Keyzer F (2007) Extracranial applications of diffusion-weighted magnetic resonance imaging. *European radiology* 17(6):1385–1393
12. Herrera, Victoria Carnerero, et al. "Abdominal desmoid tumors: a pictorial review." European Congress of Radiology 2012, 2012.
13. Wang, Yong, et al. "An abdominal desmoid-type fibromatosis." *Quantitative imaging in medicine and surgery* 3.4 (2013): 228.
14. Low RN et al (2009) Diffusion-weighted MRI of peritoneal tumors: comparison with conventional MRI and surgical and histopathologic findings—a feasibility study. *American Journal of Roentgenology* 193(2):461–470
15. Usuda, Katsuo, et al. "Diffusion-weighted imaging can differentiate between malignant and benign pleural diseases." *Cancers* 11.6 (2019): 811.
16. Castrillon, German A., et al. "Diffusion-weighted imaging of the gastrointestinal tract and peritoneum." *Diffusion MRI Outside the Brain*. Springer, Berlin, Heidelberg, (2012). 231-254.

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