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ORIGINAL ARTICLE

Added-Value of Diffusion-Weighted Imaging (DWI) and Dynamic Contrast-Enhanced (DCE-MRI) Magnetic Resonance Imaging in the Preoperative Assessment of Cervical Cancer

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Abstract

Purpose To evaluate the added-value of diffusion-weighted imaging (DWI) and dynamic contrast-enhanced magnetic resonance imaging (DCE-MRI) in the preoperative assessment of carcinoma cervix.

Methods This prospective study was carried out on histopathologically proven 45 patients of carcinoma cervix presented to a tertiary care hospital with bleeding per vagina between August 2017 and July 2018. Relevant local per vaginal examination and MRI examination of the pelvis were performed.

Results A total of 45 patients with carcinoma of the cervix, having 11 patients (24.4%) in Stage-I, 22 patients (48.9%) in Stage-II, 3 patients (6.7%) in Stage-III and 9 patients (20%) in stage-IV, were included in this study sample. The mean ADC value of the carcinoma of cervix was 0.802 ± 0.123 [SD] $\times 10^{-3}$ mm^2/s. The stage-I carcinoma cervix had a mean ADC value of 0.915 ± 0.109 [SD] $\times 10^{-3}$ mm^2/s, Stage-II 0.778 ± 0.099 [SD] $\times 10^{-3}$ mm^2/s, Stage-III 0.762 ± 0.123 [SD] $\times 10^{-3}$ mm^2/s and Stage-IV 0.737 ± 0.116 [SD] $\times 10^{-3}$ mm^2/s. ROC curve analysis showed the percentage of signal intensity changes within cervical tumor on arterial phase of DCE-MRI had a threshold value of 42.25 in differentiating Stage-I carcinoma of cervix from other stages with a sensitivity of 81.8% and specificity of 44.1%.

Conclusion The DWI and DCE-MRI added valuable inputs over conventional MR sequences in the early diagnosis and preoperative staging of carcinoma cervix. DCE-MRI had a high accuracy for assessing the cervical stromal and parametrial invasions, which helps in selecting the optimal therapeutic protocol and prognostication in gynecological malignancies.

Keywords Magnetic resonance imaging (MRI) · Cervical malignancy · Apparent diffusion coefficient (ADC)

Introduction

Cervical cancer is one of the major public health problems in developing countries like India. In 2018, cervical cancer is the fourth-most common cause of cancer incidence and mortality in women worldwide [1]. An estimated value of 570,000 cases and 311,000 deaths resulted from cervical cancer in 2018 worldwide [1]. The estimated age-standardised cervical cancer incidence was 13.1 per 100,000 women worldwide and it varied among countries from less than 2 to 75 per 100,000 women [1].

Cervical cancer accounting for 17% of all cancer deaths among women aged between 30 and 69 years [2]. 5 years of survival rates of patients with carcinoma cervix with FIGO 2018 stage-IB1, IB2, IB3, IIA1, IIA2, IIIC1 and III C2 were 95.3%, 95.1%, 90.4%, 92.4% 86.4%, 81.9% and 56.3%, respectively [3]. India alone accounts for one-quarter of the worldwide burden of cervical cancers and it contributes to

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approximately 6–29% of all cancers in women in India [2, 4].

The accurate staging of carcinoma cervix is important for guiding treatment options and determining patient prognosis. MRI is superior to CT scan in staging of carcinoma of the cervix and it may aid in differentiating residual or recurrent tumor from radiation fibrosis [5]. In post-treated patient with carcinoma cervix, reappearance of T2WI hypointensities in the cervical stroma indicates complete response to radiotherapy or chemotherapy and which helps in follow-up assessment [5]. Cross-sectional imaging plays an important role in the revised 2018 International Federation of Gynecology and Obstetrics (FIGO) staging system for uterine cervical cancer [6].

MRI can determine the parametrial invasion on basis of loss of T2WI hypointense cervical stromal ring [5] with a negative predictive value of 94–100% [7]. Additional features of parametrial invasion are spiculated tumor-parametrium interface, enhancing soft tissue extension into parametrium or encasement of periuterine vessels [7].

Increase in the tumor cellularity, there will be low apparent diffusion coefficient and low tumor cellularity had high ADC value. Diffusion-weighted imaging (DWI) provides a metabolic and physiological status of tumor microenvironment [3]. Malignant cervical tissue shows restricted diffusion with low ADC value as compared to the normal cervical tissue and by these characteristics DWI with ADC mapping can differentiate benign from malignant zones of cervix with high sensitivity and specificity [8, 9]. Even ADC can differentiate histological types and grading of cervical cancer [10]. Poorly differentiated cervical tumors had lower ADC value than well or moderately differentiated tumors [11, 12].

Lymph nodes can be easily detected on DW images as ovoid structures of high signal intensity and which increases the diagnostic accuracy in differentiating malignant and benign lymph nodes based on ADC value [13]. Lymphadenopathy detected at cross-sectional imaging is a major prognostic factor for survival and an important determinant in treatment planning [14].

DCE-MRI indirectly evaluates the distribution of contrast by measuring the tissue enhancement over a period of time. The signal intensity (SI) values can be recorded before, during and after contrast administration for creating a dynamic time-signal intensity (TSI) curve generated by using a fixed region of interest (ROI) within the organ imaged [15].

This study aims to evaluate the added-value of diffusion-weighted imaging (DWI) and dynamic contrast-enhanced magnetic resonance imaging (DCE-MRI) in the preoperative assessment of carcinoma cervix.

Materials and Methods

A prospective cross-sectional study was conducted at our institution on histopathologically proven 45 patients of carcinoma cervix presented with bleeding per vagina between August 2017 and July 2018. This study was approved by institutional ethics review committee.

MRI Protocols

The patients underwent an MRI scan of the Pelvis, using a 1.5 T MR scanner, Siemens Magnatom Avanto (Siemens Medical Systems, Erlangen, Germany). Conventional MRI protocol sequences of female pelvis were obtained with phased-array surface coil followed by DWI and DCE-MRI imaging. The various MRI findings were correlated with histopathological findings.

Various MRI Sequences Parameters

Sagittal T1WI images were obtained with TE: 10–12 ms, TR: 500–600 ms, slice thickness: 4 mm, flip angle: 150°, Matrix 256 × 256, FOV: 190–200.

Sagittal T2WI images were obtained with TE: 90–105 ms, TR: 4800–6000 ms, slice thickness: 4 mm, flip angle: 150°, Matrix 256 × 256, FOV: 190–200.

T2WI true coronal images were obtained with TE: 90–105 ms, TR: 5000 -6000 ms, slice thickness: 4 mm, flip angle: 150°, Matrix 256 × 256, FOV: 240–260.

Fat-suppressed axial T2WI images were obtained with TE: 90-100 ms, TR: 4500–5500 ms, slice thickness: 4 mm, Matrix 256 × 256, FOV: 200–240.

DWI images were obtained with TE: 80-90 ms, TR: 2800-3200 ms, slice thickness: 5 mm, Matrix 256 × 256, FOV: 200–240 with b values b = 1000 s/mm^2.

Post-contrast sagittal T1-VIBE sequences were obtained with TE: 1.25 ms, TR: 3.2 ms, slice thickness: 1.4 mm, flip angle: 10°, Matrix 256 × 256, FOV: 220–320. After injecting I.V. Gadopentetate dimeglumine at a dose of 0.1 mmol/kg body weight and infusion rate of 3–4 ml/s followed by 20 ml normal saline flush obtained four Phases including pre-contrast, arterial, venous and equilibrium phases.

Exclusion Criteria

Post-treated patient with cervical malignancy with radiotherapy or chemotherapy.

Conventional MRI Analysis

The conventional MR images were analyzed for.

1. Tumor signal intensity on T1 and T2 weighted images and DWI compared with that of adjacent myometrium.
2. Tumor size on T2W images in correlation with DCE-MRI.
3. Presence of cervical stromal invasion: assessed on T2W images by detecting the disruption of hypointense cervical stroma. Extension of tumor into uterus, vaginal vault, vagina, pelvic sidewall, urinary bladder, rectum, para-cervical/ parametrial regions assessed only on T2W images and correlated with DCE-MRI + T2WI and DWI + T2WI.
4. The presence of enlarged pelvic or retroperitoneal lymph node with SAD of 10 mm or more was noted.
5. Diffusion characteristics of cervical tumor with ADC value measurement.
6. Dynamic contrast MRI evaluation of cervical stromal infiltration, determining percentage signal changes within tumor and normal-appearing uterine myometrium in arterial and equilibrium phases on DEC-MRI.

Revised 2018 FIGO Staging Analysis

Two radiologists blinded to the histopathological reports evaluated the MRI scans and performed a consensus MR imaging interpretation of the cervical stromal or myometrial invasion and stage of cervical cancer according to the revised 2018 FIGO staging. A combination of T2WI, DCE-MRI + T2WI and DWI + T2WI was used in the staging of cervical cancer.

Quantitative DWI and ADC Mapping Analysis

The ADC values were generated in the operating system console using ROI (region of interest) placed in the cervical tumor and normal-appearing uterine myometrium. Constant diameter of circular ROI was used with a minimum area of 0.1–0.2 cm^2, and then mean ADC value was obtained.

Semi-quantitative Analysis of DCE-MRI

The percentage of signal intensity changes is determined by = (SI post-contrast − SI pre-contrast)/ SI pre-contrast × 100. SI post-contrast is the SI of the ROI on post-contrast images, and SI pre-contrast is the SI of the ROI on the pre-contrast images. The relative enhancement of the tumor with respect to the normal uterine myometrium (tumor-to-myometrial index) was calculated in both arterial and equilibrium phases. Relative tumor enhancement index = Percentage of SI changes of the tumor/Percentage of SI changes of the normal-appearing myometrium were also calculated in both arterial and equilibrium phases. The ROIs were placed within the cervical tumor and normal-appearing myometrium in pre-contrast, arterial and equilibrium phases of post-contrast images. Constant diameter ROI placement and value were recorded for each of the three time points.

Statistical Analysis

All statistical analyses were performed using Statistical Package for the Social Science (SPSS, version 16). Accuracy of conventional MRI with DWI and Dynamic contrast-enhanced (DCE-MRI) sequences was done. An independent unpaired t test and One-Way ANOVA test were used to compare the mean ADC value of cervical mass with respect to the staging and histological grading. Statistical analysis was used to compare the percentage of signal intensity (SI) changes within the cervical tumor, normal-appearing myometrium and tumor-to-myometrial enhancement index in the arterial, as well as equilibrium phases of DCE-MRI sequence. Receiver operating characteristic (ROC) curve analysis was performed for comparison of various stages of 2018 Revised FIGO staging by using percentage of signal intensity (SI) changes in tumors and tumor-to-myometrial enhancement index. Statistical significance was considered when the p value was ≤ 0.05.

Results

Of the 45 female patients of cervical cancer in our study sample, having a mean age of 51.7 ± 10.7 [SD] years, majority of 17 patients (37.8%) belonged to the 51–60 years age group followed by 10 patients (22.2%) in the 41–50 years age group. Thirty-seven (82.8%) patients presented with episodes of bleeding per vagina, foul smelled white discharge, 6 (13.3%) patients with bleeding per vagina and decreased urination and 2 (4.4%) patients with rectal and per vaginal bleeding. Stage-I carcinoma cervix observed in 11 patients (24.4%), Stage-II in 22 patients (48%) (Figs. 1, 2, 3), stage-III in 3 patients (6.7%) and stage-IV in 9 patients (20%) (Fig. 4) according to 2018 Revised FIGO staging. T2WI isointense signal in cervical tumor is observed in 26 patients (57.8%) (Fig. 4), T2WI hyperintensities in 13 patients (28.9%) (Fig. 1, 3) while T1WI isointensities in 27 patients (60%) and hypointensities in 18 patients (40%).

Table 1 shows the mean ADC values of various stages of cervical carcinoma according to the 2018 Revised FIGO staging. The mean ADC value of the carcinoma of cervix was 0.802 ± 0.123 [SD] × 10^{-3} mm^2/s. The stage-I carcinoma cervix had mean ADC value of 0.915 ± 0.109 [SD] × 10^{-3} mm^2/s, Stage-II 0.778 ± 0.099 [SD] × 10^{-3} mm^2/s, Stage-III 0.762 ± 0.123 [SD] × 10^{-3} mm^2/s and Stage-IV 0.737 ± 0.116 [SD] × 10^{-3} mm^2/s. There was a statistically significant correlation found between the mean ADC value of Stage-I carcinoma cervix with II, III and IV with p value < 0.05 Table 1.

ROC analysis of mean ADC values of various stages of carcinoma cervix is shown in (Fig. 5). ROC curve analysis showed threshold mean ADC value of 0.811×10^{-3} mm^2/s for stage-I with a sensitivity of 90.9% and specificity of 70.6%, 0.729×10^{-3} mm^2/s for Stage-II with a sensitivity of 68.2% and specificity of 30.4%, 0.752×10^{-3} mm^2/s for Stage-III with a sensitivity 66.7% and specificity of 38.1%, 0.707×10^{-3} mm^2/s for Stage-IV with a sensitivity of 66.7% and specificity of 22.2% for differentiating one from other stage of carcinoma cervix.

Histopathologically, 41 patients (91.1%) were squamous cell carcinoma and 4 patients (8.9%) were adenocarcinoma. Adenocarcinoma showed a lower mean ADC value compared to squamous cell carcinoma Table 1.

The histopathologically well-differentiated carcinoma cervix had mean ADC value of 0.839 ± 0.132 [SD] $\times 10^{-3}$ mm^2/s, moderately differentiated had 0.783 ± 0.075 [SD] $\times 10^{-3}$ mm^2/s and poorly differentiated had 0.743 ± 0.113 [SD] $\times 10^{-3} mm^2/s$. There was a statistically significant correlation between the mean ADC value of well-differentiated carcinoma cervix with poorly differentiated carcinoma cervix with p value of 0.027. However, no statistically significant correlation was found between the mean ADC of well-differentiated and moderately differentiated carcinoma cervix with p value of 0.233 Table 1.

On dynamic contrast-enhanced MRI (DCE-MRI), all cervical cancer showed increased signal intensity (SI) on both arterial and equilibrium phases after contrast administration. The mean percentage SI changes for all cervical tumors in the arterial and equilibrium phases were 57.8% and 46.2%, respectively. The percentage SI changes and tumor-to-myometrial enhancement index of cervical tumor according to

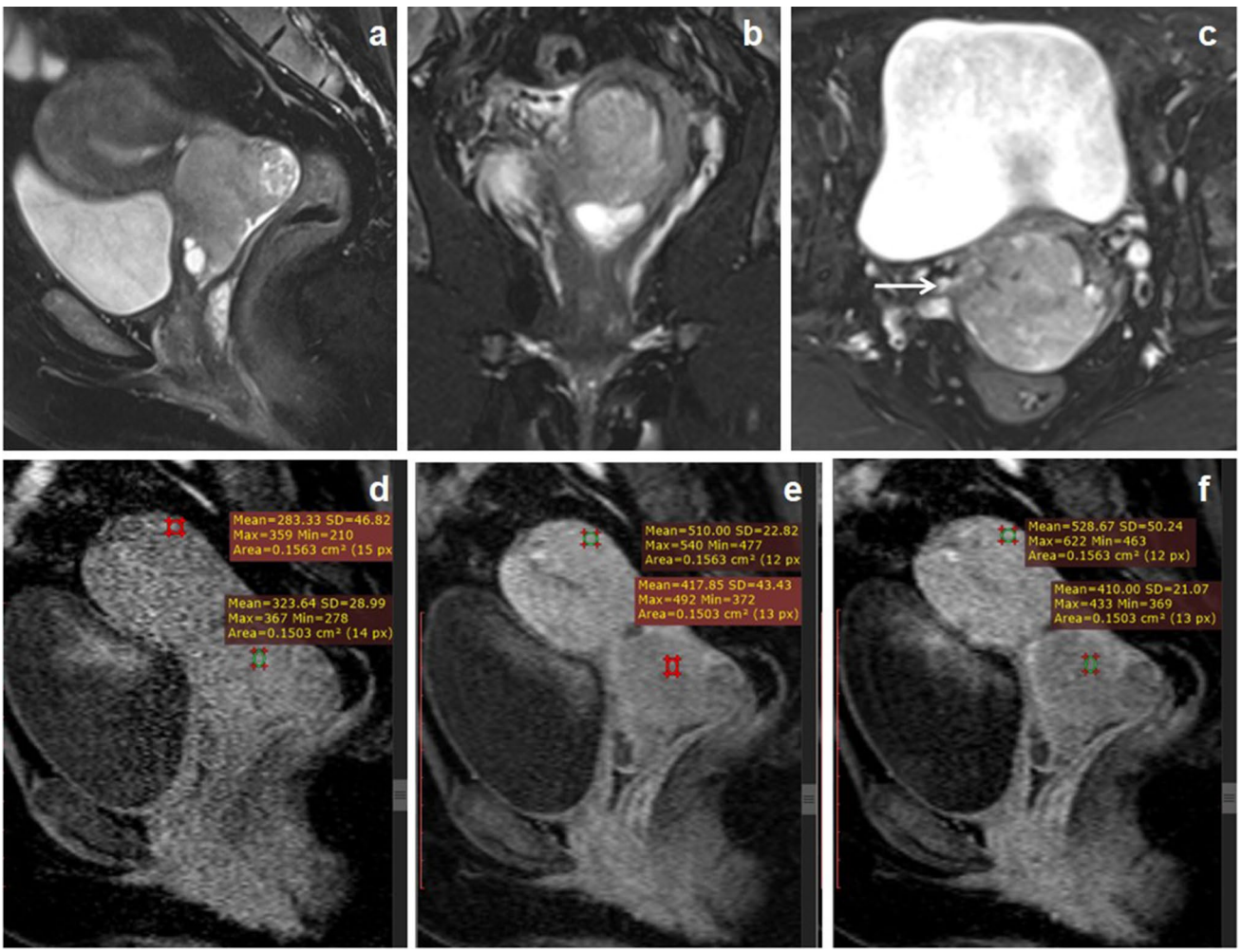


Fig. 1 38-year-old female presented with bleeding per vagina with stage-IIA1 carcinoma of cervix. Sagittal, coronal and axial fat-suppressed T2W images (**a**–**c**) show iso to slight hyperintense lesion in cervix affecting both anterior and posterior lips with loss of peripheral T2WI hypointense cervical stroma (→arrow) without parametrial infiltration. Sagittal pre-contrast, arterial and equilibrium phases of dynamic contrast-enhanced MRI (DCE-MRI) images (**d**–**f**) showed the placement of ROI within the enhancing cervical tumor and normal-appearing myometrium for the relative enhancement of the tumor with respect to the normal uterine myometrium

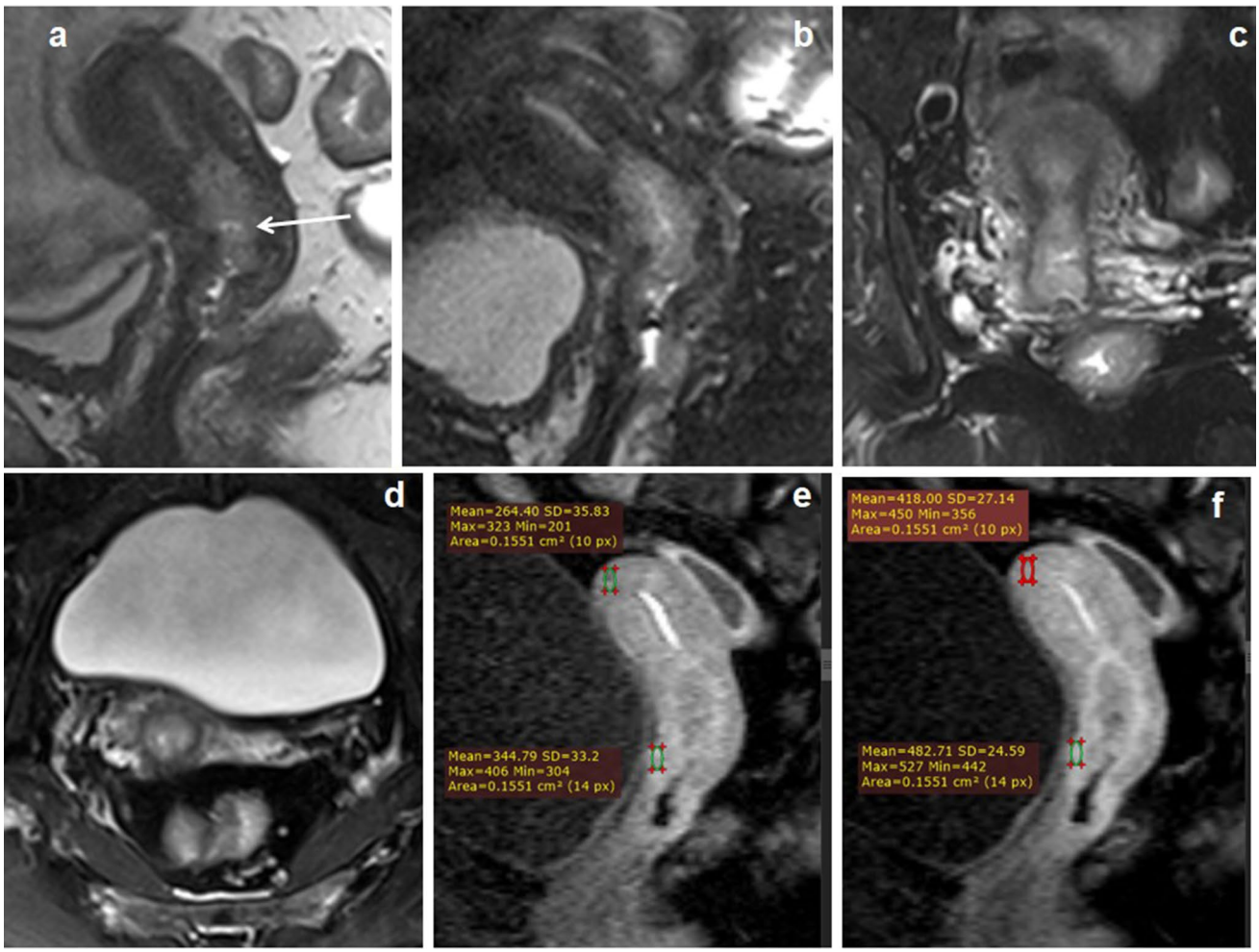


Fig. 2 50-year-old female with stage-IIA2 carcinoma of cervix. Sagittal T2WI, fat-suppressed T2WI sagittal, coronal and axial images (**a**–**d**) showed T2WI iso to slight hyperintense lesions along the endocervical canal (← arrow) superiorly extend around the lower endometrial canal and inferior into upper 1/3rd of vaginal walls. Sagittal arterial and equilibrium phases of dynamic contrast-enhanced MRI (DCE-MRI) images (**e**, **f**) showed the placement of ROI within the irregular peripherally enhancing cervical tumor and normal-appearing myometrium

the revised FIGO staging and histological grades are shown in Table 2. There was a statistical significance (p value of 0.035) for SI changes in cervical tumors in the arterial phase for differentiating Stage-I carcinoma of cervix from other stages on DCE-MRI Table 5. ROC curve analysis showed a percentage of SI change threshold of 42.25 in the arterial phase that can differentiate Stage-I carcinoma of cervix from other stages with a sensitivity of 81.8% and specificity of 44.1%. The highest relative tumor-to-myometrial enhancement indexes were observed on arterial phase in Stage-I and lowest indexes were found in Stage-III. There were no significant differences between well-differentiated and poorly differentiated cervical tumors in relative tumor-to-myometrial enhancement index in either phase (arterial, p value = 0.94; equilibrium, p value = 0.721) Table 3. Table 4 shows the comparison between the MRI and pathological staging of cervical cancer according to the revised 2018 FIGO staging.

Discussion

Cervical cancer is a major cause of morbidity and mortality in developing countries. Institution of screening, prevention measures with early MRI detection and staging of cervical cancer helps to guide proper treatment, radiation treatment planning/monitoring and detection of post-treatment recurrence [16].

MRI plays an important role in accurate staging of cervical cancer to distinguish early disease (stage-I and IIA) that can be treated surgically or concurrent chemoradiotherapy from the advanced disease (stage-IIB or greater) that is

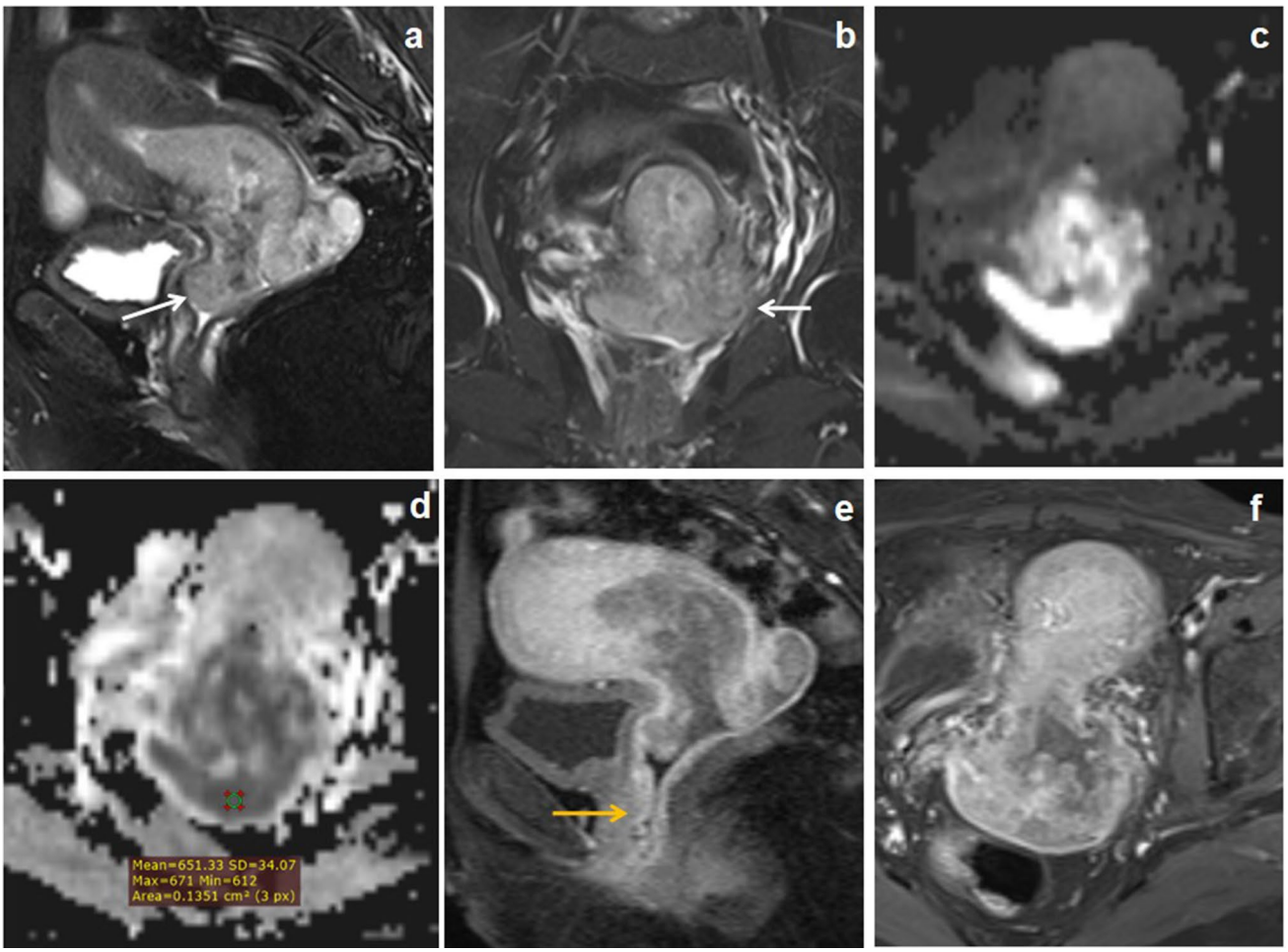


Fig. 3 40 years female with Stage-IIB carcinoma of cervix. Fat-suppressed sagittal and coronal T2WI images (**a**, **b**) showed T2WI iso to hyperintense lesions extend beyond the cervix into the lower uterine segment and inferiorly into upper 1/3rd of vagina (→arrow). Infiltration of tumor seen in left parametrial region (←arrow). Axial DWI and ADC map images (**c**, **d**) showed diffusion restriction within the cervical tumor with low ADC value. ROI placement for calculation of ADC value is shown in image d. Sagittal and coronal post-contrast MRI images (**e**, **f**) showed heterogenous enhancement of the cervical tumor with abnormal soft tissue thickening extends along the upper $1/3^{rd}$ of anterior vagina (→arrow)

usually treated with radiation therapy or concurrent chemoradiotherapy. The outcome following standard therapeutic approaches were governed by accurate MRI detection of tumor location, size, depth of stromal invasion, parametrial invasion, lower uterine segment affection, vaginal extension, pelvic sidewall invasion and associated lymph nodal involvement with advanced MRI imaging like DWI, DCE-MRI and MR spectroscopy [7, 12].

Several published studies evaluated the prognostic significance of ADC value in the diagnosis and management of the cervical cancer. Nakamura et al. [10] observed statistical significance of mean ADC value of cervical tumor with the FIGO stage, tumor size, stroma and parametrial infiltration, lymph node metastasis and lymphovascular space involvement in 80 surgically treated patients. T2WI able to detect early cervical tumors as hyperintense lesion with disruption of the T2W hypointense cervical stromal ring, speculated tumor invasion and encasement of periuterine vessels [17].

Various previous studies showed increasing ADC value in the post-treatment carcinoma cervix in patient response to the treatment [18–20]. Chen et al. [21] observed 100% sensitivity and 84.8% specificity of DWI for the detection of cervical cancer. In our study sample, the mean ADC value of the carcinoma of cervix was 0.802 ± 0.123 [SD] $\times 10^{-3}$ mm^2/s, where stage-I carcinoma cervix had mean ADC value of 0.915 ± 0.109 [SD] $\times 10^{-3}$ mm^2/s, Stage-II 0.778 ± 0.099 [SD] $\times 10^{-3}$ mm^2/s, Stage-III 0.762 ± 0.123 [SD] $\times 10^{-3}$ mm^2/s and Stage-IV 0.737 ± 0.116 [SD] $\times 10^{-3}$ mm^2/s Table 1. In our study sample, ADC mapping had a sensitivity of 90.9% and specificity of 70.6% in detecting Stage-I, sensitivity of 68.2% and specificity 30.4% in Stage-II, sensitivity of 66.7% and specificity 38.1% in Stage-III and

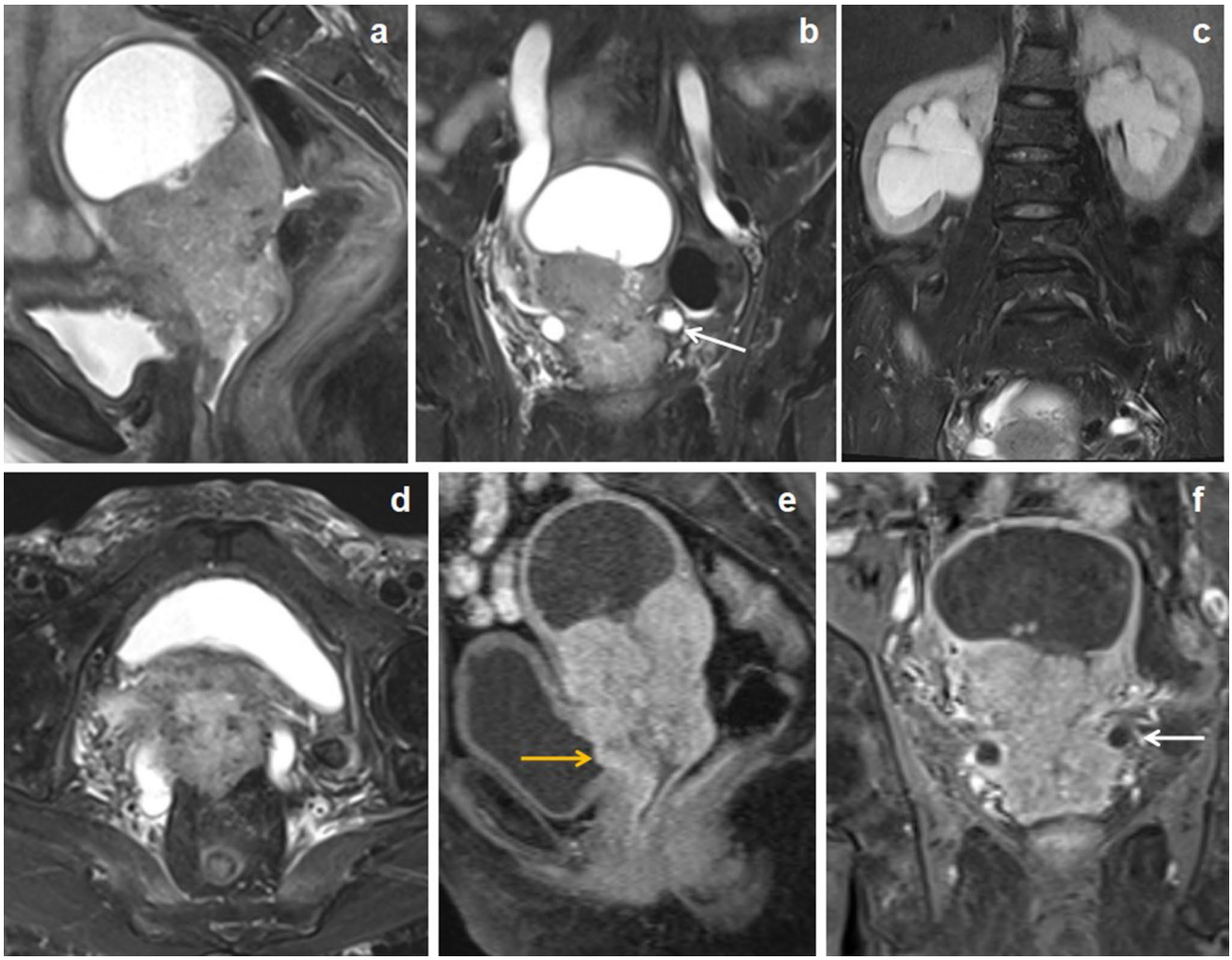
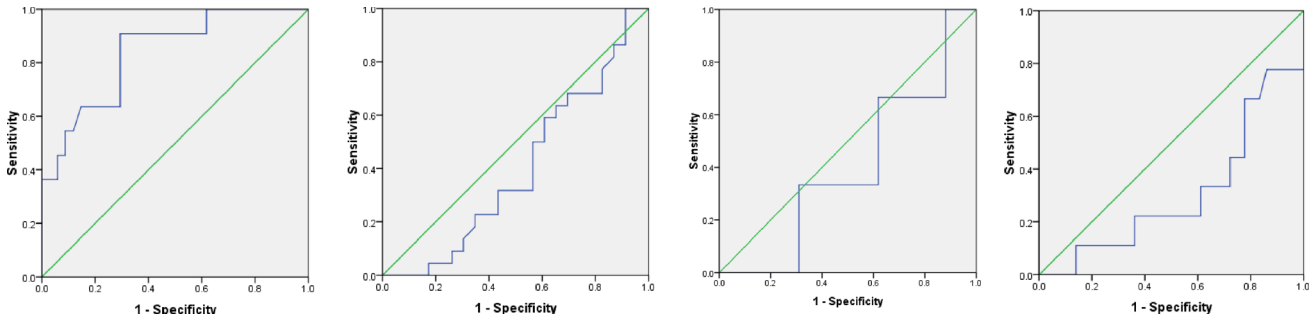


Fig. 4 53 years female presented with bleeding per vagina and decreased urination with stage-IVA carcinoma of cervix. Fat-suppressed sagittal, coronal and axial T2W images (**a**–**d**) showed T2WI iso to hyperintense cervical growth infiltrates into bilateral parametrial tissues, upper 1/3rd of vagina, base of urinary bladder and bilateral distal ureters (←arrow) with subsequent bilateral moderate hydroureteronephrosis. Sagittal and coronal post-contrast MRI images (**e**, **f**) showed irregular moderate heterogenous enhancement of the cervical tumor infiltrating base of urinary bladder (→arrow) and encasing bilateral distal ureters (←arrow)

Table 1 Apparent diffusion coefficient mapping in 45 patients of carcinoma cervix

	Parameters	Mean ADC value of cervical mass ($\times 10^{-3}$ mm2/sec)	*p* value
According to 2018 Revised FIGO staging	Stage-I ($n=11$)	0.915 ± 0.109 [SD]	0.002
	Stage-II ($n=22$)	0.778 ± 0.099 [SD]	
	Stage-III ($n=3$)	0.762 ± 0.123 [SD]	
	Stage-IV ($n=9$)	0.737 ± 0.116 [SD]	
According to Histopathological (HPE) Grading	Well differentiated ($n=24$)	0.839 ± 0.132 [SD]	0.075
	Moderately		
Differentiated ($n=9$)	0.783 ± 0.075 [SD]		
	Poorly		
Differentiated ($n=12$)	0.743 ± 0.113 [SD]		



Stage –I Stage -II Stage –III Stage -IV

Revised 2018 FIGOStage	AUC(Area under curve)	Threshold ADCvalue (x 10^{-3}mm2/sec)	Sensitivity	Specificity
Stage -I	0.838	0.811	90.9%	70.6%
Stage -II	0.399	0.729	68.2%	30.4%
Stage -III	0.397	0.752	66.7%	38.1%
Stage-IV	0.307	0.707	66.7%	22.2%

Fig. 5 Receivers operating characteristic (ROC) curve analysis of mean ADC value of carcinoma of cervix according to revised 2018 FIGO staging

sensitivity of 66.7% and specificity of 22.2% in Stage-IV (Fig. 5]. Nakamura et al. [10] found mean ADC value of cervical cancer was 0.852×10^{-3} mm^2/s which is correlated with our study sample.

In our study sample, the mean ADC value of well-differentiated carcinoma was 0.839 ± 0.132 [SD] $\times 10^{-3}$ mm^2/s, while poorly differentiated carcinoma was 0.743 ± 0.113 [SD] $\times 10^{-3} mm^2/s$ as shown in Table 2. Nakamura et al. [10] found mean ADC value of well-differentiated carcinoma was 1.2×10^{-3} mm2/sec while poorly differentiated carcinoma was 1.1×10^{-3} mm^2/s.

DCE-MRI can detect the permeability, vascular density and perfusion of the tumor microenvironment by detecting the temporal changes of increasing signal intensities after intravenous contrast agent administration [22]. Central tumor recurrence in the vagina and cervix, as well as tumor recurrent in parametrium and pelvis side wall, was accurately detected with MRI, especially with DCE-MRI and diffusion-weighted imaging [22].

If MRI with DCE-MRI done within 2 to 2.5 weeks after post-treatment of cervical cancer, there will be more post-contrast enhancement or increassing DCE-MRI parameters within the tumor represent better tumor regression or tumor response. And after about 2-2.5 weeks these post-contrast enhancement pattern and DCE-MRI parameters will be decreases [22]. However, persistence tumor enhancement at cervical tumor site likely represents residual disease with increased risk of tumor recurrence and poor survival [23]. Hence, MRI acts as a dominant determinant for the outcome and treatment response of cervical cancer along with histological differentiation, histological subtypes and lymphnodal status [24].

Limitations

There are some limitations to our study. As the number of patients in our study is relatively small, a larger series must be conducted to verify our results.

Conclusion

The DWI and DCE-MRI imaging increases the accuracy of conventional MR sequences in the early diagnosis and preoperative staging of carcinoma cervix. DCE-MRI had a high accuracy for assessing the cervical stromal and parametrial invasions, which helps in selecting the optimal therapeutic protocol and prognostication in gynecological malignancies. DWI helps in assessing treatment response with increasing ADC value within the tumor and able to differentiate from residual or recurrent tumor.

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Authors' contribution All authors have contributed significantly and approved the content of the manuscript.

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Table 2 Various DCE-MR imaging parametric findings in 45 patients of carcinoma of cervix

	Parameters	Tumor signal intensity changes (%) in DCE-MRI			Normal myometrial signal intensity changes (%) in DCE-MRI			Relative tumor-to-myometrial enhancement index in DCE-MRI		
		Arterial phase	Equilibrium phase	*p* value	Arterial phase	Equilibrium phase	*p* value	Arterial phase	Equilibrium phase	*p* value (paired t test)
According to 2018 Revised FIGO staging	Stage-I ($n=11$)	59.7 ± 12.8 [SD]	44.8 ± 14.2 [SD]	Arterial phase = 0.341 Equilibrium phase = 0.351	56.5 ± 10.4 [SD]	68.3 ± 15.4 [SD]	Arterial phase = 0.341 equilibrium phase = 0.341	1.04 ± 0.14 [SD]	0.65 ± 0.18 [SD]	Arterial phase = 0.746 Equilibrium phase = 0.0880
	Stage-II ($n=22$)	52.4 ± 19.7 [SD]	53.1 ± 35.3 [SD]		60.4 ± 20.7 [SD]	86.2 ± 43.3 [SD]		0.91 ± 0.32 [SD]	0.63 ± 0.24 [SD]	
	Stage-III ($n=3$)	86.6 ± 30.4 [SD]	62.5 ± 17.3 [SD]		111.3 ± 74.2 [SD]	89.4 ± 12.6 [SD]		0.89 ± 0.26 [SD]	0.69 ± 0.12 [SD]	
	Stage-IV ($n=9$)	58.1 ± 16.2 [SD]	39.1 ± 9.8 [SD]		59.9 ± 14.6 [SD]	70.3 ± 19.0 [SD]		1.00 ± 0.33 [SD]	0.58 ± 0.18 [SD]	
According to Histopathological Grading	Well differentiated ($n=24$)	53.8 ± 15.1 [SD]	47.4 ± 26.1 [SD]	arterial phase = 0.307 Equilibrium phase = 0.536	56.2 ± 12.6 [SD]	76.1 ± 28.7 [SD]	arterial phase = 0.363 equilibrium phase = 0.402	0.98 ± 0.29 [SD]	0.63 ± 0.24 [SD]	Arterial phase = 0.377 Equilibrium phase = 0.281
	Moderately Differentiated ($n=9$)	58.4 ± 23.7 [SD]	58.4 ± 37.3 [SD]		67.1 ± 25.8 [SD]	89.6 ± 52.7 [SD]		0.90 ± 0.24 [SD]	0.66 ± 0.17 [SD]	
	Poorly Differentiated ($n=12$)	72.8 ± 41.2 [SD]	44.9 ± 15.4 [SD]		72.8 ± 41.2 [SD]	75.1 ± 19.1 [SD]		0.97 ± 0.31SD]	0.61 ± 0.17 [SD]	

Table 3 Comparison of enhancement pattern of Stage-I carcinoma cervix on DCE-MRI from the other stages on ROC curve analysis

Parameter	Area under curve(AUC)	Threshold value	Sensitivity	Specificity	*p* value
Post-contrast value of cervix mass					
Arterial phase	0.467	457.5	81.8%	29.4%	0.099
Equilibrium phase	0.350	405.5	72.7%	11.8%	0.251
SI changes in cervical mass					
Arterial phase	0.584	42.25	81.8%	44.1%	0.035
Equilibrium phase	0.460	41.7	72.7%	41.2%	0.419
Relative tumor-to-myometrial enhancement index					
Arterial phase	0.635	0.875	90.9%	41.2%	0.640
Equilibrium phase	0.531	0.57	72.7%	35.3%	0.820

Table 4 Comparison between the MRI findings and pathological findings in terms of revised FIGO staging of cervical cancer

MRI sequence/sequences	Revised FIGO staging 2018 on MRI ($n=45$)			Pathological staging ($n=45$)		
	Stage-I disease ($n=11$)			Stage-I disease ($n=11$)		
	IB1	IB2	IB3	IB1	IB2	IB3
DCE-MRI + T2WI	5	4	1	6	4	1
DWI + T2WI	4	3	1	6	4	1
T2WI	3	5	1	6	4	1
	Stage-II disease ($n=22$)			Stage-II disease ($n=22$)		
	IIA1	IIA2	IIB	IIA1	IIA2	IIB
DCE-MRI + T2WI	1	9	12	1	9	12
DWI + T2WI				1	9	12
T2WI				1	9	12
	Stage-III disease ($n=3$)			Stage-III disease ($n=3$)		
	IIIA	IIIB	IIIC	IIIA	IIIB	IIIC
DCE-MRI + T2WI	1	1	1	1	1	1
DWI + T2WI				1	1	1
T2WI				1	1	1
	Stage-IV disease ($n=9$)			Stage-IV disease ($n=9$)		
	IVA	IVB		IVA	IVB	
DCE-MRI + T2WI	8	1		8	1	
DWI + T2WI				8	1	
T2WI				8	1	

Declarations

Conflict of interest The authors declare that they have no conflict of interest.

Ethical Standards We confirm that this manuscript has not been published elsewhere and it not under consideration by another journal.

Ethical Statement All investigations and procedures in the study were in accordance with the ethical standards of the institution.

Informed Consent Informed consent was obtained from all individual participants included in the study.

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