We report our PET/MRI experience from a pilot study that compared the diagnostic performance of 18F-FDG PET/MRI versus PET/CT in staging of cervical cancer. **Methods:** Six adults with newly diagnosed cervical cancer underwent a single 18F-FDG injection with a dual-imaging protocol: standard-of-care PET/CT followed by research PET/MRI. The diagnostic interpretation and SUVmax, for the 2 modalities were compared. **Results:** Both modalities detected all primary tumors (median size, 0.9 cm) and all 4 metastases present in 2 of the 6 patients (median size, 3.9 cm). PET/MRI provided greater diagnostic confidence than PET/CT and upstaged the disease in 4 patients. On the basis of the imaging findings alone, the additional information from PET/MRI would have led to a change in clinical management in 3 of 6 patients. The primary lesion showed a median SUV of 12.8 on PET/CT and 18.2 on PET/MRI (\(P = 0.03\)). SUVs, however, correlated strongly between the 2 modalities (\(p = 0.96, P < 0.001\)). **Conclusion:** Our pilot study supports the notion that PET/MRI has the potential to impact clinical decisions and treatment strategies in women with cervical cancer. Further studies are, however, warranted to define the value that PET/MRI adds to PET/CT.

**Key Words:** 18F-FDG PET; PET/CT; PET/MRI; cervical cancer; female

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Gynecologic malignancies are common causes of morbidity and mortality in women (1). The International Federation of Gynecology and Obstetrics (FIGO) system is used for staging of most gynecologic malignancies in women (2). It is based on the physical examination and a few other procedures such as colposcopy, conization of the cervix, cystoscopy, and rectosigmoidoscopy. A major limitation of FIGO staging is that it lacks locoregional nodal evaluation. Therefore, advanced imaging modalities (CT, MRI, or PET) are often necessary. In this regard, PET/CT with 18F-FDG is a valuable modality for initial staging and restaging of pelvic gynecologic malignancies (3–7). Contrast-enhanced MRI is an established imaging modality that has numerous clinical applications due to its superb soft-tissue contrast and lack of ionizing radiation and to its ability to assess cellular density by diffusion-weighted imaging and tissue perfusion by dynamic contrast-enhanced imaging (6,8,9). MRI also has the potential to complement the metabolic imaging provided by PET. Therefore, the combination of PET and MRI in an integrated PET/MRI system promises to have a positive impact on disease diagnosis, staging, and restaging. In this article, we report our PET/MRI experience from a pilot study comparing the diagnostic performance of 18F-FDG PET/MRI with standard-of-care (SOC) PET/CT in primary staging of cervical cancer.

**MATERIALS AND METHODS**

**Patient Population**

to be included in this pilot study, the patients had to be at least 18 y old, have biopsy-proven pelvic cervical cancer, and be undergoing a SOC 18F-FDG PET/CT examination for initial staging. Patients were excluded if they were pregnant; had significant claustrophobia; had a history of an allergic reaction to gadolinium-based contrast agents; had contraindications to undergoing MRI including a cardiac pacemaker or metal devices; or had renal insufficiency according to our institutional policy. The study was approved by the Institutional Review Board, and all patients signed an informed-consent form. Six patients were enrolled (median age, 58 y; range, 36–76 y) and underwent a single 18F-FDG injection with a dual-imaging protocol: SOC whole-body PET/CT followed by research pelvic and whole-body PET/MRI. Histopathology at baseline and clinical stage based on FIGO, SOC pelvic MRI, and PET/CT imaging served as the reference standard.

**SOC PET/CT**

SOC PET/CT of the torso (base of skull to upper thigh) was performed on a Discovery 710 PET/CT scanner (GE Healthcare). The glucose level was less than 200 mg/dL before the 18F-FDG injection. In 2 patients, low-dose, unenhanced CT data (120 kVP, 120 mA, 1.375 pitch) were acquired for attenuation correction and anatomic correlation with PET data. In the remaining patients, diagnostic CT images were obtained for both attenuation correction and diagnostic interpretation, on the basis of institutional guidelines (120 kVP; automatically adjusted amperage; 1.375...
The role of PET/MRI in the clinical management of pelvic gynecologic malignancies. In our pilot study, both PET/CT and PET/MRI detected all primary tumors and all 4 metastases suspected in 2 of the 6 patients. However, PET/MRI provided greater diagnostic confidence and accuracy in disease staging and, in 4 of the 6 (67%) patients, was associated with a higher rate for detecting parametrial and peritoneal disease, which was not seen on PET/CT (Table 1). In 1 patient, the upstaging at PET/MRI was minor and would not have resulted in a change in clinical management (patient 3). On the basis of the imaging results only, PET/MRI would have led to a change in clinical management in 3 of the 6 patients (50%). In 2 of these 3 patients, the disease stage was IB on PET/CT (patients 4 and 5) and IIB on PET/MRI. But because they were deemed to have FIGO stage IIB disease, both patients underwent concurrent chemoradiation instead of radical hysterectomy with pelvic nodal dissection. This clinical decision would be consistent with that based on the PET/MRI results. The imaging findings for patient 5 are summarized in Figure 1. In the remaining patient, the disease stage was IIB on PET/CT, which would entail chemotherapy with concurrent pelvic radiotherapy and intracavitary brachytherapy. The disease was upstaged to IVC on PET/MRI because of peritoneal disease (patient 6; Fig. 2). But because the FIGO stage was IIB, the patient underwent chemotherapy with concurrent pelvic radiotherapy and interstitial brachytherapy, which is comparable to the management used for stage IVB disease with peritoneal invasion, as seen on PET/MRI.

The primary lesion had a median SUV\textsubscript{max} of 12.8 (range, 10.9–26.4) on PET/CT and 18.2 (range, 12.9–33.7) on PET/MRI (P = 0.03). Four suspected metastases showed a median SUV\textsubscript{max} of 4.3 (range, 2.8–7.9) and 4.9 (range, 2.8–10.6) on PET/CT and PET/MRI, respectively (P = 0.13). The lesion SUVs (of all primaries and metastases) correlated strongly between the 2 modalities (\( \rho = 0.96; P < 0.001 \)).
<table>
<thead>
<tr>
<th>Patient no.</th>
<th>Age (y)</th>
<th>FIGO stage</th>
<th>PET/CT stage</th>
<th>PET/MRI stage</th>
<th>Imaging comments</th>
<th>Change in clinical management? (PET/CT vs. PET/MRI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>61</td>
<td>IIB (involving vaginal fornix, with suspected parametrial involvement)</td>
<td>IVB (T2A N0 M1)</td>
<td>IVB (T2B N0 M1)</td>
<td>M1, paraaortic LN, on both modalities</td>
<td>No (both IVB); concurrent chemotherapy with cisplatin, EBRT to pelvis, and interstitial brachytherapy</td>
</tr>
<tr>
<td>2</td>
<td>55</td>
<td>IIB (extending into parametrium and upper third of vagina)</td>
<td>IIIB (T2A N1 M0)</td>
<td>IIIB (T2B N1 M0)</td>
<td>MRI detection of parametrical involvement, T2B</td>
<td>No (both IIIB); concurrent chemotherapy with cisplatin, pelvic EBRT, and intracavitary brachytherapy</td>
</tr>
<tr>
<td>3</td>
<td>76</td>
<td>IIB (involving parametrium, without sidewall involvement)</td>
<td>IIA (T2A N0 M0)</td>
<td>IIB (T2B N0 M0)</td>
<td>MRI detection of parametrical involvement, T2B</td>
<td>No (IIA vs. IIB); concurrent chemotherapy with cisplatin, pelvic EBRT, and intracavitary brachytherapy</td>
</tr>
<tr>
<td>4</td>
<td>60</td>
<td>IIB (involving upper third of vagina and parametrium)</td>
<td>IB (T1B N0 M0)</td>
<td>IIB (T2B N0 M0)</td>
<td>MRI detection of parametrical involvement, T2B</td>
<td>Yes; radical hysterectomy with pelvic nodal dissection (IB) vs. concurrent chemotherapy with cisplatin, pelvic EBRT, and intracavitary brachytherapy (IIB)</td>
</tr>
<tr>
<td>5</td>
<td>49</td>
<td>IIB (extending into right fornix and right parametrium)</td>
<td>IB (T1B N0 M0)</td>
<td>IIB (T2B N0 M0)</td>
<td>MRI detection of parametrical involvement, T2B</td>
<td>Yes; radical hysterectomy with pelvic nodal dissection (IB) vs. concurrent chemotherapy with cisplatin, pelvic EBRT, and intracavitary brachytherapy (IIB)</td>
</tr>
<tr>
<td>6</td>
<td>36</td>
<td>IIB (involving parametrium with extension to pelvic sidewall)</td>
<td>IIB (T2B N0* M0)</td>
<td>IVB (T2B N0 M1)</td>
<td>MRI detection of peritoneal involvement, M1</td>
<td>Yes; concurrent chemotherapy with cisplatin, pelvic EBRT, and intracavitary brachytherapy (IIB) vs. interstitial brachytherapy (IVB)</td>
</tr>
</tbody>
</table>

* N0 (focal ureter activity falsely denoted as N1 on PET/CT).

EBRT = external-beam radiotherapy.
corroborative imaging findings such as those from pelvic MRI or \( {^{18}}\text{F-FDG PET/CT.} \) In our cohort, T staging on FIGO showed more advanced tumor infiltration than PET/CT did, but FIGO was compatible with PET/MRI in most cases. As a result, the actual clinical management of the patients did not differ from the management that would have been based on the PET/MRI results.

For cervical cancer staging, current National Comprehensive Cancer Network guidelines recommend imaging (CT, PET/CT, and MRI) for stage IB1 or higher (12). Even though image fusion software is available for clinical use, the coregistration of separately acquired MRI data and PET data is often suboptimal, particularly in the body (13). Differences in matrix size, imaging plane, and body positioning, as well as other factors related to respiratory motion and physiologic motion of nonrigid structures, can limit an accurate coregistration of the 2 modalities. On the other hand, hybrid PET/MRI provides a precise spatial correlation of data, allowing for an optimal imaging interpretation. More importantly, simultaneous hybrid imaging enables multiparametric PET and MRI measurements, with the potential to provide valuable insight into tumor phenotype and prognostication (14,15). PET/MRI is associated with greater diagnostic confidence and accuracy than PET/CT because MRI provides higher soft-tissue contrast than CT. In 4 of our 6 (67%) patients, PET/MRI detected parametrical and peritoneal disease that was missed on PET/CT. Our pilot study affirms the strength of PET/MRI, compared with PET/CT, in diagnostic confidence and accuracy for pelvic staging, as is consistent with previous studies with similar patient populations (11,16–18). Because of the upstaging with PET/MRI, 2 patients would have undergone definitive chemoradiation instead of radical hysterectomy with bilateral pelvic lymph node dissection (12,16,17).

Grueneisen et al. found that PET/MRI with gadolinium contrast provided correct T staging in 23 of 27 patients (85%) with cervical cancer (19). Sensitivity, specificity, and diagnostic accuracy for nodal disease were 91%, 94%, and 93%,
respectively. The results of subsequent studies supported the high diagnostic potential of PET/MRI in cervical cancer staging (16–18,20). A recent metaanalysis consisting of 7 studies, with a total of 215 patients for staging and restaging, showed that PET/MRI data provide high diagnostic accuracy in gynecologic malignancies of the pelvis (21). On a per-patient basis, the pooled sensitivity and specificity of 18F-FDG PET/MRI were 0.95 (95% confidence interval, 0.86 ± 0.09) and 0.95 (95% confidence interval, 0.74 ± 1.00), respectively. On a lesion basis, the pooled sensitivity and specificity were 0.89 (95% confidence interval, 0.84 ± 0.93) and 0.87 (95% confidence interval, 0.74 ± 0.95), respectively. The overall area under the curve was 0.968 (SE, 0.026).

We acknowledge the limited sample size in our pilot study and the lack of histopathologic confirmation for nodal disease, which limits the generalizability of the results. The SOC PET/CT was undertaken before the research PET/MRI after a single 18F-FDG administration. The time delay between the 2 examinations led to confounding bias concerning the SUV measurements, resulting in higher lesion SUVs as well as higher lesion-to-background SUV ratios on PET/MRI than on PET/CT (11,18,22). Nonetheless, the correlation of SUVs remained strong between the 2 modalities. We did not match the PET reconstruction parameters between the 2 modalities (e.g., number of iterations and time-of-flight technique), because our intention was to compare lesion detectability based on the standard image parameters of each scanner. We did not measure the apparent-diffusion-coefficient values to demonstrate the magnitude of diffusion restriction in our pilot study, as the applied b-values were inconsistent among patients during our effort to optimize diffusion-weighted imaging. Currently, diffusion-weighted imaging is the most important functional MRI application as part of PET/MRI, providing valuable information on tissue cellularity and membrane integrity (14,15,19,23–27).

CONCLUSION

Our pilot study supports the notion that PET/MRI provides greater diagnostic confidence and accuracy than PET/CT in the initial staging of cervical cancer. Most importantly, PET/MRI complements FIGO staging and has the potential to impact clinical decisions and treatment strategies. Further studies are warranted to define the added value of PET/MRI to PET/CT.

DISCLOSURE

No potential conflict of interest relevant to this article was reported.

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REFERENCES


