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NUCLEAR MEDICINE

PET/MRI and PET/CT in advanced gynaecological tumours: initial experience and comparison

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Abstract
Purpose To compare the diagnostic accuracy of PET/MRI and PET/CT for staging and re-staging advanced gynaecological cancer patients as well as identify the potential benefits of each method in such a population.
Material and methods Twenty-six patients with suspicious or proven advanced gynaecological cancer (12 ovarian, seven cervical, one vulvar and four endometrial tumours, one uterine metastasis, and one primary peritoneal cancer) underwent whole-body imaging with a sequential trimodality PET/CT/MR system. Images were analysed regarding primary tumour detection and delineation, loco-regional lymph node staging, and abdominal/extra-abdominal distant metastasis detection (last only by PET/CT).
Results Eighteen (69.2 %) patients underwent PET/MRI for primary staging and eight patients (30.8 %) for re-staging their gynaecological malignancies. For primary tumour delineation, PET/MRI accuracy was statistically superior to PET/CT ($p<0.001$). Among the different types of cancer, PET/MRI presented better tumour delineation mainly for cervical (6/7) and endometrial (2/3) cancers. PET/MRI for local evaluation as well as PET/CT for extra-abdominal metastases had therapeutic consequences in three and one patients, respectively. PET/CT detected 12 extra-abdominal distant metastases in 26 patients.
Conclusion PET/MRI is superior to PET/CT for primary tumour delineation. No differences were found in detection of regional lymph node involvement and abdominal metastases detection.
Key Points
- *PET/MRI is superior to PET/CT for primary tumour delineation*
- *PET/CT represents a reliable tool to detect extra-abdominal distant metastasis*
- *PET/MRI might be the preferred imaging modality for staging cervical and endometrial tumours*
- *Whole-body staging for detection and evaluation of extra-abdominal metastases is mandatory*

Keywords PET/CT · PET/MRI · Advanced gynaecological tumours · Staging · Re-staging

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Introduction

The diagnostic assessment of advanced pelvic gynaecological tumours, i.e. uterine malignancies and ovarian carcinoma, may require a multi-modality approach, including anatomical and molecular imaging methods [1–4]. A concise diagnosis

has impact on therapeutic decision and, therefore, on the patient's prognosis [5, 6].

MRI alone with different protocols and techniques has been already proposed for diagnostic work-up and loco-regional staging of pathologies of the female genital organs, e.g. adnexal tumours or staging and re-staging of endometrial and cervical cancers [7–10].

Additionally, many studies have established the role of ^{18}F-fluorodeoxy-D-glucose (FDG) positron emission tomography (PET)/computed tomography (CT) for different gynaecological cancers, either for staging and monitoring treatment response [11–13]. MRI, due to its higher soft tissue contrast, was proven superior for characterization of adnexal masses and loco-regional tumour staging, e.g. the identification of parametrial invasion in cervical cancer or the depth of myometrial invasion of endometrial carcinoma [7–10]. However, there is still a controversial discussion concerning advantages of MRI compared to CT and PET/CT for detection of suspicious lymph nodes [2, 14]. Furthermore, whole-body staging is important, especially in advanced gynaecological cancer, in which incidence of extrapelvic disease at time of diagnosis is high [15]. PET/MRI currently emerges as a hybrid imaging modality that combines the functional ability of PET with the morphological high soft-tissue contrast provided by MRI. It is expected to be a promising tool for different oncological indications, such as head and neck cancers [16], liver metastases [17], and soft-tissue sarcomas [18] as well as for gynaecological cancers [2].

Thus, PET/MRI might provide complete information regarding TNM staging of gynaecological malignancies as a single, one-stop shop modality, which is not partly not possible using PET/CT (e.g. not enough for precise T-staging [19]) or MRI-only (whole-body protocol staging not yet established and ability to detect recurrence is inferior to PET/MRI [20, 21]).

The aims of our study were to: 1) compare the diagnostic accuracy of PET/CT and PET/MRI concerning staging and re-staging in advanced gynaecological cancer patients; 2) identify the potential benefits of each method for staging and re-staging in such a patient population.

Materials and methods

Patient population

From September 2011 to February 2013, a total of 26 consecutive women (mean age 60 years, range 37 – 81 years) with suspected and/or proven advanced gynaecological malignancies (for endometrial cancers, FIGO stages IB or higher; for cervical cancer, FIGO stages IIB to IVB; for ovarian cancers, FIGO stages III and IV) were enrolled in this prospective study. Patients were all referred for a clinical PET/CT examination for primary staging or re-staging (imaging performed after treatment) and additionally underwent an MRI of the abdomen and pelvis within a trimodality setup as part of the study protocol. No further selection was applied for patient inclusion. Exclusion criteria were unwillingness to participate in the study, claustrophobia, MRI-incompatible medical devices (e.g. cardiac pacemakers, neurostimulators, cochlear implants, and insulin pumps), possible metallic fragments in the body, or renal insufficiency (i.e., glomerular filtration rate< 60 ml/min). The institutional review board approved this prospective study and signed informed consent was obtained from all patients prior to the examination.

PET/CT and MR imaging

Sequential PET/CT, ceCT, and ceMRI were performed on a trimodality PET/CT-MRI setup (full ring, time-of-flight Discovery PET/CT 690, 3 T Discovery MR 750w, both GE Healthcare, Waukesha, WI, USA). The dedicated MR- and CT-compatible shuttle transfer mechanism connecting the MR and PET/CT systems allowed for PET/CT imaging free of radiofrequency (RF) coil-induced artefacts and ascertained the placement of dedicated RF coils for MRI without repositioning of the patient [17, 22].

The workflow of the PET/CT-MRI from the arrival of the patient until the end of the examination comprises: (1) Interview and consent; (2) FDG-injection (1 min); (3) Uptake time resting (25 min); (4) Uptake time performing MR (30-35 min); (5) Shuttle from MR to PET/CT (2 min); (6) PET/CT (15 min).

Patients fasted for at least 4 h prior to injection of a standard dose of an average of 4.5 MBq per kg body weight, according to European Association of Nuclear Medicine recommendations [23]. After the initial uptake time, the patients step to the MRI and were then positioned on the shuttle table in the MR suite, and the MR acquisition covering the whole abdomen, and specifically the pelvis, was performed. The images were acquired by the use of a dedicated RF phase array GEM anterior arrays coil (40-Channel HD, GE Healthcare, Waukesha, WI, USA). Total MRI duration was approximately 30-35 min (scanning parameters are shown in Table 1). The intravenously (IV) injected amount of contrast media (Gadoterate, Dotarem®, Guerbet, France) was 0.2 ml/kg body weight with an injection at a rate of 1.5 ml/s.

After completion of the MRI, coils were removed and the patients were transferred to the PET/CT, still being positioned on the shuttle board. After shuttle transfer to the adjacent PET/CT system, unenhanced low-dose CT and PET emission data were acquired from the mid-thigh to the vertex of the skull. Directly after the acquisition of the PET data, 70 ml IV contrast agent (Visipaque® 320, GE Healthcare, Switzerland) were injected at a rate of 3 ml/s.

Table 1 MR acquisition parameters

Parameter	T2w SSFSE	T1w LAVA	DWI EPI	Axial T2w Propeller	Sag T2w Propeller	ceT1w LAVA flex
Repetition time/Echo time (ms\)	Min/80	3.8/Min Full	x/Min (70.10	9876/89	7898/96	3.8/Min Full
Echo train length	NA	NA	NA	26	28	NA
Flip angle (°)	NA	15	NA	142	142	15
Inversion time (ms)	NA	NA	Auto	NA	NA	NA
Slice thickness /Spacing(mm)	5 (1)	5.4	6 (1)	4 (1.5)	5 (1)	5.4
Receiver bandwidth (kHz)	125	142.86	NA	62.5	83.3	142.86
Field of view (cm)	40	40	44	30	24	40
Matrix	352×224	256×224	100×180	288×288	320×320	256×224
NEX	NA	1	NA	3	2.5	1
b-value (s/mm)	NA	NA	800	NA	NA	NA
Number of directions	NA	NA	3	NA	NA	NA
Anatomical coverage	Upper abdomen	Pelvis	Pelvis	Pelvis	Pelvis	Pelvis

Note: T1w LAVA, T1-weighted spoiled gradient echo pulse sequence; T2w SSFSE, Single-shot T2-weighted fast spin echo sequence; ceT1w LAVA flex, 2-point Dixon based 3D contrast enhanced T1-weighted gradient echo sequence; DWI, Diffusion weighted imaging sequence; NEX, number of excitations; NA, not applicable

Image processing

The acquired PET, ceCT, and ceMRI images were transmitted to a dedicated review workstation (Advantage Workstation, Version 4.5, GE Healthcare, Milwaukee, WI, USA), which enables review of the PET, ceCT, and ceMRI images side by side or in fused/overlay mode (cePET/CT; cePET/MRI). Because of the calibrated trimodality system, non-rigid software-based image registration was not necessary. A previously conducted study validated the image registration accuracy with less than 4 mm lateral misalignment between CT, PET, and MRI datasets, similar to the intrinsic error assessed with phantom measurements [24].

Image analysis

The analyses were performed in different steps. A board-certified radiologist/nuclear medicine physician and a radiologist with substantial PET/CT experience, both with expertise in gynaecological imaging (P.V.H. overall 11 years experience, M.Q. overall 6 years experience), performed the evaluation of fused PET/CT and PET/MRI in consensus. Fused PET/CT and PET/MRI were evaluated again 6 weeks later by two senior radiologists with expert experience in gynaecological imaging and PET/CT (R.K.H. > 20 years experience and B.F.C. > 10 years experience). When substantial differences in detection were noticed, a consensus was reached between all readers.

Reading was executed in different steps. First, the *detection* step was assessed concerning the presence of the following findings: (a) primary tumour; (b) loco-regional lymph nodes; (c) abdominal metastases; (d) distant extra-abdominal metastases; (e) recurrence. Detection of extra-abdominal metastasis was only assessed by PET/CT. PET/MRI was performed exclusively for abdomen and pelvis. No comparison between these two methods (PET/CT vs. PET/MRI) has been done regarding this issue (extra-abdominal metastasis). Then, the *delineation* step was evaluated regarding the relation of the tumour with the following surrounding structures: (a) parametria; (b) vagina; (c) myometrium; (d) bladder; (e) rectum; (f) abdominal wall; and (g) vessels. The evaluation of the surrounding structures was based on the type of primary cancer. On a per-patient base, a comparison between PET/CT and PET/MRI on both steps (detection and delineation) was then assessed, scored by (1) PET/CT>PET/MRI, (2) PET/CT= PET/MRI, and (3) PET/CT<PET/MRI. This assessment was performed considering only loco-regional situation (T- and N-staging) and presence of abdominal metastasis. The influence in treatment was also assessed according to the extra-abdominal distant metastases detected by PET/CT. Lastly, the patients scored by (3) PET/CT<PET/MRI were investigated whether the information provided by PET/MRI had impact on therapeutic decision.

An additional comparison between PET/CT and PET/MRI was performed for the patients according to their histological subtype of primary gynaecological cancer (cervical vs. endometrial vs. ovarian vs. others) and according to their treatment status (staging vs. restaging).

Detection of suspicious malignant lesions was based on a combination of morphological and functional criteria. The morphological assessment was defined for (1) primary/recurrent tumour: a mass-forming lesion with consecutive contrast enhancement and/or necrotic areas; (2) lymph nodes with at least one of the following criteria: larger than 1.0 cm in the short axis, necrotic centre, round-shaped, cluster

formation, irregular boundary of the capsule and extracapsular spread, high signal on DWI, and low signal on ADC map; (3) abdominal metastasis: lesions with high signal on T2-weighted (but less than liquid signal) and contrast enhancement; thickening and/or stranding of peritoneum fat with/without contrast enhancement; irregular nodules or thickening with contrast enhancement in the spleen, pancreas, adrenal or intestine; (4) distant extra-abdominal metastasis. The functional criterion was based on PET-positivity [maximum standardized uptake value (SUVmax) significantly higher than the background liver activity]. If discordant findings were found, the combination of the most relevant findings (morphological and/or functional) was taken into account (e.g. an enlarged and irregular lymph node was considered malignant even if there was no FDG uptake).

The standard of reference comprised histopathology of the detected lesions after surgery or biopsy and clinical follow-up including all clinical examinations, laboratory reports, and follow-up imaging. There is histological confirmation for 24/26 primary/recurrent tumours, 11/26 loco-regional lymph nodes, 12/26 abdominal metastases, and 5/26 distant extra-abdominal metastases. Thus, at least one lesion was histologically confirmed in all patients. The remaining lesions were assessed by FDG-uptake, morphological appearance, and contrast media uptake.

Statistical analysis

All statistical tests were performed using SPSS Statistics Version 21 (IBM, Armonk, NY, USA). p-values<0.05 were considered statistically significant. McNemar test was used to evaluate differences in the accuracy of PET/CT and PET/MRI. Wilcoxon signed rank test was applied to analyse the difference between PET/CT and PET/MRI for primary tumour delineation. Kolmogorov-Smirnov test was used to evaluate the differences in tumour delineation using the categories described in the methods section (PET/CT>PET/MRI, PET/CT=PET/MRI, and PET/CT<PET/MRI) among the diverse types of cancers and among staging and re-staging patients.

Results

Eighteen (69.2 %) patients underwent PET/CT-MRI for primary staging and eight (30.8 %) for re-staging of advanced gynaecological malignancies. The most prevalent primary tumour origin was ovary (46.2 %) and followed by cervix (26.9 %). Mean follow-up time was 361 days (range 106 – 778 days). The patient with the shortest follow-up died after that period. Overall, three patients died during follow-up. Patients' tumours and characteristics are summarized in Table 2.

Table 2 Patient and Tumour Characteristics

Number of patients	26
Age in years, mean (range)	60 (37-81)
Uptake time (min)	73±14
FDG injected dose (MBq)	304±39
Indication, number (%)	
Staging	18 (69.2)
Re-staging	8 (30.8)
Primary site, number (%)	
Ovary (including tube)	12 (46.2)
Cervix	7 (26.9)
Endometrium	4 (15.4)
Uterine Metastasis	1 (3.8)
Peritoneal Cancer	1 (3.8)
Vulva	1 (3.8)
Treatment, number (%)	
- Surgery	**16 (57.7)**
Surgery only (or curettage)	8 (30.8)
With additional chemotherapy	7 (26.9)
- No surgery	**8 (30.8)**
RChT*	3 (11.5)
ChT*	4 (15.4)
RT*	1 (3.8)
- No treatment	**1 (3.8)**
- Dead before treatment	**1 (3.8)**

*RChT, radiochemotherapy; ChT, chemotherapy; RT, radiotherapy

Bold data signifies the differences in number between surger, non-surgical patients and the two other patients

Regarding *detection* of malignancies related to gynaecological cancers, there was no statistical significant difference between PET/CT and PET/MRI. Overall patient-based diagnostic accuracy for PET/CT and PET/MRI in the evaluation of primary tumour, loco-regional lymph nodes, and abdominal metastasis detection in gynaecological tumours are shown in Table 3.

Table 3 Sensitivity, specificity, positive predictive value (PPV), negative predictive value (NPV), and accuracy of PET/CT and PET/MRI

	Primary tumour detection		Regional lymph node metastasis		Abdominal metastasis	
	PET/CT	PET/MRI	PET/CT	PET/MRI	PET/CT	PET/MRI
Sensitivity	100.0 %	100.0 %	72.7 %	72.7 %	100 %	100 %
Specificity	66.7 %	66.7 %	100.0 %	91.7 %	100 %	100 %
PPV	95.8 %	95.8 %	100.0 %	88.9 %	100 %	100 %
NPV	100.0 %	100.0 %	80.0 %	78.6 %	100 %	100 %
Accuracy	96.2 %	96.2 %	87.0 %	82.6 %	100 %	100 %
p-value	P>0.05		p>0.05		p>0.05	

Table 4 Detection of regional lymph node, abdominal, and distant extra-abdominal metastases by PET/CT and PET/MRI

Detection	Positive on standard of reference	PET/CT	PET/MRI	Changes in treatment
Primary/Recurrent tumour	24	24	24	0
Regional lymph nodes metastases	11	11	11	0
Abdominal metastases (peritoneal, liver, colon, and adrenal)	14	14	14	0
Distant extra-abdominal metastases (lung, mediastinum, bone, supraclavicular, and axilar LNs)	5	5	N/A	1 (due to PET/CT)

PET/CT and PET/MRI both accurately detected 24 primary/recurrent tumours, 11 loco-regional metastatic lymph nodes, and 14 abdominal metastases (Table 4). Whole-body PET/CT detected accurately five patients (5/26) with distant metastasis confirmed by histology, determining change in therapy one patient (1/26). The PET/MRI detected no distant extra-abdominal metastases (*see also* Materials and methods).

Concerning *delineation* of the primary/recurrent tumour, there was invasion of surrounding structures detected in 12 patients (12/26). The parametria (4) and vagina (3) were the most prevalent structures compromised by the tumours (Figs. 1, 2, 3).

PET/MRI was superior compared to PET/CT in 14 cases (58.3 %) and equal in 10 cases (41.7 %) with statistical significant difference ($p<0.001$). These findings defined changes in therapy in three patients (thus, overall change in management in four patients when combining both procedure). Among the different types of detected gynaecological cancer (24/26), PET/MRI was better than PET/CT for tumour delineation mainly for cervical (6/7) and endometrial tumours (2/3), defining changes in therapy in three out of seven patients with cervical cancer. For ovarian cancers, PET/MRI was equal to PET/CT in six and better in five out of 11 patients, without determining any changes in treatment. (*See* Table 5.)

Concerning staging and re-staging patients with detected gynaecological malignancies (24/26), PET/MRI was better than PET/CT for *tumour delineation* in 12 out of 17 staging patients, defining changes in therapy in three of them, mainly regarding alteration on treatment modality or intention (e.g. from curative to palliative or surgery instead chemotherapy due to cervical cancer upstage found in PET/MR, but not in PET/CT). For re-staging patients, PET/MRI was better than PET/CT only in two patients and did not determine any changes in therapy. (*See* Table 6.)

The cases that PET/MRI was superior to PET/CT regarding tumour delineation are listed in Table 7.

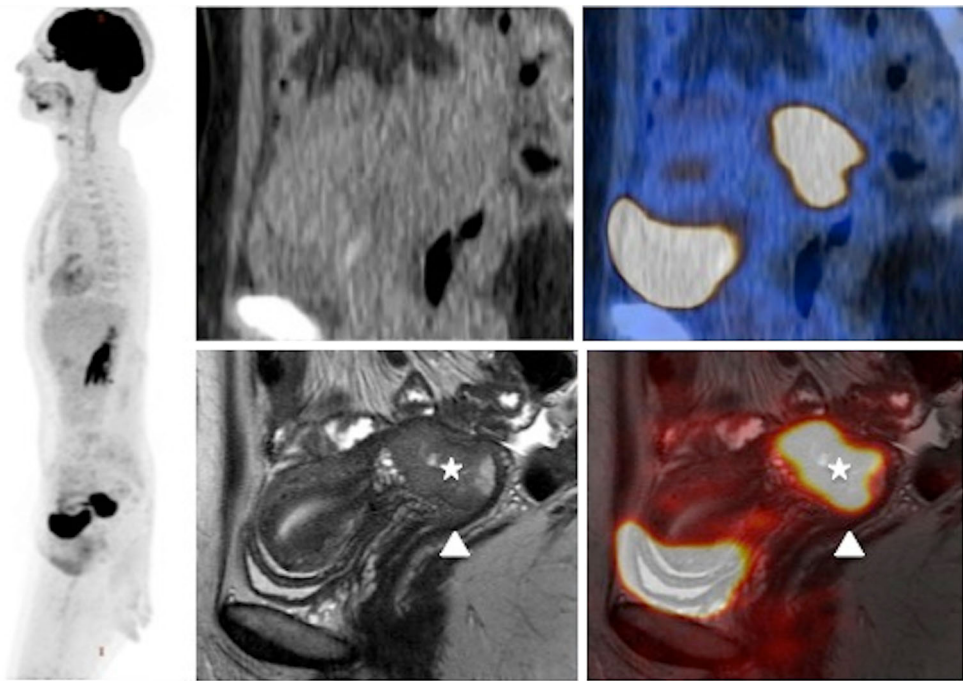

Fig. 1 38 year old woman with cervical squamous cell carcinoma. *Left column*: Sagital MIP. *Upper row*: non-contrast enhanced CT and PET/CT in sagittal planes. *Lower row*: T2w propeller and PET/MRI in sagittal planes. Note the superior delineation of the tumour (*star*) and its relation with surrounding structures in MRI and PET/MRI. It is possible to identify the infiltration of the upper third of the vagina (*arrowhead*), which was later confirmed by histology. PET/MRI upstaged the tumour

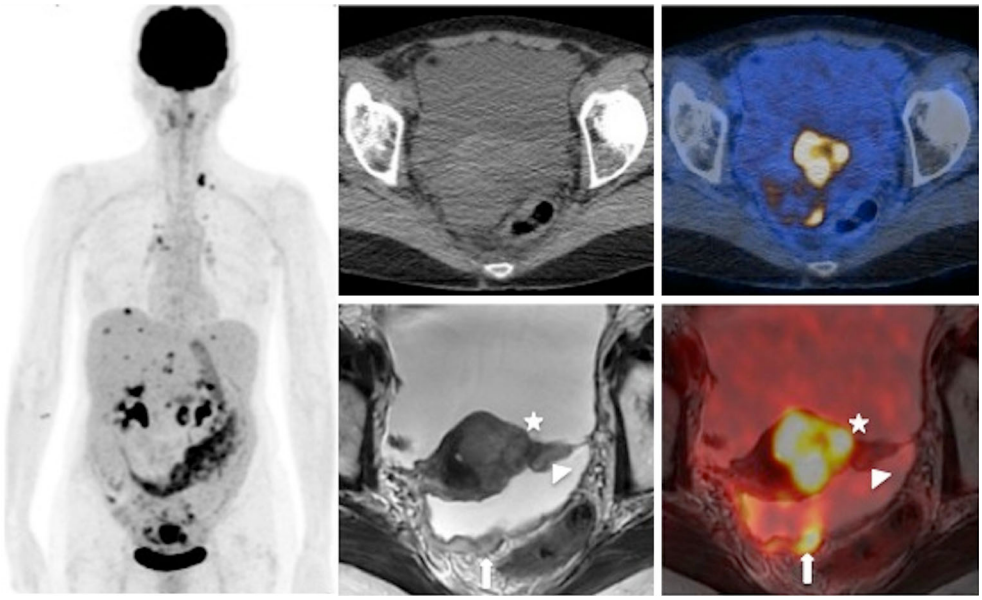

Fig. 2 60 year old woman with poorly differentiated endometrial carcinoma. *Left column*: Coronal MIP. *Upper row*: CT and PET/CT in axial plane. *Lower row*: T2w propeller and PET/MRI in axial planes. Note the superior delineation of the tumour and its relation with surrounding structures in axial T2w. On MRI an PET/MRI, it is possible to see the infiltration of the left tube (*asterisk*) and ipsilateral broad ligament (*arrowhead*). Note also peritoneal carcinomatosis (*solid arrow*) better delineated on MRI and PET/MRI. Coronal MIP shows diffuse peritoneal carcinomatosis, mediastinal and left cervical distant lymph nodes metastasis

Discussion

The potential clinical benefits of PET/MRI over PET/CT have been extensively investigated. Our study compared the ability of PET/CT and PET/MRI, within a trimodality setting, in detection and delineation of advanced gynaecological cancers. It has been shown that PET/MRI is more efficient for evaluating the local pelvic situation, mainly for staging of cervical and endometrial cancers, while PET/CT is a reliable tool for the detection of extra-abdominal distant metastases of advanced gynaecological malignancies.

Detection of gynaecological malignancies

Primary/recurrent tumour

PET/CT has been shown to be useful for the detection and staging gynaecological cancers. Nam et al have shown that PET/CT

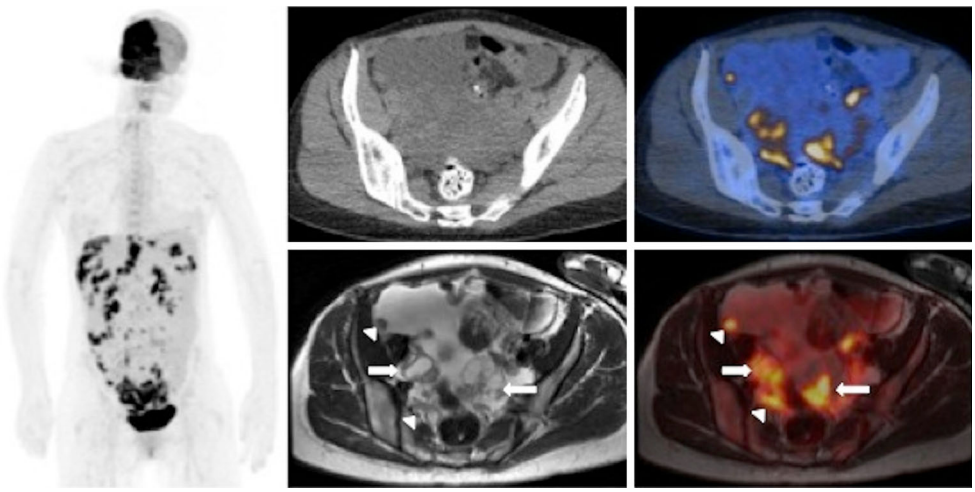

Fig. 3 46 year old woman with serous papillary adenocarcinoma of the ovaries. *Left column*: Coronal MIP. *Upper row*: CT and PET/CT in axial planes. *Lower row*: T2w propeller and PET/MRI in axial planes. On PET/MRI, note the superior delineation of the tumour in both ovaries (*solid arrows*) and the improved anatomical correlation of the peritoneal carcinomatosis (*arrowheads*)

Table 5 Differences in tumour delineation among different types of gynaecological cancers

Tumour types	Number of patients positive on standard of reference	PET/CT> PET/MRI	PET/CT= PET/MRI	PET/MRI> PET/CT	Changes in treatment due to PET/MRI
All tumours	*24*	*0*	*12*	*14*	*3*
Ovarian Cancer	11	0	7	5	0
Cervical Cancer	7	0	1	6	3
Endometrium Cancer	3	0	1	2	0
Others	3	0	2	1	0

is superior to pelvic ultrasound, abdomino-pelvic CT and pelvic MRI for diagnosis of malignant ovarian tumours [25].

Rockall et al has demonstrated that PET/CT has current application for staging cervical cancers with FIGO stage IIB or above in order to facilitate optimal radiotherapy planning and for prognostication [19]. For endometrial cancers, PET/CT has been shown to be the most reliable modality to predict myometrial invasion, cervical involvement, and lymph nodes metastases when compared to MRI and ultrasound [3].

In recent years, PET/CT has been shown to be useful for evaluating the overall tumour extent in a variety of recurrent gynaecological cancers [26–28]. Furthermore, PET/CT was able to change the primary diagnosis based MRI or CT in up to 22 %, leading to significant alteration of treatment planning [5]. Thus, when combining PET and MRI this potentially should yield some additional advantages compared to those aforementioned imaging modalities. Thus, comparing with our results (admittedly with a smaller patient population), we found that PET/MRI was superior to PET/CT especially for *tumour delineation,* mainly for cervical and endometrial tumours, with a somewhat significant influence on therapeutic decisions. Furthermore, PET/MRI proved to be partly superior compared to PET/CT in staging of patients rather then re-staging. This might be not surprising since the local pelvic situation with its soft tissue organs can be better evaluated by the MRI-component.

Additionally, in our study, PET/MRI was significantly superior compared to PET/CT concerning the delineation of gynaecological primary tumours. This resulted in a change in therapy decision in almost 19 % of our patient population with primary tumours. This advantage is mainly based on the MRI-information component and is thus in-line with previous publications on MRI discussed above. Also, Vargas and coworkers found that retrospective fusion of PET and MRI acquired on different systems (PET-MRI) provided a higher diagnostic confidence and higher interreader agreement compared to MRI or PET/CT alone when evaluating the infiltration of tumour surroundings in recurrent tumours [29].

Other studies have shown that PET/MRI provides advantages in terms of sensitivity and especially specificity compared with MR imaging or PET/CT alone in ovarian cancers [29]. However, in our population, such findings could not be confirmed since the detection rates for pelvic and abdominal lesions are not significantly different. The main reason for those differences is probably that we used a trimodality system where PET/CT and MRI are done in a direct sequential setup, and thus fusion and overlay are more accurate than image acquisition on separate and not connected systems.

Regional lymph nodes

The presence of lymph node metastases represents generally a poor prognostic factor and is partly influential on therapy planning, especially in cervical and endometrial cancers [14, 15, 30].

In most cases of our study, both PET/CT and PET/MRI were concordant concerning detection of regional lymph node involvement. There was one case where PET/CT finding was true

Table 6 Differences in tumour delineation between staging and restaging patients

Staging/ Re-staging	Number of patients	PET/CT> PET/MRI	PET/CT= PET/MRI	PET/MRI> PET/CT	Changes in treatment due to PET/MRI
All tumours	*24*	*0*	*12*	*14*	*3*
Staging	17	0	6	12	3
Re-staging	7	0	6	2	0

Table 7 Superiority of PET/MRI over PET/CT in tumour delineation

PET/MRI>PET/CT	n=14 patients
Parametrial/upper third of vagina invasion	6
Relation to surrounding structures (vessels, bladder, rectum, abdominal wall)	4
Myometrial invasion	3
Tumour characterisation	1

negative and PET/MRI finding was false positive showing a suspicious lymph node based on its morphology and restricted diffusion. These results are partially in accordance with the current literature. Chung and co-workers have shown that MRI is more sensitive, but less specific than PET/CT in detecting lymph node involvement of uterine cervical cancer [14]. However, Kim and co-workers have presented data that fused PET/MRI favoured the detection of lymph nodes more than PET/CT in a population of 79 patients with cervical cancer [31].

Abdominal and extra-abdominal metastases

Both PET/CT and PET/MRI detected the same number of abdominal metastases, mainly based (like in lymph node metastases) on the identical PET dataset used. However, this finding might not be true for all abdominal organs and in all settings. Recent papers have shown the superiority of PET/MRI and even of MRI alone over PET/CT for detection of liver metastases. For instance, Seo and co-workers have shown that gadoxetate disodium-enhanced MRI is more accurate than PET/CT to detect liver metastases, particularly for the detection of small (<1.0 cm) lesions [32]. Beiderwellen and co-workers have proved that PET/MRI provides higher lesion conspicuity and diagnostic confidence compared to PET/CT for characterization of liver lesions [33]. However, it must be emphasized that to achieve those results, several sequences focusing on the liver, partly in combination with liver-specific contrast media, are warranted. Since the focus of our study was on gynaecological cancers, only one non-breathing triggered T2-w and T1-w sequence without customized contrast media was used to cover the upper abdomen. Not least, it can be assumed the additional metabolical information from the PET might partly compensate for the lack of proper liver-focused MRI in our study.

Hematogenous dissemination of advanced gynaecological cancers is not uncommon at the time of primary diagnosis. For advanced epithelial ovarian cancers, the incidence of supradiaphragmatic adenopathy ranged from 43 % to 67 % [34, 35]. For this reason, it is generally necessary to have a whole-body staging in advanced cancers. Indeed, in our study, PET/CT yielded distant metastases overall in five patients. Those findings, however, translated into a change in therapy in only one patient since the other patients presented previously known extended abdominal disease. Since we used a trimodality setup to evaluate our patients, PET/MRI was not performed as a whole-body imaging set. Whole-body imaging in the context of PET/MRI, even though desirable, still needs further research as it might impose problems on clinical workflow, spatial resolution and imaging time.

Limitations

The relatively low number of patients with different gynaecologic primary tumours is certainly a limitation. This may be explained by our rather strict inclusion criteria, since we have selected only patients with proved or suspicious advanced gynaecological cancers. Nevertheless, the histological confirmation of at least one lesion per patient strengthens our results. Another limitation already mentioned above is that PET/MRI could not be performed as a whole-body procedure. Because of unequal coverage comparison of both procedures is limited. The MRI-portion of the protocols does not cover the whole abdomen with all sequences. However, there is an increasing body of literature that optimized PET/MR protocols are needed to avoid redundant information.

However, as discussed above, the trimodality setup has its own advantages compared to whole-body (or even simultaneous) PET/MRI.

Conclusion

Trimodality staging work-up of patients with advanced gynaecological cancers has been proven to be effective to evaluate both the local tumour staging as well as detection of distant metastases. While PET/MRI was found to be superior compared to PET/CT for primary tumour delineation, no differences were found in accuracy of regional lymph node involvement and abdominal metastases detection. However, PET/CT is reliable in detection of extra-abdominal distant metastases and is therefore still needed in cases in advanced gynaecological tumours.

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