Simultaneous $^{18}$F Choline Positron Emission Tomography/Magnetic Resonance Imaging of the Prostate

Initial Results

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Purpose: The purposes of this study were to evaluate the feasibility of simultaneous $^{18}$F choline positron emission tomography (PET) and magnetic resonance imaging (MRI) of the prostate and to present the first clinical results of the method.

Materials and Methods: From March 2012 to October 2012, a total of 15 consecutive patients were examined with simultaneous $^{18}$F choline PET/MRI. At the time of the examination, 8 patients had histologically proven prostate cancer, 2 patients had repeated prostate biopsies with negative results, and 5 patients had repeated prostate cancer with an elevated or rising specific antigen level but did not have a prostate biopsy. Sequence protocol comprised T2-weighted high-resolution images and diffusion-weighted images of the prostate in addition to PET imaging. Image quality was assessed by 2 radiologists, and the PET images were evaluated quantitatively and qualitatively.

Results: Simultaneous PET/MRI of the prostate was accomplished successfully in all patients. The method proved to be robust without technical failure, and the image quality was rated to be diagnostic in all examinations except in 1 diffusion-weighted imaging (DWI) data set that was judged to be nondiagnostic because of susceptibility artifacts. High-resolution T2-weighted images allowed exact correlation of elevated focal or diffuse choline uptake to suspicious T2-weighted lesions of the prostate. A high accordance was found between PET and DWI. However, PET-positive lesions were found in 3 patients wherein DWI did not indicate tumor in suspicious T2-weighted lesions.

Conclusions: Simultaneous positron emission tomography/magnetic resonance imaging of the prostate has the advantage of combining high-resolution prostate images, functional studies, and metabolic/molecular imaging. The PET component adds diagnostic confidence to the MRI-based parameters in identifying and localizing tumor in the prostate.

Key Words: PET/MRI, PET/CT, prostate carcinoma, DWI, $^{18}$F choline

(Invest Radiol 2013;48: 00–00)

Molecular imaging of prostate cancer with the radiolabeled choline derivates $^{11}$C choline and $^{18}$F choline has been examined in several studies and shows equivocal results. Some groups reported a high sensitivity for the detection of primary prostate cancer, whereas other groups demonstrated only a moderate or poor detection rate. A large systematic review of the results with $^{18}$F choline defined possible indications for the use of combined $^{18}$F choline positron emission tomography (PET) and computed tomography (CT) in prostate cancer. The method was recommended for targeting prostate biopsies in men at high risk for prostate cancer with repeated biopsies having negative results or for the initial staging of intermediate- to high-risk populations.

A restraint of combined PET/CT of prostate cancer is the limited value of CT because of an insufficient delineation of the zonal anatomy of the prostate. This is mainly because of the poor soft tissue contrast of CT. On the contrary, magnetic resonance imaging (MRI) with an endorectal coil or ultrahigh-field MRI at 3 T allows an excellent depiction of the prostate anatomy with a reliable discrimination of the different anatomical areas of the prostate. Therefore, MRI is increasingly used for the diagnosis and staging of prostate cancer, either if cancer detection by means of prostate biopsy fails or if a detailed depiction of the prostate anatomy needs to be provided to distinguish organ-confined tumors from capsular penetrating tumors. In this coherence, multiparametric MRI that combines anatomical and functional data has been shown to be superior over T2-weighted anatomical imaging alone. For the evaluation of prostate cancer, it might be especially meaningful to combine radiolabeled choline PET and MRI wherein anatomical, functional, and molecular/metabolic data can be analyzed together to identify possible synergistic effects in the diagnostic process. The goals of this study were to evaluate the practical use of combined $^{18}$F choline PET/MRI of the prostate and to present the first results of the method.

MATERIALS AND METHODS

This study was approved by the local ethics committee, and informed consent was obtained from all patients.

Patients

From March 2012 to October 2012, a total of 15 patients were examined with simultaneous $^{18}$F choline PET/MRI. Median age was 65 years. The mean prostate specific antigen (PSA) level of the patient collective was 23.0 ng/mL (± 22.5 ng/mL). Eight patients had a biopsy-proven prostate carcinoma at the time of the examination with a median Gleason score of 7. Two patients had repeated prostate biopsies without evidence of prostate cancer. Five patients had suspected prostate cancer with an elevated or rising PSA level but did not have a prostate biopsy so far.

The Department of Urology assigned the patients to our PET/CT and PET/MRI unit with the question of local extend and lymph node metastasis (8 patients with biopsy-proven prostate cancer) and for targeting biopsies and initial staging, respectively (2 patients with repeated biopsies having negative results and 5 patients with suspected prostate cancer). After the combined $^{18}$F choline PET/CT was completed, the patients were transferred to the PET/MRI unit. A simultaneous PET/MRI examination was accomplished, and the PET/MRI images were analyzed.
Simultaneous Positron Emission Tomography/ Magnetic Resonance Imaging Procedure

After PET/CT was completed, the patients were transferred to the PET/MRI unit. Positron emission tomography/magnetic resonance imaging scans started approximately 150 minutes after injection of $^{18}$F choline. Simultaneous PET/MRI scans were conducted on a 3-T magnetic resonance (MR) scanner (Biograph mMR, Siemens Healthcare, Erlangen, Germany) with an axial field of view of 25.8 cm. The PET acquisition was carried out with Lutetium Oxyorthosilicate based avalanche photodiodes. The PET/MRI scan comprised a pelvis PET scan with 1 bed position. Emission time of the PET scan was 20 minutes. The PET data were reconstructed using Fourier rebinning algorithm and attenuation-weighted ordered subset expectation maximization with 3 iterations and 21 subsets. A post reconstruction Gaussian filter with 5.0 mm full width at half maximum was applied. Attenuation correction of the PET data was accomplished according to the method described by Martinez-Möller et al.9 Signal reception was accomplished with a spine-and phased-array body coil. The mean examination time amounted to 30 minutes. A protocol of the analyzed sequences is listed in Table 1.

Data Analysis

Positron emission tomography/magnetic resonance images were analyzed by 2 radiologists with 8 years of experience in prostate MRI and 8 years of experience in PET/CT imaging. Image quality of MR images was evaluated visually using a scale from 1 to 4 (1, excellent; 2, good; 3, moderate; and 4, bad [nondiagnostic] image quality). The image quality was judged in consensus. Results of the visual scoring were noted for the T2-weighted and diffusion-weighted images separately.

The prostate MR images were analyzed in accordance with the 2012 European Society of Urogenital Radiology prostate MR guidelines10 for the T2-weighted and diffusion-weighted images including apparent diffusion coefficient (ADC) maps (at b-values of 1000 s/mm²) regarding the depiction of malignant tumor. Diffusion-weighted imaging (DWI) data were analyzed qualitatively.

The localization of focal or diffuse increased choline uptake in the prostate was noted and qualitatively analyzed. Also, standardized uptake values (SUVmax) were measured with a region-of-interest analysis. After the image analysis was completed, a diagnosis was made in consensus.

Statistical Analysis

For the patient collective, descriptive statistics was calculated including the median age, the mean PSA levels, and the median Gleason score. The means and standard deviations of the SUVmax were calculated. Comparison of the means and testing for statistical significance was calculated using 1-tailed Mann-Whitney test. All statistical calculations were performed using the R software environment for statistical computing.11

RESULTS

Simultaneous PET/MRI of the prostate was accomplished successfully in all patients. The procedure was well tolerated by all patients, and no side effects were observed. In addition, the method proved to be robust without technical failure in all examinations.

Image Quality

The images of all MRI data sets that were acquired simultaneously during the PET scan were rated to be of good or excellent diagnostic quality except 2 DWI data sets that were rated to be of moderate quality. In 1 patient, the DWI data set could not be used for analysis because of susceptibility artifacts. Furthermore, we observed sporadic movement artifacts, which could all be compensated by acquired sequences in a second image plane.

Patients With Histologically Proven Prostate Cancer

We examined 8 patients with biopsy-proven prostate cancer at the time of the examination (Table 2). In 7 of the 8 patients, we found areas of focal elevated $^{18}$F choline uptake (Figs. 1–3). One patient (B.1.) demonstrated no focal but rather a diffuse uptake of $^{18}$F choline (SUVmax, 3.7). This patient had transurethral resection of the prostate before where prostate cancer was incidentally diagnosed. In 2 of the 8 patients (B.1., B.7 [Fig. 1]), we found PET-positive lesions in which DWI did not exhibit a restriction of water diffusion.

Patients With Repeated Negative Prostate Biopsy Results

We examined the 2 patients with repeated negative prostate biopsy results.

The first patient (R.1.; Fig. 4) had 2 biopsies with negative results and a rising PSA level. The T2-weighted images were not suggestive of prostate cancer, and the peripheral zone showed uniform high signal (score, 1). The transitional zone displayed some hypointense homogenous areas of low signal intensity with well-defined margins (score, 2). There was no restricted water diffusion (score, 1). Positron emission tomographic results demonstrated discrete elevated focal choline uptake in a hyperplastic nodule in the right transitional zone. On the basis of the imaging and PET results, we concluded that there was no carcinoma but recommended that a subsequent biopsy be targeted at the right transitional zone. A subsequent biopsy was not performed to date.

The second patient (R.2.) had 3 prostate biopsies with negative results in the past. T2-weighted MRI results demonstrated a pronounced hyperplasia with a prominent transitional zone and a small peripheral zone. In the peripheral zone, some geographic areas of lower signal intensity were visible (score, 2). The transitional zone was heterogeneous with many hypointense and hyperintense nodules (score, 3). The PET findings demonstrated an irregular choline uptake of the nodules (SUVmax, 5.0), which, we believed, was caused by the hyperplastic changes.

**TABLE 1.** Sequence Parameters

<table>
<thead>
<tr>
<th>Sequence</th>
<th>TR (ms)</th>
<th>TE (ms)</th>
<th>FoV (mm)</th>
<th>Slice Thickness (mm)</th>
<th>Matrix</th>
<th>b Values (s/mm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>TIRM coronal</td>
<td>3110</td>
<td>56</td>
<td>380</td>
<td>5</td>
<td>448</td>
<td>—</td>
</tr>
<tr>
<td>T2 FSE axial</td>
<td>4311</td>
<td>114</td>
<td>400</td>
<td>7</td>
<td>512</td>
<td>—</td>
</tr>
<tr>
<td>T2 FSE axial</td>
<td>4320</td>
<td>101</td>
<td>200</td>
<td>3</td>
<td>320</td>
<td>—</td>
</tr>
<tr>
<td>T2 FSE coronal</td>
<td>4000</td>
<td>101</td>
<td>200</td>
<td>3</td>
<td>320</td>
<td>—</td>
</tr>
<tr>
<td>DWI</td>
<td>9600</td>
<td>93</td>
<td>260</td>
<td>3.6</td>
<td>160</td>
<td>0, 800, 1000</td>
</tr>
</tbody>
</table>

FoV indicates field of view; FSE, fast spin echo; TIRM, turbo inversion recovery magnitude; TE, echo time; TR, repetition time.
<table>
<thead>
<tr>
<th>Biopsy-proven PCA</th>
<th>PSA (ng/mL)</th>
<th>Biopsy Gleason Score</th>
<th>T2-Weighted Images</th>
<th>DWI</th>
<th>PET</th>
<th>SUVmax</th>
<th>Radiological Diagnosis</th>
<th>Result of Prostatectomy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Patient 1 (B.1.)</td>
<td>8.9</td>
<td>3 + 3 = 6</td>
<td>PZ: score, 4</td>
<td>Score, 1</td>
<td>Bilateral elevated choline uptake</td>
<td>3.7</td>
<td>Bilateral PZ carcinoma</td>
<td>pT2c</td>
</tr>
<tr>
<td>Patient 2 (B.2.)</td>
<td>3.9</td>
<td>4 + 5 = 9</td>
<td>PZ: score, 5</td>
<td>Score, 5</td>
<td>Bilateral focal elevated choline uptake</td>
<td>8.4</td>
<td>Bilateral carcinoma with extracapsular extension</td>
<td>—</td>
</tr>
<tr>
<td>Patient 3 (B.3.)</td>
<td>27.8</td>
<td>3 + 3 = 6</td>
<td>PZ: score, 2</td>
<td>Score, 5</td>
<td>Focal elevated choline uptake on the left side, small elevated choline uptake on the right side</td>
<td>6.4</td>
<td>TZ carcinoma with suspected extracapsular extension</td>
<td>—</td>
</tr>
<tr>
<td>Patient 4 (B.4.)</td>
<td>48.7</td>
<td>4 + 3 = 7</td>
<td>PZ: score, 5 (left), score, 4 (right)</td>
<td>Score, 5</td>
<td>Bilateral focal elevated choline uptake (left &gt; right)</td>
<td>14.2</td>
<td>TZ and PZ prostate carcinoma on the left side, PZ carcinoma on the right side</td>
<td>pT2c</td>
</tr>
<tr>
<td>Patient 5 (B.5.)</td>
<td>80</td>
<td>4 + 5 = 9</td>
<td>PZ: score, 5</td>
<td>Score, 5</td>
<td>Bilateral focal elevated choline uptake (left &gt; right)</td>
<td>8.6</td>
<td>Bilateral PZ prostate carcinoma</td>
<td>—</td>
</tr>
<tr>
<td>Patient 6 (B.6.)</td>
<td>18.6</td>
<td>3 + 4 = 7</td>
<td>PZ: score, 4</td>
<td>Not usable due to susceptibility artifacts</td>
<td></td>
<td></td>
<td></td>
<td>—</td>
</tr>
<tr>
<td>Patient 7 (B.7.)</td>
<td>57</td>
<td>4 + 5 = 9</td>
<td>PZ: score, 5</td>
<td>Score, 1</td>
<td>Pronounced rather diffuse choline uptake on the right side, less on the left side</td>
<td>5.0</td>
<td>Bilateral PZ and TZ prostate carcinoma</td>
<td>T3b</td>
</tr>
<tr>
<td>Patient 8 (B.8.)</td>
<td>32</td>
<td>3 + 4 = 7</td>
<td>PZ: score, 4</td>
<td>Score, 5</td>
<td>Bilateral focal elevated choline uptake TZ, on the right side PZ</td>
<td>4.8</td>
<td>Bilateral PZ and TZ prostate carcinoma</td>
<td>—</td>
</tr>
</tbody>
</table>

Repeated prostate biopsies with negative results

| Patient 1 (R.1.)   | 18.0 | — | PZ: score, 1 | Score, 1 | Focal choline uptake in hyperplastic nodule | 2.8 | No prostate cancer detected, hyperplasia | —                     |
| Patient 2 (R.2.)   | 9    | — | PZ: score, 2 | Not performed | Irregular choline uptake in TZ | 5.0 | Benign prostatic hyperplasia | —                     |

Suspected prostate cancer, no biopsy

| Patient 1 (S.1.)   | 13   | Biopsy after PET/MRI: 3 + 3 = 6 | PZ: score, 4 | Score, 1 | Bilateral focal elevated choline uptake | 2.77 | Bilateral prostate carcinoma without extracapsular extension | pT2c                   |
| Patient 2 (S.2.)   | 8.3  | Biopsy after PET/MRI: all results of biopsy samples negative for prostate cancer | PZ: score, 1 | Score, 1 | Focal choline uptake in TZ | 2.8 | Suspicious lesion left TZ, benign prostatic hyperplasia | —                     |
| Patient 3 (S3)     | 8.2  | — | PZ: score, 1 | Score, 1 | No elevated choline uptake | 3.0 | No prostate cancer detected | —                     |

(continued on next page)
Patients With Suspected Prostate Cancer and No Previous Biopsies

We examined the 5 patients with suspected prostate cancer. The first patient (S.1.; Fig. 5) had a rising PSA level of up to 13 ng/mL. T2-weighted imaging results demonstrated large areas of low signal bilaterally in the peripheral zone without extracapsular extension (score, 4). Also, the transitional zone displayed ill-defined hypointense areas (score, 4). Diffusion-weighted imaging was without restriction of water diffusion. The PET results demonstrated focal areas of elevated choline uptake in the low signal areas of T2-weighted images (SUVmax, 2.8). On the basis of the results of T2-weighted imaging and PET, we diagnosed a bilateral prostate carcinoma without extracapsular extension. The biopsy after PET/MRI revealed prostate carcinoma with a Gleason score of 3 + 3 = 6. The patient underwent surgery of the prostate, and the result from the pathology unit was pT2c.

The second patient (S.2.) had a rise of PSA level to 8.3 ng/mL. Benign prostatic hyperplasia was known for 10 years. The peripheral zone was homogenously hyperintense in the T2-weighted images (score, 1). The transitional zone on the left side displayed some areas of ill-defined hypointense areas (score, 4). The DWI result was inconspicuous. The PET results showed a slight focal elevated choline uptake in the transitional zone in the areas with hyperplastic changes and in the ill-defined areas of the transitional zone (SUVmax, 2.8). On the basis of the results, we recommended a prostate biopsy especially of the left transitional zone. During the further course, the patient underwent prostate biopsy and all samples had negative results.

The third patient (S.3.) had a rise of PSA level to 8.2 ng/mL. The peripheral and transitional zones were inconspicuous (score, 1). Diffusion-weighted imaging was without restriction of water diffusion (score, 1). The PET results demonstrated no focal elevated choline uptake. On the basis of these results, we concluded that there was no prostate carcinoma. In the follow-up period, the PSA level dropped to 2 ng/mL. Hence, a prostatitis was likely the diagnosis.

The fourth patient (S.4.) had a rise of PSA level to 9 ng/mL. The T2-weighted images showed some geographic areas of low signal intensity (score, 2). The transitional zone displayed some areas of more homogenous low signal (score, 2) and areas with ill-defined low signal (score, 4). There was a hypointense area in the right apex (score, 4) with a slight increase in choline uptake (SUVmax, 2.9). Diffusion-weighted imaging in this area demonstrated a moderate increase in signal with a corresponding reduced ADC value. We suspected prostate cancer in the right apex and recommended that a prostate biopsy be focused on the right apex, which has not been performed to date.

The fifth patient (S.5.) had a slowly rising PSA of up to 3 ng/mL at the time of PET/MRI. The T2-weighted images revealed bilateral hypointense areas with mass effect on the right side (score, 5). The transitional zone displayed some areas of more homogenous low signal (score, 2) and areas with ill-defined low signal (score, 4). The hypointense area in the right apex displayed a restricted water diffusion and an elevated choline uptake (SUVmax, 5.8). We diagnosed bilateral prostate cancer. After PET/MRI, a prostate biopsy was performed and revealed prostate cancer (Gleason score, 3 + 3 = 6) in the left apex. Furthermore, the other samples revealed active and chronic granulomatous prostatitis. In the further course, the patient underwent surgery and a histopathological examination of the whole prostate resulted in severe active granulomatous prostatitis besides focal clusters of invasive adenocarcinoma.

Maximum Standard Uptake Values

Mean (SD) SUVmax in the patients with positive biopsy results was 6.9 (3.4) versus 3.6 (1.3) in the patients with negative biopsy results. The difference was not statistically significant ($P = 0.08$).

DISCUSSION

The current study carries 2 messages that we believe to be important: first, combined PET/MRI of the prostate is technically...
feasible, and to our knowledge, this is the first trial describing the technique for the depiction of prostate carcinoma. Second, the PET component adds diagnostic confidence to the MRI-based parameters in identifying and localizing tumor in the prostate.

Simultaneous PET/MRI of the prostate offers the opportunity to combine the advantages of prostate MRI with its unsurpassed high-resolution depiction of the organ anatomy with the metabolic imaging of PET and its possibility to look inside tumor metabolism. As already mentioned in the Introduction section, the results of combined PET/CT of the prostate with radiolabeled choline are equivocal, with varying detection rates of prostate carcinomas. A problem in this coherence is the substantial overlap of elevated choline uptake in benign prostatic hyperplasia, prostatitis, and prostate carcinoma. Another restraint of PET/CT is the poor resolution of the prostate anatomy in CT images. Nevertheless, 2 systematic reviews of the literature defined some indications for radiolabeled choline PET of the prostate, which are initial staging, biopsy targeting, restaging of recurrent disease, selection of men for salvage radiotherapy, and therapy monitoring.

In this pilot study, we evaluated the new method of PET/MRI in patients with suspected prostate carcinoma (biopsy targeting, decision about further proceeding) and patients with biopsy-proven prostate carcinoma (initial staging). All patients were initially referred to the PET/CT unit, and after the PET/CT examination, a PET/MRI was additionally conducted in accordance to our study protocol. Because the examination can be quite time-consuming, we decided to use a relatively short sequence protocol. For a real multiparametric approach, of course, a dynamic contrast-enhanced sequence should have been added.

After having examined 15 patients, we can prove that PET/MRI of the prostate can be consistently applied under routine conditions. All prostate images were of diagnostic quality (except DWI in 1 patient due to susceptibility artifacts), and the examination time was acceptable. This is worth to be noticed because it is an immense technical challenge to combine a PET scanner and an MR scanner in 1 machine with limited space.

The findings of T2-weighted images, DWI, and PET were not always concordant. In 3 patients with histologically proven prostate cancer, the DWI results did not indicate tumor, whereas the PET result was positive. In these cases, PET imaging added diagnostic confidence and led to the right diagnosis. This underlines that simultaneous PET/MRI might play an important part of prostate cancer imaging in the future. If, for example, an ambiguous T2-weighted lesion of the peripheral zone does not exhibit any diffusion restriction but a pathological choline uptake, one will rather rate the lesion as malignant compared with a situation when choline uptake is normal. A reservation must be made, however, that the elevated uptake of choline in patient B.1. was presumably, in part, a consequence of the

![Figure 1](image1.png)

**FIGURE 1.** Patient B.7. with histologically proven prostate cancer (Gleason score, 4 + 5 = 9): axial T2-weighted image demonstrates ill-defined hypointense areas near the base of the prostate on the right side (arrow). Diffusion-weighted image without restricted water diffusion (b = 1000). Axial fusion image of PET/MRI displaying a large area of elevated choline uptake (arrow).

![Figure 2](image2.png)

**FIGURE 2.** Patient B.2. with biopsy-proven prostate carcinoma (Gleason score, 4 + 5 = 9): axial T2-weighted image demonstrates cancer-suspicious regions of low signal in the peripheral and transitional zones (arrows). Axial DWI image (b = 1000) shows high signal (arrows). Axial fusion image of PET and MRI demonstrates focal elevated choline uptake in the hypointense T2-weighted lesions. Note the physiological choline uptake in the rectum (dotted arrow).
previous transurethral resection of the prostate in terms of reactive changes of the cells. Apart from the 3 patients, we found a high accordance between PET and DWI and further studies with a larger patient collective are needed to rule out the possible synergistic effects of DWI and PET.

In this respect, patient S.2. should be noted, wherein we observed a slight choline uptake in the left transitional zone with normal DWI. All results of the biopsy samples were negative, so DWI pointed in the right direction, and the slight choline uptake was probably because of benign hyperplasia (providing that this patient has true-negative results). Therefore, it is important to classify the PET component as an additional tool in a multiparametric approach together with DWI.

The results of a recently published study underline this observation. Park et al14 examined the value of parametric fusion PET/MRI based on $^{11}$C choline PET/CT and DWI data. The quotient of $^{11}$C choline over ADC significantly improved tumor-to-background contrast in comparison with sole PET/CT or DWI. Given the high anatomical resolution capacity of T2-weighted images of the prostate, the choline uptake together with DWI will help to increase the diagnostic confidence of the reader. This is of great value compared with PET/CT, wherein the prostate anatomy can hardly be depicted and functional imaging is not possible.

In our study group, the mean SUVmax in the patients with positive biopsy results was higher than in patients with negative biopsy results, however, not being statistically significant. This might be because the study group was very small, and a significant difference may arise if a larger study group is investigated. On the contrary, 1 patient (S.5.) in our collective displayed a pronounced choline uptake, which was presumably less because of carcinoma but more because of an active granulomatous prostatitis, which was predominantly found on histopathological examination of the prostate after radical prostatectomy. This patient, together with the previously discussed patient S.2., demonstrates that the results of the quantitative analysis of choline uptake should be carefully interpreted at this stage. It is also important to analyze the metabolic behavior of prostatitis and benign prostatic hyperplasia because we could see that typical areas of BPH showed a pronounced choline uptake. This finding is echoed in the literature because several studies that evaluated the diagnosis of primary prostate cancer with radiolabeled choline PET/CT found an overlap between choline uptake of benign prostatic hyperplasia and prostate cancer.15,16 With the introduction of PET/MRI, the diagnostic uncertainty caused by elevated choline uptake of both BPH and prostate cancer could be conquered because MRI allows a much better discrimination of the areas of BPH from tumor-suspicious lesions as does CT. Regions of elevated choline uptake

![FIGURE 3. Patient B.3. with biopsy-proven prostate cancer (Gleason score, $3 + 3 = 6$): coronal T2-weighted image indicating a large hypointense lesion of the left transitional zone with a broad capsular contact. Axial DWI image ($b = 1000$) demonstrates restricted water diffusion with increased signal within the lesion. Axial fusion image of PET and MRI displays elevated choline uptake.](image)

![FIGURE 4. Patient R.1. with repeated negative prostate biopsy results with a rising PSA level: axial T2-weighted image without cancer-suspicious lesions in the peripheral zone. Nodular hyperplastic changes in the transitional zone. Normal signal on DWI. Axial fused PET/MRI with discrete focal elevated choline uptake in a hyperplastic nodule. We recommended that next biopsy be targeted at the right transitional zone.](image)
Simultaneous \textsuperscript{18}F Choline PET/MRI of the Prostate

FIGURE 5. Patient S.1. with suspected prostate carcinoma with a rising PSA level (13 ng/mL): the patient underwent prostatectomy after PET/MRI, and the pathologic report was pT2c prostate carcinoma. Axial T2-weighted image shows regions of ill-defined hypointensities in the peripheral and transitional zones (arrows). No restriction of water diffusion. Axial fusion image of PET and MRI demonstrates focal elevated choline uptake in the suspicious areas (arrows).

can thus be safely characterized and classified. In this coherence, it might be better to choose a qualitative approach of PET data analysis and use SUVmax as a guideline, as proposed by Scher et al.\textsuperscript{16}

Clearly, the current study is not without some limitations. We could not provide histopathological correlation in all patients because only 5 patients underwent radical prostatectomy and, altogether, 10 patients had positive biopsy results. Three patients had negative biopsy results and fell into a "watch and wait" category, and in 1 patient, a biopsy was planned but was not available, to date. One patient had a PSA drop, and prostatitis was the likely diagnosis. A biopsy was not planned in this patient. Because this study is considered an initial trial showing the feasibility of PET/MRI of the prostate, a statistical evaluation of the data beyond our analysis was not performed.

Another possible restraint of our study might be the quite long time between the injection of \textsuperscript{18}F choline and the start of simultaneous PET/MRI, which was, in average, 150 minutes. However, the PET signal was high in all examined patients. Because the radioactive half-life of \textsuperscript{18}F choline accounts for 110 minutes, we would not have expected a strong signal decay after 150 minutes. In this context, a study that examined the biokinetics of \textsuperscript{18}F choline demonstrated no difference of activity concentration of different organs except the kidneys for a period of 4 hours after the injection.\textsuperscript{17} In addition, because, in PET/MRI, the PET scan is operated simultaneously with MRI, it is possible to expand the emission time. It lasted 20 minutes in our protocol, which is a long time in comparison with the emission time of PET/CT, which was 2 minutes per bed position. Thereby, it is possible to increase the PET signal and to compensate potential signal attenuation due to the delayed MR examination.

In conclusion, we present the first data on simultaneous PET/ MRI of the prostate. The method is feasible and works in clinical routine. Combined PET/MRI of the prostate has the advantage of combining high-resolution prostate images, functional studies, and metabolic/molecular imaging. If the method will improve diagnosis and staging of primary prostate cancer in comparison with MRI alone must be evaluated in larger studies.

REFERENCES