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# Evaluation of [<sup>68</sup>Ga]-DOTATOC PET/MRI in Patients with Meningioma of the Subcranial and Intraorbital Space

Aleksandar Milosevic<sup>1</sup>, Hanna Styczen<sup>1</sup>, Johannes Grueneisen<sup>1</sup>, Yan Li<sup>1</sup>, Manuel Weber<sup>2</sup>, Wolfgang P. Fendler<sup>2</sup>, Julian Kirchner<sup>3</sup>, Philipp Damman<sup>4</sup>, Karsten Wrede<sup>4</sup>, Lazaros Lazaridis<sup>5</sup>, Martin Glas<sup>5</sup>, Maja Guberina<sup>6</sup>, Anja Eckstein<sup>7</sup>, Tobias Blau<sup>8</sup>, Ken Herrmann<sup>2</sup>, Lale Umutlu<sup>1</sup>, Michael Forsting<sup>1</sup>, Cornelius Deuschl\*<sup>1</sup>, and Benedikt Schaarschmidt\*<sup>1</sup>

<sup>1</sup>*Institute of Diagnostic and Interventional Radiology and Neuroradiology, University Hospital Essen, Düsseldorf, Germany;*

<sup>2</sup>*Department of Nuclear Medicine, University Hospital Essen, Düsseldorf, Germany;* <sup>3</sup>*Institute of Radiology, University Hospital*

*Düsseldorf, Düsseldorf, Germany;* <sup>4</sup>*Department of Neurosurgery and Spine Surgery, University Hospital Essen, Düsseldorf, Germany;*

<sup>5</sup>*Department of Neurology and Neurooncology, University Hospital Essen, Düsseldorf, Germany;* <sup>6</sup>*Department of Radiotherapy,*

*University Hospital Essen, Düsseldorf, Germany;* <sup>7</sup>*Department of Ophthalmology, University Hospital Essen, Düsseldorf, Germany;*

*and* <sup>8</sup>*Department of Neuropathology, University Hospital Essen, Düsseldorf, Germany*

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Meningiomas are known to express somatostatin receptor (SSTR) type 2 to a high degree. Therefore, radiolabeled somatostatin analogs, such as DOTATOC, have been introduced for PET imaging of meningiomas. However, the benefit of hybrid SSTR PET/MRI is still debated. Here, we report our experience with [<sup>68</sup>Ga]-DOTATOC PET/MRI.

**Methods:** PET/MRI was performed in 60 patients with suspected or diagnosed meningiomas of the skull plane and eye socket. Acquired datasets were reported by 2 independent readers regarding local tumor extent and signal characteristics. Histopathologic results and follow-up imaging served as the reference standard. SUVs of target lesions were analyzed according to the corresponding maximal tracer uptake. The diagnostic accuracy of PET/MRI and conventional MRI was determined independently and compared with the reference standard. **Results:** In total, 60 target lesions were identified, with 54 considered to be meningiomas according to the reference standard. Sensitivity and specificity of PET/MRI versus MRI alone were 95% versus 96% and 75% versus 66%, respectively. The McNemar test was not able to distinguish any differences between PET/MRI and the reference standard or MRI and the reference standard. No differences were found between the 2 modalities with respect to local infiltration. **Conclusion:** SSTR PET/MRI and MRI yielded similar accuracy for the detection of meningiomas of the skull base and intraorbital space. Here, sequential low-dose SSTR PET/CT might be helpful for the planning of radioligand therapy or radiotherapy.

**Key Words:** meningioma; oncologic imaging; DOTATOC; somatostatin receptor ligands; PET

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**M**eningiomas are the most common tumors of the meninges and account for 25%–34% of all primary neurocranial tumors, with an estimated annual incidence ranging from 7.62 cases out of 100,000 people to 97.5 cases out of 100,000 people in the United

States (1,2). Although mostly regarded as benign tumors, atypical or anaplastic meningiomas usually bear a higher rate of mutation and can display more aggressive characteristics (3). Clinical symptoms depend on the primary location and the consecutive compression or, rather rarely, infiltration of adjacent structures (4). Therefore, the accurate depiction of the tumor and its surroundings is key to a successful treatment, especially in anatomically complex regions such as the skull base. Due to excellent soft-tissue contrast and, in many cases, characteristic radiographic features, MRI is the current gold standard in meningioma diagnostics (5). However, the value of MRI is limited in select cases, especially if infiltration of the skull base or the cavernous sinus is suspected (6). Therefore, molecular imaging, most notably PET using tracer ligands bound to the somatostatin receptor subtype 2 (SSTR<sub>2</sub>), is progressively considered to be an important adjunct in the diagnosis and therapeutic planning of meningiomas (7,8). SSTR<sub>2</sub> is a surface antigen that is expressed to a particularly high degree in meningiomas (9). Our institution has used the <sup>68</sup>Ga-labeled somatostatin analog DOTATOC successfully because it features more favorable imaging characteristics than its predecessors (10). In terms of diagnostic accuracy, [<sup>68</sup>Ga]-DOTATOC possesses properties similar to those of its [<sup>68</sup>Ga]-DOTATATE counterpart (11). The introduction of modern PET/MRI systems into clinical practice has led to considerable advantages in neuroradiologic imaging (12–14). PET/MRI combines the high-resolution properties of MRI with molecular information derived from the PET dataset. Current studies emphasize the superiority of PET/MRI when compared with conventional MRI or PET/CT. According to the published literature, PET/MRI enhances delineation of tumor margins and has become a potential adjunct in pretreatment planning (7,8,15). In the present study, we evaluate the diagnostic accuracy of integrated [<sup>68</sup>Ga]-DOTATOC PET/MRI for meningiomas of the skull base and the orbital space compared with the accuracy with MRI, which is the current gold standard.

## MATERIALS AND METHODS

### Patients and Reference Standard

This study was approved by the local ethics committee in accordance with the declaration of Helsinki (application number 22-10703-BO, approval date May 23, 2022). The requirement to obtain informed consent was waived because of its retrospective design.

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For correspondence or reprints, contact Aleksandar Milosevic (aleksandar.milosevic@uk-essen.de).

\*Contributed equally to this work.

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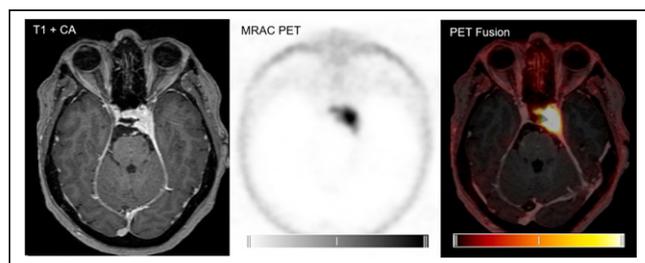
Patients who underwent [<sup>68</sup>Ga]-DOTATOC PET/MRI for initial tumor or recurrence diagnostics of meningioma from August 2012 to April 2022 were included in this analysis. Because histologic sampling is not always available during meningioma treatment, a combined reference standard including histopathologic workup as well as imaging follow-up as proposed in the literature was used in the present study (16). Clinical information and data regarding treatment and the course of disease were obtained from digital patient files.

### PET/MRI

The examination was performed 45 ± 25 min after intravenous injection with a mean activity of 79 ± 21 MBq [<sup>68</sup>Ga]-DOTATOC. All PET/MRI scans were performed on a 3-T Biograph mMR (Siemens Healthineers). The scan ranged from the skull cap to the neck. Using a dedicated 20-channel radiofrequency coil for the head area, we performed diagnostic MRI in parallel with a PET scan in list mode without respiratory gating (1 bed position, 20 min per bed position). Parallel imaging (generalized autocalibrating partially parallel acquisitions, acceleration factor 2) was used. PET images were reconstructed using the 3-dimensional ordered-subsets expectation-maximization method (3 iterations, 21 subsets, gaussian filter of 4 mm in full width at half maximum, 344 × 344 matrix size). Attenuation correction of PET data was performed by implementing a 4-compartment-model map, calculated from obtained Dixon sequences. MRI protocols are displayed in Supplemental Table 1 (supplemental materials are available at <http://jnm.snmjournals.org>).

### Image Analysis

Examinations were reviewed in random order by 2 radiologists with more than 2 y of experience in hybrid imaging using a dedicated viewing software for hybrid imaging (Syngo.Via; Siemens Healthineers). Both readers were unaware of the tumor location, histopathologic results, and consecutive therapy. In the first session, readers were instructed to identify meningioma on the basis of clinically established features as proposed by the meningioma task force of the European Association of Neuro-Oncology. These criteria include an isointense signal on T1-weighted sequences, a hyperintense signal on T2-weighted sequences, a strong contrast enhancement, and the presence of a dural tail at the perimeter of the target lesions (5). To evaluate the tumor size, transversal and coronal contrast-enhanced T1-weighted images were used. PET/MR images were analyzed in a second assessment 4 wk later to avoid recognition bias. SUVs (SUV<sub>max</sub>, SUV<sub>peak</sub>, and SUV<sub>mean</sub>) were measured by implementation of an isocontour volume of interest, with a threshold level at 40% of the maximal uptake (Fig. 1). Both readers assessed PET datasets qualitatively. As proposed elsewhere (17), an SUV<sub>max</sub> of 2.3 or greater was considered indicative of meningioma. Furthermore, sites of tumor infiltration were evaluated during both assessments. Tumoral infiltration was assumed if one of the following criteria was met: there was morphologically visible infiltration of a surrounding structure, cuffing of a surrounding structure, visible compression of a surrounding structure, an atypically increased tracer uptake of the surrounding structures (valid only for PET/MRI;



**FIGURE 1.** [<sup>68</sup>Ga]-DOTATOC uptake in sphenoid wing meningioma. CA = contrast agent; MRAC = MR-based attenuation correction.

threshold, SUV<sub>max</sub>, 2.3). The following structures were identified as relevant sites of infiltration: optic chiasm, contra- and ipsilateral optical nerve, contra- and ipsilateral internal carotid artery (ICA), pituitary fossa, and cavernous sinus. A Likert scale was used by the readers to assess the readers' certainty (ranging from 1 being absolutely certain to 6 being absolutely uncertain). Consensus reading of both readers in combination with provided clinical reports and follow-up imaging served as the reference standard for infiltration.

### Statistical Analysis

Diagnostic accuracy was calculated for MRI (first assessment) and PET/MRI (second assessment) in relation to the reference standard and compared using the McNemar test. Additionally, sensitivity, specificity, positive predictive value, and negative predictive value were calculated for each modality. Item scores were calculated using the provided Likert scales to depict certainty in the estimation of tumor infiltration. Likert scales were then compared by a Mann-Whitney *U* test. Cohen  $\kappa$  coefficient was calculated for both diagnosis and infiltration conspicuity to estimate the interreader variability. *P* values of 0.05 or less were considered to be statistically significant.

Excel 2013 (Microsoft Corp.) and SPSS Statistics 28 (IBM Technology Corp.) were used for statistical analysis.

## RESULTS

### Patients

Sixty patients (78% female [46/60]; 22% male [14/60], mean age, 57.1 ± 15.0 y) were subsequently included in our retrospective analysis. All patients suspected of recurrence of meningioma (*n* = 14) had been treated at the primary diagnosis. Histopathologic assessment was available in 33.3% (20/60) of the cases after biopsy or resection. Follow-up MRI was performed at a median time point of 10.7 mo after the initial PET/MRI. Histopathologic analysis confirmed meningioma in 23.3% (14/60) of the cases. Histologic subtypes are displayed in Table 1. Seven percent (4/60) of patients displayed B-cell-type lymphoma, 5% (3/60) displayed marginal cell lymphoma, and 2% (1/60) displayed diffuse large B-cell lymphoma. Furthermore, sampling found cavernous venous malformation in 1 patient and lymphoid hyperplasia in another patient. Measured SUVs of lesions are displayed in Table 2. At the time point of data analysis, therapy for meningioma was concluded in 43 patients. In 16 cases, primary or partial surgical resection was performed. Four patients with involvement of the optic nerve received optic decompression. Thirty-nine patients received primary or adjuvant radiation therapy. Radionuclide therapy with <sup>177</sup>Lu- or <sup>90</sup>Y-DOTATOC was conducted in 5 patients.

**TABLE 1**  
Distribution of Patients According to  
Histopathologic Sampling

Histology	Number of patients with primary lesion	Number of patients with recurrent lesion
Meningothelial (WHO I)	8.3% (5/60)	10.0% (6/60)
Choroidal differentiation (WHO II)	1.6% (1/60)	0.0% (0/60)
Atypical (WHO II)	0.0% (0/60)	3.3% (2/60)
Other	10.0% (6/60)	0.0% (0/60)

WHO = World Health Organization.

**TABLE 2**  
SUV Analysis

Group	Subtype	n	SUV <sub>max</sub>	SUV <sub>peak</sub>	SUV <sub>mean</sub>
All patients	Total	60	12.9	9.4	5.9
Meningioma	Total	54	14.0	10.2	6.4
	OSM	20	6.2	4.2	3.8
	SWM	18	25.0	18.6	8.9
	Other*	16	11.4	8.3	6.9
Nonmeningioma	Total	6	2.5	1.9	1.5
	MCL	3	1.7	1.4	1.0
	DLBCL	1	3.6	2.9	2.2
	CVM	1	4.3	3.0	2.6
	LH	1	1.8	1.2	1.0

\*Cavernous sinus, petroclival junction, planum sphenoidale.

OSM = optic sheath meningioma; SWM = sphenoid wing meningioma; MCL = marginal cell lymphoma; DLBCL = diffuse large B-cell lymphoma; CVM = cavernous venous malformation; LH = lymphoid hyperplasia.

### Lesion Detection

Sixty target lesions were identified, with 54 considered to be meningiomas according to the reference standard. Mean values for the maximal diameter of observed lesions was  $2.7 \pm 1.4$  cm. Both PET/MRI and MRI detected all of the above-mentioned lesions. According to both reading sessions, MRI and PET/MRI misidentified meningioma as nonmeningioma in 3.7% (2/54) of patients. In contrast, MRI falsely diagnosed meningioma in 2 patients, and PET/MRI falsely diagnosed meningioma in 3 patients (Table 3). On the basis of this observation, we confirmed a sensitivity of 95%, a specificity of 75%, a positive predictive value of 98%, and a negative predictive value of 50% with PET/MRI and a sensitivity of 96%, a specificity of 66%, a positive predictive value of 96%, and a negative predictive value of 66% with MRI (Table 4). Diagnostic accuracy was 93% for both MRI and PET/MRI. The McNemar test was not able to discriminate any significant differences between PET/MRI and the reference standard ( $P = 0.625$ ) or MRI and the reference standard ( $P = 1.0$ ).

### Tumor Infiltration

Only 1 lesion (2%) displayed no signs of local invasion related to the above-mentioned criteria. According to MRI, invasion of the optic chiasm was found in 28% (16/60) of patients. The ipsilateral and contralateral optic nerves were affected in 85% (51/60) and 15% (9/60) of patients, respectively. PET/MRI confirmed infiltration of the optic chiasm in 30% (18/60) of patients and infiltration of the ipsilateral and contralateral optic nerves in 87% (52/60) and 15% (9/60) of patients, respectively. No differences were found between the 2 modalities concerning the infiltration of the pituitary fossa (60% [24/60]) and ipsilateral ICA (57% [34/60]). MRI found infiltration of contralateral ICA in 15% (9/60) of patients. In PET/MRI, infiltration of contralateral ICA was visible in 12% (7/60) of patients. Infiltration of the cavernous sinus was diagnosed in 57% (34/60) of patients by both MRI and PET/MRI. Rates of infiltration are displayed in Figure 2. Both readers were able to provide safe assumptions for infiltration in both assessments, according to the calculated item scores. Readouts for both MRI and PET/MRI achieved high confidence with respect to infiltration of surrounding structures. Mean item scores assumed a value between 1.0 (absolutely certain) and 2.0 (certain). Comparison of Likert scales via a Mann–Whitney *U* test revealed no significant differences in the assessment of infiltration between PET/MRI and MRI ( $P > 0.05$ ). Interreader agreement is displayed in Supplemental Table 2.

### DISCUSSION

This retrospective study investigated our institutional experience with [<sup>68</sup>Ga]-DOTATOC PET/MRI of meningiomas of the skull base. During our analysis, we were able to make one key observation. The inclusion of [<sup>68</sup>Ga]-DOTATOC PET in a dedicated MRI protocol did not significantly improve the detection and differentiation of meningioma and nonmeningioma lesions. In fact, true-negative ratings were slightly lower than those of conventional MRI.

The implementation of somatostatin receptor (SSTR)-avid diagnostic radioligands such as [<sup>68</sup>Ga]-DOTATOC into imaging workflows has been proven to facilitate the diagnosis of meningioma by providing additional information on SSTR density (18,19). Thus, hybrid imaging has rightfully established its position in high-quality diagnostics of meningioma and subsequent therapy planning (19,20). For instance, published data demonstrated a significantly improved detection of osseous infiltration in SSTR PET/CT when compared with detection with conventional contrast-enhanced MRI (21).

**TABLE 3**  
Detection of Suspected Meningioma in MRI and PET/MRI

Parameter	MRI				PET/MRI			
	Total	OSM	SWM	Other*	Total	OSM	SWM	Other*
True positive	52	18	18	16	53	19	18	16
False positive	2	2	0	0	3	3	0	0
True negative	4	4	0	0	3	3	0	0
False negative	2	2	0	0	1	1	0	0
Total	60	26	18	16	60	26	18	16

\*Cavernous sinus, petroclival junction, planum sphenoidale.

OSM = optic sheath meningioma; SWM = sphenoid wing meningioma.

**TABLE 4**  
Determined Values for Sensitivity, Specificity, Positive Predictive Value, and Negative Predictive Value

Parameter	MRI (%)				PET/MRI (%)			
	Total	OSM	SWM	Other*	Total	OSM	SWM	Other*
Sensitivity	96	90	100	100	95	86	100	100
Specificity	66	67	100	100	75	75	100	100
PPV	96	90	100	100	98	95	100	100
NPV	66	67	100	100	50	50	100	100

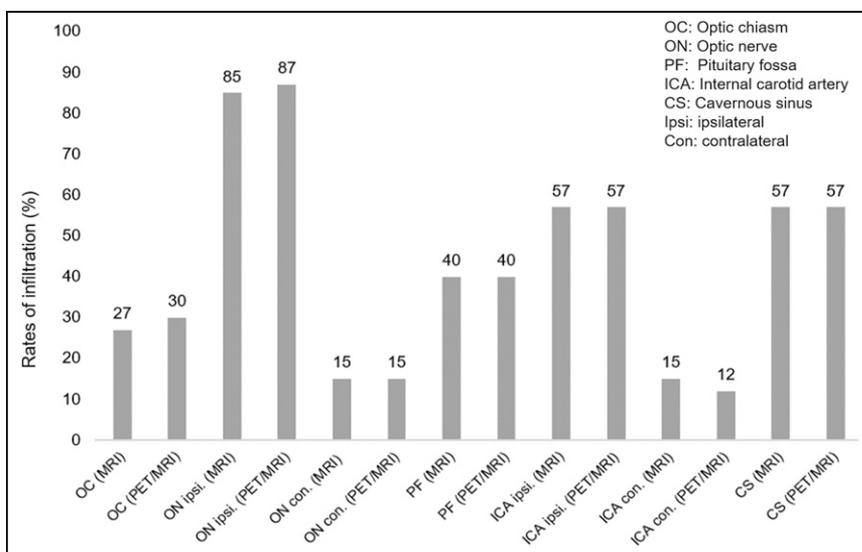
\*Cavernous sinus, petroclival junction, planum sphenoidale.  
OSM = optic sheath meningioma; SWM = sphenoid wing meningioma.

Furthermore, hybrid imaging inherently influences treatment planning by enhancing delineation of meningioma volume before radiation therapy (22). Despite the overall outstanding diagnostic performance of PET/CT, its clinical application is limited because of potential adverse effects from ionizing radiation (23). Further limitations result from the confined range of  $\beta$ -radiation inside the tissue, which may produce inherent blurs in the imaging of intracranial structures. This is especially true for the skull base, a region of high anatomic complexity (24). Hence, the introduction of dedicated and simultaneously acquired PET/MRI datasets has positively influenced diagnostic security and enabled accurate depiction of morphologic relations. This is confirmed in established literature by a direct comparison of the diagnostic performance of PET/CT and PET/MRI, highlighting the superior sensitivity and specificity of PET/MRI (18,25). Further studies investigated additional benefits of PET/MRI in the diagnosis of meningiomas. A recently published study was able to accentuate the relevance of PET/MRI regarding therapeutic planning and differentiation of scar tissue versus a residual tumor (26). However, the current guideline on diagnosis and management of meningioma of the European Association of Neuro-Oncology lists MRI as the gold standard in initial and follow-up imaging of meningioma. According to the European Association of Neuro-Oncology

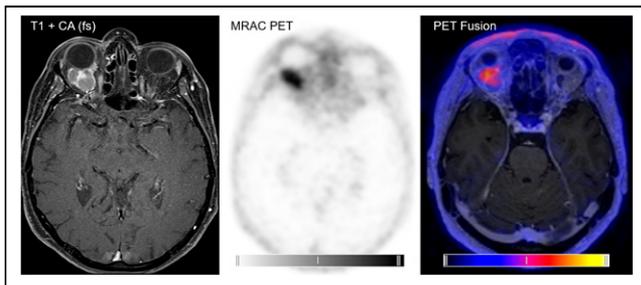
guideline, PET imaging is recommended if the extension of meningioma or the diagnosis itself is uncertain (recommendation level C) (5). Although published data favor PET/MRI over PET/CT or conventional MRI, the limited availability of PET/MRI fuels debate about its actual clinical significance. However, further factors play a prominent role in this debate as well. Physiologic  $SUV_{max}$  in [ $^{68}Ga$ ]-DOTATOC imaging shows large intra- and interindividual differences as well as very heterogeneous distribution patterns (27). Kim et al. demonstrated that appropriate cutoff values for PET-assisted diagnosis of meningiomas still remain controversial and uncertain. They proposed an  $SUV_{ratio}$  relative to the superior sagittal sinus with a threshold at 3.2, which may provide an optimal level of sensitivity (26). Rachinger et al. proposed a cutoff value at 2.3 for  $SUV_{max}$  to discriminate between meningioma and nonmeningioma tissues (17).

In imaging of meningioma of the skull base, evidence regarding the clinical value of [ $^{68}Ga$ ]-DOTATOC PET/MRI is still lacking. However, our results do not show a significant benefit for PET/MRI in this diagnostic scenario because sensitivity, specificity, positive predictive value, negative predictive value, and diagnostic accuracy displayed similar results. However, the specificity of PET/MRI was slightly superior (75%) to that of MRI (66%). These findings agree with previous studies on PET imaging of

meningioma. Rachinger et al. provided comparable values for sensitivity (90%) and specificity (73%) in their DOTATATE PET assessment at a threshold of 2.3 for  $SUV_{max}$  (17). At the same time, Kim et al. observed lower values for sensitivity (78%) while maintaining high values for specificity (98%) in their assessment (threshold,  $SUV_{max}$ , 4.7) (26). However, due to the different properties of DOTATOC and DOTATATE, a direct comparison with the above-mentioned studies is limited, although substantial differences in terms of diagnostic quality have not been demonstrated yet (28,29). As observed in our cohort, mischaracterization of lymphoma still poses a challenge in SSTR PET-assisted imaging. Individual studies have already demonstrated immunopositivity of lymphoma cells for SSTR<sub>2</sub>, especially for diffuse large B-cell lymphoma subtypes (30,31). As observed in our cohort,



**FIGURE 2.** Rates of infiltration as detected by MRI and PET/MRI.



**FIGURE 3.** [ $^{68}\text{Ga}$ ]-DOTATOC uptake in diffuse large B-cell lymphoma of right orbital space. CA = contrast agent; fs = fat saturation; MRAC = MR-based attenuation correction.

SSTR<sub>2</sub>-positive lymphoma may mimic meningioma and lead to a false diagnosis (Fig. 3). Significantly increased tracer uptake was also found in a patient with a cavernous venous malformation of the intraconal space ( $\text{SUV}_{\text{max}}$ , 4.3). Cavernous venous malformations are among the most common benign intraorbital lesions in adults (32). The literature shows examples of hemangiomas and vascular formations in other locations that have shown increased tracer uptake in [ $^{68}\text{Ga}$ ]-DOTATOC PET, most likely due to blood pooling (33,34).

Comparably, false positives and false negatives also predominantly involved suspected optic sheath meningioma in the MRI assessment. Atypical MRI signaling of 2 lesions in the course of the optic nerve evaluation led to misidentification of histologically proven optic sheath meningioma. Furthermore, MRI failed to expose the intraorbital cavernous venous malformation because it displayed characteristics of atypical meningioma. Another lesion could not be assigned definitively to a specific entity on MRI and was therefore wrongfully interpreted as atypical meningioma. This patient was later diagnosed with lymphoproliferative hyperplasia. This tumor can display morphologic similarity to optic sheath meningioma, especially considering its homogeneous contrast enhancement. Just as in the PET/MRI assessment, misdiagnoses in the MRI assessment were exclusively related to intraorbital tumors. Although malignant and benign lesions of the orbital space can be well differentiated on the basis of morphologic characteristics on cross-sectional imaging (35), pretherapeutic baseline imaging cannot replace surgical assessment for diagnostic differentiation (36). As the example of Tolosa-Hunt syndrome shows, space-occupying lesions in this area are difficult to differentiate morphologically and therefore often require further diagnostic measures (37). Hence, imaging of intraorbital lesions should be considered primarily for treatment planning and secondarily for confirmation of diagnosis.

Infiltration and compression of surrounding structures such as the cavernous sinus or ICA have a major impact on therapeutic planning and the eligibility for a surgical approach (6,38). Therefore, imaging must provide reliable information on contacts and infiltration of the neighboring structures. In particular, infiltration of the cavernous sinus is difficult to assess with MRI. Although PET/MRI provided us with complementary information on tumor characteristics, it did not provide a significant advantage for tumor infiltration when compared with the results from MRI in our study. Specifically, SSTR positivity of the pituitary gland posed a source of error in the evaluation of this region. Nevertheless, SSTR PET can be beneficial in therapeutic planning because of supplementary

information gained by PET and improved delineation of tumor margins (20,22,39). The visualization of the SSTR<sub>2</sub> status is the basic requirement for radioligand therapy (40). Despite there being no current consensus on the detailed dosage and administration modality of peptide-receptor radioligand therapy in meningioma patients, SSTR PET has to be considered an important asset in the process of treatment planning of meningiomas and should therefore be widely available (41). This is particularly relevant for patients with inoperable meningiomas at the skull base. Due to the limited availability of PET/MRI, a 2-step approach consisting of a diagnostic MRI and a sequential low-dose PET/CT could provide a practical and cost-sensitive approach in such cases or in equivocal findings in morphologic imaging alone. Integrated [ $^{68}\text{Ga}$ ]-DOTATOC PET/MRI should be reserved for tertiary care centers or clinical studies.

One of the limiting factors of our study was its retrospective characteristic. MRI protocols changed over the time span of the investigation, thus leading to slight alterations in imaging results. In particular, limited access to histopathologic data proved to be challenging for our evaluation. Additionally, there were no histopathologic data available to us with which to correlate the image features of infiltration and the actual infiltration. Surgical specimens of all suspected lesions would have been desirable as a reliable reference standard. However, current guidelines do not require histologic confirmation of meningioma before the initiation of therapy (5). Additionally, because our focus was on the skull base, most analyzed lesions were difficult to access. The risk of complications outweighed the benefit of histologic confirmation. In accordance with previous studies, the reference standard was composed of the available histopathologic data and cross-sectional imaging, including follow-up examinations.

## CONCLUSION

Our results demonstrate the comparable diagnostic performance of conventional MRI and [ $^{68}\text{Ga}$ ]-DOTATOC PET/MRI for the detection and evaluation of meningioma of the skull plane and orbital space. However, PET assessment can give supplementary information on therapy-relevant factors. Furthermore, it provides the basis for radionuclide therapy by quantifying SSTR expression of meningioma. To optimize the acquisition of diagnostic information, we propose the inclusion of a 2-step approach consisting of high-quality MRI and sequential low-dose SSTR PET/CT in equivocal cases or before peptide-receptor radioligand therapy or radiotherapy.

## DISCLOSURE

Aleksandar Milosevic has received travel grants from Bayer AG. Wolfgang Fendler reports fees from SOFIE Biosciences (research funding), Janssen (consultant, speaker), Calyx (consultant), Bayer (consultant, speaker, research funding), Parexel (image review), Novartis (speaker), and Telix (speaker) outside of the submitted work. Manuel Weber reports fees from Boston Scientific, Terumo, Advanced Accelerator Applications, and Eli Lilly outside of the submitted work. Lazaros Lazaridis received honoraria and travel support from Novocure. Benedikt Schaarschmidt received report fees from AstraZeneca (speaker), PharmaCept (research grant), and the Else-Kröner-Fresenius foundation (research grant). No other potential conflict of interest relevant to this article was reported.

## KEY POINTS

**QUESTION:** Are there any significant benefits of implementing SSTR PET/MRI into diagnostic workflows of meningioma patients when compared with MRI only?

**PERTINENT FINDINGS:** We observed no significant differences between the 2 modalities. There was no significant improvement in detection and evaluation of meningiomas on PET/MRI.

**IMPLICATIONS FOR PATIENT CARE:** Conventional MRI is sufficient to assess local tumor extent. Additional molecular characteristics, such as screening for peptide-receptor radioligand therapy, can be obtained by sequential PET/CT without loss of information.

## REFERENCES

1. Wiemels J, Wrensch M, Claus EB. Epidemiology and etiology of meningioma. *J Neurooncol.* 2010;99:307–314.
2. Dolecek TA, Dressler EVM, Thakkar JP, Liu M, Al-Qaisi A, Villano JL. Epidemiology of meningiomas post-public law 107-206: the benign brain tumor cancer registries amendment act. *Cancer.* 2015;121:2400–2410.
3. Bi WL, Prabhu VC, Dunn IF. High-grade meningiomas: biology and implications. *Neurosurg Focus.* 2018;44:E2.
4. Neuschmelting V, Goldbrunner R. Meningeome. In: Schmol H-J, Höffken K, Possinger K, eds. *Kompandium Internistische Onkologie.* Springer Reference Medizin. Springer; 2021.
5. Goldbrunner R, Stavrinou P, Jenkinson MD, et al. EANO guideline on the diagnosis and management of meningiomas. *Neuro Oncol.* 2021;23:1821–1834.
6. Kotapka MJ, Kalia KK, Martinez AJ, Sekhar LN. Infiltration of the carotid artery by cavernous sinus meningioma. *J Neurosurg.* 1994;81:252–255.
7. Afshar-Oromieh A, Giesel FL, Linhart HG, et al. Detection of cranial meningiomas: comparison of  $^{68}\text{Ga}$ -DOTATOC PET/CT and contrast-enhanced MRI. *Eur J Nucl Med Mol Imaging.* 2012;39:1409–1415.
8. Mahase SS, Roth O'Brien DA, No D, et al. [ $^{68}\text{Ga}$ ]-DOTATATE PET/MRI as an adjunct imaging modality for radiation treatment planning of meningiomas. *Neurooncol Adv.* 2021;3:vdab012.
9. Arena S, Barbieri F, Thellung S, et al. Expression of somatostatin receptor mRNA in human meningiomas and their implication in in vitro antiproliferative activity. *J Neurooncol.* 2004;66:155–166.
10. Frilling A, Sotiropoulos GC, Radtke A, et al. The impact of  $^{68}\text{Ga}$ -DOTATOC positron emission tomography/computed tomography on the multimodal management of patients with neuroendocrine tumors. *Ann Surg.* 2010;252:850–856.
11. Poeppel TD, Binse I, Petersenn S, et al.  $^{68}\text{Ga}$ -DOTATOC versus  $^{68}\text{Ga}$ -DOTATATE PET/CT in functional imaging of neuroendocrine tumors. *J Nucl Med.* 2011;52:1864–1870.
12. Deuschl C, Kirchner J, Poeppel T, et al.  $^{11}\text{C}$ -MET PET/MRI for detection of recurrent glioma. *Eur J Nucl Med Mol Imaging.* 2018;45:593–601.
13. Kirchner J, Schaarschmidt BM, Sauerwein W, et al.  $^{18}\text{F}$ -FDG PET/MRI vs MRI in patients with recurrent adenoid cystic carcinoma. *Head Neck.* 2019;41:170–176.
14. Schaarschmidt BM, Heusch P, Buchbender C, et al. Locoregional tumour evaluation of squamous cell carcinoma in the head and neck area: a comparison between MRI, PET/CT and integrated PET/MRI. *Eur J Nucl Med Mol Imaging.* 2016;43:92–102.
15. Graef J, Furth C, Kluge AK, et al.  $^{68}\text{Ga}$ -DOTATOC-PET/MRI: a secure one-stop shop imaging tool for robotic radiosurgery treatment planning in patients with optic nerve sheath meningioma. *Cancers (Basel).* 2021;13:3305.
16. Grueneisen J, Schaarschmidt BM, Heubner M, et al. Integrated PET/MRI for whole-body staging of patients with primary cervical cancer: preliminary results. *Eur J Nucl Med Mol Imaging.* 2015;42:1814–1824.
17. Rachinger W, Stoecklein VM, Terpolilli NA, et al. Increased  $^{68}\text{Ga}$ -DOTATATE uptake in PET imaging discriminates meningioma and tumor-free tissue. *J Nucl Med.* 2015;56:347–353.
18. Afshar-Oromieh A, Wolf MB, Kratochwil C, et al. Comparison of  $^{68}\text{Ga}$ -DOTATOC-PET/CT and PET/MRI hybrid systems in patients with cranial meningioma: initial results. *Neuro Oncol.* 2015;17:312–319.
19. Galldiks N, Albert NL, Sommerauer M, et al. PET imaging in patients with meningioma: report of the RANO/PET group. *Neuro Oncol.* 2017;19:1576–1587.
20. Gehler B, Paulsen F, Öksüz MÖ, et al. [ $^{68}\text{Ga}$ ]-DOTATOC-PET/CT for meningioma IMRT treatment planning. *Radiat Oncol.* 2009;4:56.
21. Kunz WG, Jungblut LM, Kazmierczak PM, et al. Improved detection of transsosseous meningiomas using  $^{68}\text{Ga}$ -DOTATATE PET/CT compared with contrast-enhanced MRI. *J Nucl Med.* 2017;58:1580–1587.
22. Graf R, Nyuyki F, Steffen IG, et al. Contribution of  $^{68}\text{Ga}$ -DOTATOC PET/CT to target volume delineation of skull base meningiomas treated with stereotactic radiation therapy. *Int J Radiat Oncol Biol Phys.* 2013;85:68–73.
23. Salmon E, Bernard Ir C, Hustinx R. Pitfalls and limitations of PET/CT in brain imaging. *Semin Nucl Med.* 2015;45:541–551.
24. Welsh JS. Beta radiation. *Oncologist.* 2006;11:181–183.
25. Einhellig HC, Siebert E, Bauknecht H-C, et al. Comparison of diagnostic value of  $^{68}\text{Ga}$ -DOTATOC PET/MRI and standalone MRI for the detection of intracranial meningiomas. *Sci Rep.* 2021;11:9064.
26. Kim SH, Roytman M, Madera G, et al. Evaluating diagnostic accuracy and determining optimal diagnostic thresholds of different approaches to [ $^{68}\text{Ga}$ ]-DOTATATE PET/MRI analysis in patients with meningioma. *Sci Rep.* 2022;12:9256.
27. Mikat C, Boy C, Heusner T, et al.  $^{68}\text{Ga}$ -DOTATOC-PET/CT imaging and somatostatin receptor “fingerprints” in physiological human tissues: “SUVmax meets mRNA expression” [in German]. *Rofa.* 2010;182:VO101\_4.
28. Johnbeck CB, Knigge U, Loft A, et al. Head-to-head comparison of  $^{64}\text{Cu}$ -DOTATATE and  $^{68}\text{Ga}$ -DOTATOC PET/CT: a prospective study of 59 patients with neuroendocrine tumors. *J Nucl Med.* 2017;58:451–457.
29. Velikyan I, Sundin A, Sörensen J, et al. Quantitative and qualitative intrapatient comparison of  $^{68}\text{Ga}$ -DOTATOC and  $^{68}\text{Ga}$ -DOTATATE: net uptake rate for accurate quantification. *J Nucl Med.* 2014;55:204–210.
30. Juntikka T, Vaitinen S, Vahlberg T, Jyrkkö S, Minn H. Somatostatin receptors and chemokine receptor CXCR4 in lymphomas: a histopathological review of six lymphoma subtypes. *Front Oncol.* 2021;11:710900.
31. Ruuska T, Ramírez Escalante Y, Vaitinen S, et al. Somatostatin receptor expression in lymphomas: a source of false diagnosis of neuroendocrine tumor at  $^{68}\text{Ga}$ -DOTANOC PET/CT imaging. *Acta Oncol.* 2018;57:283–289.
32. Calandriello L, Grimaldi G, Petrone G, et al. Cavernous venous malformation (cavernous hemangioma) of the orbit: current concepts and a review of the literature. *Surv Ophthalmol.* 2017;62:393–403.
33. Gilardi L, Vadrucchi M, Grana CM. Multiple vertebral hemangiomas: a potential pitfall in  $^{68}\text{Ga}$ -DOTATOC PET/CT interpretation. *Endocrine.* 2017;55:992–993.
34. Schreiter NF, Nogami M, Steffen I, et al. Evaluation of the potential of PET-MRI fusion for detection of liver metastases in patients with neuroendocrine tumours. *Eur Radiol.* 2012;22:458–467.
35. Ben Simon GJ, Annunziata CC, Fink J, Villablanca P, McCann JD, Goldberg RA. Rethinking orbital imaging: establishing guidelines for interpreting orbital imaging studies and evaluating their predictive value in patients with orbital tumors. *Ophthalmology.* 2005;112:2196–2207.
36. Eisen MD, Yousem DM, Loevner LA, Thaler ER, Bilker WB, Goldberg AN. Preoperative imaging to predict orbital invasion by tumor. *Head Neck.* 2000;22:456–462.
37. Kline LB, Hoyt WF. The Tolosa–Hunt syndrome. *J Neurol Neurosurg Psychiatry.* 2001;71:577–582.
38. Larson JJ, van Loveren HR, Balko MG, Tew JM. Evidence of meningioma infiltration into cranial nerves: clinical implications for cavernous sinus meningiomas. *J Neurosurg.* 1995;83:596–599.
39. Barone F, Insera F, Scalia G, et al.  $^{68}\text{Ga}$ -DOTATOC PET/CT follow up after single or hypofractionated gamma knife ICON radiosurgery for meningioma patients. *Brain Sci.* 2021;11:375.
40. Unterrainer M, Niyazi M, Tonn J, Ilhan H, Bartenstein P, Albert NL. Current status of SSR-directed imaging and therapy in meningioma. *Clin Transl Imaging.* 2019;7:171–180.
41. Filippi L, Palumbo I, Bagni O, Schillaci O, Aristei C, Palumbo B. Somatostatin receptor targeted PET-imaging for diagnosis, radiotherapy planning and theranostics of meningiomas: a systematic review of the literature. *Diagnostics (Basel).* 2022;12:1666.