Role of ^{68}Ga-DOTA-TOC PET/CT in the Evaluation of Meningiomas with Osseous Involvement

Sharjeel Usmani[1,2], Syed Furqan Hashmi[3], Anjali Jain[4], Khulood Al Riyami[5], Rashid al Sukaiti[6], Najeeb Ahmed[7], Muhammad Shahzad Shamim[8]

Abstract

Meningiomas with osseous involvement present unique diagnostic and therapeutic challenges due to their variable patterns of bone remodelling, hyperostosis, and direct bone infiltration. While MRI and CT remain the standard imaging modalities for evaluating soft-tissue extension and bony architecture respectively, they often fall short in accurately distinguishing true tumour invasion from reactive changes, particularly in complex skull-base and calvarial locations. ^{68}Ga-DOTA-TOC PET/CT represents a pivotal advancement in the imaging of meningiomas with osseous involvement, enhancing diagnostic accuracy, enabling multimodality management, and supporting personalized therapeutic strategies.

Keywords: ^{68}Ga-DOTA PET/CT; meningiomas; radiotherapy planning

DOI: https://doi.org/10.47391/JPMA.26-14

Introduction

Meningiomas are the most common primary intracranial tumours, arising from arachnoid cap cells and typically exhibiting a slow-growing, extra-axial pattern. Although often benign, a substantial proportion demonstrates biologically aggressive behaviour, complex anatomical extension, or involvement of adjacent bone.[1] Osseous involvement—manifesting as hyperostosis, cortical erosion, or frank marrow infiltration, represents a distinct imaging and clinical challenge. These changes may occur in up to one-third of meningiomas, particularly those involving the sphenoid wing, orbit, and skull base. Differentiating true tumour infiltration from reactive hyperostosis is critical, as it directly influences surgical planning, the extent of resection, and the need for adjuvant therapy. However, conventional imaging modalities, especially MRI and CT, frequently struggle to make this distinction with sufficient accuracy, especially in cases with previous surgery, radiotherapy, or complex skull-base anatomy.[2]

Molecular imaging with ^{68}Ga-DOTA-TOC PET/CT has emerged as a powerful complementary modality in this context. By targetting somatostatin receptor subtype 2 (SSTR2), which is strongly expressed in most meningiomas, ^{68}Ga-DOTA-TOC provides highly specific functional information that significantly enhances tumour visualization.[3,4] Its superior lesion-to-background contrast allows for accurate delineation of both soft-tissue and osseous components, supporting improved diagnostic confidence in complex and postoperative cases.[5]

Osseous involvement occurs in approximately 25–30% of meningiomas, particularly in skull-base tumours such as the sphenoid wing and orbitofrontal region.[6] It may present as reactive hyperostosis, caused by tumour-induced osteoblastic activity and periosteal stimulation, or as true tumour infiltration into the bone marrow. Clinically, osseous involvement influences surgical strategy, as reactive changes may not require extensive resection, whereas infiltrative lesions necessitate wider margins. (Figure). A small cohort study by Matschke J et al., suggests that there is high expression of somatostatin receptor 2A (SSR2A) in the histogenesis of hyperostosis in meningioma.[7]

^{68}Ga-DOTA-TOC PET/CT is a functional imaging modality that targets somatostatin receptor subtype 2 (SSTR2), highly expressed in the majority of meningiomas. By visualizing metabolically active tumours with high lesion-to-background contrast, it complements MRI and CT, particularly in differentiating true osseous infiltration from reactive hyperostosis. This capability allows precise assessment of tumour extent within both bone and soft tissue.[8] PET/CT also detects residual or recurrent disease, even in regions obscured by scar tissue or post-radiotherapy changes. Quantitative metrics such as standardized uptake values (SUV) and tumour-to-background ratios provide additional information on tumour activity, burden, and aggressiveness. Integration with MRI or CT enhances preoperative planning by accurately delineating tumour margins in complex skull-

[1,3-6]Department of Radiology and Nuclear Medicine, Sultan Qaboos Comprehensive Cancer Care and Research Center (SQCCCRC), University Medical City, Muscat Oman; [2,7]Hull Molecular Imaging and Research Center, UK; [8]Section of Neurosurgery, Aga Khan University hospital, Karachi, Pakistan.
Correspondence: Muhammad Shahzad Shamim.
e-mail: shahzad.shamim@aku.edu
ORCID ID: 0000-0001-8305-8854

base anatomy, while guiding targetted radiotherapy to minimize geographic miss. ^{68}Ga-DOTA-TOC PET/CT accurately identifies areas of active tumour within the bone, enabling improved assessment of tumour extent and more confident differentiation of neoplastic versus non-neoplastic bone changes.[9,10] Moreover, high SSTR2 expression identified on PET/CT establishes a theranostic pathway for peptide receptor radionuclide therapy (^{177}Lu-DOTA-TATE), offering a personalized treatment option for recurrent or unresectable meningiomas. Overall, ^{68}Ga-

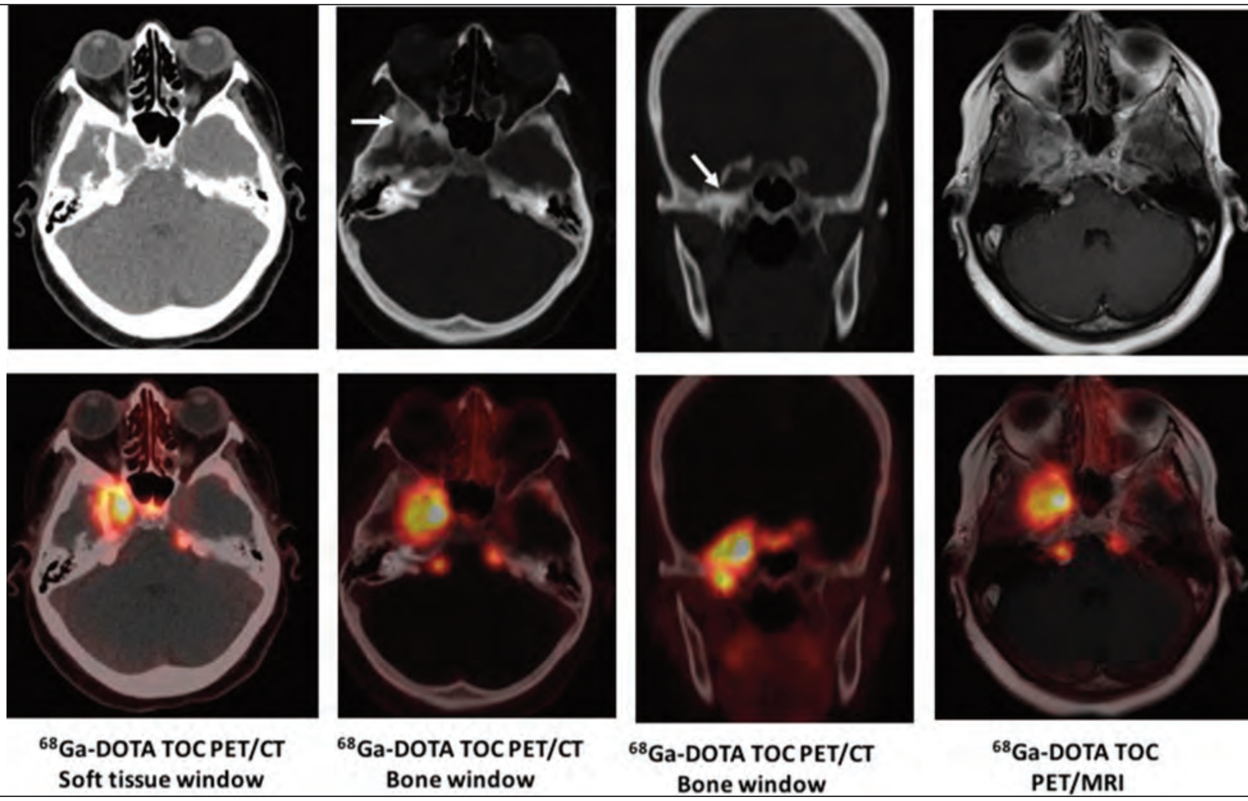

Figure: Large somatostatin avid extraaxial lesion at right sphenoid region along with multiple ^{68}Ga- DOTATOC avid dural lesions along bilateral petrous part of temporal bone and lessor wing of left sphenoid. Corresponding CT shows hyperostosis/ periosteal reaction of the adjacent bone and subcortical calcification (white arrow). ^{68}Ga- DOTATOC PET CT findings are suggestive of somatostatin receptor–avid meningioma with tumour infiltration of the underlying right sphenoid bone.

Table: Comparison of MRI, CT, and ^{68}Ga-DOTA-TOC PET/CT in Meningiomas With Osseous Involvement.

Parameter	MRI	Outcome	^{68}Ga-DOTA-TOC PET/CT
Primary Strength	Superior soft-tissue contrast and dural assessment	Best for detecting hyperostosis, bone remodelling, and calcification	Highly specific molecular imaging of SSTR2 expression; excellent lesion contrast
Detection of Osseous Involvement	Limited in differentiating tumour infiltration from reactive hyperostosis	Excellent for structural bone assessment, limited in differentiating tumour infiltration	Best for distinguishing true tumour infiltration from reactive changes
Soft-Tissue Extension	Excellent delineation of dural and parenchymal involvement	Limited	High sensitivity, complements MRI for exact extent
Accuracy in Complex Skull Base Anatomy	Can be limited by artifacts or postoperative changes	Good visualization of bone anatomy, but not tumour activity	Superior lesion-to-background contrast; precise mapping in skull base regions
Differentiating Active Tumour vs Post-Treatment Changes	Difficult; enhancement may be nonspecific	Not suitable	Excellent—captures viable tumour based on SSTR expression
Radiotherapy Planning	Useful but may overestimate or underestimate margins	Limited; structural only	Provides highly specific GTV definition; improves target volume accuracy
Surgical Planning Value	Identifies dural tail and soft tissue involvement	Defines areas of hyperostosis, cannot identify infiltration	Clarifies tumour extent in bone; guides need for wider resection
Assessment of Recurrence	Challenging due to scar and inflammation	Poor	Highly accurate for detecting residual or recurrent disease
Theranostic Link	None	None	Enables selection for ^{177}Lu-DOTA-TATE therapy
Overall Role	Best for initial soft-tissue evaluation	Best for structural bone assessment, limits viable tumour assessment	Best for functional characterization and defining true tumour burden

DOTA-TOC PET/CT bridges anatomical and functional imaging, improving diagnostic accuracy, treatment planning, and individualized management in meningiomas with osseous involvement. Comparison of MRI, CT, and ^{68}Ga-DOTA-TOC PET/CT in meningiomas with osseous involvement mentioned in Table.

^{68}Ga-DOTA PET/CT integration allows precise gross tumour volume (GTV) definition, particularly in complex skull-base anatomy where MRI and CT may underestimate tumour extent. By identifying metabolically active tumour, PET-guided contouring reduces the risk of geographic miss and ensures more targeted delivery of radiation while sparing adjacent critical structures.[11,12] Incorporating 68Ga-DOTA PET/CT can effectively differentiate benign bone changes e.g. post operative scar or bone oedema from viable tumour and in addition to increasing tumour volume, can also lead to reduced tumour volumes, especially those involving critical structures in the brain, therefore reduce morbidity with better outcomes.

^{68}Ga-DOTA-TOC PET/CT also effectively distinguishes recurrent tumour from postoperative changes or fibrosis, enhancing early detection and guiding timely intervention.[13] Its high specificity and sensitivity reduce false positives that can confound MRI interpretation, particularly in previously irradiated areas.[14]

Despite its clear advantages, 68Ga-DOTA-TOC PET/CT has several limitations in the evaluation of meningiomas with osseous involvement. Availability and accessibility remain restricted in many regions due to the need for specialized radiotracers and PET/CT facilities. Sensitivity may vary in higher-grade or atypical meningiomas, which can exhibit heterogeneous SSTR2 expression, potentially leading to underestimation of tumour burden. Standardized imaging protocols and quantitative thresholds for osseous tumour assessment are still evolving, limiting cross-center comparability and reproducibility. Cost considerations may also restrict widespread adoption. Additionally, interpretation requires expertise to avoid false positives from non-specific SSTR uptake in inflammatory lesions or other intracranial tumours.

Conclusion:

Meningiomas with osseous involvement pose significant diagnostic and management challenges due to the difficulty of distinguishing true tumour infiltration from reactive bone changes using conventional imaging alone. The integration of ^{68}Ga-DOTA-TOC PET/CT has transformed this landscape by providing highly specific SSTR2-targetted molecular information that complements the anatomical detail of MRI and CT. Incorporation of PET data into radiotherapy planning enhances target volume accuracy, while postoperative evaluation benefits from reliable differentiation between recurrence and treatment-related changes.

Conflict of interest: None.

References

1. Rogers L, Gilbert M, Vogelbaum MA. Intracranial meningiomas of atypical (WHO grade II) histology. J Neurooncol. 2010;99:393–405 .
2. Goldbrunner R, Minniti G, Preusser M et al. EANO guidelines for the diagnosis and treatment of meningiomas. Lancet Oncol. 2016; 17:e383–e391
3. Theodoropoulou M, Stalla GK. Somatostatin receptors: from signaling to clinical practice. Front Neuroendocrinol. 2013; 34:228–52.
4. Usmani S, Jain A, Hashmi SF, et al. 68Ga-DOTA-peptide PET/CT for radiotherapy planning and evaluating treatment response in the management of meningiomas. J Pak Med Assoc. 2023;73:1340-1343.
5. Usmani S, Jain A, Al Riyami K, Hashmi SF, Khalid J, Kheruka S. Molecular Perspectives on Meningioma with Osseous Infiltration Revealed by 68Ga-DOTA TOC PET-CT. Mol Imaging Radionucl Ther. 2025;34:152-155
6. Akutsu H, Sugita K, Sonobe M, Matsumura A. Parasagittal meningioma en plaque with extracranial extension presenting diffuse massive hyperostosis of the skull [published correction appears in Surg Neurol. 2004 ;61:503]. Surg Neurol. 2004;61:165-169.
7. Matschke J, Addo J, Bernreuther C, Zustin J. Osseous changes in meningioma en plaque. Anticancer Res. 2011;31:591-596.
8. Palmisciano P, Watanabe G, Conching A, et al. The Role of [68Ga]Ga-DOTA-SSTR PET Radiotracers in Brain Tumors: A Systematic Review of the Literature and Ongoing Clinical Trials. Cancers (Basel). 2022;14:2925.
9. Kunz WG, Jungblut LM, Kazmierczak PM, Vettermann FJ, Bollenbacher A, et al. Improved detection of transosseous meningiomas using (68)Ga-DOTATATE PET/CT compared with contrast-enhanced MRI. J Nucl Med. 2017;58:1580–1587.
10. Perlow HK, Siedow M, Gokun Y, McElroy J, Matsui J, et al. 68Ga-DOTATATE PET-Based Radiation Contouring Creates More Precise Radiation Volumes for Patients With Meningioma. Int J Radiat Oncol Biol Phys. 2022;113:859-865.
1 . Milker-Zabel S, Zabel-du Bois A, Henze M, et al. Improved target volume definition for fractionated stereotactic radiotherapy in patients with intracranial meningiomas by correlation of CT, MRI, and [68Ga]-DOTATOC-PET. Int J Radiat Oncol Biol Phys. 2006;65:222-227.
12. Kowalski ES, Khairnar R, Gryaznov AA, Kesari V, Koroulakis A,, et al. 68Ga-DOTATATE PET-CT as a tool for radiation planning and evaluating treatment responses in the clinical management of meningiomas. Radiat Oncol. 2021;16:151. doi: 10.1186/s13014-021-01875-6. PMID: 34399805; PMCID: PMC8365988.
13. Kong MJ, Yang AF, Vora SA, Ross JS, Yang M. The Complementary Role of 68Ga-DOTATATE PET/CT in Diagnosis of Recurrent Meningioma. J Nucl Med Technol. 2022 Aug 30:jnmt.122.263949. doi: 10.2967/jnmt.122.263949. Epub ahead of print. PMID: 36041874.
14.. Bashir A, Larsen VA, Ziebell M, et al. Improved Detection of Postoperative Residual Meningioma with [68Ga]Ga-DOTA-TOC PET Imaging Using a High-resolution Research Tomograph PET Scanner. Clin Cancer Res. 2021;27:2216-2225.