Review Article

Exploring the Role of Neuroradiologists in NeuroOncology Tumor Boards: A Review

Alisha Ahmed[1,*], Sumaira Rehman[1], Fatima Shaukat[2], Zainab Anwar[1]

[1]*Jinnah Sindh Medical University, Karachi, Pakistan.*

[2]*Department of Radiation Oncology, Cyberknife and Tomotherapy Centre, Jinnah Postgraduate Medical Center (JPMC), Karachi, Pakistan.*

Abstract: The role of Neuroradiology in diagnosing and managing nervous system malignancies places it as an essential component of Neuro-oncology multidisciplinary tumor boards. Lesions are identified and characterized using advanced imaging, and choices of therapy are guided. They provide crucial insights to surgeons in planning resections and biopsies in vitally sensitive brain regions. In addition, they aid post treatment follow-up and radiotherapy. They collaborate with neurosurgeons, neuropathologists, radiation and medical oncologists in these meetings to review cancer cases, integrate imaging with histopathology, formulate treatment plans for best patient interest. The paper aims to study the role of Neuroradiologists in nMTB. Neuroradiologists face many challenges and limitations during interdisciplinary collaborations owing to the complexities of emerging neuroradiological imaging modalities. Other than that there are problems such as communication barriers mainly due to the use of technical words, lack of patient communication, and lack of interpersonal communication between neuroradiologists and referring clinicians that can have a negative impact on the understanding or potentially the clinical outcomes of MTBs. The new and emerging diagnostic modalities can be useful to neuroradiologists in accurate diagnosis, grading, management, and prognosis prediction in multidisciplinary. Advanced AI models such as Radionomics, radiogenomics, and deep learning models can detect complex imaging features, and distinguish between brain GBM and brain metastasis which can help predict patient survival. However, their potential rests in the new knowledge about this condition as these clinical data are limited due to lack of generalizability and reproducibility. Interpreting neuroradiological results are precise; accurate diagnosis requires specialized training in neuroradiology. Structured training program also ensures that neuroradiologist adheres to standardized practices and prevents any clash of difference among neuroradiologists.

Keywords: Neuro oncology Multidisciplinary Tumor Board (nMTB), Glioblastoma, Multidisciplinary Tumor Board (MTB), Radionomics, Neuroradiologist.

INTRODUCTION

Most medical specialties view cancer as very complex disease. It is important to examine new advances in the era of precision medicine, which is defined as the information being gathered about a person's genetics, environmental situation, and lifestyle to select suitable therapy. Precision oncology, or focused changes chosen based on the type of cancer, is driving a massive increase in cancer research. For determining specific targeted therapies and precise treatment modalities when considering cancer care, there comes multidisciplinary cancer care teams [1]. According to the Calman-Hine report, which outlines the principles for organizing and structuring exceptional multidisciplinary treatment given the reality of increasing complexity of managing cancer and its inconsistent results, this is where these teams commence their activities [2].

Multidisciplinary Tumor boards (MTBs) review newly diagnosed and ongoing cancer cases. Regularly scheduled meetings including multiple clinicians, focus to improve clinical outcomes and to provide cost- effective care in complex malignancies, in addition to it, some boards focus on rare cases for instructional purposes [3, 4].

* Address correspondence to this author at the Jinnah Sindh Medical University, Karachi, Pakistan. Email: alishaahmed019@gmail.com

Neuro oncology is a field of medicine concerned with diagnosis and treatment of tumor localization of the nervous system and main directions of treatment are surgery, radiation therapy, and medications (usually consisting of chemotherapy, immunomodulators, etc). Nervous system tumors necessitate a collaborative approach, and neuroradiology must have a leading role in the care of these patients. Patients with neurological symptoms, with indications for the use of imaging methods, in most cases MRI of spine and brain. Neuroradiology is a subspecialty of radiology that is mainly involved in diagnosis giving radiographic possibilities to neuro oncologists [5].

Indeed, neuroradiologists are essential to the diagnostic process and facilitate a clear diagnosis through providing important and essential information in such a way. Imaging is initially performed to identify and characterize the lesion and then precisely maps its anatomical location within the brain [6]. In other words, we need neuroradiology to know if the lesion is a glioma and then further imaging is done to define it. Advanced imaging techniques can help to determine if a lesion lies in an area amenable to surgical resection or a biopsy. When the lesion is close to or within eloquent brain areas, it is impossible to test any intervention without exacerbating neurologic deficits [7]. In the case of a glioma, these tumors may arise in the cerebral hemispheres or may even invade deep brain structures such as the corpus

 © 2025 NIBD Publications

callosum, where image guided tissue biopsy may be preferable to surgical resection in some cases and the role of neuroradiologists is crucial in making these decisions while achieving the balance between a good quality of diagnostic clarity and risk of intervention [7, 8]. In addition to diagnosis, neuroradiological guidance is important in making therapeutic decisions and in assessing therapeutic response. These include pre-operative imaging methods to assist surgeons in planning the safest route to resect tumors, such as stimulation mapping, corticospinal tract imaging (diffusion tensor imaging based on MRI and transcranial magnetic stimulation) and somatosensory evoked potential techniques; as well as intraoperative neuronavigation, MRI aiding in maximal tumor resection; radiotherapy techniques like diffusion tensor imaging or functional MRI to delineate a tumor focus without surgery; and post treatment imaging assisting in documenting treatment induced alterations or recurrence rate, and so on, providing a measure of treatment efficacy [9-12]. Follow up imaging is invaluable in a timely management of recurrence.

Neuroradiology plays a valuable role in every area of the neurooncology care continuum from the initial diagnosis to continued therapy and progression monitoring. The aim of this paper is to assess the role and impact of neuroradiologists in nMTB where neuroradiologists' specialty niche added value to the patient pathway with the benefit of imaging. In this paper, we will explore how their contributions not only improve tumor staging and surgical planning, but how they are included in patient management long term. The contributions of neuroradiologists in these collaborative settings demonstrates an essential component of neuro-oncology care, which is integrated, team based.

NEURO-ONCOLOGY MTB IMPLEMENTATIONS AND OUTCOMES

A retrospectively reviewed clinical data of paediatric CNS tumor patients have reported reduced histological diagnostic interval following the implementation of MTBs. Additionally, the 5 years overall survival rate has improved significantly in patients with medulloblastoma and other rare CNS tumors [13]. Neuro-oncology MTB plays a vital role in not only determining the histological diagnosis in central nervous system lymphoma (CNSL) but also stratifying surgical candidates. Moreover, nMTBs clinical and radiological assessment showed high diagnostic concordance in cases of relapsing CNSL [14].

Notably, cases discussed during nMTB were reported to have a short referral time compared to those not discussed, highlighting their roles in improved clinical decision making. These discussions further lead to appropriate and timely referral to first line specialists such as neurosurgeons [15, 16].

THE ROLE OF NEURORADIOLOGISTS IN TUMOR BOARDS

Neuro oncology Multidisciplinary tumor boards (nMTB) relies heavily on neuroradiologists. CNS tumors have a major impact in diagnosis, prognosis, and assessing treatment response [17]. When a patient reports with neurological complaint, clinical evaluation collectively with imaging studies helps in formulating the diagnosis. Most common modality used in this regard is Magnetic resonance imaging (MRI) and Computed Tomography scans for diagnosis and follow-up [7]. Although MRI and CT scans proved phenomenal in initial workup, with latest advancement in neuroradiology, nowadays patient workup is strengthened by Positron Emission Tomography (PET) scans which provide essential information about metabolism and proliferation of various cancers [18]. A more current approach now warrants the use of PET/MRI hybrid models [19]. In both combined models, MRI with the ability to generate high resolution images and exceptional tissue contrast adds to the value. Additionally, its subtype, Diffusion weighted imaging (DWI), enhances image to better evaluate cell density, assess tumor grade and extent which can aid in forming surgical resection plan and following prognostic outcomes [20, 21]. On the contrary, PET scans give valuable insights on brain metabolism and functioning, it assists in distinguishing high grade tumors from low grade tumors. Post-treatment PET scans can help detect recurrence and malignant transformation of tumors [22, 23].

In the challenging field of neuro oncology, neuroradiologists play a significant part in augmenting patient care by providing constructive remarks through radiological insights, during tumor board meetings. Thus their input speaks for their role in nMTB and is extremely crucial for standardized patient care. Complex cases of neuro-oncology are discussed in nMTB. The case presentation involves patient history, clinical presentation, imaging differentials, diagnostic studies and proposed treatment strategy. The later domains include integral input from neuroradiology. They discuss diverse image findings which are integrated with histopathological reports. Keeping that in mind, radiological records about diagnosis, anatomical locations, risk to adjacent tissues of the brain and post treatment follow up, the best possible treatment plan is formulated [24].

OTHER SPECIALTIES COLLABORATIVE DYNAMICS

Care for nervous system tumor patients must be multifaceted. Neuro-oncologists in turn work alongside many supportive providers, such as neurosurgeons, radiation oncologists, neuroradiologists, neuropathologists, medical oncologists, palliative medicine, and radiation therapy. Neurosurgeons take great care in developing approaches to resectable tumors or biopsies, while also advising them on important preoperative and postoperative care. Once the tissue samples are obtained they are sent to neuropathologists, who play a crucial role in correlating the tumor's histopathology with radiographic and other investigative findings [5]. Radiation oncologist details the use of intensity-modulated radiotherapy (IMRT), volumetric-modulated arc therapy (VMAT) and stereotactic radiosurgery (SRS). These modalities ensure delivery of higher dose radiations to target pathological focus and also minimize irradiations to adjacent normal brain tissue [25]. Apart from these specialists, input from radiation oncologists is crucial in cases of brain metastasis or to determine appropriate types of radiation therapy [5]. Together these providers show their collaborative role in neuro-oncology tumor board meetings. These meetings ensure efficient patient care as multiple specialists are collaborating to establish diagnosis, making cost effective treatment regimens and post treatment follow up plans [24].

CHALLENGES AND LIMITATIONS

Technical and Interpretation Problems

Variability and complexities in imaging make neuroradiologists face different interpretative and technical challenges and errors. Radiology diagnostic discrepancies are divided into interpretation and perception discrepancies. A study that examined 254 cases of radiological diagnosis errors indicated that interpretation and perception discrepancies were 25.2%, and 74.8%, respectively. The study also showed that two times more interpretation errors could happen in a clinical case when neuroradiologists have not been practicing for less than 5 years. Infectious, autoimmune, and inflammatory diseases are linked to more interpretation discrepancies, whereas perception discrepancy was associated with burden and frequencies of cases read every hour [26]. Another study reports that there is a 2% clinically significant rate of discrepancies in CT and MRI interpreting studies mainly involving vascular and neoplastic lesions [27]. Conditions such as oligodendroglioma exhibit challenging variability in imaging interpretation, as demonstrated by a study that reported visual interpretation difficulties and interobserver discrepancies, even among clinical experts in inferring oligodendroglioma histopathological grading [28]. MRI interpretation variability in traumatic brain injury patients between two neuroradiologists was reported to be problematic, resulting in inconsistent diagnoses and incorrect treatment approaches, which can lead to compromised healthcare and medicolegal issues [29]. The interpretation of large amounts of data generated by advanced imaging modalities poses another challenge for neuroradiologists because it requires specialized knowledge, such as diffusion tensor imaging, and can lead to misinterpretation if not standardized [30].

Communication Barriers

Neuroradiologists encounter numerous barriers and obstacles in trying to communicate with non radiologists what are often quite complicated neuroradiological results. This may be owed to the fact that radiology reports can often include technical terms that patients, and other clinicians, might struggle to understand. Unfavorable effects on healthcare system and on future imaging research may result. The negative impact of communicating incidental findings can be mitigated by including accompanying resources that elaborate on radiological terms in lay terms [31]. Furthermore, neuroradiologists face challenges in communicating critical imaging findings to clinicians, but ongoing feedback from clinicians can improve compliance [32]. Radiologists may also face challenges such as a lack of education and experience in patient communication, navigating clinical uncertainties and coordinating with interprofessional teams, dealing with an expanded scope of practice, and frequently conveying serious news [33].

The lack of interpersonal communication between radiology practitioners and referring clinicians caused by the transition from face-to-face communication to digital imaging and reporting techniques has a negative impact on understanding and, potentially, clinical outcomes [34].

Addressing Discrepancies in Multidisciplinary Setting

Discrepancies and divergent opinions among the tumor board members are addressed during multi-disciplinary neuroradiology imaging review conferences, which have been shown to facilitate radiation treatment planning and management in these patients. A study reports nearly half (47%) of cases presented in MTB experienced a change in imaging interpretation, with 32% experiencing substantial alterations and 14% experiencing subtle changes, resulting in significant changes in the therapeutic management of about 40% of patients, highlighting the significance of neuroradiologist in MDT [35].

Advancements in Neuroradiology and their Impact

Emerging Imaging Technologies

Recent advances in neuro-oncological imaging are poised to revolutionize and improve the diagnosis, histological grading, staging, managing, and monitoring of the neoplasms of the brain. Diffusion-Weighted-Imaging technique (DWI), a valuable aspect of MRI, is used to estimate cell concentration, histopathological tumor grade, and extent, as well as to guide radiotherapy and surgical resection. Positron emission tomography, or PET, gives insight into the metabolic and other functional processes by which the body functions. Differentiation between advanced and early grade tumors and degree of resection, recurrence, and progression to higher grade malignancy is done with this [36].

PET/MRI

PET/MRI using C11-methionine in the form of a tracer has been associated with cancer cells having increased susceptibility for brain cancerous tissues and is independent of metabolism with distinguishing recurrence and post treatment changes of brain tissue. It was found that the hybrid C11-MET-PET/MRI has a higher accuracy, specificity, and sensitivity than MRI or PET alone [37-39].

MR perfusion imaging has surfaced as a promising modality, evaluating blood flow at a tissue level called cerebral blood volume (CBV) to assess the grading of tumors, targeted therapy, disease prognosis and treatment outcomes, and guide biopsies [40]. Increased CBV is found to be associated with higher malignancies [41]. It is also helpful in the diagnostic differentiation of

CNS neoplasms. The three main techniques of MR perfusions are Dynamic-Susceptibility-Contrast-Enhancement (DSC), Arterial-Spin-Labeling (ASL) and Dynamic-Contrast-Enhancement (DCE).While ASL primarily uses arterial blood that has been labeled magnetically alongside using water as an unrestricted diffusion tracer. DSC and DCE monitors density of contrast material to assess the diffusivity and hemodynamic volume using a T1 and T2-weighted acquisition, respectively [42, 43].

Magnetic-Resonance-Fingerprinting

Magnetic-Resonance-Fingerprinting (MRF) is another emerging modality in the domain of neuro-oncologic medicine, reflecting quantification and identification of tissues, helpful in tumor margin detection, discerning primarily originating and metastatic brain tumors, and differentiating between well-differentiated and low-differentiated neoplasms. Three different studies reported that MRF can differentiate between solid tumors (STs) from contralateral white matter (CWM) and in a total of 19 cases, it managed to discern peritumoral white matter (PWM) from (CWM) [44-46].

Magnetic-Resonance-Spectroscopy

Magnetic-Resonance-Spectroscopy (MRS) is a minimally disruptive radiographic modality that determines chemical and metabolic constituents of tissue by detecting signals from the spin of active nuclei within a molecule. Hydrogen (H1), or proton-MRS, detects hydrogen atoms found more commonly in brain tissues as water and lipid molecules. It measures the concentration of various metabolic derivatives like creatine (Cr), N-acetylaspartate (NAA), and choline (Cho) reflecting particular biological processes, giving a close insight into the CNS tissue biochemical states and characterizing different CNS tumors [47]. It can also be useful in guiding biopsies by recognizing areas with high metabolic rates having increased cho levels and low NAA levels [48, 49]. High concentration of Cho is a reflection of proliferation and high cell membrane turnover, which can fluctuate depending on the cellular density, grade of tumor, and necrosis, whereas NAA represents a decline in neuronal cell density, making both a diagnostic marker for gliomas [50].

Magnetic-Resonance-Elastography

Magnetic-Resonance-Elastography (MRE) is another neuro-oncological diagnostic technique which assesses the altered mechanical properties of tissue, such as the varying tissue stiffness demonstrated by CNS neoplastic cells and their surrounding microenvironment. MRE can determine the grade and IDH status of CNS tumors. Advanced-grade gliomas are found to be softer as compared to indolent tumors and the IDH mutant type. Diffusion Tensor Imaging (DTI) is an additional diagnostic technique yielding insights regarding the tumor microstructure leading to differentiation of CNS tumors [51, 52].

AI (Artificial Intelligence) and Machine Learning

A recent study reported that AI models such as Gemini 1.5 pro and GPT 4.0 outperformed radiologists when presented with clinical data alone. However, radiologists surpassed AI models when provided with imaging data alone. The radiologist further improved their performance when provided with both clinical and imaging data and had a better diagnostic accuracy when they had access to suggestions from the AI model [53].

Radionomics entails retrieval of quantitative and subvisual data from certain radiological approaches, like PET or MRI scans, and forms a 3-dimensional tumor representation. Radiogenomics is another important concept correlating genetic mutation status and radiological features. Convolutional-Neural-Networks (CNNs) are a variety of deep learning methods that not only mimic human neurocognitive functioning but can comprehend and discern subtle and complex imaging features [54, 55]. A deep CNN model was developed that can distinguish between brain GBM and brain metastasis using tissue oxygen saturation (mitoPO2) and cerebral metabolic rate of oxygen (CMRO2) with more precision than those made by radiologists [56]. A different radiomic feature was created that could accurately differentiate GBM's peritumoral region (PTR) from low-grade gliomas (LGGs) [57]. Another study using deep CNN and near-infrared-fluorescence imaging for intraoperative diagnosis of gliomas proved to be beneficial. At high levels of sensitivity, this model can potentially improve neurosurgical outcomes by correcting neurosurgical errors [58]. Furthermore, MRI-derived radiomics was used in multiple studies and reported to accurately predict the survival outcome of the patients [59]. Another model called an Artificial Neural Network (ANN) was developed and reported to prognosticate a more precise survival outcome than the Response-Assessment-in-Neuro-Oncology (RANO) guidlines.

Despite the development and success of multiple radiomics and deep learning models in predicting clinical outcomes, the implications of these models in clinical settings are still limited owing to the scarcity of reproducibility and generalizability among the scanners and sites and the insufficient correlation between the fundamental biological characteristics and radiomics features [60]. However, the new and emerging diagnostic modalities can be useful to neuroradiologists in accurate diagnosis, grading, management, and prognosis prediction in multidisciplinary settings.

Educational and Training Aspects

With the growing complexity of neuroimaging and the critical importance of this imaging to patient care, there is a need for specialized neuroradiology training. As half of the visits of the emergency department are concerned with imaging involving neurological complaints, practitioners equipped with specialised training in different neuroimaging are required for precise results interpretation and accurate diagnosis making [61].

Importance of Specialized Training in Neuroradiology

The experience of a neuroradiologist can be guaranteed by having a structured training program that ensures their proficiency, equips them with the skills and knowledge to perform and interpret complex imaging procedures, and ensures the safest, state of the art patient care. Better adherence to standardized practices and protocols, no variations in clinical practice among professionals and to ensure that all physicians are equally knowledgeable and expert in all topics and modalities a standardized training curriculum covering all essential topics and modalities should be developed for all. In this manner, further minimization of disagreements and differences between neuroradiologists in an interdisciplinary setting may be accomplished. An entire evaluation system of written, oral, practical exams are established to ensure only qualified persons are hired meeting the extensive training program requirements, better outcomes for their patients as well as patient safety overall [62].

It also decreases chances of interpretative error, which is common in emergency situations, and other perpetual errors [63]. With a better understanding of neuroanatomy and pathology, they will feel more certain about their diagnosis and their diagnosis accuracy. These specialists are much less likely to miss pathology and incidentalomas compared to general radiologists, especially with new neuroanatomy imaging techniques such as fMRI and DSA [64, 65] for example, senior neuroradiologists and new trainees should come together to develop a culture of mentorship and leadership to educate and drive clinical work and academic activities. As new treatment modalities are introduced and expanded, new treatment modalities should be accompanied by updated training programs that reflect the developments in the field of neuroradiology.

CONCLUSION

The involvement of neuroradiologists may have a large impact in regards to the treatment decisions in MTBs. Advanced diagnostic modalities have opened up the previously strict anatomical field of neuroradiology to more functional and metabolic aspects that can lead to better tumor management, particularly in interdisciplinary settings where neuroradiologists can serve as a liaison between pathology, surgery, and radiooncology by using their sophisticated techniques. Studies have shown that their involvement in MTBs has resulted in more accurate tumor response assessment, grading, diagnosis, and most importantly-differentiation of treatment-induced effects and tumor progression.

Furthermore, it should be further studied how neuroradiologists in MTBs should receive the required training in working together with other professions and how radiogenomics should be included in MTBs to make it possible to predict treatment outcome and improve cancer care decision making for the patients.

ABBREVIATIONS

CNNs: Convolutional-Neural-Networks.

CNS: Central Nervous System.

CT: Scan Computed Tomography Scans.

DWI: Diffusion-Weighted-Imaging technique.

fMRI: Functional MRI.

GBM: Glioblastoma.

IMRT: Intensity-Modulated Radiotherapy.

MRE: Magnetic-Resonance-Elastography.

MRF: Magnetic-Resonance-Fingerprinting.

MRI: Magnetic Resonance Imaging.

MRS: Magnetic-Resonance-Spectroscopy.

MTB: Multidisciplinary Tumor Board.

PET: Positron Emission Tomography.

SRS: Stereotactic Radiosurgery.

VMAT: Volumetric-Modulated Arc Therapy.

AUTHORS' CONTRIBUTION

Alisha Ahmed and **Sumaira Rehman**: Conceptualization, Writing Draft, Critical review and revision the manuscript, Final approval, Final proof to be published.

Fatima Shaukat and **Zainab Anwar**: Conceptualization, Critical review and revision the manuscript, Final approval, Final proof to be published.

ACKNOWLEDGEMENTS

Declared none.

ETHICAL DECLARATIONS

Data Availability

Not applicable.

Ethical Approval

Not applicable.

Consent to Participate

Not applicable.

Consent for Publication

Consented.

Conflict of Interest

Declared none.

Competing Interest/Funding

Declared none.

Use of AI-Assisted Technologies

The authors declare that no generative artificial intelligence (AI) or AI-assisted technologies were utilized in the writing of this manuscript, in the creation of images/graphics/tables/captions, or in any other aspect of its preparation.

REFERENCES

[1] Schwartzberg L, Kim Es, Liu D, Schrag D. Precision oncology: who, how, what, when, and when not? Am Soc Clin Oncol Educ Book 2017; 37: 160-9. https: //ar.iiarjournals.org/content/38/11/6041

[2] Haward RA. The Calman-Hine report: A personal retrospective on the UK's first comprehensive policy on cancer services. Lancet Oncol 2006; 7(4): 336-46.

[3] Kurpad R, Kim W, Rathmell WK, Godley P, Whang Y, Fielding J, *et al.* A multidisciplinary approach to the management of urologic malignancies: Does it influence diagnostic and treatment decisions? Urol Oncol 2011; 29(4): 378-82.

[4] Pillay B, Wootten AC, Crowe H, Corcoran N, Tran B, Bowden P, *et al.* The impact of multidisciplinary team meetings on patient assessment, management and outcomes in oncology settings: A systematic review of the literature. Cancer Treat Rev 2016; 42: 56-72.

[5] Barbaro M, Fine HA, Magge RS. Foundations of neuro-oncology: A multidisciplinary approach. World Neurosurg 2021; 151: 392-401.

[6] Larsson EM, Wikström J. Overview of neuroradiology. Handb Clin Neurol 2017; 145: 579-99.

[7] Langen KJ, Galldiks N, Hattingen E, Shah NJ. Advances in neuro-oncology imaging. Nat Rev Neurol 2017; 13(5): 279-89.

[8] Omuro A. Glioblastoma and other malignant gliomas: A clinical review. JAMA 2013; 310(17): 1842.

[9] Nimsky C, Bauer M, Carl B. Merits and limits of tractography techniques for the uninitiated. In: Schramm J, Ed. Advances and Technical Standards in Neurosurgery. Cham: Springer International Publishing 2016; pp. 37-60.

[10] Pujol S, Wells W, Pierpaoli C, Brun C, Gee J, Cheng G, *et al.* The DTI challenge: Toward standardized evaluation of diffusion tensor imaging tractography for neurosurgery. J Neuroimaging 2015; 25(6): 875-82.

[11] Krieg SM, Sabih J, Bulubasova L, Obermueller T, Negwer C, Janssen I, *et al.* Preoperative motor mapping by navigated transcranial magnetic brain stimulation improves outcome for motor eloquent lesions. Neuro Oncol 2014; 16(9): 1274-82.

[12] Kumar A, Chandra PS, Sharma BS, *et al.* The role of neuronavigation-guided functional MRI and diffusion tensor tractography along with cortical stimulation in patients with eloquent cortex lesions. Br J Neurosurg 2014; 28(2): 226-33.

[13] Foo JC, Jawin V, Yap TY, Ahmad Bahuri NF, Ganesan D, Mun KS, *et al.* Conduct of neuro-oncology multidisciplinary team meetings and closing the "gaps" in the clinical management of childhood central nervous system tumors in a middle-income country. Childs Nerv Syst 2021; 37: 1573-80.

[14] Velicu MA, Lavrador JP, Sibtain N, Vergani F, Bhangoo R, Gullan R, *et al.* Neurosurgical management of central nervous system lymphoma: Lessons learnt from a neuro-oncology multidisciplinary team approach. J Pers Med 2023; 13(5): 783.

[15] Ameratunga M, Miller D, Ng W, Wada M, Gonzalvo A, Cher L, *et al.* A single-institution prospective evaluation of a neuro-oncology multidisciplinary team meeting. J Clin Neurosci 2018; 56: 127-30.

[16] Khalafallah AM, Jimenez AE, Romo CG, Kamson DO, Kleinberg L, Weingart J, *et al.* Quantifying the utility of a multidisciplinary neuro-oncology tumor board. J Neurosurg 2020; 135(1): 87-92.

[17] Nandu H, Wen PY, Huang RY. Imaging in neuro-oncology. Ther Adv Neurol Disord 2018; 11: 1756286418759865.

[18] Young RJ, De Souza França PD, Pirovano G, Piotrowski AF, Nicklin PJ, Riedl CC, *et al.* Preclinical and first-in-human-brain-cancer applications of [18F] poly (ADP-ribose) polymerase inhibitor PET/MR. Neurooncol Adv 2020; 2(1): vdaa119.

[19] Deuschl C, Kirchner J, Poeppel TD, Schaarschmidt B, Kebir S, El Hindy N, *et al.* 11C-MET PET/MRI for detection of recurrent glioma. Eur J Nucl Med Mol Imaging 2018; 45(4): 593-601.

[20] Sabeghi P, Katal S, Chen M, Taravat F, Werner TJ, Saboury B, *et al.* Update on positron emission tomography/magnetic resonance imaging: Cancer and inflammation imaging in the clinic. Magn Reson Imaging Clin N Am 2023; 31(4): 517-38.

[21] Rakheja R, Chandarana H, DeMello L, Jackson K, Geppert C, Faul D, *et al.* Correlation between standardized uptake value and apparent diffusion coefficient of neoplastic lesions evaluated with whole-body simultaneous hybrid PET/MRI. AJR Am J Roentgenol 2013; 201(5): 1115-9.

[22] Pederson C. PET/MRI in pediatric neuroimaging: Primer for clinical practice. Am J Neuroradiol 2022; 43(7): 938-43.

[23] Nihashi T, Dahabreh IJ, Terasawa T. Diagnostic accuracy of PET for recurrent glioma diagnosis: A meta-analysis. AJNR Am J Neuroradiol 2013; 34(5): 944-50.

[24] Snyder J, Schultz L, Walbert T. The role of tumor board conferences in neuro-oncology: A nationwide provider survey. J Neurooncol 2017; 133(1): 1-7.

[25] Scaringi C, Agolli L, Minniti G. Technical advances in radiation therapy for brain tumors. Anticancer Res 2018; 38(11): 6041-5.

[26] Patel SH, Stanton CL, Miller SG, Patrie JT, Itri JN, Shepherd TM. Risk factors for perceptual-versus-interpretative errors in diagnostic neuroradiology. Am J Neuroradiol 2019; 40(8): 1252-6.

[27] Babiarz LS, Yousem DM. Quality control in neuroradiology: Discrepancies in image interpretation among academic neuroradiologists. Am J Neuroradiol 2012; 33(1): 37-42.

[28] Aboud O, Shah R, Vera E, Burton E, Theeler B, Wu J, *et al.* Challenges of imaging interpretation to predict oligodendroglioma grade: A report from the Neuro-oncology branch. CNS Oncol 2022; 11(01): CNS83.

[29] Laalo JP, Kurki TJ, Tenovuo OS. Interpretation of magnetic resonance imaging in the chronic phase of traumatic brain injury: What is missed in the original reports? Brain Injury 2014; 28(1): 66-70.

[30] Radue EW, Weigel M, Wiest R, Urbach H. Introduction to magnetic resonance imaging for neurologists. Continuum (Minneap Minn) 2016; 22(5): 1379-98.

[31] Rancher CE, Shoemaker JM, Petree LE, Holdsworth M, Phillips JP, Helitzer DL. Disclosing neuroimaging incidental findings: A qualitative thematic analysis of health literacy challenges. BMC Medical Ethics 2016; 17(1): 58.

[32] Babiarz LS, Lewin JS, Yousem DM. Continuous practice quality improvement initiative for communication of critical findings in neuroradiology. Am J Med Qual 2015; 30(5): 447-53.

[33] Meyer EC, Lamiani G, Luff D, Brown SD. Voices emerging from the shadows: Radiologic practitioners' experiences of challenging conversations. Patient Educ Couns 2017; 100(1): 133-8.

[34] Reiner BI. Strategies for radiology reporting and communication. Part 1: Challenges and heightened expectations. J Digit Imaging 2013; 26(4): 610-3.

[35] Rao D, Fiester P, Patel J, Rutenberg M, Holtzman A, Dogan R, *et al.* Multidisciplinary imaging review conference improves neuro-oncology radiation treatment planning and follow-up. Cureus 2019; 11(10): e5882.

[36] Sabeghi P, Zarand P, Zargham S, Golestany B, Shariat A, Chang M, *et al.* Advances in Neuro-oncological imaging: An update on diagnostic approach to brain tumors. Cancers 2024; 16(3): 576.

[37] Jabeen S, Arbind A, Kumar D, Singh PK, Saini J, Sadashiva N, *et al.* Combined amino acid PET-MRI for identifying recurrence in post-treatment gliomas: Together we grow. Eur J Hybrid Imaging 2021; 5: 15.

[38] Pyatigorskaya N, Sgard B, Bertaux M, Yahia-Cherif L, Kas A. Can FDG-PET/MR help to overcome limitations of sequential MRI and PET-FDG for differential diagnosis between recurrence/progression and radionecrosis of high-grade gliomas? J Neuroradiol 2021; 48: 189-94.

[39] Sogani SK, Jena A, Taneja S, Gambhir A, Mishra AK, D'Souza MM, *et al.* Potential for differentiation of glioma recurrence from radionecrosis using integrated 18F-fluoroethyl-L-tyrosine (FET) positron emission tomography/magnetic resonance imaging: A prospective evaluation. Neurol India 2017; 65: 293-301.

[40] Grazzini I, Venezia D, Del Roscio D, Chiarotti I, Mazzei MA, Cerase A. Morphological and functional neuroradiology of brain metastases. Semin Ultrasound CT MRI 2023; 44(3): 170-93.

[41] Law M, Young RJ, Babb JS, Peccerelli N, Chheang S, Gruber ML, *et al.* Gliomas: Predicting time to progression or survival with cerebral blood volume measurements at dynamic susceptibility-weighted contrast-enhanced perfusion MR imaging. Radiology 2008; 247: 490-8.

[42] Raslan O, Ozturk A, Oguz KK, Sen F, Aboud O, Ivanovic I, *et al.* Imaging cancer in neuroradiology. Curr Probl Cancer 2023; 47(2): 100965.

[43] Jain, R. Measurements of tumor vascular leakiness using DCE in brain tumors: Clinical applications. NMR Biomed 2013; 26: 1042-9.

[44] Badve C, Yu A, Dastmalchian S, Rogers M, Ma D, Jiang Y, *et al.* MR fingerprinting of adult brain tumors: Initial experience. AJNR Am J Neuroradiol 2017; 38: 492-9.

[45] de Blank P, Badve C, Gold DR, Stearns D, Sunshine J, Dastmalchian S, *et al.* Magnetic resonance fingerprinting to characterize childhood and young adult brain tumors. Pediatr Neurosurg 2019; 54: 310-8.

[46] Springer E, Cardoso PL, Strasser B, Bogner W, Preusser M, Widhalm G, *et al.* MR Fingerprinting-A radiogenomic marker for diffuse gliomas. Cancers 2022; 14: 723.

[47] Galanaud D, Nicoli F, Chinot O, Confort-Gouny S, Figarella-Branger D, Roche P, *et al.* Noninvasive diagnostic assessment of brain tumors using combined *in vivo* MR imaging and spectroscopy. Magn Reson Med 2006; 55: 1236-45.

[48] Hall WA, Martin A, Liu H, Truwit CL. Improving diagnostic yield in brain biopsy: Coupling spectroscopic targeting with real-time needle placement. J Magn Reason Imaging 2001; 13: 12-5.

[49] Hermann EJ, Hattingen E, Krauss JK, Marquardt G, Pilatus U, Franz K, *et al.* Stereotactic biopsy in gliomas guided by 3-tesla 1H-chemical-shift imaging of choline. Stereotact Funct Neurosurg 2008; 86: 300-7.

[50] Stadlbauer A, Gruber S, Nimsky C, Fahlbusch R, Hammen T, Buslei R, *et al.* Preoperative grading of gliomas by using metabolite quantification with high-spatial-resolution proton MR spectroscopic imaging. Radiology 2006; 238: 958-69.

[51] Pepin K, McGee K, Arani A, Lake DS, Glaser KJ, Manduca A, *et al.* MR elastography analysis of glioma stiffness and IDH1-mutation status. AJNR Am J Neuroradiol 2018; 39: 31-6.

[52] Huisman TA, Patel R, Kralik S, Desai NK, Meoded A, Chen K, *et al.* Advances in imaging modalities for pediatric brain and spinal cord tumors. Pediatr Neurosurg 2023; 58(5): 240-58.

[53] Le Guellec B, Bruge C, Chalhoub N, Chaton V, De Sousa E, Gaillandre Y, *et al.* Comparison between multimodal foundation models and radiologists for the diagnosis of challenging neuroradiology cases with text and images. Diagn Interv Imaging 2025; Online ahead of print.

[54] Gillies RJ, Kinahan PE, Hricak H. Radiomics: Images are more than pictures, they are data. Radiology 2016; 278: 563-77.

[55] Einhellig HC, Siebert E, Bauknecht H-C, Teitze A, Graef J, Furth C, *et al.* Comparison of diagnostic value of 68Ga-DOTATOC PET/MRI and standalone MRI for the detection of intracranial meningiomas. Sci Rep 2021; 11: 9064.

[56] Stadlbauer A, Heinz G, Marhold F, Meyer-Base A, Ganslandt O, BuchFelder M, *et al.* Differentiation of glioblastoma and brain metastases by MRI-based oxygen metabolomic radiomics and deep learning. Metabolites 2022; 12: 1264.

[57] Malik N, Geraghty B, Dasgupta A, Maralani PJ, Sandhu M, Detsky J, *et al.* MRI radiomics to differentiate between low grade glioma and glioblastoma peritumoral region. J Neurooncol 2021; 155: 181-91.

[58] Kickingereder P, Isensee F, Tursunova I, Petersen J, Neuberger U, Bonekamp D, *et al.* Automated quantitative tumour response assessment of MRI in neuro-oncology with artificial neural networks: A multicentre, retrospective study. Lancet Oncol 2019; 20: 728-40.

[59] Shen B, Zhang Z, Shi X, Cao C, Zhang Z, Hu Z, *et al.* Real-time intraoperative glioma diagnosis using fluorescence imaging and deep convolutional neural networks. Eur J Nucl Med Mol Imaging 2021; 48: 3482-92.

[60] O'Connor JPB, Aboagye EO, Adams JE, Aerts HJWL, Barrington SF, Beer AJ, *et al.* Imaging biomarker roadmap for cancer studies. Nat Rev Clin Oncol 2017; 14: 169-86.

[61] Gravino G, Patel J, Ratneswaren T, Craven I, Chandran A. Diagnostic and interventional neuroradiology training in the UK: A national trainee survey. Clin Radiol 2024; 79(6): e854-67.

[62] Miyachi S. Training and specialists' qualification system for neuroendovascular therapists in Japan. No Shinkei Geka 2023; 51(2): 192-200.

[63] Hussien AR, Abdellatif W, Siddique Z, Mirchia K, El-Quadi M, Hussain A. Diagnostic errors in neuroradiology: A message to emergency radiologists and trainees. Canad Assoc Radiol J 2022; 73(2): 384-95.

[64] Hedderich DM, Schmitz-Koep B, Schuberth M, Schultz V, Schlaeger SJ, Schinz D, *et al.* Impact of normative brain volume reports on the diagnosis of neurodegenerative dementia disorders in neuroradiology: A real-world, clinical practice study. Front Aging Neurosci 2022; 14: 971863.

[65] Lövblad KO. Highly specialized neuroradiology. J Neuroradiol 2015; 42(4): 191-2.

Received: October 01, 2024 Revised: June 20, 2025 Accepted: June 23, 2025

© 2025. The Author (s), National Journal of Health Sciences.
This is an open access article distributed in accordance with the Creative Commons Attribution Non Commercial (CC BY- NC 4.0) license, which permits others to distribute, remix, adapt, build upon this work non- commercially, and license their derivative works on different terms, provided the original work is properly cited, appropriate credit is given, any changes made indicated, and the use is non-commercial. See: http://creativecommons.org/licenses/by-nc/4.0/.