2

Brain Tumour Imaging

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1. Introduction

There is now a plethora of different imaging techniques used for diagnosing and treating brain tumours. Different contrast agents in magnetic resonance imaging – coupled with amino acid tracers used in positron emission tomography – are the new weapons in radiologists' armoury which allow them to target and measure tumours more accurately.
Brain tumours are among the top causes of tumour-related deaths, with ten to 15 out of every 100,000 people diagnosed in Europe and USA every year.
The evaluation of tumours with medical imaging modalities is now one of the primary concerns of radiology departments. Computed tomography (CT), magnetic resonance imaging (MRI) and various advanced MRI techniques like perfusion MRI and dynamic susceptibility contrast (DSC) MRI play a vital role in brain tumour assessment.
In this chapter, we will summarize the current clinical applications of Computed Tomography, gadolinium contrast agents in neuro-imaging, including contrast-enhanced MRI, perfusion-weighted imaging and positron emission tomography (PET) for evaluation of brain tumour lesions. We will also discuss the advantages and limitation of each modality with respect to answering the specific clinical concerns.

2. Role of imaging in brain tumour assessment

In the management of patients with confirmed / suspected intracranial tumours, imaging of brain is often required at various stages and has a significant role at each level. Several stages of management may be considered although they are in practice often integrated with each other [1].

i. Detection / confirmation of a structural abnormality
ii. Localization and assessment of extent of the lesion
iii. Characterization – distinction between neoplastic and non-neoplastic lesions, if neoplastic then differentiation among malignant and benign
iv. Staging of the tumour: lymphatic spread or other organ involvement
v. Looking for involvement of any vital brain area which might be of concern for therapy planning
vi. Facilitate surgical planning or other therapeutic interventions
vii. Intraoperative control of resection procedure
viii. Monitoring prognosis and follow up

CT is often the first line of imaging study in tumour assessment because it is cheap, minimally invasive and widely available in clinical settings. It is a very good screening method in demonstration of supratentorial abnormalities but MRI is additional sequences which are mandatory for better anatomical distinction when it comes to decision of surgical interventions.

There are various structural features which are of interest to radiologist in answering the critical question in tumour assessment:

i. Signal contrast with respect to normal brain parenchyma
ii. Tumour structure, margins, extent of perifocal edema
iii. Indirect tumour signs (compression syndrome, midline shift etc.)
iv. Tumour vascularity, main vessels supplying the tumour and its course
v. Degree of contrast enhancement

The information provided by MRI in evaluating brain lesions is critical for accurate diagnosis, therapeutic intervention and prognosis. Contrast-enhanced MR neuro-imaging using gadolinium (Gd) contrast agents depicts blood-brain barrier disruption, thereby demonstrating the location and extent of the tumour by depicting the increased extracellular-extravascular space (EES) contrast concentration in these areas.

However, simple contrast-enhanced morphologic imaging is limited in accurately predicting tumour aggressiveness. Adding dynamic contrast-enhanced and perfusion-weighted imaging can solve this problem by providing physiological information – such as haemodynamic and neo-angiogenic status – in addition to pure lesion morphology. T1-w and T2* perfusion imaging in a follow-up scan can differentiate treatment success by differentiating between radiation necrosis and tumour recurrence.

Most available Gd-contrast agents have similar T1 and T2 relaxivities, and thus comparable tissue-enhancing properties. The exceptions are gadobenate, gadoxetate and gadofosveset, all of which have transient protein-binding capability that is responsible for up to twice (and more) the R1 and R2 relaxivity as compared to the other agents at all magnetic field strengths [2].

Table 1 summarizes the indication, advantages and limitation of CT and MRI before we move on to each modality in details.

3. Magnetic resonance imaging studies in brain tumour

MR imaging is an important diagnostic tool in the evaluation of intracranial tumours. Its effectiveness is due to its inherent high sensitivity to pathologic alterations of normal parenchymal water content, as demonstrated by abnormal high or low signal intensity on T2- or T1-weighted images, respectively. Compared to CT, MR imaging allows more accurate determination of lesion location, extent and better demonstrates subtle mass effects or atrophy, particularly along the cerebral convexities. MR imaging better depicts the presence of subacute or chronic haemorrhage and permits more accurate distinction between a vascular structure and adjacent parenchyma. CT is superior in depicting the presence of calcification and bone abnormalities, e.g. destruction, erosion, permeation, and hyperostosis. MR imaging is superior to CT for differentiating between tumour and perifocal edema, for defining extent of tumour, and for showing the relationship of the tumour to critical adjacent structures. Heavily T2-weighted sequences are the most sensitive for the detection of tumour and edema extent (discussed later in the chapter), but the tumour focus is not well separated from surrounding edema. T1-weighted images following

contrast enhancement generally provide better localization of the tumour nidus and improved diagnostic information relating to tumour grade, blood-brain barrier breakdown, haemorrhage, edema and necrosis. Contrast-enhanced T1-weighted images also better show small focal lesions such as metastases, small areas of tumour recurrence, and ependymal or leptomengeal tumour spread because of improved signal contrast. Proton density images are useful for distinguishing tumour and edema from adjacent cerebrospinal fluid, which may have a similar appearance as high-signal areas on heavily T_2-weighted images. All this information is essential for surgical planning.

Modality	*Indications*	*Limitations*
Computed Tomography	1. Shorter imaging time 2. Low cost of scanning 3. Better spatial resolution 4. Good for extra-axial brain tumour assessment 5. Superior in detection of calcifications, skull erosion, penetration, destruction	1. Poor definition of edema 2. Only one plane acquisition and most of the time non-isotropic 3. X-ray radiation risk 4. Poor tissue characterization 5. Imaging of posterior fossa is limited due to bone artifacts
Magnetic Resonance Imaging	1. Good in demonstration of edema of parenchyma (early sign for tumour detection) 2. Accurate delectating extent of edema and compression effects 3. Better detection of mass effects and atrophy 4. High neuroanatomical definition (tissue differentiation) 5. Accurate detection of vascularity of tumour (in various planes acquisition)	1. Poor detection of calcification and bone erosions 2. Not possible in intraoperative assessment 3. Lower spatial fidelity 4. Sometime sequence are very time consuming

Table 1. Comparison of CT and MRI in assessment of Brain Tumours

As indicated in various studies, imaging findings in MR studies roughly correlate with the *histologic grading* of cerebral gliomas. Generally, masses that are sharply marginated, are homogeneous in signal intensity, and show little or no contrast enhancement tend to be low-grade gliomas. Masses that have indistinct margins, are inhomogeneous in appearance, and demonstrate intense, irregular contrast enhancement tend to be high-grade gliomas. These are generalizations and all of the imaging findings and contrast-enhancing patterns must be considered together. Additionally, individual cases may differ from the norm. Some low-grade astrocytomas that are primarily infiltrating and histologically benign demonstrate poor margination with the surrounding brain and some rapidly growing malignant gliomas may show sharp margination from the surrounding brain.

Dean *et al.* (1990) found the degree of mass effect and the presence of cyst formation or necrosis to be statistically significant positive *predictors of tumour grade*. Central nonenhancing zones within an enhanced mass suggest areas of necrosis and indicate rapid tumour growth that outstrips the blood supply. This is a manifestation of malignant

behaviour and should suggest the diagnosis of glioblastoma multiforme. Similarly, areas of hemorrhage within a mass also favour a malignant lesion and are most often seen with glioblastomas or metastases.

Very large zones of edema surrounding an enhancing intra-axial tumour also favour the diagnosis of a malignant lesion and contribute to the mass effect associated with these tumours. A notable exception to this rule is meningioma, which, although a benign tumour, is often associated with large areas of adjacent edema and mass effect. However, these tumours are readily distinguished from malignant gliomas by their extra-axial location. Low-grade gliomas tend to exhibit an infiltrating pattern resembling edema on neuroimaging studies, but the lack of contrast enhancement and the absence of large mass effects that generally accompanies large zones of cerebral edema help to distinguish these entities.

Calcification within a tumour usually indicates a slowly growing neoplasm. Calcification can frequently be demonstrated in classic oligodendrogliomas and gangliogliomas and may occasionally be seen in astrocytomas and ependymomas.

Limitations to the usefulness of MR imaging to date are the following:

1. It does not provide a precise histologic diagnosis because of considerable overlap between the characteristic morphologic changes associated with various intracranial lesions necessitating surgical biopsy in virtually all cases prior to definitive therapy.
2. MR images represent computer-generated maps of a spatial representation of differences in water proton T1 and T2 relaxation characteristics. Although significant pathologic abnormalities usually alter these characteristics, in some instances they may not change detectably from normal. If, as may occur with small tumours or with infiltrative gliomas, there is no significant mass effect distorting normal anatomy, the lesion may go undetected.
3. Even when there is a well-defined enhancing tumour nidus, infiltrating tumour and isolated tumour cells can extend several centimetres beyond the enhancing region into the surrounding 'edematous' zone and, in some cases, beyond any abnormality seen on the image.
4. Bulk calcium emits no MR signal, making tumour calcification difficult or impossible to detect unless present in large amounts.
5. Artefacts can degrade image quality to nondiagnostic levels. Patient motion during image acquisition may introduce abnormal 'bright' or 'dark' areas in a normal brain that can even simulate a lesion.
6. Magnetic field inhomogeneity presents problems with spatial resolution.

4. Brain tumour imaging using gadolinium contrast agents

The most common clinical application of CE-MR neuroimaging is in the evaluation of primary and secondary brain tumours. The goals of conventional brain tumour imaging are the sensitive detection and delineation of tumour to make a correct diagnosis and accurate tumour grading to facilitate appropriate intervention.

In addition, CE-MR helps localize adjacent critical structures such as vessel or nerves to aid surgical or radiotherapeutic planning. MRIs of brain lesions also play a vital role in post-interventional monitoring by determining response to treatment – and hence prognosis – as early identification of treatment failure can help to select an alternative therapeutic approach, thus potentially improving patient outcomes.

The protocol followed by most of the clinicians includes a T1w, T2w and also T1 post-contrast image acquisition of the brain tumour prior to present perfusion maps. T1 and T2 images give a good anatomical image quality and contrast with well-demarcated tumour boundaries. We also need T1-w for selecting good region of interest (ROI) of the tumour for relevant perfusion map (Figure 1). Dynamic Susceptibility Contrast (DSC) MRI can provide information on tumour vascularity which might not be obvious by T1/T2 imaging only but will be potential in grading the tumour and management options [3].

A standard dose of gadolinium contrast agent is considered to be 0.1mmol/kg bodyweight, although many studies have been published demonstrating improved diagnostic performance with double (0.2mmol/kg) or even triple (0.3mmol/kg) doses,[4;5] and this has become routine clinical practice.

Although higher doses of contrast agent have potentially increased the cost of MR examinations and are associated with higher false-positive rates,[5;6] such doses are very sensitive when determining the extent of the disease is the primary goal. The high molarity 1% Gd contrast gadobutrol (Gadovist) is also shown to be very sensitive (Figure 1) in detecting tumour activity [7]. Essig et al. compared 0.1 and 0.2 mmol/kg body weight doses of 1 M gadobutrol and gadobenate dimeglumine at 1.5 T in healthy volunteers and found that although the peak signal fall with the double dose of both agents was larger, there were no statistical differences between agents or doses (Fig. 5) [8]. Moreover, a signal drop of approximately 40% was produced by single doses of both agents, sufficient to permit calculation of highquality CBV and CBF maps. In this case, bolus widths achieved with gadobenate dimeglumine and gadobutrol were sharp and comparable, and therefore, the reduced injection time of gadobutrol did not have a positive effect on the bolus geometry. Essig and colleagues concluded that at 1.5 T, both the 1 M gadobutrol and the higher relaxivity gadobenate dimeglumine permitted a sufficient drop in SI to afford robust and reproducible quantification of haemodynamic parameters and that the slightly lower volume of the injection of gadobutrol did not produce any major advantage in terms of bolus geometry [8].

Improving the diagnostic performance by using a higher relaxivity contrast agent is an equally good alternative to increasing gadolinium dose. Early dosing studies demonstrated that double doses of gadobenate dimeglumine are potentially beneficial, with enhanced sensitivity in brain tumour detection, although no further benefit is seen when increasing to triple dose [9;10].

The more significant evidence of improved diagnostic performance by the higher relaxivity agent, however, came from a series of intra-individual crossover studies directly comparing gadobenate dimeglumine with gadopentetate dimeglumine,[11-16] gadoterate meglumine [11;13], gadodiamide[11;17] and gadofosveset trisodium. In these crossover studies, patients underwent two otherwise identical MR examinations, one with each contrast agent, within a gap of two days to two weeks, thus enabling any differences between the two imaging sets to be directly attributed to the contrast agents being used (Figure 2-5) [2;12-14].

The first such crossover study, performed in 2001, demonstrated that in patients with metastatic central nervous system (CNS) disease, the sensitivity for lesion detection with gadobenate dimeglumine (93%-100%) was much higher than that with an equal dose of comparator (65%-73%), like gadopentetate dimeglumine (N=13), gadodiamide (N=4), or gadoterate meglumine (N=5)[11]. In addition, tissue contrast in the main lesion-to-normal

brain parenchyma was consistently greater for gadobenate dimeglumine (143%) than for an equal dose comparator (127%) as compared to unenhanced images.

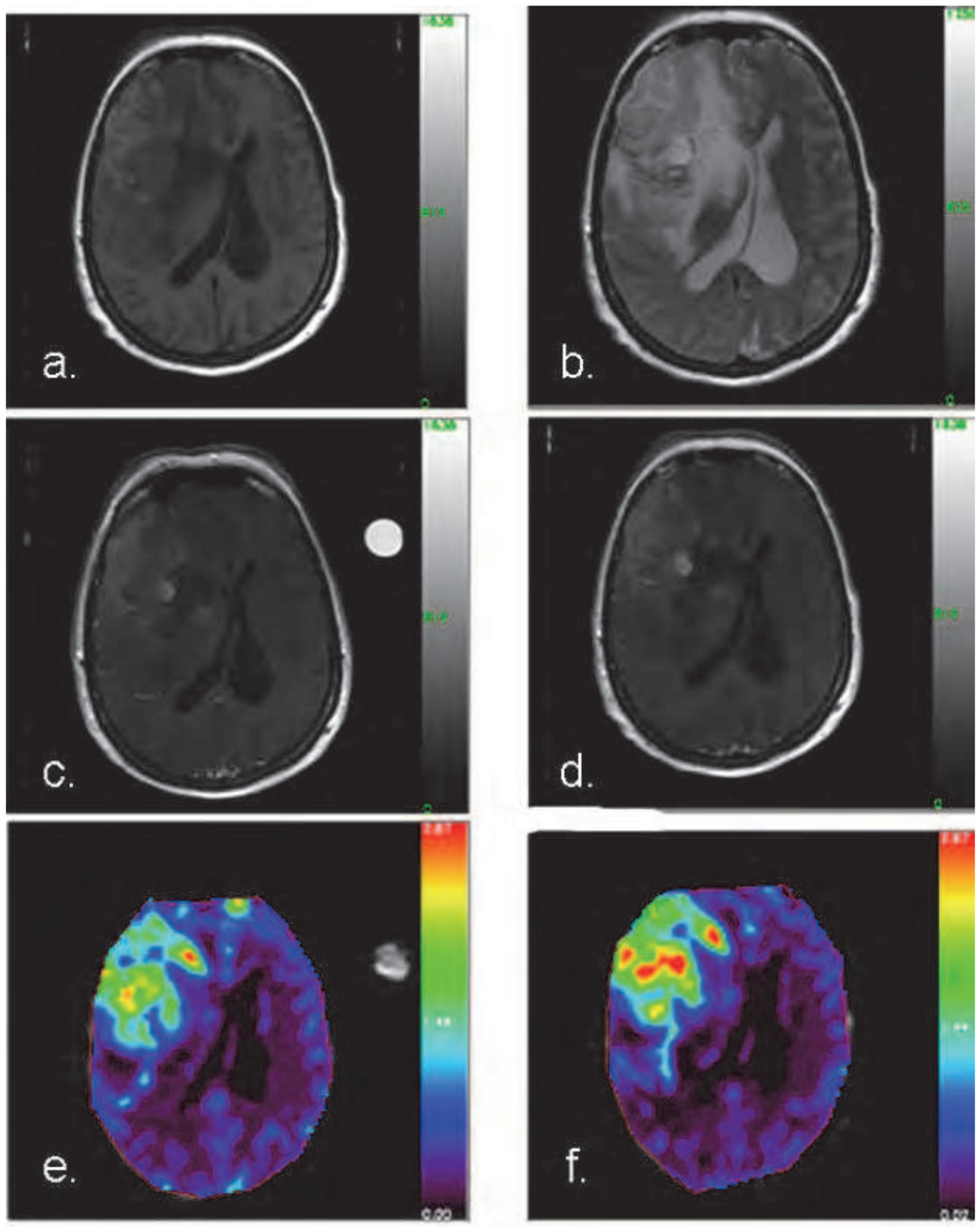


Fig. 1. a) T1-weighted; b) T2-weighted; c) T1-w post Gd-DTPA contrast; d) T1-w post Gadobutrol contrast; e) T2* weighted parametric CBV map with Gd-DTPA; f) T2* weighted parametric CBV map with Gadobutrol. Gadobutrol is shown to be more sensitive and show more number of active lesions in tumour with high blood supply.[4].

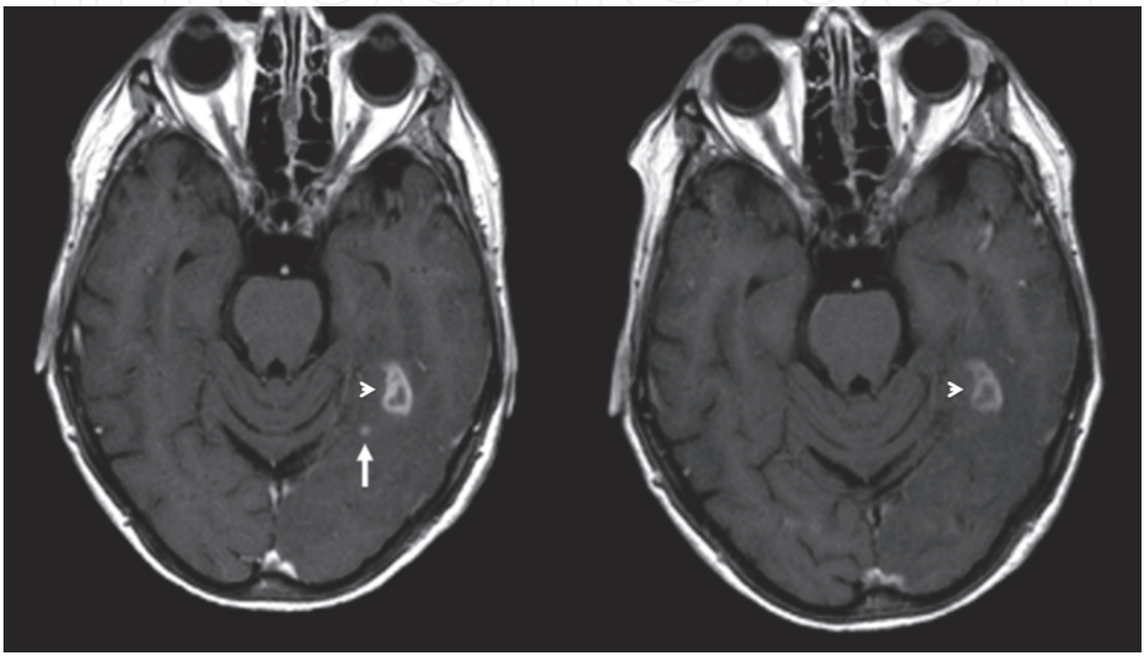


Fig. 2. Matched pairs of T1-weighted spin echo images from intraindividual comparative studies with high relaxivity enhanced images shown on the left and the comparator-enhanced image on the right. Where present, arrows highlight additional information present on gadobenate-dimeglumine-enhanced images. From Colosimo et al. [13] presenting a patient with malignant glioma (arrow head) gadobenate dimeglumine-enhanced MRI, which allows beside the stronger enhancement, the depiction of a satellite lesion (arrow) not present on the comparator image. The satellite-enhancing lesion should be integrated into the target volume for therapeutic intervention.

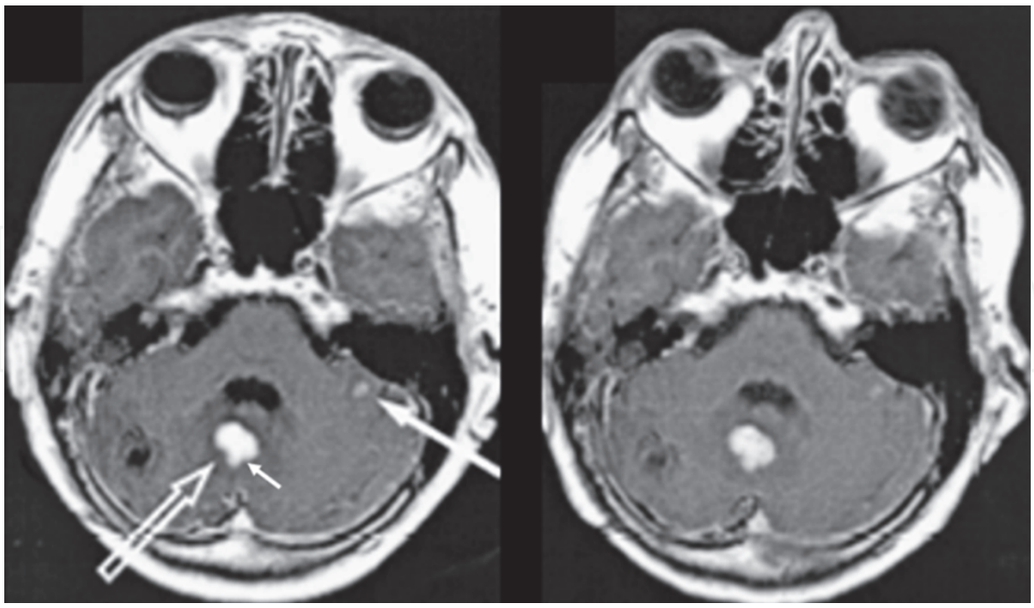


Fig. 3. A patient with multiple cerebral metastases, gadobenate dimeglumine-enhanced MRI is able to show additional metastases in the left cerebellar hemisphere (left) and a larger appearance of the lesion in projection of the midline (from Knopp et al. [12]). High relaxivity enhanced images shown on the left and the comparator-enhanced image on the right.

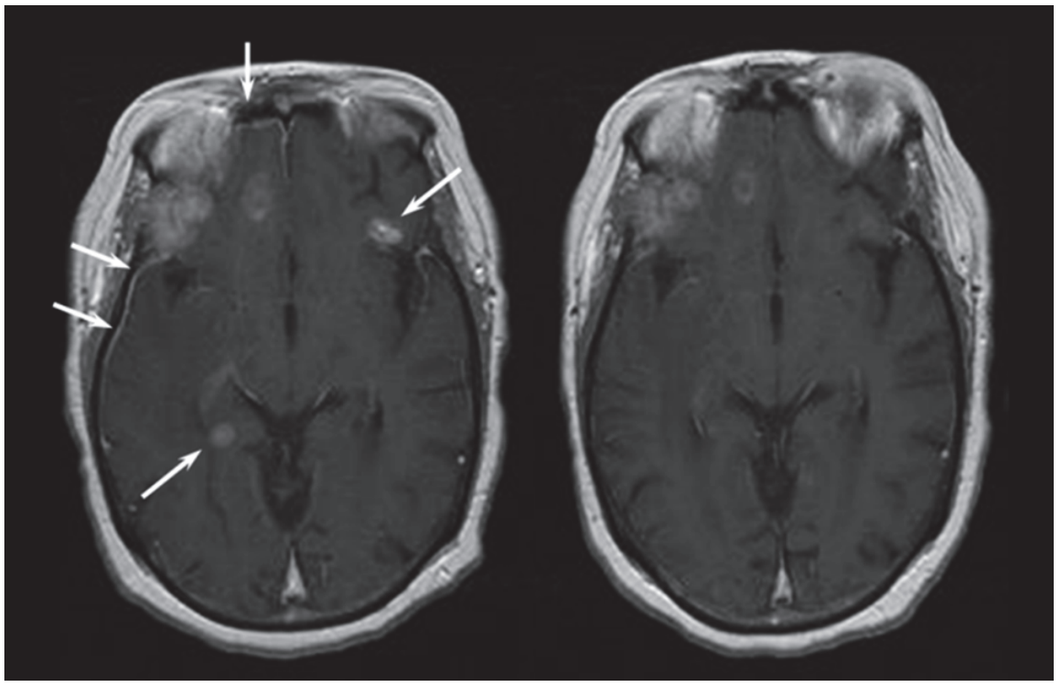


Fig. 4. A patient with multiple metastases, a high relaxivity agent allowed the detection of additional lesions and the proved the infiltration of the meninges (from Maravilla et al. [14]). High relaxivity enhanced images shown on the left and the comparator-enhanced image on the right.

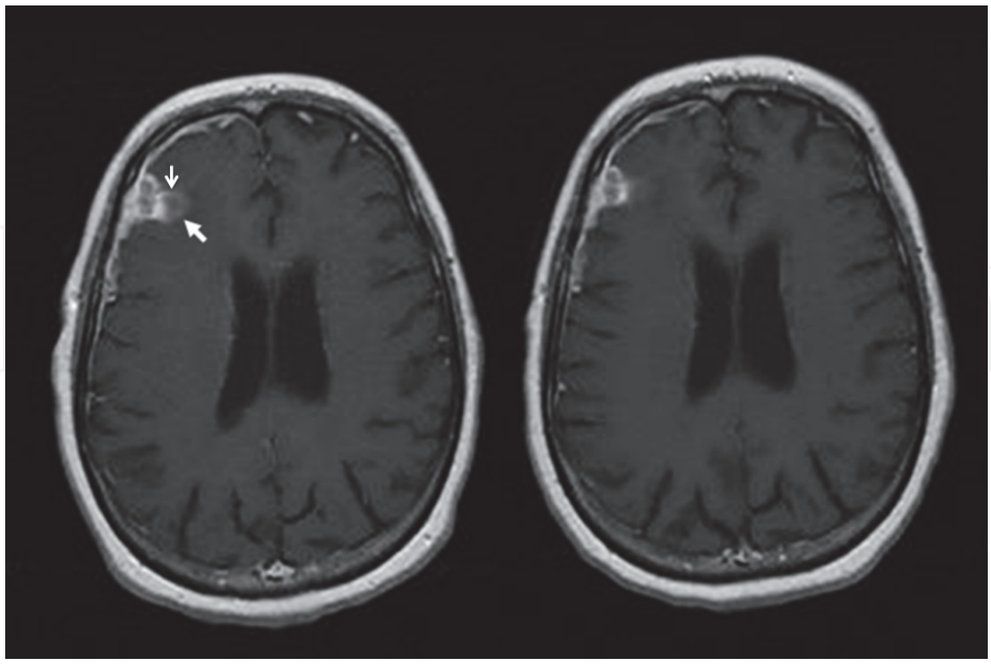


Fig. 5. The patient with an infiltration of the menigiosis carcinomatosa and a focal metastatic lesion, the enhancement is more pronounced with the use of a high relaxivity agent, and the lesion appears to be substantially larger (from Essig et al.[2]). High relaxivity enhanced images shown on the left and the comparator-enhanced image on the right.

Since then, five larger, prospective, randomised, intra-individual crossover studies have been performed with a total of 355 patients in which gadobenate dimeglumine was directly compared with an equal dose of other non-protein-binding contrast agents for MRI of primary and secondary CNS lesions[12-14;16;17].

Qualitatively blinded readers expressed global preference for images enhanced with gadobenate dimeglumine versus the other standard agents. Additionally, an independent analysis of intra-axial enhancing brain lesions (N=158) demonstrated a highly significant ($p \leq 0.0156$, all readers) improvement with gadobenate dimeglumine compared to gadopentetate dimeglumine, both qualitative and quantitatively[15].

All of the above-mentioned comparison studies between various MR contrast agents were performed using the field strength of 1.5T or less, while the recent crossover study by Rumboldt et al was performed using a 3T magnet[16]. The study demonstrated the persistent benefits of high-relaxivity agents even at higher field strengths, which will be the focus of clinical research in coming years.

An additional consideration recently is the fear of nephrogenic systemic fibrosis (NSF) developing in certain patient populations when higher doses of Gadolinium are used [18-20], NSF and other side-effects of MR contrast agents are beyond the remit of this chapter, but are worth mentioning here.

5. T1 weighted MR imaging in brain tumours

T1 weighted (T1w) MRI needs a special mention in brain tumour evaluation, because on many occasions the blood-brain barrier (BBB) is damaged in tumours, which alters the

normal one-compartment physiological model used in imaging for perfusion analysis. The T1-w enhancement of contrast agent is attributed to BBB leakage associated with angiogenesis and capillary damage in regions of active tumour growth.

Angiogenesis is an important contributor to tumour growth and correlates with tumour aggressiveness. As angiogenesis increases microvascular cerebral blood volume (CBV), CBV-imaging may provide a unique insight into tumour physiology, histology and response to therapeutic agents. Different imaging modalities such as PET and MRI-CBV methods have been employed in tumour imaging for some time, but both require appropriately timed injection of contrast agents and subsequent post-processing, making them logistically difficult.

Recently, a new MRI approach called vascular-space-occupancy (VASO) imaging was developed as a non-invasive method for detecting CBV changes accompanying neuronal activation. VASO is a T1-weighted MRI approach that exploits the T1 difference between blood and tissue to null intravascular blood signal, simultaneously giving an image of extravascular tissue water, but only as it relates to parenchyma tumour.

While VASO has shown consistent sensitivity to CBV changes in functional MRI, it has not been tested extensively in the clinical setting for tumour imaging. Recently, VASO images with and without contrasts were combined to quantitatively assess absolute CBV in brain tumours, showing promise for assessing tumour grade assessment. However, this approach is confounded by the assumption that the administered contrast remains in the vasculature (single-compartment perfusion model), which may not be applicable in regions of BBB breakdown (two-compartment perfusion model).

The studies have also demonstrated that VASO and MPRAGE (magnetisation prepared rapid gradient echo) MRI provide contrast complementary to Gd-T1w and FLAIR (fluid attenuation inversion recovery) MRI for tumour imaging. Interestingly, FLAIR, VASO and MPRAGE are all inversion-based MRI sequences. However, they each offer a range of T1w contrasts, of which a collective analysis provides information not otherwise evident[21].

6. MR Spectroscopy (MRS) in tumour grading

Clinical applications of magnetic resonance spectroscopy (1H-MRS) are increasing as the techniques with (techniques and hardware have become more robust with fast processing) hardware have become more robust and fast processing. Proton MRS provides biochemical and metabolic information about tumours and normal brain [22]. The information obtained from MRS for tumour is unique and complimentary to other MR Imaging techniques.

As with other organs spectroscopy of brain tumours can be done in single- or multi- voxel forms. The two most widely used methods for volume selection are stimulated echo acquisition mode (STEAM) and point-resolved spectroscopy sequence (PRESS). In general STEAM is better as shorter echo times can be achieved with it but, it is more sensitive to motion related artefacts [23]. In theory, for the same total echo time, the signal of PRESS is twice as great as that of STEAM; also PRESS is also less sensitive to motion. With faster and better softwares PRESS is getting more commonly used method of volume selection in clinical practice.

Single voxel MRS is sometimes better as it's faster and quick to acquire but it lacks the high spatial resolution and hence regional mapping of metabolic variations. Brain tumours are heterogeneous in their tumours potentials; therefore single voxel spectroscopy might not be

very reliable in tumour grading based on its metabolic activity. Poor spatial resolution also makes it vulnerable to high partial volume artefacts.

In the spectroscopy the most commonly used echo times are 144 msec and 270 msec at which the spectrum is dominated by 5 different metabolite peaks. These are the choline (Cho), creatine (Cr), N-acetylaspartate (NAA), lactate, and lipid. The choline peak reflects cell membrane turnover; Creatine is a good marker for energy synthesis, and NAA is exclusive to neuronal cells. Lactate resulting from anaerobic metabolism (which is uncommon in normal brain parenchyma) is detected in necrotic/infarcted tumour [24]. Cellular and myelin breakdown products result in prominent lipid peaks in MRS. MR Spectroscopy allows analysis of these specific metabolites within brain tissue. Tumours, especially primary brain tumours show very specific pattern in elevation of choline and loss of N-Acetyl Aspartate peaks [25;26].

Combined with MRI, MRS can aid in the evaluation of tumour type and grade. The higher-grade gliomas tend to exhibit higher Cho/Cr and Cho/NAA ratios. MR spectroscopy can help differentiate enhancing tumour from other causes of enhancement (mainly necrosis) and is more specific in differentiating nonenhancing tumour from edema and other causes of T2 prolongation. These qualities have been exploited in order to better define the true extent and morphology of gliomas. This information has the potential to significantly alter target volumes and radiation therapy doses of brain gliomas when compared with conventional radiotherapy. Although this is an attractive concept, there are no studies to show benefits, changes in failure patterns, or improved survival. MR spectroscopy is utilized more and more by different groups in assessing response to therapy in patients with primary brain tumours or metastases. MR spectroscopy can noninvasively enable the distinction between a solitary metastasis and high-grade gliomas, particularly when combined with perfusion MR imaging [27]. In their study, Law et al showed that measurements of Cho and mean rCBV in the perienhancing region are useful in differentiating solitary metastases from high-grade gliomas. In the perienhancing region, T2 prolongation is partly due to tumour infiltration (nonenhancing tumour) in patients with high-grade gliomas. Whereas in the case of metastases, the hyperintensity surrounding the region of enhancement is due to vasogenic edema or nonspecific treatment effects rather than infiltrating tumour. Therefore, elevated levels of choline and/ or rCBV surrounding a peripherally enhancing mass reflect tumour infiltration in a high-grade glioma.

Post- treatment, MRS has a much limited role in the assessment of patients. Frequently, there is a mixture of ruminant tumour and necrosis after therapy. This limits the utility of MRS in differentiating residual/recurrent tumour from radiation necrosis, as is the case with MR perfusion. As a tumour responds to treatment, the choline decreases and lactate and/or lipids may increase [28;29]. MR spectroscopy can play a useful role after treatment in assessing the therapeutic response. This is particularly important for early detection of treatment failure so that an ineffective treatment can be modified prior to a significant progression of disease.

7. Molecular imaging and PET in brain tumour imaging

PET imaging is a non-invasive diagnostic imaging tool that has an advantage over anatomical imaging in that it is a metabolic imaging tool that is able to distinguish between benign and malignant tumours. It is often used to accurately determine the stage of the

brain tumour. PET images produce visual impression of detailed biochemical changes caused by brain tumours and their metabolic activities.

Despite the recognized limitations of fluorodeoxyglucose positron emission tomography (FDG-PET) in brain tumour imaging due to the high background of normal gray matter, this imaging modality provides critical information for the management of patients with cerebral parenchyma tumours by providing a:

- Global picture of the tumour and thus guiding the appropriate site for biopsy, thereby improving accuracy of the technique and reducing the number of biopsy samples
- Prediction of metabolic activity and aggressiveness of the tumour, thereby enhancing the ability to provide a prognosis.

Another area, which has been investigated extensively in tumour imaging, is differentiating between recurrent tumour and treatment-related changes – for example, radiation necrosis or postsurgical changes. The aggressive tumour responds with a bright signal because of its high uptake of FDG, but radiation necrosis will show no changes.

FDG-PET has equally demonstrated its usefulness in differentiating lymphoma from infectious toxoplasmosis in patients with acquired immune deficiency syndrome with almost 100% accuracy, and is the investigation of choice in that setting [30].

In recent years, an increasing number of brain tumour PET studies have used other tracers, such as labeled methionine, tyrosine, thymidine, choline, fluoromisonidazole, EF5 and so on, of which positron-labeled amino acid analogues, nucleotide analogues, and the hypoxia imaging tracers are of special interest [30]. The major advantage of these radiotracers over FDG is the markedly reduced background activity in gray matter, which allows detection of even smaller lesions and low-grade tumours with high precision.

The promise of the amino acid PET (Figure 6) tracers has been emphasized due to their higher sensitivity in imaging recurrent tumours (particularly the low-grade) and better accuracy for differentiating between recurrent tumours and treatment-related changes compared with FDG. O-(2-[18F]fluoroethyl)-L-tyrosine (FET) is a potential new amino acid PET tracer that has been shown to be helpful as an additional tool in few patients by allowing better differentiation of tumour tissue from inflammatory tissue. Another possible application of 18F-FET PET being considered is in the monitoring of radio- or chemo-therapy of squamous cell carcinoma (SCC), because the reaction of the tumour tissue may be specifically detected without the interfering the uptake by inflammatory or reactive tissue [31].

The newer PET tracers have also shown great potential to image important aspects of tumour activity and thereby demonstrate ability in predicting right prognosis response. The value of hypoxia imaging tracers (such as fluoromisonidazole or more recently EF5) is substantial in radiotherapy planning and predicting treatment response. In addition, they may play an important role in the future in directing and monitoring targeted hypoxic therapy for tumours with hypoxia.

8. Future trends

With the further technological advancements in imaging modalities and contract agents the brain tumour imaging is getting benefited. The high relaxivity contrast agents are able to provide vital information on tumour vascularity and higher magnetic strength scanner having higher SNR are getting more focus for clinical usage. The PET-MR is no more a

research prototype but is getting validated with clinical trials which will be available for clinics very soon. Even the newly available CT technology, Multi-Energy Computed Tomography, which operates on material characterization properties by multi-energy (commonly two) CT acquisition is the promising technology for anatomical and tumour functional information accessed at the same time [32].

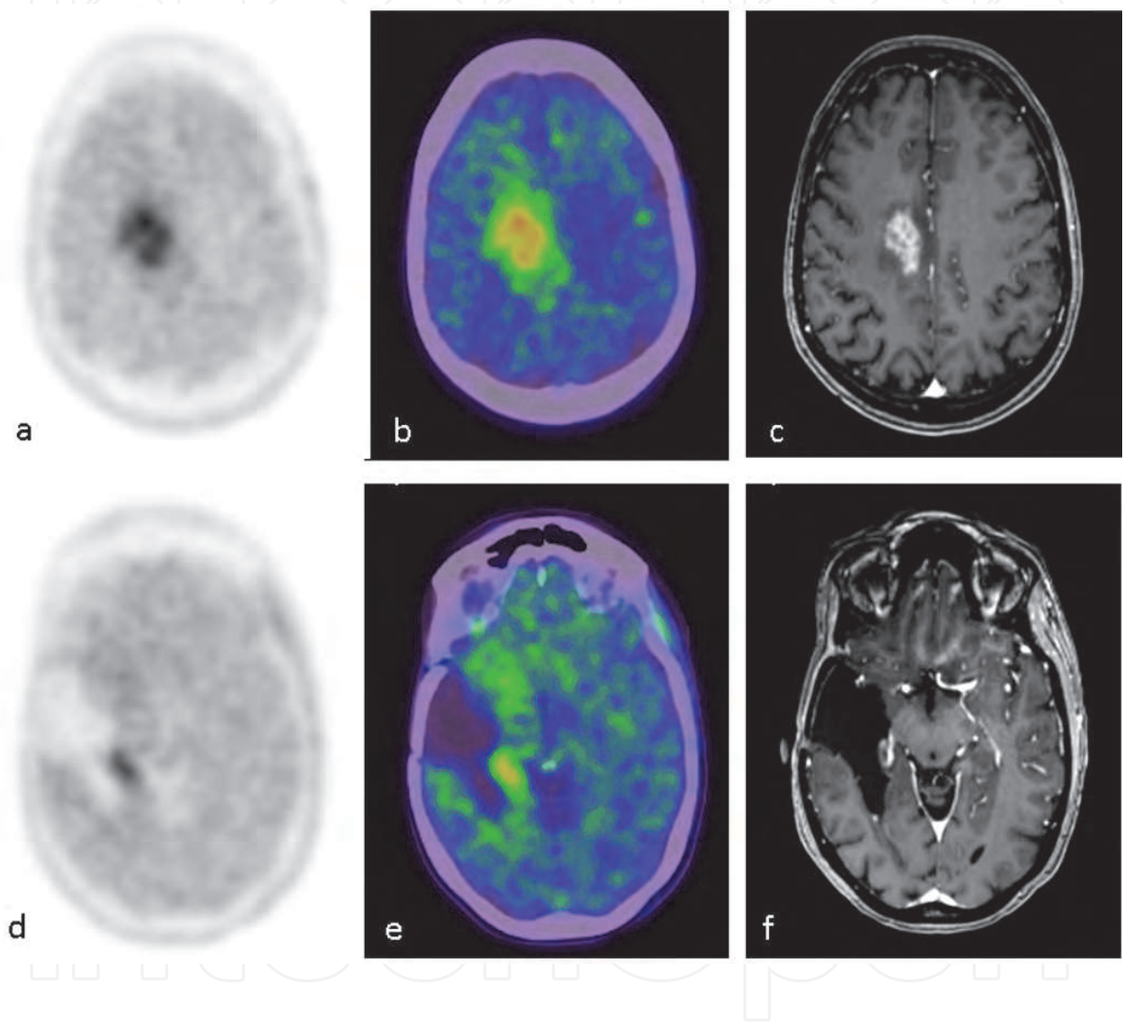


Fig. 6. Patient with a recurrent locoregional brain lesion – images show tumour before and after neurosurgery and radio-chemotherapy. a, d) FET-PET image showing intense uptake in the tumour tissue before and recurrent tumour after neurosurgery; b, e) Fused PET-CT image confirming the location of the tumour and recurrent lesion before and after surgery; c, f) post contrast MRI image in concordance to strong FET-tracer uptake shown in PET/CT. Furthermore, an additional brain lesion was identified in the right parietal lobe medial area of the brain tissue resected area, presenting a high FET-tracer uptake in PET/CT and strong contrast enhancement in MRI.

9. Conclusion

Brain tumour imaging consists of anatomical imaging with CT and perfusion MRI and functional imaging with PET. Physicians need both anatomical and functional imaging information to be assessed at the same time for appropriate treatment planning. The future of tumour imaging lies in developing optimal image registration and segmentation strategies from multimodality imaging as well as novel PET tracers. This approach is also set to play a role in the era of intensity-modulated radiotherapy, and is likely to have important clinical and research applications in radiotherapy planning in patients with brain tumours.

10. Reference

[1] Kandel EI, Schavinsky YV. Stereotaxic apparatus and operations in Russia in the 19th century. J Neurosurg 1972; 37:407-411

[2] Giesel FL, Mehndiratta A, Essig M. High-relaxivity contrast-enhanced magnetic resonance neuroimaging: a review. Eur Radiol 2010; 20:2461-2474

[3] Essig M. Clinical experience with MultiHance in CNS imaging. Eur Radiol 2003; 13 Suppl 3:N3-10

[4] Goyen M. Gadofosveset-enhanced magnetic resonance angiography. Vasc Health Risk Manag 2008; 4:1-9

[5] Sze G, Johnson C, Kawamura Y, et al. Comparison of single- and triple-dose contrast material in the MR screening of brain metastases. AJNR Am J Neuroradiol 1998; 19:821-828

[6] Schneider G, Kirchin MA, Pirovano G, et al. Gadobenate dimeglumine-enhanced magnetic resonance imaging of intracranial metastases: effect of dose on lesion detection and delineation. J Magn Reson Imaging 2001; 14:525-539

[7] Giesel FL, Mehndiratta A, Risse F, et al. Intraindividual comparison between gadopentetate dimeglumine and gadobutrol for magnetic resonance perfusion in normal brain and intracranial tumors at 3 Tesla. Acta Radiol 2009; 50:521-530

[8] Essig M, Lodemann KP, Le-Huu M, Bruning R, Kirchin M, Reith W. Intraindividual comparison of gadobenate dimeglumine and gadobutrol for cerebral magnetic resonance perfusion imaging at 1.5 T. Invest Radiol 2006; 41:256-263

[9] Schneider G, Kirchin MA, Pirovano G, et al. Gadobenate dimeglumine-enhanced magnetic resonance imaging of intracranial metastases: effect of dose on lesion detection and delineation. J Magn Reson Imaging 2001; 14:525-539

[10] Baleriaux D, Colosimo C, Ruscalleda J, et al. Magnetic resonance imaging of metastatic disease to the brain with gadobenate dimeglumine. Neuroradiology 2002; 44:191-203

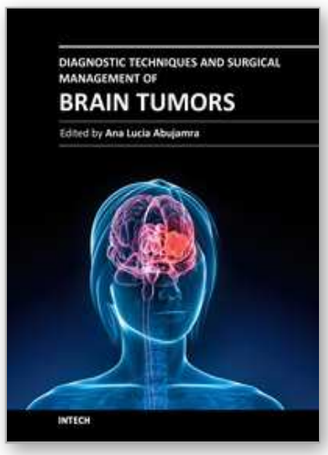
[11] Colosimo C, Ruscalleda J, Korves M, et al. Detection of intracranial metastases: a multicenter, intrapatient comparison of gadobenate dimeglumine-enhanced MRI with routinely used contrast agents at equal dosage. Invest Radiol 2001; 36:72-81

[12] Knopp MV, Runge VM, Essig M, et al. Primary and secondary brain tumors at MR imaging: bicentric intraindividual crossover comparison of gadobenate dimeglumine and gadopentetate dimeglumine. Radiology 2004; 230:55-64

[13] Colosimo C, Knopp MV, Barreau X, et al. A comparison of Gd-BOPTA and Gd-DOTA for contrast-enhanced MRI of intracranial tumours. Neuroradiology 2004; 46:655-665

[14] Maravilla KR, Maldjian JA, Schmalfuss IM, et al. Contrast enhancement of central nervous system lesions: multicenter intraindividual crossover comparative study of two MR contrast agents. Radiology 2006; 240:389-400
[15] MJ, Picozzi P, Maldjian JA, et al. Evaluation of intraaxial enhancing brain tumors on magnetic resonance imaging: intraindividual crossover comparison of gadobenate dimeglumine and gadopentetate dimeglumine for visualization and assessment, and implications for surgical intervention. J Neurosurg 2007; 106:557-566
[16] Rumboldt Z, Rowley HA, Steinberg F, et al. Multicenter, double-blind, randomized, intra-individual crossover comparison of gadobenate dimeglumine and gadopentetate dimeglumine in MRI of brain tumors at 3 tesla. J Magn Reson Imaging 2009; 29:760-767
[17] Rowley HA, Scialfa G, Gao PY, et al. Contrast-enhanced MR imaging of brain lesions: a large-scale intraindividual crossover comparison of gadobenate dimeglumine versus gadodiamide. AJNR Am J Neuroradiol 2008; 29:1684-1691
[18] Broome DR, Girguis MS, Baron PW, Cottrell AC, Kjellin I, Kirk GA. Gadodiamide-associated nephrogenic systemic fibrosis: why radiologists should be concerned. AJR Am J Roentgenol 2007; 188:586-592
[19] Sadowski EA, Bennett LK, Chan MR, et al. Nephrogenic systemic fibrosis: risk factors and incidence estimation. Radiology 2007; 243:148-157
[20] Kanal E, Broome DR, Martin DR, Thomsen HS. Response to the FDA's May 23, 2007, nephrogenic systemic fibrosis update. Radiology 2008; 246:11-14
[21] Donahue MJ, Blakeley JO, Zhou J, Pomper MG, Laterra J, van Zijl PC. Evaluation of human brain tumor heterogeneity using multiple T1-based MRI signal weighting approaches. Magn Reson Med 2008; 59:336-344
[22] Howe FA, Opstad KS. 1H MR spectroscopy of brain tumours and masses. NMR Biomed 2003; 16:123-131
[23] Castillo M, Kwock L, Mukherji SK. Clinical applications of proton MR spectroscopy. AJNR Am J Neuroradiol 1996; 17:1-15
[24] Nelson SJ. Multivoxel magnetic resonance spectroscopy of brain tumors. Mol Cancer Ther 2003; 2:497-507
[25] Usenius JP, Kauppinen RA, Vainio PA, et al. Quantitative metabolite patterns of human brain tumors: detection by 1H NMR spectroscopy in vivo and in vitro. J Comput Assist Tomogr 1994; 18:705-713
[26] Usenius JP, Vainio P, Hernesniemi J, Kauppinen RA. Choline-containing compounds in human astrocytomas studied by 1H NMR spectroscopy in vivo and in vitro. J Neurochem 1994; 63:1538-1543
[27] Law M, Cha S, Knopp EA, Johnson G, Arnett J, Litt AW. High-grade gliomas and solitary metastases: differentiation by using perfusion and proton spectroscopic MR imaging. Radiology 2002; 222:715-721
[28] Shino A, Nakasu S, Matsuda M, Handa J, Morikawa S, Inubushi T. Noninvasive evaluation of the malignant potential of intracranial meningiomas performed using proton magnetic resonance spectroscopy. J Neurosurg 1999; 91:928-934
[29] Graves EE, Nelson SJ, Vigneron DB, et al. Serial proton MR spectroscopic imaging of recurrent malignant gliomas after gamma knife radiosurgery. AJNR Am J Neuroradiol 2001; 22:613-624

[30] Basu S, Alavi A. Molecular imaging (PET) of brain tumors. Neuroimaging Clin N Am 2009; 19:625-646
[31] Pauleit D, Zimmermann A, Stoffels G, et al. 18F-FET PET compared with 18F-FDG PET and CT in patients with head and neck cancer. J Nucl Med 2006; 47:256-261
[32] Mehndiratta A, Kapal JM, A P. Iodine mapping in brain tumor imaging using dual-energy computed tomography. Med Hypotheses 2011 May, 76(5):764.;



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The focus of the book Diagnostic Techniques and Surgical Management of Brain Tumors is on describing the established and newly-arising techniques to diagnose central nervous system tumors, with a special focus on neuroimaging, followed by a discussion on the neurosurgical guidelines and techniques to manage and treat this disease. Each chapter in the Diagnostic Techniques and Surgical Management of Brain Tumors is authored by international experts with extensive experience in the areas covered.

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