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Clinical Radiology
The Royal College of Radiologists

Recommendations for cross-sectional imaging in cancer management, Second edition

Tumours of the brain

Faculty of Clinical Radiology

Contents

Brain primary tumours

Clinical background

Attempts at developing a TNM-based classification and staging system for central nervous system (CNS) tumours have been unsuccessful due to a lack of utility in predicting patient outcomes. Reasons for this include the fact that primary tumour (T-stage) size is significantly less relevant than tumour histology and location in predicting outcome. Nodal staging (N-stage) does not apply to brain tumours. Metastases (M-stage), when they do occur, are usually found in paediatric neoplasms and spread through the cerebrospinal fluid.

Who should be imaged?

All patients suspected of having a primary brain tumour should be imaged initially with magnetic resonance imaging (MRI) or computed tomography (CT).[1]

Imaging objectives

- To detect tumour.
- To characterise tumour.
- To determine extent of tumour.
- To select optimal site for obtaining histological material (preferably where tumour grade is highest and to avoid eloquent areas and areas of necrosis or cyst formation).

MRI is the investigation of choice in the evaluation of primary cerebral neoplasms.[2] It is superior to CT for tumour detection due to better contrast resolution, which gives a high sensitivity to any alteration in the nature of brain tissue. However, CT can provide unique information not readily available on MRI (for example, the presence of calcification) and is still used in the primary investigation of non-specific neurological presentations, which may occasionally be caused by tumour. If a mass-like lesion is detected on CT, MRI should be undertaken for further characterisation and to assess the full extent of disease. Nevertheless, MRI is still unable to predict tumour type and histological grade reliably. Signal intensity and contrast enhancement characteristics may assist the surgeon in choosing a site for biopsy and imaging may be used for guiding stereotactic biopsy procedures. Proton MR spectroscopy (1H-MRS), single photon emission computed tomography (SPECT) and positron emission tomography (PET) remain experimental procedures in the evaluation of brain tumours. Though spectroscopy is now considered routine in some specialist centres. High-resolution CT is useful in addition to MRI in preoperative assessment and follow-up of skull base tumours.

Imaging should be able to discriminate between tumours and other intracranial mass lesions; for example, infarcts, haemorrhage or inflammatory/demyelinating lesions. Some tumours have characteristic features on imaging which allow a definite diagnosis to be reached before biopsy. However, most tumours will need to be biopsied for histological classification.

Unlike tumours elsewhere in the body, a biopsy is not usually obtained prior to definitive surgery. Intraoperative histological evaluation by a specialist neuropathologist is, however, commonly obtained. A decision will be made on imaging as to whether image-guided biopsy, open biopsy or resection is most appropriate for patient management. In some instances, it will be decided that biopsy is neither feasible nor clinically appropriate. Depending on the presumed diagnosis, these patients may have surveillance follow-up imaging or referral for palliative radiotherapy.

Imaging

MRI

For the majority of supratentorial tumours, conventional MRI is undertaken with the use of intravenous contrast medium enhancement using a small molecular weight, gadolinium-containing contrast agent such as Gd-DTPA. As 70% of adult brain tumours are supratentorial,[3] the following technique is advised.

Protocol for imaging of adult brain tumours

Sequence	Plane	Slice thickness	Field of view
T2W	Axial	5 ± 1 mm	Whole brain
T1W	Sagittal	5 ± 1 mm	Whole brain
DWI*	Axial	5 ± 1 mm	Whole brain
FLAIR**	Coronal	5 ± 1 mm	Whole brain
T2*W***	Axial	5 ± 1 mm	Whole brain
T1W	Axial	5 ± 1 mm	Whole brain
T1W with contrast medium enhancement	3D with MPR****	5 ± 1 mm	Whole brain

* Diffusion-weighted images **Fluid attenuated inversion recovery *** gradient recall echo **** Multi-planar reconstruction

Diffusion-weighted imaging (DWI) is of value in discriminating between infarcts and tumours, and abscesses and necrotic or cystic tumours.

Variations to the standard 'brain' protocol are necessary for investigation of tumours at specific sites such as the cerebellopontine angle and parasellar region. A fat-suppressed sequence may be helpful for tumours involving the skull base.

In the paediatric population, a higher percentage of tumours (around 60–70%) are located in the posterior fossa.[2] Sagittal imaging can be useful in assessment of medulloblastoma and other midline tumours, such as pineoblastomas and germ cell tumours which tend to occur in younger patients and coronal post-gadolinium FLAIR for identifying meningeal disease.

Preoperative MRI of the whole spine to look for meningeal 'drop' metastases is essential in paediatric patients with tumours of the posterior fossa or pineal gland.

Protocol for imaging the spine for meningeal metastases

Sequence	Plane	Slice thickness	Field of view
T1 pre- and postcontrast medium	Sagittal	3 ± 1 mm	Large
T1 pre- and postcontrast medium	Axial where abnormal	4 ± 1 mm	Small

CT

- 1–5 mm axial sections using spiral technique from the skull base to the vertex, parallel to the clivus to avoid irradiation of the orbits.
- Scans should be obtained pre- and post-injection of 50–100 ml of intravenous contrast medium.
- Using multidetector CT (MDCT), slice thickness will depend on scanner capability. In general, sections are acquired at 1.25–2.5 mm and reformatted at 5 mm for viewing.

Values of $CTDI_{vol}$ should normally be below the relevant national reference dose for the region of scan and patient group (see Appendix and Radiation protection for the patient in CT in Section 2).

Immediate pre- and intraoperative imaging
Both CT and MRI, often performed with fiducial markers, are used for directing image-guided biopsy. This will be performed in dedicated neurosurgical units. Additional sequences that aid in surgical planning may need to be performed. These may include MR angiography (MRA), MR venography (MRV) and CT angiography (CTA). MRS, SPECT and PET are all techniques that may be of value in identifying the area of highest grade of malignancy and therefore influence the choice of biopsy site. ^{18}F-FDG PET shows increased uptake relative to normal cortex with high and intermediate grade tumours and in low-grade tumours ^{11}C-methionine may be useful to define tumour extent.[4]

Follow-up

Patients may be treated by complete or partial tumour resection, radiotherapy, chemotherapy alone or in combinations. Conservative management (that is, adopting a wait and watch policy) may also be appropriate. Thus the requirement for follow-up imaging of different CNS tumours is variable and the local brain tumour multidisciplinary team (MDT) will usually determine follow-up protocols.

MRI is the optimum imaging modality. In obtaining any follow-up imaging, care should be taken to obtain sequences in an identical manner to previous studies, with the same scanning plane (including angle), slice thickness and sequence types. When hard copy rather than the picture archiving and communication system (PACS) is used for archiving imaging data, it is advisable to have an agreed convention with the local neuroscience unit for displaying images in terms of orientation (for example, sagittal, right to left; coronal, front to back; axial, bottom to top). This allows for ease of comparison on subsequent follow-up imaging.

Following surgery, meningeal enhancement is frequently seen and may last for years. Enhancement of the parenchyma adjacent to the resection cavity usually appears within the first 24 hours but resolves in six to 12 months. It is seen earlier and more clearly on MRI than on CT. A variety of changes, including white matter signal abnormality, may be seen following radiotherapy. Since the incidence of recurrence of brain tumours is high,[5] it is useful to have a post-treatment baseline scan approximately three months after completion of therapy. Further imaging is indicated when new symptoms develop. Paediatric tumours are commonly scanned within 24 hours of surgery to assess the extent of residual disease.

Follow-up protocols for gliomas are various and depend on the underlying histology, patient symptoms, and the nature and extent of treatment. Prolonged survival with low-grade glioma is common, but these tumours may transform to high-grade glioma. PET-CT, MRS and perfusion imaging may help to distinguish recurrent brain tumour from radiation necrosis.[1] Follow-up scans are best performed at intervals as determined by the local brain tumour MDT.

Vestibular schwannona (that is, acoustic neuromas) and pituitary tumours are other examples of tumours, which may require long-term imaging follow-up with MRI.

Protocol for imaging of acoustic neuroma

Sequence	Plane	Slice thickness	Field of view
T2W	Axial	5 ± 1 mm	Whole brain
T2W	Axial or coronal	3 ± 0.3 mm	Small
T1W	Axial	3 ± 0.3 mm	Small
T1W with contrast medium enhancement	Axial	3 ± 0.3 mm	Small

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When screening for possible acoustic neuroma, 3D volume T2W steady state sequences such as contiguous imaging steady state (CISS) or fast imaging employing steady state acquisition (FIESTA) are usually sufficient.

Acoustic neuromas are commonly managed conservatively with surveillance scanning. Volume T2W using the sequences described above is usually sufficient, but post-contrast T1W sequences in the coronal plane may be performed. Postoperative or post-radiotherapy follow-up of acoustic neuromas does require a contrast medium-enhanced scan to detect nodular areas of recurrence. Linear enhancement of the internal auditory meatus (IAM) and adjacent dura is a normal post-surgical finding.

Protocol for imaging of pituitary or parasellar tumours

Sequence	Plane	Slice thickness	Field of view
T2W	Axial	5 ± 1 mm	Whole brain
T1W	Sagittal & coronal	3 ± 0.3 mm	Small
T2W (optional)	Coronal	3 ± 0.3 mm	Small

Enhancement with gadolinium is not recommended for routine use in the investigation of pituitary microadenoma. On the first examination of a presumed pituitary macroadenoma, contrast medium enhancement will be helpful to discriminate between other sella or suprasella tumours, such as craniopharyngiomas or meningiomas. Dynamic scanning after contrast enhancement using fast echo planner imaging (EPI) is helpful in preoperative localisation of pituitary tumours in patients with Cushing's disease and for localisation of small tumours before surgery.

Follow-up imaging of histologically verified pituitary macroadenomas does not normally require contrast medium enhancement. A baseline scan should be delayed for three to six months post-surgery to allow post-surgical changes within the sella to resolve.

Tips

- The TNM system is not useful for primary brain tumours.
- Histology of tumour is by far the most important prognostic factor.
- MRI should be able to discriminate between tumours and other intracranial lesions.
- Following treatment, meningeal enhancement may be prolonged and should be interpreted with caution.
- Pre-contrast CT may demonstrate calcification and haemorrhage within tumours.

Brain metastases

Clinical background

All malignant tumours can metastasise to brain with lung, breast and melanoma doing so most frequently. Brain metastases from gastrointestinal (GI) and genitourinary tract (GU) tumours occur less commonly. The majority of brain metastases (80%) are supratentorial and only 15% are in the cerebellum;[6] Within the cerebral hemispheres, the grey/white matter junction is the most common site of metastases. Diagnosis is usually made on the basis of multiple lesions, but solitary brain metastases occur and may be resectable. Multiple lesions are treated with chemotherapy, corticosteroids or radiotherapy; radiotherapy may be given to the whole brain or to individual lesions by stereotactic external beam radiotherapy or gamma knife irradiation.

Who should be imaged?

All patients with a previous history of malignancy and symptoms or signs suggesting metastatic disease to the brain should be imaged initially with MRI or CT.

Imaging objectives

- To detect the presence of brain metastases.
- To identify the number of metastases.
- To determine tumour extent.

Imaging

MRI

Metastases are usually of high signal intensity on T2W and of intermediate signal intensity on T1W MRI, although this signal pattern is sometimes reversed in haemorrhagic metastases, melanoma and mucinous adenocarcinoma. There is usually surrounding vasogenic oedema and its degree may be variable, but it is often disproportionate to the size of the lesion. Metastases situated in grey matter tend to be associated with less oedema than those found in white matter. Enhancement with contrast medium is typical and may be seen throughout the lesion or only at its rim. DWI is useful for distinguishing them from abscess.

Meningeal metastatic disease is diagnosed by the presence of multiple-enhancing nodules in the leptomeninges. A modest degree of dural enhancement is normal and may be increased after a cerebrospinal fluid (CSF) tap. Meningeal metastatic disease may be present in the absence of meningeal enhancement and confirmed by cytology even when MRI is entirely normal. Conversely, no malignant cells may be found on cytology despite abnormal meningeal enhancement.

Protocol for imaging of brain metastases

Sequence	Plane	Slice thickness	Field of view
T2W	Axial	5 ± 1 mm	Whole brain
FLAIR	Coronal	5 ± 1 mm	Whole brain
T1W	Axial	5 ± 1 mm	Whole brain
DWI	Axial	5 ± 1 mm	Whole brain
T2*W	Axial	5 ± 1 mm	Whole brain
T1W with contrast medium	Axial/coronal/sagittal	5 ± 1 mm	Whole brain

The dose of gadolinium containing contrast medium given may vary with therapeutic intent. Normally, 0.1 mmol/kg patient body weight of Gd-DTPA is given (or equivalent, if contrast agents of higher relaxivity are used), but this may be increased to increase the sensitivity of the examination. Higher doses may be used if resection or targeted irradiation is being contemplated.

CT

- 1–5 mm axial sections using spiral technique from the skull base to the vertex, parallel to the clivus to avoid irradiation of the orbits.
- Scans should be obtained pre- and post-injection of 50–100 ml of intravenous contrast medium.
- Using MDCT, slice thickness will depend on scanner capability. In general, sections are acquired at 1.25–2.5 mm and reformatted at 5 mm for viewing.

Values of $CTDI_{vol}$ should normally be below the relevant national reference dose for the region of scan and patient group (see Appendix and Radiation protection for the patient in CT in Section 2).

PET-CT

Although intracranial metastases may show uptake with ^{18}FDG, PET-CT is not generally used for intracranial lesion detection because grey matter demonstrates (normal) physiological uptake of this tracer.

Follow-up

After resection/targeted radiotherapy of a solitary metastasis or whole-brain radiotherapy for multiple brain metastases, follow-up MRI may be performed three months after completion of treatment to serve as a baseline. However, patients may also be managed expectantly and only re-imaged when new symptoms develop.

CT is sometimes used at diagnosis and follow-up. If metastases can be adequately demonstrated as enhancing lesions in the brain and treatment can be planned accordingly, it may not be necessary to undertake MRI at follow-up. However, contrast-enhanced MRI is the most accurate available technique for establishing the site, size and number of metastatic intracranial lesions and is similarly best for follow-up imaging.

Tips

- Pre-contrast CT or MRI scans are useful in patients with suspected metastases from testicular non-seminomatous germ cell tumours, which are frequently haemorrhagic.
- Malignant melanoma metastases are frequently of high signal intensity on pre-contrast MRI T1W images due to the paramagnetic effects of melanin, and of high density on pre-contrast CT scans.

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