Chapter 4

Radiology Imaging Techniques of Brain Tumours

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Additional information is available at the end of the chapter

http://dx.doi.org/10.5772/53470

1. Introduction

The development of radiological imaging techniques for the evaluation of brain tumours has progressed significantly in recent years. Two modalities that play a crucial role in the evaluation of brain tumours in preoperative time to detach are computed tomography (CT) and magnetic resonance imaging (MRI).

Despite the new digital radiological techniques, which are used widely in clinical practice, imaging methods such as CT and MRI eliminate x-ray from the examination algorithm of brain tumours. An x-ray of the skull may detect changes that can lead to suspicion of a tumour in the intracranial space and subsequent examination using CT or MRI.

It is important to distinguish tumoural from non-tumoural lesions, and to determine their spatial location. New, advanced imaging CT and MRI techniques provide more detailed characteristics of brain tumours, and thus, more choices of appropriate therapeutic management of the patient. These techniques also play a significant role in monitoring the effect of the therapy.

Diagnosis of tumours has improved considerably due to the introduction of new imaging CT and MRI techniques. These techniques, and the contrast medium in particular, provide anatomical and structural information about brain tumours, and information about the physiology, metabolism, and haemodynamics of individual tumours. The importance of radiology imaging techniques, and their role, in the diagnosis of brain tumours are listed in Tables 1 and 2.

Radiology Imaging Techniques of Brain Tumours	
MODALITY	**IMPORTANCE**
CT	screening method
MRI	method of choice
DSA	mostly used for determination of blood supply and embolization of hypervascular tumours
US	intraoperative navigation
X – ray	limited
Conventional invasive X – ray methods	obsolete

Table 1. Importance of radiology imaging techniques in the diagnosis of brain tumours.

Role of Radiology Imaging Techniques		
Preoperatively	Detection	
	Characterization	localization
		size
		margins
		extension
		midline shift
		compression
		contrast enhancement
		vascularity
		supplying vessels
		perifocal oedema
	Differentiation	benign vs malignant
	Staging	
	tumour embolization	
	surgical planing	
Intraoperative	surgical navigation	
Postoperatively	monitoring the effect of treatment	
	exclude recurrence	
	distinguishing recurrent tumour from radiation necrosis	

Table 2. Role of radiology imaging techniques in brain tumours

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2. Conventional imaging methods

For decades, diagnostic imaging dominated conventional non-invasive and invasive methods, and later invasive contrast x-ray techniques. During the second half of the twentieth century, a number of different projection x-ray radiographs of the head and their modifications, as well as complex invasive contrast imaging techniques, such as pneumoencephalography, ventriculography, and myelography, were improved [1]. Another imaging method is ultrasonography, which can be used for neuronavigation during operation of brain tumours.

2.1. Conventional non-invasive X-ray methods

In the past, conventional non-invasive x-ray examination (radiography of the head) was the basic diagnostic method in neuroradiology. The baseline projections are posteroanterior (PA) and lateral x-ray projections of the skull. A PA projection is centred by orbitomeatal lines and provides anatomical information about the skull and frontal structures. A lateral projection shows the configuration of the skull and the skull base.

Modification of a PA projection by Caldwell with an x-ray beam inclination of 15°–23°, caudal to the orbitomeatal line, provides a clearer view of the *os petrosum*. With an x-ray beam inclination of 37°, caudal to the orbitomeatal line, we obtain a semiaxial Waters projection, which shows paranasal cavities and structures of the zygomaticomaxillar complex. An x-ray beam inclination of 30°, caudal to the orbitomeatal line, in the anteroposterior (AP) direction provides the Towne's projection, which is appropriate for imaging the *os spheoidale*, foramen magnum, and pyramids, and their dorsal edges in particular.

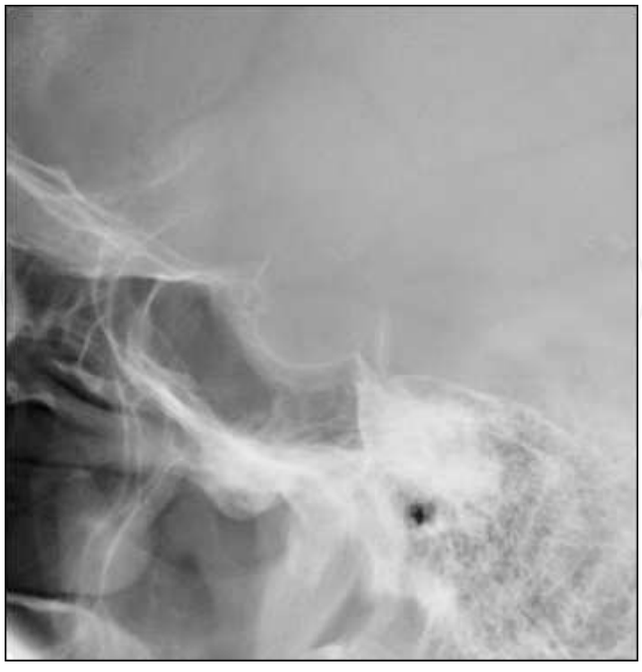

Figure 1. Sella turcica (lateral projection): destruction by tumour

A submentovertical projection is an axial projection of the skull with the x-ray beam passing approximately perpendicular to the orbitomeatal line, and is suitable for imaging the *os sphenoidale* and the base middle *fossa foramina*. The Stenvers projection with a 45° rotation of the head from the PA line, and with a caudal x-ray beam inclination of 10°–15°, is the most common projection for imaging the *os petrosum*, providing a good display of the tip of the pyramid, the structures of the inner ear, and the *meatus acusticus internus*. The Schüller projection is a lateral projection with a caudal x-ray beam inclination of 30° and is employed for enhanced imaging and evaluation of the *processus mastoideus* pneumatization. A modification of these projections is a lateral projection by Runström I, with an x-ray beam inclination of 15° and a projection by Runström II with a caudal x-ray beam inclination of 45° [1]. Other special projections focus on the *sella turcica* (Figure 1.), *canalis opticus.*

2.2. Conventional invasive X-ray methods

Pneumoencephalography is an imaging method in which the lumbar or suboccipital approach is used to instill air into the cerebral ventricles and the subarachnoid spaces after removing approximately 10–30 mL of cerebrospinal fluid [2].

Ventriculography is an imaging method in which, through a trepanation hole, air is introduced into each lateral brain ventricle after the collection of cerebrospinal fluid [3].

These imaging x-ray methods are currently not used in clinical practice.

Before the era of CT and MRI, panangiography was the essential imaging technique of neuroradiology in the diagnosis of brain tumours. A brain tumour manifests itself in angiographic images by indirect signs, such as dislocation of intracranial arteries, depending on tumour size and location; tumoural vessels filling with the contrast medium, tumour vascularization; or vascular occlusion and stenosis [2].

With the onset of CT and MRI, the position of angiography has gradually changed. Currently, due to a new generation of digital radiological technology and rapid development of intracranial catheterization techniques and instrumentation, digital subtraction angiography is a highly specialized imaging method in interventional radiology, with many therapeutic implications.

2.3. Ultrasound

Ultrasound is a widely available, non-invasive diagnostic method without negative biological effects. Principally, it is applied, in the primary examination of the brain in prenatal and postnatal diagnoses, and in the examination of cerebral arteries. Currently, ultrasonography, used in planning operational strategy and choice of neurosurgery access, has been replaced by new, and more accurate, neuronavigation systems using MRI data. Ultrasound with a high-frequency transducer can be used to monitor changes during brain tumour operations in real time [1] (Figure 2.).

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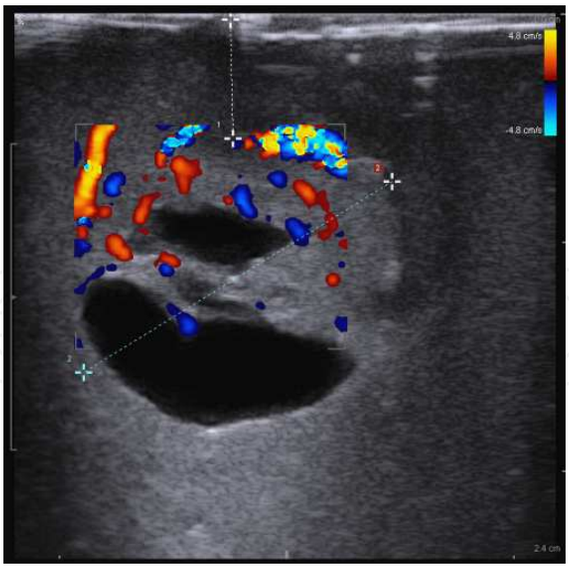

Figure 2. Intraoperative ultrasound navigation with colour flow mapping, showing peripheral vascularization of a brain tumour with solid and cystic parts

3. Computed Tomography – CT

From its first test scan on a mouse, in 1967, to current medical practice, the CT scanner has become a core imaging tool. Initially financed by money from Beatles' record sales, the first patient scan was performed in 1971. Only 8 years later, a Nobel Prize in Physics and Medicine was awarded to Gofrey Newbold Hounsfield and Allan McLeod Cormack for their discovery [4]. The prototype (EMI Ltd.) was installed at Atkinson Morley's Hospital in South London where the first patient, a middle aged lady with a suspected frontal lobe tumour, was scanned on 1st October 1971 [5].

The rapid development of CT scanners, a new generation of CT devices, and advanced post-processing technologies in recent years has enabled the creation of progressive, advanced CT protocols for the diagnosis of individual anatomical regions with respect to the pathological processes that can be diagnosed. Technological improvements and new CT applications in neuroradiology are mainly related to CT angiography and CT perfusion with a dynamic contrast agent bolus [1].

The basic CT examination of brain tumours involves standard non-contrast enhanced and contrast enhanced imaging (Figure 3.). Compared to MR, CT is superior in the detection of calcification and bone abnormalities, and it is also less time consuming.

In CT diagnosis, depending on the type of examination, iodinated contrast agents are administered, in different quantities and by different modes. Iodinated contrast agents are divided into ionic, high-osmolar contrast agents and non-ionic, low-osmolar or iso-osmolar contrast agents. Intravenous administration of contrast agents may cause various negative

allergic reactions, which are divided into early (within 20 min) and late effects. In practice, non-ionic contrast media are generally preferred as, due to their low osmolarity, they result in significantly fewer negative effects [6].

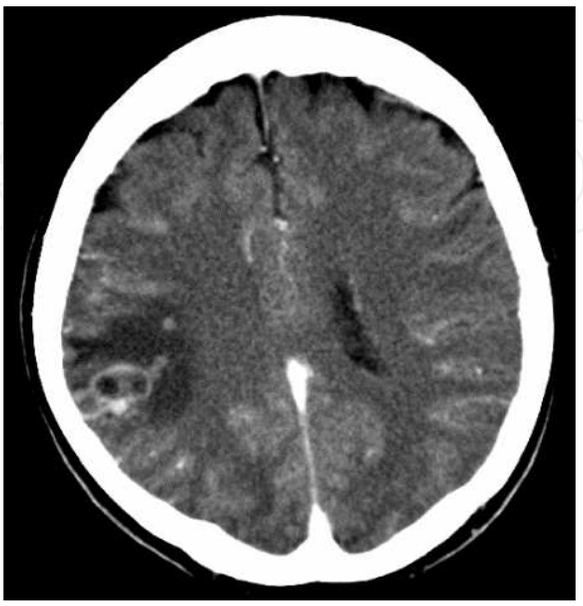

Figure 3. Contrast enhanced CT of brain tumour: irregular peripheral enhancement of glioblastoma (the image displayed is of the same patient as displayed in Figure 2)

Examination of blood vessels using CT angiography is a non-invasive imaging method which is conducted in various ways: imaging individual sections, maximum-intensity projection (MIP), shaded surface display (SSD), the volume-rendering technique (VRT), multiplanar reconstruction (MPR), and virtual angiography. Improvement in the quality of CT angiography, and the new generation of CT equipment gives rise to the possibility of longer scans, faster scan times with display of the arterial phase of contrast filling with the lowest venous infiltration, and better resolution with improved vascular details.

CT perfusion (Figure 4.) in the diagnosis of brain tumours allows assessment of tumours on the microvascular level through a dynamic scanning sequence during an intravenous bolus injection of a contrast agent. This is a relatively new technique that is used in neuroimaging for quantitative and qualitative assessment of cerebral perfusion by the parameters of cerebral blood flow (CBF), cerebral blood volume (CBV), mean transit time (MTT), and time to peak (TTP). Maps with colour-coded flow rates can be obtained by using postprocessing software. Due to this technique, it is possible to assess the state of vascularization and haemodynamics of brain tumours and their differentiation [7 - 9].

4. Magnetic resonance imaging – MRI

Historically, many scientists have contributed to the study of NMR (MRI), which led to construction of reliable MR scanners for clinical practice. Isidor Isaac Rabi in 1930 began by

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studying the magnetic properties of atomic nuclei (Nobel Prize in Physics in 1944) [10]. The first successful nuclear magnetic resonance experiment with NMR precision measurements was made independently in 1946 by Felix Bloch and Edward Mills Purcell (they jointly received the Nobel Prize in Physics in 1952). In 1971, Raymond Vahan Damadian, measured T1 and T2 relaxation times of excised normal and cancerous rat tissue and stated that tumour tissue had longer relaxation times than normal tissue. He is the inventor of the first MR Scanning Machine (1977) [11]. In March 1973 Paul C. Lauterbur published the first 2D NMR images of two 1 mm capillaries filled with water [10] and in 1974 the image of thoracic cavity of mouse. He called his imaging method zeugmatography. This term was later replaced by NMR imaging [12]. Peter Mansfield with Grannel described the use of magnetic field gradients to acquire spatial information in NMR. P.C. Lauterbur and Sir Peter Mansfield received the Nobel Prize in 1952. The first commercial MR scanner (Picker Ltd.) in Europe was installed in 1983 in Manchester Medical School.

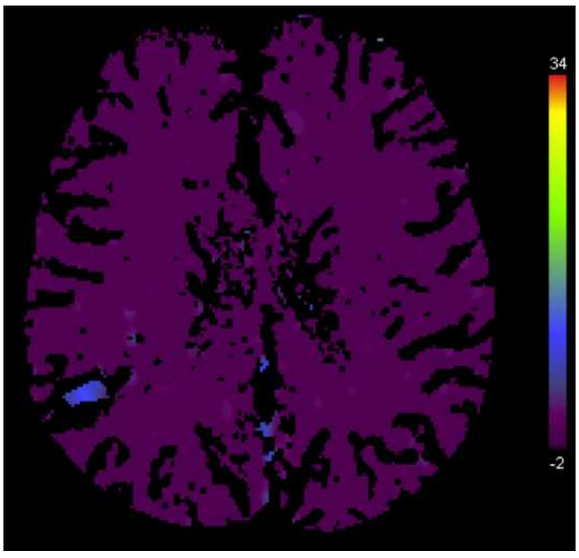

Figure 4. CT perfusion of a brain tumour across the solid part of the tumour (the image displayed is of the same patient as displayed in Figure 2).

The main advantages of MRI are the possibilities of imaging individual anatomical regions in vivo with high tissue contrast, imaging in arbitrary planes, non-invasivity, and the absence of demonstrable detrimental effects on human health. Qualitative evaluation of tissues allows for four basic physical attributes: T1 and T2 relaxation, proton density, motion, and flow.

4.1. Conventional MRI techniques

Conventional MRI techniques provide information about the anatomical conditions of brain tissue, the tumour itself, and its relationship with its surroundings. In contrast to CT, conventional MRI techniques are significantly more sensitive, but as they are nonspecific, they often provide limited information about tumour physiology.

The conventional MRI protocol in the diagnosis of brain tumours includes standard T1-weighted imaging (spin echo [SE], turbo spin echo [TSE], gradient echo, three-dimensional [3D] sequences, and dynamic studies), T2-weighted imaging (SE, fast spin echo [FSE] or TSE, and 3D sequences), "dark fluid" T2-weighted imaging (proton density [PD] and fluid-attenuated inversion recovery [FLAIR]), gradient echo (GRE T2, T2 * GRE, and GRE 3D T1), inversion recovery (IR) (FLAIR, T1 IR, and short-time inversion recovery [STIR]), and fat suppression (FS) (STIR and T1 FS) [13] (Figure 5.).

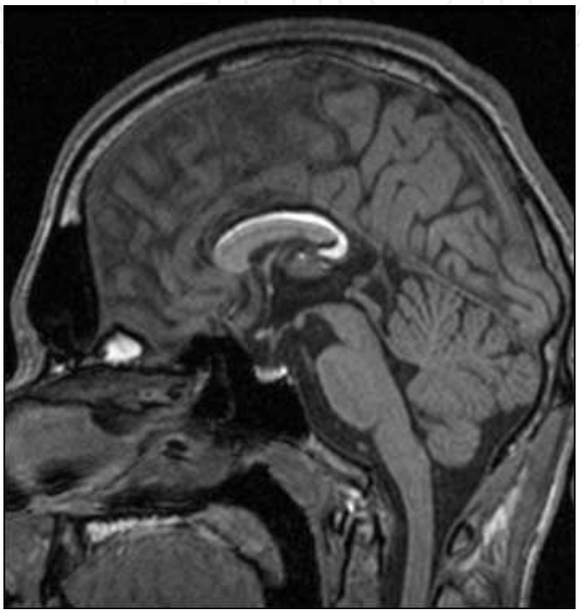

Figure 5. Sagittal non-contrast enhanced T1W image: hyperintense signal of pericallosal lipoma.

Brain tumours show variable pathomorphological manifestations in MRI, which depend on the structure of different types of tumours. They may have a homogeneous or an inhomogeneous structure, and depending on whether they are focal lesions or infiltrative and growing, they are sharply contoured or diffuse [14].

In general, brain tumours in T1-weighted imaging are hypo- or isointense and in T2-weighted imaging are hyper- or isointense. The tumour's signal is modified by the intralesional proportion of individual components. Tumours may contain solid, cystic, necrotic, or haemorrhagic components, fatty tissue, or an increased proportion of protein in intracystic components. Not all tumours cause oedema of the brain tissue, which may have a different range [13, 15].

In some cases, visualization of brain tumours in non-contrast imaging can be difficult; therefore administration of a paramagnetic contrast agent is necessary. Contrast enhancement of brain tumours is variable and dependent on tumour neovascularization.

MRI shows intracranial arteries, veins, and venous sinuses at high-quality. Magnetic resonance angiography (MRA) can be implemented using several techniques: phase-contrast MRA (PC MRA), time-of-flight MRA (TOF MRA), and contrast-enhanced MRA (CE MRA) [16].

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Tumour angiogenesis can be dynamically monitored in vivo by 3D-CTA and 4D-CE-MRA. Of the two methods, 3D-CTA has better spatial resolution, but 4D-CE-MRA allows temporal resolution of tumour angiogenesis [17].

MRA allows detailed evaluation of intracranial vascular structures, not only because of purely pathological changes of vascular origin, but also in relation to brain tumours.

4.1.1. Contrast agents

In addition to non-contrast enhanced imaging, magnetic resonance examination is realized with contrast agents, which improves visualization and demarcation of the tumour. Contrast agents used in MRI are paramagnetic substances containing gadolinium chelates; they cause shortening of the T1 and T2 relaxation times, resulting in a stronger T1 and a lower T2 signal, and they also increase the contrast between two tissues with different quantities of the contrast agent. Increase of T1 signal is more significant, compared with the degree of weakness of the T2 signal; therefore T1-weighted sequences are used after contrast administration (Figures 6-8.).

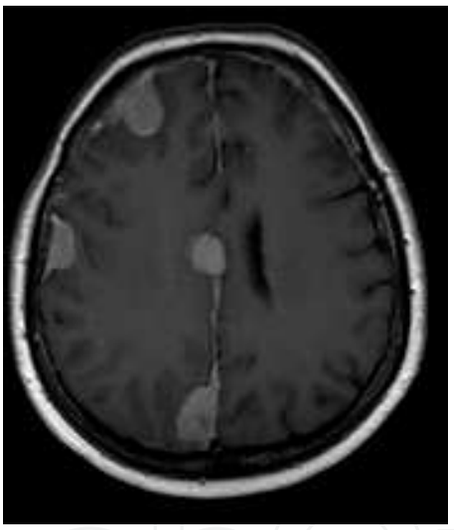

Figure 6. Axial contrast enhanced T1W image: homogeneous enhancement of multiple meningiomas right supratentorial in patient with neurofibromatosis type 2.

Contrast agents for MRI can be divided into several categories: intravenous contrast agents, which include the majority of non-specific and specific contrast agents; oral contrast agents for display purposes of the gastrointestinal tract; and interstitial contrast agents. According to the space distribution of contrast agents, they are classified into extracellular organ-non-specific and intracellular organ-specific contrast agents. In the diagnosis of brain tumours intravenous extracellular organ-non-specific contrast agents are used, which have the ability to pass through the blood–brain barrier [18].

Different types of contrast enhancement and common types of brain tumour are listed in Table 3.

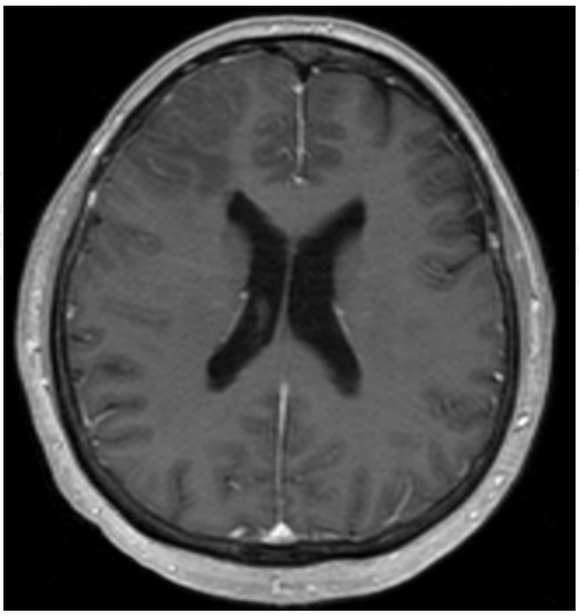

Figure 7. First patient examination. Axial contrast enhanced T1W image displays almost no contrast enhancement in the right frontal

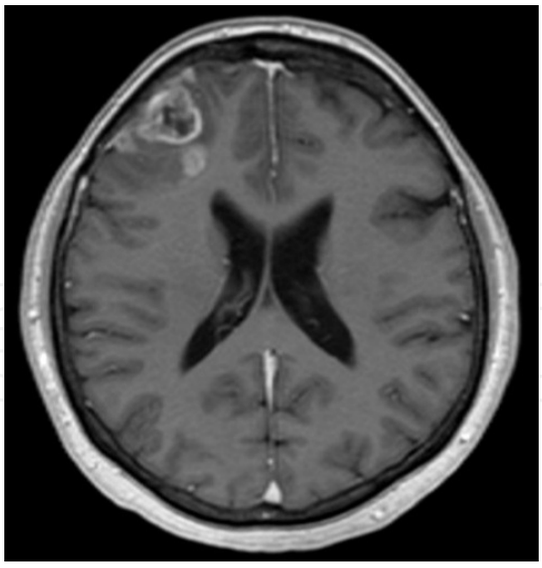

Figure 8. Second patient examination. Axial contrast enhanced T1W image displays irregular peripheral enhancement of right frontal tumour (the image displayed is of the same patient as displayed in Figure 7, 3 months later; glioblastoma was confirmed by histology).

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Different types of contrast enhancement	
no enhancement	Low grade astrocytoma
diffuse homogeneous	Meningioma
diffuse inhomogeneous	Pleomorphic xanthoastrocytoma
ring enhancement	Metastasis
irregular peripheral enhancement	Glioblastoma
mural nodule enhancement	Haemangioblastoma

Table 3. Different types of contrast enhancement of brain tumours and common types of brain tumour.

4.2. Advanced MRI techniques

Early and accurate diagnosis is the first precondition of the successful treatment of brain tumours. The basic method of determining species diagnosis and grading is the histopathological examination. Biopsy is an invasive method with the risk of possible complications. At the time of the development and practical use of modern, advanced diagnostic techniques, the role of radiodiagnostic imaging modalities was not limited to the assessment of pathological-anatomical conditions [9].

Advanced magnetic resonance techniques in neuroradiology evaluate changes at the microvascular, haemodynamic, and cellular levels of brain tumours, and in addition to structural changes, evaluate changes at the metabolic and biochemical levels [19].

Incorporation of new diagnostic techniques, such as diffusion-weighted imaging (DWI), diffusion tensor imaging (DTI), tractography, perfusion-weighted imaging (PWI), magnetic resonance spectroscopy (MRS), and functional MRI (fMRI), into the diagnostic protocol allows us to obtain detailed information about tumour lesions. This presents the best possibility of accurate grading of brain tumours in the preoperative time, allowing us to select the most appropriate therapeutic management for the patients [20].

New techniques lead to better quality monitoring of the effects of therapy.

4.2.1. Diffusion-weighted imaging (DWI)

The theory of diffusion is based on constant, disordered, random motion of water molecules in all directions (Brownian motion). Biological tissues in which diffusion is the same in all directions is isotropic; if diffusion is restricted in one direction, tissues are anisotropic. The most common barrier to diffusion is the cell wall. Cerebrospinal fluid is the isotropic field; diffusion in gray matter in all directions compared to the liquor is limited but also isotropic. White matter is the anisotropic region because here diffusion progresses with greater intensity in the direction within axons [21].

DWI is echo-planar imaging that measures the random motion of water molecules (i.e. diffusion in biological tissue). The diffusion capacity of water protons is tissue-specific and cre-

ates a specific contrast on DWI. On diffusion sequences, the motion of water protons in biological tissue causes changes in the signal. These signal changes are quantified by calculating the apparent diffusion coefficient map (ADC) [22] (Figure 9.).

DWI, which is currently a routine part of imaging protocols, plays an important role in the assessment of the cellularity of biological tissue. In the diagnosis of brain tumours, DWI is applicable in differential diagnosis of cystic lesions, abscesses, necrosis, and metastases. In addition, DWI has a fundamental role in the evaluation of the age of brain ischemia, in imaging of traumatic changes, and in evaluation activities of demyelinating lesions [23].

Possibilities of using the ADC in differential diagnosis of intracranial tumours, and differentiating peritumoural oedema and infiltration, have been studied since the beginning of the 21st century. Most studies have concluded that the ADC is useful for distinguishing peritumoural infiltration only and cannot provide information on the degree of differentiation of glial tumours. However, they found that in tumour tissue with high cellularity, ADC values were reduced compared to tumours with low cellularity; thus the probability of higher grading is reduced for solid tumours with high values of the ADC. For tumours with a cystic component, such as glioblastoma multiforme, the relationship between the ADC and the grading is below the level of statistical significance [24].

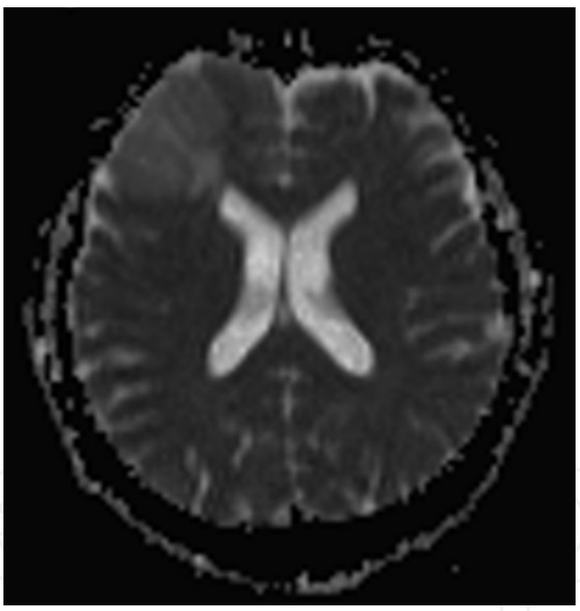

Figure 9. Axial ADC map showing the right frontal hyperintensity of a tumour (the image displayed is of the same patient as displayed in Figure 7).

4.2.2. Diffusion tensor imaging (DTI)

DTI is an advanced magnetic resonance technique that allows visualization of white matter tracts, and describes the movement of water molecules by using two parameters, mean diffusivity (MD) and fractional anisotropy (FA), which represent the directionality of water diffusion [25].

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The postprocessing of DTI data using software generates maps of FA and ADC using DWI images. Reduction of FA surrounding white matter of the tumour indicates the suspicion of peritumoural white matter infiltration by tumoural elements [26]. Using 3D software applications, 3D image tracts are created, allowing imaging of the spatial configuration of white matter structures, such as the corticospinal tract, and configuration of the *corpus callosum* [27]. DTI is able to demonstrate structural changes of white matter tracts related to brain tumours, such as the detection of alterations, integrity, or dislocation of individual tracts (Figure 10.).

Thus, DTI provides other important information that can help distinguish infiltrative growing tumours from bounded tumours and, together with assessment of the ADC and conventional MRI with a contrast agent, the grading of tumours can be better specified [28 - 30].

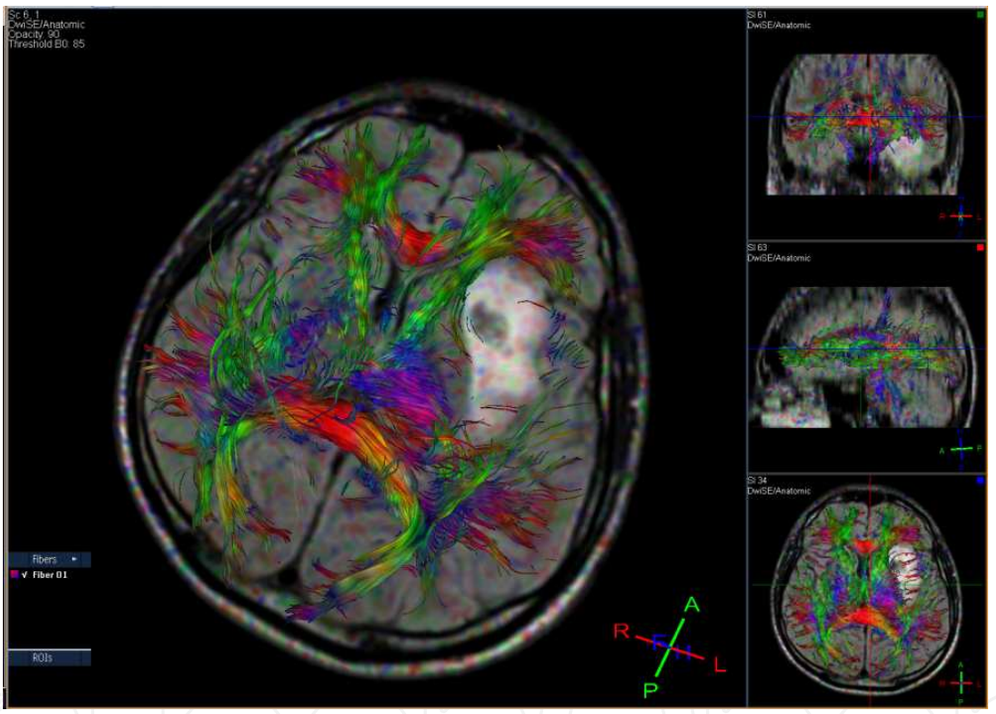

Figure 10. DTI: destruction and deviation of white matter tracts by anaplastic astrocytoma.

4.2.3. Perfusion-weighted imaging (PWI)

The rapid growth of cells is a result of the increased metabolic demands of a tumour. Cellular hypoglycaemia and hypoxia result in the production of cytokines of angiogenesis (vasoactive endothelial growth factor) followed by tumour neovascularization, which leads to a higher volume of blood flow through tumour tissue. Tumour neovascularization and haemodynamic changes are the basic principles of perfusion MRI, which evaluate the blood supply to brain tissue by four parameters: CBV (the quantity of blood in a given volume in mL/100mg), CBF (the blood flow in brain tissue in mL/100g/min), MTT (the average time for

arteriovenous passage of blood in a given volume in seconds), and TTP (the average time to maximum density in the scanning area in seconds) [31, 32].

PWI uses fast, dynamic, epiplanar imaging sequences with a bolus of a paramagnetic contrast agent, 0.2 mmol/kg body weight, at an injection rate of 5 mL/s, approximately 5-10 seconds after the start of imaging sequences, followed by an injection of 20-30 mL of saline. The passage of the contrast agent through vascularized parts of the tumour leads to a reduction in signal intensity. Converting the values of individual parameters by postprocessing to the colour range creates maps with different blood flows. Regional cerebral, and tumour, vascularity is correlated with the CBV.

With PWI it is possible to determine tumour grading non-invasively. In general, high-grade tumours have higher CBV values than low-grade tumours. PWI is also used for localization of the parts of a tumour with a high degree of vascularity for the purpose of stereotactic biopsy. PWI helps to define the edge of a tumour, which is important in planning surgical treatment radiotherapy. PWI is also used to monitor the effect of treatment on patients. In the field of radiation changes, using conventional magnetic resonance techniques, it is difficult to differentiate the eventual recurrence of a tumour. Postirradiation changes have lower CBV values, and through PWI, it is possible to detect areas with increased perfusion, which correspond to tumour recurrence. Increasing specificity in these cases allows the combination of PWI with MRS [33].

4.2.4. Magnetic resonance spectroscopy (MRS)

Based on recent achievements in the field of MRS, the diagnostic proportion of proton MRS has significantly increased, in the past decade progressing from basic and clinical research to routine clinical practice. MRS is a non-invasive method and currently is part of the advanced diagnostic protocol in neuroradiology. MRS can determine pathological changes in brain tissue long before conventional techniques [34].

MRS provides biochemical and metabolic information about brain tumours and their surrounding tissues. Thus MRS, contributes significantly to the distinguishing of tumour from non-tumour lesions, the type of diagnosis and tumour grading in preoperative time, oedema from infiltrative growing tumours, the monitoring of tumour response to treatment and distinguishing postirradiation necrosis from tumour recurrence [35].

MRS by non-invasive and non-destructive methods detects, in vivo in brain tissue, diagnostically important compounds such as those containing choline (Cho – a key marker of cell membrane stability), creatine (Cr – an indicator of the energy status, often used as a reference value), *N*-acetylaspartate (NAA – the main indicator of the structure and function of neurons), lactate (Lac – in normal tissue its concentration is on the edge of detectability and is increased in anaerobic metabolism), and lipids. The magnetic resonance spectrum of human brain metabolites is relatively constant [36].

Changes in biochemical processes at the cellular level precede macroscopic changes; therefore, MRS is able to detect the development of pathological processes in brain tissue before conventional MRI techniques. MRS and MRI use magnetic characteristics of the atomic nu-

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cleus; in obtaining the signal, they work on the same physical principle, but the data processing and interpretation for each are different. MRI provides detailed information about the pathological-anatomical state of brain tissue [37].

Whereas, MRS detects metabolic signals and results in a spectrum in which the position of the signal of a specific metabolite is expressed on the horizontal axis in chemical shifts specified in parts per million (ppm), and the vertical axis reflects the intensity of the signal. The chemical shift and shape of the signal is characteristic for each metabolite [38] (Figure 11.).

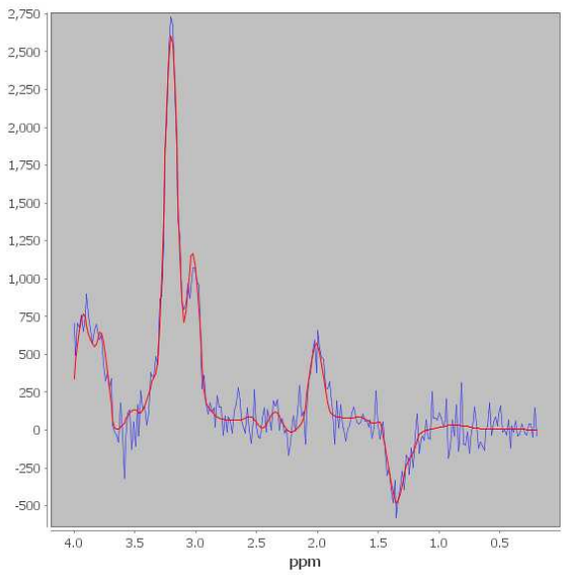

Figure 11. MRS: a typical sample 1H MR spectrum in the lesion. Cre2, Cho, Cre, NAA, lac (the image displayed is of the same patient as displayed in Figure 10).

In practice, there are two basic techniques of MRS, single voxel spectroscopy (SVS) and chemical shift imaging (CSI). The result of SVS is one spectrum, which shows the overall distribution of individual metabolites in a limited volume of tissue (voxel) in a volume of 2-8 mL. CSI measures the concentration of metabolites in a selected volume of brain tissue divided into many small voxels. The result is an individual spectrum for each voxel, and the imaging of the distribution of the concentration of individual metabolites in the examined area is produced as a spectroscopic map (Figure 12.).

In clinical practice, MRS is realized through the anatomical imaging of brain tissue using conventional MRI. The spectra are displayed together with conventional MRI images, which characterize the anatomical location of the measured area selected for spectroscopy [38].

The results of the spectra are evaluated by the relative intensity of the signals and the ratios of observed metabolites are typically set to creatine or choline (for example, NAA/Cr, NAA/Cho, or NAA/Cr + Cho). Different types of tumours are manifested by a characteristic spec-

troscopic profile. Primary tumours are characterized by reducing the concentrations of NAA and *N*-acetylaspartylglutamate, Cr, and creatinephosphate, and increasing the concentrations of Cho and (in astrocytoma) inositol (Ins). Increased concentrations of Lac and lipids (Lip) are characteristic of necrosis. Peritumoural oedema is characterized by low concentrations of all metabolites. The interpretation of results may not be accurate using ratios in the evaluation of the spectra; therefore, different quantification programs using standard reference values are currently being tested and used [35 - 36].

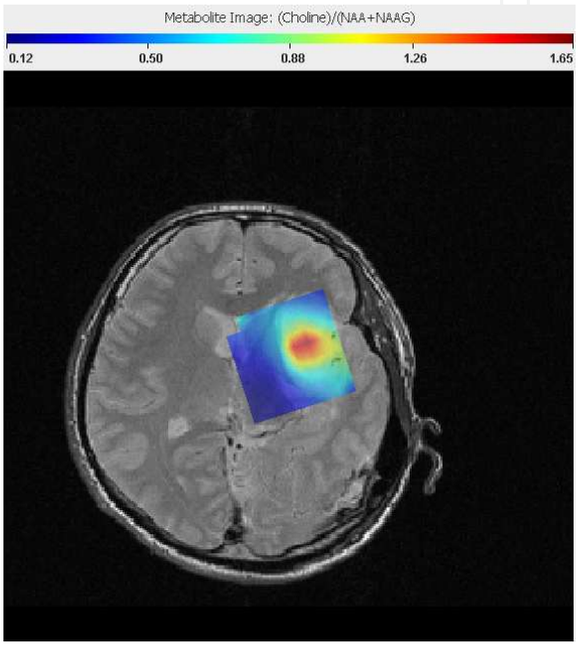

Figure 12. MRS: Coloured metabolic map of the metabolic ratio of total cholines to the signal of the total NAA signal (not resolved to its components), tCho:tNAA (the imaged displayed is of the same patient as displayed in Figure 10).

4.2.5. Functional magnetic resonance imaging (fMRI)

Functional magnetic resonance imaging (fMRI) is an MRI procedure that indirectly measures the brain activity by means of deoxyhaemoglobin concentration or blood perfusion changes.

The 1st technique, known as BOLD (blood oxygenation level dependent), is the most popular and frequently used [39]; a relative decrease in deoxyhaemoglobin concentration in the active brain tissue, due to an excessive increase of regional blood flow, and corresponding increase of oxyhaemoglobin. Oxyhaemoglobin is, however, less effectively deoxygenated by active brain tissue compared to inactive brain tissue in physiological conditions. Relative changes of diamagnetic oxyhaemoglobin and paramagnetic deoxyhaemoglobin can be easi-

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ly measured by fast T2-weighted echo-planar (EPI) acquisitions. Their temporal resolution, approximately 100 ms per image slice, is good enough to compare several brain images in rest and active (performing sensory, motor or cognitive task) conditions. The statistical maps that result from this, coregistered with structural MRI (Figure 13.), can provide precise information (in the order of millimetres) about the position and the size of brain regions involved in the processing of each respective task, and, sometimes the dynamics of such processing.

The 2nd group of techniques can evaluate the changes of blood flow in brain tissue using special exogenous diffusible tracers like fluorinated halocarbons, deuterated water, ^{17}O -water and ^{13}C-hydrocarbons, or magnetically labelled endogenous blood water (arterial spin labelled perfusion, ASL). The latter technique is non-invasive and very promising for future clinical applications. It can substitute some nuclear medicine diagnostic methods while providing images with better spatial and temporal resolution. Compared to BOLD techniques, ASL can provide not only relative differential maps, but it also provides quantifiable information about absolute blood flow values (in ml/g/min) in selected brain regions [40]. Thus, it can show the regions activated by some tasks, and also pathological tissue with increased or decreased perfusion compared to normal brain tissue [41]. However, the intrinsic signal-to-noise ratio of ASL is lower compared to BOLD measurements, and currently the majority of scanners are not equipped with the respective product sequences to perform routine clinical ASL procedures.

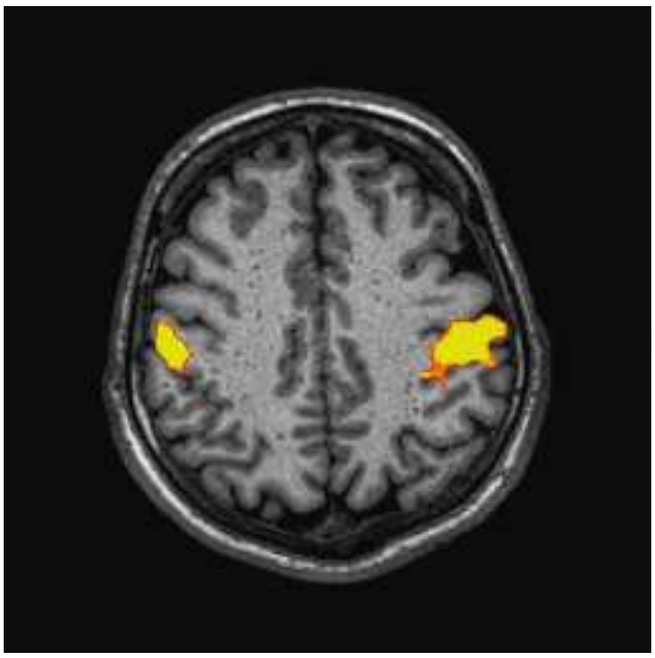

Figure 13. fMRI: activation of motor cortex during physical stimulation.

Presently, in tumour imaging, fMRI is used predominantly for the preoperative localization of eloquent cortical regions that may have been displaced, distorted or compressed by the tumour [42]. FMRI can provide an alternative to invasive mapping techniques (IMTs), with many benefits, particularly in those patients that are unable to undergo awake craniotomy or other stereotactic diagnostic procedures. FMRI data can be very helpful in neuronavigation, especially if the eloquent region is hidden in the depth of sulci and/or cannot be stimulated during the surgery [43].

The sensitivity of fMRI recordings can be increased by the use of stronger magnetic fields. A shorter scanning procedure, higher signal-to-noise-ratio, and increased spatial resolution of the resultant images favour the usage of 3T and are stronger compared to conventional 1,5T scanners [44].

However, the limitations of fMRI are not a result of poor engineering or the low power of the scanners; the main pitfalls are due to complicated functional brain organization and inappropriate diagnostic protocols that ignore this organization [45]. There are always several brain regions involved in the processing of every sensory/motor/cognitive task. It is upon the examiner to choose the best one, to adjust the statistical thresholds of the fMRI map (which determines the number and the size of activated brain regions), and to recognize which regions are eloquent.

A coregistration of the data provided by several different functional and/or structural MRI techniques (e.g. BOLD, ASL, diffusion tensor imaging, MR spectroscopy, ^{23}Na-MRI) is suitable for future improvements of functional MRI diagnostics.

4.2.6. Neuronavigation and intraoperative imaging modalities

Introduction of CT, MRI, and microsurgical operating techniques into clinical practice have resulted in progress in the neurosurgical therapy of brain tumours. The application of new MRI techniques and microsurgery allows for the resection of tumours in functionally important brain regions.

Neuronavigation is a common method of preoperative localization of brain tumours. It uses imaging materials of preoperative MRI examinations, 3D sequences and DTI and fMRI data, that are transferred to a computer database of a neuronavigation device; which, after data processing and registering of the patient's head position, allows for planning of an optimal trajectory for operating on the brain tumour [46].

According to the virtual reality planning, neurosurgeons could obtain more anatomic information and choose the best approach for tumour resection, which would result in a better prognosis for patients [47].

The disadvantage of current navigation systems is that it is impossible to update data during the neurosurgical procedure. A shift in brain structures and tracts of white matter as a result of the evacuation of cerebrospinal fluid, tumour resection, or gravity makes navigation inaccurate. These disadvantages deal intraoperative using of imaging methods – intraoperative ultrasonography and MRI [48].

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Intraoperative MRI displays actual dynamic changes in deformable brain tissue during surgery, and helps in early detection of potential tumour residue. Data transfer from intraoperative MRI to the neuronavigation system is possible, and data for neuronavigation can be updated repeatedly. For this purpose, different types of magnetic resonance devices are used. The presence of a magnetic field requires the use of compatible surgical instruments.

Intraoperative ultrasonography with new devices and high resolution is a cheaper alternative to MRI, with the advantage of imaging in real time; it provides actual images of the tumour, surrounding structures, and major blood vessels during surgery [1].

5. Digital subtraction angiography - DSA

Digital subtraction angiography (DSA) is a computer-assisted x-ray technique that subtracts images of bone and soft tissue to permit viewing of the cardiovascular system [49].

At the beginning of the process of subtraction, an image (the mask) is obtained before arrival of contrast material at the area of interest, and the mask image is placed into one of two digital memories. Then, one or more subsequent images are obtained after the arrival of a contrast bolus and placed into a second digital memory. The mask image is digitally subtracted from the succeeding contrast image, resulting in contrast-filled structures that are rendered visible free of background detail. Subtraction is performed in real time [50].

Iodine contrast media are used for the visualization of vessels, however cerebral angiography using gadolinium as an alternative contrast medium in a patient with severe allergy to iodinated contrast medium may be performed [51].

Radiation, today known as X-rays, was discovered by the German physicist Wilhelm Röntgen (March 27, 1845–February 10, 1923) on November 8, 1895 [52]. Discovery of X-rays is ranked as one of the best discoveries in medicine. X-rays are electromagnetic waves. The range of wavelengths corresponding to diagnostic imaging span from about 0.1 nm (at 12.4 keV) to 0.01 nm (at 124 keV) [53]. This type of radiation is ionizing.

In a vacuum X-ray tube, the electrons that make up the beam are emitted by a heated cathode filament. The electrons are then focused and accelerated towards the focal spot by a high voltage that is applied between the cathode filament and the anode. A generator is used to supply the X-ray tube with a controlled high voltage between the cathode and anode, and a controlled current to the cathode. The electron beam strikes the rotating anode "target" and part of its kinetic energy (less than 1%) is converted into X-ray photons, while the rest is converted into heat, which heats up the anode. The X-ray beam leaves the tube through the tube window and passes onto the patient. Some of the X-rays pass through the patient, while some are absorbed. The resulting radiation pattern is detected by a flat panel digital X-ray detector (FPD).

FPD system is superior to the image intensifier as it visualizes small intracranial vessels combined with a significant reduction of radiation dose, and is able to create high-quali-

ty 3D DSA images on which high spatial resolution allows precise visualization of small vessels, such as perforating vessels [54]. DSA images are then displayed on the LCD monitor with high resolution and different screen layouts, which can be connected to several image sources.

The first carotid angiography was performed by Portuguese Egas Moniz (1874-1955) in 1927; he is considered as a pioneer of cerebral angiography. He reported the first case of cerebral angiography at the Societe de Neurologie in Paris on July 7, 1927 [55]. Surprisingly, most angiograms were performed to visualize the intracranial portion of the carotids in cases of tumours, to look for abnormal displacement of arterial branches, with little interest in the vascular disease itself [56].

The technique, how to obtain safe access to blood vessels was published by Sven-Ivar Seldinger (1921-1998) in 1953 [57]. DSA is an invasive technique, performed using a catheter; the most commonly used approach is the transfemoral approach. At the end of angiography, the puncture site can be safely closed by a closure device [58].

DSA is used to detect the blood vessels supplying the brain tumours, and also to control the hypervascular tumour embolization (meningiomas, paragangliomas, haemangiopericytomas, juvenile nasopharyngeal angiofibromas and intraaxially located tumours: haemangioblastomas (Figure 14.), hypervascularized metastases and ependymomas). Presurgical or palliative embolization of a tumour can be performed by either an intraarterial catheterization approach or direct puncture of the tumour artery [59].

DSA may also be used for a balloon occlusion test [60]. Although 4D-CE-MRA may be useful for evaluating tumour stain in hypervascular brain, head and neck tumours, it is not able to replace DSA in planning interventional procedures [61].

Modern biplane DSA devices are very useful for neurovascular interventions, which also allows: 2D and 3D navigation for advanced embolization guidance; overlay of a DSA reference image over the matching live fluoro for guidance with less contrast media and less dose; cross-sectional imaging to view anatomical structures of tumours in combination with the feeding vessels of the tumour; single-colour vascular flow visualization from a 2D DSA image series to visualize tumour perfusion tumour vascularization, tumour blush and demonstrate postembolization result; to fuse the dataset with a preprocedural CT, MR or PET image to show tumour activity; synchronize the 3D image to the gantry position; PACS connectivity; the reporting of patient exposure following an intervention.

Modern systems update dynamically to movements of the C-arm, table, zoom and source-to-image distance to facilitate efficient workflow during interventional procedures. By providing more effective and faster guidance, this potentially reduces the use of contrast agents and radiation dose. Pulse frequencies can be adapted to clinical needs according to the ALARA principle (As Low as Reasonably Achievable).

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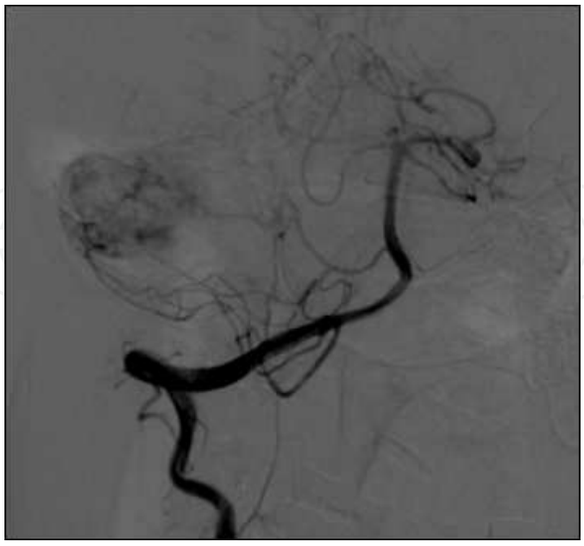

Figure 14. DSA (right vertebral angiogram): intra-axial hypervascularized haemangioblastoma supplied mainly by right anterior inferior cerebellar artery.

6. Conclusion

Radiology has an important role in the diagnosis of brain tumours. A significant factor for success in the treatment of brain tumours is the determination of the extent of the tumour and infiltration of important structures using the CT and MRI imaging methods. Currently, conventional CT protocols, and particularly MRI protocols, have been expanded by sophisticated new techniques that are used in practice. They have significantly contributed to the more detailed species diagnosis of tumours, and to a more accurate estimate of their malignant potential and relationship to the surrounding tissue. With the new techniques, we can evaluate not only detailed tumour morphology, but also the character of the tumour at the microvascular, haemodynamic and cellular level, and the metabolic and biochemical level. With new methods of imaging, exact operational planning approaches on brain tissue can be achieved. Postoperative monitoring of the effect of therapy is highly refined, with more accurate detection of tumour recurrence, and differentiation from postoperative and postradiation changes. Some characteristics of selected brain tumours are presented in Tables 4 and 5.

Hybrid systems have presented new possibilities in brain tumour imaging. The hybrid brain PET/MR allows for molecular, anatomical and functional imaging with uncompromised MR image quality and a high accordance of PET results between PET/MR and PET/CT [62].

Characteristics of selected intracranial tumours					
AGE	**LOCALIZATION**		**TYPE**	**CHARACTERISTIC**	**TYPICAL CT / MR FINDINGS**
Children	Intra-axial tumours	Supratentorial tumours	Astrocytoma	infiltrative / non-infiltrative types	No contrast enhancement in low-grade astrocytomas
			Meduloblastoma	highly malignant	variable contrast enhancement
		Infratentorial tumours	Pilocytic astrocytoma	most common (85% of cerebellar astrocytomas); solid/cystic focal lesion	well-demarcated cysts with a contrast enhancing mural nodule
			Posterior fossa astrocytoma		
			Brainstem astrocytoma	95% of brainstem neoplasms	variable MR appearance (may be totally or partly solid with a cystic, necrotic, or haemorrhagic component)
			Meduloblastoma	highly malignant, frequently disseminate into the leptomeninges; cystic components may be present in up to 80%; hydrocephalus is often observed	variable contrast enhancement
			Ependymoma	arise from the ependyma of the fourth ventricle	foci of high intensity (necrotic areas and cysts) and low intensity (calcifications or haemorrhage) on T2-WI
			Haemangioblastoma	Uncommon except in patients with von Hippel Lindau disease	small contrast-enhancing nodule with or without cyst
			Teratoma	in infants, second most commoon type of germ cell tumours, occurs more common in males, may contains calcification, cysts; fatty components can cause a chemical meningitis	variable signal on T1-WI and T2-WI
	Extra-axial tumours	Supratentorial tumours		rare	
		Sella region	Craniopharyngioma	may contain cysts, lipid components, and calcification	variable signal on T1-WI and T2-WI
		Infratentorial tumours		rare	

Table 4. Characteristics of selected intracranial tumours in children

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Characteristics of selected intracranial tumours

AGE	LOCALIZATION		TYPE	CHARACTERISTIC	TYPICAL CT / MR FINDINGS
Adults	Intra-axial tumours (located in the brain or brainstem)	Supratentorial tumours	MTS (metastases)	approximately 33% of intracranial tumours	circumscribed sphenoid peripheral to nodular enhancing lesion, often multiple, axonal oedema
			Glioblastoma	most common primary CNS tumour, highly malignant, can cross corpus callosum	irregularly marginated tumour with necrosis and peripheral oedema
			Astrocytoma	infiltrative / non-infiltrative types	No contrast enhancement in low-grade astrocytomas
			Lipoma	benign fatty lesion commonly affecting corpus callosum	density of fat, high T1-WI signal, signal suppression on FS (fat suppression) or STIR method
			Oligodendroglioma	uncommon slow-growing gliomas	clump-like calcification
		Infratentorial tumours	Cerebellar metastases	especially lung and breast cancer, also melanoma, thyroid malignancies, and renal cell cancer; can present with obstructive hydrocephalus	melanoma MTS – high T1-WI signal
			Haemangioblastoma	typically multiple in patients with von Hippel-Lindau disease	small contrast-enhancing nodule with or without cyst
			Lymphoma	primary CNS lymphoma – more common than secondary (can involve the leptomeninges), B cell lymphoma more common; in immunocompromised patients	diffuse leptomeningeal enhancement
			Choroid plexus papilloma	Choroid plexus papilloma of fourth ventricle, rare neoplasm, usually prominent contrast enhancement, calcifications may be associated, hydrocephalus	MR features of choroid plexus carcinoma and papilloma overlap
	Extra-axial tumours	Supratentorial tumours	Meningioma	most common extraaxial tumour, usually benign, multiple in neurofibromatosis type 2	dural-based lesions (the dural tail sign), prominent enhancement, calcifications may be associated
		Sella region	Pituitary adenoma	common benign slow-growing, endocrine abnormalities	microadenomas typically enhance less than normal pituitary tissue – early phase of dynamic imaging
		Infratentorial tumours	Acoustic schwanoma	90% of intracranial schwannomas 75% of lesions in the cerebellopontine angle cisterns	prominent contrast enhancement; can be heterogeneous in large lesions

Characteristics of selected intracranial tumours				
AGE	**LOCALIZATION**	**TYPE**	**CHARACTERISTIC**	**TYPICAL CT / MR FINDINGS**
	(arise from the skull, meniges, or tissues other than brain)		multiple seen with neurofibromatosis type 2	
		Meningioma	can result in compression of dural venous sinuses; rarely invasive – malignant type	same as supratentorial
		Paraganglioma	lesions, also referred to as chemodectomas, arise from paraganglia	prominent contrast enhancement; tubular zones of flow voids; often erosive bone changes

Table 5. Characteristics of selected intracranial tumours in adults

Tables 4 and 5 are modified according to [13 – 14, 63 - 64].

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