Imaging the Patient with Epilepsy

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Introduction

Approximately 4 % of the general population will experience a seizure during their lifetime. Imaging in these "first-ever" seizure patients is in most cases normal, and abnormalities are only present in approximately 15 % of patients as seizures can be provoked by fever, sleep deprivation, stroboscopic lights, or drugs. However, an underlying lesion will lower the seizure threshold and thus make a patient more susceptible to experience a seizure. As "first-ever seizures" are a medical emergency, the treatment modality of choice in these cases is an unenhanced CT to exclude acute medical emergencies that may go along with seizures prior to a more extensive workup depending on clinical history and presentation. Imaging abnormalities encountered in patients experiencing their first-ever seizures include (but are not restricted to) virtually all diseases affecting the brain. As such you may find vascular abnormalities (such as microangiopathy, arteriovenous malformations (AVM), sinus thrombosis, hemorrhage, cavernomas, or stroke), tumors (metastases, primary tumors), infections (encephalitis, meningitis, abscess), sequelae of previous head injury, and toxic or metabolic conditions (e.g., PRES) in these patients.

In contrast to the "first-ever seizure," patients diagnosed with "epilepsy" have recurrent and unprovoked seizures. Approximately 1 % of the general population will be diagnosed with this condition, and as seizures are recurrent and unprovoked, an underlying lesion is far more common as compared to patients with their first-ever seizure. Being "unprovoked," lesions that can irritate the brain (i.e., are "epileptogenic") may be present. On brain imaging, lesions will be seen in nearly 50 % of patients; however, these are nonspecific and can encompass a wide variety of underlying conditions that can provoke the recurrent seizure attacks. Imaging findings in patients with epilepsy include but are not restricted to vascular conditions such as microangiopathy, previous ischemia, vascular malformations, previous hemorrhage or cavernomas, tumors (metastases, primary tumors), remote infections (encephalitis, abscess), previous head injury, congenital malformations, or toxic metabolic conditions. Imaging of choice in patients with epilepsy is MRI, given the larger variety of potential underlying diseases.

The vast majority of patients with epilepsy can be treated satisfactorily with antiepileptic drugs. However, 0.4 % of the general population will have recurrent and unprovoked seizures that do not respond to medication. These patients are potentially treatable with surgery, and surgical intervention is an appropriate consideration for 3 % of people who develop epilepsy [1]. The major focus of this chapter will be on the imaging findings in those patients who are diagnosed with "medication-refractory" epilepsy, i.e., patients where the seizure focus is too strong to be controlled by medication which indicates that the underlying lesion has to have a strong epileptogenic potential. In these patients, structural imaging will find a large proportion of abnormalities reaching up to 85 % of patients. Lesions with a strong epileptogenic potential are either close to epileptogenic structures or consist of abnormal neurons. Lesions that are often involved in medication refractory epilepsy are mesial temporal lobe sclerosis (MTS) (primary or secondary to a long-standing seizure disorder), malformations of cortical development, certain epileptogenic tumors (e.g., dysembryoplastic neuroepithelial tumors (DNET), temporal lobe glioma or

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ganglioglioma), vascular malformations, post-traumatic, post-infectious, and certain phakomatoses. Imaging findings in some of these conditions will be subtle which necessitate both a dedicated imaging protocol (as compared to a standard MR) and an "expert" experienced in reading these types of scans. In a landmark study of von Oerzten et al. [2], the sensitivity of "nonexpert" reports of standard MRI for focal lesions was 39 %, while sensitivity of "expert" reports of standard MRI increased to 50 %. "Expert" reports of epilepsy-dedicated MRI further increased the sensitivity in detecting subtle lesions to 91 %. Dedicated MRI showed focal lesions in 85 % of patients with "nonlesional" standard MRI. Neuropathological diagnoses were predicted correctly in 22 % of "nonexpert" standard MRI reports but by 89 % of dedicated MRI reports. Thus, the combination of dedicated MRI protocols and dedicated radiologists trained in evaluating patients with medication refractory seizures increases significantly the sensitivity of MRI in this subgroup of patients. A multidisciplinary approach that involves close communication between epilepsy neurology, neuroradiology, EEG, nuclear medicine, neuropsychology, and neurosurgery is an important feature of modern epilepsy imaging.

The necessity of expert MR reading with a dedicated imaging protocol is further highlighted by the fact that postsurgical seizure freedom is achieved significantly more often when a circumscribed, resectable epileptogenic lesion can be identified on MRI preoperatively compared to patients that are rated nonlesional [3]. As pointed out by Wellmer et al. in [4], the possible reasons for undetected epileptic lesions in standard outpatient MRI are insufficient clinical information from the referring clinician, routine MR protocols not optimized for the spectrum of epileptogenic lesions, and unfamiliarity with the spectrum of epileptogenic lesions. Wellmer pointed out that "because even the best focus hypothesis and most profound knowledge of epileptogenic lesions do not permit the detection of lesions when they are invisible on the MRI scan, the starting point for any improvement of outpatient MRI diagnostics should be defining an MRI protocol that is adjusted to common epileptogenic lesions."

This indicates that a specific imaging protocol to identify these lesions is necessary. This protocol should take into account that – as small epileptogenic lesions are usually those that provide the best chance for postoperative seizure freedom – slice thickness should be adjusted to detect small lesions, and multiple (coronal, axial, sagittal) cut planes are acquired to ensure that physiologic structures or partial volume effects within the folded cortex are not taken for pathology and vice versa. Coronal sequences have to be angulated perpendicular to the hippocampal axis to allow hippocampal volume estimation, and caution has to be taken that they are oriented in a plane that ensures direct comparison with the contralateral hemisphere. In our practice, we employ this coronal angulation for both T2/FLAIR and T1 IR sequences. High-resolution T1-weighted sequences with isotropic voxel sizes allow for multiplanar reformation and further evaluation (including 3D reformats, "pancake" views, surface rendering, and volumetric assessments). T2 gradient echo or susceptibility-weighted sequences are highly sensitive to detect blood products or calcifications and should therefore be part of a seizure imaging protocol (Fig. 1).

In a recent analysis performed by Wellmer et al. on the prevalence of epileptogenic lesions among 2740 patients, the following pathologies were found: mesial temporal lobe sclerosis in 32 % of patients; tumors (including low- and high-grade tumors as well as malformative tumors and benign epilepsy associated tumors) in approximately 17 %; cortical dysplasias in 11 %; glial scars (including posttraumatic, postischemic, posthemorrhagic, postinfectious/abscess, ulegyria, and postsurgical scars) in 11 %; vascular diseases (cavernoma, AVM, pial angiomatosis) in 5 %; malformations of cortical development including nodular heterotopia, subcortical band heterotopia, polymicrogyria, lissencephaly, pachygyria, agenesis of corpus callosum, craniocephalic malformations, hemiatrophy, lobar dysgenesis, hemimegalencephaly, or hamartomas in 3 %; and sequelae of encephalitis in 1 %, while in approximately 20 %, no lesion could be detected.

Lesion location – presumably related to the different epileptogenic potentials in different brain regions – demonstrates preponderance for the temporal lobes (60 %) followed by the frontal lobe (20 %), the parietal lobe (10 %), the periventricular white matter (5 %), and the occipital lobe (5 %).

The suitability of MR imaging to detect these findings varies between different sequences. It is generally recommended that for an epilepsy-specific protocol, T2/FLAIR, T2/STIR in two parallel planes, T2 gradient echo/SWI sequences, and an isotropic 3D-T1 are necessary. We strongly recommend these imaging sequences to be done on a 3 T scanner given the higher spatial resolution [5, 6]. The use of even higher field strengths (7 T) (Fig. 2) will probably further increase the detection rate of epileptogenic substrates such as mesial temporal lobe sclerosis (MTS), focal cortical dysplasia (FCD), and polymicrogyria [7–10].

Functional MRI (fMRI) can map eloquent cortex and provide information regarding language lateralization [11] (Fig. 3), and the use of diffusion tensor imaging (DTI) and tractography may help to avoid injury to the optic radiation during temporal lobe resection [12].

Radionuclide imaging can add useful information in selected cases [13]. Subtraction of ictal and interictal SPECT coregistered to MRI (SISCOM) can show a seizure-induced hyperperfusion (Fig. 4), whereas ^{18F}FDG PET may show hypometabolism in the seizure onset zone. This is particularly

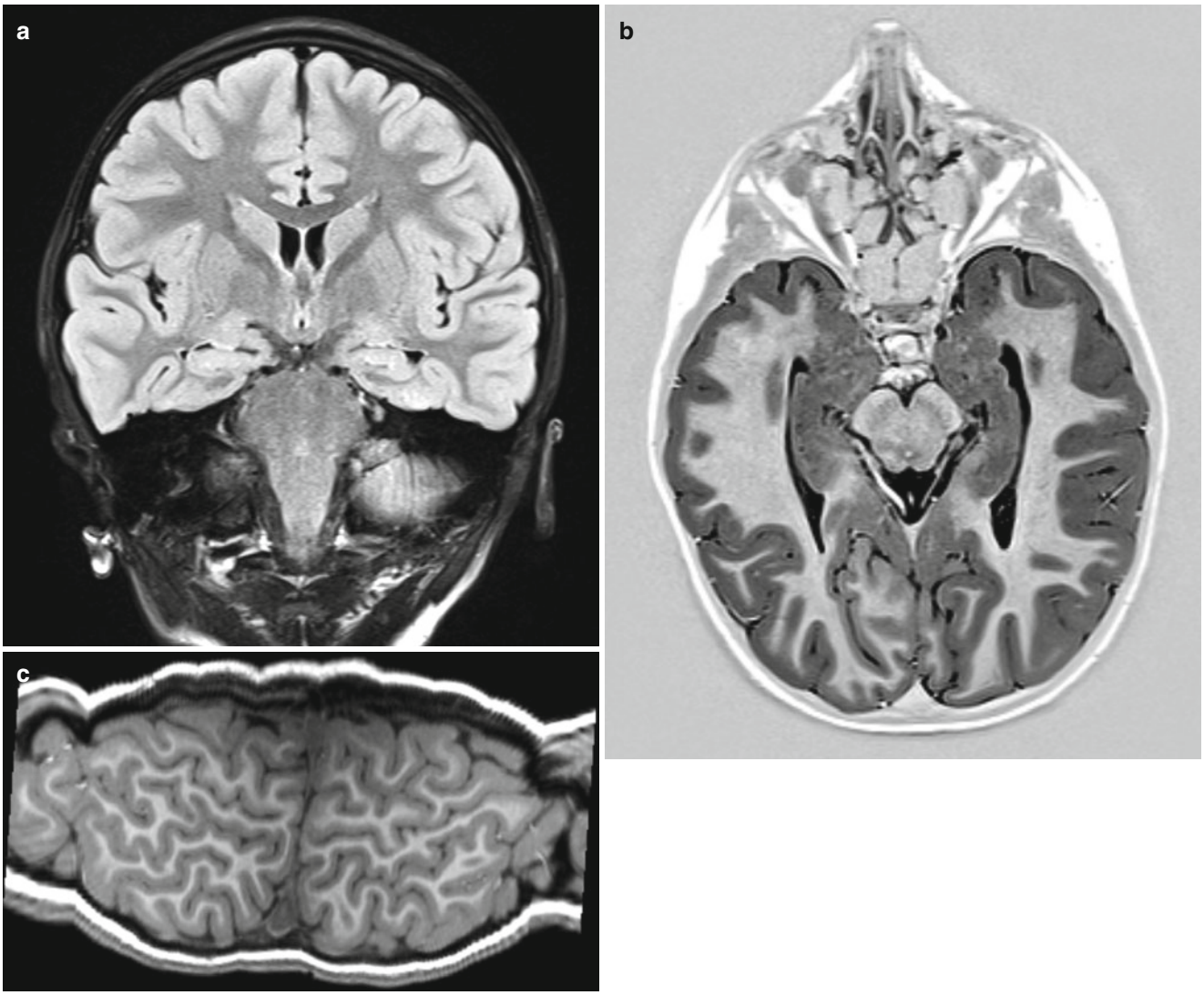


Fig. 1 (**a**–**c**): Some examples of good sequences in a dedicated epilepsy protocol: (**a**) coronal T2/FLAIR, perpendicular to the hippocampal axis; (**b**) axial T1 inversion recovery (IR) parallel to the hippocampal axis; (**c**) T1 3D image set presented as "pancake view" for a better overview of the gyral pattern

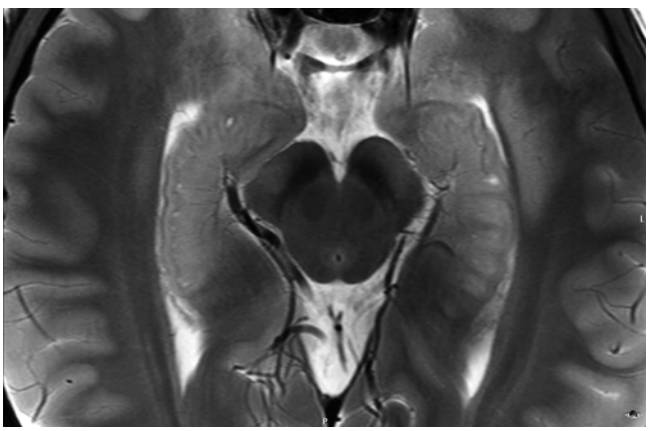


Fig. 2 Axial T2 at 7 T parallel to the hippocampal axis. Excellent in-plane resolution provides detailed imaging of the hippocampus

useful in lateralization of temporal lobe epilepsy in the MR-negative patient.

Imaging evaluation should be standardized using a stepwise approach to evaluate the hippocampus and mesial temporal lobe structures, the ventricular outline, and the gyral and the sulcal anatomy (Table 1). Particular emphasis should be paid upon the T2/FLAIR signal within the cortex and hippocampus, its similarity to other regions of neo- and archicortex, the internal architecture of the hippocampus, the indentations of the pes hippocampi, the fornix and mammillary bodies, and the gray-white matter interface of the neocortex (blurring, gray matter thinning or thickening).

In the following, we will discuss the imaging features of epileptogenic lesions, highlighting imaging pearls and pitfalls.

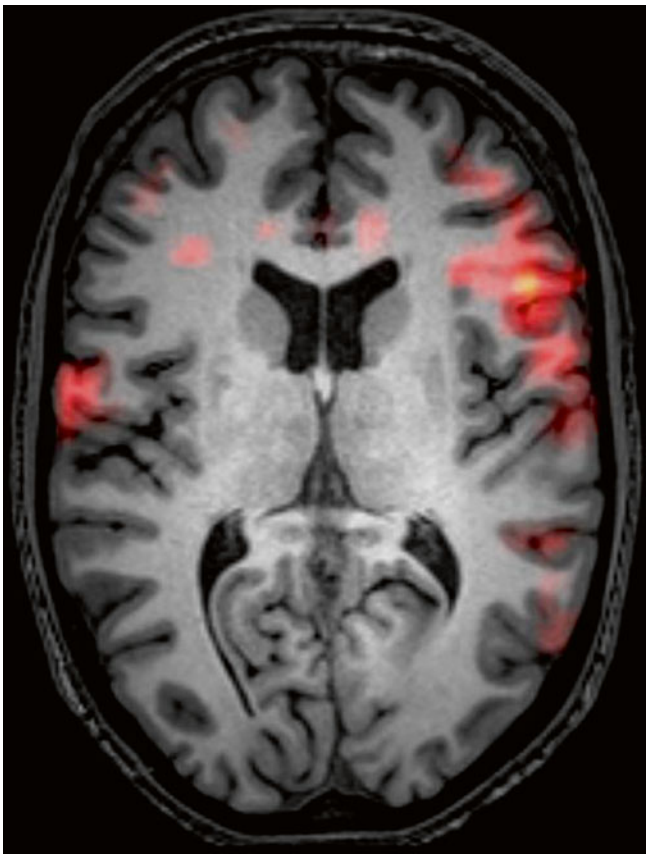


Fig. 3 Functional MRI. *Red* areas indicate activation during a simple word generation task. Activation is seen predominantly in the left hemisphere in the frontal language region; typical language lateralization

Mesial Temporal Lobe/Hippocampal Sclerosis

Patients with mesial temporal sclerosis (MTS) harbor complex partial seizures with a seizure semiology that is characterized by déjà vu sensations, epigastric auras, lip smacking, or other oral automatisms and often have in their past medical history febrile seizures as a child with progressive worsening of seizure frequency and severity over time. On MR imaging, you will find atrophy of the hippocampus as well as signs for gliosis/sclerosis within the hippocampus that will manifest itself as T2/FLAIR hypersignal (Fig. 5). The atrophy will lead to loss of the indentations of the pes hippocampi and widening of the temporal horn and atrophy of the white matter of the temporal lobe. As a consequence of Wallerian degeneration, there will be atrophy of the projecting pathways of the hippocampus, i.e., the Papez cycle, with

Table 1 Checklist for a structured, stepwise approach to evaluate MRI in the patient with epilepsy

Hippocampus, fornices, and mamillary bodies
Ventricular outline
Sulcal morphology, CSF clefts
Gray matter thickening or thinning
Blurring of gray-white matter junction
T2 prolongation
Paramagnetic artifact
Atrophy

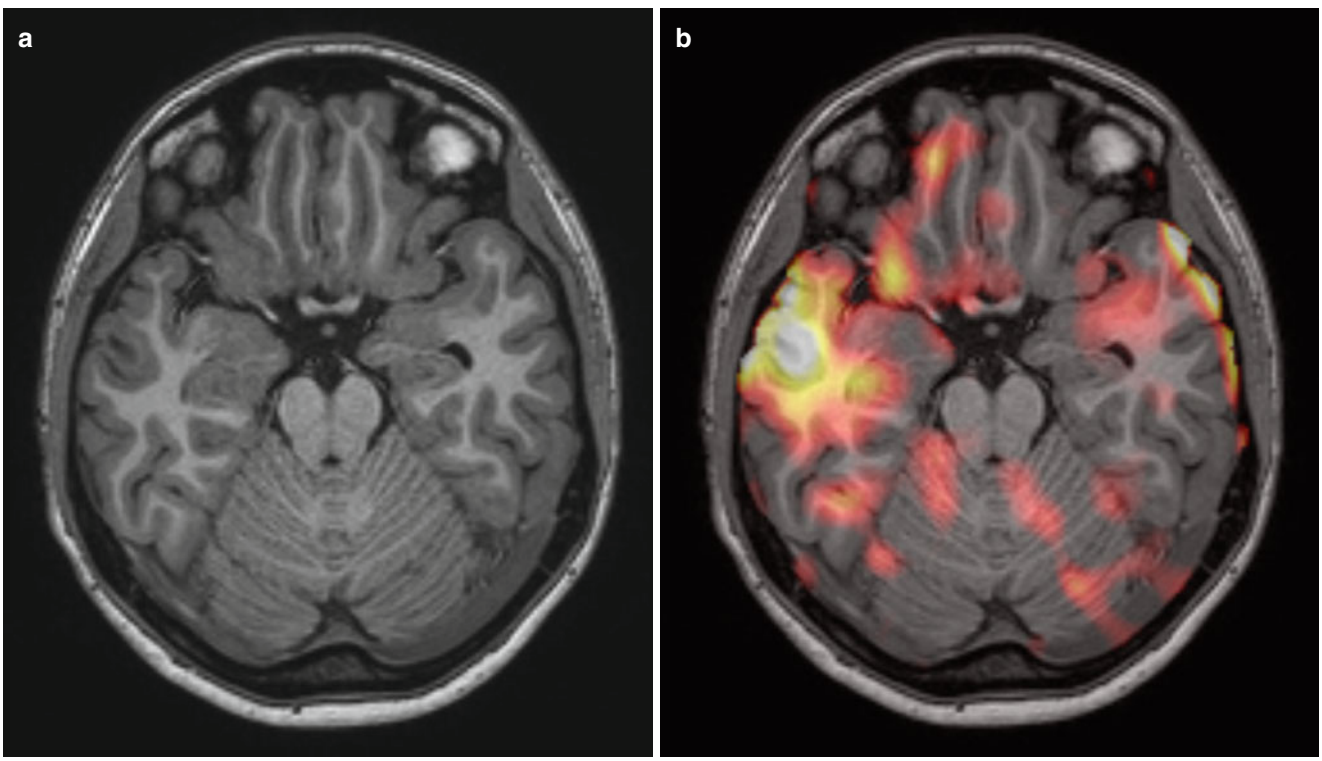


Fig. 4 (**a**, **b**) SISCOM: (**a**) axial T1 with small subcortical area in the right temporal lobe with prolonged T1; (**b**) coregistration of SPECT on MR images shows ictally hyperperfused area exactly in the same spot as the suspected lesion

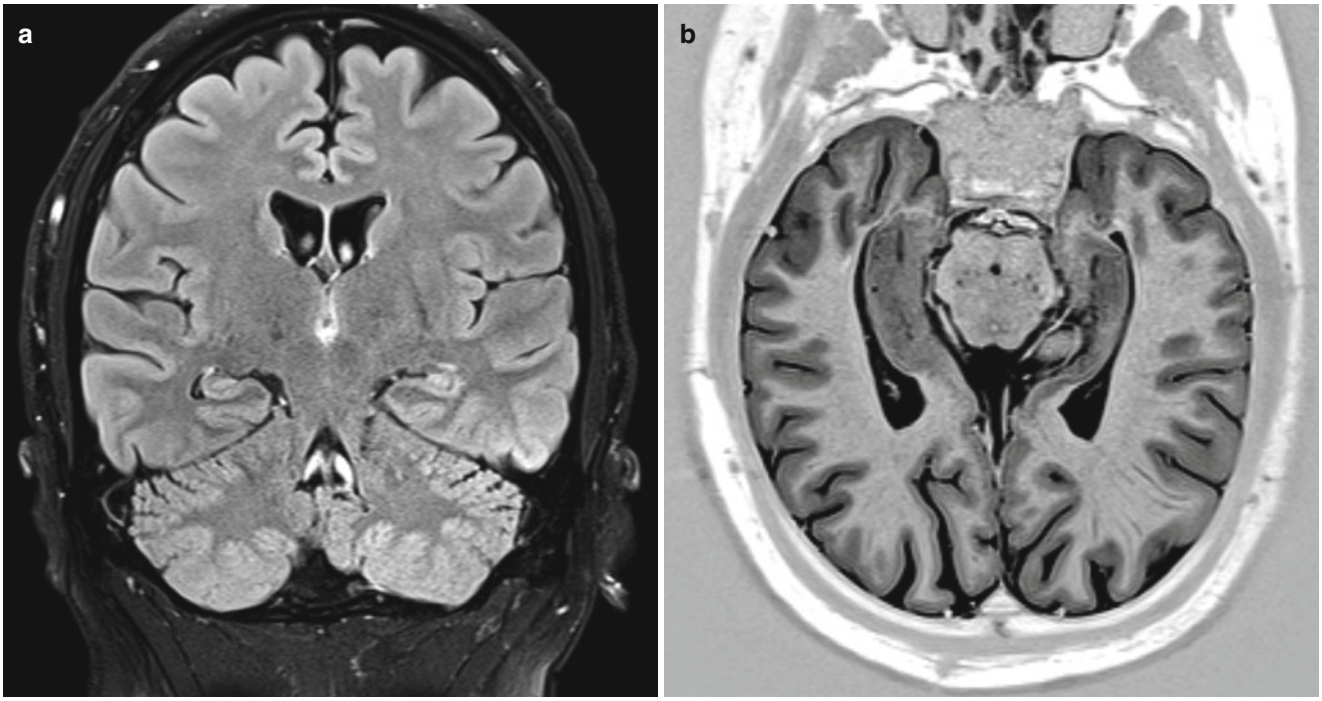


Fig 5 (**a**, **b**) Mesial temporal sclerosis (MTS): (**a**) coronal T2/FLAIR shows increased signal in the left hippocampus; (**b**) axial T1 IR demonstrates volume loss in the left hippocampus. The findings shown are relatively subtle. MRI fails to recognize pathologically detected mesial temporal lobe sclerosis in up to 20 % of the cases

atrophy of the fornix and the ipsilateral mammillary body. In the early stages of mesial temporal lobe sclerosis, the imaging findings are subtle and involve loss of the granular cell layer symmetry (i.e., the internal architecture of the hippocampus) without associated FLAIR signal changes. Hard windowing of the FLAIR-weighted sequences will make identification of the diseased hippocampus easier. In nearly 20 % of patients with mesial temporal lobe sclerosis, dual pathology is present with a second epileptogenic focus. It is believed that in these cases, the other epileptogenic lesion triggered the mesial temporal lobe sclerosis (similar to febrile seizures as a child can trigger or "kindle" a mesial temporal lobe sclerosis). Identification of the second focus is of great importance as failure to do so may result in surgical failure if only a selective amygdalohippocampectomy is performed, thus leaving the "primary" focus behind. On the other hand, failure to identify MTS in patients with other lesions may also lead to surgical failure following lesionectomy. Dual pathology may consist also of bilateral mesiotemporal lobe sclerosis as one hemisphere may trigger the other hippocampus to become sclerotic thus constituting bilateral abnormalities. As the internal reference (i.e., the contralateral hippocampus) is similarly affected, comparison of the signal with other regions of archicortex (three-layered cortex) can identify whether a mesial temporal lobe sclerosis is present bilaterally. Thus, if the T2/FLAIR signal of the hippocampus is bilaterally symmetrical but higher as compared to the cingulum or insula, you have to consider bilateral mesial temporal lobe sclerosis.

Malformations of Cortical Development

In order to understand the different types of malformations of cortical development, it is important to briefly review the embryological development of the cortex: During the 7th week of gestation, neuronal proliferation in the subependymal germinal matrix occurs. After the 8th week, these cells migrate outward in multiple waves of radial outward migration aided by radial glial cell guidance in a process coined as chemotaxis. The third and last part of the cortical development, the lamination, is the organization of the cells within different cortical layers a process that is orchestrated by the subplate (the lowest layer of cortex). Chromosomal mutations, destructive events (ischemia/infections) or toxins may inhibit either of these three processes (proliferation, chemotaxis, or cortical organization) which will lead to abnormalities in stem cell development, migration or lamination [14].

Malformations of cortical development are present in up to 25 % of patients with intractable childhood epilepsy. They are associated with chromosomal alterations, congenital infections, or in utero ischemia. In addition to epilepsy, these patients will have developmental delay and focal neurological deficits.

Malformations related to abnormal stem cell development include the focal or transmantle cortical dysplasias (balloon cell or type II FCDs) and the hemimegalencephalies.

FCD type II is characterized on histology by enlarged (balloon) cells without dendrites or axons and are identical to cortical hamartomas in tuberous sclerosis. The abnormal cells extend from the ventricle to the cortex; thus, a linear hyperintensity from the ventricle toward the cortex (the radial band or foot) can be seen in association with a subcortical FLAIR hyperintensity. The abnormal FLAIR hypersignal is again better seen with a hard window that will exaggerate the abnormal T2 signal. The junction between the cortex and white matter is indistinct, and the gray matter may be focally thickened (Fig. 6).

In hemimegalencephaly, a diffuse hamartomatous overgrowth as a result of abnormal stem cell proliferation is present, resulting in broad gyri, shallow sulci, and a blurred gray-white matter junction. The ipsilateral ventricle is often enlarged and demonstrates an abnormal straight course of the frontal horn (Fig. 7). Clinically, patients present with macrocephaly, hemiplegia, developmental delay, and seizures. The affected hemisphere has no function and thus hemispherectomy can be proposed to these patients. However, hemispherectomy is contraindicated if there are cortical malformations in the contralateral hemisphere which have to be specifically sought after.

Malformations related to abnormal migration are the lissencephalies, the agyria-pachygyrias, and the heterotopias.

In the lissencephalies, there has been a global halt in the migration due to an impaired last phase of neural migration leading to paucity of the gyral and sulcal development with a smooth brain surface and diminished white matter. Patients present with global developmental delay and seizures. Two different types of lissencephaly can be distinguished: the posterior agyria (related to an alteration on chromosome 17) and the anterior agyria which is an x-linked disease (Fig. 8).

Female carriers of the affected x-chromosome present with band heterotopias that is more present in the frontal lobes compared to the parietal lobes. Thus, if females present with band heterotopias, genetic counseling may be indicated. The band may be thin or thick depending on the amount of arrested migration. Patients with a thick band have less normal cortex (that can be thinned) and present with a more severe developmental delay.

In addition to the "band heterotopia," focal subcortical heterotopia can be present. On imaging, swirling, curvilinear bands of gray matter as well as thin cortex, and paucity of the white matter are seen. The ipsilateral ventricle may be distorted, and there can be an associated callosal hypogenesis.

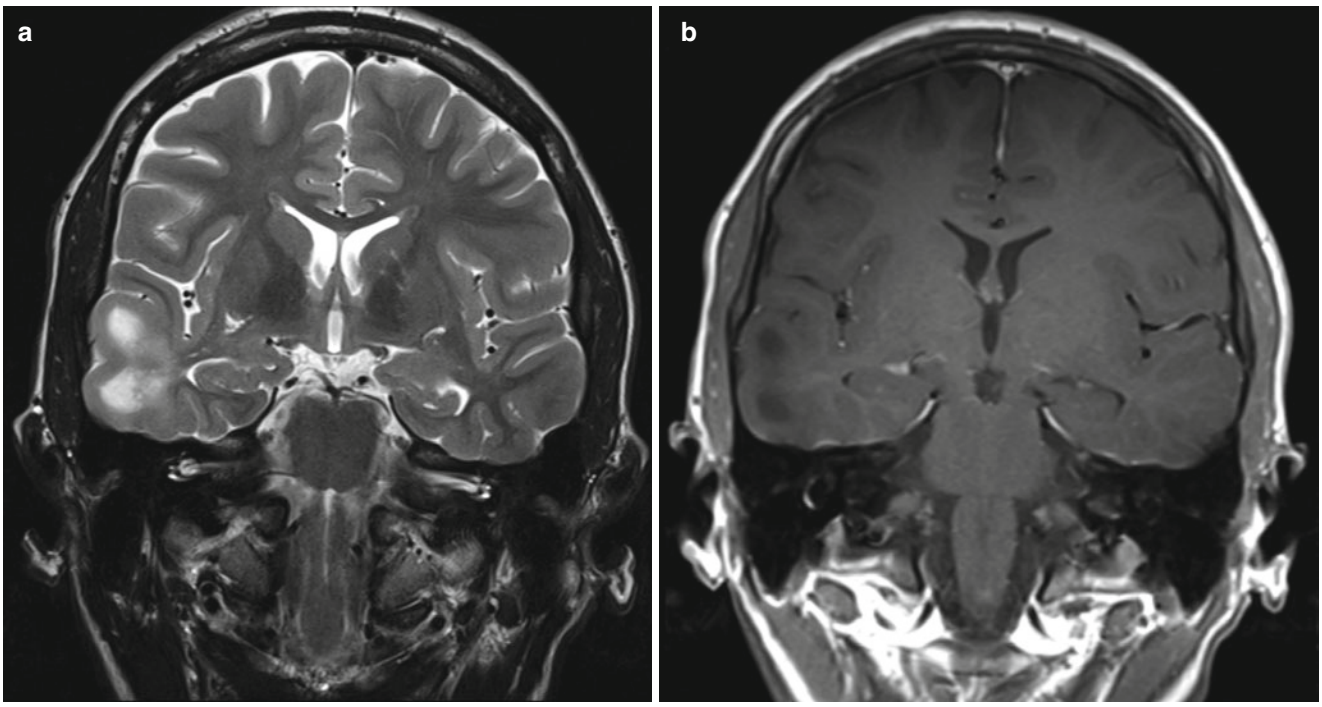


Fig 6 Three cases of focal cortical dysplasia type II. (**a**, **b**) patient 1; (**a**) coronal T2 with large subcortical area in the right temporal lobe with prolonged T2. The increased signal stretches in to the temporal horn of the right ventricle; (**b**) coronal T1 with gadolinium. The corresponding area has decreased signal on T1-weighted image. No enhancement. (**c**, **d**) patient 2; (**c**) axial T1 IR with very subtle signal changes at the bottom of a sulcus lateral in the frontal lobe; (**d**) coronal T2/FLAIR shows increased signal in the same area with a faint band stretching toward the lateral ventricle. (**e**) patient 3, boy, 3 months old, axial T1 IR shows a region with thickened cortex in the right frontal lobe. Notice the premature myelination of the white matter tracts involved in the seizures

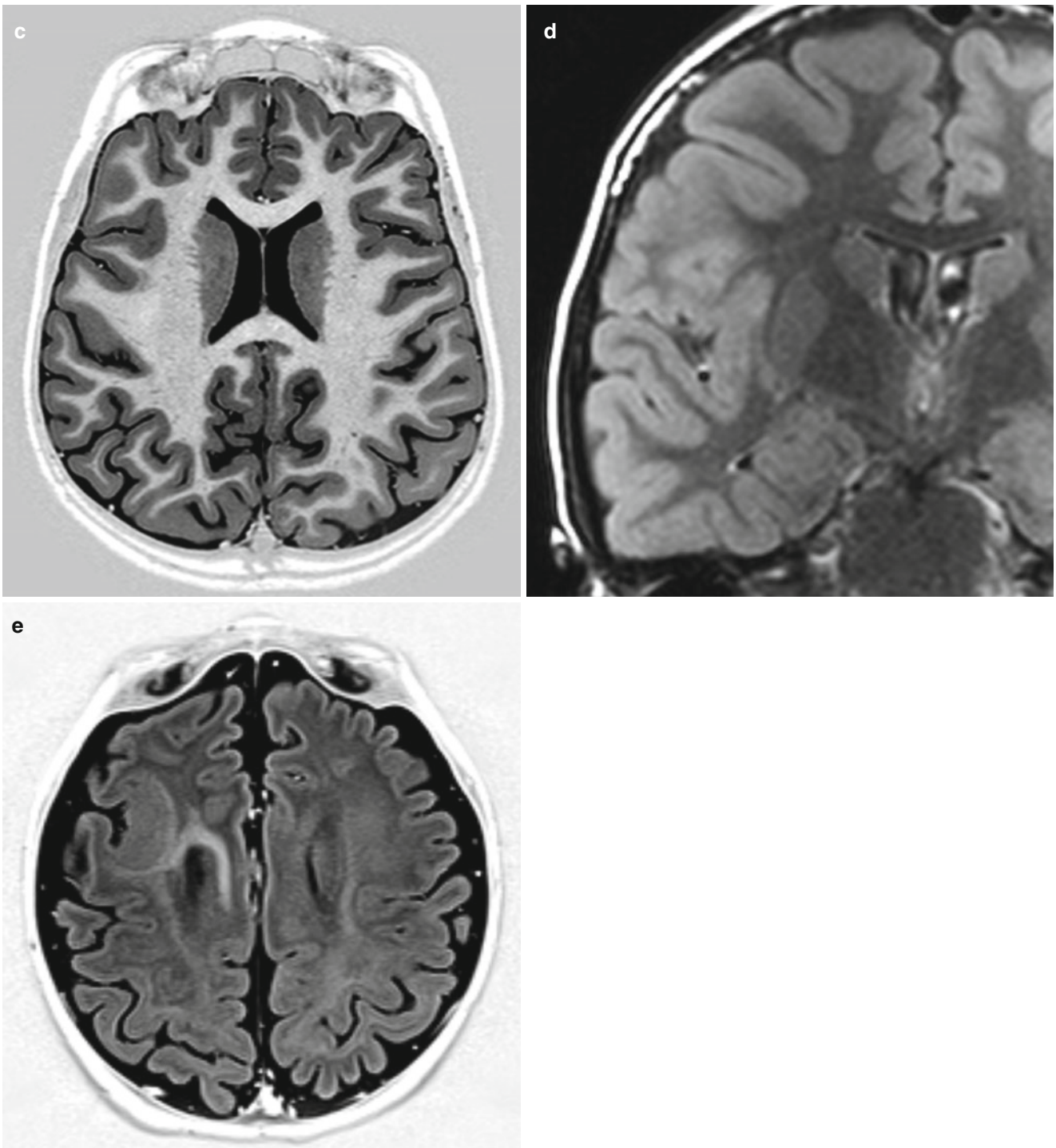


Fig. 6 (continued)

The third type of heterotopia is called perventricular nodular heterotopia or subependymal heterotopia. On imaging, an exophytic smooth ovoid mass in the residual germinal matrix, i.e., along the ventricle, is seen (Fig. 9). Again you may have associated anomalies including Chiari malformations, cephaloceles, corpus callosum agenesis, or a Dandy-Walker syndrome. In contrast to the other malformations of abnormal migration, the periventricular nodular heterotopia may exhibit quite mild symptoms with normal development and late onset of seizures. If the periventricular heterotopia completely lines the walls of both ventricles, a familiar form has to be considered, and genetic counseling may be indicated.

Malformations related to abnormal cortical organization encompass polymicrogyria, schizencephaly, and FCD type

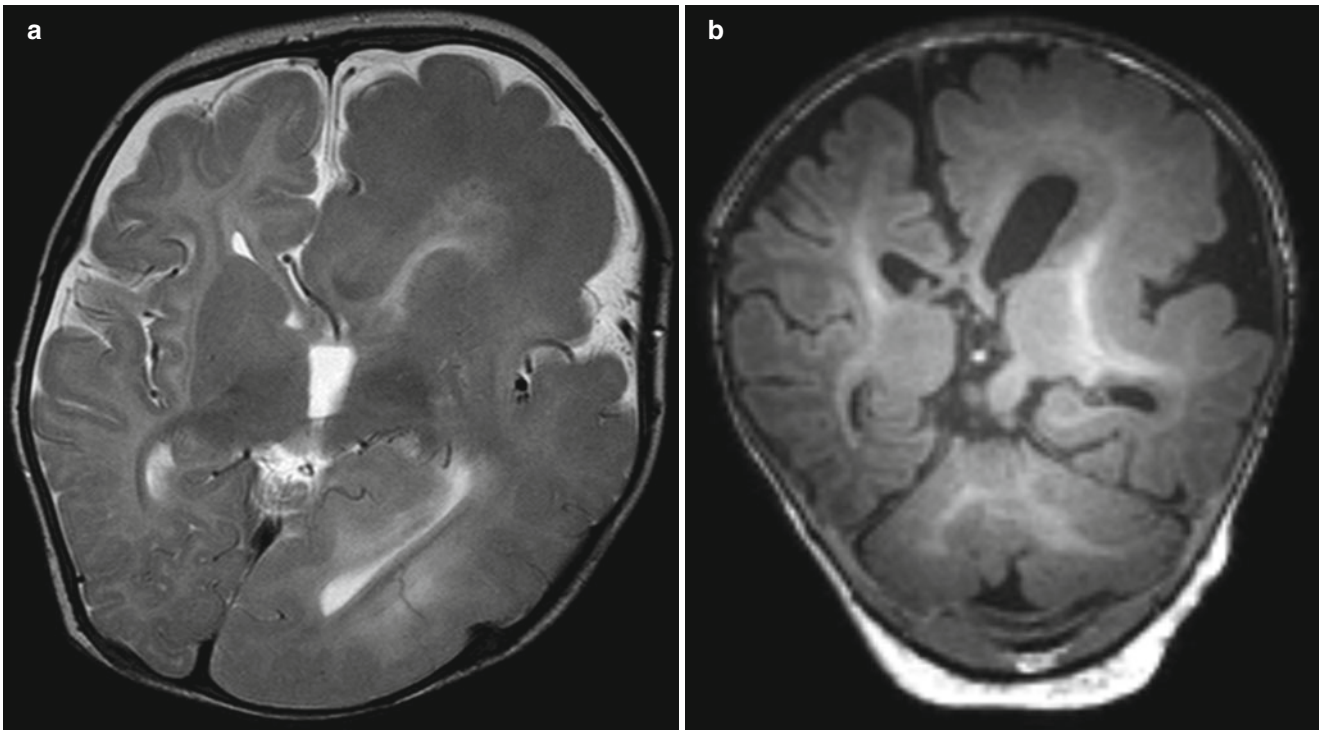


Fig. 7 (**a**, **b**) Boy, 6 months old. Hemimegalencephaly. (**a**) axial T2; (**b**) coronal T1. The left hemisphere is enlarged with broad gyri and shallow sulci. The ipsilateral ventricle is enlarged with an abnormal shape of the frontal horn. Indistinct gray-white matter junction

I (non-balloon cell). In polymicrogyria, neurons reach the cortex but distribute abnormally; thus, multiple small gyri are formed (Fig. 10). Polymicrogyria is most commonly found around the posterior sylvian fissures; when bilaterally present in the perisylvian region, patients present with pseudobulbar palsy.

In open-lip schizencephaly, a cleft that is lined by gray matter reaches from the periphery to the ventricle, while in the closed-lip schizencephaly, gray matter is reaching from the periphery to the ventricle, and a dimple is seen in the ventricular wall. Schizencephaly can be multifocal and bilateral. The cortex lining the defect is polymicrogyric with ill-defined margins to the white matter. Finally, FCD type I (non-balloon cell) is a disorder of lamination. Imaging features are very subtle, and only mild focal blurring of the gray-white matter junction may be present. This type of dysplasia is often undetectable on MRI.

Epileptogenic Tumors

While virtually all tumors may cause epilepsy, there are certain tumors that have a very high propensity of eliciting medication refractory seizures. As most of these are benign and just by means of location (i.e., within the cortical white matter interface and with temporal lobe predilection) cause the seizures, these are often very good candidates for surgery. As a general discussion of all tumors is beyond the scope of this chapter, we will focus only on three tumors that are commonly associated with seizures: the ganglioglioma, the DNETs, and the tuber cinereum hamartomas.

Gangliogliomas are cortically based, partly cystic tumors that may calcify and that harbor an enhancing nodule (Fig. 11). Gangliogliomas occur in young adults and older children; when present under the age of ten, they are often larger with more cystic components. They are mainly located in the temporal lobes but can also occur in parietal and frontal lobes. Cortical dysplasias (coined type III) can be associated with a ganglioglioma. Top differential diagnoses for gangliogliomas are DNETs, pilocytic astrocytomas, pleomorphic xanthoastrocytomas, gliomas, and neurocysticercosis.

DNETs are well-demarcated, bubbly, intracortical masses that also are most common in the temporal, parietal, and frontal lobes (Fig. 12). They may calcify, but enhancement is very rare and if present should lead to more intensive follow-up, as the enhancing portion of a DNET may recur following surgery. Top differential diagnoses for DNETs are cortical dysplasia, ganglioglioma, pilocytic astrocytoma, glioma, neuroepithelial cysts, and dilated VR spaces.

Tuber cinereum hamartoma presents with the combination of gelastic seizures and precocious puberty. They are located at the floor of the third ventricle (i.e., the tuber cinereum) and do not enhance and are isointense to the cortex

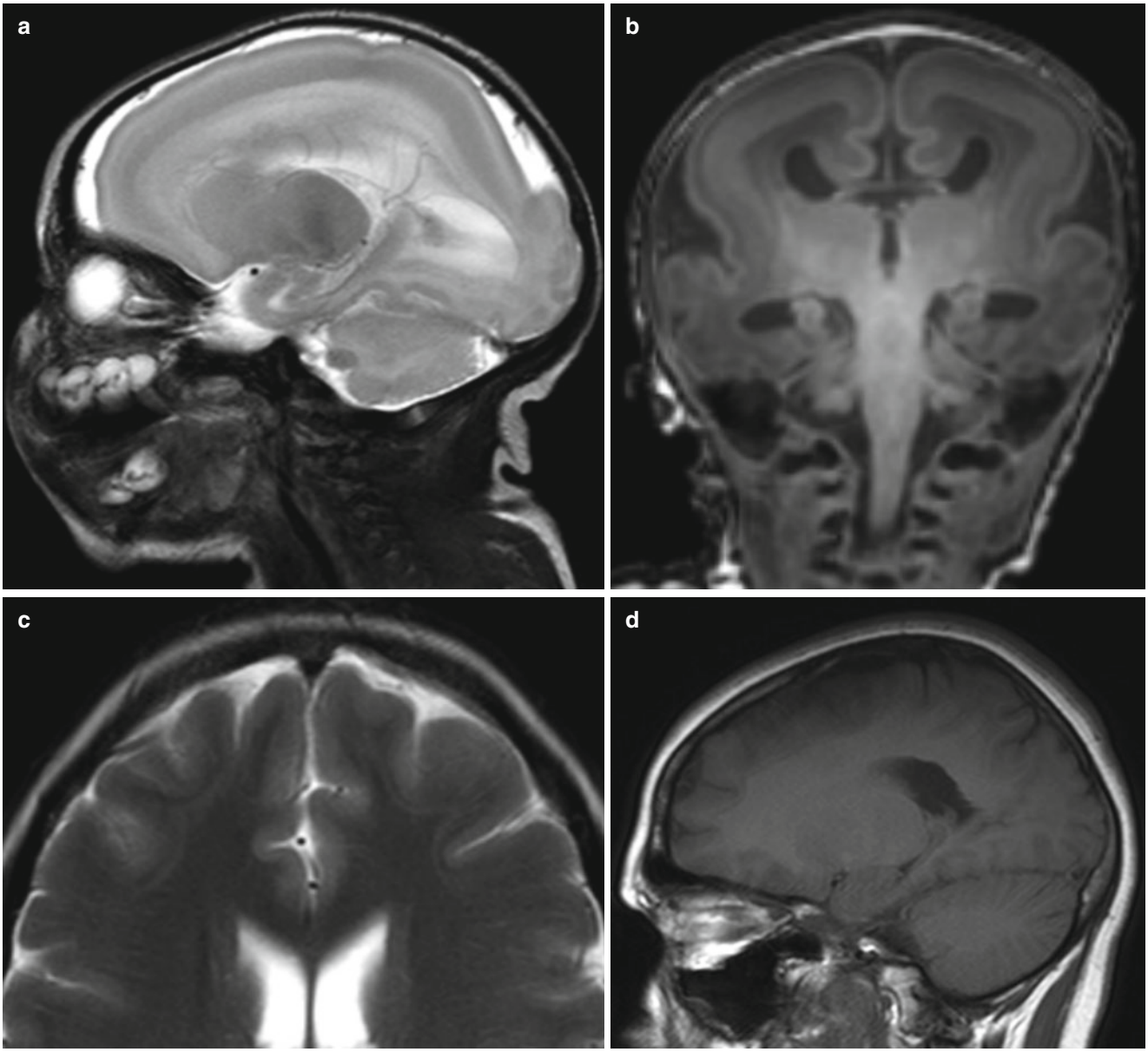


Fig. 8 (**a**, **b**) X-linked lissencephaly, boy, 2 weeks old. (**a**) sagittal T2; (**b**) coronal T1. Lissencephaly with agyria more pronounced in the anterior part of the brain. In addition callosal hypogenesis. (**c**, **d**) the mother of the boy in (**a**) and (**b**), female carrier. **c**: axial T2 (detail); (**d**) sagittal T1; Subtle subcortical band heterotopia in both frontal lobes

(Fig. 13). They are nonneoplastic tumors with disorganized collection of neurons and glia.

Miscellaneous: Vascular Malformations/ Trauma/Infection/Phakomatoses

Similar to the previous paragraph, it is beyond the scope to in detail describe imaging features of vascular malformations, infections, or trauma that can go along with seizures, and most of the entities are described in other chapters of this syllabus. We therefore only want to highlight few epilepsy-relevant facts and features of these miscellaneous conditions.

Brain AVMs can cause seizures due to previous hemorrhage and scarring, hemosiderin deposits (especially when close to the cortex), or gliosis. AVMs in the temporal lobe have a higher likelihood of producing seizure due to interference of the normal blood supply and drainage of potentially epileptogenic structures such as the hippocampus.

While cavernomas that are deeply located in the white matter rarely cause seizures, those that are cortically located and have hemosiderin staining reaching the cortex, and in particular the mesial temporal lobe structures, are very often associated

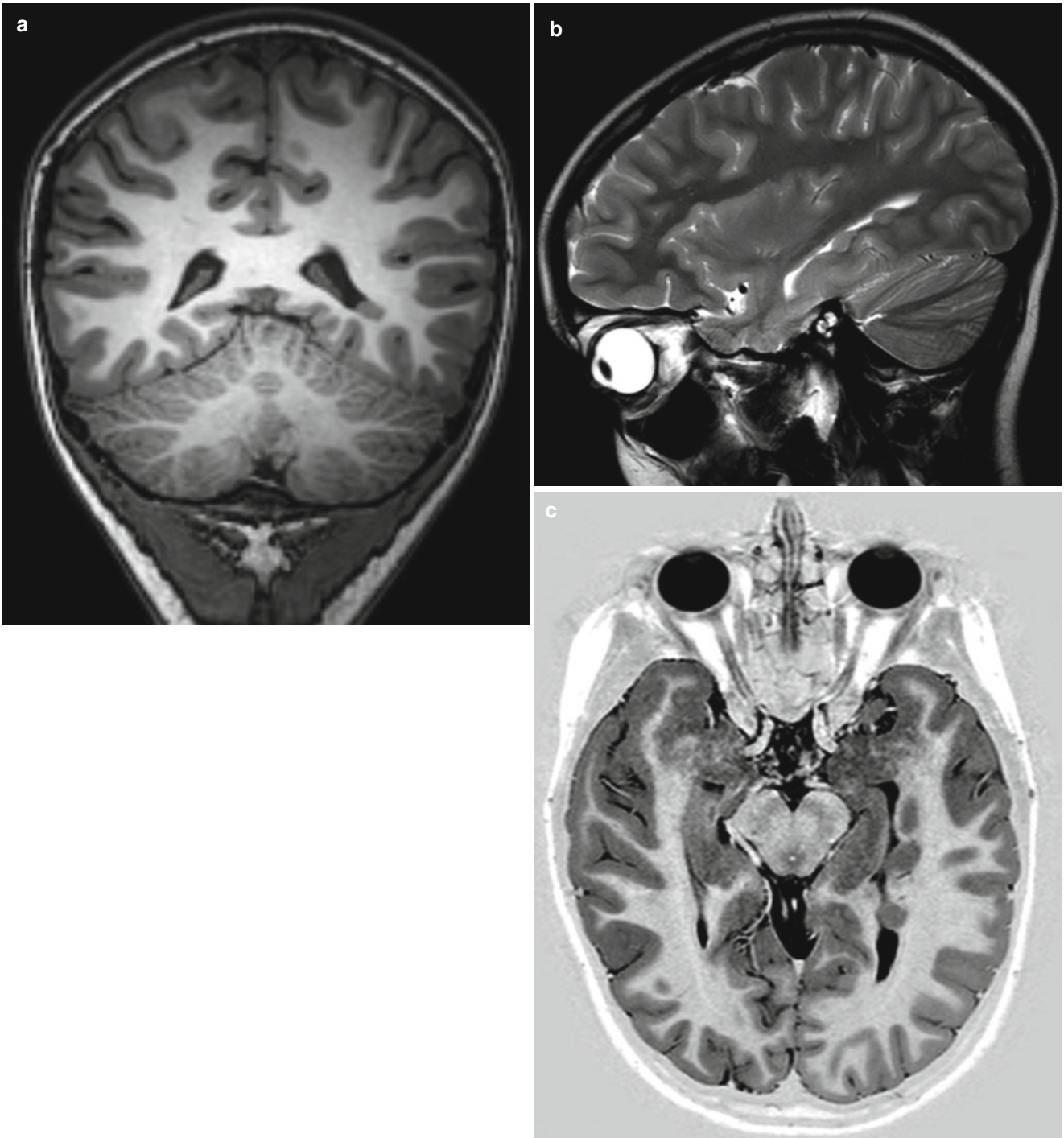


Fig. 9 (**a**–**c**) Periventricular nodular heterotopia: (**a**) coronal T1; (**b**) sagittal T2; (**c**) axial T1 IR. Well-delineated smooth ovoid masses lateral to the trigone and temporal horn of the left ventricle. Note that the signal is identical to that of cortex in all sequences

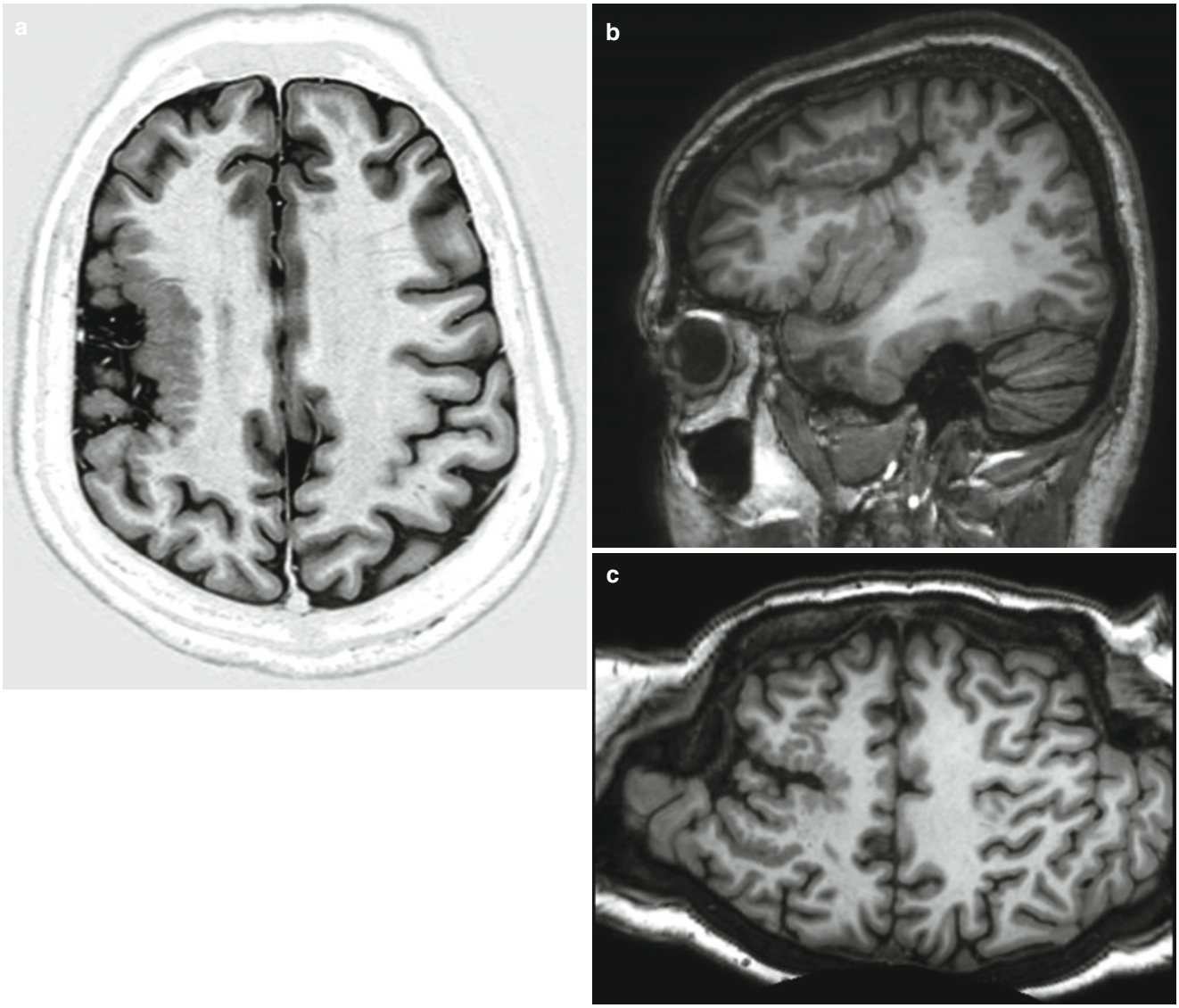


Fig. 10 (**a**–**c**) Two patients with polymicrogyria. (**a**) axial T1 IR; (**b**) sagittal T1. Patient 1. Abnormal gyration in the right hemisphere with a large region with polymicrogyria. (**c**) Patient 2, "pancake view" from a 3D T1 sequence gives a very good overview of the migration anomalies in the right hemisphere. It also increases the chance to detect subtle changes – see small area with polymicrogyria in the *left* hemisphere!

with seizures as the hemosiderin stain is believed to have a strong irritative potential for neurons. They are best visualized on T2 gradient echo or SWI sequences where they demonstrate with the classical blooming artifact (Fig. 14). Cavernomas may be multiple, and they can be associated with developmental venous anomalies (DVA). New intracavernomatous thrombosis or hemorrhage may lead to change in seizure frequency.

Patients with previous trauma can experience posttraumatic seizure disorder, especially after having sustained contusional hemorrhages of their temporal lobes as gliosis and

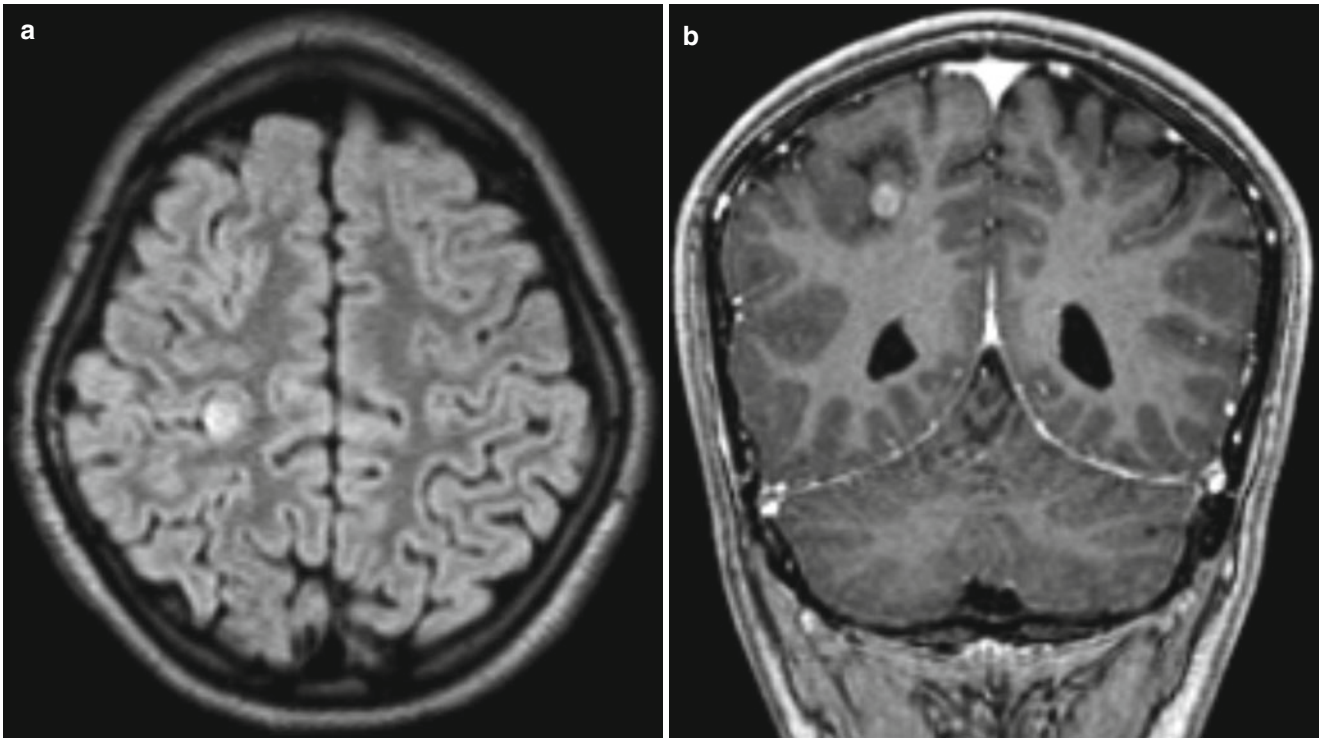


Fig. 11 (**a**, **b**) Ganglioglioma close to the right postcentral sulcus. (**a**) axial T2/FLAIR with a small, cortical/subcortical, nodular high-signal area in the right parietal lobe close to the postcentral sulcus; (**b**) coronal T1 with gadolinium shows contrast enhancement in the nodulus

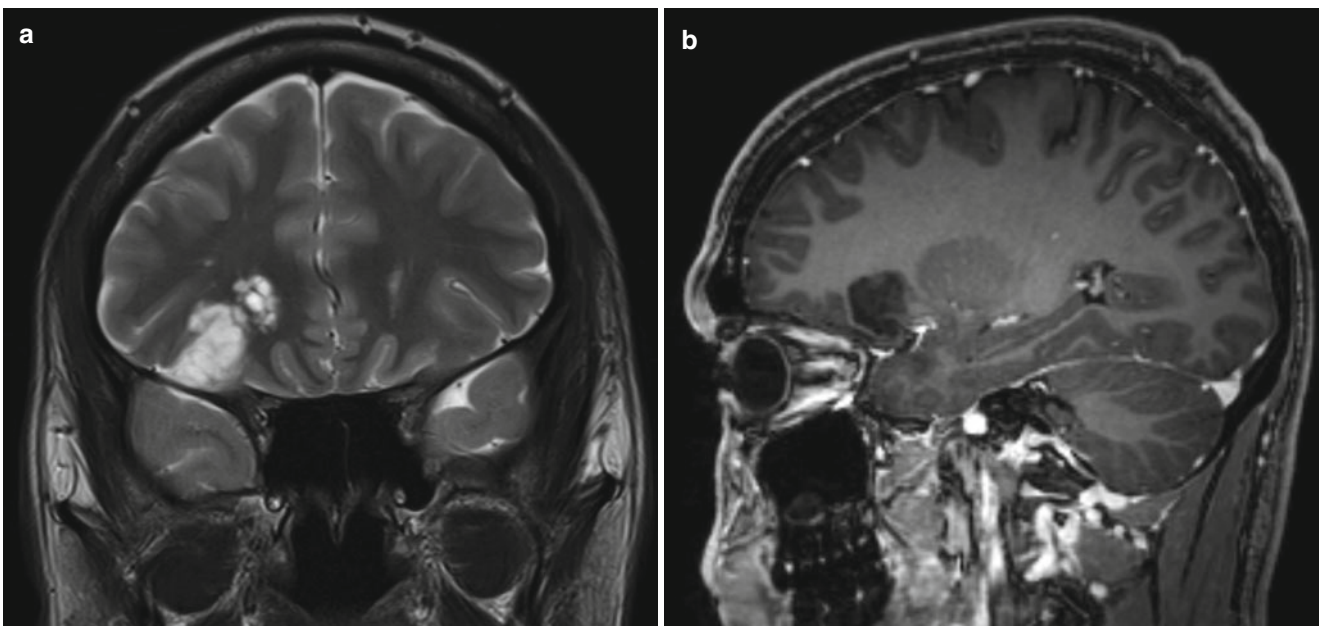
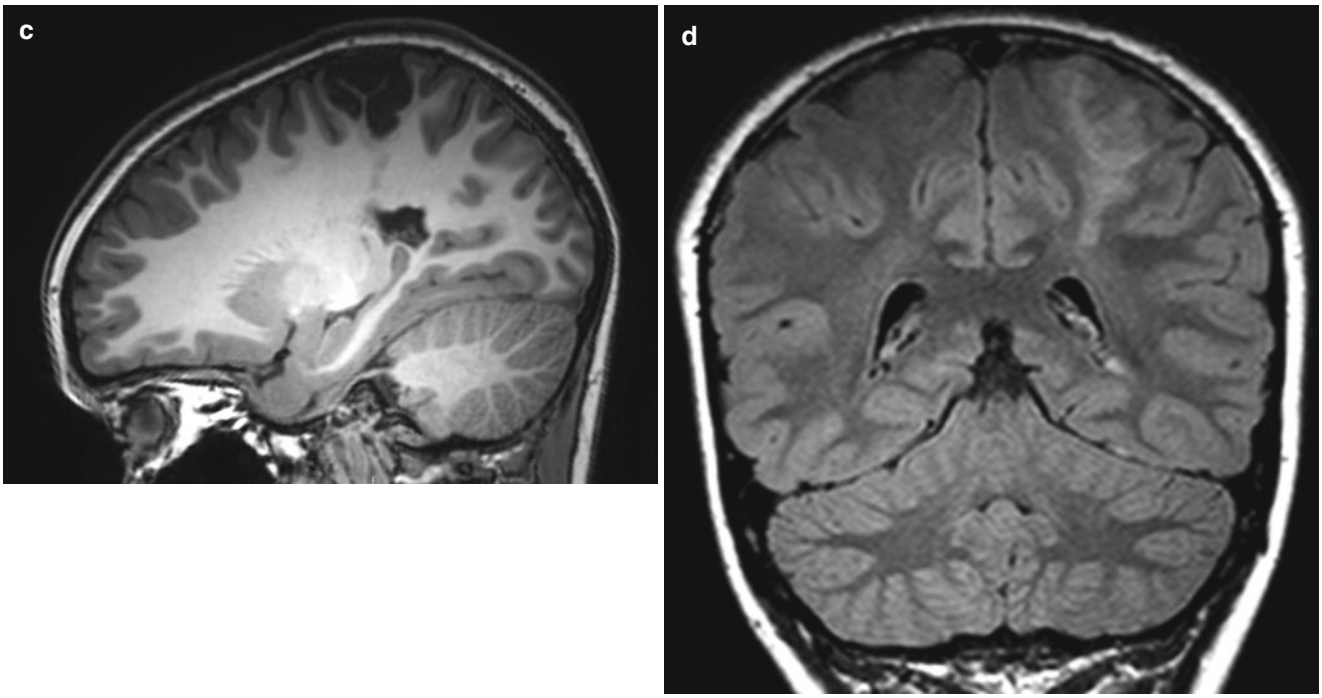


Fig. 12 Two patients with DNET. (**a**, **b**) patient 1. (**a**) coronal T2; (**b**) sagittal T1 with gadolinium; well-delineated cortical/subcortical bubbly mass in the right frontal lobe with prolonged T2 and no contrast enhancement typical of a DNET. (**c**, **d**) patient 2: (**c**) sagittal T1; (**d**) coronal T2/FLAIR. This DNET in the left parietal lobe is associated with a FCD type II. Notice the streak with signal changes which stretches toward the lateral ventricle



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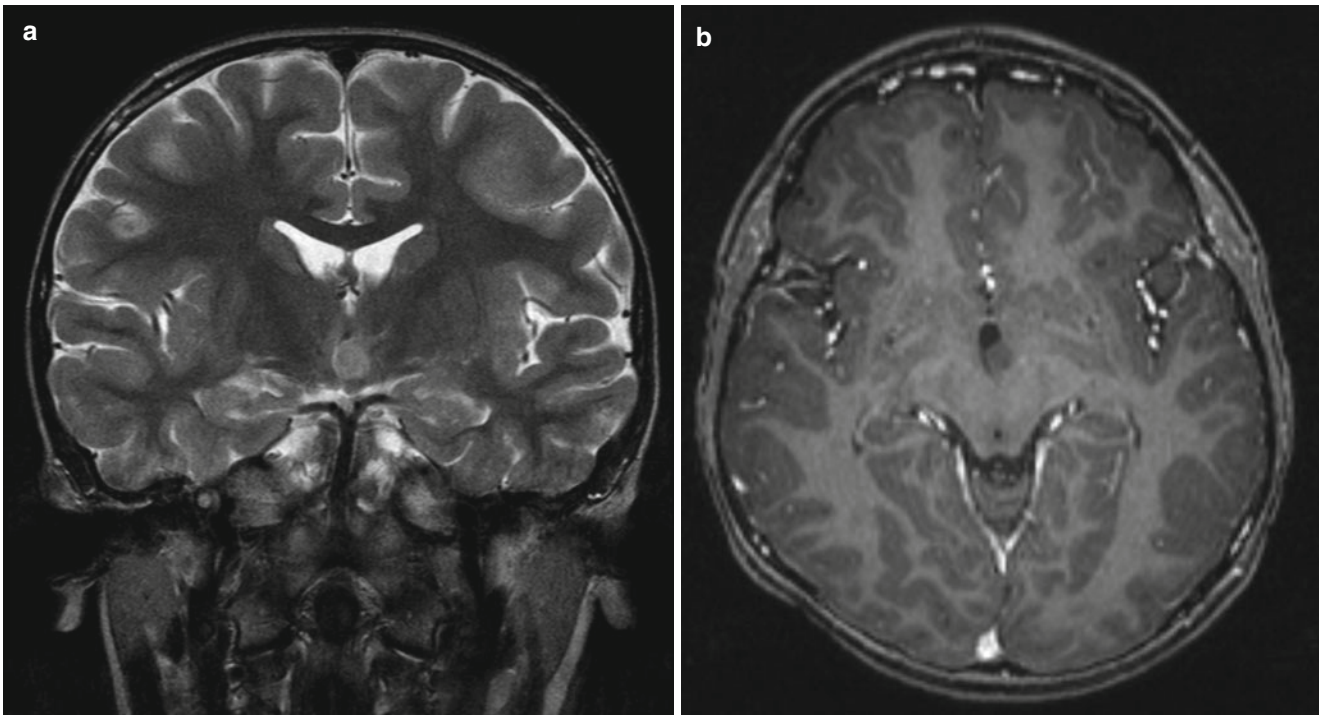

Fig 13 (**a**, **b**) Hypothalamic hamartoma. (**a**): Coronal T2 with a lobular mass close to the left wall of the third ventricle. (**b**): Axial T1 with gadolinium detects no contrast enhancement in the mass

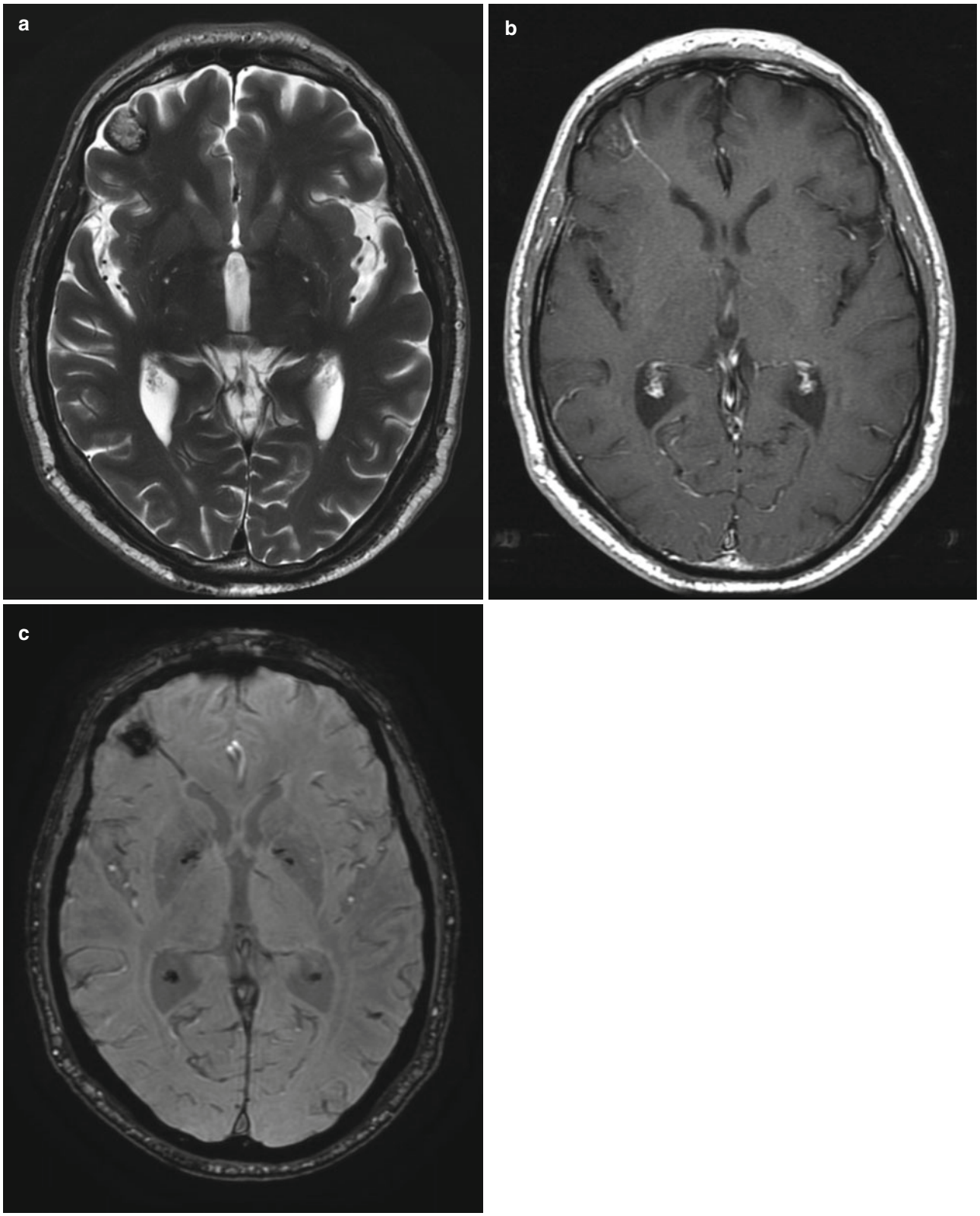

Fig. 14 (**a**–**c**) Cavernoma in the right frontal lobe with an associated DVA. (**a**): axial T2 shows the superficial lesion with heterogeneous signal; (**b**): axial T1 with gadolinium shows an associated vascular structure, a DVA; (**c**): axial SWAN sequence. This susceptibility sensitive sequence shows the classical blooming effect of the cavernoma

hemosiderin staining can cause irritation of the surrounding cortex.

Neonatal anoxic ischemia or hypoxemia can cause ulegyria – i.e., a scar/defect of the cerebral cortex that mainly involves the cortex in the depth of the sulcus – whereas the cortical crowns remain relatively unaffected. This peculiar pattern can be explained by the vascular supply of the gyri in the newborn that leads to a better perfusion of the apices of the gyri as compared to the depth of the sulci. There will be paucity of the white matter and, as the lesion occurred prior to complete myelination, a relatively mild gliosis. If the perinatal ischemia has only involved one hemisphere (perinatal stroke), a Dyke-Davidoff-Masson syndrome will ensue where stable hemiatrophy is present with hypertrophy of the skull and the sinuses, paucity of white matter, ventricular enlargement, and mild gliosis.

Virtually any infection (bacterial, fungal, parasitic) can produce epileptogenic lesions, and worldwide infections are the leading cause of epilepsy. A typical example is neurocysticercosis which in the late nodular phase is a very common cause of focal epilepsy in the developing world.

Antero-basal temporal lobe encephaloceles are lesions that are either related to a congenital defect of the bone or to previous trauma. Brain tissue can extend into the pterygopalatine fossa through the bony defect at the base of the greater sphenoid wing in the region of the foramen rotundum and pterygoid process. The herniated brain demonstrates high T2/FLAIR signal in the area believed to be the epileptogenic focus. Following resection of the abnormal brain tissue, seizure freedom can be obtained in a very large proportion of cases.

Rasmussen's encephalitis is a presumably autoimmune-mediated chronic inflammation of the brain that presents with progressive gliosis and volume loss. Patients experience seizures and a progressive hemiparesis.

The two phakomatoses commonly associated with seizures are tuberous sclerosis and Sturge-Weber syndrome. In tuberous sclerosis, multiple hamartomas are present within the cortical/subcortical region (Fig. 15). These are similar in histology to the FCD type II and are therefore believed to be epileptogenic. In addition, patients may develop subependymal calcification as well as a subependymal giant cell astrocytoma; however, the latter two lesions are not believed to be epileptogenic. In Sturge-Weber syndrome, the cortical calcification and the pial angiomatosis along the cortex are presumably related to the seizures. In addition, patients may present with choroid plexus hypertrophy and brain hemiatrophy as well as a facial port-wine stain (Fig. 16).

Conclusion

Neuroimaging in patients with refractory epilepsy will find abnormalities in as high as 85 % of cases and therefore plays a crucial role in the identification of epileptogenic lesions and their possible surgical removal. A dedicated epilepsy protocol is necessary to identify these lesions, and the MR should be interpreted in conjunction with EEG, neuropsychological testing, and clinical semiological data to increase the likelihood of identifying these often very subtle lesions.

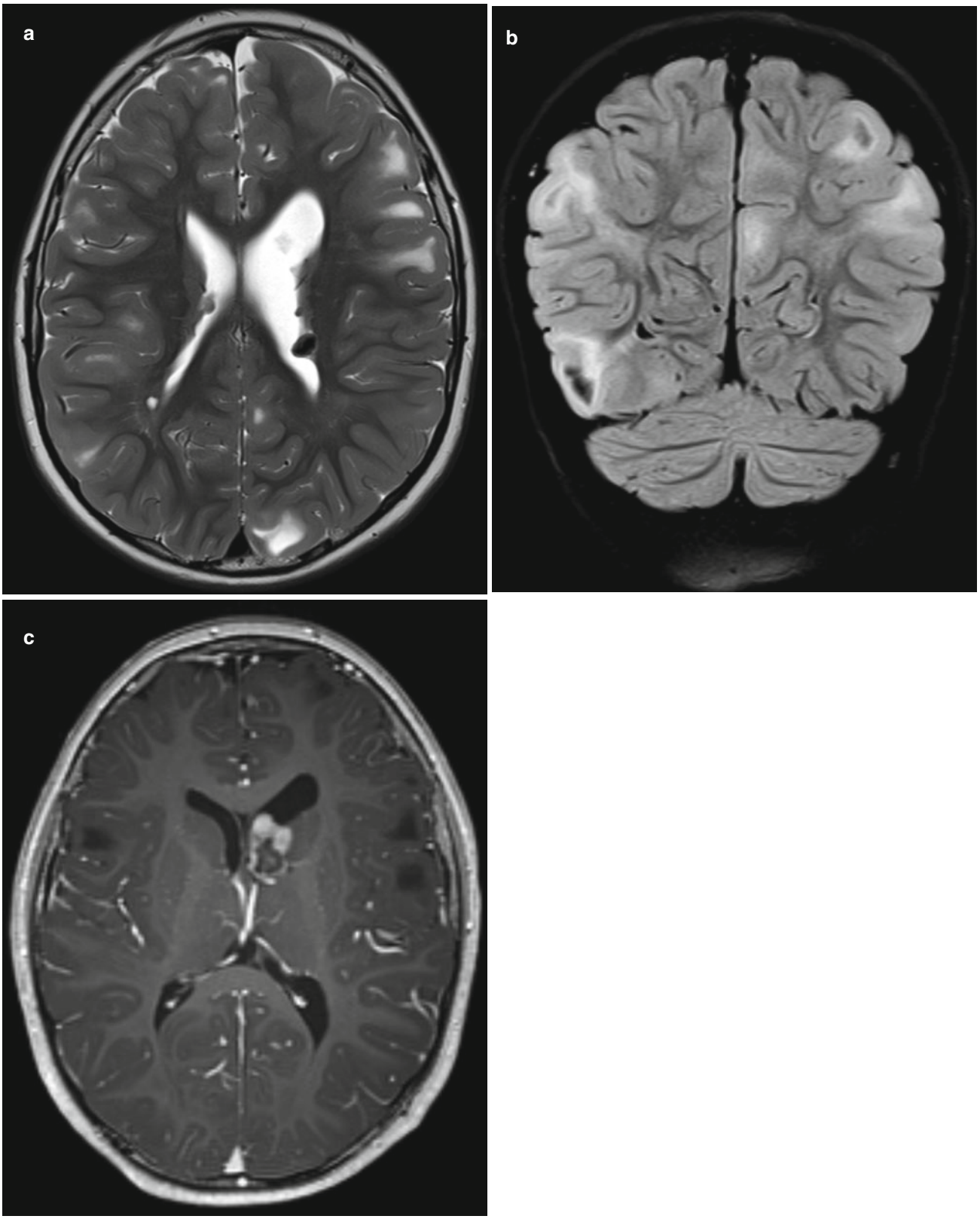

Fig. 15 (**a**–**c**) Tuberous sclerosis; (**a**) axial T2 and (**b**): coronal T2/FLAIR show subependymal hamartomas and widespread cortical and subcortical signal changes; (**c**) axial T1 with gadolinium with a large giant cell astrocytoma in a classical position, close to the foramen of Monro in the left lateral ventricle

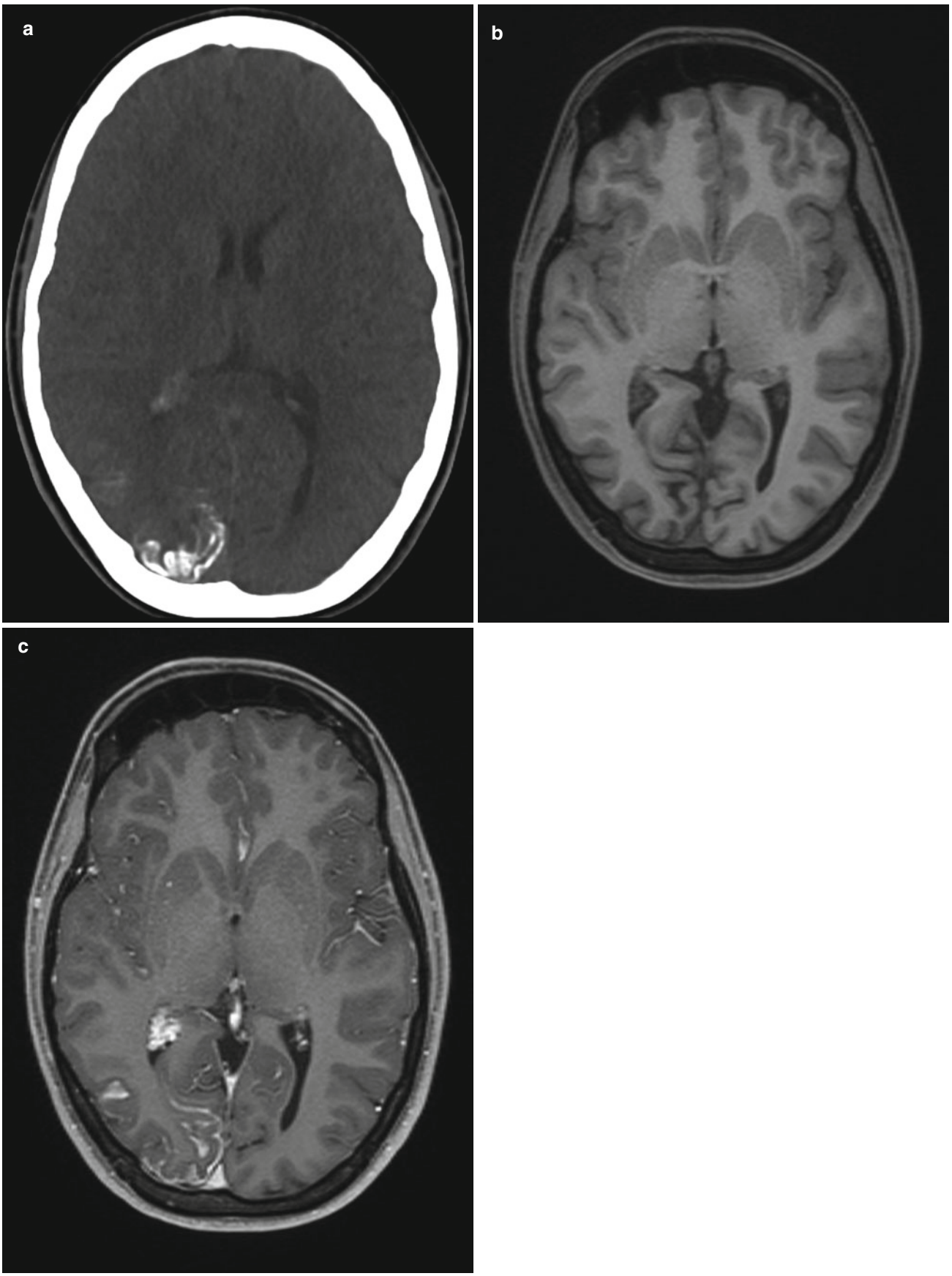

Fig. 16 (**a**–**c**) Sturge-Weber syndrome; (**a**) axial CT shows curvilinear cortical calcifications in the right occipital lobe; (**b**) axial T1 without and **c**: with gadolinium shows contrast enhancement caused by pial angiomatosis. Note also hypertrophy of the ipsilateral choroidal plexus, typical for this syndrome

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