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Imaging of Lymphomas Involving the CNS: An Update-Review of the Full Spectrum of Disease with an Emphasis on the World Health Organization Classifications of CNS Tumors 2021 and Hematolymphoid Tumors 2022

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ABSTRACT

SUMMARY: Lymphomas of the CNS are the second most frequent primary brain malignancy in adults after gliomas. Presurgical suspicion of lymphoma greatly impacts patient management. The radiologic features of this tumor have been widely covered in the literature for decades, but under current classifications, mainly corresponding to the most common presentations of the most frequent type: primary diffuse large B-cell lymphoma of the CNS. Nevertheless, rarer presentations of this specific lymphoma and of other World Health Organization lymphoma subtypes with different imaging features are rarely treated. Moreover, important advances in imaging techniques, changing epidemiologic factors with relevant impact on these tumors (eg, immunodeficiency/dysregulation), and recent updates of the World Health Organization Classification of CNS Tumors 2021 and Hematolymphoid Tumors 2022 may have rendered some accepted concepts outdated. In this article, the authors aim to fulfill a critical need by providing a complete update-review, emphasizing the latest clinical-radiologic features of the full spectrum of lymphomas involving the CNS.

ABBREVIATIONS: ALK+/ALK− = anaplastic lymphoma kinase positive and negative; CLIPPERS = chronic lymphocytic inflammation with pontine perivascular enhancement responsive to steroids; DLBCL = diffuse large B-cell lymphoma; EBV = Epstein-Barr virus; MALT = mucosa-associated lymphoid tissue; NK = natural killer; PSR = percentage of signal recovery; WHO = World Health Organization

Lymphomas of the CNS are the second most frequent primary brain malignancy in adults after gliomas, accounting for 7% of all malignant tumors.¹ A presurgical suspicion of this tumor will greatly impact patient management. Corticoids should be avoided before a definitive diagnosis is made, and prompt biopsy is recommended to prioritize chemoradiotherapy instead of tumor resection, such as in the case of suspected glioblastoma.^{2,3}

The radiologic features of these tumors have been widely covered in the literature in recent decades. Imaging characteristics of lymphomas may be considered typical, leading to a potential misunderstanding of this tumor as a straightforward presurgical suspicion. Nevertheless, this is often far from the reality in daily practice. In fact, the typical appearance of lymphomas is currently almost exclusively related to the most common presentations of

the most frequent type: primary diffuse large B-cell lymphoma (DLBCL) of the CNS, negative for Epstein-Barr virus (EBV). If rarer presentations of this specific lymphoma or other specific subtypes with different characteristic imaging features are considered, the complexity increases, and it becomes a great mimicker with a challenging differential diagnosis. Also, important advances in imaging techniques, dynamic changes in epidemiologic factors with relevant impact on these tumors (eg, immunodeficiency/dysregulation), and recent changes in the World Health Organization (WHO) classifications of CNS² and hematolymphoid⁴ tumors may have rendered some well-accepted concepts of the disease outdated.⁵⁻⁸

The Research Ethics Committee of the Hospital Universitari de Bellvitge approved this article for publication (PR348/22).

WHO Classification of Tumors, 5th Edition

Insights. Some basic concepts regarding WHO classifications need to be understood for an optimally up-to-date comprehension of lymphomas in the CNS. First, these tumors fall between two 5th edition WHO classifications: the CNS² and the hematolymphoid.⁴ Second, despite impressive advances in molecular pathology, the mainstay in lymphomas remains histology of biopsy specimens; this differs greatly from other brain tumors such as gliomas, for which molecular pathology is vital. Nevertheless, clinically relevant pathogenesis, mutation profiles, and genetic drivers have been characterized in recent years. Recurrent mutations frequently

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activate the B-cell receptor, toll-like receptor, and NF- κ B pathways, and alterations in genes involved in chromatin structure and modification, cell-cycle regulation, and immune recognition are common. *MYD88* and *CD79B* mutations may be of clinical interest because they can be detected in several body fluids (plasma and CSF), potentially assisting in disease-monitoring under treatment and in minimally-invasive initial diagnosis. Also, knowledge of genetically activated pathways, tumor immune microenvironment, and expression of immune-response biomarkers may point to specific treatment targets. Finally, lymphoma classifications include clinical factors, especially regarding the immune status of patients, which plays an essential role in tumor classification with important treatment implications.^{2,4}

Updates. Thus, some changes may be identified in the updated WHO Classifications of CNS Tumors 2021 and Hematolymphoid Tumors 2022, first in CNS immunodeficiency-associated lymphoma. Whereas the prior CNS classification included a heterogeneous group of diseases primarily defined by the patient immunodeficiency setting, currently, it is exclusively defined as DLBCL and EBV positive (both essential criteria) lymphoma.² Moreover, the current spectrum of immunodeficiency includes immune-dysregulation according to the hematolymphoid classification, in which immunocompromised settings without a fully demonstrable immunodeficiency, such as immunosenescence (among others), are included.^{2,4}

Next, a change in terminology is recommended in the upcoming hematolymphoid classification, representing a paradigm shift. Currently, the type of immunodeficiency-associated lymphoma is not first determined by the immunodeficiency/dysregulation setting, as in the previous classification (eg, AIDS-related DLBCL). Instead, it is defined primarily by the tumor histology with the so-called 3-part nomenclature, composed of the following: 1) histologic lesion, 2) oncogenic virus status, and 3) immunodeficiency background of the patient (eg, DLBCL, EBV-positive, and autoimmune setting).⁴ This integrated nomenclature allows the grouping of specific types of immunodeficiency-associated lymphomas (such as DLBCL EBV-positive), despite the underlying immunodeficiency/dysregulation, to better define the unique shared pathogenetic mechanisms.^{4,9,10}

On the other hand, lymphomatoid granulomatosis is no longer considered an immunodeficiency-associated entity. It occurs exclusively in immunocompetent patients, and in the case of an underlying immunodeficiency, it should be considered a subtype of a polymorphic lymphoproliferative disorder.⁴

Also, according to the WHO classification of hematolymphoid tumors, the term primary CNS lymphoma may be considered imprecise, and it is no longer recommended for referring specifically to primary DLBCL of the CNS,⁴ which is the currently preferred term.^{2,4}

Finally, some tumors do not differ in their specific histology but rather in their precise location. This is because in the new WHO hematolymphoid classification, primary DLBCL of the CNS is classified together with DLBCL of the vitreoretina and of the testes of immunocompetent patients as primary DLBCL of immune-privileged sites. All these entities arise in so-called immune sanctuaries created by their anatomic and functional immune regulatory

barriers (eg, the blood-brain barrier). However, large B-cell lymphomas occurring in the dura (dural lymphoma) or inside the brain vessels (intravascular lymphoma) escape these immune privileges and are, therefore, classified separately.^{2,4}

With all these upgraded concepts in mind, the authors aim to provide a complete update-review of imaging features of the full spectrum of lymphomas involving the CNS, mainly based on those entities included in the 5th edition WHO Classification of Tumors of the CNS 2021.² Primary DLBCL of the CNS, immunodeficiency-associated CNS lymphoma, lymphomatoid granulomatosis, intravascular large B-cell lymphoma of the CNS, mucosa-associated lymphoid tissue (MALT) lymphoma of the dura, other low-grade B-cell lymphomas of the CNS, anaplastic large-cell lymphoma (anaplastic lymphoma kinase positive and negative [ALK+/ALK-]), and T-cell and natural killer (NK)/T-cell lymphoma are discussed. Finally, the clinical-radiologic entity “lymphomatosis cerebri” and secondary lymphomas are also reviewed.

Imaging of CNS Lymphomas

Primary DLBCL of the CNS. Primary DLBCL of the CNS corresponds to 80%–85% of all CNS lymphomas, occurs almost always in immunocompetent patients, is EBV-negative, and is of unknown etiology.² The term primary CNS lymphoma may be considered imprecise, and it is no longer recommended by the WHO classification of hematolymphoid tumors⁴ for referring specifically to primary DLBCL of the CNS, which is the currently preferred term.^{2,4}

It usually appears as single or multiple (30%–35%) parenchymal lesions, located supratentorially (>80%), with a particular affinity for the basal ganglia, periventricular regions, midline, and corpus callosum (\approx 45%). It is also frequent in brain hemispheres (\approx 40%), rarely found in the posterior fossa, and exceptionally in the spinal cord (Fig 1).² Associated leptomeningeal or subependymal enhancement is characteristic, but an exclusive presentation of the disease in this location may raise suspicion of secondary lymphoma. The typical perivascular histologic pattern also carries a characteristic perivascular enhancement on imaging (Fig 1). Parenchymal lesions are most frequently solid and homogeneous, but their presentation can range from well-defined expansive to ill-defined infiltrative lesions.^{2,5-7,11}

Notably, these lesions are frequently hyperattenuating on NCCT,^{2,5-7,11} which is important to keep in mind because CT is the first-line radiologic examination and suspicion at this point may lead to corticoid avoidance (Fig 1). If administered, corticoids can complicate subsequent imaging and histologic diagnosis.^{2,3,12}

Regarding specific tumor MR imaging features, lymphoma typically appears hypointense on T2WI with marked diffusion restriction on DWI. Nevertheless, a T2-blackout effect consisting of a persistent hypointensity on $b = 1000$ images due to very low T2 signal may lead to misinterpretation. Thus, ADC map hypointensity might be more reliable than $b = 1000$ hyperintensity in assessing actual diffusion restriction.^{2,5-7,11} NCCT hyperattenuation, low T2 signal, and diffusion restriction correlate with high cellularity on histology, with Ki-67 proliferation indexes usually above 90% (Fig 1).¹³

Historically, the presence of hemorrhage or signs of necrosis on preoperative imaging in immunocompetent patients have been considered a factor arguing strongly against a diagnosis of lymphoma.¹⁴ However, the histologic appearance of tumor

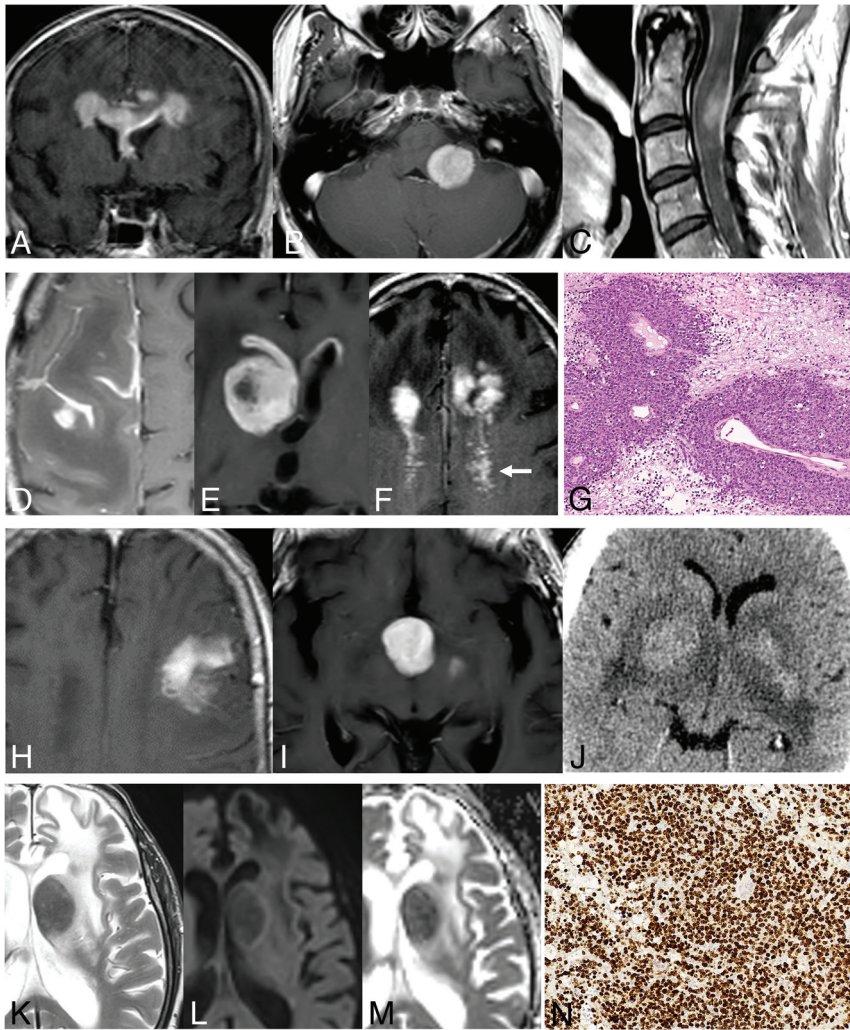


FIG 1. Primary DLBCLs of the CNS, EBV-negative. A–C: Usual deep, periventricular, corpus callosum, and midline location (A); a rare location in the posterior fossa (B); and exceptional in the spinal cord (C). D–G: Parenchymal lesions with associated characteristic leptomeningeal (D), subependymal (E), and perivascular (arrow, F) enhancement patterns. Histologic hematoxylin-eosin stain (original magnification $\times 20$) shows highly cellular, perivascular accumulation of lymphoma cells (G). H–J: Mass lesion with ill-defined infiltrative (H) or well-defined expansive (I) margins. Hyperattenuated lesions on NCCT (J). K–N: Deep T2 hypointensity of a lesion (K) with a T2-blackout effect at $b = 1000$ image (L) but a low signal of actual diffusion restriction on the ADC map (M). Ki-67 proliferation index by immunohistochemistry (original magnification $\times 20$) exceeding 90% (N).

samples frequently includes hemorrhagic tumors with central necrosis.² Accordingly, recent literature reports the presence of hemorrhage on imaging in up to 50% of patients evaluated with SWI (20% with T2WI) and heterogeneous or ring enhancement (usually associated with necrosis) in up to 10%–15% of cases.^{3,15} Therefore, the authors discourage this classic assumption and believe that a certain degree of hemorrhage and heterogeneous or ring enhancements does not rule out suspicion of lymphoma, considering other imaging features as well (Fig 2).

Regarding quantitative imaging techniques beyond DWI, ¹H-MR spectroscopy and DSC-PWI, included in consensus recommendations for imaging CNS lymphoma,¹⁶ have shown promising results for presurgical diagnosis. Attention must be paid to pulse-sequence parameters (TE, TR, flip angle), prebolus usage, and leakage corrections for DSC-PWI, but in general terms, this

tumor shows low-to-intermediate CBV, a high percentage of signal recovery (PSR), and characteristic time-intensity curve morphology.^{7,17,18} Lower CBV values in lymphomas have paradoxically been related to a worse prognosis of survival.¹⁹ ¹H-MR spectroscopy can also reinforce a presurgical suspicion in basically 2 ways: Short TE depicts much lower mIns (described as a glial marker) than that associated with enhancing non-necrotic astrocytoma (ie, grade 3), and long TE shows much lower mobile lipids (associated with necrosis) than glioblastoma or metastasis (Fig 2).²⁰

Brain FDG-PET may play a role in the presurgical differentiation of lymphoma and other malignant brain tumors such as glioblastoma and metastasis because most lymphoma lesions are highly FDG-avid, with homogeneous uptake.¹⁶

As an additional comment on primary DLBCL of the CNS, it has been reported that “sentinel” inflammatory lesions, which may disappear after anti-inflammatory treatment, can precede the diagnosis of lymphoma by up to 2 years,²¹ so attention must be paid to the patient’s history of prior inflammatory brain lesions (Fig 3).

Immunodeficiency-Associated CNS Lymphoma. According to the latest WHO classification, the immunodeficiency-associated CNS lymphoma subtype specifically corresponds to primary DLBCL of the CNS, EBV-positive. Indeed, large B-cell histology and lymphotropic EBV tissue-positivity are currently the essential diagnostic criteria

for immunodeficiency-associated lymphoma of the CNS.² It represents 8%–10% of all primary CNS lymphomas. Despite being considered an infrequent entity, this is the second most frequent type of primary lymphoma of the CNS. Its clinical context has changed during recent decades. Whereas in the 1990s, AIDS due to HIV was the leading cause, currently and especially in more developed countries, other causes predominate, such as post transplant status, autoimmune disease, and iatrogenesis.^{22–28} This shift in the mechanisms of immunodeficiency and other developments in patient monitoring as well as in imaging techniques have also resulted in a change in the main differential diagnoses to consider. Currently, therefore, glioblastoma or metastases are more likely than opportunistic infections, in contrast to previous decades.^{8,29,30}

Morphologic imaging of this lymphoma is quite characteristic, and the opposite of that of the “typical” CNS lymphoma. It can

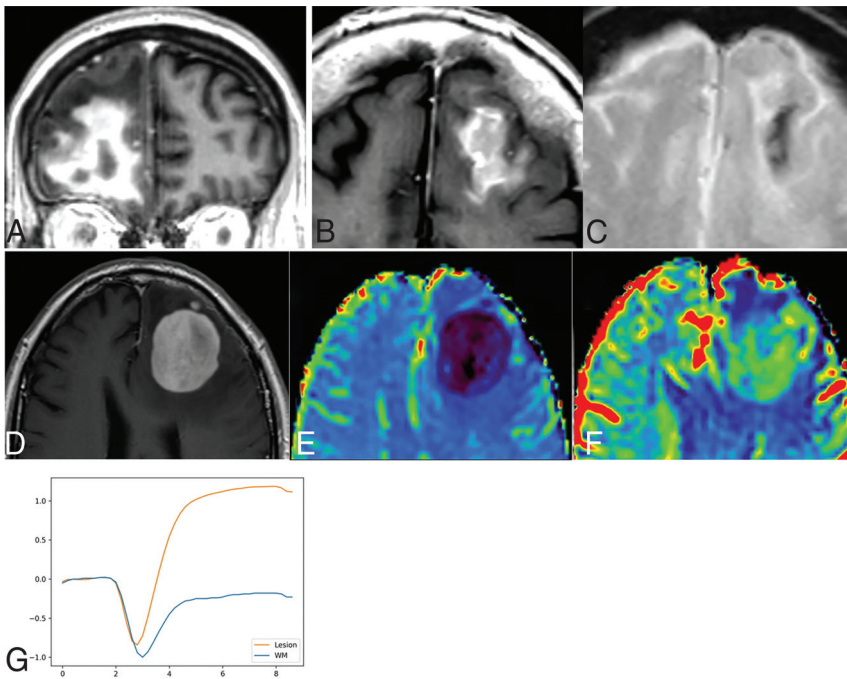


FIG 2. A–C: Primary DLBCLs of the CNS, EBV-negative, with imaging signs of central necrosis (A) and tumoral hemorrhage (B and C). D–G: DSC-PWI features of a left frontal primary DLBCL of the CNS, EBV-negative (D). Low-to-intermediate CBV on noncorrected (E) and corrected (F) color maps. Characteristic lymphoma DSC-PWI time-intensity curve morphology with ascending-part of the curve recovering signal intensity far above the baseline (high PSR) (G).

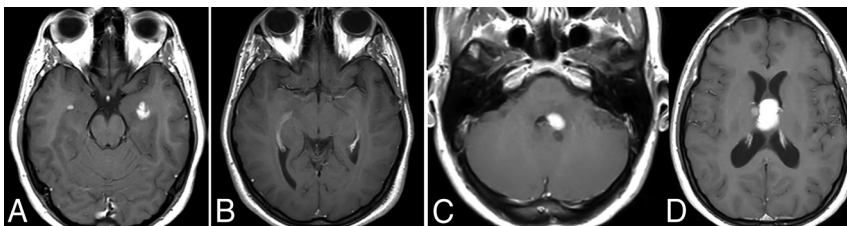


FIG 3. Sentinel inflammatory lesions preceding primary DLBCL of the CNS. Two enhancing periventricular temporal lesions were detected in a patient (A). A biopsy was obtained, and histopathology showed an inflammatory infiltrate without evidence of neoplasia. The lesions disappeared on further imaging controls during the following 2 years (B). In a subsequent MR imaging control, new masslike lesions reappeared (C and D). A biopsy of the new lesions yielded the final histopathologic diagnosis of primary DLBCL of the CNS.

be deep or hemispheric, with a slightly greater tendency to multiplicity. It is almost constantly highly necrotic with ring enhancement and intermediate-to-prominent signs of hemorrhage. T2WI and DWI signal patterns are both variable and inconsistent. In summary, it is a tumor that differs from the typical appearance of lymphoma and, rather, presents more like the main differential diagnoses, which are glioblastoma and metastasis.^{8,29,30} A characteristic T2WI heterogeneous hypointensity of the nonenhancing “necrosis,” not corresponding to blood products or mineralization, has recently been suggested in these tumors, in contrast to the usual hyperintense T2 signal of nonhemorrhagic necrosis in other tumors (Fig 4).⁸

While conventional imaging is often insufficient to reach a presurgical diagnosis of this challenging entity, quantitative imaging, especially DSC-PWI, can provide diagnostic clues. Indeed,

the perfusion features of this lymphoma follow those of low-to-intermediate CBV, high PSR, and the characteristic time-intensity curve morphology when depicting an ROI in the solid parts of tumors (Fig 4).⁸ Finally, the ¹H-MR spectroscopy pattern seems of low value for presurgical characterization as lymphoma because this tumor has prominent mobile lipids overlapping with necrotic glioblastomas or metastasis.²⁰

In conclusion, we suggest that in dealing with a necrohemorrhagic tumor, potential immunodeficiency/dysregulation of the patient must be thoroughly examined. If this cannot be ruled out, DLBCL EBV-positive should be considered, and careful DSC-PWI assessment can provide a presurgical diagnostic clue.

Lymphomatoid Granulomatosis. According to the new WHO classification of hematolymphoid tumors, lymphomatoid granulomatosis is a lymphoproliferative disorder with large atypical EBV-positive B-cells, T-cell infiltration, and tissue necrosis occurring exclusively in immunocompetent patients.⁴ Previously, it was included in the group of immunodeficiency-associated entities, but currently, the identification of an underlying immunocompromised status rules out lymphomatoid granulomatosis, and it should instead be considered a subtype of a polymorphic lymphoproliferative disorder in the setting of immunodeficiency/dysregulation.⁴ Lymphomatoid granulomatosis is a very rare entity that exceptionally occurs primarily in the CNS, though CNS involvement is

usually secondary. It represents a spectrum of lymphoid disease graded from 1 to 3, with corresponding degrees of aggressiveness from indolent to very aggressive.^{2,4}

On imaging, typical findings are those of secondary lymphoma with frequent subependymal or leptomeningeal involvement and perivascular enhancement. Occasionally, it may be angiocentric and angiodestructive, resembling intravascular lymphoma. When there is isolated CNS involvement, it usually corresponds to grade 3 disease, and brain biopsy demonstrates DLBCL EBV-positive,^{2,4} in which case imaging findings may consist of masslike lesions with hemorrhage and necrosis.^{2,4,31,32}

In the recent literature, lymphomatoid granulomatosis has been correlated with chronic lymphocytic inflammation with pontine perivascular enhancement responsive to steroids (CLIPPERS). Some authors hypothesize that this entity is a kind of a sentinel

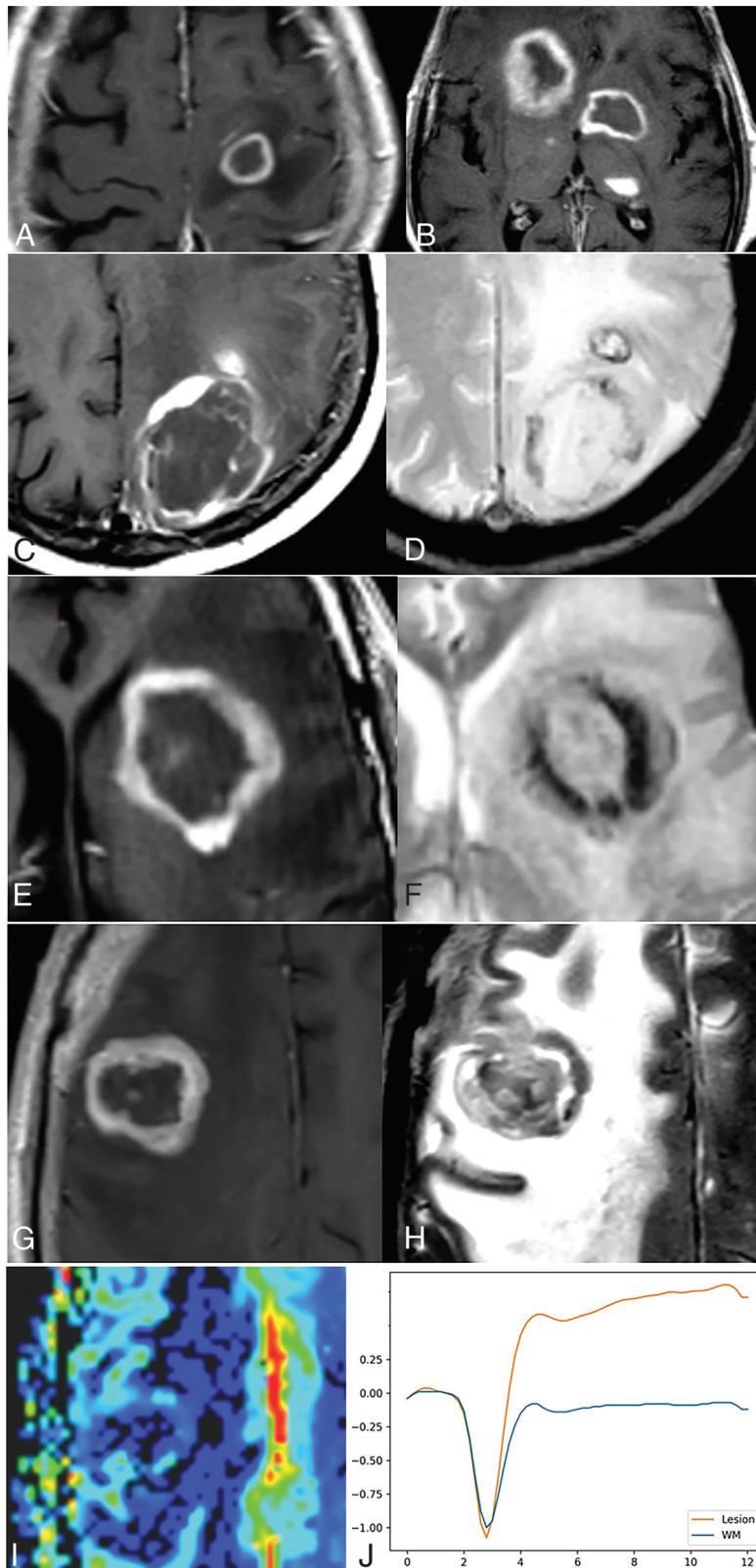


FIG 4. Primary DLBCLs of the CNS, EBV-positive (immunodeficiency/dysregulation-associated). Single (A) and multiple (B) lesions with prominent necrosis (C and E) and tumoral hemorrhage (D and F). Heterogeneous deep T2 hypointensity (H) of the nonenhancing central content (G) of lesions, so-called necrosis. Low-intermediate CBV on the corrected color map (I) and DSC-PWI time-intensity curve with high PSR (J), also very characteristic of this lymphoma subtype.

lesion, while others postulate that CLIPPERS may be an inflammatory response to lymphomatous tumor cells, responding to corticosteroids preceding the definitive tumor recurrence.^{33,34}

Intravascular Large B-Cell Lymphoma of the CNS. Intravascular large B-cell lymphoma of the CNS is defined by the selective proliferation of malignant B large-tumor cells within the brain vessels, particularly small- to medium-sized blood vessels, without or with minimal parenchymal extension. The tumor cells may occlude vessels causing patched bleeding and ischemia. Also, it is not exceptional for some tumor cells to extravasate beyond the vessels, focally reaching brain parenchyma. Regarding clinical presentation, strokelike symptoms are typical, though not always present.³⁵

The main phenomena detected on imaging are ischemic and hemorrhagic lesions, which usually suggest the differential with vasculitis, emboli, or hypercoagulability. The ischemia-like lesions appear dynamic and evanescent between near-in-time imaging follow-ups. Furthermore, those possible tumor cells that extravasate beyond the vessels may focally reach the brain parenchyma, forming tumor islands that can appear as enlarging areas of parenchymal enhancement.^{2,36} Morphologic imaging features on these enhancing islands may be helpful for presurgical suspicion because they can express the signal characteristics of typical lymphoma. In addition, ependymal and leptomeningeal enhancement may also be present.^{36,37} Advanced imaging features may include a tumoral pattern on ¹H-MR spectroscopy with high Cho to NAA ratios, as well as a characteristic DSC-PWI pattern with shortened MTT (differing from ischemic lesions), low-to-intermediate CBV, high PSR, and the characteristic time-intensity curve morphology of lymphomas in the CNS.^{7,18,20}

In summary, this entity should be kept in mind whenever encountering MR imaging with hemorrhage and multiple dynamic ischemic lesions on T2WI and DWI, enlarging parenchymal enhancement, and possible associated leptomeningeal or subependymal disease (Fig 5).^{36,37}

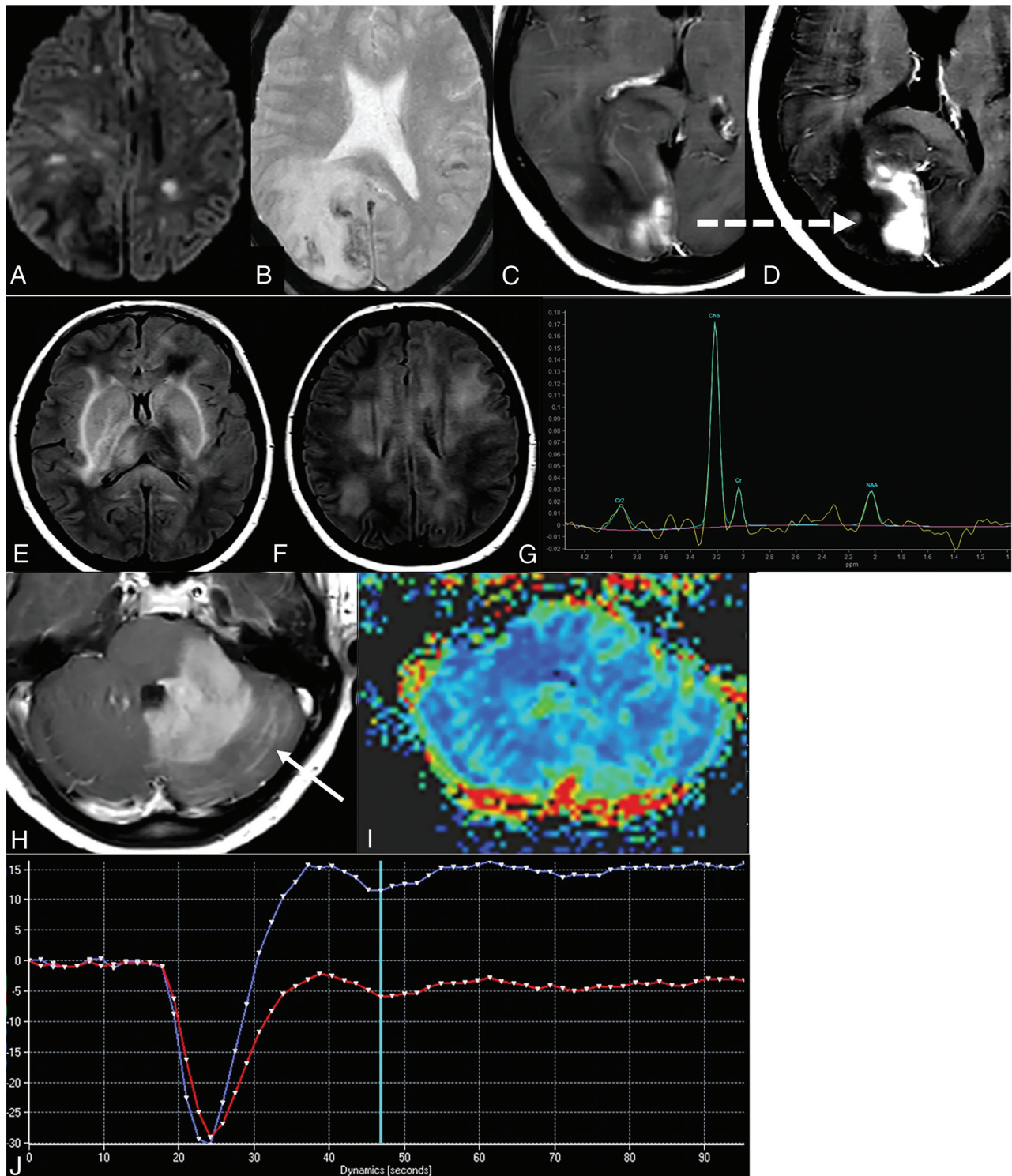


FIG 5. Intravascular lymphoma (A–D). Acute patched ischemia-like lesions on DWI (A), hemorrhages (B), and an area of enhancement (C), which grows on the subsequent few days of imaging control (D). Dashed arrow in C–D indicates the growth of the same enhancing-lesion in few days. DLBCL following a lymphomatosis cerebri pattern (E–J): extensive, patched, bilateral, and diffuse FLAIR hyperintensity on the basal ganglia (E) and white matter (F), with an area of enhancement in the left cerebellum (H) and associated leptomeningeal disease (arrow in H). Intermediate CBV in DSC-PWI color maps (I) and characteristic high PSR and time-intensity curve morphology (J). Tumoral pattern on ¹H-MR spectroscopy at long TE with a high Cho-to-NAA ratio (H) and absent mlins at the short TE (not shown), helpful in the differential diagnosis with nontumoral entities and gliomatosis cerebri, respectively.

MALT Lymphoma of the Dura. Lymphomas arising primarily in the dura are rare ($\approx 1\%$) and usually correspond to MALT lymphoma. Occasionally, large B-cell lymphoma may also be primarily dural. Etiology and underlying associations are unknown.^{2,38}

On conventional imaging, they appear as extra-axial lesions with a wide dural base, soft attachment angles, and a possible CSF cleft between the lesion and brain parenchyma. In addition, edema or brain tissue infiltration can occur. They usually appear

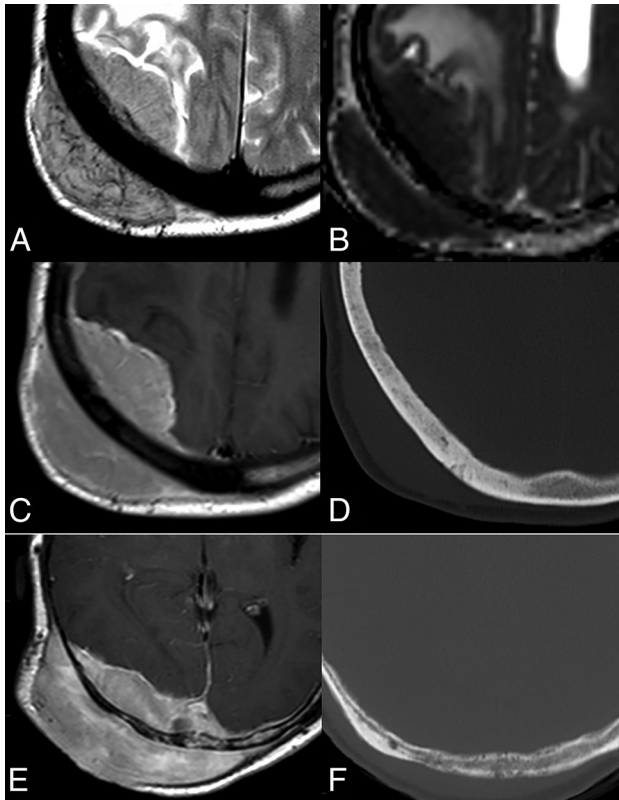


FIG 6. Dural lymphomas. MALT dural lymphoma (A–D) with extra-axial lesion features such as a CSF cleft (A) and a wide-implantation dural base with soft marginal angles (C), as well as T2-hypointensity (A) and diffusion restriction (B). Almost normal calvarial bone; only subtle sclerosis seen (D), despite the great soft-tissue component on both sides of the diploe (A–C). Similar imaging features with minimal bone destruction and a subtle permeative pattern (F) in comparison with the prominent soft-tissue component (E) in another diffuse large B-cell dural lymphoma (E and F).

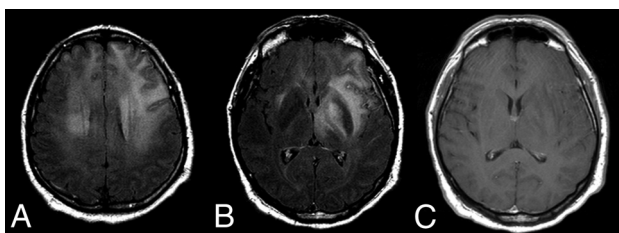


FIG 7. NK/T-cell lymphoma presenting with a lymphomatosis cerebri radiologic pattern (A–C). Patched and diffuse, bilateral and asymmetric, deep and subcortical, hyperintense lesions on FLAIR (A and B) without contrast enhancement (C).

homogeneous, NCCT hyperattenuated, T2WI hypointense, and with restricted diffusion; however, these features overlap with those of the most frequent extra-axial tumor in adults, meningioma (Fig 6).^{39,40}

Regarding advanced imaging, ¹H-MR spectroscopy can be of help for the differential diagnosis because meningiomas characteristically present with alanine, metastases present abundant mobile lipids, and the rarer solitary fibrous tumors (formerly termed hemangiopericytoma) show a high myo-inositol peak.³⁹

A clue for the presurgical suspicion of this tumor is provided by a characteristic pattern of bone infiltration or transdiploic extension. Characteristically, lymphoma presents as an extensive soft-tissue mass without bone destruction (normal bone to subtle permeative patterns) (Fig 6). This pattern is explained by the extension of tumor cells through Haversian canals. It differs from what is seen in meningiomas with hyperostosis or in plasmacytoma or metastasis with aggressive lytic destruction.³⁹

Other Low-Grade B-Cell Lymphomas of the CNS, Anaplastic Large Cell Lymphoma ALK+/ALK-, T-Cell and Natural Killer (NK)/T-Cell Lymphoma. The CNS WHO classification 2021 includes low-grade B-cell lymphoma of the CNS, ALK+/ALK-, T-Cell, and NK/T-cell lymphoma classified as miscellaneous, rare lymphomas in the CNS.² They represent a heterogeneous group of tumors with scarce evidence of concrete imaging findings. While low-grade B-cell lymphomas may occasionally appear as lymphoma-like lesions, other very different radiologic appearances are described, such as resembling edema, glial tumor, meningioma, and gliosis.⁴¹ Regarding anaplastic large-cell and T-cell or NK/T-cell lymphomas, some authors postulate that they may resemble lymphoma or lymphomatosis cerebri on imaging, with other nonspecific presentations also possible (Fig 7). In summary, very heterogeneous imaging presentations, occasionally resembling lymphoma, can be seen in this heterogeneous group of exceptional entities.⁴¹⁻⁴³

Lymphomatosis Cerebri. Lymphomatosis cerebri corresponds to a clinical-radiologic pattern that is not included as a concrete histopathologic WHO entity. It may be observed in the context of different histologic lymphoma subtypes, but in most cases, it corresponds to primary DLBCL of the CNS. The typical clinical presentation is a subacute onset of dementia, cognitive impairment, and personality changes.^{44,45}

It consists of a nonenhancing or scarcely-enhancing (30%) T2-FLAIR hyperintense infiltration of brain tissue. It is usually located in white matter regions, with different distributions ranging from focal to patched or diffuse. The main differential includes gliomatosis cerebri (also considered a radiologic pattern and not a WHO entity) and inflammatory and toxic-metabolic diseases. Of note, in this form of CNS lymphoma, brain lesions may be highly variable and change between near-in-time follow-up scans.⁴⁴⁻⁴⁷

In line with what was detailed in the intravascular lymphoma section, the detection of a tumoral pattern on ¹H-MR spectroscopy without relevant amount of mIns (potential glial marker present in gliomatosis) in abnormal areas of T2-FLAIR hyperintensity, as well as the above-described characteristic DSC-PWI pattern in the possible enhancing lesions, supports presurgical suspicion^{46,47} (Fig 5).

Secondary Lymphomas of the CNS. Secondary lymphoma refers to the CNS spread of lymphoma that originated elsewhere. It may be as an isolated recurrence or as a synchronic systemic disease with an overall incidence of around 5%–10% in patients with systemic lymphomas, usually non-Hodgkins. Its occurrence is directly correlated with pathologic aggressiveness and ranges from <3% in the indolent, less-aggressive histologies to as high as 50% in the very aggressive ones such as Burkitt lymphoma.⁴⁸

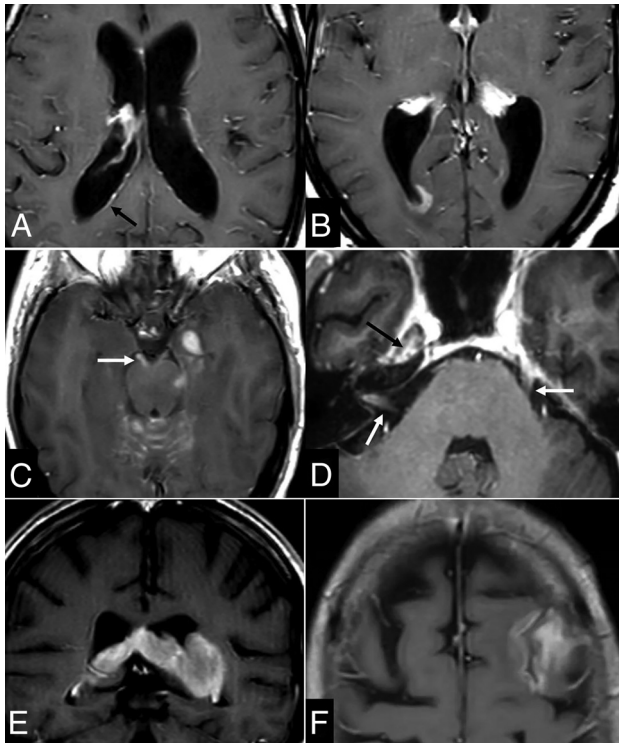


FIG 8. Imaging findings in secondary lymphomas of the CNS. A–B: Thin subtle linear (arrow in A) and nodular (B) subependymal enhancements. C–D: Prominent leptomenigeal disease along the superior vermis and cerebellar folia and third cranial nerve (arrow in C) as well as inside the right internal auditory canal—cranial nerves VII and VIII—and along the trigeminal nerve in the right Meckel cave and the left cisternal segment (arrows in D). Associated parenchymal mass in the left temporal lobe (C). E–F: Secondary lymphomas presenting as predominant intraparenchymal lesions with associated adjacent subependymal (E) and leptomenigeal (F) disease.

Although historically, it has been thought that secondary lymphomas presented with leptomenigeal involvement in a high proportion of cases (around 70%¹¹); more recent data differ, suggesting parenchymal involvement in 40%–60%, leptomenigeal in 20%–30%, and both in 10% (Fig 8).^{49,50} This higher proportion of parenchymal involvement in secondary lymphoma is important to consider in the radiologic interpretation because it is non-specific for differentiation from primary CNS lymphoma, in which parenchymal lesions are almost constant.¹¹ Despite these differing disease distributions, imaging can frequently overlap, and differentiation between primary and secondary must rely on other staging examinations, such as a PET/CT scan, bone marrow aspiration, testicular sonography, vitreal examination, and the patient's history of systemic lymphoma.^{48,50}

CONCLUSIONS

The classification of CNS lymphomas is evolving. The radiologist plays a key role in the initial management of lymphomas, and a failure to suggest the possibility of this diagnosis on initial imaging may have a negative clinical impact. For this reason, the radiologist needs to be aware of the full spectrum of imaging presentations of CNS lymphoma. In this sense, we note some key points:

- 1) Primary DLBCLs of the CNS present as homogeneous lesions, hyperdense on NECT, T2 hypointense, and with restricted diffusion. The presence of a certain degree of hemorrhage or signs of necrosis should not rule out their presurgical diagnosis.
- 2) Immunodeficiency-associated lymphomas (primary DLBCLs of the CNS, EBV-positive) appear as necrohemorrhagic tumors in potentially immunocompromised hosts. Special attention must be paid to the features of DSC-PWI, which may provide findings that suggest lymphoma.
- 3) Dural lymphoma should be suspected when a disproportionate soft-tissue mass without relevant bone destruction is identified in an extra-axial transdiploic tumor.
- 4) Intravascular lymphoma and lymphomatosis cerebri may be evolutive diagnoses of suspicion when dynamically changing T2-FLAIR areas of signal abnormality (and hemorrhage in intravascular lymphoma) are found. Also, attention must be paid to leptomenigeal and subependymal enhancement.
- 5) DSC-PWI and ¹H-MRS provide clues of great help in the differential diagnosis for each lymphoma subtype.
- 6) Secondary lymphomas often appear as parenchymal lesions. Isolated leptomenigeal or subependymal disease is characteristic but apparently less prevalent than formerly assumed.

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REFERENCES

1. Miller KD, Ostrom QT, Kruchko C, et al. **Brain and other central nervous system tumor statistics, 2021.** *CA Cancer J Clin* 2021;71:381–406 [CrossRef Medline](#)
2. World Health Organization. **Central Nervous System Tumors.** *WHO Classification of Tumours Online, 5th ed.* <https://tumourclassification.iarc.who.int/welcome/>. Accessed January 16, 2023
3. Velasco R, Mercadal S, Vidal N, et al; GELTAMO and GENOSEN Group. **Diagnostic delay and outcome in immunocompetent patients with primary central nervous system lymphoma in Spain: a multicentric study.** *J Neurooncol* 2020;148:545–54 [CrossRef Medline](#)
4. World Health Organization. **Hematolymphoid Tumours.** *WHO Classification of Tumours Online, 5th ed.* <https://tumourclassification.iarc.who.int/welcome/>. Accessed January 16, 2023
5. Tang YZ, Booth TC, Bhogal P, et al. **Imaging of primary central nervous system lymphoma.** *Clin Radiol* 2011;66:768–77 [CrossRef Medline](#)
6. Mansour A, Qandeel M, Abdel-Razeq H, et al. **MR imaging features of intracranial primary CNS lymphoma in immune competent patients.** *Cancer Imaging* 2014;14:1–9 [CrossRef Medline](#)
7. Pons-Escoda A, Garcia-Ruiz A, Naval-Baudin P, et al. **Presurgical identification of primary central nervous system lymphoma with normalized time-intensity curve: a pilot study of a new method to analyze DSC-PWI.** *AJNR Am J Neuroradiol* 2020;41:1816–24 [CrossRef Medline](#)
8. Pons-Escoda A, Garcia-Ruiz A, Naval-Baudin P, et al. **Diffuse large B-cell Epstein-Barr virus-positive primary CNS lymphoma in non-AIDS patients: high diagnostic accuracy of DSC perfusion metrics.** *AJNR Am J Neuroradiol* 2022;43:1567–74 [CrossRef Medline](#)
9. Cree IA. **The WHO Classification of Haematolymphoid Tumours.** *Leukemia* 2022;36:1701–02 [CrossRef Medline](#)
10. Li W. *The 5(th) Edition of the World Health Organization Classification of Hematolymphoid Tumors.* In: Li W, ed. Brisbane (AU) 2022

11. Haldorsen IS, Espeland A, Larsson E-M. **Central nervous system lymphoma: characteristic findings on traditional and advanced imaging.** *AJNR Am J Neuroradiol* 2011;32:984–92 [CrossRef Medline](#)
12. Deckert M, Brunn A, Montesinos-Rongen M, et al. **Primary lymphoma of the central nervous system: a diagnostic challenge.** *Hematol Oncol* 2014;32:57–67 [CrossRef Medline](#)
13. Brunn A, Nagel I, Montesinos-Rongen M, et al. **Frequent triple-hit expression of MYC, BCL2, and BCL6 in primary lymphoma of the central nervous system and absence of a favorable MYC(low)BCL2 (low) subgroup may underlie the inferior prognosis as compared to systemic diffuse large B cell lymphomas.** *Acta Neuropathol* 2013;126:603–05 [CrossRef Medline](#)
14. Jhaveri MD. **Chapter 173: diffuse large B-cell lymphoma.** In: Jhaveri MD, Osborn AG, Salzman KL. *Diagnostic Imaging: Brain*. 4th ed. Elsevier; 2020:602–06
15. Sakata A, Okada T, Yamamoto A, et al. **Primary central nervous system lymphoma: is absence of intratumoral hemorrhage a characteristic finding on MRI?** *Radiol Oncol* 2015;49:128–34 [CrossRef Medline](#)
16. Barajas RF, Politi LS, Anzalone N, et al. **Consensus recommendations for MRI and PET imaging of primary central nervous system lymphoma: guideline statement from the International Primary CNS Lymphoma Collaborative Group (IPCG).** *Neuro Oncol* 2021;23:1056–71 [CrossRef Medline](#)
17. Lee MD, Baird GL, Bell LC, et al. **Utility of percentage signal recovery and baseline signal in DSC-MRI optimized for relative CBV measurement for differentiating glioblastoma, lymphoma, metastasis, and meningioma.** *AJNR Am J Neuroradiol* 2019;40:1145–450 [CrossRef Medline](#)
18. Xing Z, You RX, Li J, et al. **Differentiation of primary central nervous system lymphomas from high-grade gliomas by rCBV and percentage of signal intensity recovery derived from dynamic susceptibility-weighted contrast-enhanced perfusion MR imaging.** *Clin Neuroradiol* 2014;24:329–36 [CrossRef Medline](#)
19. Valles FE, Perez-Valles CL, Regalado S, et al. **Combined diffusion and perfusion MR imaging as biomarkers of prognosis in immunocompetent patients with primary central nervous system lymphoma.** *AJNR Am J Neuroradiol* 2013;34:35–40 [CrossRef Medline](#)
20. Mora P, Majós C, Castañer S, et al. **1H-MRS is useful to reinforce the suspicion of primary central nervous system lymphoma prior to surgery.** *Eur Radiol* 2014;24:2895–905 [CrossRef Medline](#)
21. Hussein L, Saleh A, Reifenberger G, et al. **Inflammatory demyelinating brain lesions heralding primary CNS lymphoma.** *Can J Neurol Sci* 2012;39:6–10 [CrossRef Medline](#)
22. Levine AM. **Lymphoma complicating immunodeficiency disorders.** *Ann Oncol* 1994;5(Suppl 2):29–35 [CrossRef Medline](#)
23. Gandhi MK, Hoang T, Law SC, et al. **EBV-associated primary CNS lymphoma occurring after immunosuppression is a distinct immunobiological entity.** *Blood* 2021;137:1468–77 [CrossRef Medline](#)
24. Mahale P, Shiels MS, Lynch CF, et al. **Incidence and outcomes of primary central nervous system lymphoma in solid organ transplant recipients.** *Am J Transplant* 2018;18:453–61 [CrossRef Medline](#)
25. Verdu-Bou M, Tapia G, Hernandez-Rodriguez A, et al. **Clinical and therapeutic implications of Epstein-Barr virus in HIV-related lymphomas.** *Cancers (Basel)* 2021;13:5534 [CrossRef Medline](#)
26. Kaulen LD, Karschnia P, Dietrich J, et al. **Autoimmune disease-related primary CNS lymphoma: systematic review and meta-analysis.** *J Neurooncol* 2020;149:153–59 [CrossRef Medline](#)
27. Mancuso S, Carlisi M, Santoro M, et al. **Immunosenescence and lymphomagenesis.** *Immun Ageing* 2018;15:1–7 [CrossRef Medline](#)
28. Barosi G. **An immune dysregulation in MPN.** *Curr Hematol Malig Rep* 2014;9:331–39 [CrossRef Medline](#)
29. Suh CH, Kim HS, Lee SS, et al. **Atypical imaging features of primary central nervous system lymphoma that mimics glioblastoma: utility of intravoxel incoherent motion MR imaging.** *Radiology* 2014;272:504–13 [CrossRef Medline](#)
30. Sauter A, Faul C, Bitzer M, et al. **Imaging findings in immunosuppressed patients with Epstein Barr virus-related B cell malignant lymphoma.** *Am J Roentgenol* 2010;194:W141–49 [CrossRef Medline](#)
31. Patsalides AD, Atac G, Hedge U, et al. **Lymphomatoid granulomatosis: abnormalities of the brain at MR imaging.** *Radiology* 2005;237:265–73 [CrossRef Medline](#)
32. Tateishi U, Terae S, Ogata A, et al. **MR imaging of the brain in lymphomatoid granulomatosis.** *AJNR Am J Neuroradiol* 2001;22:1283–90 [Medline](#)
33. De Graaff HJ, Wattjes MP, Rozemuller-Kwakkel AJ, et al. **Fatal B-cell lymphoma following chronic lymphocytic inflammation with pontine perivascular enhancement responsive to steroids.** *JAMA Neurol* 2013;70:915–18 [CrossRef Medline](#)
34. Dang YL, Kok HK, McKelvie PA, et al. **Chronic lymphocytic infiltration with pontine perivascular enhancement responsive to steroids (CLIPPERS) and its association with Epstein-Barr virus (EBV)-related lymphomatoid granulomatosis: a case report.** *BMC Neurol* 2021;21:80 [CrossRef Medline](#)
35. Fonkem E, Dayawansa S, Stroberg E, et al. **Neurological presentations of intravascular lymphoma (IVL): meta-analysis of 654 patients.** *BMC Neurol* 2016;16:9 [CrossRef Medline](#)
36. Baehring JM, Henchcliffe C, Ledezma CJ, et al. **Intravascular lymphoma: magnetic resonance imaging correlates of disease dynamics within the central nervous system.** *J Neurol Neurosurg Psychiatry* 2005;76:540–44 [CrossRef Medline](#)
37. Yamamoto A, Kikuchi Y, Homma K, et al. **Characteristics of intravascular large B-cell lymphoma on cerebral MR imaging.** *AJNR Am J Neuroradiol* 2012;33:292–96 [CrossRef Medline](#)
38. Quinn ZL, Zakharia K, Schmid JL, et al. **Primary dural diffuse large B-cell lymphoma: a comprehensive review of survival and treatment outcomes.** *Clin Lymphoma Myeloma Leuk* 2020;20:e105–12 [CrossRef Medline](#)
39. Pons Escoda A, Naval Baudin P, Mora P, et al. **Imaging of skull vault tumors in adults.** *Insights Imaging* 2020;11:23 [CrossRef Medline](#)
40. Smith AB, Horkanyne-Szakaly I, Schroeder JW, et al. **From the Radiologic Pathology Archives: mass lesions of the dura—beyond meningioma, radiologic-pathologic correlation.** *Radiographics* 2014;34:295–312 [CrossRef Medline](#)
41. Jahnke K, Schilling A, Heidenreich J, et al. **Radiologic morphology of low-grade primary central nervous system lymphoma in immunocompetent patients.** *AJNR Am J Neuroradiol* 2005;26:2446–54 [Medline](#)
42. Magaki S, Satyadev R, Chen Z, et al. **Central nervous system ALK-negative anaplastic large cell lymphoma with IRF4/DUSP22 rearrangement.** *Brain Tumor Pathol* 2022;39:25–34 [CrossRef Medline](#)
43. Menon MP, Nicolae A, Meeker H, et al. **Primary CNS T-cell lymphomas: a clinical, morphologic, immunophenotypic, and molecular analysis.** *Am J Surg Pathol* 2015;39:1719–29 [CrossRef Medline](#)
44. Izquierdo C, Velasco R, Vidal N, et al. **Lymphomatosis cerebri: a rare form of primary central nervous system lymphoma: analysis of 7 cases and systematic review of the literature.** *Neuro Oncol* 2016;18:707–15 [CrossRef Medline](#)
45. Hatanpaa KJ, Fuda F, Koduru P, et al. **Lymphomatosis cerebri: a diagnostic challenge.** *JAMA Neurol* 2015;72:1066–67 [CrossRef Medline](#)
46. Li L, Rong JH, Feng J. **Neuroradiological features of lymphomatosis cerebri: a systematic review of the English literature with a new case report.** *Oncol Lett* 2018;16:1463–74 [CrossRef Medline](#)
47. Yu H, Gao B, Liu J, et al. **Lymphomatosis cerebri: a rare variant of primary central nervous system lymphoma and MR imaging features.** *Cancer Imaging* 2017;17:26 [CrossRef Medline](#)
48. Nagpal S, Glantz MJ, Recht L. **Treatment and prevention of secondary CNS lymphoma.** *Semin Neurol* 2010;30:263–72 [CrossRef Medline](#)
49. Ferreri AJM, Doorduijn JK, Re A, et al; International Extranodal Lymphoma Study Group (IELSG). **MATRIX-RICE therapy and autologous haematopoietic stem-cell transplantation in diffuse large B-cell lymphoma with secondary CNS involvement (MARIETTA): an international, single-arm, phase 2 trial.** *Lancet Haematol* 2021;8:e110–21 [CrossRef Medline](#)
50. Bobillo S, Khwaja J, Ferreri AJM, et al. **Prevention and management of secondary central nervous system lymphoma.** *Haematologica* 2022. Nov 17 [CrossRef Medline](#)