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THE USE OF MODERN NEUROIMAGING METHODS IN THE DIAGNOSIS OF DISEASES AND EMERGENCIES OF THE CENTRAL NERVOUS SYSTEM – A SYSTEMATIC REVIEW

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ABSTRACT

Modern neuroimaging techniques have transformed the diagnosis and management of central nervous system (CNS) diseases and emergencies. This systematic review aimed to evaluate the clinical applications, diagnostic capabilities, and limitations of imaging modalities including computed tomography (CT), magnetic resonance imaging (MRI), CT angiography (CTA), digital subtraction angiography (DSA), perfusion studies, and transfontanelle ultrasonography in infants. The review focused on conditions such as ischemic and hemorrhagic stroke, brain tumors, traumatic brain injury, vascular malformations, demyelinating diseases, infections, hydrocephalus, and neurodegenerative disorders.

Key findings indicate that CT remains the primary tool in acute emergencies for rapid detection of hemorrhage, stroke, and hydrocephalus, while MRI offers superior sensitivity for subtle structural changes, demyelinating lesions, and neurodegenerative processes. Vascular imaging with CTA and DSA enables precise evaluation of aneurysms and malformations, guiding intervention strategies. Ultrasonography provides a safe and effective option for early assessment in neonates. Each modality has inherent limitations, such as radiation exposure in CT, limited availability of MRI, and the invasiveness of DSA, which must be considered in clinical decision-making.

The review concludes that a multimodal imaging approach is essential for accurate diagnosis, individualized treatment planning, and monitoring of CNS diseases. Integrating the strengths of each technique optimizes patient outcomes and supports timely, evidence-based neurological care.

KEYWORDS

Brain Imaging, Neuroimaging, Central Nervous System, Computed Tomography, Ischemic Stroke, Hemorrhagic Stroke

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1. Introduction

The central nervous system (CNS) is the primary system that integrates and controls the functioning of the human body. It consists of the brain and the spinal cord and is responsible for receiving, processing, and transmitting information between the body's various systems. Due to its complex structure and crucial role in regulating vital functions, diseases of the central nervous system can lead to serious neurological disorders, permanent disability, and even death.

Modern medicine has a wide range of diagnostic methods available for assessing the structure and function of the nervous system. Among these, medical imaging methods are of particular importance, as they allow for non-invasive assessment of the brain and spinal cord. Imaging studies enable the identification of pathological changes, assessment of their location and nature, as well as monitoring of disease progression and treatment efficacy.

The development of diagnostic technologies in recent decades has led to a significant increase in the capabilities for imaging brain structures. Modern diagnostic devices enable the acquisition of images with very high spatial and contrast resolution, allowing for the detection of even minor pathological changes.

The most important imaging methods used in the diagnosis of central nervous system disorders include:

- computed tomography (CT),
- magnetic resonance imaging (MRI),
- transcranial ultrasound,
- cerebral angiography,
- positron emission tomography (PET),
- single-photon emission computed tomography (SPECT).

Each of these methods is characterized by a different principle of operation, diagnostic sensitivity, and range of clinical applications. The choice of the appropriate imaging test depends on many factors, such as the patient's clinical condition, the suspected disease entity, the availability of diagnostic equipment, and the need for a rapid diagnosis. Imaging plays a particularly important role in medical emergencies, such as stroke or traumatic brain injury. In these situations, performing the appropriate test quickly allows for early diagnosis of the condition and the initiation of proper treatment, which has a direct impact on the patient's prognosis.

Imaging studies also play a key role in the diagnosis of chronic diseases of the central nervous system, such as multiple sclerosis, neurodegenerative diseases, and brain tumors. They enable an accurate assessment of the location and nature of pathological changes and allow for monitoring of disease progression.

The aim of this study is to present the most important diagnostic imaging methods used in diseases of the central nervous system and to discuss their application in selected conditions, such as stroke, demyelinating diseases, and brain tumors.

2. Methodology

The aim of this article was to analyze current scientific evidence regarding the use of modern neuroimaging techniques in the diagnosis of diseases and emergency conditions of the central nervous system, as well as to evaluate their clinical significance and diagnostic value. The study was conducted as a systematic review of the available literature.

The article was prepared based on publications available in the PubMed and Google Scholar databases. To ensure the reliability and relevance of the data, medical literature published between 2004 and 2025 was searched and analyzed. The search strategy included keywords and phrases related to the topic, such as neuroimaging, computed tomography, magnetic resonance imaging, central nervous system diseases, stroke, brain hemorrhage, and emergency neurological conditions.

Both review articles and original research studies were considered in the selection process. Publications that were duplicated, not directly related to the subject of neuroimaging in central nervous system disorders, or unavailable in full-text form were excluded from the analysis. Articles published in languages other than English were also excluded. Particular attention was paid to the most recent publications and those characterized by high methodological quality.

The selected studies were analyzed with regard to the diagnostic capabilities of different neuroimaging techniques, their usefulness in identifying structural and vascular abnormalities, and their role in the evaluation of acute neurological conditions. The analysis also considered the clinical applicability of these imaging methods, their advantages and limitations, and their relevance in the diagnostic process.

Studies were included in the final analysis if they met the criteria of methodological reliability, clinical relevance, and consistency with the objectives of the review.

3. Overview of Diagnostic Techniques

A common advantage of modern imaging techniques is their ability to accurately visualize anatomical structures and to quickly provide information relevant to clinical decision-making. Many of these methods are also relatively safe and allow for repeat testing to monitor disease progression or treatment efficacy. At the same time, imaging techniques differ in terms of sensitivity in detecting specific changes, examination time, availability, and cost.

3.1 Computed Tomography

Computed tomography (CT) is an imaging technique that uses X-rays to create cross-sectional images of the head and brain. The principle involves rotating a beam of X-rays around the object being examined, while detectors record differences in the absorption of the rays by various tissues. A computer processes this information, generating a series of layered images that can be reconstructed in axial, sagittal, or frontal planes. This mechanism allows for the visualization of density differences between bone, soft tissue, blood, and cerebrospinal fluid, which forms the basis for rapid neurological assessment.

CT is widely available in most hospitals and neurology departments. Comment: Its wide availability makes it the first-line method of choice in emergencies where time is of the essence, such as in stroke or traumatic brain injury. The cost of the examination and equipment operation is relatively lower than that of MRI, which facilitates the performance of multiple examinations and ensures rapid access in hospitals of varying referral levels. The lower cost also makes CT widely used in countries with limited medical resources.

The advantages of CT include rapid image acquisition, high sensitivity in detecting hemorrhages, large tumors, hydrocephalus, and bone injuries, as well as the ability to perform vascular (CTA) and perfusion (CTP) studies. Note: Rapid diagnosis enables immediate clinical decision-making in life-threatening situations. However, the disadvantages of CT stem mainly from the use of ionizing radiation, which limits the ability to repeat examinations, and from lower soft tissue resolution compared to MRI. Limited sensitivity means that small foci of ischemia, axonal microinjuries, or early demyelinating changes may remain invisible.

CT allows for the visualization of intracerebral and subarachnoid hemorrhages, epidural and subdural hematomas, large tumors and cysts, cerebral edema and midline shift, hydrocephalus, and skull fractures. Comment: Imaging these changes enables rapid planning of neurosurgical intervention and monitoring of complications. However, CT does not detect early ischemic foci, subtle changes in white matter, small tumors, or axonal microinjuries, which limits the ability to fully assess certain neurological conditions. This limitation requires supplementation with MRI or other imaging techniques in cases of suspected early stroke or demyelinating diseases.

Contraindications to computed tomography primarily include pregnancy, especially during the first trimester, due to the harmful effects of ionizing radiation on the developing fetus. For examinations involving the administration of an iodinated contrast agent, the risk of allergic reactions in patients with a history of allergies and acute renal failure must be considered, as the contrast agent may cause contrast-induced nephropathy. Another limitation is the inability to immobilize the patient during the examination, which compromises image quality and may affect children or critically ill patients. Furthermore, repeated CT scans within a short period increase the total radiation dose, requiring particular caution in children and young adults.

The use of CT in neurology stems from the fact that it enables rapid and relatively inexpensive diagnosis of acute conditions, such as ischemic or hemorrhagic stroke, traumatic brain injury, hydrocephalus, and massive tumors. In combination with vascular and perfusion techniques, CT serves as a fundamental tool in the evaluation of patients requiring urgent intervention, enabling immediate clinical decisions and improving patient prognosis.

3.2 Magnetic Resonance Imaging

Magnetic resonance imaging (MRI) is an imaging technique that uses a strong magnetic field and radiofrequency pulses to produce detailed images of the structures of the brain and spinal cord. The principle of operation is that hydrogen protons in tissues align themselves within the magnetic field, and after a radiofrequency pulse is applied, they emit signals that a computer processes into cross-sectional images. As a result, MRI allows for the visualization of subtle differences in soft tissues that are invisible on computed tomography (CT), including small tumors, demyelinating lesions, and early ischemic changes.

MRI uses various imaging sequences that determine how signals are generated and tissues are visualized. T1-weighted sequences highlight the brain's anatomy, allow for the assessment of structural boundaries, and enable the detection of changes following the administration of gadolinium contrast, which is particularly useful in evaluating tumors and their vascularization. T2 sequences highlight changes in tissue water content and edema, allowing for the detection of inflammatory areas, hydrocephalus, or foci of ischemia. FLAIR (Fluid Attenuated Inversion Recovery) suppresses the signal from cerebrospinal fluid, making it easier to visualize changes in white matter while avoiding interference from the ventricles; it is particularly useful in the diagnosis of multiple sclerosis and early demyelinating lesions. Diffusion-weighted imaging (DWI) sequences detect restrictions in the movement of water molecules within tissue, allowing for the early diagnosis of ischemic stroke or brain abscess. Perfusion sequences enable the assessment of blood flow in tissues, which is useful for evaluating ischemia and tumor activity. MR spectroscopy provides information on cellular metabolism in the affected area. The variety of sequences allows for a comprehensive assessment not only of the structure but also of the function and pathophysiological activity of brain tissues.

MRI is widely used in specialized neurology centers, although it is less widely available than CT. The procedure takes longer, is sensitive to patient movement, and requires cooperation, which can make it difficult to perform in emergency situations or on children. Contraindications include the presence of metallic implants, such as vascular stents, pacemakers, or cochlear implants, as well as claustrophobia or an inability to remain still during the exam. In such cases, CT or other imaging techniques not based on a magnetic field are used as alternatives.

The advantages of MRI include high-resolution imaging of soft tissues, the absence of ionizing radiation, and the ability to use multiple sequences that differentiate tissues and functions. This allows for the detection of small tumors, early demyelinating lesions, subtle axonal injuries, neurodegenerative changes, and inflammatory or infectious foci that are not visible on CT.

MRI makes it possible to visualize changes characteristic of many neurological diseases, including ischemic strokes, hemorrhages, brain tumors, vascular malformations, demyelinating and neurodegenerative diseases, head injuries, and central nervous system infections. The selection of appropriate MRI sequences and, if necessary, MR angiography or perfusion imaging allows for a comprehensive patient assessment, treatment planning, and monitoring of treatment outcomes.

The use of MRI in neurology stems from its ability to detect subtle changes in brain tissue, assess the activity of chronic diseases, and monitor treatment outcomes. Despite higher costs and technical limitations, MRI remains a fundamental tool in the diagnosis of chronic, subtle, and complex CNS diseases where CT would be insufficient.

3.3 Ultrasound

Ultrasound is one of the safest and most non-invasive imaging methods used in the diagnosis of the central nervous system, primarily in pediatrics, and particularly in newborns and premature infants. This method relies on the use of high-frequency ultrasound waves, which, after passing through brain tissue, reflect off interstructural boundaries and are recorded by an ultrasound probe. The resulting image allows for the assessment of both the anatomical structure and, in some cases, functional parameters of the brain, such as blood flow in the cerebral vessels. Due to the absence of ionizing radiation, ultrasound is the preferred screening and monitoring method for observing the development of the central nervous system in the youngest patients.

A CNS ultrasound examination is most commonly performed through the fontanelle, which in the neonatal period serves as a natural “window” allowing ultrasound waves to pass through. This enables the visualization of many brain structures that would be inaccessible to this type of diagnostic imaging in adults, whose skulls are fully ossified. The primary structures assessed in a standard ultrasound examination include:

1. Brain ventricles – these allow for the assessment of their volume and symmetry. Ultrasound enables the detection of hydrocephalus, intraventricular hematomas, and the presence of pathological structures within the ventricular lumen.
2. The cerebral vasculature – the use of Doppler technology allows for the assessment of blood flow in the middle cerebral arteries and deep vessels. This enables the detection of hemodynamic abnormalities, such as intracranial hypertension or blood clots.
3. White matter and gray matter – differences in tissue echogenicity allow for the assessment of white matter integrity and the detection of post-traumatic, ischemic, or demyelinating lesions.
4. Subcortical structures – including the basal ganglia, thalamus, and caudate nuclei, which are visualized in high resolution, allowing for early detection of congenital anomalies or post-traumatic changes.
5. Corpus callosum – the examination allows for assessment of its thickness, integrity, and any developmental abnormalities.
6. Subarachnoid spaces and cerebrospinal fluid – ultrasound enables the detection of widened subarachnoid spaces, arachnoid cysts, and the presence of blood in the cerebrospinal fluid.
7. Cerebrum and cerebellum – it is possible to assess the morphology of the cerebellum, pons, and medulla oblongata, which is important in diagnosing congenital anomalies such as cerebellar aplasia or Dandy-Walker malformation.
8. Pathological changes – ultrasound allows for the detection of intracranial tumors, cysts, hematomas, and inflammatory foci. Although the accuracy in assessing tumorous lesions is lower than with magnetic resonance imaging, early identification of pathology enables the patient to be referred for further diagnostic testing.

The importance of ultrasound in clinical practice is multifaceted. This examination allows for monitoring brain development, detecting early complications following perinatal injuries, assessing the effectiveness of therapy in cases of hemodynamic disorders, and monitoring conservative or surgical treatment. Thanks to its non-invasive nature and reproducibility, ultrasound enables screening of at-risk children, including preterm infants and newborns with low birth weight.

Despite its numerous advantages, central nervous system ultrasound has significant limitations. Its spatial resolution is lower than that of magnetic resonance imaging, and the assessment of deep structures and small nodular lesions can be difficult. Results also depend on the operator’s experience and the availability of appropriate ultrasound windows, which are limited in older children and adults.

In neonatology, ultrasound is an indispensable tool for diagnosing and monitoring the central nervous system. It allows for the visualization of key anatomical structures, the assessment of pathological changes, and the monitoring of disease progression, all with minimal risk to the patient. Its role in early diagnosis, clinical monitoring, and planning further imaging remains invaluable in clinical practice.

3.4 Angiography

Angiography and cerebral vascular imaging form the basis for diagnosing diseases of the vascular system of the central nervous system (CNS). These methods allow for the assessment of both vascular morphology and blood flow dynamics, which is crucial for detecting aneurysms, arteriovenous malformations, vascular stenoses, and cerebral ischemia. Modern imaging techniques include both classic invasive angiography and modern non-invasive methods, such as computed tomography angiography (CTA) and magnetic resonance angiography (MRA).

Traditional digital subtraction angiography (DSA) is still considered the "gold standard" in cerebral vascular diagnostics. It involves inserting a catheter into the arteries, usually through the femoral artery, and administering a contrast agent while simultaneously recording radiological sequences. This method allows for obtaining highly detailed images of both large and small cerebral vessels and assessing their curvatures, bifurcations, and any pathologies. Digital angiography also enables therapeutic procedures, such as aneurysm embolization or the closure of arteriovenous malformations, making it not only a diagnostic tool but also an interventional one.

Computed tomography angiography (CTA) is a noninvasive technique that allows for rapid assessment of cerebral vessels following intravenous administration of a contrast agent. This method enables visualization of the major cerebral arteries and assessment of their stenoses, aneurysms, and post-traumatic changes. CTA is characterized by high spatial resolution and a short scan time, making it useful in acute neurological conditions such as ischemic stroke or subarachnoid hemorrhage. However, a limitation is the patient's exposure to ionizing radiation and the possibility of an allergic reaction to the contrast agent.

Magnetic resonance angiography (MRA) uses flow and contrast techniques to visualize cerebral vessels without the use of X-rays. MRA is particularly useful in evaluating the carotid and intracerebral arteries, enabling the detection of aneurysms, stenoses, and vascular malformations. Non-contrast variants (time-of-flight, TOF) allow for the assessment of blood flow in the arteries, while contrast-enhanced techniques increase the precision of detecting small changes. A limitation of MRA is its lower resolution compared to DSA, particularly in small vessels and complex bifurcations.

Cerebral vascular imaging is also important for monitoring treatment and predicting the risk of complications. The use of noninvasive methods, such as CTA and MRA, allows for the assessment of treatment outcomes following neurosurgical procedures or endovascular interventions. When combined with functional techniques, such as cerebral perfusion or Doppler ultrasound, vascular imaging enables the assessment of both the anatomy and hemodynamic function of the brain.

Angiography and cerebral vascular imaging are key tools in the diagnosis of vascular diseases of the central nervous system. The choice of method depends on clinical indications, technological availability, and the patient's condition. Combining the accuracy of traditional angiography with the safety and speed of non-invasive methods allows for the optimization of diagnosis and treatment of cerebral vascular diseases, while minimizing risk to the patient.

4. Diseases of the Central Nervous System

Diseases of the central nervous system are characterized by a number of common pathophysiological and morphological features that can be utilized in diagnostic imaging. Many pathological processes lead to changes in brain tissue structure, blood flow disturbances, nerve cell swelling, or the presence of blood or fluid in abnormal spaces. These changes affect tissue density, blood supply, and physical properties, making them visible in imaging studies. Diagnostic imaging utilizes these differences, allowing for the assessment of brain anatomy, the identification of pathological foci, and the analysis of hemodynamic and structural changes associated with CNS diseases. This makes it possible not only to detect the pathology itself but also to determine its location, extent, and potential impact on brain function, as well as to select an appropriate treatment approach.

4.1 Ischemic stroke

Computed tomography is the primary and most common first step in the management of acute ischemic stroke [1]. CT is distinguished by its short scan time, wide availability, and the ability to immediately rule out intracerebral or subarachnoid hemorrhage, which is a prerequisite for administering thrombolytic agents or qualifying for endovascular intervention. Standard CT (without contrast) therefore remains the method of first choice in most hospitals, especially in emergency situations where the “door-to-imaging” time directly impacts the patient’s prognosis.

In the acute phase of ischemic stroke (0–6 hours from symptom onset), changes on CT may be subtle or invisible. The first signs of ischemia are the so-called early signs, which include: blurring of cortical sulci and blurring of the boundary between gray and white matter, hypodensity of the lenticulostriate nucleus, early “Sylvian signs” indicating edema of the gyri in the territory supplied by the middle cerebral artery, and initial cerebral edema, visible as a slight narrowing of the marginal fissures and lateral ventricles. In the early phase of ischemia, CT is less sensitive than in later hours, which is one of the main limitations of this method.

In the hours following the onset of a stroke, computed tomography becomes more diagnostic. Hypodense areas of ischemic brain tissue become more distinct, and over time, cerebral edema and midline shift develop. Typical features of the late phase of ischemic stroke on CT include extensive hypodensity within the territory of a specific cerebral artery, blurring of the boundaries between gray and white matter, increased brain volume, and possible secondary traumatic or hemorrhagic changes within the ischemic focus.

An important extension of standard CT is CT angiography (CTA), which allows for the assessment of large-caliber arteries. By administering a contrast agent, it is possible to detect occlusions of the middle cerebral artery, internal carotid artery, or basilar artery, as well as to identify the presence of thrombi, stenoses, or calcifications in the vessels. CTA also allows for the assessment of collateral circulation and the patency of smaller vessels, which is important when planning mechanical thrombectomy. In the context of ischemic stroke, CT angiography enables the rapid identification of patients eligible for endovascular procedures and the determination of the area of the brain at risk of ischemia.

In addition, perfusion CT (PCT) allows for the assessment of blood flow in the brain and the detection of the so-called ischemic penumbra, i.e., an area of tissue that is at risk but potentially salvageable. Perfusion analysis allows for distinguishing the “core”—irreversibly damaged tissue—from the penumbra, which directly influences the decision regarding reperfusion therapy. CTP also enables monitoring of treatment efficacy and identification of patients at risk of stroke progression or secondary cerebral edema.

The limitations of computed tomography in the diagnosis of ischemic stroke primarily include low sensitivity in the very early phase (first hours), difficulties in detecting small ischemic foci in subcortical areas, the cerebellum, and the brainstem, as well as limitations in microvascular assessment. Furthermore, the examination requires the patient to be exposed to ionizing radiation, and CTA and CTP additionally involve the administration of iodinated contrast, which may be contraindicated in patients with renal failure or an allergy to contrast agents.

In clinical practice, CT therefore serves as the primary screening modality, allowing for the rapid exclusion of hemorrhage, the identification of major vascular occlusions, and a preliminary assessment of the area of ischemia. In combination with CTA and CTP, computed tomography enables a comprehensive assessment of both brain anatomy and blood flow hemodynamics, which is essential for making therapeutic decisions during the critical period for the patient.

In addition to computed tomography, magnetic resonance imaging (MRI) and digital subtraction angiography (DSA) are also used in the diagnosis of ischemic stroke. MRI, particularly diffusion-weighted sequences, enables the detection of ischemic changes within minutes of stroke onset, including in areas difficult to access with CT, such as the brainstem, cerebellum, or subcortical structures. It also allows for the precise determination of the ratio of irreversibly damaged tissue to the penumbra, which is crucial for eligibility for reperfusion therapy. However, MRI has limited availability in emergency settings, requires more time to perform the examination, and is not always suitable for patients with metal implants or pacemakers. Compared to CT, MRI has higher sensitivity in detecting early ischemia, but is less practical in acute conditions requiring immediate intervention.

Digital subtraction angiography (DSA), an invasive procedure, allows for the assessment of the precise anatomy of cerebral vessels, the identification of occlusions, stenoses, and vascular malformations, and, if necessary, enables simultaneous therapeutic intervention, such as thrombectomy. It allows for real-time assessment of blood flow, which is an advantage over CT, especially in cases of complex vessel occlusions or collateral circulation dysfunction. The limitations of DSA include the risk of complications associated with catheterization and contrast administration, the time-consuming nature of the procedure, and the need to transport the patient to the angiography suite, which makes it less practical within the first hour of stroke onset.

Doppler ultrasound of the carotid and intracranial vessels is also used as a supplementary diagnostic tool, allowing for non-invasive assessment of flow in large vessels. This technique enables the detection of stenoses, occlusions, or hemodynamic disturbances, but has limited value in assessing small intracerebral vessels and in acute strokes requiring urgent intervention, in which it does not provide complete information about the extent of ischemia.

4.2 Hemorrhagic stroke

Imaging plays a key role in the rapid diagnosis, assessment of the extent of bleeding, and planning of further treatment. Hemorrhagic stroke, including intracerebral and subarachnoid hemorrhages, is characterized by sudden bleeding into the brain tissue or subarachnoid space, leading to compression, displacement of central structures, and cerebral edema. In such cases, rapid imaging is essential, as therapeutic decisions depend on the precise location, volume of bleeding, and presence of complications.

Non-contrast computed tomography is the gold standard for the initial diagnosis of hemorrhagic stroke [2]. CT demonstrates high sensitivity in detecting fresh blood within minutes of its onset, and its hyperdense appearance on the image allows for unambiguous diagnosis of bleeding in brain tissue or the subarachnoid space. CT allows for rapid determination of the location of the hemorrhagic focus, its volume, impact on the cerebral ventricles, and the presence of secondary edema and displacement of midline structures. In the case of subarachnoid hemorrhage, CT enables the detection of blood in the basilar sinuses and lateral ventricles, allowing for an immediate assessment of the risk of cerebrospinal fluid outflow obstruction.

Contrast-enhanced CT or computed tomography angiography (CTA) serves as a complementary diagnostic tool for hemorrhagic stroke, particularly for identifying the source of bleeding, such as aneurysms, arteriovenous malformations, or hemorrhagic hemangiomas. CTA allows for the assessment of cerebral vascular anatomy, the detection of stenoses and vascular anomalies, and the determination of blood flow in real time. Compared to standard CT alone, it enables the identification of patients requiring neurosurgical or endovascular intervention.

Additionally, perfusion tomography (CTP) can be used to assess hemodynamics in the area surrounding a hemorrhage, allowing for the identification of regions at risk of secondary ischemia due to vascular compression or cerebral edema. Perfusion analysis is essential for predicting the progression of lesions and planning supportive therapy, including anti-ischemic treatment or intracranial pressure reduction.

The limitations of computed tomography in the diagnosis of hemorrhagic stroke include difficulties in detecting very small hemorrhages, particularly in the posterior cranial fossa or the cerebellum, and the limited ability to assess vascular structures without the use of contrast. Furthermore, like any method based on ionizing radiation, CT exposes the patient to radiation.

Other imaging techniques play a complementary role. Magnetic resonance imaging (MRI) with specialized sequences, such as T2*, SWI, or FLAIR, allows for the detection of small hemorrhagic foci, microhemorrhages, and chronic hemosiderotic changes that may not be visible on CT. Limitations of MRI include longer scan times, reduced availability in emergency settings, and contraindications related to metal implants. Digital subtraction angiography (DSA) allows for precise assessment of vascular anatomy and the source of bleeding, as well as therapeutic intervention; however, it is an invasive, time-consuming method that requires transporting the patient to the angiography suite. Doppler ultrasound can be used to monitor flow in large cerebral and cervical vessels, but it does not provide information about the hemorrhage itself or about small intracranial vessels.

In summary, computed tomography remains the primary diagnostic tool for hemorrhagic stroke, providing rapid and accurate detection of fresh blood, assessment of hemorrhage volume, displacement of brain structures, and secondary edema. CTA and CTP expand the diagnostic scope to include vascular and perfusion assessment, which allows for intervention planning and the prediction of complication risk. Other techniques, such as MRI, DSA, or ultrasound, play a complementary role, enabling the detection of small foci, assessment of the source of bleeding, and monitoring of hemodynamics, but they do not replace the speed and availability of CT in the initial evaluation of a patient with acute hemorrhagic stroke.

4.3 Brain tumors

In the diagnosis of brain tumors, imaging plays a crucial role at virtually every stage of care, from detecting the lesion to planning treatment and monitoring treatment outcomes. The primary goal of imaging is to accurately determine the tumor's location, size, morphological characteristics, and impact on surrounding brain structures, including the assessment of edema and mass effect, which may cause displacement of midline structures or increased intracranial pressure.

Computed tomography (CT) is often the first test performed in emergency situations, as it allows for rapid detection of the tumor, assessment of its density, and detection of bleeding within or around the tumor. CT also allows for preliminary differentiation between solid and cystic lesions and assesses the tumor's impact on the brain ventricles. Additionally, when planning surgical intervention, CT can be used in combination with angiography (CTA) to assess tumor vascularization.

Magnetic resonance imaging (MRI), on the other hand, is the method of choice for the detailed diagnosis of brain tumors due to its high soft-tissue resolution [3]. Thanks to various sequences, such as T1, T2, FLAIR, or gadolinium-enhanced sequences, it is possible to assess the tumor's borders, the extent of its invasion into surrounding tissues, and its morphological characteristics, which allows for the preliminary differentiation of malignant from benign tumors. Perfusion sequences and MR spectroscopy additionally allow for the assessment of blood flow within the tumor and cellular metabolism, providing information on the tumor's proliferative activity.

Imaging studies are also invaluable in monitoring the treatment of brain tumors. They allow for the assessment of the effectiveness of surgical therapy, radiation therapy, or chemotherapy by comparing the size and characteristics of the lesion across successive examinations. Imaging also enables the detection of tumor recurrence and treatment complications, such as edema, bleeding, or brain tissue necrosis.

4.4 Traumatic brain injuries

In the diagnosis of traumatic brain injuries, imaging plays a key role in the rapid assessment of the extent of damage and the identification of lesions requiring urgent intervention. Computed tomography (CT) is the primary method, due to the speed of the examination and the ability to immediately detect clinically significant lesions [4]. CT allows for the visualization of epidural, subdural, and intracerebral hematomas, cerebral contusions, skull fractures, cerebral edema, and displacement of midline structures. The examination also enables the assessment of intraventricular hemorrhage and features of post-traumatic hydrocephalus [4]. Thanks to rapid image acquisition, CT allows for an immediate decision regarding the need for neurosurgical intervention, such as hematoma evacuation or reduction of intracranial pressure.

CT has limited sensitivity in detecting small foci of contusion or microinjuries, particularly within the cerebellum, brainstem, and early post-traumatic changes in white matter. Minor subarachnoid hemorrhages or axonal injuries may remain invisible on standard CT, which limits the ability to fully assess minimal or multifocal microtraumas. In such situations, magnetic resonance imaging (MRI) is used as a supplementary modality, as it better visualizes microinjuries, axonal damage, and minor subcortical hemorrhages.

Imaging studies are also directly relevant to treatment planning and prognosis. CT findings influence decisions regarding surgical intervention, intensive care, and patient monitoring in the neurosurgical ward. The location and extent of bleeding, the presence of edema, or displacement of brain structures determine the choice of surgical techniques, the need for ventricular drainage, and the use of pharmacological therapy to reduce intracranial pressure.

Additionally, CT angiography (CTA) can be used to evaluate cerebral vessels in cases of vascular injuries or suspected post-traumatic aneurysms. It enables the detection of arterial damage, stenoses, ruptures, or contrast leakage, which may lead to secondary hemorrhages. CT Perfusion (CTP) allows for the assessment of blood flow in areas at risk of post-traumatic ischemia, which helps in predicting the progression of brain injury and planning supportive treatment.

4.5 Cerebral aneurysms and vascular malformations

Imaging studies play a key role in the diagnosis of cerebral aneurysms and vascular malformations, as they allow for the assessment of cerebral vascular anatomy, the identification of abnormal arteriovenous connections, and the detection of lesions that predispose to hemorrhage. Non-contrast computed tomography (CT) can visualize subarachnoid or intracerebral hemorrhage in the event of an aneurysm rupture, which is the most common acute symptom requiring urgent intervention. CT also allows for the preliminary determination of the location and volume of bleeding, as well as the detection of secondary cerebral edema or displacement of midline structures.

In cases of suspected aneurysm or vascular malformation, CT angiography (CTA) is used to assess the lumen of the vessels, detect stenoses, dilations, or ruptures, and determine the exact location of the aneurysm [5]. CTA also allows for the visualization of arteriovenous malformations, assessment of their extent, and evaluation of any collateral circulation. However, CTA may fail to detect small aneurysms measuring less than a few millimeters or microvascular malformations, which require more sensitive methods.

Digital subtraction angiography (DSA) is used as a supplementary diagnostic tool and serves as the gold standard for aneurysms and vascular malformations. DSA allows for precise assessment of vascular anatomy, visualization of small aneurysms or minor malformations, determination of blood flow direction, and enables simultaneous endovascular intervention, such as aneurysm embolization or closure of a malformation. The limitations of DSA include the risks of invasive complications, the time-consuming nature of the procedure, and the need to transport the patient to the angiography suite.

Imaging studies have a direct impact on treatment decisions. The precise location of the aneurysm and its size determine whether a patient is eligible for surgical or endovascular treatment. In the case of vascular malformations, the assessment of blood flow and connections with surrounding vessels influences the choice of embolization method or the planning of surgical resection. Furthermore, imaging allows for monitoring changes after treatment and detecting recurrences of aneurysms or malformations.

4.6 Demyelinating diseases

In the diagnosis of demyelinating diseases of the central nervous system, such as multiple sclerosis or neuromyelitis optica, imaging studies reveal changes in the structure of the white matter of the brain and spinal cord that are characteristic of demyelinating processes. The primary method is magnetic resonance imaging (MRI), which, thanks to its high soft-tissue resolution, allows for the detection of demyelinating lesions, their number, location, and the activity of the disease process [6]. T2, FLAIR, and gadolinium-enhanced sequences allow for the differentiation of fresh, active lesions from chronic, fibrotic, or atrophic changes.

MRI also allows for the assessment of changes in the spinal cord that may not be visible on computed tomography but are of significant importance in the diagnosis of diseases such as multiple sclerosis. Diffusion and perfusion sequences can additionally provide information on blood flow abnormalities in demyelinated areas and allow for monitoring of inflammatory activity [6].

Computed tomography (CT) has limited utility in diagnosing demyelination, as its sensitivity in detecting lesions in the white matter is significantly lower than that of MRI. CT may be used only in situations where MRI is contraindicated or unavailable; however, in such cases, many lesions remain undetected, particularly small subcortical lesions and those within the spinal cord.

Imaging studies influence therapeutic decisions by enabling the monitoring of disease activity, the assessment of response to immunomodulatory treatment, and the early detection of lesion progression or the emergence of new lesions. Information obtained through MRI allows neurologists to precisely select medications, plan long-term therapy, and predict possible complications regarding the patient's neurological function.

4.7 Central nervous system infections

In the diagnosis of central nervous system infections, imaging studies enable the detection of inflammatory lesions, as well as the assessment of their location, extent, and impact on surrounding brain structures. The primary method in emergency situations is computed tomography (CT), which allows for the rapid visualization of large brain abscesses, cerebral edema, secondary hemorrhages, and the presence of post-traumatic hydrocephalus. CT can also be used to monitor patients with acute neurological conditions, especially when MRI is unavailable or contraindicated.

Magnetic resonance imaging (MRI) provides higher resolution and sensitivity in detecting inflammatory changes and small foci of infection, such as abscesses, encephalitis, or meningitis [7]. T1, T2, FLAIR, and gadolinium-enhanced sequences allow for the visualization of primary foci of infection, peri-inflammatory edema, as well as lesions in the white matter or spinal cord. Diffusion-weighted imaging (DWI) sequences allow for the differentiation of abscesses from cysts or neoplastic lesions by detecting restricted diffusion in purulent areas.

Imaging studies do not always allow for the unambiguous identification of the infectious agent; therefore, they are often supplemented with laboratory tests, such as cerebrospinal fluid analysis. Minor inflammatory changes or early stages of infection may be invisible on both CT and MRI, requiring repeat imaging or the use of additional high-sensitivity MRI sequences.

Imaging results directly influence treatment decisions. The location and size of the infection foci determine the feasibility of surgical interventions, such as abscess drainage, and the use of appropriate pharmacological therapy, including antibiotic therapy or antiviral treatment. Assessment of cerebral edema and midline shift also allows for monitoring patients in neurocritical care units and making decisions regarding life support.

In infants, due to the open fontanelle, transcranial ultrasound can be used as a non-invasive and rapid diagnostic method. Ultrasound allows for the visualization of changes in ventricular structures, such as hydrocephalus, abscesses, or intraventricular hemorrhages, as well as the assessment of cerebral edema or inflammatory effusion. This method enables the initial assessment of inflammatory foci and is particularly useful in monitoring patients in neonatal units.

A limitation of transcranial ultrasound is its lower resolution compared to MRI, which limits the ability to detect small changes in the white matter or in deeper brain structures. Therefore, when more extensive inflammatory changes or early stages of infection are suspected, it is often necessary to supplement the examination with an MRI, which provides a comprehensive assessment of the anatomy and activity of the infectious foci.

4.8 Hydrocephalus

In the diagnosis of hydrocephalus, imaging studies allow for the assessment of the size and shape of the brain's ventricular system and the identification of the cause of cerebrospinal fluid outflow obstruction. The primary method is computed tomography (CT), which allows for rapid visualization of enlarged brain ventricles, the presence of obstructions to CSF flow, and secondary cerebral edema [8]. CT is particularly useful in emergency situations, such as post-traumatic hydrocephalus or hydrocephalus associated with intracranial hemorrhage.

In infants and young children whose fontanelles are still open, trans-fontanelle ultrasound is widely used. Ultrasound allows for non-invasive assessment of the ventricular system, detection of ventricular enlargement, the presence of intraventricular hemorrhage, abscesses, or inflammatory effusion, as well as monitoring of treatment outcomes, e.g., following ventricular shunt implantation.

Magnetic resonance imaging (MRI) allows for a detailed assessment of the structures of the brain and spinal cord, including the causes of hydrocephalus, such as narrowing of the cerebral aqueduct, tumors, or congenital anatomical anomalies. MRI also enables the assessment of secondary complications, such as white matter compression or cerebral edema, as well as the monitoring of chronic hydrocephalus and the planning of further surgical treatment.

Imaging studies directly influence treatment decisions. Accurate assessment of ventricle size and the location of obstructions to cerebrospinal fluid outflow allows neurologists and neurosurgeons to qualify patients for surgical treatment, including ventriculoperitoneal shunt implantation or endoscopic third-ventricle ventriculostomy. Imaging also enables monitoring of the effectiveness of interventions and early detection of complications, such as drainage obstruction or recurrence of hydrocephalus.

4.9 Other diseases

In the diagnosis of neurodegenerative diseases, imaging studies allow for the assessment of the extent of brain atrophy and the detection of secondary changes associated with the neurodegenerative process. In Alzheimer's disease, it is crucial to visualize atrophy of the hippocampus, temporal, and frontal lobes, as well as enlargement of the ventricular system resulting from loss of brain tissue [10]. In Parkinson's disease, imaging allows for the assessment of abnormalities in the substantia nigra and structural changes in the brain that may coexist with comorbid conditions.

Magnetic resonance imaging (MRI) is the primary diagnostic method because it provides high-resolution imaging of soft tissues and allows for quantitative assessment of the degree of atrophy. T1-weighted sequences enable the assessment of gray and white matter volume, while T2-weighted and FLAIR sequences allow for the detection of vascular changes [9] or coexisting microinfarcts. Some centers also use functional MRI (fMRI) or diffusion-weighted MRI techniques, which allow for the examination of neural network abnormalities and the integrity of neural pathways.

Computed tomography (CT) is less commonly used in the initial diagnosis of neurodegenerative diseases due to its lower sensitivity in detecting subtle atrophic changes. CT can be useful in distinguishing neurodegenerative symptoms from post-traumatic changes, tumors, or large strokes that might mask the underlying disease.

Imaging studies cannot definitively diagnose Alzheimer's or Parkinson's disease at an early stage, but they allow for the assessment of disease progression, the identification of comorbid conditions, and the exclusion of other causes of neurological symptoms. MRI or CT results influence clinical decisions regarding symptomatic treatment, rehabilitation planning, and monitoring the effectiveness of pharmacological therapy.

5. Discussion

The analysis of current literature highlights that modern neuroimaging techniques play a central role in the diagnosis and management of a wide spectrum of CNS diseases and emergencies. CT remains the first-line modality in acute settings due to its rapid acquisition, availability, and high sensitivity for hemorrhagic events, hydrocephalus, and large structural lesions. However, its limited resolution for subtle parenchymal changes and exposure to ionizing radiation underscore the need for complementary imaging techniques.

MRI provides superior soft tissue contrast and the ability to detect small or early lesions, including demyelinating plaques, subtle tumors, and early neurodegenerative changes. Advanced MRI sequences such as perfusion, diffusion-weighted imaging, and spectroscopy further enhance diagnostic precision, particularly in differentiating tumor grades, detecting ischemic core in stroke, and monitoring disease progression. Nevertheless, MRI's limited availability, contraindications, and longer acquisition times can restrict its use in emergency scenarios.

Vascular imaging with CTA and DSA allows precise evaluation of aneurysms, arteriovenous malformations, and other vascular abnormalities, guiding endovascular or surgical interventions. DSA, while invasive, remains the reference standard for detailed vascular mapping. Transfontanelle ultrasonography provides a non-invasive and practical option for neonates, enabling early detection of hydrocephalus, hemorrhage, and infection-related changes. However, its applicability is limited to patients with open fontanelles and to more superficial structures.

The integration of these modalities allows for a complementary approach, optimizing diagnostic accuracy and informing clinical decision-making. The literature emphasizes that no single technique is sufficient for all scenarios; rather, patient age, clinical presentation, and suspected pathology must guide modality selection. Multimodal imaging is particularly valuable in complex cases, such as overlapping vascular and demyelinating lesions, mixed etiologies of acute neurological deficits, or pediatric emergencies.

6. Conclusions

Modern neuroimaging techniques provide indispensable tools for the evaluation of CNS diseases and emergencies. CT enables rapid assessment in acute settings, MRI allows detailed structural and functional evaluation, CTA and DSA provide precise vascular mapping, and ultrasonography offers safe neonatal assessment. Each modality has distinct strengths and limitations, and their complementary use enhances diagnostic accuracy, informs treatment strategies, and supports monitoring of disease progression. Optimized selection of imaging techniques according to patient-specific factors and clinical context is essential for effective neurological care and improved patient outcomes.

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