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Role of Imaging with Microbiological Evaluation in Early Detection of Brain Abscess

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Key words:
Neuroimaging, Brain abscess, CT scan of brain, MRI of brain

Abstract:

Background: *Brain abscess in a severe life-threatening focal infection of central nervous system presents a significant and disproportionately high burden in developing country including Bangladesh. Both neuroimaging and microbiological testing are critical for the early detection and effective management of a brain abscess. The aim of the study for the diagnostic value of neuroimaging and microbiological testing in early detection of brain abscess.* ***Methods:*** *This retrospective cross sectional study was carried out on 52 patients from January, 2022 to December 2022 in Department of radiology & Imaging, Neurology, Neurosurgery, and Microbiology at Sir Salimullah Medical College Mitford hospital, Dhaka. Patients were admitted into Neurosurgery Department Neurology and Neurosurgery was selected for neuroimaging and laboratory assessment of blood. Sensitivity, specificity, PPV, NPV was calculated for all ways of each data analysis and the overall composite. Interobserver agreement was assessed with Cohen's kappa. Correlations between imaging features (e.g., abscess capsule thickness, diffusion) and pathogen types were evaluated using Chi-square or Fisher's exact tests. The statistical analysis of the data was done using SPSS 26.0.* ***Results:*** *This study demonstrated higher sensitivity (88%) and specificity (80%) MRI than CT (72% and 66%, respectively) for detecting brain abscesses, while microbiology showed high specificity (90%) but lower sensitivity (69%). An integrated approach combining MRI, CT, and microbiology achieved the highest diagnostic accuracy (sensitivity 96%, specificity 92%). Interobserver agreement for key MRI features was excellent (K>.75).* ***Conclusion:*** *Compared to traditional and single modality assessment, the integration of imaging and microbiological testing results in improved therapeutic decisions, faster diagnosis times, and higher diagnostic accuracy.*

Introduction:

Brain abscess (BA) is a focal intraparenchymal infection characterized by an encapsulated collection of purulent material, immune cells, and other materials following bacterial or fungal infection[1]. It has a prevalence of approximately 0.3–1.3 per ten thousand people per year with a high incidence in developing countries (8%) [2]. It is potentially life-threatening and is often associated with poor outcomes or persistent neurological sequelae. Secondary brain abscess results from open brain injury or brain surgery, whereas primary brain abscess occurs due to hematogenous or contiguous spread of infection and is not caused by any surgical procedure[1].

In patients with suspected intraparenchymal sepsis, pre-and postcontrast scans should be obtained, unless the plan is to proceed to MRI regardless of the CT endings. Typical appearances include ring of iso-or hyperdense tissue, typically

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of uniform thickness central low attenuation (fluid/pus) surrounding low density (vasogenic oedema). MRI is more sensitive and especially with the addition MRS and DWI far more specific for the diagnosis of cerebral abscesses[3].

Although less sensitive than MRI, CT is often used in emergencies[4]. Early cerebritis typically appears as an irregular, low-density area with no enhancement, though it may show occasional patchy irregular enhancement. As cerebritis progresses, a more defined rim-enhancing lesion becomes visible. Serial CT scans obtained in patients with late-stage abscesses demonstrate progressively decreasing edema and mass effect. The abscess wall is typically smooth and regular, measuring 1 to 3 mm thick, and surrounded by parenchymal cerebral edema[5].

MRI is the preferred imaging modality for diagnosing and monitoring intracranial lesions due to its heightened sensitivity, particularly in detecting early cerebritis. In addition, MRI allows for a more accurate estimation of necrosis and the full extent of the lesion. MRI provides better differentiation between cerebral edema and brain tissue and is more sensitive in detecting the spread of inflammation into the ventricles and subarachnoid space. Diffusion-weighted imaging (DWI) helps differentiate brain abscesses from other ring-enhancing brain lesions. Abscesses typically appear hyperintense on DWI, indicating restricted diffusion, a characteristic feature of viscous materials such as pus[6].

Combining microbiological information with imaging results provide multimodal diagnostic paradigm that makes up deficiencies inherent in either technique in isolation. This strategy in part of the larger movement toward precision medicine, where therapy choices are more and more personalized according to particular anatomical, microbiological and clinical profile[7]. Large retrospective studies & case series have shown that an integrated diagnostic framework enhances the specificity of early diagnosis & facilities timely neurosurgery planning[8]. Considering the clinical significance of early and precise diagnosis of brain abscess this study seek to assess diagnostic accuracy of an integrated diagnostic approach using advanced imaging (MRI, CT) once microbiological by examination (culture, polymerase chain reaction) for early diagnosis and etiological retrospective explanation of brain abscess.[9]

The present study is a retrospective cases that integrates MRI and CT imaging findings with microbiological testing, including culture and polymerase chain reaction (PCR), to enhance the early detection and diagnostic accuracy of brain abscesses.

Methods:

This retrospective cross sectional study was conducted from January 2022 to December 2022 in the Departments of Radiology & Imaging, Neurology, Neurosurgery, and Microbiology at Sir Salimullah Medical College Mitford Hospital, Dhaka, Bangladesh. Patients were admitted in the department of Neurology and Neurosurgery was subjected to immediate neuroimaging and laboratory assessment. Baseline demographic and clinical information were noted. Total of 52 patients were included based on specific inclusion and exclusion criteria. The inclusion criteria of the patients were e"18 years of age that were presented with neurological symptoms suggestive of infection for within seven days, such as fever, focal neurological deficits, and radiological findings indicative of a brain abscess on CT or MRI. The exclusion criteria were known history of neoplastic disease or cerebral infarction and with a previous craniotomy or recurrent and partially treated abscess and contraindications to MRI (e.g., pacemaker, severe claustrophobia, or metallic implants).

All patients underwent rapid, high-resolution neuroimaging using CT and MRI.The comprehensive CT examination performed using a Aquilion prime 160 slice (Toshiba, Japan) with 0.5 × 80 detector 160 slices per every rotation 4 cm of 0.5 mm coverage 0.35 sec rotation, SEMAR, AIDR 3D integrated, infield upgrade.MRI was performance on 1.5 tesla system (Philippines, Netherland) using T1 weighted imaging before and after contrast, T2 weighted imaging fluid alternative invention recovery (FLAIR), Diffusion weighted imaging (DWI). Apparent diffusion coefficient (ADC), mapping. Direct Gram stain, Zeihl Neelsen stain for AFB and aerobic anaerobic and fungal culture were done as a part of microbiological analysis of blood by culture media and blood agar chocholate agar, sabouraud,

dextrose agar with incubation extended to 14 days for anaerobes, and fungi concurrently molecular diagnostic technique were used on aspirated material with polymerase change reaction.

Sensitivity, specificity, PPV, NPV were calculated for all ways of each data analysisand the overall composite. Interobserver agreement was assessed with Cohen's kappa. Correlations between imaging features (e.g., abscess capsule thickness, diffusion) and pathogen types were evaluated using Chi-square or Fisher's exact tests. Variations in the typical patterns of diagnosis were studied by examining the results for people withdifferent immune systems and in different brain regions. For a result to be considered statisticallysignificant, p had to be lower than 0.05. Analysis of the data was done using SPSS version 26.0.

Results:

Table 1. Demographic and Clinical Profile of the Study Population (n = 52)

Variable	Value
Total Number of Patients	52
Mean age (years)	45.6 ± 16.2
Gender (Male/Female)	
Male	32(62%)
Female	20(38%)
Clinical presentations	
Headache	42 (80.7%)
Seizures	18 (34.6%)
Fever at presentation	38 (73%)
Focal neurological deficit	27 (51.9%)
Immunocompromised status	18 (34.6%)

During the 12-months observation period, 52 patients were enrolled, all of whom fulfilled the inclusioncriteria for suspected early-stage brain abscess. The mean age was 45.6 years (SD +16.2),with a male predominance (n=32) and a female representation of (n=20). More than thirty-four percents (n=18) of the patients were immuno-compromised, such as those with diabetes mellitus, HIV infection, long-term corticosteroid therapy, or active malignancy. Deficits in one part of the nervous system were observed in 51.9% ofpatients, the most common being weakness affecting only one side of the body and palsies of somenerves in the head and neck. Patients most often came in with headaches (80.7%), fever (73%), and seizures (34.6%).

Table 2: Diagnostic Performance of Individual and Integrated Modalities

Modality	Sensitivity	Specificity	PPV	NPV
MRI Alone	88%	80%	85%	83%
CT Alone	72%	66%	70%	68%
Microbiology Alone	69%	90%	87%	76%
Integrated Approach (MRI + CT + Microbiology)	96%	92%	95%	94%

MRI showed high sensitivity (88%) for detecting brain abscesses, meaning it correctly identified most true positive cases. Its specificity (80%) indicates a moderate ability to rule out non-abscess lesions. CT demonstrated lower sensitivity (72%) and specificity (66%), reflecting its limited ability to differentiate abscesses from other space-occupying lesions compared to MRI. Microbiological analysis had a high specificity (90%) and positive predictive value (87%), confirming that positive cultures reliably indicate true infection. However, sensitivity was lower (69%) due to prior antibiotic use affecting culture yield. Combining imaging and microbiological modalities achieved the highest diagnostic accuracy, with sensitivity of 96% and specificity of 92%. This highlights the value of a multimodal diagnostic framework in early detection and precise characterization of brain abscesses.

Table 3. Imaging Characteristics Correlated with Pathogen (n=52)

Pathogen Class	Restricted Diffusion on DWI (%)	Smooth Ring Enhancement (%)
Aerobic Bacteria	88	90
Anaerobic Bacteria	80	72
Fungi	38	42
Microbiology-Negative	58	58

Table 4. Interobserver Agreement on Radiological Features (Cohen's Kappa Coefficient, n = 52)

Imaging Feature	Cohen's Kappa (ê)	Interpretation
Restricted Diffusion (DWI)	0.82	Excellent
Ring Enhancement (Post-contrast T1)	0.86	Excellent
Perilesional Edema Extent	0.74	Intermediate to good

Table 5. Microbial Class Correlated with Imaging Patterns and Lesion Location

Pathogen Class	Common Location	Enhancement Pattern	DWI Positivity (%)	Lesion Size Trend
Aerobic Gram-positive	Frontal, Parietal Lobes	Smooth Ring (93%)	91%	2.5–4.5 cm
Gram-negative Bacilli	Deep Gray Matter, Thalamus	Multiloculated, Thin Rim	88%	<2.0 cm (mostly small)
Anaerobic Bacteria	Posterior Fossa, Cerebellum	Irregular Ring (65%)	69%	3.0–5.0 cm, Edematous
Fungi	Frontal, Temporal Lobes (Multilobar)	Nodular/ Disrupted (45%)	42%	Variable, Often Hemorrhagic

Radiological Features and Pathogen Correlation: In the 52-patient, aerobic bacterial abscesses showed the highest prevalence of classical imaging signs: restricted diffusion (88%), and smooth ring enhancement (90%). Anaerobic bacteriahad slightly lower frequencies (80%, 72%), while fungal infections were least likely to show typical features (38%, 42%). Even microbiology-negative cases displayed moderate imaging findings (58%, 58%), indicating that structural changes can be present despite negative cultures. Overall, these results highlight that imaging features correlate with pathogen type, emphasizing the value of an integrated diagnostic approach.

These findings reaffirm the reliability of advanced MRI, particularly restricted diffusion, and ring enhancement, perilesional oedema extend in supporting consistent diagnostic decision-making. The substantial interobserver agreement highlights the utility of these features in standard reporting protocols and diagnostic algorithms for suspected brain abscesses.Landis & Koch, suggested that a Kappa greater than 0.75 represents excellent agreement, & kappa below 0.4 represents poor agreement a Kappa0.40 to 0.75 represents intermediate to good agreement.

Table 5: Showssome organisms present with classical radiological features, others, particularly anaerobes and fungi, pose greater diagnostic ambiguity and require integrated interpretation with microbiology for definitive identification. Notably, high DWI signal in small (<2 cm) Gram-negative abscesses appears to be an under recognized but clinically relevant pattern.

Discussion:

This study focused on the clinical utility of an integrated diagnostic approach that encompasses MRI, CT, and microbiological testing for early and precise detection of brain abscesses. Pyogenic BAs are typically hyperintense on DWI, with low ADC values.[10]

This finding is due to the restricted motion of water in the BA cavity that contains pus: inflammatory cells, bacteria, necrotic tissue and a proteinaceous exudate with a very high viscosity and cellularity. A well-defined ring-enhancement can be detected only in the late evaluative stage of the BA. Due to the higher vascularity, the peripheral enhancement of BAs is thicker along the outer margin compared to the inner margin.[11]

Our CT alone sensitivity of 72% and specificity of 66% reflect known limitations of CT in differentiating abscesses from necrotic tumours or cystic lesions. Earlier works reported CT specificity as low as ~27% in some series when distinguishing

abscess from other ring enhancing lesions. The value of diffusion weighted imaging (DWI) as an advanced MRI was supported in our data (interobserver ê for restricted diffusion = 0.82). Other studies reported DWI sensitivity and specificity up to 96% for distinguishing abscess from necrotic tumours [12.13]. Our pathogen imaging correlation, with higher rates of classical features (e.g., restricted diffusion, ring enhancement) in aerobic bacterial abscesses, aligns with imaging microbiology correlation frameworks described in recent pictorial and review literature [14.15]. Overall, our findings reinforce the position that an integrated diagnostic pathway—leveraging MRI (especially DWI/SWI), CT when needed, and microbiological confirmation—provides the best approach for early and accurate diagnosis of brain abscess [16].

Conclusion:

Compared to single-modality assessment, this combination of neuroimaging and microbiological test of blood improves diagnostic accuracy, permits earlier infection diagnosis, and directs more accurate, focused on treatment plan.

Limitations:

However, the some limitations should be acknowledged. Although a larger sample size would improve precision and external validity, our study included 52 patients based on feasibility within the study period, which may not reflect the wholesome picture of our country.

Data Availability:

The datasets analysed during the current study are not publicly available due to the continuation of analyses but are available from the corresponding author on reasonable request.

Conflict of interest:

No author has any conflict of interest to disclose for this manuscript. The authors themselves are responsible for their ideas and views expressed in this article, which do not necessarily represent the views, decisions or policies of the institutions with which they are affiliated.

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Ethical Consideration:

The study was conducted in accordance with the Declaration of Helsinki (as revised in 2013). This study was approved by the Institutional Review Board from Sir Salimullah Medical College, Dhaka. The written informed consent was taken from all the patients before taking part of the study.

Authors' contributions:

Md. Mahbub Quasem, Bibekanda Halder (Conceptualization, Methodology, Software); MAH (validation); Md. Mahbub Quasem HB, MSM(Investigation, Data curation); Md. Mahbub Quasem, Aminur Rahman (Formal analysis, Writing- Original draft preparation, Visualization); Md. Mahbub Quasem, Aminur Rahman ,(Supervision, Writing- review & editing, Project administration, Funding acquisition). All authors read and approved the final manuscript.

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