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Original Research Article

MAGNETIC RESONANCE IMAGING-DERIVED LESION BURDEN IN CEREBRAL SMALL VESSEL DISEASE: QUANTITATIVE INSIGHTS INTO COGNITIVE DECLINE AND VASCULAR RISK CORRELATION

Bhavani Bangaru[1], Telugu Ramakrishna[2], P. Narsingrao[3]

[1]*Associate Professor, Department of Radiology, Kakatiya Medical college, Hanumakonda, Telangana, India.*
[2]*Associate professor, Department of Neurophysiology, Government Medical College, Ramagundam, Telangana, India.*
[3]*Associate Professor, Department of Neuro Surgery, Government Medical College, Bhadadri kothagudam, Telangana, India.*

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Corresponding Author:
Dr. Bhavani Bangaru,
Associate Professor, Department of Radiology, Kakatiya Medical college, Hanumakonda, Telangana, India.
Email: Bhavanibangaru 15@gmail.com

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ABSTRACT

Background: Cerebral small vessel disease (CSVD) is a major contributor to stroke and cognitive impairment, yet often goes underdiagnosed due to its subtle and variable presentation. Magnetic Resonance Imaging (MRI), with its superior sensitivity, plays a crucial role in early detection and characterization of CSVD-related changes such as white matter hyperintensities, lacunes, microbleeds, and enlarged perivascular spaces.

Materials and Methods: This hospital-based observational study was conducted over a period of 12 months in a tertiary care neurology department. A total of 120 patients aged ≥50 years with clinical suspicion of CSVD underwent detailed clinical assessment and brain MRI. MRI sequences included T1, T2, FLAIR, SWI, and DWI. CSVD markers were graded using standardized rating scales. Associations between imaging findings and clinical variables such as cognitive scores and vascular risk factors were analyzed using Pearson's correlation and multivariate regression.

Results: White matter hyperintensities were observed in 86.6% of patients, lacunes in 60%, and cerebral microbleeds in 32.5%. A robust association was observed between overall CSVD score and cognitive decline ($r = -0.72$, $p < 0.001$). Hypertension and diabetes were significantly associated with higher lesion burden ($p = 0.005$ and $p = 0.021$, respectively).

Conclusion: MRI is a valuable, non-invasive tool in the assessment of CSVD. Quantitative evaluation of MRI markers provides insight into disease burden and cognitive decline, reinforcing its utility in early diagnosis, risk stratification, and management.

Keywords: Small vessel cerebral pathology, magnetic resonance imaging, white matter lesions, small subcortical infarcts, brain micro-hemorrhages, cognitive dysfunction.

INTRODUCTION

Cerebral small vessel pathology (CSVD) encompasses various disease processes affecting the brain's microscopic vascular structures, including small arteries, arterioles, capillaries, and small veins. It represents one of the leading vasculitic conditions causing cognitive decline and contributes significantly to ischemic and hemorrhagic strokes in older adults.[1] With the increasing global burden of aging populations, CSVD has emerged as a major public health concern, not only due to its direct neurological sequelae but also its role in accelerating neurodegenerative processes.[2]

The clinical manifestations of CSVD are often insidious and include subtle cognitive decline, gait disturbances, mood alterations, and stroke-like episodes. These symptoms frequently overlap with other neurological disorders, complicating diagnosis based solely on clinical features.[3] Consequently, neuroimaging plays a central role in identifying the hallmark radiological signs of CSVD, which include

white matter hyperintensities (WMHs), lacunar infarctions, cerebral microbleeds (CMBs), and enlarged perivascular spaces (EPVS).[4]

Among the various imaging modalities, Magnetic Resonance Imaging (MRI) remains the most sensitive technique for visualizing CSVD-related changes. MRI allows for the detection and quantification of WMHs on T2-weighted and FLAIR sequences, identification of lacunes, microbleeds on susceptibility-weighted imaging (SWI), and assessment of EPVS within basal ganglia and centrum semiovale.[5] Furthermore, standardized rating scales, such as the Fazekas scale for WMHs and the Microbleed Anatomical Rating Scale (MARS), facilitate objective disease burden assessment.[6]

Despite MRI's widespread use, variability exists in the interpretation and clinical correlation of radiological findings. The prognostic implications of different imaging markers, especially when assessed collectively through a total CSVD score, remain an area of active investigation. Moreover, the relationships between MRI findings and vascular risk factors such as hypertension, diabetes, and hyperlipidemia continue to garner interest in cerebrovascular research.[7]

Given the clinical complexity and variable radiological presentations of CSVD, this study was designed to systematically assess the utility of MRI in detecting and characterizing CSVD markers in a cohort of neurologically symptomatic adults. We also aimed to correlate imaging findings with cognitive performance and cardiovascular risk profiles to reinforce the value of MRI as a diagnostic and prognostic tool in CSVD.

MATERIALS AND METHODS

This prospective study was conducted in the Department of Radiology, over an 12-month period from February 2024 to January 2025. Patients of 50 years and above, presenting with symptoms suggestive of small vessel disease (e.g., cognitive decline, gait disturbance, transient neurological symptoms), were consecutively recruited after informed consent. Exclusion criteria included known large vessel strokes, demyelinating diseases, intracranial tumors, and contraindications to MRI.

Data Collection: Demographic data, vascular risk factors (hypertension, diabetes, smoking, dyslipidemia), and Mini-Mental State Examination (MMSE) scores were recorded. MRI scans were performed using a 3.0 Tesla scanner. The imaging protocol included axial T1, T2-weighted, FLAIR, SWI, and DWI sequences. CSVD markers were assessed as follows:

- White Matter Hyperintensities: Graded using Fazekas scale (0–3).
- Lacunes: Defined as subcortical lesions 3–15 mm, hyperintense on T2/FLAIR.
- Cerebral Microbleeds: Detected using SWI; counted and anatomically localized.
- EPVS: Counted in basal ganglia and centrum semiovale and graded on a semi-quantitative scale.

A total CSVD score (range 0–4) was derived by assigning one point for the presence of each of the above markers.

Statistical Analysis: Data were entered in SPSS v26. Descriptive statistics were reported as means ± standard deviation (SD) for continuous variables and frequencies (%) for categorical data. Associations between imaging findings and risk factors were assessed using chi-square test and Pearson correlation. Multivariate linear regression was applied to identify predictors of cognitive impairment (MMSE score). Statistical significance was defined at $p<0.05$. Institutional Ethics Committee approval was secured for the study protocol, and written consent was acquired from all participants before enrollment.

RESULTS

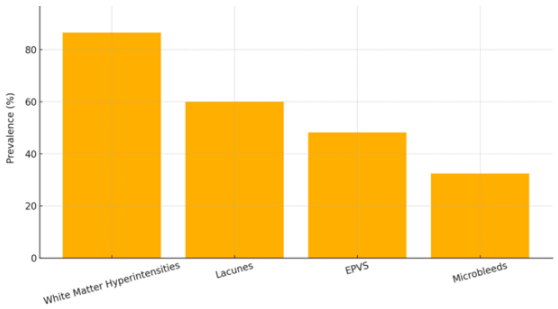

Figure 1: A bar graph depicting the percentage prevalence of individual CSVD markers.

In our study of 120 patients clinically suspected to have cerebral small vessel disease, the most frequent radiological abnormality was the appearance of hyperintense white matter areas (86.6%), followed by lacunes (60.0%), enlarged perivascular spaces (48.3%), and cerebral microbleeds (32.5%). Only 6.7% of patients had no detectable CSVD markers, indicating the high sensitivity of MRI in this clinical setting.

The CSVD score showed a skewed distribution with 34.2% of participants scoring 3 and 15.0% scoring the maximum of 4. This reflects the frequent coexistence of multiple pathological features in symptomatic patients.

A strong inverse correlation was found between CSVD score and MMSE score ($r = -0.72$, $p < 0.001$), confirming that higher radiological burden is significantly associated with poorer cognitive performance.

Analysis of vascular risk factors revealed that hypertension (91.5% vs 67.2%, $p = 0.005$), diabetes (66.1% vs 47.5%, $p = 0.021$), and smoking (40.7% vs 24.6%, $p = 0.048$) were significantly more prevalent in patients with high CSVD scores (≥3) compared to those with lower scores. These findings emphasize

the multifactorial etiology of CSVD and the central role of modifiable cardiovascular risk factors.

Overall, these results highlight the robustness of MRI in detecting the diverse spectrum of CSVD lesions and its capacity to quantify disease burden using a composite score. The statistically significant associations with clinical cognition and vascular comorbidities underscore its value in risk stratification and guiding preventive strategies.

Table 1: Demographic and Clinical Characteristics (n = 120).

Variable	Value
Mean Age (years)	67.3 ± 8.9
Male Gender	72 (60.0%)
Hypertension	95 (79.2%)
Diabetes Mellitus	68 (56.7%)
Dyslipidemia	43 (35.8%)
Smoking History	39 (32.5%)
Mean MMSE Score	22.4 ± 3.9

Table 2: MRI Findings – CSVD Markers

MRI Marker	Frequency (%)
White Matter Hyperintensities	104 (86.6%)
Lacunes	72 (60.0%)
Cerebral Microbleeds	39 (32.5%)
Enlarged Perivascular Spaces	58 (48.3%)

Table 3: CSVD Score Distribution

Total CSVD Score	Number of Patients (%)
0	8 (6.7%)
1	17 (14.1%)
2	36 (30.0%)
3	41 (34.2%)
4	18 (15.0%)

Table 4: Correlation Between CSVD Score and MMSE Score

Variable	Correlation Coefficient (r)	p-value
CSVD Score vs MMSE	−0.72	<0.001

Table 5: Association Between Vascular Risk Factors and High CSVD Score (≥3)

Risk Factor	High CSVD Score (n=59)	Low CSVD Score (n=61)	p-value
Hypertension	54 (91.5%)	41 (67.2%)	0.005
Diabetes Mellitus	39 (66.1%)	29 (47.5%)	0.021
Smoking	24 (40.7%)	15 (24.6%)	0.048

DISCUSSION

Cerebral small vessel disease (CSVD) has emerged as a significant contributor to neurological morbidity, particularly in aging populations. This study reinforces the pivotal role of MRI in identifying and quantifying the burden of CSVD using standardized imaging markers.

The rationale for our study stemmed from the increasing clinical encounters of patients with cognitive dysfunction and vascular risk factors in whom conventional imaging failed to yield definitive diagnostic clues. MRI, with its superior spatial resolution and multiplanar imaging capabilities, offers a non-invasive window into cerebral microvascular pathology that otherwise goes unnoticed.[8]

In our cohort, the prevalence of white matter hyperintensities (86.6%), lacunes (60%), and microbleeds (32.5%) closely aligns with the rates reported in other hospital-based studies. Wardlaw et al,[9] documented WMHs in 85% and lacunes in 55% of CSVD patients, while Debette et al,[10] found CMBs in 28% using SWI sequences. The higher frequency of EPVS in our study (48.3%) may be attributed to enhanced detection at 3.0 Tesla resolution.

One of the most striking findings was the inverse correlation between total CSVD score and MMSE scores ($r = -0.72$, $p < 0.001$), consistent with the results of Jokinen et al,[11] who also observed an inverse correlation ($r = -0.69$) in a prospective dementia cohort. This underscores the neurocognitive implications of CSVD, often underrecognized in early stages.

Hypertension, diabetes, and smoking showed statistically significant associations with high CSVD scores, consistent with the findings of Vermeer et al,[12] and Pantoni et al.[13] These risk variables cause endothelial damage, blood-brain barrier failure, and sustained cerebral underperfusion, all of which are implicated in CSVD pathogenesis.

Clinically, our findings advocate for routine MRI screening in elderly individuals with cognitive symptoms or known vascular risk profiles, even in the absence of overt strokes. The CSVD score offers a practical, reproducible tool to stratify risk and

monitor progression, which may influence both therapeutic planning and prognostication.

However, certain limitations must be acknowledged. Our study was cross-sectional and hospital-based, possibly introducing referral bias and limiting generalizability. Cognitive assessment was limited to MMSE; more nuanced tools such as MoCA or neuropsychological batteries could yield additional insights. Furthermore, longitudinal follow-up was not performed, precluding assessment of disease progression.

CONCLUSION

This study highlights the critical utility of Magnetic Resonance Imaging in the diagnosis and assessment of cerebral small vessel disease. MRI effectively detects the hallmark features of CSVD—white matter hyperintensities, lacunes, microbleeds, and perivascular spaces—with high sensitivity. The total CSVD score derived from imaging correlates strongly with cognitive impairment and is significantly associated with common vascular risk factors such as hypertension, diabetes, and smoking. These findings support the role of MRI not only in confirming the diagnosis but also in stratifying patients based on lesion burden and predicting cognitive outcomes. Given its prognostic value and non-invasive nature, MRI should be an integral part of routine evaluation in older adults presenting with cognitive or cerebrovascular symptoms. Further longitudinal studies are warranted to explore its role in disease progression and therapeutic monitoring.

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