International Journal of Multiphysics
Volume 18, No. 3, 2024
ISSN: 1750-9548

Serum S100B as A Promising Early Biomarker for Cognitive Impairment in End-Stage Renal Disease

Fatma M. Attia Elsayed, Fatma Ayman Abdelmaksoud, Esameldin Mahmoud Lotfy, Ibrahim Mohamed Salem, Hala M Allam, Safaa Mahmoud Elalawy

Internal Medicine Department, Faculty of Medicine, Zagazig University, Sharkia, Egypt

Corresponding author: Fatma Ayman Abdelmaksoud Ramadan.

E-mail: fatmaayman683@gmail.com

Abstract

Cognitive impairment (CI) is a recognized complication of end-stage renal disease (ESRD) and its treatment. Because CI increases the risk for poor outcomes in patients with ESRD, such as disability, hospitalization, withdrawal from dialysis, and death, nephrologists must assess cognitive function in patients with ESRD. Recognition of CI in patients with ESRD is also an essential form of effective management of ESRD comorbidities. S100B protein is a known neurobiochemical marker of brain damage. S100B is a calcium-binding protein accumulated in glial cells, astrocytes, and Schwann cells. S100B is also detected in adipose cells, skin, melanoma, and glioblastoma multiform. Despite the controversies surrounding their brain specificity, S100B have been investigated in different brain diseases as peripheral markers. We concluded that early accurate diagnosis of cognitive impairment in patients with ESRD must be the major goal of the physician while facing these cases from the first second to avoid the probable dangerous sequences. We also concluded that S100B has great potential in predicting cognitive impairment in patients with ESRD. We recommend considering the assessment of S100B as a tool to achieve early prediction cognitive impairment in patients with ESRD and paying attention to this fact while outlining the recent guidelines for diagnosis and management of these patients. In addition, further studies must be done to analyze all aspects of this issue.

Key words: S100B, Cognitive Impairment, ESRD and MMSE.

Introduction:

Cognitive impairment (CI) is a recognized complication of end-stage renal disease (ESRD) and its treatment. The prevalence of CI among patients with ESRD is 30-70% depending on the sample and the definition of CI used. These rates are threefold higher than those in age-matched general populations ***(Park et al., 2020).*** Because CI increases the risk for poor outcomes in patients with ESRD, such as disability, hospitalization, withdrawal from dialysis, and death, nephrologists must assess cognitive function in patients with ESRD. Recognition of CI in patients with ESRD is also an essential form of effective management of ESRD comorbidities. The pathogenesis of CI in patients with ESRD has not yet been determined ***(Tamura & Yaffe, 2011).***

Because brain magnetic resonance imaging in unselected patients with ESRD demonstrates a large burden of large vessel stroke and small vessel ischemia, cerebrovascular disease may have a prominent role in CI. Another study revealed that nephrogenic factors such as anemia, albuminuria, uremic solutes, inflammation, and oxidative stress are associated with CI in patients with ESRD ***(Sehgal et al., 1997).*** Furthermore, treatment-related factors, such as intradialytic hypotension and hyper-viscosity, may be associated with CI in patients with ESRD. S100B protein is a known neurobiochemical marker of brain damage ***(Chaves et al., 2010).***

S100B is a calcium-binding protein accumulated in glial cells, astrocytes, and Schwann cells. S100B is also detected in adipose cells, skin, melanoma, and glioblastoma multiform. Despite the controversies surrounding their brain

specificity, S100B have been investigated in different brain diseases as peripheral markers ***(Park et al., 2020; Schroeter et al., 2013).***

Aim of work:

To investigate the potential role of S100B in predicting cognitive impairment in patients with ESRD.

End-stage renal disease (ESRD): a continuous debate

End-stage renal disease (ESRD) is a prevalent disease worldwide. The development of chronic kidney disease (CKD) and its progression to this terminal disease remains a significant cause of reduced quality of life and premature mortality ***(Jiang et al., 2025).*** Chronic kidney disease (CKD) is a debilitating disease, and standards of medical care involve aggressive monitoring for signs of disease progression and early referral to specialists for dialysis or possible renal transplant. The Kidney Disease Improving Global Outcomes (KDIGO) foundation guidelines define CKD using kidney damage markers, specifically markers that determine proteinuria and glomerular filtration rate ***(Gusev et al., 2021).*** By definition, the presence of both factors (glomerular filtration rate [GFR] less than 60 mL/min and albumin greater than 30 mg per gram of creatinine) along with abnormalities of kidney structure or function for greater than three months signifies chronic kidney disease. End-stage renal disease is defined as a GFR of less than 15 mL/min ***(Wouk, 2021).***

Each nephron in a normal kidney contributes to the total glomerular filtration rate (GFR). The decline of kidney function is gradual and may initially present asymptomatically. The natural history of renal failure depends on the etiology of the disease but ultimately involves early homeostatic mechanisms involving hyperfiltration of the nephrons ***(Gusev et al., 2021).*** The kidney maintains GFR, despite the progressive destruction of nephrons because the remaining normal nephrons develop hyperfiltration and compensatory hypertrophy. As a result, the patient with mild renal impairment can show normal creatinine values, and the disease can go undetected for some time ***(Jiang et al., 2025).*** This nephron adaptability allows for continued normal clearance of plasma solutes. This adaptive mechanism will run its course and eventually cause damage to the glomeruli of the remaining nephrons. At this point, antihypertensives such as angiotensin converting enzyme (ACEs) or angiotensin receptor blocker (ARBs) may be beneficial in slowing the progress of the disease and preserving renal function ***(Fiseha & Osborne, 2023).***

Cognitive Impairment: a global dilemma

Memory loss is a common complaint among older adults, and cognitive impairment (CI) can present in various ways. It is a part of the normal aging process, subjective cognitive impairment (symptomatic complaints with normal neurocognitive test results), mild cognitive impairment, or dementia. CI was deemed to represent a borderline between normal aging and very early dementia ***(Song et al., 2025).*** The earlier criteria for CI diagnosis were found inadequate when it was realized that not all patients with CI progressed to dementia and that memory impairment was not the only cognitive domain affected. These criteria included cognitive complaints from the patient or family members, deficits in any cognitive domain and not only memory, preserved overall general function but increasing difficulties in activities of daily life, and no dementia ***(Anand & Schoo, 2024).***

The concept of CI traveled outside the realm of research to provide clinicians with a useful diagnosis, often for close monitoring. Further clinical research resulted in the development of novel clinical criteria for providers. It is characterized by a decline in one or more cognitive domains, which is both subjectively and objectively observable. However, this decline does not interfere with the individual's ability to perform daily activities independently ***(Deright, 2021).*** CI can also be classified based on the type of cognitive domain that is affected. CI can potentially affect one or more of the following 6 cognitive domains: learning and memory, language, complex attention, executive function, social cognition, and visuospatial function. CI can be classified as "amnestic" or "non-amnestic" with deficits in single or multiple cognitive domains ***(Barisano et al., 2022).*** Advancing age is the strongest risk factor for CI. Other risk factors include male sex, family history of cognitive impairment, and the presence of the apolipoprotein E (APOE) allele ***(Manly et al., 2022).***

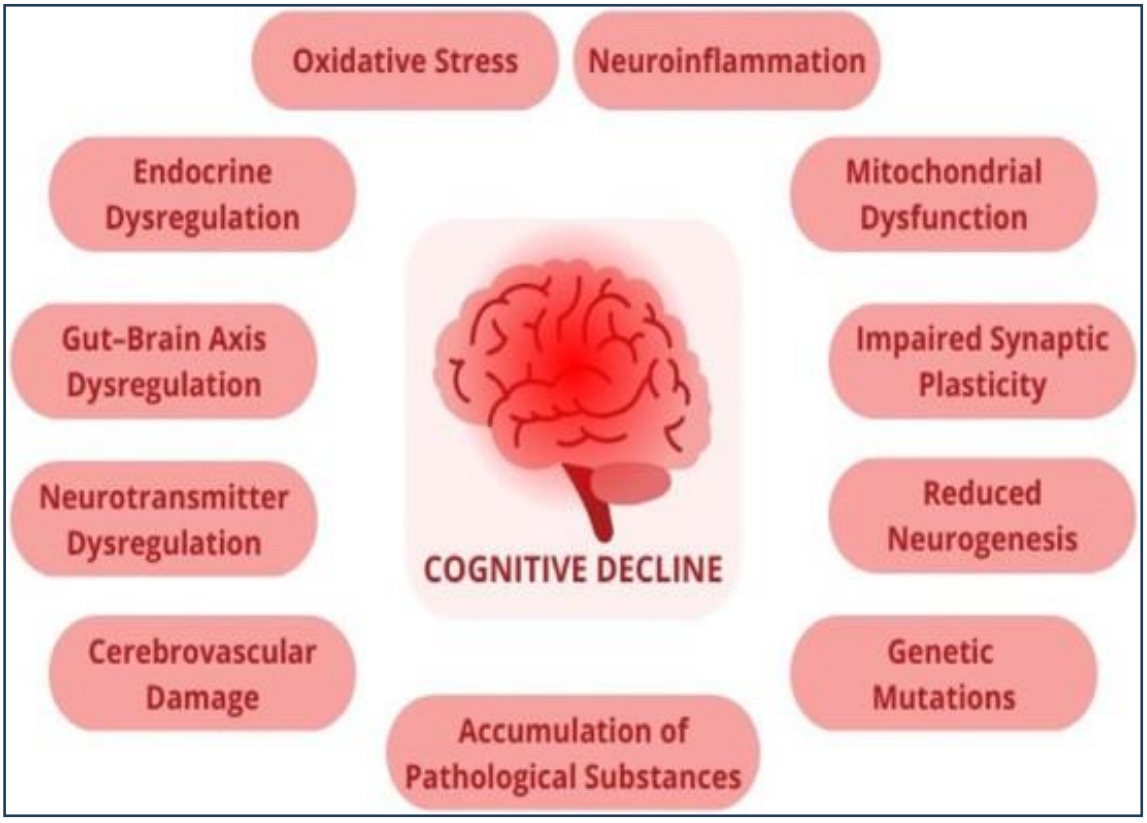

Figure (1): Etiology and risk factors of CI ***(Mlynarska et al., 2024).***

Cognitive Impairment in ESRD: a challenging concern

Patients with ESRD are notably susceptible to cognitive impairment, which may develop more quickly and severely than in the age-matched general population, ranging from mild cognitive impairment to severe dementia. Although cognitive impairment warrants attention due to its profound impact on individuals' Quality of life, treatment adherence and overall health outcomes, this condition remains underestimated and poorly managed in patients with kidney diseases ***(Capasso et al., 2025).*** Beyond the detrimental effects on outcomes and healthcare costs, cognitive impairment in ESRD patients has a profound clinical impact, affecting multiple aspects of health and QoL. Cognitive impairment can decrease the ability to perform daily activities, reducing independence and social interaction, which may in turn trigger a higher risk of depression and anxiety, further complicating disease management ***(Pei et al., 2025).***

Importantly, there is a significant additive interaction between ESRD and depression in terms of increased risk of cognitive impairment. This suggests that ESRD and depression synergistically affect cognitive impairment, especially when moderate–severe depression co-occurs with ESRD. Clinicians should be mindful of the combined impact of ESRD and depression on patients with cognitive impairment ***(Tsuruya & Yoshida, 2024).*** Despite the various patterns of cognitive impairment that have been described, some key aspects characterize the clinical manifestation of this condition among ESRD patients. At the more severe end of the cognitive spectrum, individuals exhibit functional dependence, characterized by the inability to perform basic and instrumental activities of daily living, as well as significant impairment across multiple cognitive domains ***(Bolignano et al., 2025).***

An intermediate construct along this cognitive continuum in ESRD is mild cognitive impairment, which falls between normal cognition and dementia. Mild cognitive impairment is characterized by decreased cognitive performance in one or more cognitive domains, but with preserved functional autonomy. ESRD patients with mild cognitive impairment can progress to manifest dementia ***(Gela et al., 2021).*** Recently, it has been suggested that ESRD-related cognitive impairment presents diverse morphological, functional and pathogenetic features compared with the general population; therefore, some authors have proposed that ESRD-related cognitive impairment should be considered a distinct clinical

entity ***(Pei et al., 2025).*** Moreover, ESRD patients with severe cognitive impairment show neuroimaging and neuropsychological patterns more similar to those of patients with vascular dementia, suggesting substantial differences between 'renal' dementia and Alzheimer's disease. Generally, ESRD patients display reduced cognitive performance in global cognition and relevant cognitive domains (i.e. attention and processing speed, memory, language and executive functions) ***(Capasso et al., 2025).*** On the other hand, other domains (i.e. construction and motor praxis and perception) seem rarely affected. The specific cognitive domains most severely impaired in ESRD patients are not entirely clear. While cognitive changes in memory and language skills can also be present, these appear to occur with a lower incidence compared with deficits in the aforementioned domains. Attention and processing speed deficits can be present even in mild–moderate ESRD populations ***(Tollitt et al., 2021).***

ESRD-related cognitive impairment involves a complex interplay of various factors, including vascular disease, metabolic disturbances and inflammation. All these factors tend to be interdependent and increase the evidence for the complex interaction of ESRD on brain functioning. The chronic inflammatory state in ESRD is characterized by elevated levels of pro-inflammatory cytokines, such as interleukin-6 and tumour necrosis factor alpha ***(Murtaza & Dasgupta, 2021).*** Chronic inflammation promotes microglial activation, astrocyte dysfunction and blood–brain barrier (BBB) disruption. This fosters neuroinflammation and neurodegeneration, which are implicated in the pathogenesis of cognitive impairment. Moreover, the high prevalence of vascular disease observed in ESRD patients suggests that cerebrovascular impairment is the predominant pathology underlying this association ***(Bolignano et al., 2025).***

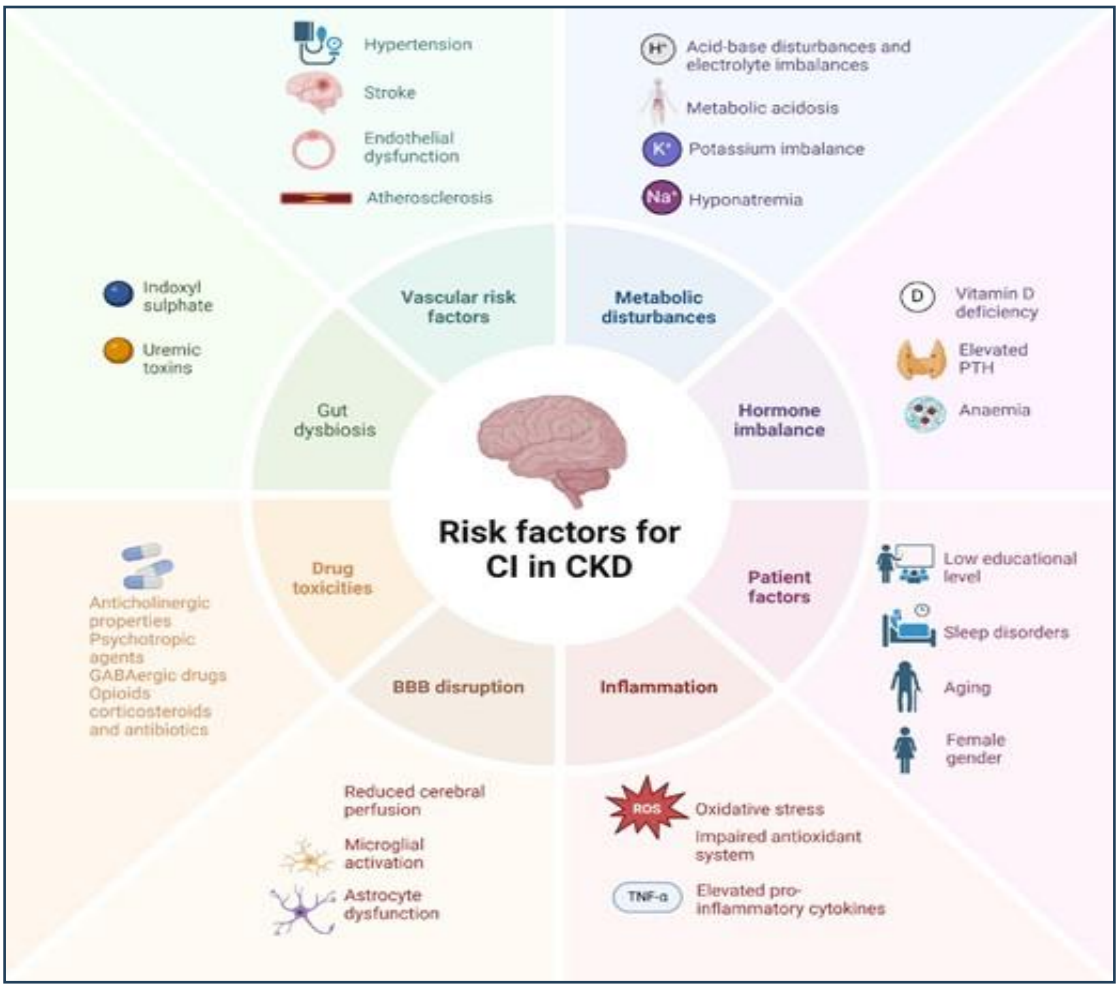

Figure (2): Risk factors of CI in CKD ***(Bolignano et al., 2025).***

Mechanisms underlying cognitive impairment related to small vessel disease in ESRD also encompass BBB dysfunction, diminished cerebrovascular activity and compromised perivascular clearance. BBB disruption in ESRD was

recently explored through the assay of circulating levels of brain-derived neurotrophic factor (BDNF) and neuron-specific enolase (NSE) ***(Pei et al., 2025).*** Additionally, ESRD is characterized by metabolic dysregulation, including acid–base disturbances and electrolyte imbalances. These abnormalities can adversely affect cerebral perfusion, neuronal function and synaptic plasticity, thereby predisposing ESRD patients to cognitive decline ***(Gela et al., 2021).*** Although direct evidence linking metabolic acidosis to cognitive disorders is limited, a comprehensive study involving hypertensive adults, with or without ESRD, revealed a correlation between serum bicarbonate levels and diminished cognitive and executive functions. Notably, overt metabolic acidosis is uncommon in the early stages of CKD, characterized by an increasing prevalence of mild cognitive impairment ***(Capasso et al., 2025).*** However, even subtle shifts in arterial pH can result in nuanced changes in brain interstitial fluid pH, potentially aggravating cognitive decline through hyperventilation, cerebral blood flow modulation and neuronal activity. While the direct impact of acidosis on cognitive disorders is not fully established, it may indirectly influence cognition by affecting systemic inflammation and the release of uraemic neurotoxins and compromising overall kidney health ***(Tollitt et al., 2021).***

Moreover, hyponatraemia, which is prevalent in ESRD, is also associated with reversible mild cognitive impairment. Even slight decreases in plasma sodium levels impair attention and psychomotor function, possibly due to cellular responses to hypo-osmolar stress. Nonetheless, the precise impact of potassium imbalances on cognition remains uncertain, as this topic remains underexplored ***(Kelly & Rothwell, 2022).*** Although evidence suggests that higher potassium intake may offer protective effects against dementia, the precise impact of potassium imbalances on cognition remains uncertain. Elevated phosphate levels in ESRD patients correlate with a higher risk of haemorrhagic stroke, but a direct association with cognitive decline requires further investigation ***(Tsuruya & Yoshida, 2024).***

Another relevant factor of ESRD-related cognitive impairment is the disruption in the balance of various hormones, including insulin, thyroid hormones and sex hormones, which play critical roles in neuronal survival, synaptic plasticity and cognitive function. Patients with ESRD present a higher risk of adverse drug reactions affecting the central nervous system via two major pathways ***(Murtaza & Dasgupta, 2021).*** First, ESRD-associated BBB disruption and, second, the impact of reduced kidney function and dialysis on drug pharmacokinetics. Lastly, chronic dialysis treatment can inherently impact brain function, significantly contributing to cognitive dysfunction. Intradialytic hypotension is one of the most critical factors ***(Bolignano et al., 2025).***

S100B: a growing hope

The term S100B refers to a protein identified in the mid-1960s from brain extracts to compare proteins identified in the nervous tissue with those localized in other tissues. It is characterized by an intriguing, unusual solubility in a 100% saturated solution with ammonium sulfate, and this characteristic was the basis of its denomination, which was originally S100 protein ***(Lu et al., 2025).*** At present, the S100 protein family comprises more than 20 calcium- binding proteins, mostly formed by two identical peptides (homodimers), exhibiting structural similarities with different degrees of amino acid homology, located in different tissues where they modulate the activity of many targets ***(Michetti et al., 2023).***

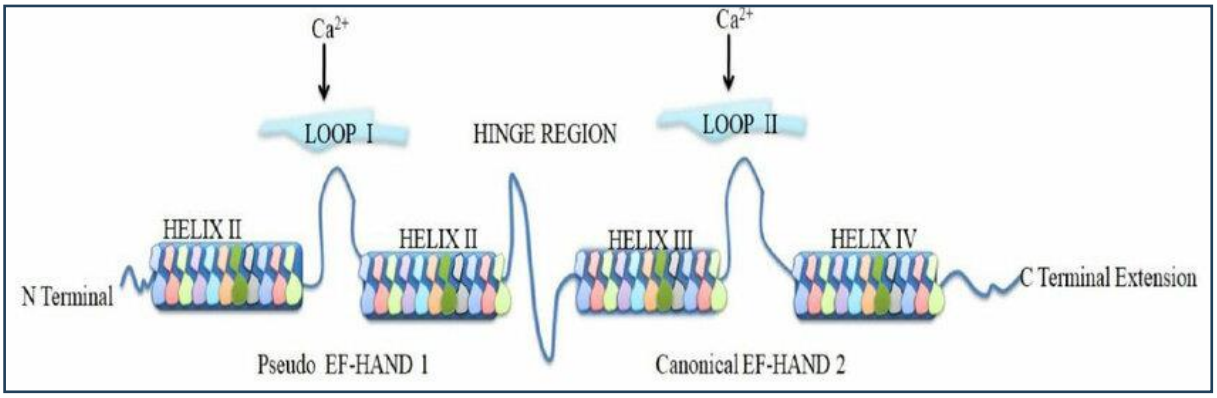

Figure (3): Structure of S100B ***(Langeh & Singh, 2021).***

Interestingly, the amino acid composition and conformation of S100B, as for other proteins of the S100 family, are highly conserved in vertebrate species, suggesting that it may have a crucially conserved biological role(s), although they have not been identified ***(Langeh & Singh, 2021).*** In the nervous system, although S100B is mainly concentrated in astrocytes, it is also expressed in other glial cell types, such as oligodendrocytes, Schwann cells, ependymal cells, retinal Müller cells, and enteric glial cells. The protein has even been reported to be contained in specific neuronal subpopulations in the brainstem and some ganglionic peripheral cells ***(Arrais et al., 2022).*** In addition, as above indicated, S100B has also been detected in definite non-neural cell types, such as chondrocytes, melanocytes, Langerhans cells, dendritic cells of lymphoid organs, some lymphocyte cell types, adrenal medulla satellite cells, skeletal muscle satellite cells, tubular kidney cells, non-nervous structures of the eye, such as corneal endothelial cells and lens, iris, ciliary body epithelial cells, Leydig cells, and adipocytes, which constitute a site of concentration for the protein comparable to astrocytes ***(Polyakova et al., 2022).***

While the functional characteristics and cell localization of neural S100B have been extensively studied, its properties in non-neural locations have received poor attention, although they would reasonably deserve analogous consideration. These risks become a gap in studies concerning the role of S100B in physiological and/or pathological conditions ***(Michetti et al., 2023).*** Indeed, the cell distribution of this protein does not offer conclusive clues to its functional role(s). In general terms, S100B, such as other calcium-binding proteins belonging to the S100 family, appears to regulate a variety of intracellular activities, interacting with different molecules located in different cell types ***(Gayger et al., 2023).*** The different functions attributed to the protein, which include the regulation of cellular calcium homeostasis and enzyme activities, interaction with the cytoskeleton, cell survival, cell differentiation, and cell proliferation, do not appear to delineate a clear, univocal intracellular role for S100B ***(Lu et al., 2025).***

In contrast, growing evidence indicates an increasingly clearer role for S100B when it is secreted—reasonably mostly by astrocytes in the nervous system—in the extracellular compartment. Extracellular S100B is regarded as interacting with target cells mainly, but not exclusively, through the muti-ligand transmembrane Receptor for Advanced Glycation End Products (RAGE), initiating intracellular signaling cascades that may result in physiological regulation at low nanomolar concentrations (“Jekyll side”) or various pathological conditions, acting as a Danger/Damage Associated Molecular Pattern (DAMP) protein at higher micromolar concentrations (“Hyde side”) ***(Langeh & Singh, 2021).*** Thus, increased levels of S100B have also been shown in different biological fluids (cerebrospinal fluid, peripheral and cord blood, amniotic fluid, saliva, urine, and feces) during various pathological conditions involving the nervous system (neurodegenerative diseases such as Alzheimer’s disease (AD), Parkinson’s disease (PD), amyotrophic lateral sclerosis (ALS), multiple sclerosis (MS), traumatic and vascular acute brain injury, epilepsy, and also inflammatory bowel disease, perinatal neural disorders, glioma, and psychiatric disorders), but also extra-neural districts (obesity and diabetes, melanoma) ***(Arrais et al., 2022).***

S100B and CI: a worldwide interest

Astrocytes, which are known to be the main site of concentration for S100B in the central nervous system, are also known to be its main homeostatic regulator; in CI, they exert both neuroprotective and neurotoxic effects depending on the disease stage and microenvironmental factors ***(Langeh & Singh, 2021).*** Essentially, based on their involvement in neuroinflammatory processes through the activation of intracellular pathways and the release of proinflammatory cytokines, they are believed to actively participate in CI pathogenic processes ***(Lu et al., 2025).*** Astrocytic S100B has been shown to be a neurotrophic factor. S100B in biological fluids has been regarded as a reliable biomarker for the disease. Collectively, the above data delineate a scenario where the S100B protein stands at the crossroads of different pathological conditions. Its pathogenic role has been proposed in processes caused by different etiologic factors and displaying different symptoms ***(Polyakova et al., 2022).***

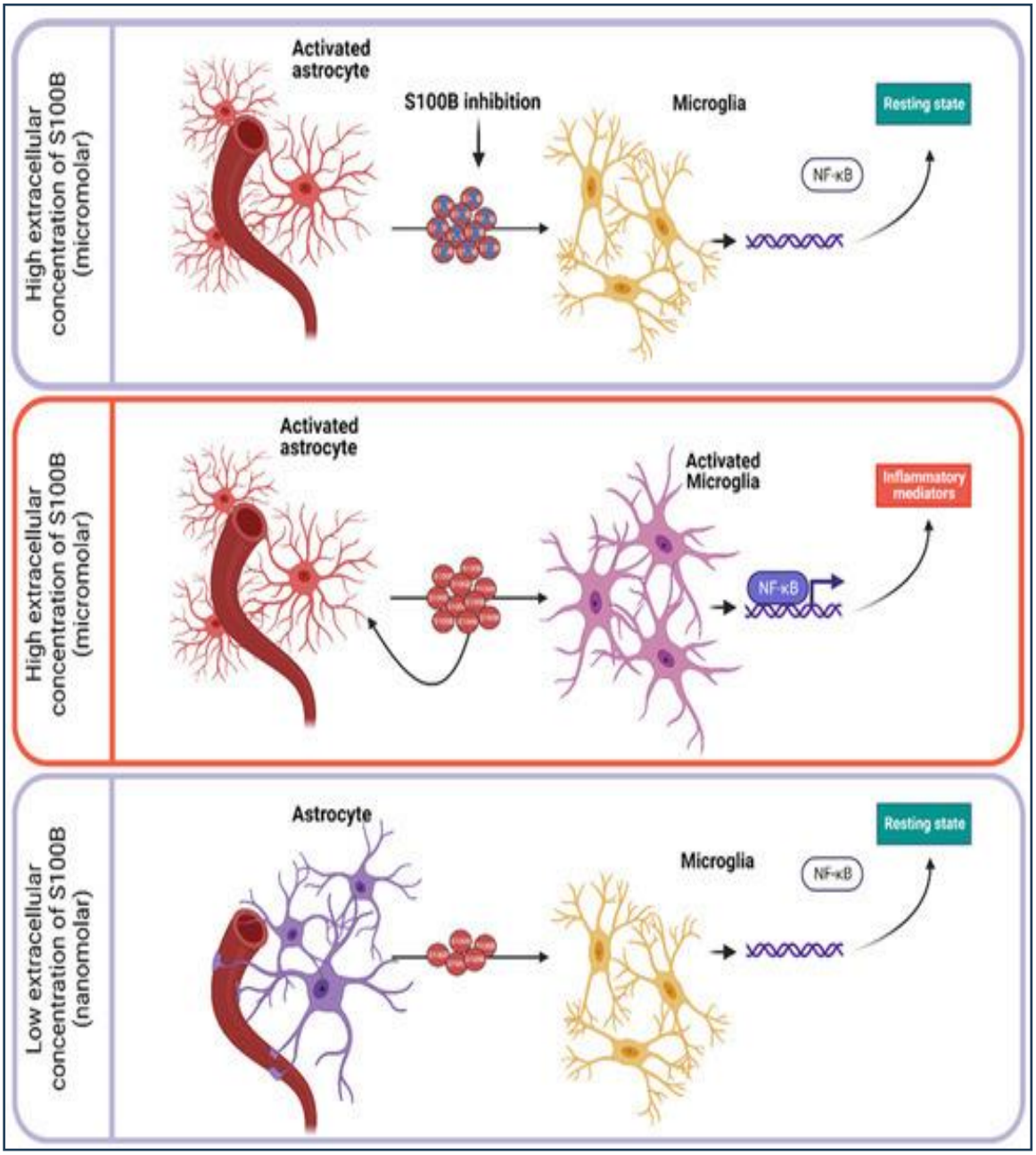

Figure (4): Schematic representation of effects induced by extracellular astrocytic S100B ***(Michetti et al., 2023).***

However, these disorders, regardless of their origin, appear to involve processes that share aspects attributable to inflammation. This view might depict S100B as an unspecific putative pathogenic factor, comprehensibly regarded with some suspicion. However, this view also presents S100B as a wide-ranging tool that may reasonably lead to unifying solutions, thus offering a promising perspective ***(Polyakova et al., 2022).*** Interestingly in this respect, the range of diseases where S100B is putatively involved in pathogenic processes, at least based on results in experimental models, is now enlarging outside the nervous system (e.g., muscular dystrophy, obesity, diabetes, ocular disorders); potentially, it is expected to parallel the cellular distribution of the protein, which is definite but significant ***(Arrais et al., 2022).*** Indeed, at present, the S100B protein is not the unique inflammatory molecule for which a wide therapeutic target role is putatively recognized. As examples, the prototype of DAMP proteins, HMGB1, as well as the inflammatory mediators' resistin-like molecules, are currently regarded as interesting unifying therapeutic targets for different disorders. It should

also be noted in this respect that RAGE ligands, including DAMPs, have been considered potential therapeutic targets for a variety of disorders ***(Lu et al., 2025).***

Conclusion and recommendations:

We concluded that early accurate diagnosis of cognitive impairment in patients with ESRD must be the major goal of the physician while facing these cases from the first second to avoid the probable dangerous sequences. We also concluded that S100B has great potential in predicting cognitive impairment in patients with ESRD. We recommend considering the assessment of S100B as a tool to achieve early prediction cognitive impairment in patients with ESRD and paying attention to this fact while outlining the recent guidelines for diagnosis and management of these patients. In addition, further studies must be done to analyze all aspects of this issue.

References:

1. Anand, S., & Schoo, C. (2024). Mild cognitive impairment. StatPearls, 9 (2), 1-5.
2. Arrais, A. C., Melo, L. H. M., Norrara, B., Almeida, M. A. B., Freire, K. F., Melo, A. M. M., ... & Cavalcanti, J. R. L. (2022). S100B protein: general characteristics and pathophysiological implications in the Central Nervous System. International Journal of Neuroscience, 132(3), 313-321.
3. Barisano, G., Montagne, A., Kisler, K., Schneider, J. A., Wardlaw, J. M., & Zlokovic, B. V. (2022). Blood–brain barrier link to human cognitive impairment and Alzheimer's disease. Nature cardiovascular research, 1(2), 108-115.
4. Bolignano, D., Simeoni, M., Hafez, G., Pepin, M., Gallo, A., Altieri, M., ... & Capasso, G. (2025). Cognitive impairment in CKD patients: a guidance document by the CONNECT network. Clinical Kidney Journal, 18(2), sfae294.
5. Capasso, G., Franssen, C. F., Perna, A. F., Massy, Z. A., Menzies, R. I., Zoccali, C., ... & Unwin, R. J. (2025). Drivers and mechanisms of cognitive decline in chronic kidney disease. Nature Reviews Nephrology, 1-17.
6. Chaves, M. L., Camozzato, A. L., Ferreira, E. D., Piazenski, I., Kochhann, R., Dall'Igna, O., ... & Portela, L. V. (2010). Serum levels of S100B and NSE proteins in Alzheimer's disease patients. Journal of neuroinflammation, 7, 1-7.
7. Deright, J. (2021). Mild cognitive impairment. Essential Neuropsychology: A Concise Handbook for Adult Practitioners, 179.
8. Fiseha, T., & Osborne, N. J. (2023). Burden of end-stage renal disease of undetermined etiology in Africa. Renal Replacement Therapy, 9(1), 44.
9. Gayger, V., Vizuete, A. F., Rodrigues, L., Wartchow, K. M., Bobermin, L., Leite, M. C., ... & Gonçalves, C. A. (2023). How S100B crosses brain barriers and why it is considered a peripheral marker of brain injury. Experimental Biology and Medicine, 248(22), 2109-2119.
10. Gela, Y. Y., Getu, A. A., Adane, A., Ayal, B. M., Akalu, Y., Ambelu, A., ... & Yeshaw, Y. (2021). Cognitive impairment and associated factors among chronic kidney disease patients: a comparative cross-sectional study. Neuropsychiatric disease and treatment, 1483-1492.
11. Gusev, E., Solomatina, L., Zhuravleva, Y., & Sarapultsev, A. (2021). The pathogenesis of end-stage renal disease from the standpoint of the theory of general pathological processes of inflammation. International journal of molecular sciences, 22(21), 11453.
12. Jiang, Y., Du, W., Li, Y., Gao, B., Liu, N., Song, Q., ... & Miao, Y. (2025). Disturbed dynamic brain activity and neurovascular coupling in end-stage renal disease assessed with MRI. Journal of Magnetic Resonance Imaging, 61(4), 1831-1844.
13. Kelly, D. M., & Rothwell, P. M. (2022). Disentangling the relationship between chronic kidney disease and cognitive disorders. Frontiers in neurology, 13, 830064.
14. Langeh, U., & Singh, S. (2021). Targeting S100B protein as a surrogate biomarker and its role in various neurological disorders. Current neuropharmacology, 19(2), 265-277.
15. Lu, S., Zhang, J., He, X., & Huang, J. (2025). S100B in postoperative cognitive impairment: systematic review and meta-analysis. Clinica Chimica Acta, 120380.

16. Manly, J. J., Jones, R. N., Langa, K. M., Ryan, L. H., Levine, D. A., McCammon, R., ... & Weir, D. (2022). Estimating the prevalence of dementia and mild cognitive impairment in the US: the 2016 health and retirement study harmonized cognitive assessment protocol project. JAMA neurology, 79(12), 1242-1249.
17. Michetti, F., Clementi, M. E., Di Liddo, R., Valeriani, F., Ria, F., Rende, M., ... & Romano Spica, V. (2023). The S100B protein: a multifaceted pathogenic factor more than a biomarker. International Journal of Molecular Sciences, 24(11), 9605.
18. Młynarska, E., Jakubowska, P., Frąk, W., Gajewska, A., Sornowska, J., Skwira, S., ... & Franczyk, B. (2024). Associations of Microbiota and Nutrition with Cognitive Impairment in Diseases. Nutrients, 16(20), 3570.
19. Murtaza, A., & Dasgupta, I. (2021). Chronic kidney disease and cognitive impairment. Journal of Stroke and Cerebrovascular Diseases, 30(9), 105529.
20. Park, B. S., Lee, H. W., Lee, Y. J., Park, S., Kim, Y. W., Kim, S. E., ... & Park, K. M. (2020). Serum S100B represents a biomarker for cognitive impairment in patients with end-stage renal disease. Clinical Neurology and Neurosurgery, 195, 105902.
21. Pei, X., Bakerally, N. B., Wang, Z., Bo, Y., Ma, Y., Yong, Z., ... & Zhao, W. (2025). Kidney function and cognitive impairment: a systematic review and meta-analysis. Renal failure, 47(1), 2463565.
22. Polyakova, M., Mueller, K., Arelin, K., Lampe, L., Rodriguez, F. S., Luck, T., ... & Schroeter, M. L. (2022). Increased serum NSE and S100B indicate neuronal and glial alterations in subjects under 71 years with mild neurocognitive disorder/mild cognitive impairment. Frontiers in Cellular Neuroscience, 16, 788150.
23. Schroeter, M., Sacher, J., Steiner, J., Schoenknecht, P., & Mueller, K. (2013). Serum S100B represents a new biomarker for mood disorders. Current Drug Targets, 14(11), 1237-1248.
24. Sehgal, A. R., Grey, S. F., DeOreo, P. B., & Whitehouse, P. J. (1997). Prevalence, recognition, and implications of mental impairment among hemodialysis patients. American Journal of Kidney Diseases, 30(1), 41-49.
25. Song, Y., Yuan, Q., Liu, H., Gu, K., & Liu, Y. (2025). Machine learning algorithms to predict mild cognitive impairment in older adults in China: a cross-sectional study. Journal of Affective Disorders, 368, 117-126.
26. Tamura, M. K., & Yaffe, K. (2011). Dementia and cognitive impairment in ESRD: diagnostic and therapeutic strategies. Kidney international, 79(1), 14-22.
27. Tollitt, J., Odudu, A., Montaldi, D., & Kalra, P. A. (2021). Cognitive impairment in patients with moderate to severe chronic kidney disease: the Salford kidney cohort study. Clinical Kidney Journal, 14(6), 1639-1648.
28. Tsuruya, K., & Yoshida, H. (2024). Cognitive impairment and brain atrophy in patients with chronic kidney disease. Journal of Clinical Medicine, 13(5), 1401.
29. Wouk, N. (2021). End-stage renal disease: medical management. American family physician, 104(5), 493-499.