Health & Medical Sciences Volume: 3, Number 1, 2025, *Page*: 1-13

The Role of GFAP as a Marker of Astrocyte Activation in the Pathogenesis of Alzheimer's Dementia: A Literature Review

Komang Trisna Sumadewi*

Department of Anatomy, Faculty of Medicine and Health Science, Warmadewa University, Indonesia

DOI:
https://doi.org/10.47134/phms.v3i1.519
Corespondence: Komang Trisna Sumadewi
Email:
trisna.sumadewi@warmadewa.ac.id

Received: 14-09-2025
Accepted: 18-10-2025
Published: 29-11-2025

Abstract: This study aims to comprehensively review the role of glial fibrillary acidic protein (GFAP) as a marker of astrocyte activation in Alzheimer's disease (AD). The research utilized a descriptive-qualitative literature review approach by analyzing various current scientific sources, including indexed international journal articles, research reports, and relevant academic documents published between 2015 and 2025. Data collection involved systematic literature search techniques, followed by analysis comprising theme identification, data reduction, concept categorization, and inductive conclusion drawing to obtain a holistic understanding of the phenomenon under study. The study results show that GFAP plays a crucial role as a sensitive biomarker for astrocyte activation that occurs since the preclinical phase of Alzheimer's, demonstrating a strong correlation with amyloid-beta accumulation and the neuroinflammatory process. In addition to its function in early detection, GFAP is also capable of predicting the conversion of mild cognitive impairment (MCI) to Alzheimer's dementia with high diagnostic accuracy. Despite limitations in specificity and measurement variation, the integration of GFAP with other biomarkers such as pTau, NfL, and YKL-40 significantly enhances diagnostic validity and its potential for therapy monitoring. In conclusion, GFAP is a multifunctional biomarker that not only deepens our understanding of the mechanisms of reactive astrocytosis in AD pathogenesis but also provides new directions for the development of non-invasive diagnostics and more precise therapeutic strategies in neurodegenerative diseases.

Keywords: GFAP, Astrocytes, Alzheimer's, Biomarker, Neuroinflammation.

Introduction

Alzheimer's disease (AD) is the most common form of dementia worldwide, with prevalence continuing to rise as the global population ages. According to WHO estimates, the number of people with dementia is projected to exceed 150 million by 2050. This condition imposes a significant social and economic burden due to its progressive and incurable nature. Therefore, efforts to detect AD at the earliest stage have become a major focus of modern neurological research (Holper, 2024) .

In the context *of neurodegeneration*, scientists are now focusing on *glial* cells, particularly astrocytes, which play a central role in maintaining neural tissue homeostasis. Astrocyte activation or *astrogliosis* has been identified as a characteristic response to neuronal stress and brain injury. One of the main indicators of this process is increased expression of *glial fibrillary acidic* protein (GFAP), which is now considered *a* potential *biomarker* for detecting pathological changes in AD (Kim, 2023; Leipp, 2024) .

GFAP is the primary *intermediate filament* protein in astrocytes and is the most sensitive marker for the activation of these cells. In recent years, research has shown that increased GFAP levels, both in cerebrospinal fluid (CSF) and blood, correlate strongly with amyloid-β (Aβ) and tau burden in the brain (Chatterjee, 2021; Pereira, 2021) . This correlation makes GFAP a promising candidate *biomarker* for early diagnosis and monitoring *of* AD *progression*.

The urgency of research on GFAP is increasing due to the limitations *of* conventional *biomarkers* such as Aβ and tau, which, although specific, still require *invasive* and expensive procedures like *lumbar puncture* or PET *scans*. In contrast, GFAP can be measured *non-invasively* from blood, offering the opportunity for screening high-risk populations at a lower cost (Cicognola, 2020; Holper, 2024) .

Several longitudinal studies also indicate that elevated GFAP levels can occur even before clinical symptoms of AD appear. This suggests that reactive *astrocytosis* is one of the early events in the pathogenesis of this disease (Chatterjee, 2021; Varma et al., 2024) . Thus, GFAP holds great potential as *a* predictive *biomarker* for detecting the *preclinical* phase of AD.

However, the role of GFAP is not entirely specific to Alzheimer's disease. Its expression may also increase in various other neurological conditions such as brain trauma, multiple sclerosis, and other *neuroinflammatory* diseases. Therefore, *the specificity* of GFAP as a single diagnostic marker remains a major challenge (Leipp, 2024; Ozcelikay-Akyıldız et al., 2024) .

To overcome these limitations, a number of recent studies have proposed the use of GFAP in combination with other *biomarkers* such as Aβ, tau, and *neurofilament light chain* (NfL) to improve diagnostic accuracy. This combination *of multimodal biomarkers* shows increased sensitivity in distinguishing AD from other forms of dementia (Ally, 2023; Kim, 2023) .

Additionally, a multidimensional approach involving blood *biomarkers*, brain imaging, and cognitive assessment is expected to create a more comprehensive integrated diagnostic system. The use of GFAP in this context is not only as a diagnostic marker but also as an indicator of pathological activity and a potential target for *neuroprotective* therapy (Bellaver, 2021; De Bastiani, 2023) .

Molecularly, increased GFAP expression in AD is associated with astrocyte-mediated metabolic dysfunction and *neuroinflammation*. Research indicates that Aβ accumulation triggers an inflammatory response that affects GFAP expression and exacerbates neuronal damage (Ferrari-Souza, 2022; Pereira, 2021) . Thus, GFAP is not merely **a** passive **biomarker** but also part of the pathogenic mechanism of AD.

The current research gap lies in the lack of understanding of the temporal dynamics of GFAP expression during the course of the disease. Although it is known that GFAP increases in the early stages, there is no consensus on a clinically applicable diagnostic threshold (Holper, 2024; Leipp, 2024) .

Additionally, variations between analytical platforms, differences in sampling methods, and patient heterogeneity pose challenges in standardizing the use of GFAP as *a* global *biomarker*. Cross-population studies and meta-analyses are needed to confirm the validity and *reproducibility* of these findings (Kim, 2023; Oeckl et al., 2022) .

In the context of clinical translation, a better understanding of the role of GFAP could accelerate the development of new intervention strategies, including therapies targeting reactive astrocytes. Such interventions are expected to suppress *neuroinflammation* and slow *the progression of neurodegeneration* (De Bastiani, 2023; Sánchez-Juan et al., 2024) .

With increasing evidence supporting the critical role of astrocytes in AD pathology, the assessment of GFAP becomes increasingly relevant both theoretically and practically. Theoretically, this research contributes to the understanding of the molecular and cellular mechanisms of *neurodegeneration.* Practically, the results open up opportunities for developing more efficient methods for early detection and disease monitoring (Leipp, 2024; Varma et al., 2024) .

Based on this description, this article aims to comprehensively review the role of GFAP as a marker of astrocyte activation in Alzheimer's dementia. The discussion will cover the relationship between GFAP and amyloid and tau pathology, its diagnostic potential, limitations, and future research directions. Through a systematic literature review approach, this article aims to provide a scientific foundation for the development *of* astrocyte-based *biomarkers* in the context of Alzheimer's detection and management.

Method

This study uses a qualitative approach with a descriptive method conducted through *library research.* This approach was chosen because it is suitable for exploring in depth the concepts and empirical findings related to the role of *glial fibrillary acidic* protein (GFAP) as a marker of astrocyte activation in Alzheimer's dementia. Qualitative methods allow researchers to understand phenomena from various scientific sources comprehensively and contextually (Bingham, 2023; Pratt, 2025) . Through a literature review, this study focuses on collecting, examining, and analyzing relevant academic literature to present a meaningful scientific synthesis of the research topic (Bandaranayake, 2024; Togia, 2017) .

The data sources used in this study consist of indexed international scientific articles, research reports, academic books, and official documents relevant to the topics of Alzheimer's disease and GFAP *biomarkers*. The selection criteria for sources were publications from at least 2015 to 2025, in order to reflect the latest developments in biomarker research and qualitative methodology. The articles used include journals such as *Neurology, Molecular Psychiatry, Brain, Cells,* as well as methodological references from the

International *Journal of Qualitative Methods and the Journal of Research in Nursing* (Abraham, 2024; Doyle, 2019; Ferrari-Souza, 2022; Holper, 2024) .

Data collection techniques were carried out through scientific literature searches using databases such as PubMed, ScienceDirect, and Scopus. Each publication was selected based on its relevance to the themes of astrocyte activation, GFAP expression, and descriptive qualitative research methodology. The literature selection process was carried out systematically by reviewing the titles, abstracts, and main results of the studies. After the selection stage, all literature that met the inclusion criteria was classified based on major themes, including: (1) the relationship between GFAP and Alzheimer's pathology, (2) the diagnostic value of GFAP, and (3) qualitative analysis methodology (Bingham, 2023; Leipp, 2024; Pereira, 2021) .

The data analysis procedure was carried out in stages: theme identification, data reduction, concept categorization, and inductive conclusion drawing. In the initial stage, the researchers identified the main ideas and concepts from each source, then reduced the data by removing irrelevant information. The next stage was to group the data based on categories such as *biomarkers, neuroinflammation,* and the diagnostic validity of GFAP. Finally, conclusions were drawn inductively by combining empirical findings from various sources, thereby forming a complete conceptual understanding (Bingham, 2023; Vila-Henninger et al., 2022) .

The inclusive criteria for literature include sources that: (1) are published in reputable journals and have a DOI; (2) discuss GFAP, Alzheimer's, or qualitative research methods; and (3) are relevant to the biomedical context or research methodology. Meanwhile, the exclusion criteria include publications that have not undergone *peer review,* lack empirical data, or are editorial in nature. To maintain data validity, source triangulation is used by comparing findings from various studies and disciplines, as well as ensuring consistency of information between references (Doyle, 2019; Fife, 2024) .

The validity of the analysis results is maintained through conceptual audit trails and theoretical *peer review*, as recommended in modern qualitative research (Bingham, 2023; Pratt, 2025) . Audit trails are carried out by documenting every analysis decision, while *peer review* is used to assess the accuracy of interpretations of the literature. This qualitative-descriptive approach through literature review enables researchers to generate a deep, valid, and accountable understanding of the role of GFAP in the context of Alzheimer's dementia, in line with the goal of strengthening the theoretical basis and direction of *neurodegenerative biomarker* research.

Results and Discussion

The results of the literature review show that *glial fibrillary acidic* protein (GFAP) is the primary biomarker reflecting astrocyte activation (*astrogliosis*) in Alzheimer's disease (AD). All analyzed literature consistently reports increased GFAP levels, both in cerebrospinal fluid (CSF) and plasma, in line with disease progression from the *preclinical* stage to dementia (Holper, 2024; Kim, 2023; J. Shen et al., 2024) . These findings support the

role of GFAP as a sensitive *non-invasive* indicator of pathological changes in the brain even before cognitive symptoms appear.

Biologically, GFAP functions as an *intermediate filament* protein expressed by astrocytes to maintain cytoskeletal stability and blood-brain barrier integrity. In AD, there is increased GFAP expression due to astrocyte reactivation triggered by amyloid-β (Aβ) accumulation and *neuroinflammatory* changes (Ferrari-Souza, 2022; Leipp, 2024) . This activation not only indicates a protective response but also contributes to AD pathogenesis through the release of inflammatory mediators and disruption of ionic homeostasis (Chatterjee, 2021; Shir et al., 2022) .

Analysis of various cohort studies and meta-analyses reveals a strong association between plasma GFAP levels and Aβ burden in the brain. In studies by (Yang et al., 2023) and (X , GFAP levels were significantly elevated in individuals with Aβ deposition detected by PET imaging, even when tau biomarkers were still within normal limits. This confirms that GFAP is an early marker of *neuroinflammatory* processes that precede tau pathology and overt cognitive decline.

Additionally, several longitudinal studies have shown that increased GFAP levels can predict conversion from *mild cognitive impairment* (MCI) to *Alzheimer's dementia*. Studies by (Cicognola, 2020) and (Montoliu-Gaya et al., 2023) found that MCI patients with high plasma GFAP levels had twice the risk of conversion to AD compared to individuals with normal levels. GFAP also correlates with hippocampal atrophy and reduced episodic memory scores (X .

In terms of diagnostic performance, GFAP shows high accuracy (AUC > 0.90) in distinguishing AD from healthy controls and non-Alzheimer's dementia such as *frontotemporal dementia* (Marksteiner, 2025; Oeckl et al., 2022) . These findings reinforce the role of GFAP as *a biomarker* that is equivalent to or even superior to pTau181 and NfL in detecting the early stages of *neurodegenerative* disorders (Yang et al., 2023) . Comparisons between studies show consistency in findings, despite variations between measurement platforms such as SIMOA and *Lumipulse* (Marksteiner, 2025) .

However, despite its sensitivity, GFAP is not entirely specific to AD. Its expression also increases in other neurological diseases such as multiple sclerosis and head trauma (Ferrari-Souza, 2022; Leipp, 2024) . Therefore, the use of GFAP alone has the potential to cause false positive results. To address this limitation, recent studies emphasize the importance of integrating GFAP into a *multimodal biomarker* panel involving Aβ42/40, pTau181, NfL, and YKL-40 (Holper, 2024; Pelkmans, 2023) .

Table 1. Key findings based on literature synthesis results

Aspect	Key Findings	Reference
Increased GFAP in AD	GFAP increases in the preclinical stage, MCI, and AD dementia	(Chatterjee, 2021; Holper, 2024; Kim, 2023; X. Shen et al., 2023)
Correlation with Aβ	GFAP levels correlate with brain Aβ burden and astrocyte activity	(Chatterjee, 2021; Ferrari-Souza, 2022; Shir et al., 2022; Yang et al., 2023)

Aspect	Key Findings	Reference
Prediction of AD Progression	GFAP predicts conversion from MCI to AD and cognitive decline	(Cicognola, 2020; Montoliu-Gaya et al., 2023; X. Shen et al., 2023)
Diagnostic Performance	AUC > 0.90; distinguishes AD from controls and other dementias	(Marksteiner, 2025; Oeckl et al., 2022; Yang et al., 2023)
***Biomarker* Integration**	Combination of GFAP + Aβ + tau + YKL-40 improves diagnostic accuracy	(Holper, 2024; Leipp, 2024; Pelkmans, 2023)

In addition to diagnostic validity, GFAP also has potential as *a prognostic biomarker* and for therapy *monitoring*. Montoliu-Gaya et al. (2023) reported that GFAP levels decreased in AD patients receiving anti-Aβ therapy, indicating that this biomarker can be used to evaluate the effectiveness of pharmacological interventions (Montoliu-Gaya et al., 2023) . Thus, GFAP not only serves as an indicator of disease status but also as a tool for assessing therapeutic response.

Overall, the findings of this literature review confirm that GFAP is a multifunctional *biomarker* capable of describing the longitudinal and multidimensional dynamics of AD pathology. Its role is not limited to identifying *astrocytosis* but also includes predicting disease progression and monitoring therapeutic response. Combined with other biomarkers, GFAP is an essential component in a more precise and personalized approach to Alzheimer's diagnosis and management.

Discussion

Analysis of the literature review results shows that *glial fibrillary acidic* protein (GFAP) plays a central role in understanding *the pathophysiology of Alzheimer's Disease* (AD) from the perspective of astrocyte activation. The key finding that GFAP levels increase from the preclinical stage reinforces the *astrocyte reactivity hypothesis,* which states that astrocytes play not only a passive role in response to neuronal damage, but also an active role as mediators in *neuroinflammation* and the progression of . Thus, increased GFAP is not merely a marker of brain damage but a dynamic indicator of *microglial* changes and disrupted neural homeostasis.

These findings expand the classical concept of AD pathogenesis, which previously focused on amyloid-β (Aβ) accumulation and tau protein hyperphosphorylation. Literature analysis shows that astrocyte reactivation via increased GFAP precedes changes in tau and strongly correlates with Aβ accumulation (Chatterjee, 2021; Yang et al., 2023) . This provides a theoretical basis that astrocytes play a role in maintaining or even exacerbating Aβ pathology through proinflammatory cytokine secretion and impaired amyloid clearance mechanisms. Thus, reactive astrocytosis is an important stage in the transition from the preclinical phase to mild cognitive impairment (MCI).

From a clinical perspective, the implications of these findings are significant. The use of GFAP as a *non-invasive* plasma biomarker opens new opportunities for early detection of AD without the need for *invasive* procedures such as lumbar puncture or PET imaging (Holper, 2024; X. Shen et al., 2023) . The high diagnostic value of GFAP (AUC > 0.90) reinforces its potential for screening high-risk populations, particularly in the context of aging and mild cognitive impairment. On the other hand, the longitudinal relationship between GFAP levels and cognitive decline suggests that this *biomarker* may also serve as a predictive tool for monitoring disease progression (Cicognola, 2020; Montoliu-Gaya et al., 2023) .

Comparative analysis with previous studies shows that GFAP performance is often comparable or even superior to traditional *biomarkers* such as pTau181 and *neurofilament light* (NfL), particularly in the early stages of disease (Oeckl et al., 2022; Yang et al., 2023) . However, conflicting results have also been found in some studies, where GFAP sensitivity decreases when used in populations with mixed *neurodegenerative* disorders. This factor may be due to differences in measurement methodologies (e.g., SIMOA vs. Lumipulse technology) or variations in the patient population (Marksteiner, 2025) .

One of the main scientific contributions of these findings is the validation of the concept of *astrocytic reactivity* as a potential therapeutic target. When GFAP is considered an indicator of *astrocytic* burden, treatment strategies that suppress excessive astrocyte activity may potentially inhibit progressive *neuroinflammation* in AD. Research by Pelkmans et al. (2023) and Ferrari-Souza et al. (2022) shows that combining GFAP with other *biomarkers* such as YKL-40 and Aβ improves diagnostic precision and enables more accurate identification of disease transition phases (Ferrari-Souza, 2022; Pelkmans, 2023) . Thus, the use of a *multimarker* panel offers a more comprehensive approach compared to the use of GFAP alone.

However, although these findings reinforce the clinical value of GFAP, there are a number of limitations that must be acknowledged. First, GFAP is not entirely specific to Alzheimer's, as its expression is also increased in other diseases such as brain trauma, reactive *gliosis* due to *hypoxia,* and *multiple sclerosis* (Leipp, 2024) . Second, heterogeneity between study populations and variations in sampling techniques can affect data reliability. Third, the lack of a universally accepted GFAP threshold (*cut-off)* level is an obstacle to widespread clinical application (Holper, 2024) .

Another limitation relates to functional interpretation: whether the increase in GFAP is a form of protective compensation or part of a destructive mechanism that exacerbates *neurodegeneration* remains a matter of debate. Further studies with a multi-center longitudinal design are needed to answer this question and to explore the causal relationship between astrocyte reactivation, *neuroinflammation,* and synaptic dysfunction (Ferrari-Souza, 2022; Yang et al., 2023) . In the future, the integration of biological *biomarkers* such as GFAP with *neuroimaging* approaches and digital cognitive assessments is expected to yield more precise and personalized Alzheimer's disease diagnostic systems.

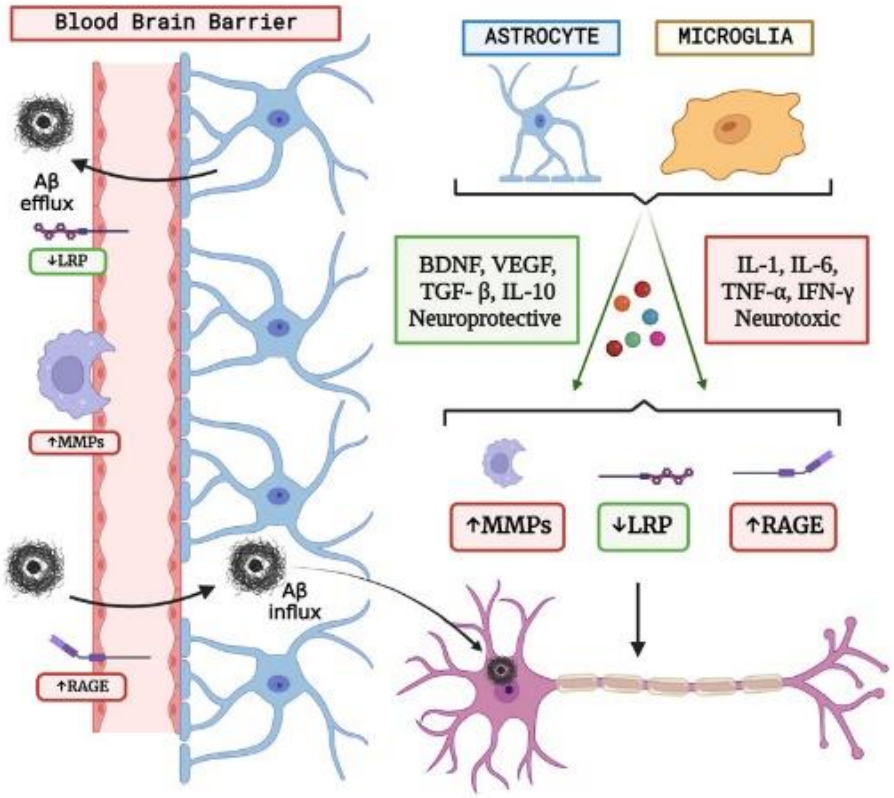

Figure 1. Illustration of the interaction between astrocytes, microglia, and neurons in the pathogenesis of Alzheimer's Disease through the mechanisms of increased GFAP, blood-brain barrier (BBB) dysfunction, and amyloid beta (Aβ) accumulation.

The figure clarifies the mechanism of interaction between astrocytes, microglia, , and neurons in the pathogenesis of Alzheimer's Disease, which is consistent with the discussion of the role of GFAP as a marker of astrocyte activation. Increased GFAP expression reflects astrocyte activation, which triggers changes in *the blood–brain barrier* through increased *matrix metalloproteinases* (MMPs), decreased *low-density lipoprotein-related protein* (LRP) receptors, and increased *receptor for advanced glycation end products* (RAGE), thereby inhibiting amyloid beta (Aβ) clearance and exacerbating its accumulation in the brain. This activation also promotes the release of proinflammatory mediators such as IL-1, IL-6, TNF-α, and IFN-γ through the *NF-κB* and *JAK/STAT3* pathways, which stimulate microglia and reinforce the chronic neuroinflammatory cycle. Thus, the image visually illustrates the central role of GFAP in marking astrocyte dysfunction and neuron-glia communication disorders that contribute to neurodegenerative progression in Alzheimer's disease.

Theoretically, these findings enrich our understanding of the complex interactions between astrocytes, neurons, and microglia in the context of neurodegeneration. Increased GFAP expression reflects activation of the astrocyte reactivity pathway, in which astrocyte cytoskeletal changes trigger the release of inflammatory mediators such as IL-1β, TNF-α, and IL-6 that contribute to neuronal dysfunction and microglial activation. In Alzheimer's dementia, this activation is associated with the *JAK/STAT3* and *NF-κB* pathways, which

stimulate the expression of proinflammatory genes and reinforce chronic neuroinflammatory feedback. Practically, this research provides a strong foundation for developing non-invasive screening strategies and biomarker-based therapy monitoring. The use of GFAP as part of a multimodal diagnostic panel could be a crucial step toward a new paradigm in Alzheimer's management that is more predictive, preventive, and personalized.

Conclusion

The results of this qualitative literature study confirm that *glial fibrillary acidic* protein (GFAP) plays an important role as *a* sensitive *biomarker* for astrocyte *activation* in Alzheimer's disease (AD), reflecting the dynamics of neuroinflammation that occur from the preclinical phase to advanced dementia. These findings reinforce the theory that astrocytosis is not merely a secondary response to neuronal damage, but rather an active element in the pathogenesis of AD that interacts closely with the accumulation of amyloid-β and tau. Conceptually, these research results expand the classical *neurodegenerative* theoretical framework by placing astrocytes as a central component in disease progression, while supporting a *multimodal biomarker* model that integrates GFAP with pTau, NfL, and YKL-40 for more precise diagnosis. Academically and clinically, these findings have implications for the development of *non-invasive* plasma-based diagnostic approaches and therapeutic strategies targeting astrocyte activity modulation. However, the limitations of the study, including the lack of consistency in measurement methods, population variation, and the absence of GFAP threshold standards, pose major challenges for global clinical application. Therefore, further research with longitudinal designs, cross-ethnic populations, and *neuroimaging* integration is recommended to deepen understanding of astrocyte reactivation mechanisms and their therapeutic potential in the broader context of neurodegeneration.

The study recommends integrating GFAP as a standardized, non-invasive biomarker for early Alzheimer's detection while urging further multidisciplinary research into its interactions with other markers to advance therapeutic strategies.

References

Abraham, D.; P., P. (2024). A Methodological Framework for Descriptive Phenomenological Research. *Western Journal of Nursing* Research, *47*

Ally, M.; S., M.; Zetterberg, H.; Blennow, K.; Ashton, N.; Karikari, T.; Aparicio, H.; Frank, B.; Tripodis, Y.; Martin, B. ; Palmisano, J. ; Steinberg, E. ; Simkin, I. ; Farrer, L. ; Jun, G. ; Turk, K. ; Budson, A. ; O'Connor, M. ; Au, R. ; Goldstein, L.; Kowall, N.; Killiany, R.; Stern, R.; Stein, T.; McKee, A.; Qiu, W.; Mez, J.; Alosco, M. (2023). Cross-sectional and longitudinal evaluation of plasma glial fibrillary acidic protein to detect and predict clinical syndromes of Alzheimer's disease. *Alzheimer's & Dementia: Diagnosis, Assessment & Disease Monitoring*, *15* . https://doi.org/10.1002/dad2.12492

Bandaranayake, P. (2024). Application of grounded theory methodology in library and information science research: An overview. *Sri Lanka Library Review*. https://doi.org/10.4038/sllr.v38i2.70

Bellaver, B.; F.-S., J.; Da Ros, L.; Carter, S.; Rodriguez-Vieitez, E.; Nordberg, A.; Pellerin, L.; Rosa-Neto, P. Leffa, D. ;. Zimmer, E. (2021). Astrocyte Biomarkers in Alzheimer Disease. *Neurology*, *96*. https://doi.org/10.1212/wnl.0000000000012109

Bingham, A. (2023). From Data Management to Actionable Findings: A Five-Phase Process of Qualitative Data Analysis. *International Journal of Qualitative Methods*, *22* . https://doi.org/10.1177/16094069231183620

Chatterjee, P.; P., S.; Stoops, E.; Goozee, K.; Villemagne, V.; Asih, P.; Verberk, I.; Dave, P.; Taddei, K.; Sohrabi, H. ;. Zetterberg, H. ;. Blennow, K. ;. Teunissen, C. ;. Vanderstichele, H. ;. Martins, R. (2021). Plasma glial fibrillary acidic protein is elevated in cognitively normal older adults at risk of Alzheimer's disease. *Translational* Psychiatry, *11*

Cicognola, C. ; J., S. ;. Hertze, J. ;. Zetterberg, H. ;. Blennow, K. ;. Mattsson-Carlgren, N. ;. Hansson, O. (2020). Plasma glial fibrillary acidic protein detects Alzheimer pathology and predicts future conversion to Alzheimer dementia in patients with mild cognitive impairment. *Alzheimer's Research & Therapy*, *13* . https://doi.org/10.1186/s13195-021-00804-9

De Bastiani, M.; B., B.; Brum, W.; Souza, D.; Ferreira, P.; Rocha, A.; Povala, G.; Ferrari-Souza, J.; Benedet, A.; Ashton, N.; Karikari, T.; Zetterberg, H.; Blennow, K.; Rosa-Neto, P.; Pascoal, T.; Zimmer, E. (2023). Hippocampal GFAP-positive astrocyte responses to amyloid and tau pathologies. *Brain, Behavior, and* Immunity, *110*

Doyle, L.; M., C.; Keogh, B.; Brady, A.; McCann, M. (2019). An overview of the qualitative descriptive design within nursing research. *Journal of Research in* Nursing, *25*

Ferrari-Souza, J.; F., P.; Bellaver, B.; Tissot, C.; Wang, Y.; Leffa, D.; Brum, W.; Benedet, A.; Ashton, N.; De Bastiani, M.; Rocha, A.; Therriault, J.; Lussier, F.; Chamoun, M.; Servaes, S. ;. Bezgin, G. ;. Kang, M. ;. Stevenson, J. ;. Rahmouni, N. ;. Pallen, V. ;. Poltronetti, N. ;. Klunk, W. ;. Tudorascu, D.; Cohen, A.; Villemagne, V.; Gauthier, S.; Blennow, K.; Zetterberg, H.; Souza, D.; Karikari, T.; Zimmer, E.; Rosa-Neto, P.; Pascoal, T. (2022). Astrocyte biomarker signatures of amyloid-β and tau pathologies in Alzheimer's disease. *Molecular Psychiatry*, *27* . https://doi.org/10.1038/s41380-022-01716-2

Fife, S. ; G., J. (2024). Deductive Qualitative Analysis: Evaluating, Expanding, and Refining Theory. *International Journal of Qualitative Methods*, *23* . https://doi.org/10.1177/16094069241244856

Holper, S.; L., P.; Churilov, L.; Italiano, D.; Watson, R.; Yassi, N. (2024). Blood Astrocyte Biomarkers in Alzheimer Disease. *Neurology*, *103* . https://doi.org/10.1212/wnl.0000000000209537

Kim, K.; S., K.; Chang, K. (2023). GFAP as a Potential Biomarker for Alzheimer's Disease: A Systematic Review and Meta-Analysis. Cells, *12*

Leipp, F.; V., J.; Mohaupt, P.; Coppens, S.; Jaffuel, A.; Niehoff, A.; Lehmann, S.; Hirtz, C. (2024). Glial fibrillary acidic protein in Alzheimer's disease: A narrative review. *Brain Communications*, *6* . https://doi.org/10.1093/braincomms/fcae396

Marksteiner, J.; H., C. (2025). Glial fibrillary acidic protein as a biomarker for diagnosis of Alzheimer's disease in cerebrospinal fluid, plasma and saliva measured with Lumipulse technology: A narrative review. *NeuroMarkers*. https://doi.org/10.1016/j.neumar.2025.100038

Montoliu-Gaya, L., Alcolea, D., Ashton, N., Pegueroles, J., Levin, J., Bosch, B., Lantero-Rodríguez, J., Carmona-Iragui, M., Wagemann, O., Balasa, M., Kac, P., Barroeta, I., Lladó, A., Brum, W., Videla, L., González-Ortiz, F., Benejam, B., Martínez, J., Karikari, T., … Fortea, J. (2023). Plasma and cerebrospinal fluid glial fibrillary acidic protein levels in adults with Down syndrome: A longitudinal cohort study. *EBioMedicine*, *90* , 104547. https://doi.org/10.1016/j.ebiom.2023.104547

Oeckl, P., Anderl-Straub, S., Von Arnim, C., Baldeiras, I., Diehl-Schmid, J., Grimmer, T., Halbgebauer, S., Kort, A., Lima, M., Marques, T., Ortner, M., Santana, I., Steinacker, P., Verbeek, M., Volk, A., Ludolph, A., & Otto, M. (2022). Serum GFAP differentiates Alzheimer's disease from frontotemporal dementia and predicts MCI-to-dementia conversion. *Journal of Neurology, Neurosurgery, and* Psychiatry, *93*

Ozcelikay-Akyıldız, G., Karadurmus, L., Çetinkaya, A., Uludağ, İ., Ozcan, B., Unal, M., Sezginturk, M., & Ozkan, S. (2024). The Evaluation of Clinical Applications for the Detection of the Alzheimer's Disease Biomarker GFAP. *Critical Reviews in Analytical Chemistry*, 1–12. https://doi.org/10.1080/10408347.2024.2393874

Pelkmans, W.; S., M.; Brugulat-Serrat, A.; Sánchez-Benavides, G.; Minguillón, C.; Fauria, K.; Molinuevo, J.; Grau-Rivera, O. ;. Escalante, A. ;. Kollmorgen, G. ;. Carboni, M. ;. Ashton, N. ;. Zetterberg, H. ;. Blennow, K. ;. Suárez-Calvet, M. ;. Gispert, J. (2023). Astrocyte biomarkers GFAP and YKL-40 mediate early Alzheimer's disease progression. *Alzheimer's &* Dementia, *20*

Pereira, J.; J., S.; Smith, R.; Mattsson-Carlgren, N.; Palmqvist, S.; Teunissen, C.; Zetterberg, H.; Stomrud, E.; Ashton, N.; Blennow, K.; Hansson, O. (2021). Plasma GFAP is an early marker of amyloid-β but not tau pathology in Alzheimer's disease. *Brain*, *144* . https://doi.org/10.1093/brain/awab223

Pratt, M. (2025). On the Evolution of Qualitative Methods in Organizational Research. *Annual Review of Organizational Psychology and Organizational Behavior*. https://doi.org/10.1146/annurev-orgpsych-111722-032953

Sánchez-Juan, P., Valeriano-Lorenzo, E., Ruiz-González, A., Pastor, A., Lara, H., López-González, F., Zea-Sevilla, M., Valentí, M., Frades, B., Ruiz, P., Saiz, L., Burgueño-García, I., Calero, M., Del Ser, T., & Rábano, A. (2024). Serum GFAP levels correlate with astrocyte reactivity, post-mortem brain atrophy and neurofibrillary tangles. Brain, *147*

Shen, J., Bu, F., Ye, Z., Zhang, M., Q., Yan, J., & Huang, T. (2024). Management of drug supply chain information based on "artificial intelligence + vendor managed inventory" in China: Perspective based on a case study. *Frontiers in* Pharmacology, *15*

Shen, X., Huang, S., Cui, M., Zhao, Q., Guo, Y., Huang, Y., Zhang, W., Chen, S., Zhang, Y., Chen, S., Chen, K., Cheng, W., Zuo, C., Tan, L., Ding, D., Dong, Q., Jeromin, A., Yen, T., & Yu, J. (2023). Plasma Glial Fibrillary Acidic Protein in the Alzheimer Disease Continuum: Relationship to Other Biomarkers, Differential Diagnosis, and Prediction of Clinical Progression. *Clinical Chemistry.* https://doi.org/10.1093/clinchem/hvad018

Shir, D., Graff-Radford, J., Hofrenning, E., Lesnick, T., Przybelski, S., Lowe, V., Knopman, D., Petersen, R., Jack, C., Vemuri, P., Algeciras-Schimnich, A., Campbell, M., Stricker, N., & Mielke, M. (2022). Association of plasma glial fibrillary acidic protein (GFAP) with neuroimaging of Alzheimer's disease and vascular pathology. *Alzheimer's & Dementia: Diagnosis, Assessment & Disease Monitoring*, *14* . https://doi.org/10.1002/dad2.12291

Togia, A. ; M., A. (2017). *Research Methods in Library and Information Science*. IntechOpen. https://doi.org/10.5772/intechopen.68749

Varma, V., An, Y., Kac, P., Bilgel, M., Moghekar, A., Loeffler, T., Amschl, D., Troncoso, J., Blennow, K., Zetterberg, H., Ashton, N., Resnick, S., & Thambisetty, M. (2024). Longitudinal progression of blood biomarkers reveals a key role of astrocyte reactivity in preclinical Alzheimer's disease. *medRxiv.* https://doi.org/10.1101/2024.01.25.24301779

Vila-Henninger, L., Dupuy, C., Van Ingelgom, V., Caprioli, M., Teuber, F., Pennetreau, D., Bussi, M., & Gall, C. (2022). Abductive coding: Theory building and qualitative (re)analysis. *Sociological Methods &* Research, *53*

Yang, Z., Sreenivasan, K., Strom, E., Osse, A., Pasia, L., Cosme, C., Mugosa, M., Chevalier, E., Ritter, A., Miller, J., Cordes, D., Cummings, J., & Kinney, J. (2023). Clinical and biological relevance of glial fibrillary acidic protein in Alzheimer's disease. *Alzheimer's Research &* Therapy, *15*