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Sleep Disturbances Across the Clinical Continuum of Alzheimer's Disease: Associations with Disease Duration and Care Environment—A Cross-Sectional Study

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Research Article

Keywords: Alzheimer's disease, sleep disturbances, sleep–wake cycle, daytime sleepiness, nursing homes, dementia

Posted Date: November 3rd, 2026

DOI: https://doi.org/10.21203/rs.3.rs-10646155/v1

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Additional Declarations: No competing interests reported.

Abstract

Background

Sleep disturbances are among the most common non-cognitive manifestations of Alzheimer's disease (AD) and contribute to functional decline, reduced quality of life, and caregiver burden. Although sleep impairment has been widely investigated in AD, the influence of care setting on sleep disturbances and their relationship with disease duration remains poorly understood. This study evaluated the prevalence and characteristics of sleep disturbances in patients with AD and examined their associations with disease duration, daytime napping, and care setting.

Methods

This cross-sectional study included 70 patients with clinically diagnosed AD recruited from nursing homes (n = 51) and community-based support services (n = 19). Sleep disturbances were assessed using a structured study-specific questionnaire supported by caregiver reports, the Athens Insomnia Scale (AIS), and the Epworth Sleepiness Scale (ESS). Cognitive and functional status was assessed using standardised clinical instruments. Associations between sleep disturbances and clinical variables were analysed using non-parametric statistical methods.

Results

Sleep disturbances were highly prevalent. The most common symptoms were excessive daytime sleepiness (90.0%), nocturnal awakenings (84.3%), difficulty initiating sleep (74.3%), and snoring (62.9%). Sleep-related symptoms preceding the clinical diagnosis of AD were reported in 47 participants (67.1%). Greater sleep disturbance burden was associated with longer disease duration (Spearman's $\rho = 0.26$, $p = 0.030$) and daytime napping ($p = 0.0047$). Nursing home residents had a greater sleep disturbance burden than community-dwelling participants (median 8 [IQR 6–9] vs 6 [5–7], $p = 0.006$) and also had higher AIS (10 [9–12] vs 6 [3–10], $p = 0.0065$) and ESS scores (9 [8–12] vs 7 [5–8], $p = 0.0013$).

Conclusions

Sleep disturbances are highly prevalent throughout the course of AD and may precede its clinical diagnosis. Greater sleep disturbance burden was associated with longer disease duration and was higher among nursing home residents than community-dwelling participants. These findings support systematic assessment of sleep disturbances as part of comprehensive dementia care across different care settings. Longitudinal studies incorporating objective sleep measures are needed to clarify the temporal relationships between sleep disturbances, disease progression, and care environment.

BACKGROUND

Sleep is increasingly recognised as a potentially modifiable determinant of neurodegeneration and has become an important focus of Alzheimer's disease (AD) research. Over the past decade, accumulating experimental, biomarker, and longitudinal clinical evidence has transformed the traditional view of sleep disturbances from a secondary consequence of neurodegeneration into an integral component of AD pathophysiology. Although cognitive decline remains the defining clinical feature of AD, non-cognitive manifestations—including disturbances of sleep and circadian regulation—substantially contribute to disability, loss of independence, caregiver burden, and institutionalisation. As the global burden of dementia continues to increase, identifying potentially modifiable factors that may influence disease progression and patient outcomes has become a major priority in both geriatric medicine and dementia research.[1–3]

Alzheimer's disease accounts for approximately 60–70% of dementia cases and currently affects millions of people worldwide, with the global burden projected to increase substantially over the coming decades.[4,5] Alongside progressive cognitive impairment, patients frequently develop behavioural and psychological symptoms as well as disturbances of circadian rhythms and the sleep–wake cycle. Sleep disturbances affect a substantial proportion of individuals with AD, although reported prevalence varies according to disease stage, diagnostic criteria, and assessment methodology. The most common manifestations include insomnia, fragmented nocturnal sleep, excessive daytime sleepiness, circadian rhythm disruption, sleep-disordered breathing, and periodic limb movements during sleep. Beyond their high prevalence, these disturbances are associated with poorer cognitive and functional outcomes, behavioural symptoms, reduced quality of life, increased caregiver burden, and institutionalisation, underscoring their clinical relevance throughout the disease course.[6–11]

Over the past decade, our understanding of the relationship between sleep and AD has fundamentally changed. Early neuropathological models primarily considered sleep disruption to be a consequence of degeneration within brain regions regulating the sleep–wake cycle, including the suprachiasmatic nucleus, hypothalamus, and brainstem nuclei. However, experimental studies subsequently demonstrated that physiological sleep facilitates the clearance of neurotoxic metabolites, including amyloid-β, providing a mechanistic link between sleep disruption and neurodegeneration.[2] More recent experimental and biomarker studies have shown that sleep–wake activity influences tau dynamics and that impaired sleep is associated with greater cerebral amyloid and tau burden.[3,4,12–15] These observations support a bidirectional model in which neurodegeneration disrupts normal sleep architecture and circadian regulation, while disturbed sleep may, in turn, contribute to pathological processes underlying AD.

Clinical and epidemiological observations further support this concept. Longitudinal studies indicate that excessive daytime sleepiness, insomnia, fragmented sleep, circadian disruption, and sleep-disordered breathing may precede clinically overt dementia and are associated with an increased risk of subsequent cognitive decline.[8–10,16–18] Consequently, disturbances of the sleep–wake cycle are

increasingly recognised not only as common clinical manifestations of Alzheimer's disease but also as potential early indicators of ongoing neurodegenerative processes. Despite growing interest in sleep as a potentially modifiable component of dementia care, however, considerably less is known about the clinical factors associated with the burden of sleep disturbances once Alzheimer's disease has been established.

Existing studies have primarily focused on biological mechanisms or individual sleep disorders, whereas less attention has been paid to environmental and care-related factors.[8,16–19] Patients residing in long-term care facilities are exposed to multiple conditions that may adversely affect the sleep–wake cycle, including reduced daytime physical activity, limited exposure to natural daylight, nocturnal environmental noise, shared accommodation, frequent nursing interventions, and disruption of habitual daily routines.[11,19] In contrast, community-dwelling individuals may retain more stable environmental cues, regular social interactions, and individualised sleep habits, factors that may support circadian regulation despite progressive neurodegeneration.[9,20] The extent to which differences in care setting contribute to the burden of sleep disturbances remains insufficiently understood.[11,19,20] Likewise, although disease duration may influence sleep through progressive neurodegeneration and increasing functional dependency, relatively few studies have simultaneously evaluated the relationships between sleep disturbance burden, disease duration, daytime napping, and care setting within the same cohort of patients with Alzheimer's disease.[9,11,12,17]

The present study aimed to characterize the clinical profile and burden of sleep disturbances in patients with Alzheimer's disease and to examine their associations with disease duration, daytime napping, and care setting. We also assessed the occurrence of sleep-related symptoms before the clinical diagnosis of Alzheimer's disease and compared sleep disturbances between nursing home residents and community-dwelling individuals.

METHODS

Study design and participants

This cross-sectional observational study was conducted between December 2021 and March 2022 in Kraków, Poland. Participants were consecutively recruited from three specialised care facilities: the St. Francis Home for Sick Priests of the Archdiocese of Kraków (*Dom Księży Chorych Archidiecezji Krakowskiej im. św. Franciszka*), the Residential Home for Older Adults (*Dom Opieki dla Starszych*), and the Community Support Centre for People with Alzheimer's Disease (*Środowiskowy Dom Samopomocy dla Osób z Chorobą Alzheimera*). The first two institutions provide long-term residential care, whereas the Community Support Centre offers multidisciplinary daytime support for community-dwelling individuals with Alzheimer's disease.

A total of 70 participants with clinically diagnosed Alzheimer's disease (AD) were enrolled, including 51 nursing home residents and 19 community-dwelling individuals attending the Community Support

Centre.

The diagnosis of Alzheimer's disease had previously been established by an experienced neurologist according to the National Institute on Aging–Alzheimer's Association (NIA-AA) diagnostic criteria for probable Alzheimer's disease.[21] Before enrolment, all diagnoses were verified by reviewing the available medical records. As part of routine clinical care preceding enrolment in the present study, cognitive function had been assessed using the Mini-Mental State Examination (MMSE)[22] and the Montreal Cognitive Assessment (MoCA).[23] These assessments were performed as part of the participants' previous routine clinical diagnostic evaluation and were not administered as part of the present study protocol. MMSE and MoCA scores were not used in the analyses reported in this study. Available structural brain magnetic resonance imaging (MRI), performed as part of routine clinical evaluation, was also reviewed to support the clinical diagnosis and exclude alternative structural causes of cognitive impairment.

Eligible participants were adults with a confirmed diagnosis of Alzheimer's disease whose clinical condition allowed completion of the study procedures. Patients with other neurodegenerative dementias or severe medical conditions interfering with study participation were excluded. Participants were recruited consecutively throughout the study period. Because the study was conducted within an established clinical cohort, the number of patients screened but not enrolled was not prospectively recorded. The study is reported in accordance with the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) statement.[24] The participant recruitment process is summarised in Fig. 1.

Figure 1. Flow chart illustrating participant recruitment and allocation according to care setting.

Clinical assessment

Sociodemographic and clinical data were collected using a structured study-specific questionnaire developed by the investigators following a comprehensive review of the literature and their clinical experience in the assessment of sleep disturbances in Alzheimer's disease. The questionnaire was used to collect demographic and disease-related information, including age, sex, educational level, place of residence, disease duration, duration of institutional care (where applicable), and selected lifestyle characteristics relevant to sleep. Clinical records were additionally reviewed to obtain information on disease duration, comorbidities, and current pharmacological treatment. When participants were unable to provide reliable information because of cognitive impairment, supplementary data were obtained from family members or healthcare professionals directly involved in their daily care. An overview of the domains assessed by the study-specific questionnaire is provided in Supplementary Table S1, and operational definitions of the principal sleep-related variables are presented in Supplementary Table S2.

Sleep assessment

Sleep disturbances were assessed using the study-specific questionnaire together with two validated instruments: the Athens Insomnia Scale (AIS) and the Epworth Sleepiness Scale (ESS). The study-specific questionnaire was designed to characterise the clinical profile of sleep disturbances, including nocturnal symptoms, excessive daytime sleepiness, daytime napping, evening agitation, and the occurrence of sleep-related symptoms before the clinical diagnosis of Alzheimer's disease. It also evaluated selected behavioural and environmental factors potentially influencing sleep. Further details regarding questionnaire development and administration are provided in Supplementary Appendix S1. The English translation of the original Polish study-specific questionnaire used for data collection is provided in Supplementary Appendix S2. For the present analyses, overall sleep disturbance burden was defined as the number of sleep-related symptoms reported as present among the 12 symptom domains assessed in the study-specific questionnaire. For calculation of the sleep disturbance burden score, “Never” was coded as absent (0), whereas any reported occurrence (< 1 time/week, 1–3 times/week, > 4 times/week, or daily) was coded as present (1).

Insomnia symptoms were assessed using the Athens Insomnia Scale (AIS), a validated eight-item questionnaire evaluating both nocturnal insomnia symptoms and their daytime consequences.[25] Excessive daytime sleepiness was assessed using the Epworth Sleepiness Scale (ESS).[26] Participants completed the questionnaires independently whenever possible. When cognitive impairment limited reliable self-reporting, the investigator read each question aloud and recorded participants' responses without interpretation or modification. Information regarding symptoms that could not be reliably reported by participants, including snoring, witnessed sleep apnoea and abnormal nocturnal behaviours, was additionally obtained from family caregivers or nursing staff familiar with the participants' daily functioning.

Cognitive assessment

Global cognitive function was assessed using the Blessed Dementia Scale, a validated instrument evaluating both cognitive impairment and functional deterioration associated with dementia.[27] Visuospatial and executive functions were additionally evaluated using the Sunderland Clock Drawing Test, a validated screening tool widely used for the assessment of cognitive dysfunction in older adults.[28] All cognitive assessments were performed by trained investigators according to standardised administration procedures.

Statistical analysis

Statistical analyses were performed using Statistica version 10.0 (StatSoft Polska, Kraków, Poland). The normality of continuous variables was assessed using the Shapiro–Wilk test. Continuous variables are presented as mean ± standard deviation (SD) or median with interquartile range (IQR), as appropriate, whereas categorical variables are presented as numbers and percentages.

Because most continuous variables were not normally distributed, non-parametric statistical methods were applied. Comparisons between two independent groups were performed using the Mann–Whitney U test, whereas comparisons involving more than two groups were conducted using the Kruskal–Wallis test. Categorical variables were compared using the chi-square test or Fisher's exact test, as appropriate. Associations between continuous or ordinal variables were assessed using Spearman's rank correlation coefficient (ρ). All statistical tests were two-sided, and a p-value < 0.05 was considered statistically significant.

Ethical considerations

The study protocol was approved by the Bioethics Committee of Andrzej Frycz Modrzewski Krakow University, Kraków, Poland (approval No. KBKA/75/O/2021; 23 November 2021). The study was conducted in accordance with the ethical principles of the Declaration of Helsinki. Written informed consent was obtained from all participants or, where appropriate, from their legally authorised representatives before enrolment. This study is reported in accordance with the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) guidelines for cross-sectional studies.[24]

RESULTS

Study population

Seventy participants with clinically diagnosed Alzheimer's disease were included in the study, comprising 51 nursing home residents (72.9%) and 19 community-dwelling individuals (27.1%). The mean age of the study population was 78.5 ± 7.9 years (range, 60–94 years), and 32 participants (45.7%) were women. Median disease duration was 5.0 years [IQR 3.0–6.0].

Nursing home residents had a longer disease duration than community-dwelling participants (5.0 [3.5–6.5] vs 3.0 [2.0–4.0] years, p < 0.001) and greater functional impairment, reflected by lower Barthel Index (55.0 [35.0–80.0] vs 95.0 [87.5–97.5], p < 0.001) and ADL scores (3.0 [1.0–5.0] vs 6.0 [6.0–6.0], p < 0.001). Depressive symptom scores were also higher among nursing home residents (14.0 [12.0–17.0] vs 8.0 [8.0–15.0], p = 0.007). The groups did not differ significantly with respect to age, sex, educational level, or AD stage. Baseline demographic and clinical characteristics are presented in Table 1.

Table 1
Demographic and clinical characteristics of the study population

Characteristic	Overall (n = 70)	Nursing home (n = 51)	Community-dwelling (n = 19)	P value
Age, years	78.5 ± 7.9	79.4 ± 7.9	76.3 ± 7.5	0.097
Female sex, n (%)	32 (45.7)	20 (39.2)	12 (63.2)	0.106
Education, n (%)				0.190
Primary	8 (11.4)	7 (13.7)	1 (5.3)	
Vocational	14 (20.0)	9 (17.6)	5 (26.3)	
Secondary	16 (22.9)	9 (17.6)	7 (36.8)	
Higher	32 (45.7)	26 (51.0)	6 (31.6)	
Disease duration, years	5.0 [3.0–6.0]	5.0 [3.5–6.5]	3.0 [2.0–4.0]	< 0.001
AD stage, n (%)				0.597
Mild	30 (42.9)	20 (39.2)	10 (52.6)	
Moderate	23 (32.9)	18 (35.3)	5 (26.3)	
Severe	17 (24.3)	13 (25.5)	4 (21.1)	
Barthel Index, points	70.0 [40.0–90.0]	55.0 [35.0–80.0]	95.0 [87.5–97.5]	< 0.001
ADL score, points	4.0 [2.0–6.0]	3.0 [1.0–5.0]	6.0 [6.0–6.0]	< 0.001
Depression scale score	13.0 [9.2–17.0]	14.0 [12.0–17.0]	8.0 [8.0–15.0]	0.007
Sleep disturbances before AD diagnosis, n (%)	47 (67.1)	35 (68.6)	12 (63.2)	0.776
Daily daytime naps, n (%)	58 (82.9)	49 (96.1)	9 (47.4)	< 0.001
Any hypnotic medication use, n (%)	53 (75.7)	43 (84.3)	10 (52.6)	0.011
Pain complaints, n (%)	50 (71.4)	40 (78.4)	10 (52.6)	0.042
Hypertension, n (%)	45 (64.3)	34 (66.7)	11 (57.9)	0.579
Diabetes mellitus, n (%)	25 (35.7)	20 (39.2)	5 (26.3)	0.406

Values are presented as mean ± SD, median [IQR], or n (%), as appropriate. Continuous variables were compared using the Mann–Whitney U test; categorical variables were compared using Fisher's exact test or the chi-square test, as appropriate. AD, Alzheimer's disease; ADL, activities of daily living; IQR, interquartile range; SD, standard deviation.

Characteristic	Overall (n = 70)	Nursing home (n = 51)	Community-dwelling (n = 19)	P value
Atrial fibrillation, n (%)	11 (15.7)	8 (15.7)	3 (15.8)	1.000
Heart failure, n (%)	32 (45.7)	24 (47.1)	8 (42.1)	0.791

Values are presented as mean ± SD, median [IQR], or n (%), as appropriate. Continuous variables were compared using the Mann–Whitney U test; categorical variables were compared using Fisher's exact test or the chi-square test, as appropriate. AD, Alzheimer's disease; ADL, activities of daily living; IQR, interquartile range; SD, standard deviation.

Prevalence and clinical profile of sleep disturbances

Sleep-related symptoms were highly prevalent and encompassed nocturnal, daytime, behavioural, and breathing-related manifestations. The most frequently reported symptom was excessive daytime sleepiness, present in 63 participants (90.0%), followed by nocturnal awakenings in 59 (84.3%), difficulty initiating sleep in 52 (74.3%), and snoring in 44 (62.9%).

Several individual sleep disturbances were significantly more frequent among nursing home residents than among community-dwelling participants. These included excessive daytime sleepiness (98.0% vs 68.4%, p = 0.001), nocturnal awakenings (92.2% vs 63.2%, p = 0.007), difficulty initiating sleep (82.4% vs 52.6%, p = 0.028), and witnessed sleep apnoea (43.1% vs 10.5%, p = 0.011). No significant between-group differences were observed for early morning awakening, evening agitation, aggressive behaviour at night, sleep–wake reversal, snoring, abnormal limb movements, nightmares, or shouting during sleep. The distribution of individual sleep disturbances is presented in Table 2.

Table 2
Frequency of individual sleep disturbances by care setting

Sleep disturbance	Overall n (%)	Nursing home n (%)	Community-dwelling n (%)	P value
Insomnia-related symptoms				
Difficulty initiating sleep	52 (74.3)	42 (82.4)	10 (52.6)	0.028
Nocturnal awakenings	59 (84.3)	47 (92.2)	12 (63.2)	0.007
Early morning awakening	32 (45.7)	22 (43.1)	10 (52.6)	0.592
Circadian/behavioural symptoms				
Evening agitation	31 (44.3)	26 (51.0)	5 (26.3)	0.104
Aggressive behaviour at night	11 (15.7)	10 (19.6)	1 (5.3)	0.267
Sleep–wake reversal	15 (21.4)	11 (21.6)	4 (21.1)	1.000
Breathing-related symptoms				
Snoring	44 (62.9)	33 (64.7)	11 (57.9)	0.781
Witnessed sleep apnoea	24 (34.3)	22 (43.1)	2 (10.5)	0.011
Parasomnia-like symptoms				
Abnormal limb movements	18 (25.7)	16 (31.4)	2 (10.5)	0.123
Nightmares	7 (10.0)	5 (9.8)	2 (10.5)	1.000
Shouting during sleep	6 (8.6)	5 (9.8)	1 (5.3)	1.000
Daytime symptoms				
Excessive daytime sleepiness	63 (90.0)	50 (98.0)	13 (68.4)	0.001

A symptom was considered present when reported at least 1–3 times per week. P values were calculated using Fisher's exact test. Symptoms are grouped according to their predominant clinical domain.

Sleep assessment and overall sleep disturbance burden

The median AIS score in the overall cohort was 10.0 [7.0–12.0], and 56 participants (80.0%) had an AIS score ≥ 6. The median ESS score was 8.0 [7.0–11.0], while 21 participants (30.0%) had an ESS score > 10.

Nursing home residents had significantly higher AIS scores than community-dwelling participants (10.0 [9.0–12.0] vs 6.0 [3.0–10.0], p = 0.006) and higher ESS scores (9.0 [8.0–12.0] vs 7.0 [5.0–8.0], p = 0.001). An AIS score ≥ 6 was observed in 90.2% of nursing home residents compared with 52.6% of community-

dwelling participants (p = 0.001), whereas an ESS score > 10 was present in 39.2% and 5.3%, respectively (p = 0.007).

The median overall sleep disturbance burden was 7.0 [6.0–9.0] symptoms. Nursing home residents had a significantly greater sleep disturbance burden than community-dwelling participants (8.0 [6.0–9.0] vs 6.0 [5.0–7.0], p = 0.006) (Table 3).

Table 3
Sleep assessment using validated instruments and study-specific sleep disturbance burden

Variable	Overall	Nursing home	Community-dwelling	P value
Athens Insomnia Scale, points	10.0 [7.0–12.0]	10.0 [9.0–12.0]	6.0 [3.0–10.0]	0.006
AIS ≥ 6, n (%)	56 (80.0)	46 (90.2)	10 (52.6)	0.001
Epworth Sleepiness Scale, points	8.0 [7.0–11.0]	9.0 [8.0–12.0]	7.0 [5.0–8.0]	0.001
ESS > 10, n (%)	21 (30.0)	20 (39.2)	1 (5.3)	0.007
Sleep disturbance burden, number of symptoms	7.0 [6.0–9.0]	8.0 [6.0–9.0]	6.0 [5.0–7.0]	0.006

Continuous values are presented as median [IQR] and compared using the Mann–Whitney U test. Threshold-based proportions were compared using Fisher's exact test. AIS, Athens Insomnia Scale; ESS, Epworth Sleepiness Scale; IQR, interquartile range. Sleep disturbance burden denotes the number of study-specific sleep symptoms present.

Factors associated with sleep disturbance burden

Sleep disturbance burden was positively associated with disease duration (Spearman's ρ = 0.259, p = 0.030). Daytime napping frequency was also significantly associated with sleep disturbance burden (Kruskal–Wallis H = 12.95, p = 0.0047). In addition, sleep disturbance burden differed significantly according to care setting, with a greater number of sleep-related symptoms among nursing home residents than among community-dwelling participants (Mann–Whitney U = 690.5, p = 0.006).

Among nursing home residents, however, the duration of institutional stay was not significantly associated with sleep disturbance burden (Spearman's ρ = 0.096, p = 0.503) (Table 4).

Table 4
Factors associated with sleep disturbance burden

Factor	Statistical test	Statistic	P value
Disease duration	Spearman rank correlation	ρ = 0.259	0.030
Daytime napping frequency	Kruskal–Wallis test	H = 12.95	0.0047
Care setting (nursing home vs community)	Mann–Whitney U test	U = 690.5	0.006
Duration of institutional stay (nursing home residents only, n = 51)	Spearman rank correlation	ρ = 0.096	0.503

Sleep disturbance burden denotes the number of study-specific sleep symptoms present. The analysis of duration of institutional stay was restricted to nursing home residents; no significant association with sleep disturbance burden was observed. The previously reported correlation obtained by coding community-dwelling participants as 0 years of institutional stay should not be interpreted as an effect of length of institutionalisation.

Sleep disturbances preceding the clinical diagnosis of Alzheimer's disease

Sleep-related symptoms preceding the clinical diagnosis of Alzheimer's disease were reported retrospectively in 47 of 70 participants (67.1%). The proportion was similar among nursing home residents and community-dwelling participants (68.6% vs 63.2%, respectively; p = 0.776) (Table 5).

Table 5
Sleep disturbances preceding the clinical diagnosis of Alzheimer’s disease

Variable	Overall (n = 70)	Nursing home (n = 51)	Community-dwelling (n = 19)	P value
Sleep disturbances before AD diagnosis, n (%)	47 (67.1)	35 (68.6)	12 (63.2)	0.776

Retrospective data were obtained from participants and/or caregivers. The database did not contain a separate variable quantifying the exact number of years between onset of sleep-related symptoms and the clinical diagnosis of Alzheimer’s disease. P value was calculated using Fisher’s exact test.

DISCUSSION

Sleep disturbances are increasingly recognised as one of the most clinically relevant non-cognitive manifestations of Alzheimer's disease (AD), reflecting not only the consequences of neurodegeneration but also biological processes that may actively contribute to disease progression. Experimental, biomarker, and longitudinal studies published over the past decade have fundamentally reshaped our understanding of the relationship between sleep and AD, demonstrating that this interaction is bidirectional. Disturbed sleep may result from progressive degeneration of neural networks regulating

circadian rhythms and sleep architecture, whereas chronic sleep disruption may further accelerate amyloid-β and tau pathology through impaired glymphatic clearance, neuroinflammation, and altered neuronal activity.[2–6, 13–15]

Against this evolving conceptual framework, the present study provides additional clinical evidence by comprehensively characterising sleep disturbances in patients with AD across two distinct care settings. Three clinically relevant findings emerged from our study. First, sleep disturbances were highly prevalent and extended beyond nocturnal symptoms to include excessive daytime sleepiness and impaired daytime alertness, indicating that disturbances of the sleep–wake cycle constitute a multidimensional clinical syndrome rather than isolated complaints of insomnia. Second, sleep-related symptoms were frequently reported before the clinical diagnosis of AD, providing further clinical support for the hypothesis that abnormalities of the sleep–wake cycle may accompany the earliest stages of neurodegeneration. Third, patients residing in nursing homes experienced a substantially greater burden of sleep disturbances than community-dwelling individuals. Although differences in disease duration and functional status between the groups preclude attribution of this finding to the care environment alone, the observed association suggests that care setting may represent an important contextual factor in the clinical expression of sleep disturbances.

One of the most clinically meaningful findings of the present study was that sleep-related symptoms were frequently reported before the clinical diagnosis of Alzheimer's disease. Although these observations were obtained retrospectively and should therefore be interpreted with appropriate caution, they provide additional clinical evidence supporting the concept that disturbances of the sleep–wake cycle may accompany the earliest stages of Alzheimer's disease rather than simply emerge as a consequence of established dementia. Importantly, this finding reflects routine clinical practice and caregiver observations, thereby complementing evidence derived from longitudinal cohort studies and biomarker-based investigations. Although our cross-sectional design does not permit conclusions regarding temporality or causality, these observations suggest that systematic assessment of sleep complaints may contribute to the early clinical evaluation of individuals at increased risk of neurodegenerative disease.

These findings are consistent with the contemporary biological model of Alzheimer's disease, which conceptualises the disorder as a prolonged continuum beginning years or even decades before the onset of overt cognitive impairment. Within this framework, disturbances of the sleep–wake cycle are increasingly recognised as among the earliest clinically detectable manifestations of ongoing neurodegeneration. Longitudinal population-based studies have demonstrated that fragmented sleep, reduced slow-wave sleep, excessive daytime sleepiness, and circadian rhythm disruption are associated with an increased risk of subsequent cognitive decline and incident dementia. Likewise, biomarker studies have shown that poor sleep quality is associated with greater cerebral amyloid-β deposition, accelerated tau accumulation, and abnormal cerebrospinal fluid biomarker profiles, even among cognitively unimpaired older adults.[8–18] Our findings extend this evidence by showing that sleep-related symptoms were frequently recognised before Alzheimer's disease was formally diagnosed in

routine clinical practice, thereby providing complementary clinical support for the hypothesis that sleep disturbances may represent an early manifestation of the disease process.

The biological plausibility of these observations is supported by several complementary mechanisms. Slow-wave sleep plays a central role in maintaining synaptic homeostasis and facilitating glymphatic clearance of neurotoxic metabolites, including amyloid-β and phosphorylated tau. Consequently, chronic sleep fragmentation and reduced slow-wave sleep may impair physiological protein clearance, promoting the progressive accumulation of pathological proteins within the brain. In parallel, early neurodegeneration involving the suprachiasmatic nucleus, locus coeruleus, and basal forebrain may disrupt circadian regulation, creating a self-perpetuating cycle in which Alzheimer's pathology further impairs sleep, while disturbed sleep may accelerate ongoing neurodegenerative processes.[3, 4, 12–15] Together, these mechanisms provide a biologically plausible explanation for the early occurrence of sleep disturbances observed in our cohort and support the concept that alterations of the sleep–wake cycle may represent an integral component of the preclinical phase of Alzheimer's disease.

Importantly, our findings should not be interpreted as evidence that sleep disturbances constitute a disease-specific prodromal marker of Alzheimer's disease. Similar abnormalities occur in other neurodegenerative disorders, psychiatric conditions, and primary sleep disorders, limiting their diagnostic specificity. Nevertheless, persistent sleep disturbances in older adults—particularly when accompanied by subtle cognitive complaints, vascular risk factors, or a family history of dementia—should prompt careful clinical evaluation and appropriate longitudinal follow-up. From a practical perspective, systematic assessment of sleep disturbances represents a simple, inexpensive, and clinically meaningful addition to routine cognitive assessment. Rather than replacing established biomarker-based diagnostic approaches, sleep assessment may complement current diagnostic pathways by identifying individuals who warrant closer monitoring and more comprehensive evaluation.

Beyond the observations preceding diagnosis, the present study demonstrated a modest but significant association between greater sleep disturbance burden and longer disease duration ($\rho = 0.259$, $p = 0.030$). Although the cross-sectional design precludes conclusions regarding causality, this finding is consistent with previous studies demonstrating that sleep disturbances become increasingly pronounced as neurodegeneration advances.[9–12] Rather than representing a static clinical feature, the observed association suggests that the burden of sleep disturbances may change across the course of Alzheimer's disease.

Several complementary mechanisms may account for this association. Progressive neurodegeneration affects interconnected brain regions involved in circadian regulation and maintenance of normal sleep architecture, resulting in increasing fragmentation of nocturnal sleep, excessive daytime sleepiness, and more frequent nocturnal behavioural disturbances. Disease progression is also accompanied by reduced physical activity, diminished exposure to natural daylight, increasing functional dependency, behavioural and psychological symptoms of dementia, and a greater burden of medical comorbidities, all of which may further aggravate sleep disturbances.[9, 11, 12, 19, 20] Consequently, worsening sleep should not be

regarded merely as an inevitable consequence of advanced dementia but rather as a clinically meaningful manifestation of disease progression that warrants regular assessment throughout follow-up.

These findings have important implications for longitudinal patient care. Repeated assessment of sleep disturbances throughout the course of Alzheimer's disease may provide valuable information regarding evolving clinical needs, facilitate timely implementation of non-pharmacological interventions, and support more individualised management strategies. Monitoring changes in sleep over time may therefore prove as clinically informative as repeated assessment of cognitive or functional decline, particularly in patients requiring long-term follow-up. Collectively, our findings suggest that sleep disturbances should be regarded not as static symptoms of Alzheimer's disease but as clinically relevant manifestations that may vary across the disease continuum.

Perhaps the most original finding of the present study was the substantially greater burden of sleep disturbances among nursing home residents compared with community-dwelling individuals with Alzheimer's disease. However, they also had longer disease duration and greater functional impairment, indicating that the observed between-group differences cannot be attributed to the care environment alone. Rather, sleep disturbances in institutionalised patients are likely to reflect a complex interplay between disease-related factors, functional dependency, and characteristics of the care environment. To our knowledge, relatively few studies have directly compared sleep disturbances between institutionalised and community-dwelling individuals with Alzheimer's disease using a comparable clinical approach. Consequently, the present study provides additional evidence addressing an important gap in the current literature.

The mechanisms underlying these differences are likely to be multifactorial. While progressive neurodegeneration provides the biological substrate for sleep disturbances, environmental and organisational characteristics of long-term care facilities may further aggravate sleep disturbances. Reduced daytime physical activity, limited exposure to natural daylight, environmental noise, shared accommodation, nocturnal nursing interventions, and less individualised daily routines have all been associated with impaired circadian synchronisation and fragmented sleep. Conversely, community-dwelling individuals often retain greater autonomy, more regular social interactions, and a more physiological light–dark cycle, all of which support healthier circadian regulation and sleep patterns.[19, 20] The present observations are therefore consistent with a multifactorial model in which sleep disturbances in Alzheimer's disease may reflect the combined influence of neurodegenerative, functional, and environmental factors.

From a clinical perspective, these observations have implications extending beyond the management of sleep symptoms alone. Because several environmental factors known to influence sleep are potentially modifiable, optimisation of the care environment may represent an important component of non-pharmacological sleep management in patients with dementia. Interventions aimed at increasing daytime physical activity, optimising exposure to natural daylight, minimising unnecessary nocturnal

disturbances, maintaining structured daily routines, and implementing individualised sleep hygiene programmes may improve sleep quality without increasing medication burden. Such strategies are particularly attractive in frail older adults, in whom sedative medications are associated with an increased risk of falls, delirium, excessive daytime sedation, and further cognitive decline. Consequently, optimisation of the care environment should be regarded as an integral component of comprehensive dementia care rather than merely a supportive nursing intervention.

Although the cross-sectional design precludes conclusions regarding causality, our findings raise an important clinical question: to what extent can targeted environmental interventions modify the burden of sleep disturbances in Alzheimer's disease? Future longitudinal and interventional studies integrating objective sleep measurements with comprehensive assessment of environmental factors are needed to address this question. Such studies may provide robust evidence to guide non-pharmacological interventions aimed at improving sleep quality, preserving functional independence, and enhancing quality of life among individuals living with Alzheimer's disease, particularly those receiving long-term institutional care.

Clinical implications

The present findings have several important implications for routine clinical practice. Collectively, they suggest that assessment of sleep disturbances should become an integral component of the longitudinal evaluation of patients with Alzheimer's disease rather than a secondary consideration addressed only after behavioural symptoms become clinically prominent. Importantly, clinical assessment should extend beyond insomnia alone to include excessive daytime sleepiness, circadian rhythm disturbances, nocturnal behavioural symptoms, and features suggestive of primary sleep disorders, thereby providing a more comprehensive evaluation of sleep disturbances.[11, 12]

Equally important, our findings reinforce the concept that many sleep disturbances are potentially modifiable. Early recognition offers an opportunity to improve quality of life for both patients and caregivers while potentially reducing caregiver burden and functional decline. Whenever feasible, management should prioritise evidence-based non-pharmacological interventions, including optimisation of sleep hygiene, promotion of daytime physical activity, structured daily routines, bright-light therapy, and caregiver education. Pharmacological treatment should remain individualised and carefully balanced against the increased susceptibility of older adults with dementia to adverse drug effects. Taken together, these findings support a multidisciplinary and patient-centred model of care involving neurologists, geriatricians, psychiatrists, sleep medicine specialists, nurses, psychologists, and caregivers in the comprehensive management of Alzheimer's disease.[11, 12]

The present study has several important strengths that enhance the clinical relevance of its findings. Unlike many previous investigations focusing on individual domains of sleep, we evaluated a broad spectrum of sleep–wake disturbances using both validated sleep questionnaires and a structured disease-specific assessment, providing a comprehensive characterisation of sleep abnormalities in

Alzheimer's disease. Furthermore, the inclusion of participants from both nursing homes and community settings enabled direct comparison between two clinically relevant care environments that remain underrepresented in the current literature. Another strength is the inclusion of caregiver-supported assessment, which allowed more reliable evaluation of sleep symptoms in individuals with cognitive impairment. Finally, all participants had a clinically established diagnosis of Alzheimer's disease based on contemporary diagnostic criteria and underwent neurological assessment supported by brain magnetic resonance imaging, resulting in a well-characterised study cohort and enhancing the diagnostic reliability of the findings.

Several limitations should also be acknowledged. First, the cross-sectional design precludes conclusions regarding temporal or causal relationships between sleep disturbances and disease progression. Second, sleep characteristics were assessed using patient- and caregiver-reported questionnaires rather than objective techniques such as polysomnography or actigraphy, limiting detailed evaluation of sleep architecture and specific primary sleep disorders. Information regarding sleep disturbances preceding the clinical diagnosis of Alzheimer's disease was collected retrospectively and is therefore susceptible to recall bias. Finally, the relatively modest sample size may have limited statistical power for selected subgroup analyses, while potentially important variables—including medication use, behavioural symptom severity, and objectively confirmed sleep disorders—were not analysed separately. Furthermore, nursing home residents differed from community-dwelling participants in several clinically relevant characteristics, including disease duration and functional status; therefore, residual confounding cannot be excluded, and the observed association between care setting and sleep disturbance burden should not be interpreted as evidence of an independent environmental effect. These limitations should be considered when interpreting the findings but do not diminish their relevance for routine clinical practice.

The present findings identify several priorities for future research. Longitudinal studies integrating comprehensive clinical assessment with objective sleep measurements—including actigraphy, polysomnography, and emerging digital biomarkers—are needed to better characterise the temporal evolution of sleep disturbances across the Alzheimer's disease continuum. Combining clinical sleep assessment with fluid and imaging biomarkers of amyloid-β and tau pathology may clarify whether specific sleep abnormalities can improve early risk stratification, facilitate disease monitoring, or serve as complementary outcome measures in therapeutic trials. Equally important, prospective interventional studies evaluating environmental modifications in long-term care facilities and community-based sleep programmes are warranted to determine whether optimisation of the care environment can improve sleep quality, functional independence, caregiver burden, and other patient-centred outcomes.

In conclusion, the present study provides further clinical evidence that sleep disturbances represent an integral component of Alzheimer's disease throughout its clinical course. Sleep disturbances were highly prevalent, were frequently reported before the clinical diagnosis of dementia, were associated with longer disease duration, and were more burdensome among nursing home residents than among community-dwelling individuals. Together, these observations support the view that sleep disturbances

represent a clinically important component of Alzheimer's disease across its course, with potential implications for assessment, monitoring, and management. As disease-modifying therapies for Alzheimer's disease continue to evolve, systematic assessment and targeted management of sleep disturbances should become integral components of personalised, patient-centred dementia care.

Declarations

Consent for publication

Not applicable.

Clinical trial number

Not applicable.

Competing interests

The authors declare that they **have no competing interests**.

Statistical methods note for the manuscript

Because P values for categorical variables are reported in Tables 1–3 and 5, the Statistical analysis section should state that categorical variables were compared using Fisher’s exact test or the chi-square test, as appropriate.

Funding

This research received **no external funding**.

Author Contribution

MW-P and AT conceptualized and designed the study.MW-P and AT collected the data and performed the statistical analysis.MW-P and AT interpreted the results and drafted the manuscript.MW-P prepared the final version of the manuscript and approved the final submission.GD supervised the study and approved the plan of the study.MR-B supervised the study and critically revised the manuscript.All authors critically revised the manuscript, read, and approved the final version.

Acknowledgement

The authors would like to thank the staff of the nursing homes and the Community Support Centre for Patients with Alzheimer’s Disease in Krakow for their assistance in participant recruitment and data collection. The authors also thank all participants and their caregivers for their valuable contribution to this study.

Data Availability

The datasets generated and/or analysed during the current study are not publicly available due to participant privacy and ethical considerations but are available from the corresponding author on reasonable request, subject to applicable ethical and data protection requirements.

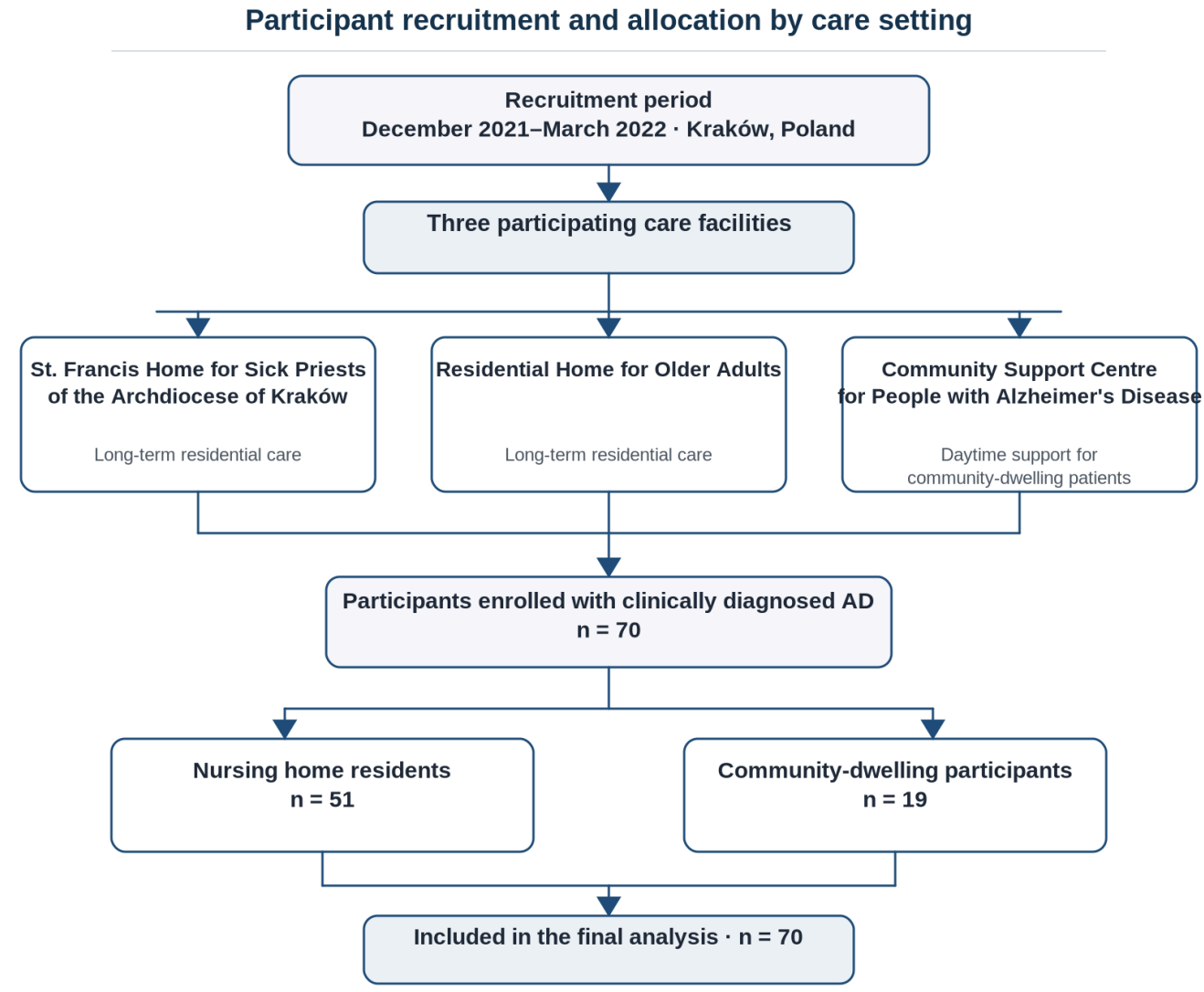
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29. Human. Ethics and Consent to Participate declarations.
30. This study was approved by the Institutional Bioethics Committee at Andrzej Frycz Modrzewski Cracow University. (approval number: KBKA/75/O/2021). All procedures were conducted in accordance with the principles of the Declaration of Helsinki. Informed consent was obtained from all participants or their legal guardians.

Figures



Note: the number of patients assessed for eligibility but not enrolled was not prospectively recorded.

Figure 1

Flow chart illustrating participant recruitment and allocation according to care setting.

Supplementary Files

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