VER
Vascular & Endovascular Review

Advances in Wearable Sensor Technology for Fall Prevention in Alzheimer's Disease: Evidence, Challenges, and Opportunities: A Narrative Review

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ABSTRACT

Background & Purpose
Alzheimer's disease (AD) is a progressive neurodegenerative disorder which is strongly associated with decline in cognition and motor control, placing patients at high risk of falls. Conventional assessments for fall risk are unable to track real world mobility fluctuations in this population. Wearable sensor technology may offer continuous and objective monitoring to detect subtle gait and balance impairments. However, the pertinent evidence specific to AD remains inconclusive.
Objective & Rationale
To review and synthesize the current evidence on wearable sensors technology for fall prevention in Alzheimer's disease, address the gap in synthesizing research specific to this population and outline challenges as well as future directions.
Methods
A narrative review was conducted in accordance with PRISMA standards. PubMed/MEDLINE, Scopus, Pedro, CINAHL, and Google Scholar were searched (2015–2025) using terms related to AD, falls, and wearable technologies. Eligible studies included randomized controlled trials, observational studies, systematic reviews, and feasibility trials assessing wearable devices (accelerometers, gyroscopes, inertial measurement units, smart footwear, wristbands, or body-mounted sensors) in populations with AD or mild cognitive impairment. Data extraction focused on sensor type, placement, intervention characteristics, outcomes, and implementation factors.
Results & Outcomes
Twenty-five studies met the inclusion criteria. Wearable devices consistently captured fall related biomarkers which included gait variability, stride length, and errors in motor planning. Sensor guided interventions demonstrated significant improvements in balance and dual task performance. However, the effects on gait and fall incidence were inconsistent. Consumer grade wearables such as wrist worn step trackers showed their caliber for low-cost risk management, while AI enabled systems achieved greater than 95% accuracy in fall detection. Patient adherence, device comfort, data overload, and privacy concerns were significant barriers. Methodological limitations in the studies were their small sample sizes, heterogeneity in outcome measures, and limited long term follow up.
Discussion & Conclusion
Wearable sensors provide valuable and objective insights into fall risk in AD which offers opportunities for establishing proactive and individualized fall prevention strategies. However, the current evidence is preliminary, with limited high-quality trials in AD specific populations. Future research should prioritize standardized protocols, larger clinical trials, and integration of wearable sensor technologies into multidisciplinary fall prevention frameworks.

KEYWORDS: Alzheimer's Disease (AD), Dementia, Wearable Sensors, Falls Prevention, Gait Analysis, Balance.

How to Cite Harpreet Singh, PT, DPT, MSHA, Rasika Bhide PT, MS, OCS, (2025) Advances in Wearable Sensor Technology for Fall Prevention in Alzheimer's Disease: Evidence, Challenges, and Opportunities: A Narrative Review, Vascular and Endovascular Review, Vol.8, No.5s, 402-418.

INTRODUCTION

Alzheimer's Disease: A Brief Overview

Cognitive and physical impairments characteristic of AD

Alzheimer's disease (AD) is the most common disease that causes Dementia.[1] It is a progressive neurodegenerative disorder characterized by a gradual decline in a patient's cognitive and psychological function. It manifests as memory impairment, executive dysfunction, and spatial disorientation. The cognitive decline is accompanied by deterioration in patient's motor control and mobility. Clinically, this is evidenced by a decreased gait speed and cadence, impaired sitting and standing balance, and impaired coordination. As the AD advances, it often leads to a gradual loss of patient's functional independence. For the 21st century, the World Health Organization has identified Dementia as a global priority for public health and social care.[2]

Global prevalence, growing public health burden

In 2021, an estimated 57 million patients worldwide were suffering from dementia, with AD constituting approximately 60% to 70% of these cases.[3, 4] This global burden is expected to escalate substantially, with the number of affected patients projected to nearly double every two decades, reaching approximately 78 million by 2030, further worsening to 139 million by the year 2050.[5] There are an estimated 416 million people aged 50 years and older across the AD continuum that includes preclinical, prodromal, and symptomatic stages.[6, 7, 8] In the United States, more than 6.9 million adults aged 65 years and above were suffering from AD in 2024, projected to increase to 13.8 million by 2060.[9]

Globally, over $50 billion and $754 million are allocated annually to medical expenses for non-fatal and fatal fall-related injuries, respectively.[10] The direct costs from fall related injuries are a staggering 0.1% of all healthcare expenditures in the United States.[11]

Falls in AD: A Major Clinical Challenge

Epidemiology of falls in dementia

Older adults diagnosed with AD face a markedly elevated risk of falls compared to their cognitively intact counterparts. Epidemiological studies indicate that patients with AD are more than twice as likely to experience at least one fall within a given year, with some investigations even reporting a relative risk increase of approximately 60% to 80%.[12] This heightened vulnerability reflects the overall impact of progressive cognitive decline, impaired motor control, and reduced ability to adapt to environmental challenges, which together compromise patient's postural stability and situational awareness.

Consequences: injuries, hospitalization, loss of independence

Falls are the leading cause of injury, long-term disability, and injury-related mortality in the older adult population.[3, 7] Among patients with AD, the consequences of falls are particularly severe. Falls occur more frequently, and they also tend to result in a higher incidence of serious injuries, such as fractures or head trauma. The consequences extend beyond the immediate physical harm; sustaining a fall significantly increases the probability of AD patients requiring higher level of care in an acute care hospital and/or nursing home. Evidence indicates that patients with AD who experience a fall are up to five times more likely to be admitted to a nursing home than those who do not fall, underscoring the significant impact of falls on independence and quality of life.[12]

Complex interaction between cognitive decline and motor impairment

Cognitive and motor functions are interconnected and deterioration in one domain often exacerbates deficits in the other. In AD, impairments in attention, executive function, and spatial orientation compromise a patient's ability to navigate their surroundings safely thereby increasing their susceptibility to gait disturbances and resultant loss of balance. These cognitive changes hinder the planning, initiation, and adjustment of movements, making it more difficult for AD patients to adapt to environmental challenges. Notably, in the preclinical stages of AD, before overt memory problems or other hallmark symptoms become apparent in patients, subtle mobility changes such as a gradual slowing of gait, reduced stride length, and impaired postural control may emerge.[12] These early motor changes serve as important clinical clues, signaling underlying neuro-pathological processes well before a formal diagnosis is made.

Mechanisms of Fall Risk in AD

Cognitive impairment: executive dysfunction, attention, spatial orientation

In AD, progressive decline in executive functions namely planning, decision-making, and task switching undermines the patient's ability to anticipate and appropriately respond to environmental hazards. Deficits in attention reduce the patient's capacity to focus on relevant visual and spatial cues, while impaired spatial orientation interferes with patients accurately judging distances or navigating unfamiliar spaces. Cumulatively, these changes disrupt patient's safe ambulation and increase the likelihood of tripping, mis stepping, or colliding with obstacles resulting in falls.

Motor dysfunction: bradykinesia, impaired gait control

Motor deficits frequently accompany cognitive decline in AD. Bradykinesia, or slowed movement affects patient's reaction time and their ability to recover from balance disturbances. Patient's gait control becomes progressively less coordinated, characterized by reduced stride length, altered cadence, and increased variability in foot placement. These impairments compromise patient's dynamic stability, making them more vulnerable to loss of balance even in routine walking situations.

Medication effects, sensory deficits, dual-task difficulties

Patients with AD are typically prescribed multiple medications, a situation known as polypharmacy, which increases the risk of side effects such as dizziness, orthostatic hypotension, or sedation, all of which can contribute to falls. In addition, the patient's sensory impairments namely diminished vision, hearing loss, or reduced proprioceptive feedback further limit environmental awareness and postural control in patients with AD.[12] Performing two tasks simultaneously, such as walking while conversing, poses a particular challenge due to reduced capacity for divided attention, leading to unsafe motor responses in real world situations.

Common Fall Risk Factors in AD

History of prior falls

A positive patient's history of previous falls is one of the strongest predictors for future falls which reflects persistent physical vulnerabilities as well as the progressive nature of AD. About half of patients who fall once are likely to fall again in the subsequent months, with physical and functional consequences, such as pain, fractures, mobility disability, amputations, institutionalization and increase in the cost of healthcare.[13]

Home environment hazards

Everyday surroundings may present hidden dangers, such as poor lighting, loose rugs, cluttered walkways, or uneven flooring. In patients with AD, these hazards are especially risky due to their impaired hazard recognition further compounded by their impaired hazard recognition and slower reaction times.

Fear of falling

After an initial fall, many patients with AD develop a significant fear of recurring falls. This often leads to their avoidance of physical activity which in turn accelerates their muscle weakness and reduced balance control. Paradoxically, this increases their actual fall risk.

Poor balance confidence

Patients with AD present with low confidence in their ability to maintain stability which alters their gait patterns and encourage overly cautious movements, both of which may inadvertently heighten the risk of instability and falls.

Limitations of Conventional Fall Risk Assessments

Conventional fall risk assessments typically rely on self-reported history, structured questionnaires or standardized clinical tests performed in a controlled environment. While valuable for initial screening, these approaches are inherently limited. In patients with AD, self-report measures are prone to recall bias and underreporting, while clinical tests may not fully reflect mobility performance under the complex and unpredictable conditions of daily life. Most importantly, these tools fail to capture continuous, real-world data on movement patterns, environmental challenges, and moment-to-moment fluctuations in stability, leaving important aspects of fall risk unmeasured.[9, 14]

Emergence of Wearable Technologies

Potential of continuous, objective, real-time data

Wearable devices that are equipped with inertial sensors, such as accelerometers and gyroscopes can record patient's detailed movement data continuously over extended periods in their natural environments.[9, 14, 15]. These devices enable precise and quantitative analysis of patient's gait patterns, posture, and physical activity levels which offers an accurate and detailed picture of a patient's mobility than intermittent clinical observations.

Applicability in early detection and prevention

Wearable technologies hold promises for early identification of patients at high fall risk by identifying subtle changes in gait variability, balance control, or activity patterns which are often detectable before noticeable functional decline. Such insights could support timely, personalized interventions aimed at preventing falls before they occur, thereby preserving patient's independence and quality of life.[14]

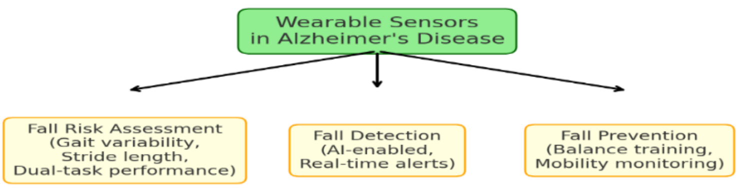

Figure 1: Application of Wearable Sensors in Alzheimer's Disease

OBJECTIVE & RATIONALE

Gap in synthesizing wearable sensor research specific to fall prevention in AD

Although wearable motion sensing systems have been widely investigated in older adult populations, research synthesizing their application specifically for fall risk assessment and prevention in AD remains scarce. Given the unique interplay of cognitive and motor impairments in AD, findings from broader geriatric studies may not fully translate to this subgroup.

Objective: To narratively review current evidence, highlight challenges, and propose future directions

The purpose of this review is to examine current evidence regarding the use of wearable sensors for monitoring and preventing falls in patients with AD. This narrative synthesis aims to identify methodological strengths and limitations within the existing literature, highlight clinical implementation challenges, and propose priorities for future research, including sensor validation, user acceptability, and integration into multidisciplinary care strategies.

METHODS

Literature Search Strategy

A structured review of literature was performed following the PRISMA standards. The objective was to include quantitative, qualitative, and mixed-method studies focusing on older adults with a diagnosis of Alzheimer's disease (AD) or Alzheimer's dementia. Studies were eligible if they investigated the use of wearable sensor technologies (i.e., accelerometers, gyroscopes, inertial measurement units (IMUs), smart footwear, smartwatches, body-mounted sensors, or devices) as tools for assessing fall risk, detecting falls, or monitoring mobility and gait in relation to fall prevention.

The search strategy was developed with three main concepts: (1) patients with AD or MCI, (2) falls and fall related-outcomes and (3) wearable or digital health technologies. Duplicate studies were removed as a part of screening process. Full-text evaluation of eligible studies was conducted following a comprehensive review of titles and abstracts.

Databases, Keywords, and Boolean Operators

Electronic databases including PubMed/MEDLINE, Scopus, Pedro, CINAHL, and Google Scholar were utilized for the literature search. Search terms were formulated around three factors - population, intervention and outcomes, and linked by Boolean operator (AND, OR, NOT). Keywords included dementia, Alzheimer's disease, wearable devices, accelerometers, gyroscopes, IMUs, smart shoes, smartwatches, fall, fall risk, gait, mobility, as well as balance.

The search was limited to peer-reviewed articles published in English from 2015-2025. Eligibility for participants was guided by the PICOS framework with interventions broadly including wearable and mobile health technology, telehealth platforms, and other digital health tools Inclusion.

Inclusion and Exclusion Criteria

Inclusion criteria

Adults (aged ≥ 60 year) diagnosed with Alzheimer's disease or Alzheimer's dementia, including populations Patients with MCI were also acceptable if data was reported separately.

Interventions involving wearable sensors and other digital health technologies for the screening of fall risk, as well as fall detection, gait and mobility monitoring.

Outcomes of interest included fall incidence, fall risk, gait/balance outcomes, lower extremity strength, endurance, safety outcomes, feasibility and usability, or QOL.

Eligible study designs included randomized controlled trials (RCTs), quasi-experimental studies, cohort and case control, cross-sectional, pilot/feasibility trials, and systematic reviews and meta-analyses were considered for eligibility.

Exclusion criteria

Studies focusing on assistive devices requiring prescriptions (e.g., walkers, wheelchairs, hearing or visual aids).
Populations without AD specific data (e.g., Parkinson's disease, stroke, or mixed dementia without subgroup analysis).

Animal or in-vitro experiments.

Non wearable technologies (such as robotics, ambient sensors, pressure mats, or camera-based systems).

Wearables applied exclusively for non-fall purposes (e.g., cardiac monitoring).
Non peer reviewed items such as commentaries, editorials, conference abstracts, or opinion pieces.
Studies lacking methodological rigor, insufficient comparative outcomes, or those not published in English

Parameters Measured (Outcome Measures)
Mobility and Balance Tests
Timed Up and Go (TUG) and the cognitive dual-task TUG (TUG-cog) mobility, balance and fall risk.
Dynamic balance was assessed using the Functional Reach Test (FRT).
Four-Square Step Test (FSST) for coordination and dynamic balance.
Single Leg Stanc e (SLS) for static balance, and postural control.

Lower Extremity Strength
Five Times Sit-to-Stand Test (5xSTS) for lower limb functional muscle strength.

Endurance
The Six-Minute Walk Test (6MWT) for endurance and global mobility ability.

Fall-related Outcomes
Number of falls per 1000 participant bed days.
A fall was characterized as "an inadvertent change, such as a slip or trip, resulting in an individual coming to rest on the ground, floor, or a lower level.

Study Selection and Screening
All search results were imported into reference manager software and duplicates were removed. Screening was conducted in two phases: (1) Review of the title and abstract and (2) full text review. Eligibility criteria were independently applied by two reviewers at each stage and disagreements were resolved by discussion. Study design, setting, sample size, participant demographics, type and purpose of technology, device characteristics and positioning, implementation, and outcomes were extracted using a predesigned template.

Quality Appraisal
The methodological quality of the included studies was assessed by two reviewers independently. Randomized trials were considered using a version of the Cochrane Risk of Bias tool and non-randomized studies using the ROBINS-I tool. The quality of systematic reviews was assessed with the AMSTAR-2 checklist. All differences were settled by discussion, reaching a consensus.

Data Synthesis
Due to variation of study design, participant sample, intervention and outcomes, no meta-analysis was conducted. Instead, findings were narratively synthesized, and thematic analysis was used where applicable. Evidence was organized by technology type, intervention pattern, and outcome type.

Priority was given to the most recent and methodologically sound evidence when more than one study addressed the same intervention. Emphasis was given to intervention effectiveness, user convenience and acceptability, and implementation challenges associated with wearable sensors.

Data Analysis
Data was structured to represent devices, positioning and design in relation to measured outcomes. Summary tables were created to facilitate comparison between different study details, wearable technology type, and fall related findings between the studies.

RESULTS & OUTCOMES

Author (s), Year	Study Type / Design	Population / Sample Characteristics	Intervention / Technology Used	Outcomes Measured	Key Findings / Results	Significance for Fall Prevention
Ponti et al., 2017	Observational Experimental	36 older adults (fallers vs non-fallers)	Waist-worn accelerometer during single/dual-task TUG	TUG time, accelerometer features	Dual-task accelerometer features improved faller classification (AUC=0.84)	Sensor-augmented TUG enhances early faller detection, useful in AD
Zhou et al., 2018	Observational	32 older adults (16 impaired, 16 intact) + 12 young	Ankle-worn sensor (iTMT platform)	Motor Planning Error (MPE), MoCA, gait	Higher MPE in impaired; correlated with MoCA (r=−0.67)	Wearables can detect cognitive frailty, a fall predictor in AD
Thordardottir et al., 2019	Systematic Review	1655 participants with cognitive impairment (incl. AD) + caregivers	Innovative assistive technologies (home sensors, fall detectors, activity bracelets)	Acceptance, adherence, usability	Facilitators: safety, familiarity; Barriers: age, tech immaturity, personalization gaps	Adoption barriers must be addressed for AD fall-prevention
Al-Naami et al., 2021	Prototype Pilot Testing	13 healthy volunteers (device designed for AD)	Smart Wearable Medical Device (SWMD): accel, gyro, HR, SpO_2, GPS	Fall detection sensitivity, vital sign accuracy, GPS alerts	93% sensitivity, 95% specificity; functional biomarker monitoring	AD-specific wearable integrates falls + vitals + GPS for safety
Cote et al., 2021	Systematic Review &	Dementia patients (n=2,516) vs	Wearables: actigraphy,	Activity, sleep, circadi	Dementia group had lower daily activity,	Wearables capture functio

	Meta-analysis	controls (n=1,224)	accelerometers, gyroscopes	an rhythm	worse sleep efficiency	nal decline markers linked to fall risk
Miranda-Duro et al., 2021	Cross-sectional Observational	31 older adults, mean age 84	Xiaomi Mi Band 2 (wrist step tracker)	Steps, distance, falls history, ADL dependency	Higher steps/distance = lower fall risk, less ADL dependency	Low-cost wearables useful for AD fall-risk stratification
Stavropoulos et al., 2021	Public Involvement (RADAR-AD)	11 PwD + 10 caregivers (Europe)	Hands-on evaluation of 4 wearable devices	User preferences (comfort, appearance, metrics)	Prioritized comfort, affordability, usability over technical detail	Human factors crucial for wearable acceptance in AD
Weizman et al., 2021	Systematic Review	6 studies; PwD (60–88 yrs)	Wearable IMUs (trunk, lumbar, chest)	Pace, rhythm, variability, FoF	IMUs feasible in lab & real-world; detect dementia gait patterns	Wearables provide objective fall-risk markers in dementia
Chakrabarti et al., 2022	Review	General consumer wearable users	Consumer smartwatches/bands + ML analytics	HR, steps, sleep, activity	Wearables + ML can detect/monitor chronic & neurologic conditions	Supports feasibility of consumer-grade wearables
di Biase et al., 2022	Narrative Review	Older adults, neuro patients	RF-based indoor monitoring (Wi-Fi, UWB radar, RFID) vs wearables/cameras	Gait analysis, fall detection, vital signs	RF provides non-contact continuous monitoring, privacy-friendly	Useful for dementia patients resistant to wearables
Guo et al., 2022	Narrative	Neurologic populatio	Wearable gait analysis	Stride length, variabi	Wearables capture gait biomarkers	Gait metrics relevan

	Review	ns (mainly PD)	(IMUs, accelerometers, vision sensors)	lity, dual support, gait speed	for PD; transferable to AD	t for predicting falls in AD
Junaid et al., 2022	Survey	General healthcare systems	Wearables + IoT + AI + Blockchain frameworks	Remote monitoring, predictive analytics	Growth of IoT-assisted wearables; challenges in cost, interoperability	AI-enabled wearables shift fall prevention from reactive to predictive
Li et al., 2022	Systematic Review & Meta-analysis of RCTs	Neurodegenerative diseases (15 RCTs, n=488; incl. 2 AD trials)	Wearable-based exercise with biofeedback (Wii, VR, IMU)	Balance, mobility, motor symptoms, falls self-efficacy	Significant balance gains; no consistent gait/mobility improvements	Wearable-guided exercise enhances balance, reducing fall risk factors in AD
Visvanathan et al., 2022	Pragmatic Cluster RCT	3240 hospitalized patients ≥65 (incl. dementia)	AmbIGeM singlet with accelerometer + gyroscope	Falls/1000 bed-days, injurious falls	No overall reduction; ward-specific benefit, adherence 49%	Feasible but mixed effectiveness; better in dementia wards
Ruiz-Garcia et al., 2023	Experimental Study	Public datasets (simulated falls/ADLs, adults 18–55)	CareFall smartwatch (accelerometer + gyroscope, AI classifiers)	Accuracy, sensitivity, specificity	ML model achieved 98% accuracy, 98.9% sensitivity	AI-wearables promising for real-time fall detection in AD
Smith et al., 2023	Narrative Review	General older adults	Wearable biosensors (accelerometers, gyroscopes, ECG, e-	Remote alerts, physiological monito	Wearables can stream physiological/motion data for	Foundation for fall detection & monito

			skin, smart garments)	ring, safety	alerts & monitoring	ring in AD
Albarqi, 2024	Systematic Review	14 studies; elderly (≥65)	Tech-assisted interventions: telehealth, wearables, smart homes, robots	Independence, QoL, safety	Improved ADLs, mental health, adherence when well-designed	Supports independence; indirectly reduces AD fall risk
Eost-Telling et al., 2024	Rapid Systematic Overview of Reviews	PlwD or MCI, 22 primary studies	Wearables, sensors, VR, exergaming	Falls, fall risk, balance	Wearables & VR differentiate fallers; exergaming improves balance	Evidence limited; strongest for risk stratification & balance improvement
Misaghian et al., 2024	Perspective	Older adults, global aging population	Concept: Immediate Fall Prevention technology	Fall mechanisms, trauma prevention	Current solutions lack immediate prediction; cognitive decline critical	Argues for predictive, last line fall prevention in AD
Jung et al., 2025	RCT (6 weeks, single-blind)	36 older adults (≥65, community-dwelling)	Interactive Cognitive-Motor Training (ICMT) with wearable sensors	Cognition, balance, strength, endurance	ICMT improved cognition (+8.6%), balance, endurance vs control	Wearable-based ICMT could reduce fall risk in early AD/MCI
Maruf et al., 2025	Narrative Review	Older adults (≥65)	Wearables, edge devices, TinyML	Fall prediction models, gait/ADL classification	TinyML & edge AI future-ready for real-time prediction	Roadmap for scalable predictive fall prevention in AD

Table 1: A comparative review of studies is summarized

Trends Across Studies

Wearable sensors have consistently been a promising topic in the in the prevention of falls in AD. However, despite the high promise of these technologies, validation in AD populations is particularly limited. Several research findings consider gait variability, stride length, and motor-planning errors as effective indicators for fall risk, indicating that wearable sensors play an important role in continuous monitoring of the patients.[33]

Wearable devices such as smartwatches and fitness bands are also being evaluated for their feasibility and cost-effectiveness, however, their accuracy in clinical population remains unclear. Studies examining their feasibility and use friendly technology, highlighting that patient comfort, ease of use and caregiver involvement are important for long-term adherence. Studies utilizing a wearable sensor based training or biofeedback intervention have showed positive balance and cognitive-motor performance improvements but consistent evidence for reduced fall risk is currently limited.

Non touch solutions, such as Radio frequency (RF) monitoring, provide another option for patient's intolerant to wearing, thereby broadening the spectrum of potential applications. Sensors combined with artificial intelligence and machine learning models have showed high accuracy in fall detection and prediction, however most work is confined to pilot stages.[34]

Taken together, the findings indicate that wearable sensors appear effective in capturing fall related biomarkers, although translation into widespread clinical practice is in its early stages. Overall trend suggests a shift in research from simple feasibility reports towards more advanced predictive and intervention-based approaches, but well-designed randomized controlled trials are still limited.

Sensor Type	**Function**	**Clinical Applications**	**Placement & Design Considerations**	**References**
Accelerometers	Measure linear acceleration along 1 to 3 axes	Detect activity levels, step counts, posture transitions, gait speed, fall events	Commonly worn on hip, ankle, lower back, wrist. Wrist placement improves compliance but less accurate for gait; hip/ankle provide higher accuracy	Patel et al, 2012; Del Din et al, 2016; Chakrabarti et al, 2022; Albarqi, 2024
Gyroscopes	Measure angular velocity (rotational movement)	Assess balance, turning, gait variability, tremor analysis	Often combined with accelerometers in IMUs. Placement on sternum or lower back improves trunk motion measurement	Del Din et al, 2016; Stavropoulos et al, 2021; Chakrabarti et al, 2022; Albarqi, 2024
Magnetometers	Detect orientation in Earth's magnetic field	Aid in 3D orientation, heading estimation, and correcting gyroscope drift	Susceptible to environmental magnetic interference; typically fused in IMUs rather than standalone	Patel et al, 2012; Chakrabarti et al, 2022; Junaid et al, 2024
Inertial Measurement Units (IMUs)	Combine accelerometer, gyroscope, ±	Comprehensive gait/mobility monitoring;	Hip, lower back, or sternum, offer	Stavropoulos et al, 2021; Li et al,

	magnetometer	fall detection; fall risk prediction	robust biomechanical data. Wrist worn IMUs are user friendly but less accurate for gait. Multi-sensor systems increase precision but reduce comfort	2022; Chakrabarti et al, 2022; Albarqi, 2024
Pressure/Force Sensors	Measure plantar pressure and ground reaction force	Gait phase detection, balance assessment, postural sway, fall risk stratification	Embedded in insoles/shoes. High accuracy but may cause user discomfort or compliance issues for long-term daily use	Patel et al, 2012; Li et al, 2022; Chakrabarti et al, 2022
RF/Doppler/Microwave based sensors	Enable contactless monitoring via radio signals, Wi-Fi, UWB	Fall detection, gait analysis, indoor positioning, vital signs, sleep monitoring	Device free systems with no wearable needed; room-based, but may raise privacy concerns	di Biase et al, 2022

Table 2: Wearable Sensor Types and Placement Considerations

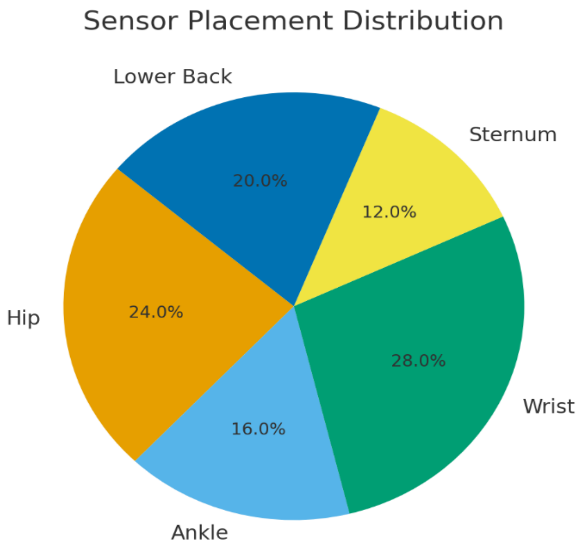

Figure 2: Sensor Placement Distribution

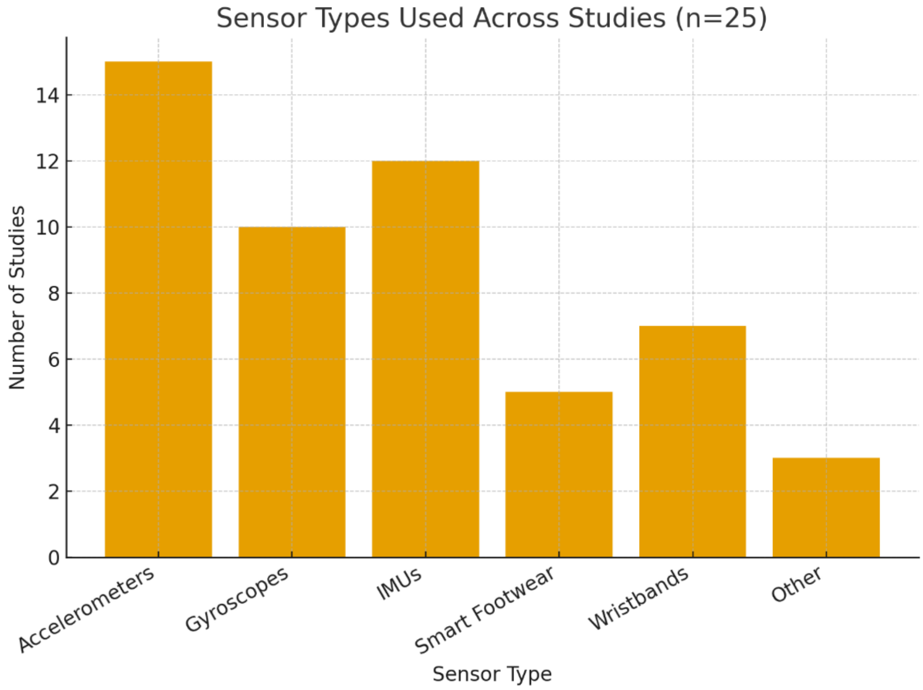

Figure 3: Sensor Types Used Across Studies

Risk of Bias within Studies
There was great variability in methodological quality of the included papers, and many issues that could have caused bias. Some were based on small samples or convenience samples; hence their generalization was limited to the larger AD population. Many studies included were observational or feasibility oriented, leading to biases in selection and statistical power.

Most studies made limited use of blinding, and adherence was often not consistently tracked, which raises concerns about performance and detection bias.[35] Comparing findings across studies is also challenging because of differences in study design, sensor technologies, and outcome measures, which may overstate the reported benefits.

In general, the risk for a bias is assessed as moderate to high, and further strong controlled trials with standardized protocols and long-term follow-up in AD-defined subjects are warranted.

DISCUSSION

Impact on Fall Prevention

Efficacy, Real Time Monitoring, and Adherence
For individuals with AD, who suffer from a disproportionately high risk of falls, wearable sensors are emergent and valuable tools for fall prevention. The evidence about their efficacy is derived from systematic reviews and RCTs. For example, Li et al demonstrated that incorporating biofeedback from wearable devices into exercise programs improved balance, a key determinant of fall risk.[12] However; their review also underscored the findings that while balance outcomes improved, gait and mobility measures demonstrated inconsistent gains. This indicates that wearable guided interventions may be most effective when they are combined with broader rehabilitation strategies, rather than as standalone solutions.

Jung et al elaborated on this observation by testing interactive cognitive motor training delivered through wearable platforms. Their RCT demonstrated significant improvement in balance concurrently with improvement in endurance and cognition, indicating how wearables may support multidimensional rehab in AD.[31] Since physical and cognitive deterioration commonly overlap in individuals with AD, the capacity to influence both domains simultaneously are highly meaningful.

Miranda-Duro et al reported that wrist worn step tracker could stratify fall risk, with higher step counts and longer walking distances indicated greater independent with lower fall risk and consequent, independent in activities of daily living.[36] While these devices are not as sophisticated as research grade sensors, their accessibility and affordability render them practical for widespread usage in residential care and community care settings.

Another advantage is the real time monitoring. Ruiz-García et al validated the CareFall smartwatch, an AI enabled system that detected falls with a greater than 98% accuracy.[26] This means that caregivers can be alerted within seconds of a fall, thereby minimizing the time to aid and consequently, preventing complications such as sustained immobility, hypothermia and/or pressure injuries. This transition from retrospective assessment to real time and proactive action represents a fundamental change in fall prevention.

Adherences, however, remains a major limitation. The AmbIGeM study, which tested a wearable garment with integrated fall-prevention sensors, demonstrated only 49% average adherence.[25] Many participants were resistant to wearing the device continuously and reported discomfort which reflected a common challenge in patients with dementia. Patients with AD and their caregivers consistently prioritize comfort, simplicity, and familiarity above sophisticated functions.[7] Consequently, the real-world effectiveness of wearable devices is significantly influenced by human factors in addition to their technical performance.

Clinical Applications and Implications

Integration into Fall Prevention Programs

By providing early and continuous risk assessment, wearable technologies may enhance traditional fall prevention programs. This is unlike conventional fall risk tools which rely on periodic testing or self-reported history as Wearables can detect subtle motor changes that occur weeks or months before the clinical decline becomes apparent. In a study by Zhou et al., researchers showed that wearable devices could detect small errors in how individuals plan their movements.[16] These errors are an early sign of cognitive frailty, a condition that is known to increase the risk of falls. If these impairments are detected before they present as obvious mobility impairments, it can provide a valuable window of opportunity to clinicians.

The traditional reactive approach to managing falls entails the providers to respond only after a fall has occurred. Instead, by using novice technologies like wearable sensors, providers can employ proactive strategy wherein these tools can assist the providers to identify individuals who are at a high risk of falling much earlier instead of waiting for a fall incident to occur. This early detection allows them to step in with focused interventions before a fall ever happens. Furthermore, these interventions are customizable to the individual's needs and may include, creating a specialized exercise program to improve their standing balance, reviewing and adjusting their medications that might cause dizziness, or making simple changes to their living environment to remove hazards. Consequently, providers can help individuals stay safe while being independent.

The benefits of wearable systems optimize when integrated with remote monitoring and telehealth platforms. Junaid et al demonstrated that IoT enabled and AI enhanced sensors can continuously collect and transmit data from patients' daily environments, thereby transforming routine activities into clinically meaningful information streams.[24] These data can then generate predictive alerts for clinicians and caregivers, allowing early detection of functional decline or imminent fall risk.

Remote monitoring is an important technology which provides a reliable and discreet safety net for individuals with AD. These individuals may present with reluctance to attend physician visits, struggle with accurate self-reporting, or present with fluctuating symptoms. Remote monitoring ensures that patient's medical and functional status is tracked without adding burden on them, while simultaneously supporting providers and caregivers by reducing uncertainty and providing reassurance that their loved one is being continuously monitored.

The development of feedback loops that are enabled by these technologies is equally significant. Information collected from wearable sensors can be synthesized into user friendly dashboards or routine reports that inform multiple stakeholders involved in care. Physical therapists can use this information to create exercise plans that are adjusted in real time. For example, if a sensor shows that someone's balance is progressively worsening, a physical therapist can immediately change their exercise regimen to focus on that specific weakness. Caregivers may also use this data to make informed decisions about the individual's home environment, like adding handrails for providing support or removing tripping hazards which may be disastrous, if not mitigated. Similarly, physicians may be prompted to review and if necessary, adjust medications or treatment plans if the data suggests a change is warranted.

This approach facilitates a "closed loop" framework. It is a continuous cycle where pertinent data is collected, analyzed, and utilized to make real time adjustments. This approach is much different from the old, "one-size-fits-all" model of fall prevention. This new approach creates a dynamic system that constantly adapts to a patient's changing condition and needs. Ultimately, this results in a highly personalized and effective method to prevent falls which keeps individuals safer while improving their overall quality of life.

Enhancing Physical Therapy and Rehabilitation

Wearable data provides an opportunity to rehabilitation professionals to customize their treatment interventions precisely. The multiple metrics such as stride variability, cadence, dual task performance, and postural sway that are collected through accelerometers and IMUs, provide a level of detail that is unable to be captured through observation alone.[13,14] This objective and continuous feedback helps clinicians track progress, identify subtle functional declines, and then adjust treatment plans accordingly. Wearables may also address the important psychological dimension of fall risk. Patients with AD often tend to limit physical activity, creating a cycle of deconditioning and increased vulnerability due to their fear of falling. Wearables can assure patients and their caregivers by providing continuous monitoring and fall detection, thereby, encouraging their safe participation in functional activities. This assurance, when combined with structured sensor guided training has the potential to improve patient's overall mobility and confidence for dynamic activities. As illustrated by Jung et al., wearable supported cognitive motor training enhanced physical outcomes and accelerated cognitive performance and endurance, thereby highlighting the holistic potential of these new technologies.[31]

CHALLENGES AND LIMITATIONS

Patient Related Challenges

Despite their promising applications, there are significant patient related barriers. Cognitive impairment interferes with the consistent use of devices, patients may forget to wear them, remove them due to discomfort, or be unable to manage charging requirements. Resistance is especially common with bulkier or unfamiliar devices. Wrist worn sensors are better tolerated, but they sacrifice accuracy when compared to hip or ankle mounted sensors.7 These challenges emphasize the need for design changes that prioritize comfort and simplicity while simultaneously maintaining clinical accuracy of the data collected.

Technical and Data Barriers

Technical limitations also limit the effectiveness. Battery life is a major concern, as frequent charging is often unrealistic for patients with AD.[14] Many commercially available devices also lag in delivering real time feedback, instead producing retrospective reports that do little to prevent immediate falls.[26] Additionally, the massive volume of data generated by the multi sensor systems can often overwhelm clinicians and caregivers. The risk of data overload becomes a barrier to adoption without decision support tools that narrow down raw outputs into actionable insights.[15] Future systems must prioritize automation, clarity, and clinician friendly interfaces for wearable technologies to be clinically viable.

Ethical and Privacy Concerns

Careful consideration must be provided to the ethical issues. Continuous monitoring of patients may raise questions about autonomy and consent, especially in populations with impaired decision-making capacity. Frequently, consent is obtained from caregivers or family members. However, this raises its own concerns about balancing patient rights with safety. Consequently, transparent processes and ongoing reassessment of patient consent are critical.

Patient privacy is another important concern. Wearable devices collect sensitive health and location data. If this data is breached, it could lead to serious breaches of patient confidentiality. Concurrently, families and caregivers require access to this data to provide patients with adequate support. Therefore, it is imperative to find a delicate but critical balance between strong security measures and caregiver accessibility that will be paramount to building trust in these technologies. In the absence of this fine balance, there are high chances that these sophisticated technologies will face significant usage resistance from patients, caregivers as well as clinicians.

FUTURE DIRECTIONS

Research Recommendations

Future research should move beyond pilot trials and focus of larger, longitudinal studies in patients with Alzheimer's disease. Unfortunately, most studies published till now are limited in their sample size or shorter follow-up periods, making it difficult to confirm the effects of wearable senor monitoring on fall related outcomes.[29] Study designs having standardized data collection techniques, sensor placements and outcome measures should be conducted to establish stronger evidence. Current lack of standardization in outcome measures, sensor positioning, and analyzation techniques prevents meaningful cross-study comparison and clinical application.[29] Standardized protocols would allow reproducibility and clinical translation.

In addition, dual-task testing that analyze the performance of the cognitive-motor interaction observed in AD should be systematically investigated given that they may offer highly sensitive indicators of fall risk that they are not observed in single-task conditions.[19] Future research should also aim at encompassing behavioral, environmental, and clinical features together with sensor-based data to improve prediction of accuracy and complexity of falls in daily life.

Technology Development

From a technology perspective, sensors must be designed while prioritizing comfort, ease of use, and sustained wearability. Heavy, awkward or complex devices tend to exhibit inconsistence in their usage, particularly among elderly individuals with cognitive deficits.[19] Future development should aim to combine physical activity tracking with cognitive indicators, like digital measurements of attention or executive function, to create a more comprehensive fall risk assessment.[21]

Machine learning and AI technologies have already demonstrated capabilities in detecting intricate physiological and behavioral alterations associated with neurological disorders. Implementing these techniques specifically for Alzheimer's disease patients could facilitate immediate prediction and prompt intervention to prevent falls. Importantly, emerging technologies should be created collaboratively with patients, caregivers, and medical professionals.

This joint development strategy will help ensure that devices are functional, user-friendly, and appropriate for practical dementia care settings.

CONCLUSION

Falls are one of the most serious and high costing issues affecting the day-to-day functions in people with Alzheimer's disease. They may result in injury, reduce an individual's level of independence, and increase the need for medical attention. The ability of wearable sensors to continuously and objectively measure gait, balance, and activity patterns provides a potential solution.[19] Consumer wearable technology, such as wristbands and smartwatches, is particularly helpful because it is affordable and accessible, allowing its use outside of specialized medical facilities and research settings.[21] Current methodological restrictions including small sample sizes, inconsistent outcomes, and inadequate extensive monitoring of Alzheimer's patients.[29], limit current research. Despite initial findings being encouraging, there is currently no strong evidence that these technologies help to reduce falls. More vast and extensive clinical research in real-world environments is urgently needed to validate their effectiveness and enable real-world implementation.[29]

In the future, development will be dependent on collaborative contribution from engineers, doctors, rehabilitation specialists, and caregivers. This kind of teamwork will be is essential to make devices that are accurate, easy to use, and used such that they will be ethically feasible in dementia care settings.[27] It may be possible to combine the data from wearable technology to switch from detecting falls after they happen to predicting and stopping them before they occur. In general, wearable sensors may prove highly beneficial to prevent falls in people with Alzheimer's disease, however they will only work if there is more evidence, consistent protocols, and collaboration between fields of study.

Disclosures

In accordance with the guidelines of the American Medical Association (AMA) and the International Committee of Medical Journal Editors (ICMJE), the authors disclose the following:

Financial relationships: The authors have not received any financial support, grants, or funding from any third party (commercial entity, government agency, or private foundation) related to the submitted work.

Personal, professional, or institutional conflicts: The authors have no relevant personal relationships, employment affiliations, or professional associations that could influence the content of this manuscript.

Intellectual property interests: The authors declare no patents, copyrights, trademarks, or other intellectual property interests directly related to the manuscript content.

Other potential conflicts: None reported.

The authors affirm the accuracy of the disclosures and takes full responsibility for the content of this statement.

Funding

There are no funders to report for this submission.

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