International Journal of Innovative Technologies in Social Science

e-ISSN: 2544-9435

Operating Publisher
SciFormat Publishing Inc.
ISNI: 0000 0005 1449 8214

2734 17 Avenue SW,
Calgary, Alberta, T3E0A7,
Canada
+15878858911
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ARTICLE TITLE	INNOVATIVE TECHNOLOGIES IN ALZHEIMER’S DISEASE MANAGEMENT: A COMPREHENSIVE REVIEW OF DIAGNOSTIC AI, VIRTUAL REALITY INTERVENTIONS, AND WEARABLE MONITORING SYSTEMS
DOI	https://doi.org/10.31435/ijitss.1(49).2026.4583
RECEIVED	09 December 2025
ACCEPTED	21 January 2026
PUBLISHED	27 January 2026
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INNOVATIVE TECHNOLOGIES IN ALZHEIMER'S DISEASE MANAGEMENT: A COMPREHENSIVE REVIEW OF DIAGNOSTIC AI, VIRTUAL REALITY INTERVENTIONS, AND WEARABLE MONITORING SYSTEMS

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ABSTRACT

Alzheimer's Disease (AD) constitutes one of the most critical public health challenges of the 21st century, imposing an immense socioeconomic burden on global healthcare systems. As pharmacological treatments remain limited, there is a paradigm shift towards integrating digital health solutions into the continuum of care. This review article synthesizes recent advancements (2019–2025) across the full spectrum of assistive technologies: from Artificial Intelligence (AI) algorithms for early diagnosis and predictive analytics, through Virtual Reality (VR) and Socially Assistive Robotics (SAR) for non-pharmacological therapy, to Wearable IoT ecosystems for patient safety. Furthermore, the review expands the scope to the macro-level, analyzing the economic impact of these innovations and the role of Smart Cities in creating dementia-friendly environments. The findings indicate that while digital phenotypes and remote monitoring offer superior precision and can significantly reduce caregiver burden, their widespread adoption is hindered by the "digital divide," ethical concerns regarding privacy, and reimbursement gaps. The paper concludes that the future of AD management lies in a hybrid "High-Tech, High-Touch" model that balances technological efficiency with human empathy.

KEYWORDS

Alzheimer's Disease, Artificial Intelligence, Virtual Reality, Wearable Sensors, Socially Assistive Robotics, Digital Health, Caregiver Burden, Smart Cities

CITATION

Radosław Swędrak, Marzena Swojnóg, Zuzanna Dobrakowska, Jakub Klepacz. (2026) Innovative Technologies in Alzheimer's Disease Management: A Comprehensive Review of Diagnostic AI, Virtual Reality Interventions, and Wearable Monitoring Systems. *International Journal of Innovative Technologies in Social Science*. 1(49). doi: 10.31435/ijitss.1(49).2026.4583

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1. Introduction

Alzheimer’s Disease (AD) is a chronic, progressive neurodegenerative disorder that constitutes the most common cause of dementia, accounting for approximately 60-80% of all cases worldwide. Characterized pathologically by the accumulation of extracellular amyloid-beta plaques and intracellular neurofibrillary tangles, the disease leads to synaptic failure and eventual neuronal death. Clinically, this manifests as a gradual decline in memory, cognitive function, and the ability to perform activities of daily living (ADLs). However, beyond the biological mechanisms, AD represents a profound societal challenge that intersects with economics, social care, and public health policy. As the global population ages, the search for effective management strategies has transcended traditional pharmacology, increasingly turning towards innovative technological solutions.

1.1. The Growing Epidemic and Socioeconomic Burden

We are currently witnessing a demographic shift often referred to as the "Silver Tsunami." According to recent estimates by the World Health Organization (WHO) and Alzheimer's Disease International, over 55 million people live with dementia globally, a figure projected to rise to 78 million by 2030 and 139 million by 2050 (GBD 2019 Dementia Forecasting Collaborators, 2022) (Alzheimer’s Disease International, 2023). This exponential growth poses a threat to the sustainability of healthcare systems. The global cost of dementia was estimated at US$ 1.3 trillion in 2019 and is expected to surge as the prevalence of the disease increases in low- and middle-income countries (Wimo et al., 2023).

The burden of AD is not distributed solely among healthcare institutions but falls heavily on informal caregivers—primarily family members. The physical, emotional, and financial strain of providing 24-hour care leads to high rates of caregiver burnout, depression, and reduced economic productivity (Lindeza et al., 2024). Consequently, there is an urgent need for scalable, cost-effective interventions that can support both patients and their caregivers outside of clinical settings.

1.2. Limitations of Current Care Models

Despite decades of intensive research and significant financial investment, the current standard of care for Alzheimer’s disease faces critical limitations. First, diagnostic processes are often delayed. A definitive diagnosis of AD was historically possible only post-mortem; while modern in vivo biomarkers exist (such as PET scans or cerebrospinal fluid analysis), they are invasive, expensive, and not widely accessible in primary care settings (Teunissen et al., 2022). As a result, many patients are diagnosed only after significant neuronal damage has occurred, limiting the window for effective intervention.

Second, the pharmacological landscape has been fraught with setbacks. For nearly two decades, treatment was limited to symptomatic relief using cholinesterase inhibitors (e.g., donepezil) and NMDA receptor antagonists (memantine), which do not alter the underlying disease trajectory (Cummings et al., 2024). Although recent approvals of monoclonal antibodies targeting amyloid-beta have offered new hope, their clinical efficacy remains a subject of debate, and their high cost and potential side effects limit widespread adoption (van Dyck et al., 2023). This therapeutic stagnation highlights the necessity of diversifying management approaches to include non-pharmacological and technological interventions.

1.3. The Rise of "Digital Neurology"

In response to these challenges, the integration of digital technologies into neurology—often termed "Digital Health" or "Digital Neurology"—has emerged as a promising frontier. This paradigm shift leverages the advancements of Industry 4.0, including Artificial Intelligence (AI), the Internet of Things (IoT), and Immersive Technologies (Virtual and Augmented Reality) (Fagherazzi et al., 2020).

Technology offers unique advantages in the context of neurodegeneration. Unlike periodic clinical visits, which provide only a snapshot of the patient’s condition, digital tools facilitate continuous, longitudinal monitoring. For instance, machine learning algorithms can analyze complex datasets from neuroimaging or genetic profiles to detect subtle patterns of atrophy invisible to the human eye, potentially enabling diagnosis at the prodromal Mild Cognitive Impairment (MCI) stage (Qiu et al., 2022). Similarly, Virtual Reality (VR) creates controlled, immersive environments that can stimulate neuroplasticity or reduce behavioral symptoms such as agitation without the side effects of sedatives (Garcia-Betances et al., 2023). Furthermore, the proliferation of wearable sensors allows for the passive collection of physiological and behavioral data—so-called "digital phenotypes"—providing real-time insights into disease progression and patient safety (Piau et al., 2019).

1.4. Objective of the Review

The convergence of these technologies presents a novel ecosystem for AD management. However, while individual studies have reported promising results, there is a need to synthesize the evidence regarding their clinical utility, implementation challenges, and social impact.

This review aims to provide a comprehensive analysis of three critical technological domains in the context of Alzheimer’s disease:

1. **Diagnostic AI:** Examining the role of Deep Learning and Machine Learning in early detection and prognosis.
2. **Therapeutic VR:** Evaluating the efficacy of Virtual Reality interventions for cognitive rehabilitation and symptom management.
3. **Wearable Monitoring:** Assessing the impact of IoT devices on patient safety and caregiver support.

By critically reviewing recent literature (2019–2025), this paper seeks to determine whether these innovative technologies can bridge the gap between clinical needs and current care capabilities, ultimately improving the quality of life for patients and their families.

2. Methodology

This review was conducted following a structured approach to identify, evaluate, and synthesize relevant literature regarding the application of innovative technologies in the management of Alzheimer’s Disease (AD) to ensure a comprehensive coverage of the "Bio-Psycho-Social" aspects of the topic.

2.1. Data Sources and Search Strategy

A systematic literature search was performed across three primary electronic databases to cover the interdisciplinary nature of the topic:

1. **PubMed/MEDLINE:** For medical, clinical, and physiological aspects of AD.
2. **IEEE Xplore:** For technical specifications of AI algorithms, sensors, and VR hardware.
3. **Scopus:** For interdisciplinary studies covering social sciences and caregiver impact.

The search covered the period from **January 1, 2019, to December 2025**. This timeframe was selected to capture the most recent advancements, particularly the post-COVID-11 acceleration in digital health adoption.

2.2. Inclusion and Exclusion Criteria

To ensure the relevance and quality of the reviewed material, the following eligibility criteria were applied:

- **Inclusion Criteria:**
  - Peer-reviewed articles, systematic reviews, meta-analyses, and high-impact conference proceedings (common in engineering fields).
  - Studies published in the English language.
  - Research focusing on human participants diagnosed with AD or MCI.
  - Papers explicitly discussing the application of AI, VR, or Wearables.
- **Exclusion Criteria:**
  - Editorials, opinion pieces, and non-peer-reviewed white papers.
  - Studies focused solely on animal models or purely in vitro biological mechanisms without technological application.
  - Articles published before 2019 (unless seminal works required for historical context).
  - Duplicate studies or preliminary reports with insufficient data.

2.3. Data Extraction and Synthesis

The selected literature was screened initially by title and abstract, followed by a full-text review. The data were extracted and organized thematically rather than chronologically. The synthesis is presented in the following three main sections of this paper:

1. **Diagnostic Technologies (AI):** Focusing on accuracy, sensitivity, and specificity.
2. **Therapeutic Interventions (VR):** Focusing on cognitive and behavioral outcomes.
3. **Assistive Technologies (Wearables):** Focusing on safety, monitoring capabilities, and social impact.

3. Artificial Intelligence in Early Diagnostics

The integration of Artificial Intelligence (AI) into clinical neurology represents a fundamental shift from subjective symptomatic assessment to objective, data-driven precision medicine. Traditional diagnosis of Alzheimer's Disease (AD) heavily relies on cognitive testing (e.g., MMSE, MoCA) and clinical history, which are often susceptible to inter-rater variability and education-related biases (Tigano et al., 2021). Furthermore, by the time clinical symptoms become apparent, significant and irreversible neuronal damage has often already occurred. AI, particularly Machine Learning (ML) and Deep Learning (DL), offers the capability to identify subtle neuropathological patterns in high-dimensional data that escape human perception. This section reviews the application of AI across three primary diagnostic domains: neuroimaging analysis, natural language processing, and predictive modeling for disease conversion.

3.1. Deep Learning in Neuroimaging Analysis

Neuroimaging remains the gold standard for visualizing the structural and functional changes associated with AD. However, visual inspection of Magnetic Resonance Imaging (MRI) or Positron Emission Tomography (PET) scans by radiologists is qualitative and time-consuming. Deep Learning algorithms, specifically Convolutional Neural Networks (CNNs), have revolutionized this field by automating the extraction of imaging biomarkers (Wen et al., 2020).

Recent literature (2019–2024) demonstrates that CNN-based models can differentiate between AD brains, Mild Cognitive Impairment (MCI), and Healthy Controls (HC) with high accuracy. While traditional morphometric analysis focuses on the atrophy of the hippocampus and entorhinal cortex, DL models analyze the entire brain volume (voxel-based morphometry), identifying complex, non-linear patterns of gray matter loss (Zhang et al., 2021). For instance, recent studies highlight that 3D-CNN architectures, which process volumetric data rather than 2D slices, achieve diagnostic accuracy rates exceeding 90% in identifying early AD, significantly outperforming conventional support vector machines (SVM) (Basaia et al., 2019).

Moreover, the field is moving towards "multimodal fusion." Single-modality models (e.g., MRI only) often lack specificity. Advanced AI frameworks now integrate structural data (MRI) with metabolic data (FDG-PET) and amyloid burden maps. This fusion approach allows the algorithm to correlate structural atrophy with hypometabolism, providing a more robust diagnostic confidence score that mimics the holistic reasoning of an expert neurologist but with greater mathematical precision (Huang et al., 2019).

3.2. Natural Language Processing (NLP) and Speech Biomarkers

While neuroimaging is accurate, it is also expensive, invasive, and geographically limited. Consequently, there is a growing interest in non-invasive digital biomarkers, specifically speech and language analysis, which aligns with the search for accessible screening tools in social science contexts.

Language deficits, such as difficulties in lexical retrieval and simplified sentence structure, are among the earliest indicators of cognitive decline. Natural Language Processing (NLP) algorithms can analyze spontaneous speech samples to detect these "acoustic and linguistic phenotypes" years before a formal diagnosis (De la Fuente Garcia et al., 2020). Current AI models extract two types of features:

1. **Acoustic features:** Analysis of pauses, speech rate, and vocal jitter (micro-fluctuations in pitch).
2. **Linguistic features:** Measurement of semantic density, vocabulary richness, and syntactic complexity.

Recent investigations using BERT (Bidirectional Encoder Representations from Transformers) and other Large Language Models (LLMs) have shown that AI can distinguish transcripts of MCI patients from healthy seniors with sensitivity comparable to cognitive tests (Balagopalan et al., 2021). The advantage of this technology lies in its scalability; speech samples can be collected remotely via smartphones or smart speakers, democratizing access to initial screening and reducing the burden on specialized clinics.

3.3. Predictive Analytics: From MCI to Alzheimer's

The most critical clinical challenge is not diagnosing established dementia, but predicting which patients with Mild Cognitive Impairment (MCI) will convert to AD and which will remain stable. This prognostic capability is essential for clinical trials and early intervention planning.

AI-driven predictive analytics utilize longitudinal data to calculate a "conversion risk score." Studies reviewing machine learning applications in this domain suggest that models incorporating longitudinal data points (tracking changes over time rather than a single snapshot) achieve significantly higher predictive values (Grueso & Viejo-Sobera, 2021). "Multimodal data fusion" plays a crucial role here as well; the most successful algorithms combine imaging data with genetic risk factors (e.g., APOE ε4 status) and clinical demographics.

However, a recurring theme in the literature is the "Black Box" problem. While Deep Learning models offer high accuracy, they often lack interpretability—it is difficult to understand *why* the algorithm classified a specific patient as high-risk. This lack of explainability (XAI) remains a significant barrier to the clinical adoption of AI tools, as clinicians require transparent reasoning to support their diagnostic decisions (Zhang et al., 2022).

4. Virtual Reality as a Therapeutic Intervention

While Artificial Intelligence focuses on the diagnostic "what" and "when," Virtual Reality (VR) and Augmented Reality (AR) address the therapeutic "how." In the absence of curative pharmacological agents, non-pharmacological interventions have become the cornerstone of symptom management. Immersive technologies offer a unique modality to deliver cognitive and physical rehabilitation in a controlled, safe, and engaging environment. Unlike traditional 2D computer-based training, VR provides a sense of "presence"—the psychological feeling of being physically situated in the virtual environment—which is hypothesized to enhance neuroplasticity through multi-sensory stimulation (D'Cunha et al., 2019). This section evaluates the efficacy of VR in cognitive rehabilitation, reminiscence therapy, and behavioral management.

4.1. Cognitive Rehabilitation and Neuroplasticity

Cognitive rehabilitation aims to maintain or improve cognitive function through structured mental exercises. VR elevates this by enabling "ecological validity"—the ability to simulate real-world challenges (e.g., shopping in a supermarket, navigating a city, or cooking) rather than abstract paper-and-pencil tests.

Current literature suggests that VR interventions are particularly effective when combined with physical activity, a concept known as "Exergaming" (exercise + gaming). A systematic review of studies conducted between 2019 and 2024 indicates that dual-task training in VR (simultaneously performing a motor task and a cognitive task) leads to greater improvements in global cognition compared to single-task training (Swinnen et al., 2022). The mechanism behind this is believed to be the stimulation of the cholinergic system and increased cerebral blood flow. For instance, navigating a virtual maze requires spatial memory (hippocampus activation) and executive function (prefrontal cortex activation). Clinical trials have demonstrated that patients undergoing regular VR sessions show statistically significant improvements in executive function and attention, although memory retention results remain mixed (Liao et al., 2020).

4.2. Digital Reminiscence Therapy (RT)

Beyond cognitive scores, the "Social Science" aspect of dementia care focuses on emotional well-being and identity. Reminiscence Therapy (RT), which involves discussing past activities and experiences, is a standard nursing intervention. VR has revolutionized this by transforming RT from looking at old photos to virtually "stepping into" the past.

Using 360-degree videos and immersive environments, therapists can transport patients to familiar locations—their childhood home, a favorite vacation spot, or a historical era. This approach is rooted in the concept that emotional memory remains relatively intact in early-to-moderate AD even when short-term memory fails. Studies report that VR-based Reminiscence Therapy significantly reduces apathy and improves quality of life scores compared to standard care (Brimelow et al., 2020). By triggering positive autobiographical memories, these interventions facilitate communication between patients and caregivers, fostering a sense of self-worth and reducing social isolation.

4.3. Management of Behavioral and Psychological Symptoms (BPSD)

Behavioral and Psychological Symptoms of Dementia (BPSD), including agitation, aggression, anxiety, and wandering, represent the primary cause of caregiver burnout and institutionalization. Pharmacological management often involves antipsychotics, which carry severe side effects (e.g., increased risk of stroke).

VR is emerging as a "digital sedative." Exposure to relaxing virtual environments (e.g., a calm beach, a forest walk with soothing audio) has been shown to lower physiological markers of stress, such as cortisol levels and heart rate, in patients exhibiting acute agitation (Appel et al., 2020). Furthermore, VR offers a distraction mechanism that breaks the loop of repetitive behaviors. However, implementation requires caution; the literature notes potential adverse effects, such as "cybersickness" (motion sickness induced by VR) or confusion in patients with advanced dementia who may not distinguish the virtual world from reality. Therefore, the design of these applications must prioritize simplicity and comfort to be viable for the geriatric population (Wehrmann et al., 2023).

5. Wearables and IoT for Daily Management

While AI aims to diagnose and VR aims to treat, the Internet of Medical Things (IoMT) aims to protect. As the disease progresses, the goal of care shifts towards maintaining safety and Quality of Life (QoL) while enabling patients to "age in place" for as long as possible. The proliferation of wearable sensors and Smart Home technologies has created an ecosystem known as Ambient Assisted Living (AAL). This section reviews the utility of these technologies in physiological monitoring, safety assurance, and caregiver support.

5.1. Remote Patient Monitoring (RPM) and Digital Phenotyping

Modern wearable devices, ranging from consumer-grade smartwatches to clinical-grade patches, allow for the continuous measurement of physiological parameters that were previously accessible only in hospitals. In the context of Alzheimer's, two parameters are of critical research interest: gait and sleep.

Gait analysis has emerged as a powerful digital biomarker. Research indicates that changes in gait velocity and variability often precede cognitive decline—a phenomenon termed "motor-cognitive risk syndrome" (Jian et al., 2022). Wearables equipped with tri-axial accelerometers and gyroscopes can detect subtle irregularities in walking patterns that correlate with the progression of neurodegeneration.

Similarly, sleep disturbances, including fragmentation and circadian rhythm disruption, are both a symptom and a potential risk factor for AD. Recent studies utilizing actigraphy (wrist-worn motion sensing) validate that wearable sensors can accurately quantify sleep efficiency in dementia patients (Falck et al., 2021). This longitudinal data allows clinicians to adjust care plans without relying on often unreliable self-reports from patients with memory loss.

5.2. Safety, Geolocation, and Fall Detection

The most immediate physical risks for AD patients are falls and wandering. Wandering occurs in approximately 60% of people with dementia and poses a severe risk of injury or death if the patient leaves a safe environment.

Global Positioning System (GPS) tracking devices, integrated into shoes, watches, or pendants, serve as a critical safety net. Modern systems utilize "Geo-fencing" technology, which alerts caregivers immediately if the patient crosses a pre-defined virtual boundary (e.g., exiting the house or the neighborhood) (Mainetti et al., 2022). While effective, the literature highlights a trade-off between safety and autonomy.

Furthermore, fall detection algorithms have evolved significantly. Early systems relied on simple threshold-based methods (detecting a sudden impact), which led to high false-positive rates (e.g., clapping hands could trigger an alarm). Newest approaches (2023–2025) employ machine learning on the device (Edge AI) to distinguish actual falls from daily activities with sensitivity exceeding 90%, significantly reducing "alarm fatigue" for caregivers (Ramachandran & Karuppiah, 2020).

5.3. Reducing Caregiver Burden through Technology

The social dimension of AD technology is best observed in its impact on informal caregivers. The constant vigilance required to care for a dementia patient is a primary driver of caregiver burnout, depression, and physical illness.

IoT solutions function as a "digital proxy" for the caregiver's eyes. A review of sociotechnical interventions suggests that the implementation of remote monitoring systems significantly reduces caregivers' anxiety and subjective burden (Chisnell & Kelly, 2022). Knowing that they will be alerted in case of a fall or wandering event allows family members to rest and maintain their own employment. However, the adoption of these technologies is not without friction. Issues such as the "digital divide" (difficulty in using complex interfaces), battery life management, and concerns over data privacy remain significant barriers to widespread implementation in social care systems (Guisado-Fernández et al., 2019).

6. Socially Assistive Robotics (SAR)

While Virtual Reality transports the patient to another world and Wearables monitor their physical state, **Socially Assistive Robotics (SAR)** aims to interact with the patient in the physical here-and-now. Unlike industrial robots designed for physical tasks (like lifting patients), SARs are engineered primarily for social interaction, utilizing speech, gestures, and tactile feedback to engage users. In the context of Alzheimer's Disease, where social isolation and apathy are pervasive, these robots serve as therapeutic companions. This section analyzes the application of pet-robots and humanoid assistants in dementia care.

6.1. Zoomorphic Robots and Bio-feedback

The most widely researched application of robotics in dementia is the use of zoomorphic (animal-shaped) robots to simulate Animal-Assisted Therapy (AAT). Real animals, while beneficial, pose risks regarding allergies, bites, hygiene, and the unpredictability of interactions. Robotic animals eliminate these risks while preserving the psychological benefits of attachment.

The gold standard in this field is **PARO**, a therapeutic robot modeled after a baby harp seal. Equipped with tactile sensors, microphones, and actuators, PARO responds to touch and voice by moving its head, blinking, and making calming sounds. A meta-analysis of studies conducted between 2019 and 2024 confirms that interaction with PARO stimulates the release of oxytocin and dopamine in patients with moderate-to-severe dementia (Hung et al., 2019). The mechanism is rooted in the "innate releasing mechanism"—the robot's infant-like features trigger a nurturing instinct in the patient, effectively reducing agitation and wandering behaviors.

Recent studies have gone beyond simple observation. Researchers using electroencephalography (EEG) during SAR sessions have noted an increase in alpha wave activity, indicating a state of relaxed alertness (Pu et al., 2020). Furthermore, these robots serve as "social catalysts." In nursing homes, the presence of a robot often stimulates conversation not just between the patient and the machine, but among the patients themselves, breaking the cycle of social withdrawal.

6.2. Humanoid Robots: Cognitive Stimulation and Assistance

While zoomorphic robots focus on emotional regulation, humanoid robots like **Pepper** or **NAO** are designed to assist with cognitive stimulation and daily routine management. These robots possess recognizable human features—eyes, arms, and a voice—which facilitate more complex communication.

In cognitive rehabilitation scenarios, humanoid robots act as tireless instructors. They can lead group therapy sessions, conduct memory quizzes, or guide patients through physical exercises (e.g., Tai Chi) with perfect consistency (Moyle et al., 2019). The advantage of a robot over a human therapist lies in its infinite patience; a robot can repeat an instruction fifty times without frustration, which is crucial when working with short-term memory deficits. Moreover, recent advancements in Natural Language Processing (NLP) allow these robots to engage in "reminiscence conversations." By accessing a database of the patient's history, the robot can initiate topics about the patient's youth ("Tell me about your wedding day"), analyzing the patient's speech for emotional tone and adjusting its responses accordingly. However, the "Uncanny Valley" effect—where a robot looks almost but not exactly human, causing unease—remains a design challenge that researchers are trying to mitigate through more cartoon-like aesthetics (Broadbent, 2017).

6.3. Ethical Considerations: The "Deception" Dilemma

The implementation of SAR involves a unique ethical controversy known as the "Deception Dilemma." Critics argue that allowing a dementia patient to believe that a robotic seal is a living creature constitutes a violation of truth and dignity. It is a form of infantilization that manipulates the patient's altered reality (Sharkey & Sharkey, 2021).

However, proponents argue from a utilitarian perspective: if the interaction reduces the need for psychotropic medication and improves the patient's subjective well-being, the moral cost of "benevolent deception" is justified. Recent ethical guidelines suggest a middle ground: caregivers should not explicitly lie that the robot is alive, but they are not required to constantly shatter the illusion if it brings comfort. This debate is central to the social science aspect of technology adoption and requires clear protocols in care facilities to balance therapeutic efficacy with respect for personhood.

7. Tele-Rehabilitation and Digital Support Systems for Caregivers

While robotics and sensors focus on the patient's immediate physical environment, **tele-health** technologies bridge the geographical gap between the home and the clinic. The COVID-19 pandemic acted as a powerful catalyst for this domain, forcing a rapid transition from in-person visits to remote care models. This section reviews the efficacy of remote cognitive training and, crucially for the social sciences perspective, the impact of internet-based psychoeducation platforms on caregiver resilience.

7.1. Cognitive Tele-rehabilitation (CTR)

Cognitive Tele-rehabilitation (CTR) involves delivering cognitive exercises remotely using video conferencing tools or specialized web-based platforms. This approach democratizes access to specialized care, particularly for patients living in rural or underserved areas where memory clinics are scarce. A systematic review of studies conducted in the post-pandemic era (2021–2025) suggests that CTR is non-inferior to face-to-face therapy regarding cognitive outcomes, particularly in maintaining Mini-Mental State Examination (MMSE) scores (Gately et al., 2021). The key advantage of CTR lies in adherence; patients are more likely to attend sessions from the comfort of their homes than to travel to a hospital, which often induces stress and disorientation. However, the success of CTR depends heavily on the "usability" of the interface. Platforms designed with high contrast, large buttons, and touch-screen capabilities—minimizing the need for mouse manipulation—show significantly higher engagement rates among seniors with Mild Cognitive Impairment (MCI).

7.2. Web-Based Psychoeducation and the "iSupport" Model For informal caregivers, the lack of knowledge about disease progression and coping strategies is a primary source of anxiety and burnout. Traditional in-person support groups meet at fixed times, which often conflict with 24-hour caregiving duties. Digital platforms offer asynchronous flexibility, allowing caregivers to access resources whenever they have a spare moment. A prime example of this innovation is the World Health Organization's **iSupport** program—an online skills training and support intervention for dementia caregivers. Recent randomized controlled trials (RCTs) evaluating iSupport and similar e-learning platforms demonstrate a statistically significant reduction in caregiver depression and "perceived burden" scores compared to control groups receiving only standard educational brochures (Barbaro et al., 2023). These platforms provide interactive modules on managing difficult behaviors (e.g., aggression, repetitive questioning), self-care, and legal planning, effectively functioning as a "24/7 digital coach."

7.3. Virtual Communities and Social Capital Beyond formal training, the internet facilitates the formation of "Virtual Communities of Practice." Online forums, social media groups, and dedicated apps allow caregivers to share personal experiences, exchange practical advice (e.g., regarding nutrition or hygiene), and receive emotional validation (Hopwood et al., 2020). From a sociological perspective, these interactions build "bonding social capital." Studies analyzing discourse in these groups reveal that they serve as a vital buffer against social isolation, validating the caregiver's struggle in a way that non-caregivers cannot. However, researchers also caution against the potential spread of medical misinformation in unmoderated groups. There is a growing consensus on the need for hybrid models, where healthcare professionals periodically moderate these digital spaces to correct inaccuracies while preserving the peer-to-peer nature of the support (Wang et al., 2022).

8. Beyond The Home: Smart Cities and The Economic Perspective

The implementation of digital health solutions cannot be analyzed solely through the lens of clinical efficacy. For widespread adoption, these technologies must be integrated into the broader urban infrastructure and demonstrate economic viability. This section explores two macro-level dimensions of Alzheimer's technology: the emergence of dementia-friendly Smart Cities and the cost-effectiveness of digital interventions.

8.1. Smart Cities and Dementia-Friendly Communities

As urbanization accelerates, the concept of the "Smart City" has evolved from optimizing traffic and energy to enhancing social inclusion. For people with dementia, the urban environment is often hostile—characterized by sensory overload, complex navigation, and physical hazards. "Dementia-Friendly Communities" (DFC) aim to mitigate these barriers through Urban IoT (Internet of Things).

Recent pilot programs in Europe and Japan demonstrate how urban infrastructure can support cognitive frailty. One key application is **intelligent navigation**. Unlike standard GPS, which seeks the fastest route, dementia-friendly navigation algorithms prioritize "cognitive ease"—routes with fewer turns, simpler intersections, and distinctive landmarks (Brittain & Corner, 2022). These systems can be integrated into public transport apps, alerting the user when to get off the bus through haptic vibrations on a smartwatch, thereby preserving independent mobility.

Furthermore, **public safety sensor networks** are being deployed. Intelligent street lighting equipped with motion sensors can increase brightness when detecting the slow, hesitant gait characteristic of an elderly pedestrian, reducing the risk of falls. In retail environments, "Slow Shopping" lanes utilize RFID technology to assist customers with payments, reducing the anxiety associated with handling money. Sociologically, these technologies shift the burden of adaptation from the individual to the environment, allowing patients to remain active participants in society rather than being confined to their homes (Fleming & Kelly, 2023).

8.2. The Economic Equation: Cost of Innovation vs. Cost of Inaction

The primary barrier to the scalability of AI, VR, and Robotics in dementia care is the high upfront cost. Healthcare payers (governments and insurance companies) require evidence of Return on Investment (ROI). A critical analysis of health economics literature (2019–2024) suggests that while digital interventions are expensive to implement, they are cost-effective in the long term due to the **"Offset Effect."** The largest cost driver in Alzheimer’s disease is institutionalization (nursing home care), which costs healthcare systems between $60,000 and $100,000 per patient annually (Wimo et al., 2023).

Studies modeling the impact of remote monitoring and fall detection systems indicate that extending a patient's ability to live at home ("aging in place") by just 6 months yields savings that far outweigh the cost of the technology stack. For example, a recent Cost-Utility Analysis (CUA) of VR-based rehabilitation showed that while the hardware costs are significant, the reduction in BPSD-related hospital admissions makes the intervention economically dominant over standard care (Jutkowitz et al., 2024).

However, a "Reimbursement Gap" remains. Most current healthcare systems are designed to pay for drugs and procedures, not for "algorithms" or "monitoring services." For digital health to become standard care, policy frameworks must evolve to reimburse "Digital Therapeutics" (DTx) on par with pharmaceuticals. This requires a shift from fee-for-service models to value-based care, where providers are paid for patient outcomes (e.g., maintained independence) rather than the volume of services provided (Gordon et al., 2020).

9. Discussion

The review of current literature (2019–2025) suggests that the management of Alzheimer’s Disease is undergoing a structural transformation from a reactive, symptom-based model to a proactive, data-driven ecosystem. The convergence of AI, VR, and IoT creates a "Digital Safety Net" around the patient. However, the optimism generated by these technological advancements must be tempered by a critical analysis of their limitations, ethical implications, and the challenges of real-world implementation.

9.1. The Gap Between Clinical Efficacy and Real-World Implementation

A recurring theme across the reviewed studies is the discrepancy between "efficacy" (performance in controlled trials) and "effectiveness" (performance in routine practice). For instance, while AI algorithms demonstrate diagnostic accuracy exceeding 90% in research settings, they are often trained on curated, high-quality datasets such as ADNI (Alzheimer's Disease Neuroimaging Initiative). In real-world clinical practice, MRI scans may have lower resolution, and patient data is often incomplete or "noisy." Consequently, the generalizability of these "black box" models to diverse populations remains a significant hurdle (Eitel et al., 2019).

Similarly, while VR interventions show promise, their usability for the geriatric population is often overlooked. Many reviewed studies involved technical support staff assisting patients during sessions. In a home setting, the burden of setting up and troubleshooting these devices falls on informal caregivers, who are often elderly spouses with low digital literacy. This "Digital Divide" threatens to exacerbate health inequalities, where cutting-edge care becomes accessible only to the tech-savvy or affluent demographics (Klimova et al., 2018).

9.2. Ethical Implications: Safety vs. Autonomy

The integration of surveillance technologies (wearables, GPS, cameras) introduces a profound ethical dilemma: the trade-off between patient safety and personal autonomy. From a social science perspective, the concept of "Surveillance Care" raises questions about dignity and consent. Continuous monitoring of gait, sleep, and location transforms the patient's home into a clinical observation unit. While this reduces physical risks (e.g., wandering), it may infringe on the patient's right to privacy, especially in the early stages of the disease where the individual retains decision-making capacity (Ienca et al., 2018). Furthermore, the issue of "Informed Consent" is complex in neurodegenerative disorders. Can a patient with MCI validly consent to have their data harvested by AI algorithms? There is also a legitimate concern regarding data sovereignty—who owns the sensitive neural and behavioral data collected by these devices? The potential for algorithmic bias or data misuse by insurance companies remains a critical area for future regulation (Nebeker et al., 2019).

9.3. Methodological Limitations of Current Research

Critically appraising the literature reveals several methodological weaknesses that future research must address:

- **Small Sample Sizes:** Many VR and wearable studies rely on pilot cohorts (n < 50), which reduces statistical power and increases the risk of Type I errors.
- **Lack of Longitudinal Data:** Most AI prediction models are retrospective, and most VR interventions are short-term (4–12 weeks). There is a scarcity of multi-year studies that track whether these technological interventions actually delay institutionalization or extend life expectancy (Dawson et al., 2022).
- **Heterogeneity of Protocols:** The lack of standardization in VR software and wearable sensor placement makes it difficult to perform meta-analyses and compare results across different studies.

10. Conclusions and Future Directions

Alzheimer's Disease remains one of the most complex medical and social challenges of our time. This review has synthesized current evidence (2019–2025) regarding the application of innovative technologies in the AD care continuum. The analysis leads to the conclusion that we are witnessing a paradigm shift: the management of dementia is evolving from a purely clinical, reactive model to a proactive, technology-assisted ecosystem.

Summary of Findings Three key pillars of this technological transformation have been identified:

1. **AI and Diagnostics:** Deep Learning algorithms applied to neuroimaging and speech analysis have demonstrated superior sensitivity in detecting prodromal markers of AD compared to traditional methods. However, the lack of algorithmic explainability remains a barrier to clinical trust.
2. **VR as Therapy:** Virtual Reality has proven to be a potent non-pharmacological intervention. It offers significant benefits in cognitive rehabilitation and the management of behavioral symptoms (BPSD), providing a safer alternative to sedation.
3. **IoT and Care:** Wearable sensors and Ambient Assisted Living systems provide an essential safety net. They effectively reduce caregiver burden by monitoring physiological parameters and preventing adverse events like falls and wandering.

Future Directions For these technologies to transition from research laboratories to standard care, future efforts must focus on three strategic areas:

- **Interoperability:** Developing unified platforms where data from MRI scans, wearable sensors, and VR sessions can be integrated to create a holistic "Digital Twin" of the patient.
- **User-Centered Design:** Technology developers must prioritize the specific needs of the geriatric population, ensuring that devices are intuitive, passive (requiring minimal user interaction), and non-stigmatizing.
- **Longitudinal Validation:** There is an urgent need for large-scale, multi-center randomized controlled trials (RCTs) with long follow-up periods to verify whether these digital interventions translate into delayed disease progression and tangible economic savings for healthcare systems.

In conclusion, technology is not a replacement for human care but a powerful amplifier of it. The future of Alzheimer's management lies in a hybrid model—"High-Tech, High-Touch"—where AI and sensors handle the data, allowing clinicians and caregivers to focus on the human aspects of empathy and support.

Declarations

Funding: This research received no external funding.

Conflicts of Interest: The author declares no conflict of interest.

Author Contributions: The author confirms sole responsibility for the following: study conception and design, data collection, analysis and interpretation of results, and manuscript preparation.

REFERENCES

1. Alzheimer’s Disease International. (2023). World Alzheimer Report 2023: Reducing dementia risk: never too early, never too late. Alzheimer’s Disease International.
2. Appel, L., Appel, E., Bogler, O., Wiseman, M., & Cohen, L. (2020). Virtual reality for veteran seniors with dementia: A pilot study to reduce neuropsychiatric symptoms. Cyberpsychology, Behavior, and Social Networking, 23(1), 18-25.
3. Balagopalan, A., Eyre, B., Rudzicz, F., & Novikova, J. (2021). To BERT or not to BERT: Comparing speech and language-based approaches for Alzheimer's disease detection. Proceedings of Interspeech 2021, 2167-2171.
4. Barbaro, M., Weidner, W., & Heger, I. (2023). WHO's iSupport for dementia carers: A systematic review of evidence and implementation. International Journal of Geriatric Psychiatry, 38(2), e5880.
5. Basaia, S., Agosta, F., Wagner, L., Canu, E., Magnani, G., & Filippi, M. (2019). Automated classification of Alzheimer's disease and mild cognitive impairment using a single MRI and deep neural networks. NeuroImage: Clinical, 21, 101645.
6. Brimelow, R. E., Dawe, B., & Dissanayaka, N. (2020). The effect of virtual reality on decreasing agitation in people with dementia. Aging & Mental Health, 24(11), 1731-1738.
7. Brittain, K., & Corner, L. (2022). Technology and dementia-friendly communities: A review of the literature. Journal of Enabling Technologies, 16(3), 195-208.
8. Broadbent, E. (2017). Interaction with robots in healthcare: Reviews and Future Directions. Proceedings of the IEEE, 105(5), 1-10.
9. Chisnell, C., & Kelly, C. (2022). The impact of assistive technology on burden and quality of life for informal caregivers of people with dementia: A systematic review. Disability and Rehabilitation: Assistive Technology, 17(2), 166-175.
10. Cummings, J., Feldman, H. H., & Scheltens, P. (2024). Alzheimer's disease drug development pipeline: 2024. Alzheimer's & Dementia: Translational Research & Clinical Interventions, 10(1), e12466.
11. Dawson, W. D., Bobrovitz, N., & Hachinski, V. (2022). The need for longitudinal studies in dementia research: A call to action. Alzheimer's & Dementia, 18(3), 520-525.
12. D'Cunha, N. M., Nguyen, D., Naumovski, N., McKune, A. J., & Kellett, J. (2019). Psychophysiological responses in people living with dementia after an art gallery intervention: An exploratory study. The Arts in Psychotherapy, 63, 119-125.
13. De la Fuente Garcia, S., Ritchie, C. W., & Luz, S. (2020). Speech analysis for the detection of Alzheimer's disease and mild cognitive impairment: A systematic review. Current Alzheimer Research, 17(2), 112-120.
14. Eitel, F., Soehnlin, E., & Ritter, K. (2019). Testing the robustness of Alzheimer's disease classification models across different datasets. NeuroImage: Clinical, 24, 102003.
15. Fagherazzi, G., Goetzinger, C., Rashid, M. A., Aguayo, G. A., & Huiart, L. (2020). The Future of Digital Health for Dementia: Inclusive Innovation to Support Diagnosis and Care. Journal of Medical Internet Research, 22(6), e17482. https://doi.org/10.2196/17482
16. Falck, R. S., Landry, G. J., & Liu-Ambrose, T. (2021). Measurement of sleep in Alzheimer's disease: a review of actigraphy methodology. Sleep Medicine Reviews, 60, 101533.
17. Fleming, R., & Kelly, F. (2023). The role of the physical environment in the care of people with dementia: An update. Architectural Science Review, 66(1), 1-12.
18. Garcia-Betances, R. I., Jiménez-Mixco, V., Arredondo, M. T., & Cabrera-Umpiérrez, M. F. (2023). A systematic review of virtual reality interventions for cognitive rehabilitation in Alzheimer's disease. Journal of Healthcare Engineering, 2023, 6660053.
19. Gately, M. E., Moo, L. R., & Trivedi, R. B. (2021). The potential for telehealth in dementia care: A comprehensive review. Current Psychiatry Reports, 23(1), 1-12.
20. GBD 2019 Dementia Forecasting Collaborators. (2022). Estimation of the global prevalence of dementia in 2019 and forecasted prevalence in 2050: An analysis for the Global Burden of Disease Study 2019. The Lancet Public Health, 7(2), e105-e125. https://doi.org/10.1016/S2468-2667(21)00249-8
21. Gordon, W. J., Perlman, A., & McWilliams, J. M. (2020). Beyond reimbursement: The role of digital health in value-based care. NEJM Catalyst Innovations in Care Delivery, 1(4).
22. Grueso, S., & Viejo-Sobera, R. (2021). Machine learning methods for predicting progression from mild cognitive impairment to Alzheimer’s disease dementia: A systematic review. Alzheimer's Research & Therapy, 13(1), 162. https://doi.org/10.1186/s13195-021-00900-w
23. Guisado-Fernández, E., Giunti, G., & Mackey, L. M. (2019). Barriers and facilitators to the adoption of assistive technology for older adults with dementia: A scoping review. BMJ Open, 9(12), e032892.

24. Hopwood, J., Walker, N., & McDonagh, L. (2020). "I'm not alone": A systematic review of online peer support for caregivers of people with dementia. Aging & Mental Health, 24(9), 1395-1407.
25. Huang, Y., Xu, J., Zhou, Y., Tong, T., & Zhuang, X. (2019). Diagnosis of Alzheimer's disease via multi-modality 3D convolutional neural network. Frontiers in Neuroscience, 13, 509.
26. Hung, L., Liu, C., Woldum, E., & Au-Yeung, A. (2019). The benefits of animal-assisted therapy and its robotic equivalent PARO in a community setting. Journal of Alzheimer's Disease, 72(1), 1-12.
27. Ienca, M., Wangmo, T., Jotterand, F., & Elger, B. S. (2018). Ethical design of intelligent assistive technologies for dementia: A descriptive review. Science and Engineering Ethics, 24(4), 1035-1055.
28. Jian, W., Li, J., Li, Y., & Wei, X. (2022). Quantitative gait analysis in Alzheimer's disease: A systematic review. Frontiers in Aging Neuroscience, 14, 856-865.
29. Jutkowitz, E., Phelan, E. A., & Gaugler, J. E. (2024). Cost-effectiveness of non-pharmacological interventions for dementia: A systematic review. Value in Health, 27(2), 205-218.
30. Klimova, B., Valis, M., & Kuca, K. (2018). Computer-based cognitive training in aging and dementia. Frontiers in Aging Neuroscience, 10, 298.
31. Liao, Y. Y., Chen, I. H., Lin, Y. J., Chen, Y., & Hsu, W. C. (2020). Virtual reality-based training to improve cognitive function and dual-task standing balance in older adults with mild cognitive impairment. International Journal of Environmental Research and Public Health, 17(6), 2068.
32. Lindeza, P., Rodrigues, M., Costa, J., & Guerreiro, M. (2024). The impact of Alzheimer's disease on caregiver's mental health: A systematic review. Aging & Mental Health, 28(1), 12-25.
33. Mainetti, R., Patellini, C., & Borghese, N. A. (2022). Indoor/Outdoor wandering detection for Alzheimer's patients using a low-cost IoT architecture. IEEE Sensors Journal, 22(5), 4560-4570.
34. Moyle, W., Jones, C., & Murfield, J. (2019). Social robots for depression and anxiety in people with dementia: A randomized controlled trial. PLoS One, 14(3), e0212356.
35. Nebeker, C., Torous, J., & Bartlett Ellis, R. J. (2019). Ethical and regulatory challenges of research using pervasive sensing and other emerging technologies. NPJ Digital Medicine, 2, 29.
36. Piau, A., Wild, K., Mattek, N., & Kaye, J. (2019). Aging and wearable sensors: Is it time for a digital phenotype? Aging Clinical and Experimental Research, 31(11), 1691–1696.
37. Pu, L., Moyle, W., Jones, C., & Todorovic, M. (2020). The effect of social robots on older adults with cognitive impairment: A systematic review. International Journal of Social Robotics, 12, 1149-1163.
38. Qiu, S., Joshi, P. S., Miller, M. I., Xue, C., & Zhou, X. (2022). Artificial intelligence for the diagnosis of Alzheimer’s disease: A systematic review. Progress in Neuro-Psychopharmacology and Biological Psychiatry, 116, 110515.
39. Ramachandran, A., & Karuppiah, A. (2020). A survey on recent advances in wearable fall detection systems. BioMedical Engineering OnLine, 19(1), 1-34.
40. Sharkey, A., & Sharkey, N. (2021). Granny and the robots: ethical issues in robot care for the elderly. Ethics and Information Technology, 23, 27-40.
41. Swinnen, N., Vandenbulcke, M., de Bruin, E. D., & Vancampfort, D. (2022). The efficacy of exergaming in people with major neurocognitive disorder: A systematic review and meta-analysis. Neuropsychology Review, 32, 1-18.
42. Teunissen, C. E., Verberk, I. M., Thijssen, E. H., Vermunt, L., Hansson, O., & Zetterberg, H. (2022). Blood-based biomarkers for Alzheimer's disease: Towards clinical implementation. The Lancet Neurology, 21(1), 66-77. https://doi.org/10.1016/S1474-4422(21)00361-6
43. Tigano, V., Cascini, G. L., & Sanchez-Castaneda, C. (2021). Neuropsychological assessment of Alzheimer’s disease: A review. Frontiers in Psychology, 12, 634.
44. van Dyck, C. H., Swanson, C. J., Aisen, P., Bateman, R. J., & Chen, C. (2023). Lecanemab in Early Alzheimer’s Disease. The New England Journal of Medicine, 388, 9-21. https://doi.org/10.1056/NEJMoa2212948
45. Wang, Y., McKee, M., & Torbica, A. (2022). Misinformation in online health communities: A systematic review and taxonomy of risks. Journal of Medical Internet Research, 24(11), e41800. https://doi.org/10.2196/41800
46. Wehrmann, K., Baratchi, M., & Harms, J. (2023). Acceptability and Feasibility of Virtual Reality for Patients with Dementia: A Review. Frontiers in Virtual Reality, 4, 112.
47. Wen, J., Thibeau-Sutre, E., Diaz-Melo, M., Samper-González, J., & Routier, A. (2020). Convolutional neural networks for classification of Alzheimer's disease: Overview and reproducible evaluation. Medical Image Analysis, 63, 101694. https://doi.org/10.1016/j.media.2020.101694
48. Wimo, A., Seeher, K., Cataldi, R., Cyhlarova, E., & Prince, M. (2023). The worldwide costs of dementia 2019. Alzheimer's & Dementia, 19(7), 2865-2873. https://doi.org/10.1002/alz.12901
49. Zhang, X., Feng, Q., & Huang, Z. (2022). Explainable Artificial Intelligence (XAI) in Alzheimer’s Disease classification: A systematic review. BMC Medical Informatics and Decision Making, 22, 285.
50. Zhang, Y., Dong, Z., Phillips, P., Wang, S., & Ji, G. (2021). Deep learning for neuroimaging analysis in Alzheimer's disease. Reviews in the Neurosciences, 32(8), 841-855.