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The Impact of a Medical Smart Home on Care Management and Independence for an Older
Adult with an Amputation and Brittle Diabetes

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Abstract

85% of adults aged 65 and older desire to age in their homes, but the management of their multiple comorbid conditions requires complex, continuous care that can be challenging to provide outside of traditional healthcare settings. With the aging population exponentially increasing in the United States, society must consider how to best support their desire to live independently while ensuring access to high-quality, cost-effective healthcare. The aging process and the management of chronic diseases can be facilitated within a medical smart home environment. The essence of a medical smart home is the adaptive integrated medical technology to foster safe, independent living. Data is collected through intuitive sensors and wearable technologies, then analyzed to create reports, alarms, and notifications about an older adult's behavior. This literature review explores the potential impacts of a medical smart home for an older adult with brittle diabetes with an above-the-knee amputation. The custom integration of technology within the home is found to promote physical safety, management of brittle diabetes, independence, dignity, and social engagement. Despite the unique potential to facilitate aging in place, technological feasibility, potential exacerbation of inequities, financial considerations, and privacy persist as limitations. While these challenges are significant, they do not overshadow the broader benefits medical smart homes provide. The implication of a medical smart home goes beyond the individual—the effect on caregivers and the overall efficiency of the healthcare system makes this technology pivotal in the changing landscape and future of healthcare.

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Table of Abbreviations and Acronyms

The following table defines the abbreviations and acronyms used throughout the thesis, presented in the order in which they appear.

Abbreviation	Meaning
ADLs	Activities of daily living
CDC	Centers for Disease Control and Prevention
AIP	Aging in place
DM	Diabetes mellitus
T1DM	Type 1 diabetes mellitus
T2DM	Type 2 diabetes mellitus
DKA	Diabetic ketoacidosis
HHS	Hyperosmolar hyperglycemic state
AKA	Above-the-knee amputation
UN	United Nations
QoL	Quality of life
WHO	World Health Organization
IoT	Internet of Things
HR	Heart rate
RR	Respiratory rate
BP	Blood pressure
SpO ₂	Oxygen saturation
SWD	Smart wearable device
OH	Orthostatic hypotension
HTN	Hypertension
SMBG	Self-monitoring of blood glucose
CGM	Continuous glucose monitor
HbA _{1c}	Hemoglobin A _{1c}
HCL	Hybrid closed-loop system
MDI	Multiple-dose insulin
VAPA	Voice-activated personal assistant
DMN	Digital memory notebook
I-Care	Interactive care platform
FDA	Food and Drug Administration
RAM	Random access memory
AI	Artificial intelligence
BADL	Basic activities of daily living
IADL	Instrumental activities of daily living
TAM	Technology acceptance model
PU	Perceived usefulness
SDOH	Social determinants of health
RN	Registered nurse

The Impact of a Medical Smart Home on Care Management and Independence for an Older Adult with an Amputation and Brittle Diabetes: An Introduction

The National Institute of Aging (2020) defines an older adult as an individual age 65 or older. With baby boomers—individuals born between 1946 and 1964—continuing to enter retirement and become older adults, the United States (U.S.) is faced with a significant demographic shift (Caplan, 2023). Although the older adult population has been steadily increasing since the 1920s, data from the U.S. Census Bureau projects the older adult population will increase by 47% by 2050, from 58 million in 2022 to 82 million (Mather & Scommegna, 2024). In fact, declines in fertility rates and immigration to the U.S. is increasing the ratio of older adults to the total population in U.S. society. This appears to be a global trend as well—in 2019, one in 11 individuals were over 65, but it estimated that one in six individuals globally will be over the age of 65 in 2050 (Hu et al., 2024). The U.S., among other countries, appears underprepared for the significant changes a growing older adult population will bring across many sectors of society. This trend will present challenges globally as life expectancy continues to increase and the presence of chronic diseases persists.

As individuals age, the risk of developing chronic diseases increases (Centers for Disease Control and Prevention [CDC], 2024b). A chronic disease is defined, by the U.S. CDC (2024d), as a condition that persists for one year or greater and either (a) requires ongoing medical attention (b) limits an individual's activities of daily living (ADLs) or (c) both. Unlike an acute illness, which is expected to resolve within hours, days, or weeks, chronic illness is a long-term phenomenon. It affects all spheres of one's life, requiring the individual to sacrifice their current lifestyle. Due to its widespread effects, chronic illness requires behavioral adaptations, psychological changes, and practical modifications in day-to-day ADLs. The prevalence of

chronic diseases is only increasing: 85% of older adults in the U.S. live with one chronic disease and 60% live with two or more chronic diseases (Fong, 2019). Cardiovascular disease, cancer, chronic respiratory disease, and diabetes are chronic diseases that disproportionately affect the older adult population. These four noncommunicable diseases are in fact the leading causes of disability and death in the United States. In turn, the care of older adults with chronic diseases is costly in the U.S.

Problem Statement

As the aging population increases, the management of comorbid, chronic diseases will challenge the capacity of the current healthcare system. Personalized healthcare solutions are required for the management of chronic diseases in the growing aging population.

Throughout this literature review, the author will explore medical smart homes as an emerging cluster of technology that can change the landscape of healthcare globally, allowing for the management of chronic diseases, locally. This innovation is part of a broader paradigm shift toward ubiquitous care, where continuous, integrated, and patient-centered healthcare extends beyond the traditional clinical settings into everyday living spaces. Specifically, the following themes will be discussed in detail: historical perspective and background, perceptions of aging, attributes of the medical smart home, physical wellness, psychosocial wellness, barriers to implementation, and implications of implementation with relation to the interdisciplinary team and healthcare system.

Background

Historical Perspective

The care of older adults has evolved over the past century. It has historically been the family's responsibility to provide care for older adults as they age. In the early 20th century,

almshouses, commonly known as “poorhouses,” were created to care for older adults, individuals with disabilities, and orphans, ensuring they had shelter and basic care (National Academies of Sciences, Engineering, and Medicine, 2022). However, these almshouses were known for poor-quality care and substandard safety and sanitation regulations. Once the Social Security Act was passed in 1935, federal assistance was no longer given to older adults residing in almshouses, forcing them to seek long-term care privately. Amendments to the act in the 1950s allowed older adults to pay for care in licensed public institutions, leading to the rapid creation and growth of nursing homes.

A significant portion of the older adult population has since sought care in nursing homes. In 2020, over 1.3 million individuals resided in nursing homes with approximately 84% of them being older adults (CDC, 2024f). However, the COVID-19 pandemic has raised questions and concerns regarding the standard of care provided in nursing homes. A 2021 poll conducted by The John A. Hartford Foundation (2021), which surveyed more than 1,000 older adults, revealed that 71% were unwilling to live in a nursing home in the future. Older adults, and their families, today are left with the choice of deciding where to seek safe, affordable care that promotes independence. Nursing homes and assisted-living facilities remain as options, but many are now exploring alternative care models, especially with contemporary advances in health information technology.

What is a Medical Smart Home?

In the recent decade with the rapid development of technology, ‘smart home’ has become a well-known term. Smart home technology serves to improve the efficiency of one’s home, thus improving one’s quality of life (Li et al., 2021). Various technologies, such as computers, security systems, and multimedia, connected into a singular network allows for “smart living,”

providing the resident a personalized platform built for their convenience. This innovation applied within the context of healthcare can improve the care of older adults. Li et al. (2021) describe an extended definition of smart home technology to incorporate its potential in healthcare:

A home or dwelling with a set of networked sensors and devices that extend the functionality of the home by adding intelligence, automation, control, contextual awareness, adaptability and functionality both remotely and locally, in the pursuit of improving health and well-being of its occupants and assisting in the delivery of health care services. (p. 5)

Since older adults spend much of their time in their homes, embedding healthcare services into a smart home can provide unique and personalized care. Gerontechnology, a field which blends gerontology with technology, has grown with the goal of developing digital products and services based on the knowledge of biological and psychosocial aspects of aging (Atta et al., 2024). Smart homes built specifically with gerontechnology were found to improve care management and support aging in place (AIP). According to a 2021 American Association of Retired Persons (AARP) survey, 85% of older adults prefer to age in place (Binette & Farago, 2021).

AIP is the ability to age independently within one's home and community, regardless of the individual's age, financial status, or functional status. An individual's functional status refers to their ability to independently complete daily tasks required to meet basic needs and maintain physical and social well-being. However, for many older adults, the presence of chronic diseases can limit their functional status and thereby compromise their ability to age in place (Yu et al., 2019). Given this limitation and the preference to age in place, smart homes are a crucial

innovation in the care of older adults, helping to manage chronic conditions while promoting independence and well-being. In this literature review, such technologically integrated environments within healthcare will be referred to as “medical smart homes.”

Patient Case Illustration

For illustrative context, an older adult with brittle diabetes with an above-the-knee amputation will be highlighted throughout this literature review.

Older Adults with Brittle Diabetes

The global burden of disease associated with diabetes continues to worsen. The prevalence of diabetes among older adults has increased from 17.0% in 1990 to 23.7% in 2019, and with the growing older adult population, it will continue to increase (Jiang et al., 2023). Diabetes mellitus (DM) is a chronic metabolic condition characterized by elevated levels of blood sugar, or elevated serum glucose (hyperglycemia). There are various forms of DM, but type 1 diabetes mellitus (T1DM) and type 2 diabetes mellitus (T2DM) will be discussed in this review.

T1DM is an autoimmune disease in which the beta cells of the pancreas are destroyed. Beta cells produce insulin, a hormone that regulates serum glucose levels (Cleveland Clinic, 2022). When an individual consumes a meal, and thereby consumes glucose, these beta cells secrete insulin. Insulin allows glucose molecules to move from the bloodstream into one’s muscles, fat, and liver cells for use or storage. Therefore, insulin acts to decrease serum glucose levels. An individual with T1DM, whose pancreatic beta cells are destroyed, does not produce insulin in response to increased serum glucose levels. The absence of insulin causes their serum glucose to remain high after consumption of a meal, producing hyperglycemia and additional

symptoms of DM. Since individuals with T1DM lack insulin, insulin is essential as first-line therapy to ensure regulation of serum glucose levels.

On the other hand, individuals with T2DM have functioning pancreatic beta cells. T2DM is characterized by impaired secretion of insulin, insulin resistance, or both (Cleveland Clinic, 2023c). Insulin resistance occurs when one's cells do not respond correctly to insulin, thereby affecting glucose metabolism and causing hyperglycemia. Since insulin resistance is common in individuals with T2DM, T2DM frequently coexists with additional metabolic disorders such as obesity. This complex chronic condition is one of genetic and environmental factors, making its treatment multifaceted. T2DM is managed through nutritional therapy, exercise routines, frequent blood glucose monitoring, and drug therapy. Insulin is a cornerstone treatment for T2DM as well, but oral agents were developed and are more frequently used.

Both T1DM and T2DM are characterized by a state of hyperglycemia, producing similar symptoms such as increased thirst, frequent urination, increased appetite, and fatigue (Cleveland Clinic, 2023b). However, with treatment, there is a risk of hypoglycemia, where insulin therapy or oral drug therapy can be misused, causing an individual's blood glucose levels to drop below normal levels. Depending on the severity of the hypoglycemic episode, symptoms can range from trembling and weakness to blurred vision and seizures (Cleveland Clinic, 2023a). Alternatively, there are acute complications of DM where one's blood sugar is extremely high, becoming life-threatening. Individuals with T1DM are at risk for developing diabetic ketoacidosis (DKA), whereas individuals with T2DM are at risk for developing hyperosmolar hyperglycemic state (HHS). Both acute complications require immediate medical evaluation and treatment.

In 1934, American physician R. T. Woodyatt identified some of his patients with DM experienced extreme changes in serum glucose levels. He coined the term “brittle diabetes” to explain uncontrolled DM with erratic glycemic control and frequent episodes of hypoglycemia or hyperglycemia (Hirsch & Gaudiani, 2021). Most physicians have viewed brittle diabetes as a condition that occurs only in young women with coexisting mental health disorders or individuals who lack access to insulin (Newman & Dinneen, 2019). However, there have been recent case studies where older adults suffer from brittle diabetes and have higher rates of complications and mortality. Hospitalization frequently occurs due to acute complications from brittle diabetes and can be prolonged, decreasing an older adult’s quality of life.

Although T1DM is more commonly seen in children, adolescents, and young adults, older adults with T1DM can suffer from brittle diabetes. Life expectancy of individuals with T1DM has increased due to the development of new forms of glucose monitoring and tailored treatment methods (Hirsch & Gaudiani, 2021). In addition, there is an increasing number of individuals being diagnosed with T1DM in their adulthood. Therefore, there are more older adults with T1DM and they are beginning to experience severe glycemic instability. Insulin therapy requires extensive understanding of types of insulin, dosages of insulin, and schedule of injections, among other factors. Older adults may unintentionally omit an insulin dose, administer an incorrect form of insulin, repeat insulin doses, or administer the wrong dosage. These medical errors contribute to an increased incidence of brittle T1DM in older adults.

Brittle diabetes is commonly associated with T1DM, but it can also affect older adults with T2DM. Over 10.5% of the world’s population has T2DM and approximately half of them are older adults (Sanz-Cánovas et al., 2022). Umegaki (2024) highlights a study estimating the prevalence of DM is highest in individuals aged 75 and older. Furthermore, a growing

understanding of T2DM and advancements in treatment have contributed to longer lifespans of older adults with DM. Traditional treatment of T2DM often loses effectiveness in older adults due to the presence of comorbidities, use of multiple medications (polypharmacy), and potential functional decline. These factors contribute to an increased risk of hypoglycemic and hyperglycemic episodes in older adults with T2DM, and current clinical guidelines do not account for them. Further research is needed to establish a clearer understanding of the safest and most effective care for older adults with brittle T2DM.

Older Adults with Above-the-Knee Amputations

The removal of any part of one's body, an essential element of human life and an individual's identity, creates physical, mental, and practical challenges (Schober & Abrahamsen, 2022). Thereby, any form of disease that leads to an amputation has significant implications for an individual's quality of life. Above-the-knee amputations (AKAs), specifically, may be performed for a variety of indications such as trauma, infection, and vascular disease (Myers & Chauvin, 2020). Vascular disease is the leading indication, as 90-96% of all major lower limb amputations are attributed to vascular disease (Schober & Abrahamsen, 2022). These are chronic conditions that may lead to interrupted blood flow, jeopardizing a limb (Nall, 2022). DM is a risk factor for vascular disease, specifically when uncontrolled, as hyperglycemia contributes to the hardening and narrowing of blood vessels. Approximately 57% of individuals who experienced limb loss had a previous diagnosis of diabetes, making DM a major risk factor for lower limb amputation (Caruso & Harrington, 2024).

Undergoing an above-the-knee amputation is life-changing for an individual of any age. Schober and Abrahamsen (2022) identified six themes within their systematic review exploring patients' experiences undergoing major lower limb amputations. Upon discussion with medical

providers about the necessity of an amputation, patients were filled with ambivalence. They knew it would ease their pain but were shocked and wished they had been prepared for this news. One patient expressed, “It’s the loss of a limb, but it’s also a loss of way of life...you have to mourn that a bit.” Despite the grieving these patients felt, they knew it was essential to maintain a positive mindset to adapt to their lives after amputation.

Once patients accepted the amputation and completed the procedure, practical and financial challenges arose regarding their new way of life. Patients did not process their amputation until they were discharged and re-entered their home. They began to be concerned about performing ADLs, taking care of their home, and living their pre-procedure lives with an amputation. Three out of four individuals with major limb amputation experience the emotional effect of their condition (Schober & Abrahamsen, 2022). They begin to realize that their physical limitations may cause them to become dependent on others, affecting the ability to control their lives. One patient describes, “Wanting and not being able to do things on your own. Always needing help; that makes you feel that you are nobody, that you are a weak one” (Gómez-Ibáñez et al., 2021). The idea of becoming dependent scared most patients, as they did not want to become a burden to their family and friends. They knew that their roles would change as parents, siblings, and individuals in the workforce. These newfound concerns morphed over time, as patients strived for independence and attempted to regain their “normal” identity from prior to amputation. Achieving their previous functional status was a significant goal as it provided a sense of pride in their journey to recovering their autonomy.

As patients experience an amputation and adjust to their lives after amputation, healthcare professionals play a significant role. Patients needed to feel adequately prepared for the procedure and feel their healthcare professionals’ understanding, compassion, and empathy

(Schober & Abrahamsen, 2022). As healthcare professionals seek to continue improving care of patients undergoing AKAs, it is essential to consider these patient perspectives. Patients must be supported through their entire care trajectory, especially as they begin to transition to life after amputation upon discharge into their homes. Care should be individualized to the patients' needs as they undergo this life-changing procedure. The implementation of a medical smart home can provide such unique, individualized care that additionally promotes healthy aging.

Perceptions of Aging

Before examining the medical smart home, it is essential to define aging and analyze the commonly understood experience of healthy aging. Health has long been perceived as the absence of disease, leading older adults to associate aging with the onset of health limitations and increased dependency (Bosch-Farré et al., 2020). Although the perception of aging is shaped by cultural and social contexts, older adults generally view aging as a period marked by chronic disease, sensory decline, and motor impairments. In a qualitative study conducted by Bosch-Farré et al. (2020) involving 71 older adult participants, one participant illustrated this sentiment by stating, "I only feel old when something falls and I have to bend down to pick it up. Phew...it's hard!" Recognizing the need to shift these perceptions, the United Nations (UN) has dedicated this decade, from 2021-2030, to healthy aging, aiming to reframe the societal perception of aging. While many individuals expect aging to bring inevitable deterioration, it should be regarded as a period of life that is just as supported, valued, and successful as periods prior.

The UN Decade of Healthy Aging is focused on targeting four action areas: combatting ageism, creating age-friendly environments, providing integrated care, and ensuring access to long-term care when the support is needed (United Nations, n.d.). The international goal is to

work toward an equitable society in which older adults can continue leading a meaningful life within their communities and environments. With life expectancy increasing, it is essential to ensure that in addition to adding quantity, we add quality to life, enabling a continued life of meaning and dignity.

Quality of Life for Older Adults

In thinking about healthy aging, older adults prioritized their quality of life (QoL), capturing their overall well-being and how that affects their day-to-day experiences. In the qualitative study conducted by Bosch-Farré et al. (2020), older adults identified three main components of QoL in order of importance: physical and mental health as the most essential, followed by family environment, and lastly financial situation. Other identified priorities for older adults are displayed in Figure 1.

Physical and Mental Health

Physical and mental health was identified as the most paramount element of QoL, as one older adult stated, “Above all, being healthy is the most important thing to have quality of life, the rest comes as an extra” (van Leeuwen et al., 2019). Older adults felt healthier and more positive about their lives when they were physically and socially capable of partaking in daily activities. Conversely, the presence of physical, mental, and cognitive disorders hinders their ability to perform their daily tasks and pursue personal interests, negatively impacting their perception of QoL. Therefore, older adults often perceive “good” health as the ability to carry out meaningful activities and take care of themselves.

Perceptions of aging are also shaped by the point of reference used by older adults. Many compare their current well-being and abilities to their past experiences in previous stages of life or to the health of others their age (van Leeuwen et al., 2019). When an older adult contrasts their

current abilities with what they were once able to do, it reinforces the perception of aging as a stage of functional decline. This mindset perpetuates a cycle of negative attitudes toward aging, as one illustrated, “I cannot do what I did ten years ago, and I get very angry...I get disgusted with myself” (van Leeuwen et al., 2019). However, other older adults may take a more adaptive approach, maintaining a positive outlook on their health despite the development of chronic conditions and frailty. One participant stated, “Health is difficult to maintain at a certain age...The state of mind of those that are in peace with themselves and the way they are living their lives is important” (Bosch-Farré et al., 2020). By embracing the latter perspective, older adults are at peace with the changes that come with growing age. This makes them committed to improving their QoL, trying to guide their lives with a positive attitude and active lifestyle. This is precisely the focus of the UN Decade of Healthy Aging: challenging societal attitudes toward aging and promoting perceptions that recognize aging as a meaningful stage of life.

The Family Environment

An additional priority for older adults to feel QoL is to have their family around and in good health and well-being. Older adults value their relationship with family members, being able to provide love and support as well as give meaning to others (van Leeuwen et al., 2019). Older adults develop the closest relationships with their partners and grandchildren, becoming a source of both joys, but also worries. One older adult expressed, “When a child gets ill, you get ill too” (Bosch-Farré et al., 2020). If an older adult suffers the loss of a close family member, their aging experience becomes more painful and difficult. Khodabakhsh (2021) reported that older adults without children tend to report lower life satisfaction, experiencing heightened anxiety and loneliness. Older adults that lack close relationships express the desire for support and companionship. One older adult expressed, “I’d just want friendship, some compassion,

understanding, empathy” (van Leeuwen et al., 2019). Generally, the healthier the family environment and the more family support, the better perceived an older adult’s QoL. The love, affection, support, and reciprocity of close relationships combat the potential loneliness that many older adults may face as they age.

Financial Status

An older adult’s financial status significantly influences their quality of life. An older adult with a stable financial status has the resources to cover basic needs and essentials, such as their bills, required medical services, transportation, and more. Beyond meeting basic needs, financial stability fosters a sense of freedom for older adults (van Leeuwen et al., 2019). Older adults with financial security have the capacity to spend money on leisure activities, such as going to the cinema or hosting friends for dinner. Many older adults become dependent on solely their retirement funds, which becomes a source of concern. One older adult described, “The main problem is the financial one; it is a big problem; if you don’t have money, who will take care of you?” (Bosch-Farré et al., 2020). The ability to not have to worry about financial security, in itself, is a key factor in enhancing the QoL for many older adults.

Independence and Autonomy

Although autonomy was not discussed as one of the key three components of QoL, it is listed as one of many enablers to healthy aging in the qualitative study conducted by Bosch-Farré et al. (2020). On a spectrum of independence, dependency and autonomy can be seen as two opposing ends. Dependency is a state that older adults try to avoid, where an individual is entirely reliant on others for daily care and routines such as mobility and medication management. Older adults associated a state of dependency with the potential to become a burden to their loved ones and others caring for them. On the other end of the spectrum is

autonomy, the ability to care for oneself, typically in one's own home, in the manner they desire. With autonomy comes a sense of control over one's life. Older adults have the desire to delay the state of dependency for as long as possible, striving to stay autonomous within their daily lives and maintain as much control as possible. According to Bosch-Farré et al. (2020), some older adults expressed that "the idea of a total dependency condition made them think about death as preferable."

As previously discussed, older adults prefer to AIP for as long as possible. The perception of nursing homes and other institutions has been evolving for decades, with the COVID-19 pandemic most recently influencing perceptions. Institutionalization is perceived to be the last option for many older adults and their families (Bosch-Farré et al., 2020). Individuals view nursing homes and other institutions as very resource-poor, very expensive, and very difficult to get into. One older adult described those within a nursing home as "abandoned," with the general point of view that institutions tend to neglect older adults. It is essential to consider the historical context of institutions and the absence of standard regulations in the past. Today, the general population continues to view nursing homes in a negative light, with the idea that they are incapable of providing adequate and safe care.

Healthy and Successful Aging

Although older adults have different perceptions of what constitutes a good QoL, the discussed common characteristics above must be understood as society improves the care of older adults. In line with this, the World Health Organization (WHO) has developed a definition of healthy aging: "The process of developing and maintaining the functional ability that enables well-being in older age" (Rudnicka et al., 2020). Healthy aging is multidimensional, considering one's physical, psychological, and social well-being, among other factors such as culture and

environment (Morris-Foster, 2024). As we focus on the UN Decade of Healthy Aging and reshape societal understanding of aging, care of older adults is also evolving to be more integrated and ubiquitous. Technological advances, changing attitudes, and a growing emphasis on integrated care are driving society toward medical smart homes as a promising approach to support healthy aging.

The Medical Smart Home

To revisit, a medical smart home is created within the older adult's pre-existing residential environment, which is key to achieving healthy aging and successful AIP (Lee & Park, 2020). Lee & Park (2020) highlight how a well-designed residential space is crucial for an older adult's health, well-being, and ability to live productively. By transforming an environment that the older adult is both familiar and comfortable with, the introduction of smart technology is only further promoting health and functional independence. The following sections will explore the key characteristics and components of a medical smart home in greater detail.

Characteristics of a Medical Smart Home

The medical smart home environment has five characteristics that make it distinct from current simple home automation: *automation*, *multi-functionality*, *adaptability*, *interactivity*, and *efficiency* (Facchinetti et al., 2023). With the combination of sensors, databases, and processing software, the medical smart home can perform automatic functions. In addition, its integration within the home allows for multi-functionality—the ability to perform various functions, which will be discussed further. Adaptability becomes essential as the older adult ages, their health status changes, and their functional status is affected. The smart environment can adapt to their ever-changing needs to promote well-being. Interactivity becomes essential when an older adult would like to communicate with their loved ones or their healthcare providers. The medical

smart home has the capacity to allow such interactions between specific users. Lastly, efficiency—the ability to perform its functions conveniently and quickly—allows for the medical smart home to be pivotal in the care of older adults, whose health status can change within an instant. As described by Facchinetti et al. (2023), the sensitivity of this medical smart home environment allows it to respond to an individual’s physical and social needs.

The Internet of Things

A medical smart home, or smart home in general, is part of a larger system known as the Internet of Things (IoT). The IoT connects physical objects and devices that people use daily to the internet, allowing them to communicate and function collaboratively (Dwivedi et al., 2022). A well-known example is a smart thermostat, which automatically adjusts the temperature of a home for both comfort and energy efficiency. Since its development, IoT has transformed various sectors of society, including agriculture, transportation, and healthcare.

The IoT begins with a singular object, such as a smart television or smart washing machine, which can be controlled remotely (Choi et al., 2019). Data from these appliances and other technologies around the home can be stored within a secure cloud server, forming an interconnected network that helps automate tasks (Dwivedi et al., 2022). A medical smart home applies this concept to healthcare, using connected devices and sensors to support older adults as they age.

Components of a Medical Smart Home

The next few sections will discuss different technological components that would be part of the greater IoT system, making it easier for caregivers and healthcare professionals to monitor older adults and improve their care. The discussion will begin with monitoring systems, including unobtrusive sensors for environmental monitoring and physiological sensors for

tracking the older adult's health. Then, wearable technologies will be highlighted, demonstrating their integration with monitoring systems to enhance support. This section will conclude with a description of various assistive technologies, including automated technology, voice-activated personal assistants, and interactive platforms. Together, these smart technologies form a comprehensive environment that enhances physical safety, promotes independence, and improves the overall well-being of older adults.

Unobtrusive Environmental Sensors

Unobtrusive environmental sensors are the center of medical smart home technology. Their nonintrusive nature allows for the collection of an older adult's behavior without directly influencing their everyday activities (Yu et al., 2019). To avoid further disturbance and bias in data collection, the sensors used are hidden within the home, are relatively small, and are very light weight (see Figure 2). They are placed strategically around the home, making them virtually undetectable. The type of sensor used depends on the room's function and the activities the older adult is likely to perform there. See Figure 3 for examples of unobtrusive environmental sensors placed in different locations.

Infrared motion sensors detect an older adult's movement in the home. With technology similar to motion-activated porch lights, these sensors detect changes in heat waves from moving objects. Data can display where the older adult is, how long they have spent in that location, and their sequential movement (Fritz & Dermody, 2019). When analyzing this information, healthcare professionals can understand how long the older adult slept last night, how many times they went into the bathroom today, and if they went outside of their home today.

Contact sensors provide information about doors, cabinets, and windows. They use magnetic relays to understand whether these fixtures are open or closed (Fritz & Dermody,

2019). A magnet is attached to the moving part, such as a door, and the contact sensor is mounted to the fixed door frame. When the door is closed, the circuit is completed as the magnet aligns with the sensor. When the door opens, the circuit is broken, and an alert can be triggered. Such sensors can be used with infrared motion sensors to create a comprehensive activity profile of an older adult.

Additional sensors include those that collect data about the environment's characteristics such as light, humidity, temperature, and carbon dioxide levels. These sensors can be placed specifically in the kitchen and bathroom, where the stove, oven, sink, and shower operate, and the older adult is more prone to accidents. The combination of this data provides information about application usage and promotes kitchen and bathroom safety.

Physiological Sensors

Physiological sensors can be implemented within the medical smart home to allow for remote monitoring of the older adult's vital signs and state of essential body function (Maswadi et al., 2020). While unobtrusive environmental sensors monitor the older adult's behavior and movement within their environment, physiological sensors specifically assess health and well-being. The collected data provides valuable insights into the individual's physical condition and overall functioning.

Vitals signs include one's body temperature, heart rate (HR), respiratory rate (RR), blood pressure (BP), and oxygen saturation (SpO₂). Each of these parameters give healthcare professionals a different look into the physical health of an individual. An individual's body temperature provides insights into their metabolism. There are varying "normal" ranges of temperature, depending on how it is measured. HR corresponds to the number of times the heart beats within a minute, with the normal adult HR lying between 60 and 100 beats per minute

(Kebe et al., 2020). RR, similarly, corresponds to the number of breaths an individual takes within a minute, with the normal being between 12 and 20 breaths per minute for an adult. An individual's BP is closely related to their cardiovascular health and circulatory status, and older adults are at risk for having both a low and high BP. The fifth basic vital sign, SpO₂, is a measure of the amount of oxygen-carrying hemoglobin in an individual's blood, reflecting their oxygen status (Rohmetra et al., 2021). Each of these five vital signs create an overall picture of an older adult's clinical status, prioritizing their airway and circulation.

Within the hospital setting, intermittent vital sign measurement is the most commonly used method to monitor clinical status (Areia et al., 2021). Continuous monitoring of such parameters can be implemented within the home with smart technology, allowing for early detection of deterioration of an older adult's status. When vital signs are being continuously monitored, it is easier to identify what the older adult's baseline vitals are and therefore quantify when their clinical status changes and intervention is necessary.

As research in gerontechnology is advancing, engineers are continually developing new technologies to measure vital signs within the context of a medical smart home. One promising approach involves the use of radar technology, a wireless and non-invasive technique that detects the HR and RR of an older adult without requiring wired device use. Radar technology is based on analyzing reflected signals from a target, which in this case is an older adult (Mehrjousesht et al., 2024). Within this system, a generator sends out electromagnetic signals, which are invisible waves that transmit into the surrounding home environment (Gharamohammadi et al., 2025). When these waves encounter objects, as well as the older adult, within the environment, they bounce back. Once amplified and filtered, the signals are transformed into a digital format that can then be processed by a computer. By analyzing the reflected signals, the computer can

determine the older adult's movement, including the subtle rise and fall of their chest as they breathe (Kebe et al., 2020). This chest-wall displacement not only provides information about the older adult's respiratory status and RR, but also provides an insight into the older adult's cardiac status and HR in real-time.

This radar technology would be placed in one or more parts of the home where the older adult spends the most time, such as the living room or bedroom (Mehrjousesht et al., 2024). It provides several advantages, other than its non-invasive nature. Since the technology is based on electromagnetic signals, the older adult does not have to be in a certain position for their HR and RR to be obtained. The radar system would work from any angle, providing both flexibility and convenience, creating a seamless experience within the home. Radar technology is additionally relatively low-cost and continuously tested, meeting safety regulations. It has been found that the radar system emits less power than that of a smartphone device (Kebe et al., 2020). Lastly, due to its ability to track an older adult's movements, it can integrate with other smart home technologies to enhance safety and monitoring. A well-designed medical smart home can maximize the potential of this multi-functional, efficient system.

Wearable Technology

Wearable Technology: Vital Sign Monitoring. Smart wearable devices (SWDs) allow for the monitoring of the other three vital signs (temperature, BP, and SpO₂), as well as additional sensitive clinical indicators of physical health. Wearable sensors are worn similarly to an article of clothing, but contain tiny sensors that gather information continuously and transmit it into a network (Sanchez-Comas et al., 2020). SWDs can be attached to shoes, glasses, earrings, clothing, and watches (Wu & Luo, 2019). Today, SWDs are used already daily by the general consumer population. Individuals wear smartwatches during the day to track their activity and

fitness, and at night to provide a sleep quality report (Zhu et al., 2023). These data parameters are then stored, and consumers obtain recommendations on how to improve their health. This very principle can be applied to the medical smart home, but to a plethora of technologies considered SWDs.

To begin, SWDs can work in junction with physiological sensors to obtain a full set of vital signs for an older adult. A singular SWD, KENZEN, has been produced with both humidity and temperature sensors that detect skin temperature and HR (Dolson et al., 2022). This device, created for use in the workforce and promotion of safety, is waterproof and wraps around the upper arm, tracking core body temperature, HR, and activity levels (Bianchi, 2020). Additional technologies are being produced using similar algorithms to that of KENZEN, accounting for the user's individual characteristics, such as age, weight, and biological sex. Wearable ear devices have also been innovated, specifically for older adults that may prefer electronics within the ear for prolonged real-time monitoring of vital signs (Ota et al., 2017). These two devices are mere examples of SWDs that can be integrated within the medical smart home for the purpose of measuring body temperature of an older adult.

SWDs may be used to measure BP as well, detecting both orthostatic hypotension (OH) and hypertension (HTN). OH refers to the decrease in BP due to position changes, such as from lying in bed to standing up straight. Older adults are more prone to OH due to age-related changes to the autonomic nervous system, frailty, pharmacologic therapy, and possible presence of coronary artery disease (Dani et al., 2021). On the other end of the spectrum, HTN refers to an increased BP, with increased prevalence in older adults due to cardiovascular risk factors. The early identification of either condition through SWDs can promote early intervention and improve health outcomes for older adults. SWDs commonly used to monitor BP include cuffless

BP sensors, wireless smartphone-enabled monitors, and remote monitoring technologies (Wu & Luo, 2019). A variety of cuffless, non-invasive BP monitoring devices have been validated and approved with accordance to clinical standards, providing data on the user's physical condition and environmental conditions (Kario, 2021).

To conclude the monitoring of an older adult's vital signs using wearable technology, SpO2 monitoring has been made available through the use of smartwatches, rings, or flexible patches applied to the skin (Takahashi et al., 2022). Specifically, popular commercial devices that can be used are the Oura ring, Fitbit, and Apple Watch. These simple, non-invasive SWDs are still being developed and improved upon, but can be integrated within the medical smart home environment as well.

Wearable Technology: Diabetes Management. For an older adult with brittle diabetes, SWDs that promote diabetes care management will be highlighted. As previously described, the primary treatment of T1DM is the administration of insulin, while the treatment of T2DM is multifaceted. Older adults with T2DM require nutritional therapy, exercise routines, frequent blood glucose monitoring, and drug therapy. SWDs have the opportunity to provide personalized, real-time and data-driven management of DM, particularly when brittle (Wu & Luo, 2019). SWDs include glucose monitoring devices, smart insulin delivery systems, and an artificial pancreas system.

Individuals with DM, whether it be T1DM or T2DM, perform self-monitoring of blood glucose levels (SMBG) to track and assess their blood sugar levels, guiding treatment decisions. However, SMBG requires frequent finger pricking and consistent use of supplies, which can become burdensome, especially for older adults with other comorbid conditions. Continuous glucose monitors (CGMs) are a relatively newer innovation and form of SWDs for individuals

with DM. CGMs are devices worn on the skin or implanted under the skin, within the subcutaneous fatty tissue (Almurashi et al., 2023). Once implanted, the CGM measures blood glucose in the interstitial fluid every 1-5 minutes, depending on the type of sensor. These devices provide real-time monitoring of blood glucose levels and include alarms for both hypoglycemia and hyperglycemia, becoming particularly helpful in the management of brittle diabetes (Toschi & Munshi, 2020).

A randomized clinical trial, Wireless Innovation for Seniors with Diabetes Mellitus (WISDM), assessed the potential benefits of CGMs for older adults, particularly those over the age of 60 and with T1DM. This study had a sample size of 203 older adults: 100 older adults continued using standard SMBG, while the other 103 used CGM systems (Pratley et al., 2020). The WISDM trial showed a 98% retention rate, improvements in blood glucose maintenance, and a reduced hypoglycemic burden in the group of older adults using a CGM (Toschi & Munshi, 2020). Blood glucose maintenance was measured through hemoglobin A1c (HbA1c), a blood test that measures the average blood glucose over the past three months. This trial showed improvements in HbA1c from 7.5% to 7.3%. In addition, the time spent with glucose levels less than 70 mg/dL (hypoglycemia) decreased from 73 minutes per day to 39 minutes per day for the group using a CGM, whereas the SMBG group remained relatively unchanged from 70 to 68 minutes per day (Pratley et al., 2020). The WISDM trial, among other clinical studies, displays how effective CGM is for the older adult population with diabetes, in preventing both hyperglycemia and hypoglycemia, making it particularly ideal for brittle diabetes management. In addition to its physical benefits, CGM systems improve psychological well-being by making older adults feel better, report less hypoglycemic fear, and express less distress about managing their diabetes (Toschi & Munshi, 2020).

Smart insulin delivery systems are particularly useful for managing brittle T1DM, which requires insulin administration via injection. While insulin pens are one form of smart delivery, they are not SWDs and will not be discussed in detail (Toschi & Munshi, 2020). In contrast, insulin pumps are wearable devices that deliver insulin continuously based on a pre-programmed basal rate and user-defined bolus doses (Almurashi et al., 2023). One example is the Omnipod system, introduced in 2015, which has undergone significant technological advancements over the past decade. It now features smartphone connectivity via Bluetooth and allows remote, real-time access to insulin administration history, and if integrated with CGM technology, provides a history of blood glucose levels. Additionally, insulin pumps such as the Omnipod offer exceptional precision and accuracy, administering doses as small as 0.1 units an hour (Toschi & Munshi, 2020). To summarize, insulin pumps are particularly beneficial for older adults with brittle T1DM, improving HbA1c, reducing the rate of hypoglycemia, and enhancing quality of life.

The final SWD that will be highlighted in this literature review is the artificial pancreas, or hybrid closed-loop system (HCL). A HCL system consists of both a CGM and insulin pump, as well as an algorithm that is established to help sustain the user's desired blood glucose levels (Almurashi et al., 2023). The system continuously senses real-time, blood glucose values and adjusts insulin secretion accordingly to keep the individual within range. This device is still considered hybrid, as users are required to bolus insulin for meals and other carbohydrate intake. A fully automated closed-loop system has not yet been developed, but the combination of CGM and insulin pump technology promotes mitigation of both hypoglycemia and hyperglycemia. The HCL reduces the user's daily engagement with the device and thereby alleviates the burden of diabetes decision-making on a day-to-day basis (Toschi & Munshi, 2020).

A recent study conducted by Telci Caklili et al. (2024) investigated the effects of switching thirty-four older adults with brittle T2DM from a typical multiple-dose insulin (MDI) injection regimen to an HCL system. Before the initiation of this experiment, participants had a median HbA1c of 9.3% and the median total daily insulin dose was 41 units. Then, participants were switched to a HCL, and their HbA1c, weight, total daily insulin dose requirement, and labs were followed for a six-month period. The results showed a remarkable improvement: the median HbA1c decreased to 7.1% and median insulin dose requirement dropped to 32 units a day (see Figure 4). Although the effectiveness of HCL technology has not been studied thoroughly in the older adult population, this study demonstrates that older adults with brittle T2DM can achieve positive outcomes with HCL systems. Telci Caklili et al. (2024) express that the HCL “improves glycemic outcomes and performs with low hypoglycemia frequency” for older adults, two essential parameters for managing brittle T2DM. Each of the three SWDs presented can be applied to older adults with both brittle T1DM and T2DM. Among them, the HCL represents the most advanced technology available today. Wearable devices, as a general technology, support health maintenance and disease management, assisting in clinical decision-making for the care of older adults.

Automated Technology

Since sensors serve solely to monitor the behaviors and health of an older adult, automated technology can be used in conjunction to enable active interventions and adaptive automation. Using the concept of the IoT, there must be one master mobile device that is used to control the automated technology in the medical smart home (Stolojescu-Crisan et al., 2021). The mobile device or app would provide a user-friendly interface with the main screen being a

dashboard with a list of all devices that can be controlled. This interface allows for the remote control of indoor temperature, the lights, the doors and windows, security, and more.

As previously mentioned, a smart thermostat is used to maintain thermal comfort and be energy efficient. Through the device or mobile app, an older adult can access and control the temperature from anywhere in the world, at any point in time. Temperatures can be read through thermostats placed around the home, as well as unobtrusive temperature sensors. Each thermostat can be configured as a different device on the app, allowing for the temperature of each individual room to be set manually. It is also possible to eliminate the need for manual adjustments—the mobile device and smart thermostats can be configured to have a schedule. For example, the temperature can be automatically lowered during the day or while the older adult leaves their home. This automaticity promotes comfort and ease within the home.

Lights within the home can also be made “smart” and controlled via a mobile app. The use of smart lights enables both convenience and energy efficiency. The app can be filtered to view solely the lights in a home, allowing older adults to see where they currently have the lights on. If they forget to turn off their bedroom lights, and they are already in the kitchen, they can simply enter their mobile devices and shut the lights. Another instance of smart lights being helpful is when an older adult awakens at night. Before getting out of bed, older adults can turn on the lights in their home through the app, promoting their safety and well-being as they are able to be mobile with the lights on. In addition to being controlled on the app, lights can be controlled using voice-compatible devices, such as a Google Home assistant or Amazon Alexa. The use of smart lights and their compatibility with voice-activated devices can be especially useful for an older adult with an above-the-knee amputation, as they eliminate the need to physically reach for light switches.

In collaboration with contact sensors, the mobile app can provide access control to gates, doors, and windows in the home. Similar to controlling smart lights, the older adult can manually, using the app, and by vocal commands, open or close doors and windows in their home. This technology provides practicality but more importantly provides accessibility for an older adult with an AKA that is unable to reach certain windows in their home. Since all points of entry and exit into the home are tracked on the mobile app, this technology can also enable a home security system. Older adults can arm and disarm the security system in their home through the app or via voice command. For additional safety, extra security can be added at night, arming only access points on the ground level of a home.

The types and numbers of smart automated technologies that can be implemented into the medical smart home and the IoT are endless. To further enable safe and comfortable living in the home, irrigation systems can be automated. A schedule can be put into place on the app to turn on the irrigation system at a certain time and leave it on as long as it is needed. Televisions, air conditioners, and humidifiers can be accessed through the app as well, allowing for remote access. The plethora of technologies available allows for the adaptability and specificity of a medical smart home. The medical smart home can be uniquely designed by selecting from a wide range of technologies, ensuring that each older adult receives a personalized and adaptable living environment that supports their AIP.

Voice-activated Personal Assistants (VAPAs)

The implementation of voice-activated devices within the IoT of a medical smart home only further engages the older adult and personalizes their AIP experience. Today, voice recognition technology is already widely used. GPS navigation, smartphones, and smart televisions are mere examples of devices that carry the capacity to interpret voice commands. By

integrating VAPAs, older adults can communicate in their native language with other smart technologies, enhancing the functionality of the smart home (Yang, 2021). The Amazon Echo, “Alexa,” and Google Home are two widely used VAPAs today.

VAPAs are a unique technology, as they are accessed through language. Language is the simplest, most natural form of expression for human thoughts and opinions (Yang, 2021). This allows technologies such as the Amazon Alexa to gap a bridge between human beings and machine technologies. Older adults do not need to use a mobile device or keyboard to retrieve information; they may simply use their voice and receive information verbally (O’Brien et al., 2019). In addition, VAPAs work through access to the internet, making them part of the active IoT network within an older adult’s medical smart home (Corbett et al., 2021). This allows older adults to use VAPAs to their advantage, as they are directly connected to the sensors and automated technology within their home.

Current literature is focused on the impact of the Amazon Echo, Alexa, within the home, as opposed to Google Home. These two devices function similarly, and can be thought of interchangeably, but the Amazon Echo saturates the market more extensively, making them the primary focus of research (Corbett et al., 2021). Several themes have emerged when analyzing the various ways older adults use Amazon Echo: information and entertainment, reminders, control of the home, and communication.

Through Amazon Echo, older adults are able to listen to music and audiobooks, play electronic games, listen to jokes, receive news, and obtain information (O’Brien et al., 2019). In reference to Alexa, one older adult stated, “She tells us jokes, answers our questions, and plays any kind of music we are interested in.” This functionality allows for an on-demand experience for older adults, making VAPAs a personalized technology within the smart home. Furthermore,

older adults can ask Alexa to set alarms or create reminders to perform basic tasks, such as drinking water or taking medications. In a study conducted by Corbett et al. (2021), a caregiver living with an older adult described, “I’ve used it to remind me of different things, ...definitely medication more than anything, doctors’ appointments, [and] grocery lists.” Although the older adult is talking to the device as if it is another human, all information is stored in the IoT network. This provides the benefit of the device “never forgetting” what an older adult has asked of it, such as reminding them to take their medications at 10 a.m. (O’Brien et al., 2019).

Like the mobile device discussed in the previous section, VAPAs can be integrated to assist with control of automated technologies in the medical smart home. However, a distinct advantage is the hands-free and eyes-free feature of the VAPA: an older adult can ask Alexa to turn off the light, and the device would be configured to complete the command (Venkatraman et al., 2021). This convenience can be life-changing for an older adult with physical limitations, such as one with an AKA, providing a greater control over their home environment (O’Brien et al., 2019).

As a communication device, Alexa also has the capacity to connect older adults with their loved ones through both voice and video calls. Various Amazon Echo models are available, some equipped with video capabilities and others designed for audio-only interactions. Regardless, an older adult can simply ask their Alexa to call someone, and the device will complete the interaction through its connect with their mobile device. Additionally, caregivers with granted permission can initiate an instant conversation with the older adult, if needed. If a caregiver is concerned about their loved one’s well-being and the older adult has an Amazon Echo with video capabilities, the caregiver can use the device’s drop-in feature to check in remotely (Corbett et

al., 2021). This allows them to see and communicate with the older adult in real-time, providing a seamless connection.

Each of these advantages of a VAPA uniquely enhances the medical smart home environment, working in conjunction with the sensors and automated technology discussed thus far. They have the potential to support daily functioning, promote health and wellness, and allow for successful AIP.

Interactive Platforms for Memory and Communication

Interactive platforms are another technology that can be integrated within the medical smart home. There are various types of platforms, but their aim is to support older adults in managing their daily tasks and promote communication between older adults and their caregivers or healthcare providers (Facchinetti et al., 2023).

The digital memory notebook (DMN) is an application that is integrated into a mobile device, but uses data acquired from the smart home environment. The DMN has an intuitive design curated specifically for older adults. There are four main pages on the main screen that can be accessed easily: "Today," "Calendar," "Profile," and "Notes" (Raghunath et al., 2020). The "Today" page opens and displays the older adult's hourly schedule for the day, as well as their to-do list. Since the DMN can be integrated within the medical smart home, some tasks are automatically checked off as they are completed, such as medication administration (Facchinetti et al., 2023). Over time, this automated task completion can help predict when an older adult's tasks should be completed and prompt reminders or notifications. The next page, the "Calendar" provides the older adult with a monthly visual with large text, allowing them to input specific events and view their activities (Raghunath et al., 2020). The "Profile" page allows the older adult to create contacts for their caregivers and healthcare providers, as well as offers an

opportunity for the older adult to input information about themselves. This page not only facilitates communication, but also reinforces the older adult's memory and understanding of their medical history. Lastly, the "Notes" page provides space for the older adult to organize information and activities in a list style. The latest iteration of the DMN was found to be very user-friendly for older adults, regardless of their cognitive abilities and familiarity with technology.

Another platform, recently developed in 2024, is the Interactive Care Platform (I-Care) which is designed to connect older adults living in their homes to their family members. I-Care was created in partnership with older adults with cognitive impairment, their caregivers, and experts in the field to promote safe, independent living (Badeaux, 2024). With functions similar to the DMN, I-Care is set up in an all-in-one computer system connected to sensors within the smart home. The system always remains on for the older adult and is placed in a location where they often reside in their home, such as the kitchen, living room, and bedroom. There are six main pages of this platform: a homepage, a calendar, a to-do list, a messaging center, a collaborative notes section, and a goals section. Similar to the DMN, an older adult can organize information collaboratively with their caregivers and healthcare professionals, as well as send messages to each other. In addition to facilitating communication and promoting memory of older adults, this system allows the older adult to stay on track with their ADLs, promoting AIP.

Classifying Smart Home Technologies

Each of the technologies discussed have their own role within the medical smart home in promoting the well-being of older adults. It is essential to establish the key differences between such technologies. Unobtrusive sensors are purely environmental, assessing the home setting and monitoring the behavior of older adults. Physiological sensors and wearable technologies are

medical, assessing the health status of older adults and monitoring trends of significant clinical markers. Assistive technologies, such as automated technology, VAPAs, and interactive platforms, primarily promote safety and convenience in everyday living, improving overall QoL.

While these technologies work together to enable AIP, not all are approved for clinical use by the U.S. Food and Drug Administration (FDA). The FDA works to regulate sales of medical devices to ensure the safety of consumers. Some technologies, particularly environmental and assistive technologies, may not meet FDA standards to be cleared or approved as medical devices. These technologies, such as the Amazon Alexa or a smartwatch that measures vital signs, may not be FDA-approved, but still play a vital role in supporting the well-being of older adults. On the other hand, the Omnipod 5 is FDA-cleared for the management of both T1DM and T2DM, making it the first insulin SWD to achieve this classification (Food and Drug Administration, 2024). Understanding these foundational distinctions is crucial when evaluating the capabilities and clinical integration of smart home technologies.

Framework of a Medical Smart Home

Various IoT architectures have been proposed in current literature to integrate sensors, technologies, and systems within a medical smart home. This literature review will focus on the framework proposed by Dwivedi et al. (2022). Typically, the IoT systems are structured into layers, such as the perception layer, gateway layer, data storage layer, and application layer (see Figure 5).

The IoT framework begins with the perception layer that is responsible for collecting data from the medical smart home environment. This layer is comprised of all technologies integrated into the medical smart home, as these devices serve as data sources (Dwivedi et al., 2022). This includes unobtrusive environmental sensors, physiological sensors, wearable devices, and

assistive technologies. Real-time data on the environment and an older adult's behavior and physical health status is collected and converted into digital signals for future use. The next layer, the gateway layer, is responsible for transmitting the data collected through either short- or long-distance network communications. Each data source in the perception layer must have connectivity for the data to be transmitted. Dwivedi et al. (2022) list types of short-range networks, such as radio-frequency identification, Bluetooth, Zigbee, and Wi-Fi, and long-range networks such as cloud computing. The type of network used depends on the configuration of the medical smart home framework created.

The third layer, the data storage layer, processes, analyzes, and stores the data collected and transmitted from the layers that precede it. Also referred to as the management service layer, massive quantities of raw data can be processed efficiently and stored securely for later interpretation (Dwivedi et al., 2022). Random access memory (RAM) is a type of fast, temporary storage used while the data is being processed by analytics tools. To illustrate, consider a device within the medical smart home that is continuously assessing an older adult's heart rate. If an irregular heart rate suddenly begins, the RAM can temporarily store the data for quick analysis and prompt an alert to a medical provider before the data is permanently stored. Once the data is processed in RAM, it is stored more permanently either in a local server, using Fog or Edge computing, or in a centralized cloud server for more extensive processing.

The final layer, the application layer, is responsible for interpreting stored data to guide clinical decisions. As data is stored, models and algorithms transform it into meaningful and actionable information about an older adult's behavior and clinical status. Artificial intelligence (AI) and deep machine learning algorithms are specifically used to enable healthcare professionals to learn from the data that is being collected (Dwivedi et al., 2022). As data is

collected over time, these machine technologies can monitor trends in an older adult's behavior, creating a picture of the adult's routine. This can inform the authorized users of the network of any changes in the data collected and intervene as needed (Yu et al., 2019). By understanding these trends, healthcare professionals that view the data can make more informed treatment decisions, helping to promote physical safety and manage chronic conditions such as brittle diabetes.

Promoting Physical Wellness

The implementation of a medical smart home for an older adult with an AKA and brittle diabetes has the ability to promote both the older adult's physical and psychosocial wellness. Physical wellness is examined first, reflecting the medical perspective that physiological stability is key to overall well-being. The following advantages of a medical smart home will be discussed: (a) enhancing functional status, (b) ensuring physical safety, and (c) improving the management of brittle diabetes.

Promoting Functional Status through the Medical Smart Home

The implementation of a medical smart home can promote functional status for an older adult with brittle diabetes with an AKA. To better understand functional status, it can be broken down into observing an older adult's ability to complete basic activities of daily living (BADLs) and instrumental activities of daily living (IADLs) (Motamed-Jahromi & Kaveh, 2021). BADLs involve self-care activities, such as bathing, dressing, toileting, feeding, and mobility (McCabe, 2019). IADLs involve more complex activities that are essential to maintain an individual's physical and social roles, including managing finances, preparing meals, using public transportation, and managing medications (Motamed-Jahromi & Kaveh, 2021).

Unobtrusive environmental sensors within the home can provide a 24-hour description of an older adult's behavior in their home, allowing for real-time monitoring of their activity (Facchinetti et al., 2023). Upon waking up in the morning, the sensors would be able to tell how long the older adult remains in bed, if they turn on the light, and when they get out of bed. Once the older adult moves toward the closet, authorized users of the system would understand that the older adult is dressing. Sensors in the bathroom can determine when someone is using the toilet, brushing their teeth, and showering, as well as how long they spend completing each activity. This is just a snapshot into what information can be tracked regarding an older adult's BADLs to ensure they are able to take care of themselves and are remaining safe in doing so. Since trends in behavior are developed through the application layer, any deviation from these trends can be cause for alarm, enabling an authorized user to investigate. Notably, monitoring such behaviors can create models to analyze for at-risk situations. For instance, as Facchinetti et al. (2023) describe the potential to "predict when people get up after in-bed restlessness and make a first dangerous-event prediction by analyzing correlations...between in-bed restlessness and getting up."

In addition to tracking an older adult's ability to perform BADLs and IADLs, assistive automated technology can facilitate these routine tasks. An older adult with an AKA that may have increased difficulty getting around their home environment can use automated technology to open windows out of reach. One participant with a physical disability of a study conducted by Cleland et al. (2024) described the convenience, "I can just press the button and the door will unlock." The introduction of assistive technologies creates an environment that is appropriate to the functional level of the older adult with an AKA, improving both their protection and their ability to perform daily activities (Mun & Kim, 2024).

Promoting Physical Safety through the Medical Smart Home

One significant goal with the care of older adults is the maintenance and promotion of physical safety. Age-related physical declines in sensory and motor function as well as comorbid conditions increase the risk of emergencies, such as falls (Hu et al., 2024).

Fall Safety: Prevention and Prompt Response

Falls are the leading cause of both fatal and nonfatal injuries in the older adult population. According to the CDC (2024a), more than one in every four older adults fall each year, but less than half inform their healthcare providers. Falls commonly remain unreported, but they are significant causes of traumatic brain injuries and hip fractures in the older adult population. Unfortunately, even if an older adult is not affected by their fall, they are at increased risk for recurrence of falls. Living in a medical smart home provides two key benefits related to falls: (a) fall prevention through assistive technology and (b) real-time monitoring, enabling prompt evaluation and response (Yu et al., 2019).

As mentioned, assistive technologies promote safety when performing ADLs by reducing fall risks. For example, older adults who wake up at night to use the restroom must get out of bed and navigate in the dark, increasing the likeliness of a fall. The use of smart lighting systems within the medical smart home addresses this risk by automatically illuminating a pathway from the bedroom to the bathroom upon detection of movement. The increased visibility reduces fall risk, promoting physical safety. Similarly, when an older adult is preparing a meal independently in their kitchen and wishes to open the window for fresh air, limited accessibility may increase risk for a fall. However, with automated technology, they can operate windows automatically via their mobile devices or a VAPA. The plethora of automated technologies provides endless opportunities to enhance safety by making routine activities more accessible, reducing fall risk.

On the other hand, the medical smart home environment can remain beneficial if a fall were to occur. Sensors would automatically detect a fall and through the use of an emergency call system, authorized individuals would be able to respond to this incident (Hu et al., 2024). Another participant of the study conducted by Cleland et al. (2024) expressed his improved sense of physical safety, “One of the things that the provider will supply for my new home is some sensors...if I fall on the floor or something, [I] can advise my brother or my mother.” At times, when an older adult falls, they do not have the support or strength to rise and call for help (Vaiyapuri et al., 2021). The implementation of a medical smart home eliminates the need for this, as caregivers and healthcare professionals would quickly be alerted to the older adult’s fall. The early identification of falls significantly improves the older adult’s health outcomes and ability to remain independently after the fall. This principle could be applied to other emergencies as well, such as fires within the home or the activation of a carbon monoxide alarm.

Additional Safety Considerations

Fall prevention and safety is one of the key motivators to implement a medical smart home, but there are other ways this modified home environment can promote physical safety. The home environment can be monitored and assessed for physical hazards. Yu et al. (2019) conducted a pilot study in China to verify the feasibility of medical smart homes for the older adult population. Participants were selected to be part of the study if they were over the aged of 65, had been living independently, and suffered from chronic conditions—criteria that align with those of our patient case illustration. Several safety parameters came to light in the results of their study. Security of the home, and therefore of the older adult, can be ensured in a medical smart home environment. If the older adult went to sleep, and doors and windows were left open, the medical smart home could alert the older adult, their caregivers, and other users of the

system. In addition, abnormal usage of water or electricity, compared to the typical baseline use, could alert users to possible safety concerns. For example, if the older adult left their home or went to sleep with the oven on, the system could alarm them and other users about this safety hazard. Hu et al. (2024) provide an instance of a bathtub's water level rising above normal, which can trigger an alert to indicate a potential incident. To reiterate, these are mere examples of the potential of the medical smart home environment and how it promotes physical safety.

Physiological sensors and SWDs provide insight as to the clinical status of an older adult within the medical smart home. A sudden increase or decrease in the older adult's vital signs trigger an alert to ensure a timely intervention, on the behalf of the older adult or their healthcare professionals. To illustrate, if an older adult exercises and gets an alert that their HR or BP has spiked beyond normal parameters, they may stop exercising or take a medication in response (Hu et al., 2024). This allows the older adult to take action before their clinical status worsens and requires extensive medical care. Vital signs are also obtained and analyzed, creating trends of the older adult's "normal" levels during their everyday activities. This continuous monitoring and trend analysis provides healthcare professionals with extensive data that can be used to inform their clinical decisions. Care can be personalized for older adults, according to their individual needs and health requirements.

Managing Brittle Diabetes in the Medical Smart Home

In previous sections, physical safety with regard to disability, such as an AKA, and overall status of older adults was described. Similarly, brittle diabetes can be more effectively managed through the integration of SWDs and interactive platforms within the medical smart home. More specifically, CGMs, insulin pumps, and HCL systems were highlighted in the management of older adults with brittle diabetes. Each of these devices have their own purpose,

benefits, and disadvantages; however, they each prove to be effective in managing user's HbA1c and improving glucose control. To further illustrate, a case study presented by Newman and Dinneen (2019) will be presented.

Newman and Dinneen (2019) described an 84-year-old woman diagnosed with diabetes mellitus at age 78 and treated with insulin since then. Her past medical history consisted of hypothyroidism, osteoporosis, controlled hypertension, and recurrent urinary tract infections, all managed with prescribed medications. She was assessed to have mild cognitive impairment. Upon her arrival at their diabetes clinical, her HbA1c was 10.5%, and her total insulin daily dose was 45 units. Despite her use of insulin, she reported episodes of symptomatic hypoglycemia. Over the next 24 months, adjustments to her insulin regimen lowered her HbA1c to 8.4%, but she continued to experience frequent hypoglycemic episodes. Her treatment regimen continued to be looked after, but within the subsequent seven months, she experienced 12 episodes of DKA and erratic glucose control within the hospital (see Figure 6).

Due to her condition and the need for continuous monitoring, she remained hospitalized for months. During this time, her cognitive status declined, and she experienced a loss of independence. Previously entirely independent and living alone, she became functionally dependent as her glucose control worsened. After years, at age 87, the healthcare team initiated continuous insulin pump therapy. This intervention stabilized her blood glucose levels, eliminating further episodes of DKA and hospitalizations. This case study underscores the debilitating nature of brittle diabetes and highlights the transformative impact of SWDs in managing the condition. Therefore, brittle diabetes can be managed independently within the homes of older adults using SWDs. In addition, interactive platforms enable real-time communication between users and healthcare providers, ensuring timely intervention in response

to erratic blood glucose levels or other complications detected through the medical smart home system.

SWDs are only one potential component of the medical smart home that can promote management of brittle diabetes. Unobtrusive sensors can be placed near medication boxes to monitor medication compliance, specifically in an older adult with brittle T2DM (Yu et al., 2019). T2DM can be managed with oral medications, so this application would be particularly beneficial for this population. When an older adult opens their medication box, sensors activate, and the system would record exactly what time the individual takes their medication. This allows healthcare professionals to track compliance and develop individualized, precise treatment plans. In addition, if the system senses that medications were not taken at the prescribed time, interactive platforms can be used to remind the older adult to take their medications. Although this literature review is focused on an older adult solely with an AKA and brittle diabetes, it is crucial to note that more than 90% of individuals with T2DM exhibit multimorbidity (Umegaki, 2024). Older adults with multiple chronic conditions may be taking five or more medications each day, a term known as polypharmacy. Polypharmacy only increases the risk of hypoglycemic episodes and poor glycemic control, potentiating brittle diabetes. This trend reinforces the impact that sensor-based medication boxes and SWDs, such as CGMs, can have on the older adult population.

To close this section, VAPAs such as the Amazon Alexa can promote management of brittle diabetes. A study conducted by Balasubramanian et al. (2021) sought to understand the impact of VAPAs on the health and well-being of their users. One cohort of this study had DM and participants were able to express their experiences using Alexa. To recall, management of DM involves nutritional therapy and counting of carbohydrates. Participants had a positive

experience with Alexa when preparing meals, asking Alexa for recipes tailored to their personal preferences. In addition, some users used Alexa to count the amount of carbohydrates they are consuming to ensure they are administering the proper units of insulin. Overall self-management with regard to nutrition, exercise, and stress-relieving activities was encouraged through Amazon Alexa. In turn, participants reported that their diabetes was better managed, and they had improved control of their blood glucose levels. The use of such technologies not only facilitates the management of brittle diabetes, but also promotes psychosocial well-being and fosters a sense of security regarding clinical status.

Promoting Psychosocial Wellness

Psychosocial wellness is just as significant in promoting healthy aging as physical wellness, as the two are closely linked. To recall, numerous stereotypes about aging contribute to an overall negative perception of it, which many older adults may internalize. A mindset focused on physical and functional decline may perpetuate a vicious cycle that results in poor mental health (Reynolds et al., 2022). Obuobi-Donkor et al. (2021) note as individuals age, their quality of life may decline due to loss of autonomy, independence, social connections, and physical abilities. These changes can foster a sense of worthlessness and hopelessness, increasing the risk of depression. Unfortunately, individuals with more than one chronic illness are more likely to experience depression, placing older adults at an even greater risk for this mental illness (CDC, 2024c).

Due to the societal stigma surrounding aging, older adults are often discouraged from seeking help for depression and feel ashamed for the way they feel. The lack of recognition and treatment of depression can escalate into suicidal ideation. Alarmingly, in 2022, individuals aged 85 or older had the highest rates of suicide, followed by those aged 75-84 (see Figure 7; CDC,

2024e). As a society, we must address this trend and target interventions to support mental health in older adults. Initiatives like the UN Decade of Healthy Aging recognize the importance of this issue, but additional solutions are needed. The implementation of medical smart homes is a promising intervention. By fostering independence, promoting dignity, and facilitating social engagement, medical smart homes can help mitigate some of the key contributing factors to depression in older adults.

Promoting Independence through the Medical Smart Home

Maintaining functional independence is one pivotal factor in psychosocial well-being and healthy aging. Older adults are able to perform their ADLs with increased independence and safety with the use of assistive technologies and VAPAs. In a study conducted by Cleland et al. (2024), individuals reported how home automation technology reduced their reliance on others. The eight participants, with varying disabilities, were able to turn lights on and off automatically and open windows, no longer having to wait for a caregiver. One participant specifically described, “I’ll turn the telly on and off and things that just give you that freedom where you don’t have to wait for a carer.” The partner of another participant noted, “home automation is just something we’ve never dreamed of...it gives him that modicum of independence.” An older adult with an AKA may experience improved QoL due to the convenience and ability to control their environment through technology. In addition, the continuous monitoring enabled by the medical smart home allows older adults to live on their own, with technology detecting deviations from typical behavior and providing timely emergency alerts (Padhan et al., 2023).

Further supporting these findings, studies conducted in Hong Kong and Australia found that older adults were satisfied with the ease of controlling their environment and home appliances through a mobile app (Hu et al., 2024). Participants even expressed a desire for

reminders and notifications regarding medication management, daily routines, and lists or bills in these 2016 to 2017 studies. Today, the technologies described in this literature review could be used to promote the older adult's IADLs, such as managing finances or going grocery shopping. Through the promotion of independence, older adults can feel empowered and valued, challenging current societal stigma that portrays them as dependent and declining in ability.

Promoting Dignity through the Medical Smart Home

Dignity is central to well-rounded care, especially for older adults. Although not explicitly a human right, dignity is a core value grounded in respect, integrity, and autonomy (Clancy et al., 2020). Healthcare professionals must strive to provide dignified care to all and use of a medical smart home can further ensure feelings of dignity. Focus on self-determination, individualization, and participation of older adults can preserve self-worth and respect, enabling older adults to feel dignified.

Self-determination in the context of healthcare refers to the ability to make one's own decisions about their care and lifestyle. Within the medical smart home, older adults can continue fulfilling their daily routines. As opposed to alternative care models and settings, such as a nursing home, individuals are able to remain in the comfort of their own home and pursue everyday activities at their own discretion. One older adult explained how home is "a place where you may walk around and do what you like. If I want to walk in the garden, I can do so...And I don't have to be afraid of what others think about what I am doing..." (Clancy et al., 2020). By preserving personal freedom, medical smart homes empower older adults to maintain their preferred lifestyle, fostering a sense of dignity.

The medical smart home further enables dignity by offering individualized care and facilitating participation, allowing older adults to engage in their own care. The technology

embedded within their home environment promotes self-care, as older adults remain in charge of their own clinical status and overall well-being. They can remain active participants of their care, rather than being passive recipients, dependent on others to manage their health and daily needs. One participant of a study conducted by Cleland et al. (2024) described, “You feel human, I guess. You don’t depend on people, carers to do things for you and you’ve got...control over your life.” This can change an older adult’s perspective on aging and help them view it as a transition in their life, rather than a challenge they must inevitably face. With this in mind, dignified care goes hand-in-hand with independence. When we uphold someone’s independence through technological innovation, we simultaneously affirm their dignity by recognizing their humanity and right to self-determination. By feeling capable, valuable, and autonomous, an older adult’s psychosocial wellness is nurtured.

Promoting Social Engagement through the Medical Smart Home

The final advantage of a medical smart home, with regard to psychosocial wellness, that will be discussed in this review is the promotion of social engagement and connectedness. Loneliness and social isolation are commonly experienced by older adults, due to possible physical disability, poor health, and widowhood (Reynolds et al., 2022). Factors such as living alone, limited social networks, and infrequent social activities contribute to social isolation and are correlated with adverse health outcomes, both physical and mental (Hu et al., 2024). As a result, the promotion of social connectedness must be a priority in the care of older adults. Medical smart homes can achieve this through two main avenues: providing channels for connection and conserving energy to prevent fatigue.

The integration of technology within their home makes older adults more likely to accept communication technologies and social network platforms. Smart technology, such as interactive

platforms, can serve as a channel to communicate with family members and friends (Hu et al., 2024). The simple use and acceptance of a smartphone encourages older adults to continue investing themselves into their social relationships. With a smartphone, older adults are more likely to call and check in with their children and grandchildren, who continue to be a beam of light for many older adults. In a qualitative study conducted by Bosch-Farré et al. (2020) involving 71 older adult participants, many expressed that having a good relationship with their grandchildren improved their well-being and was a priority for them. The ability to continue maintaining relationships with their loved ones prevents isolation and promotes a sense of belonging, offering significant mental health benefits.

The automation provided by a medical smart home allows older adults to conserve their energy, which they can then invest into social connections. The ease of completing ADLs and tasks around their home can decrease fatigue experienced on a daily basis (Cleland et al., 2024). This increased energy can be devoted to creating more social connections and participating in activities outside of home, providing the opportunity to be more engaged in the community. Engagement within the community only further impedes loneliness, improving psychosocial wellness and overall QoL. Therefore, designing a healthy personalized medical smart home environment can improve safety, promote an independent life, and enhance psychosocial well-being (Yu et al., 2019).

Limitations Regarding Implementation of Medical Smart Homes

Despite the plethora of advantages a medical smart home offers in enhancing the care and well-being of older adults, there are certain limitations that must be critically examined. A comprehensive understanding of these challenges is essential for developing effective strategies to mitigate their impact and promote the implementation of medical smart homes. Four barriers

to medical smart home adoption include concerns about technological feasibility, exacerbation of inequities, financial burden, and privacy.

Technological Feasibility and Usability of the Medical Smart Home

Although smart homes are emerging at increasing rates globally, the medical smart home is a relatively new development. A common inquiry is how such technology and the use of the IoT is practical, and how it would be implemented. This concern can be drawn back to society's overall limited perception of a medical smart home (Li et al., 2021). Individuals may not truly understand how the medical smart home functions, and the different IoT frameworks that are already available and implemented worldwide. Li et al. (2021) highlight how low levels of knowledge about smart technology in the U.S. is one of the key barriers to adoption. Survey participants expressed there is a lack of readily available information about smart home technologies in the market, which hindered their ability to consider investing in such technologies. With the case of a medical smart home, family members and caregivers have a significant impact on whether these technologies would be implemented. When evaluating care options for their loved ones, they prioritize obtaining a complete understanding of each approach prior to committing to its implementation. Therefore, ensuring that consumers have a thorough understanding of the potential of medical smart homes is essential for fostering trust and facilitating their adoption.

The lack of technical understanding impacts the degree of acceptance of technology within the older adult population as well. Many older adults internalize struggle with technology, especially with the rapid pace at which it develops (Hu et al., 2024). They may experience technology anxiety—"To elderly people, the changes brought forward by the IoT era in the form of smart homes are too radical, disruptive, and new" (Li et al., 2021). They feel more

comfortable with technology they have used for a long period of time and may experience uneasiness with the introduction of new technologies. They could question the value and applicability of gerontechnology, especially when they were unable to perceive the full utility of the system (Atta et al., 2024). For example, Hu et al. (2024) explained how older adults did not want a smartphone simply because they were unable to discriminate its functions from a conventional telephone. The technology acceptance model (TAM) can be used to better understand influential factors when consumers adopt new technologies (Li et al., 2021). Part of the TAM is the perceived usefulness (PU) of the technology, referring to the degree to which a user believes a smart technology or system will make tasks easier and more efficient. The subjective PU has a large influence on the acceptance of the smart home environment.

Contrary to popular belief, current research indicates that older adults are increasingly receptive to gerontechnology and have interest in its impact (Atta et al., 2024). Atta et al. (2024) note that there is a moderate degree of technological involvement in the older adult population. Of the older adults that own technology in their home, 75.3% demonstrate a willingness to integrate technology into their home environment. When technology anxiety is resolved and older adults are able to conceptualize the benefits of technology, they are more likely to adopt it. It is the responsibility of the interdisciplinary healthcare team and engineers to ensure older adults see the benefit of the medical smart home, are able to customize it to their own needs, and have control over it (Facchinetti et al., 2023). When older adults understand the potential of the medical smart home to detect emergencies and facilitate psychosocial well-being, they express an increased desire to transform their current living space.

Exacerbation of Inequities to Consider

The adoption of medical smart homes is intended for use to the general older adult population, but significant barriers rooted in society threaten to exclude certain populations from benefiting equally. Preexisting social determinants of health (SDOH) must be considered as technology continues to accelerate in advancements. SDOH are factors within an individual's everyday life and environment that affect health, functioning, and QoL (Office of Disease Prevention and Health Promotion, 2024). Examples of these structural inequities include transportation, discrimination, education, access to food and health care, and literacy skills. Each of these factors contribute to global health inequities. For example, living in an environment with poor air quality and unsafe streets can increase the risk of chronic health conditions, such as cardiovascular disease and diabetes. The U.S. Office of Disease Prevention and Health Promotion (2024) is addressing these SDOH with the goals of improving national health and reducing disparities experienced by vulnerable populations.

With the widespread implementation of medical smart homes, access to technology can become a SDOH. Although the intention is to create equal access to this life-changing technology, pre-existing structural inequities can create an unequal uptake of technology (Huang et al., 2023). Without deliberate efforts to address these barriers, the adoption of medical smart homes may reinforce existing disparities rather than alleviate them. With that being said, the government and policymakers must prioritize addressing such socioeconomic and technological barriers that hinder the equitable distribution of technology.

Technological and digital literacy must be considered as well to ensure equitable access to medical smart home technology. Technology literacy refers to one's ability to use and understand technology—this can be enhanced through education and training. Digital literacy is the ability to find, create, and communicate digital content to others. Huang et al. (2023)

combine these two ideas and discusses digital health literacy, the ability to seek and understand health information from the internet. Vulnerable populations with no or limited access to technology have lower rates of digital literacy, and therefore digital health literacy. Huang et al. (2023) emphasize how older adults from minority groups and low-income groups have single-digit rates of internet use, as opposed to older adults from White and wealthy groups who have a 66% rate of use. This digital divide is solely due to systemic exclusion and SDOH. This divide must be considered, as smart home implementation may unintentionally further exacerbate it (Hu et al., 2024). Deliberate efforts must be made to address SDOH and current structural inequities, requiring a multifaceted societal approach. This will be discussed later in this literature review in more depth.

Financial Considerations of the Medical Smart Home

The initial cost of implementing the plethora of technologies within a medical smart home is a third potential barrier. Older adults are vulnerable, particularly those on a fixed income and those from minority groups (Hu et al., 2024). At this time, the purchase and installation of these technological devices are often not covered by insurance or government aid programs. Beyond installation, ongoing expenses for maintenance, updates, and repairs further exacerbate financial burden and add resistance to adopting medical smart home technologies. Hu et al. (2024) suggest that the government and public health organizations step in to alleviate financial burden, thereby increasing accessibility of medical smart homes. These initiatives would address SDOH, ensuring all older adults can benefit from emerging technology, enhancing physical and psychosocial well-being.

Despite the upfront investment, medical smart homes can reduce long-term expenses in several respects. Government support for implementation could further promote adoption,

reducing the overall demand for state-funded care homes (Oladinrin et al., 2023). Individuals would be aging within their home, reducing costs for outside care environments and caregivers. In addition, as medical smart home systems become more widespread, individual costs per family are expected to decrease (Hu et al., 2024). The more families adopt medical smart homes, the more financially sustainable they become. Since the medical smart home provides seamless monitoring of all activities, 24/7 care can be minimized. Moreover, institutional settings pose an increased risk for healthcare-associated infections (Ratnayake et al., 2022). Healthcare-associated infections are acquired from care within a healthcare setting, as an individual is receiving treatment. These infections increase complications and morbidity, ultimately rising healthcare costs. By allowing older adults to AIP, the risk to healthcare-associated infections is mitigated, reducing medical expenses. Thus, not only does AIP reduce governmental costs, but it remains a cost-effective option for older adults and families. As costs of institutional care are increasing, investing in medical smart homes presents a financially sustainable option that maintains independence, yet consists of continuous support (Ratnayake et al., 2022).

To conclude, medical smart homes ease financial burden by improving health and well-being, reducing health care expenses. Through the medical smart home, health care professionals can observe the behaviors of older adults and provide individualized interventions (Hu et al., 2024). All of this can occur asynchronously, eliminating the need to make and spend on a doctor's appointment. Furthermore, the real-time data provided to medical providers can reduce the amount of time older adults need to wait to be treated for both acute and chronic conditions. The ability to respond to emergencies and emergent changes in clinical status quickly yields health benefits and reduces the need for hospital visits. The overall optimization of health can delay the transition to long-term care facilities and lower the burden on families and the

healthcare system. Although medical smart homes present with an initial financial burden, the long-term financial and health benefits make them a sustainable solution for AIP.

Privacy and Security Issues

Despite the significant benefits of smart technology, concerns about invasion of privacy remain a prominent barrier to adoption among the older adult population. According to Hu et al. (2024), many older adults worry that their health data and personal identifiable information stored in a cloud server may be vulnerable to third-party access. This concern depended on the type of smart technology used—older adults reported feeling most uncomfortable with home monitoring systems and VAPAs. They expressed concern about being under surveillance in their own living space, as well as being listened to by VAPAs. However, once older adults began to better understand the implications of a medical smart home on independence, they recognized the technology as necessary for their well-being and safety. The overall benefits such as convenience, comfort, and control, takes precedence over concerns, motivating older adults to AIP within a medical smart home (Li et al., 2021).

Implications of a Medical Smart Home

Thus far, the focus of this literature review is centered around how the medical smart home affects older adults, enabling AIP and enhancing quality of life. This final section discusses how the role of the medical smart home is not limited to individuals. Widespread implementation of such technologies plays a key role in supporting caregivers, optimizing plans of care, and transforming healthcare.

Impact on Caregivers

As family members age, caregivers often express concern about their health and safety living independently within their homes. The medical smart home can be a transformative force

psychologically and financially for all caregivers alike. Ratnayake et al. (2022) note in 2020, there were approximately 53 million informal caregivers in the U.S., estimating to one in five adults. Caregivers are spending extensive time providing support to older adults, which have negative effects on their physical health, mental health, and finances.

The implementation of real-time remote monitoring of older adults is reassuring family caregivers. The collection of data and report of potential abnormalities to healthcare professionals creates a “unique circle of communication” that ensures the safety of older adults (Oladinrin et al., 2023). Therefore, family caregivers feel a sense of security, knowing their loved ones are safe and potential emergencies would be quickly mitigated (Facchinetti et al., 2023). This effect alleviates caregiver burden, as it reduces the constant worry and need for in-person supervision of their aging loved ones. The reduced need for continuous oversight decreases stress and avoids mental exhaustion, preventing burnout of caregivers. At the same time, Ratnayake et al. (2022) highlight the value of care provided by family caregivers accumulates to \$470 billion annually. These costs can be alleviated simply through reduction of time physically spent with older adults. Caregivers would monitor their loved ones remotely, allowing them to avoid missing work or hiring additional help (Hu et al., 2024).

To conclude, medical smart homes support the well-being of older adults, while offering a promising solution to alleviate caregiver burden. The real-time monitoring of older adults reduces the physical and mental stress of caregiving, improving the health of caregivers. Furthermore, costs associated with caregiving can be reduced through remote monitoring of older adults. Embracing medical smart home technology has the potential to foster a more sustainable environment for both aging adults and caregivers.

Impact on Telehealth

Telehealth is the delivery of health care through remote communication, including consulting and diagnosing (Christopoulou, 2024). It can be enhanced with the information provided by a medical smart home, ensuring both efficient and effective healthcare delivery. The unprecedented nature of the COVID-19 pandemic has transformed Telehealth (Atta et al., 2024). It has since become a basic need for both the general population and healthcare providers, reducing resource costs, lowering disease transmission rates, and improving access to care (Monaghesh & Hajizadeh, 2020). The need for Telehealth during the pandemic has made the general population more accepting of technology use in healthcare (Atta et al., 2024). In the context of a medical smart home, Telehealth can improve overall functionality.

The technologies of a medical smart home relay data to healthcare professionals through the IoT framework. This allows healthcare professionals to remotely monitor the older adult and provide health recommendations through Telehealth (Christopoulou, 2024). Video consultations, as well as messaging through interactive platforms, are all examples of Telehealth. This continuity of care has three significant benefits that facilitate healthcare: (a) eliminating delays in patient care, (b) improving communication and information exchange between patients and healthcare professionals, and (c) encouraging patients to maintain an active role in their health promotion (Christopoulou, 2024). To illustrate, healthcare professionals can obtain real-time glucose readings from CGMs and provide care recommendations through interactive platforms and mobile devices. This capability enhances the control of brittle diabetes and reduces the need for older adults to leave their home for in-person doctor visits. Telemedicine can also support educational visits to ensure older adults understand their condition and appropriate interventions for effective care management (Zafra-Tanaka et al., 2022). Combining SWDs with Telehealth creates a more comprehensive system for monitoring and managing chronic conditions remotely.

Impact on the Registered Nurse's Role

Registered nurses (RNs) can function in various specialties and settings in healthcare with the role of providing comprehensive, patient-centered care. Currently, home health RNs visit patients alone in their homes to identify their needs, set priorities, and develop plans of care with the interdisciplinary team (Riekert, 2021). Examples of care provided include assessing changes in a patient's acute status, performing wound care, and educating a patient newly diagnosed with diabetes how to self-administer insulin. Therefore, the current role of the home health RN is focused on assessment, prioritization, and education. The shift toward ubiquitous care with the widespread implementation of medical smart homes would adjust the RNs role in patient care.

The relatively new integration of technology within healthcare necessitates RNs to be involved in smart health management and AIP. Since RNs provide individualized patient care and directly communicate with the interdisciplinary team, they have a unique role in the smart home environment. Fritz and Dermody (2019) developed the Fritz Method, showing how RNs can support the development of medical smart home technology with their clinical knowledge, ensuring data accurately represent health events. This nurse-driven method begins with a recruitment visit with the older adult and any present family caregivers, in which the RN would assess the home's readiness for technology integration. This includes evaluating the home environment, internet connectivity, and additional factors that would affect the feasibility of a medical smart home. This beginning step aligns with the RN's foundational role in patient assessment, laying the groundwork for effective implementation.

The next step would involve enrolling the patient through a home visit, ensuring they understand the various capabilities and benefits to the medical smart home. The RN would

provide specific education about what exactly the smart home does, how it can streamline care management, and its role in the event of an emergency (Fritz & Dermody, 2019). Preparedness of older adults to incorporate technology into their homes and ADLs is a critical factor for gerontechnology acceptance (Atta et al., 2024). Therefore, this step centered around education is essential for acceptance, as the RN would take the time to address any concerns about technology and address potential barriers to implementation. Assessing how receptive an older adult is to change can guide efforts to facilitate a seamless transition to the medical smart home. Furthermore, Atta et al. (2024) highlight the digital divide between urban and rural areas of the U.S., describing how rural areas may be hesitant to integrate technology within their home. The RN, with the interdisciplinary team, must keep this in mind and recognize the unique challenges associated with both urban and rural environments. They can work directly with advanced practice health professionals and policymakers in the region to promote acceptance across diverse populations. By addressing these barriers proactively, the RN plays a vital role in bridging the gap between technology and patient-centered care. Through ongoing education and collaboration with the interdisciplinary team, they can ensure medical smart home integration is understood and accessible, improving QoL for older adults.

The third step in the Fritz method is about completing a comprehensive home assessment, assessing safety risks and identifying where sensors should be placed within the home for maximal efficiency (Fritz & Dermody, 2019). A floor plan is obtained, and the older adult's daily routine is mapped to identify the areas of the home where they spend the most time (see Figure 8). From here, the medical smart home can be implemented according to the older adult's individual needs. Then begins the fourth step, involving nursing assessment visits at regular intervals. The first visit is in-person, focused on obtaining baseline physical and mental health

data. At this point forward, the nurse can engage with the patient weekly via Telehealth and monthly in-person, performing ongoing assessments and providing education. Each of these steps slightly modify the RNs current role within a home setting.

The final step of the Fritz method involves the RN in data processing and analysis to ensure accurate representation of health data. RNs can be closely involved with the training of algorithms to interpret data collected within the medical smart home, transforming raw information into actionable insights about a patient's behavior and health status (Fritz & Dermody, 2019). They can work directly with other healthcare professionals and engineers to build a clinically intelligent home and ensure the older adult's right to privacy, autonomy, and self-determination. Above all, the RN remains an advocate for the patient and serves as a bridge between technology and patient needs. They remain the key coordinator of the care process, enabling communication between providers, engineers, and family members to establish individualized care delivery.

Impact on Healthcare

The widespread implementation of medical smart homes has implications that extend beyond the individual and their caregivers. Healthcare, as a system, can be made more efficient and cost-effective, promoting patient care and safety. Facilitating AIP and managing chronic conditions with medical smart homes enhances physical safety and activity, as well as mental well-being (Facchinetti et al., 2023). The proactive nature of the medical smart home, along with its ability to respond urgently to emergencies, reduces the number of hospitalizations and can prevent a premature transition to long-term care facilities (Fritz & Dermody, 2019). The financial savings for hospitals can be reinvested into advancing patient care, expanding access to innovative technologies, and improving the overall QoL for older adults.

Conclusion

As the aging population increases, the management of multiple, comorbid conditions such as AKAs and brittle diabetes becomes difficult. The current infrastructure of healthcare must be reimagined, as the physical and psychosocial challenges older adults face demand continuous care and timely interventions. As an emerging group of technologies, the medical smart home can promote care management and AIP, improving QoL for older adults of any demographic. They integrate sensor technology, automated technology, wearable devices, and artificial intelligence seamlessly into the home environment to provide healthcare. Older adults feel safer, more dignified, and in increased control of the aging process due to the benefits medical smart homes provide. The widespread implementation of these integrated technologies can shift the societal view of aging, ensuring older adults continue leading a meaningful life with proper care.

As medical smart homes are implemented, delivery of care will shift from institutional to residential settings. Older adults may be admitted into the hospital at reduced rates, as medical smart homes promote control of chronic diseases, decreasing the rate of exacerbations and complications. At the same time, older adults may remain in their homes with this technology, as opposed to being admitted to a nursing home or assisted-living facility. The implementation of a medical smart home therefore improves individual physical and psychosocial well-being, allowing for systemic changes. This shift in care improves the efficiency of the healthcare system and allows for reinvestment into improving population health. In doing so, sustainable patient-centered care can be achieved on a global scale in the near future.

Recommendations / Need for Future Research

The medical smart home is an emerging set of technologies, and its potential is not yet realized. At this time, smart homes within the context of healthcare have not been established in the U.S. Their effects are being researched on an individual level across the globe, so additional longitudinal case studies must be conducted (Yu et al., 2019). These studies would provide detailed information about the differences in behavior and health of older adults prior to implementation of medical smart homes and then at regular intervals after. In addition, further qualitative studies should be performed to establish the effectiveness of education on acceptance of smart home technology within the home. Older adults are often reluctant to integrate sensor technology, but this must be further studied as technology advances and is increasingly used daily. Understanding the perspective of older adults allows for targeted education and modification of medical smart homes to their individualized needs.

Another sphere of research that must be further explored is how medical smart homes can begin to be implemented on a widespread basis. Policymakers, government officials, and current healthcare providers should consider the potential of smart home adoption to achieve sustainable outcomes. It is an overlooked sector of technology that must be better understood on an administrative level to allow for financial coverage and logistical implementation. Without an initiative to promote medical smart home use, it may be difficult to advocate for widespread adoption, hindering the advancement of health and well-being of older adults.

Lastly, engineers and healthcare professionals must work collaboratively to create a seamless, well-functional technological ecosystem for older adults. The IoT framework has been developed, but RNs and providers must be consulted to create an environment best suited for older adults as they continue to age. Future researchers must continue to gather data from older

adults, caregivers, and healthcare professionals to create the most comprehensive medical smart home that can bring the greatest benefits to older adults globally.

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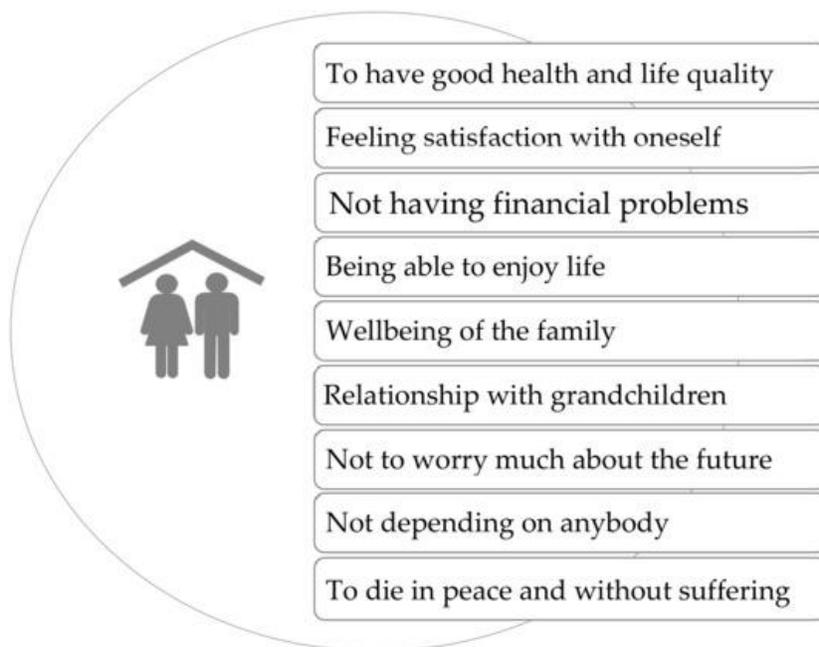
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Figures

Figure 1

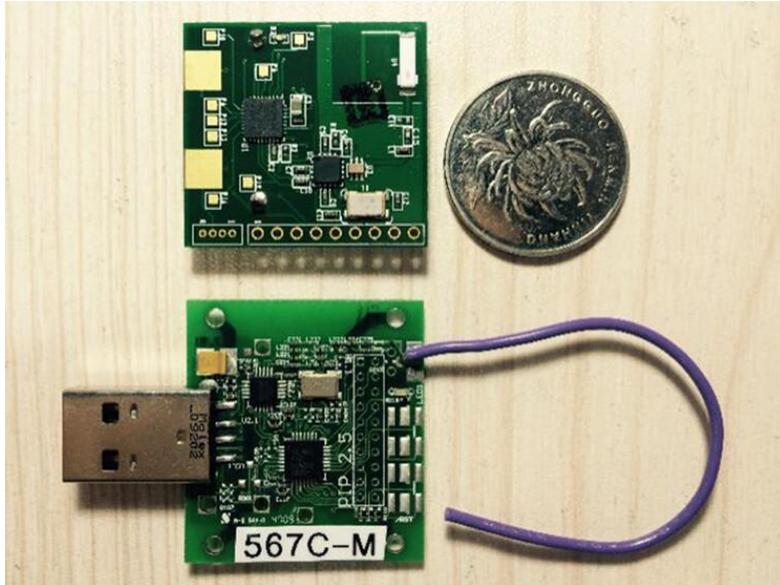
Priorities in the Lives of Older Adults



Note. This figure lists the various priorities that older adults report as significant to their QoL as they age. Reprinted from “Healthy ageing in place: Enablers and barriers from the perspective of the elderly. A qualitative study,” by C. Bosch-Farré, M. C. Malagón-Aguilera, D. Ballester-Ferrando, C. Bertran-Noguer, A. Bonmatí-Tomás, S. Gelabert-Vilella, and D. Juvinyà-Canal, 2020, *International Journal of Environmental Research and Public Health*, 17(18), 6451 (<https://doi.org/10.3390/ijerph17186451>).

Figure 2

Example Unobtrusive Sensor Photographed next to Coin



Note. This image displays the size of unobtrusive sensors compared to the size of a coin. These sensors are from a pilot study conducted in China. From “A pilot study on a smart home for elders based on continuous in-home unobtrusive monitoring technology,” by J. Yu, N. An, T. Hassan, and Q. Kong, 2019, *Health Environments Research & Design Journal (HERD)* (Sage Publications, Ltd.), 12(3), 206–219 (<https://doi-org.adelphi.idm.oclc.org/10.1177/1937586719826059>).

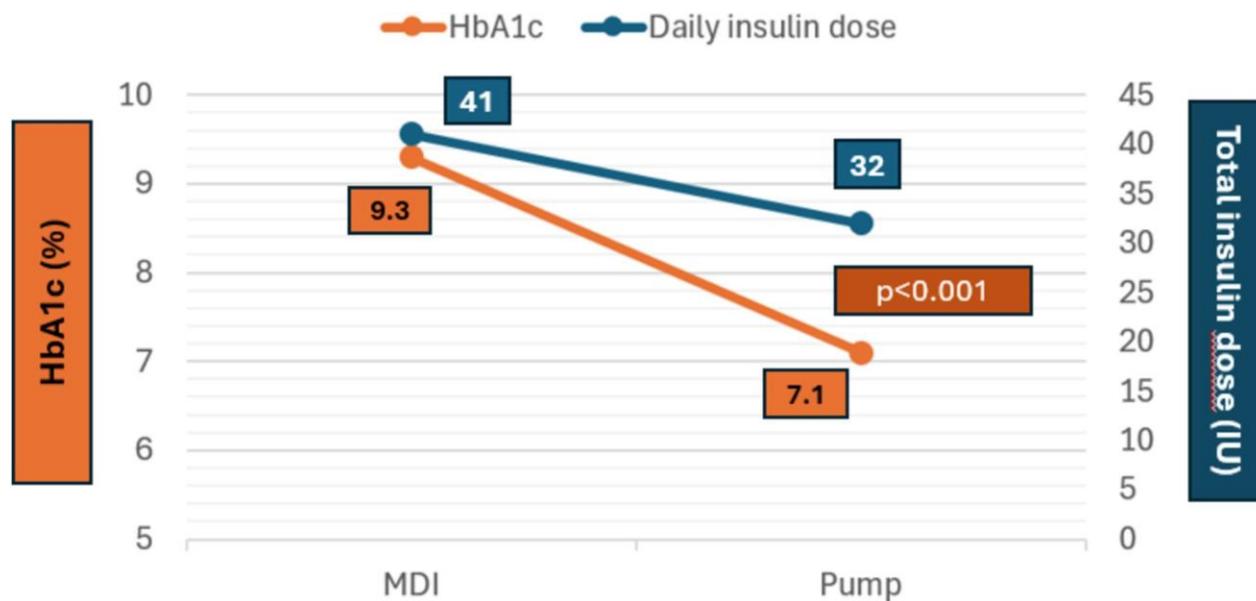
Figure 3*Installation Location of Different Types of Unobtrusive Sensors*

Types of Unobtrusive Sensors	Installation Locations	Sensing Data
Temperature and humidity	Different rooms, close to air conditioners, and close to gas stoves	Indoor temperature, indoor humidity, and temperature of gas stoves
Switch	Doors of different rooms, cabinet doors, windows, water pipes, refrigerator, and medical kit	Closure of doors and windows, occupancy of different rooms, water usage, refrigerator usage, and medicine consumption
Pressure	Chairs, couches, and beds	Sleeping, resting
Water meter	Water channels, kitchen floors, toilet bowls, sinks, and tubs	Water usage in kitchen and bathroom
Electricity meter	Televisions, heaters, air conditioners, and lights, microwave ovens	Electricity usage, use of electrical appliances

Note. From “A pilot study on a smart home for elders based on continuous in-home unobtrusive monitoring technology,” by J. Yu, N. An, T. Hassan, and Q. Kong, 2019, *Health Environments Research & Design Journal (HERD)* (Sage Publications, Ltd.), 12(3), 206–219 (<https://doi-org.adelphi.idm.oclc.org/10.1177/1937586719826059>).

Figure 4

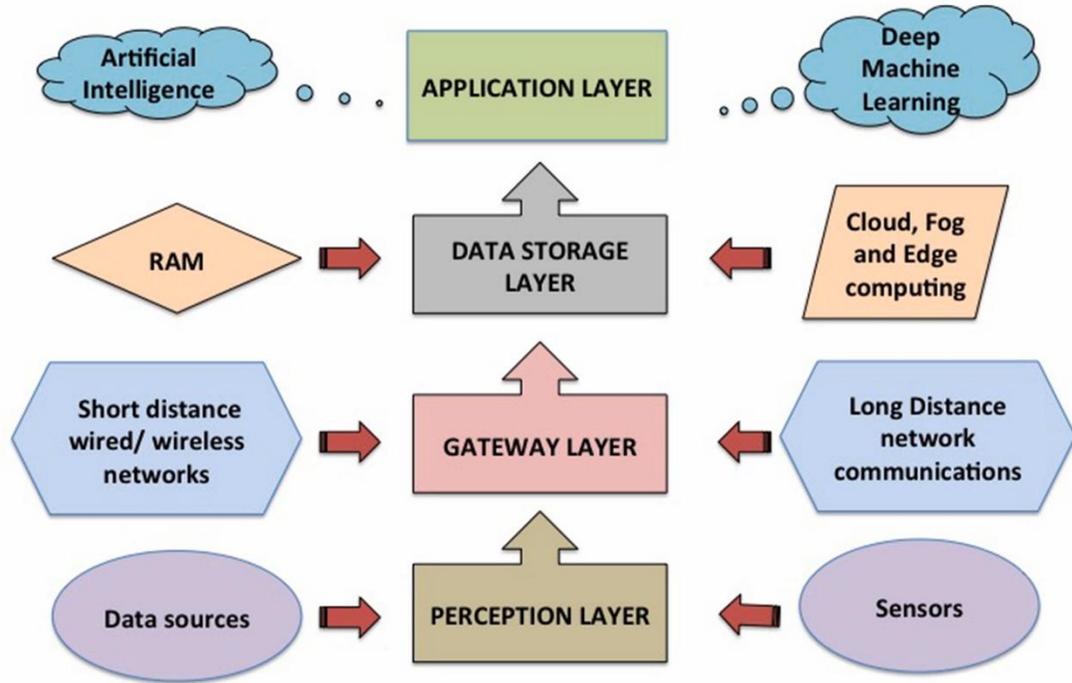
Change in HbA1c and Daily Insulin Dose After Using Insulin Pump for Six Months



Note. From “Automated insulin delivery systems in elderly patients with brittle type 2 diabetes,” by O. Telci Caklili, F. Cetin, M. Ozkan, E. Sahiner, R. Cakmak, E. Keskin, H. Hacisahinogullari, E. S. Goncuoglu, and M. T. Yilmaz, 2024, *Diabetes Research and Clinical Practice*, 218, 111913 (<https://doi.org/10.1016/j.diabres.2024.111913>).

Figure 5

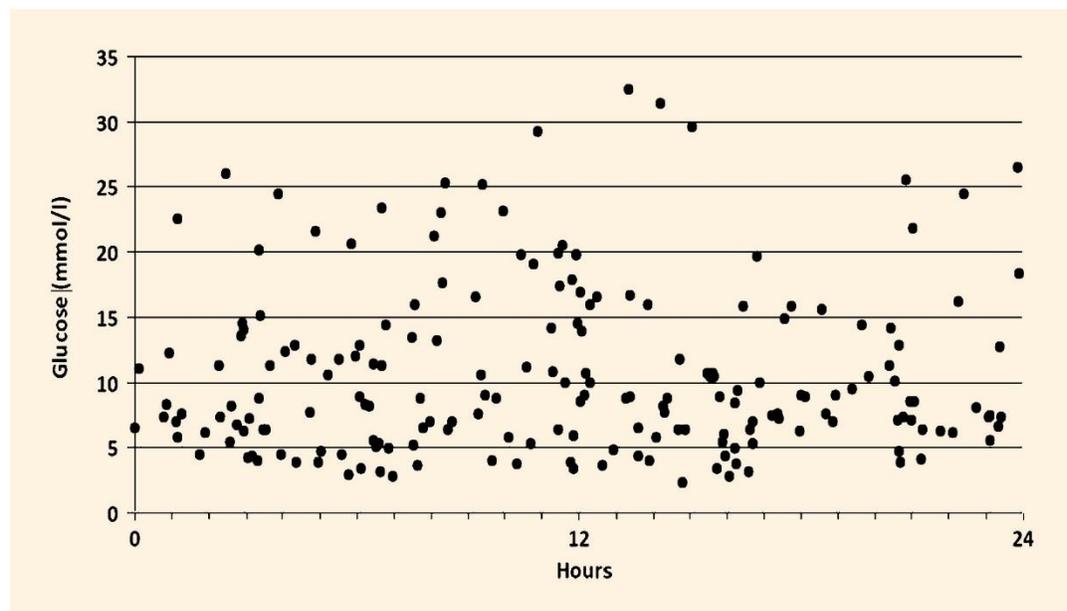
IoT Framework: Four Layers



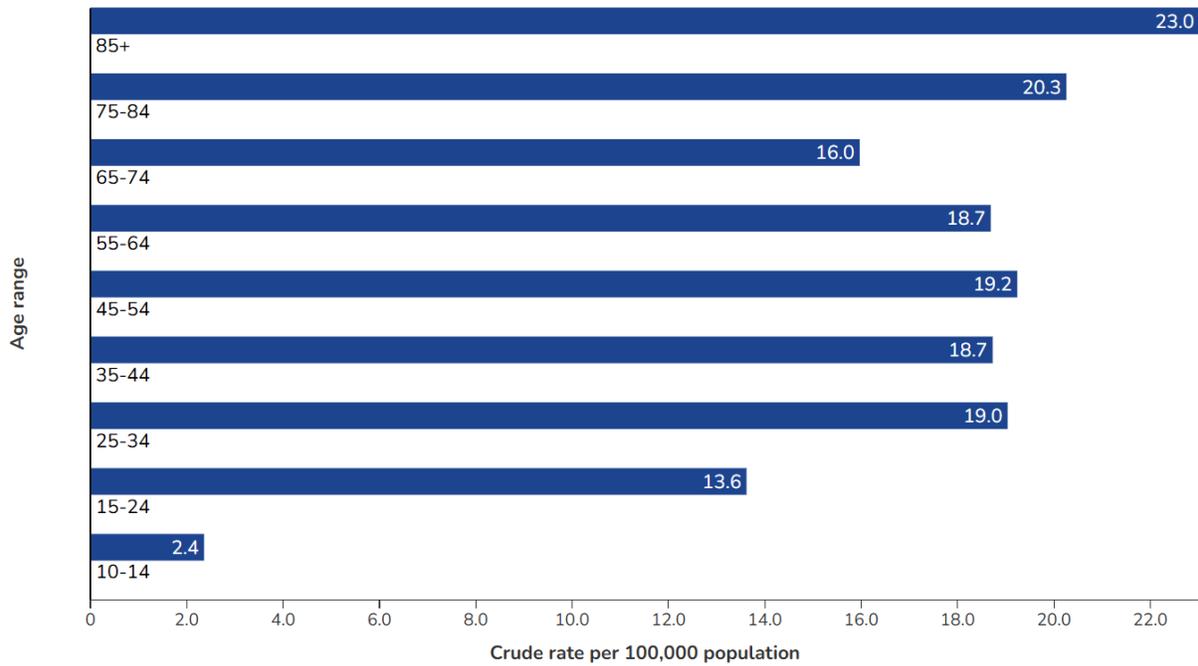
Note. From “Potential of internet of medical things (IoMT) applications in building a smart healthcare system: A systematic review,” by R. Dwivedi, D. Mehrotra, and S. Chandra, 2022, *Journal of Oral Biology and Craniofacial Research*, 12(2), 302-318 (<https://doi.org/10.1016/j.jobcr.2021.11.010>).

Figure 6

Model of Erratic Glucose Control from One Admission



Note. This model displays the erratic glucose control of a 84-year-old woman with brittle T1DM from one admission over 24 hours. From “Brittle diabetes revisited: A description of erratic and difficult-to-control diabetes in an elderly woman with Type 1 diabetes,” by C. Newman and S. F. Dinneen, 2019, *Diabetic Medicine*, 37(10), 1777–1780 (<https://doi.org/10.1111/dme.13972>).

Figure 7*Rate of Suicide by Age Group in 2022*

Note. From “Suicide data and statistics,” by the Centers for Disease Control and Prevention, 2024e (<https://www.cdc.gov/suicide/facts/data.html>).

Figure 8

Example Floor Plan Displaying Furniture and Sensor Locations



Note. From “A nurse-driven method for developing artificial intelligence in “smart” homes for aging-in-place,” by R. L. Fritz and G. Dermody, 2019, *Nursing Outlook*, 67(2), 140-153 (<https://doi.org/10.1016/j.outlook.2018.11.004>).