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Robot-Supported Remote Caregiving Systems

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Abstract

Both artificial intelligence and robots are increasingly utilized and demonstrate significant potential, particularly in caregiving. Robots, capable of enhancing or replacing certain human functions, hold considerable promise in caregiving applications. Their integration has the potential to revolutionize patient care, from basic assistance to specialized nursing tasks. For future generations, robots serving in such roles may become as common and essential as smartphones are today. In our aging society, robotic assistance in remote caregiving represents an innovative approach that can deliver critical socioeconomic benefits. This paper examines the primary limitations of current remote caregiving systems and explores how robotics can address these challenges.

Keywords: robot; caregiving; remote; telemedicine

DEMAND FOR CAREGIVING

The pursuit of longevity and even immortality has been a longstanding human aspiration (Katz, 2017; Partridge et al., 2018). While the elixir of eternal life remains elusive, advancements in modern medicine have significantly extended human lifespans (Crimmins, 2015). This increased longevity, coupled with the aging of the baby boomer generation, has led to profound demographic shifts, resulting in an increasingly older society and presenting numerous challenges (Vespa et al., 2020).

One of the most pressing issues arising from this demographic transition is the rising prevalence of chronic diseases among the elderly population. By 2035, it is projected that 35.66% of adults aged 50 and older will have at least one chronic condition, increasing to 47.81% by 2050 (Ansah & Chiu, 2023). These chronic illnesses often necessitate daily assistance and companionship for affected individuals, creating a growing demand for caregiving services (Wolff et al., 2016).

The need for professional caregivers has been further amplified by societal changes that have reshaped modern family structures. Factors such as increased geographic mobility, smaller family sizes, and higher rates of women participating in the workforce have reduced family members' availability to care for aging relatives (Carr & Utz, 2020). This shift has led to a growing reliance on professional caregiving services to meet the needs of the elderly population (Schulz & Eden, 2016).

The interplay of these factors - an aging population, increased prevalence of chronic diseases, and changing family dynamics - underscores the growing importance and escalating demand for caregiving services in contemporary society. As of 2023, there were 426,820 home care provider businesses in the United States (US), an increase of 2.3% from 2022, reflecting the rapid growth in demand for care services (IBISWorld, 2023). Moreover, the global home healthcare market size was valued at USD

390.24 billion in 2023 and is expected to grow at a compound annual growth rate of 7.96% from 2024 to 2030, reaching USD 666.9 billion by 2030 (Grand View Research, 2023).

As demographic changes, including aging populations, reshape society, addressing the caregiving needs of our aging population emerges as a critical challenge for healthcare systems, policymakers, and society as a whole (National Alliance for Caregiving & AARP, 2020; Olshansky et al., 2009). The care economy plays a crucial role in supporting vulnerable populations, including the elderly, children, and individuals with disabilities. In recent years, the U.S. has faced a growing care crisis marked by an increasing demand for caregiving services and a significant shortage of professional caregivers (Weller et al., 2020). This crisis poses far-reaching consequences for both the economy and society at large if left unaddressed. The care sector faces significant challenges, including a shortage of workers and high turnover rates, which could lead to substantial economic losses if not addressed adequately (Weller et al., 2020).

PROBLEMS OF HUMAN CAREGIVERS

Human caregivers are often regarded as superior to mechanical devices in caregiving due to their ability to provide companionship and fulfill the essential need for human touch, which is crucial for emotional and psychological well-being (Mueller et al., 2023; Schulz et al., 2009). This superiority is particularly evident in their ability to perceive and respond to nonverbal cues, a skill that current technologies and impersonal care systems struggle to replicate (Chi & Demiris, 2015). Furthermore, human caregivers possess a unique capacity to adapt to the individual personality and needs of care recipients, fostering deep emotional bonds. Such adaptability enhances not only the psychological well-being of care recipients but also contributes to measurable improvements in their physical health (Pristavec, 2019).

However, human caregivers also present several disadvantages. First, informal caregiving can impose significant financial strain on families or individuals. Reinhard et al. (2019) reported that family caregivers spend an average of $7,000 per year on out-of-pocket costs related to caregiving, with costs varying based on factors such as the care recipient's condition and the caregiver's proximity.

Second, human caregivers may experience emotional and physical exhaustion, particularly when caring for individuals with complex or demanding needs (Karimi Moghaddam et al., 2023). Caregivers are at increased risk of developing depression and anxiety (Karimi Moghaddam et al., 2023). While emotional connections between caregivers and patients can be beneficial, they may also lead to conflicts or challenges in maintaining professional boundaries, complicating care decisions.

Third, inconsistencies in the quality and type of care are a common issue, as caregivers vary in skill, experience, and compassion. Finding a suitable caregiver can be particularly challenging, especially in remote areas (Chapman et al., 2023). Moreover, a lack of continuity in caregiving, often due to changes in caregiver schedules, can be disruptive to those requiring care (Babaei & Taleghani, 2019).

Fourth, although rare, instances of mistreatment by caregivers have been reported. Pillemer et al. (2016) found that approximately 10% of older adults in the United States experience some form of elder abuse, with a significant portion perpetrated by caregivers.

Fifth, Caregivers face heightened risks of infection when caring for individuals with contagious illnesses. A study by Lee et al. (2022) demonstrated that caregivers play a significant role in nosocomial transmission during a COVID-19 outbreak, emphasizing the vulnerability of caregivers to infection.

Finally, Limitations such as the potential for human errors in care delivery, challenges in integrating caregiving with broader healthcare systems, and conflicts with family members highlight the drawbacks of human caregiving (Reinhard et al., 2019).

To address the high costs and inefficiencies associated with traditional human caregiving systems, remote patient caregiving systems have emerged as a promising solution. These innovative approaches leverage technology to deliver care, providing a scalable and efficient means of supporting patients from a distance and addressing some of the limitations of conventional caregiving models (Chi & Demiris, 2015).

THE ADVANTAGES AND LIMITATIONS OF REMOTE PATIENT CAREGIVING

Remote patient caregiving, also known as telehealth or telemedicine, refers to delivering healthcare services through digital information and communication technologies (Dorsey & Topol, 2020). These digital systems enable healthcare providers to monitor, diagnose, and treat patients remotely, often allowing individuals to receive care in the comfort of their own homes.

When compared with employing a human caregiver, remote patient care systems offer several considerable advantages:

First, remote patient care systems are generally considered cost-efficient, offering a more affordable option for many families compared to traditional caregiving arrangements. This cost-effectiveness is particularly evident in long-term care scenarios and for managing chronic conditions, as highlighted by Eze et al. (2020).

Second, remote caregiving systems provide consistent and continuous operation, making them valuable for delivering round-the-clock care. This uninterrupted availability, as highlighted by Kichloo et al. (2020), is particularly crucial for patients requiring constant monitoring and support during the COVID-19 pandemic.

Third, these systems systematically manage digital patient data, reducing the likelihood of human errors or oversight and streamlining the process of sharing and analyzing health information. The digital nature of these systems allows for more accurate record-keeping and easier access to patient histories (Campanella et al., 2016; Kruse et al., 2018).

Fourth, regarding quality, while the care provided by human caregivers can vary depending on their training and experience, remote systems can contribute to more consistent service delivery by relying on standardized protocols during implementation (Monaghesh & Hajizadeh, 2020).

Fifth, safety is a key advantage of remote systems, especially during crises such as pandemics, as they significantly mitigate the risk of infection associated with in-person interactions (Bokolo, 2021). The COVID-19 pandemic has particularly highlighted this benefit of telehealth services.

Sixth, these systems empower patients by giving them greater control over their care and enhancing their independence, particularly for individuals who might otherwise rely heavily on human caregivers (Almathami et al., 2020). This empowerment, as supported by Almathami et al. (2020), can lead to improved patient engagement and better health outcomes.

Seventh, remote monitoring may enhance the closeness between patients and providers through increased frequency and quality of interactions, a concept known as digital intimacy (Duffy et al., 2023). This increased communication can lead to better patient-provider relationships and improved care coordination.

Finally, by automating routine tasks, remote care systems alleviate the workload on human caregivers, reducing the risk of caregiver burnout (Eze et al., 2020). This automation allows healthcare providers to focus on more complex aspects of patient care.

Despite these advantages, remote patient care systems have notable limitations:

The effectiveness of remote patient care depends on patients' access to technology and their ability to use it effectively. Challenges related to digital access can indirectly contribute to healthcare disparities if not properly addressed (Piras & Miele, 2019).

Furthermore, remote interactions can cause confusion, particularly among older patients with hearing impairments or cognitive challenges (Lam et al., 2020). This limitation highlights the need for user-friendly interfaces and additional support for certain patient populations.

In addition, certain health conditions require physical examinations or in-person procedures, which remote systems cannot provide (Bokolo, 2021). This limitation underscores the continued importance of in-person healthcare alongside telehealth services.

Moreover, the absence of direct interpersonal interactions in telehealth settings can lead to communication challenges, particularly during urgent situations, emphasizing the need for clear protocols to mitigate potential misinterpretations (Piras & Miele, 2019). Zhang et al. (2020) further highlight technical, usability, and organizational challenges in prehospital communication technologies, underscoring the importance of user-centered design approaches to enhance communication effectiveness in emergency settings.

Finally, and most critically, providing care to patients who are physically immobile, bedridden, or need physical assistance or support remains a significant challenge for remote systems (Kichloo et al., 2020). This limitation underscores the ongoing necessity of in-person care for specific patient populations.

In conclusion, while remote patient caregiving offers numerous advantages in terms of cost-effectiveness, consistency, data management, and patient empowerment, it also faces challenges related to technology access, the need for physical examinations, and limitations in providing hands-on care. Addressing these limitations will be crucial as telehealth evolves to maximize its potential in healthcare delivery.

ROBOT-SUPPORTED REMOTE CAREGIVING

The success of remote patient care is constrained by technological accessibility and user proficiency. Certain conditions require in-person examinations or procedures that cannot be conducted remotely. Furthermore, the absence of face-to-face interaction can lead to communication issues, particularly during emergencies. Most critically, providing care for immobile or bedridden patients or those requiring physical assistance through remote systems remains a significant challenge. This work explores the main limitations of remote caregiving systems and discusses how robotics can help mitigate these challenges.

Lack of Physical Presence

In traditional remote caregiving systems, the absence of physical presence poses significant challenges, making it difficult to provide hands-on care, such as assisting with mobility, administering medication, or monitoring specific clinical symptoms. However, robots equipped with cameras and sensors offer a promising solution by enabling physical interaction with patients. These robots can assist with tasks such as lifting, administering medication, or acquiring vital sign data, all under the remote supervision of healthcare providers (Buhtz et al., 2018).

Communication Challenges

Remote communication often leads to misunderstandings, particularly among elderly patients who may have hearing or cognitive impairments. To address this challenge, robots equipped with natural language processing (NLP) and artificial intelligence (AI) algorithms can effectively enhance communication with patients. These robots can translate verbal instructions into simple visual cues or adapt their communication methods using various sensory inputs to accommodate the specific needs of the patient (Abdi et al., 2018).

Emergency Situations

In critical situations, immediate physical intervention may be necessary, which remote caregivers are unable to provide. Advanced robots offer a solution by performing basic emergency procedures under the remote guidance of healthcare professionals, such as administering, cardiopulmonary resuscitation or emergency medications. Additionally, these robots can send emergency alerts to telemedicine centers, ensuring timely response and coordination during urgent scenarios (Tsui et al., 2008).

Emotional Connection

Establishing a human connection remotely can be challenging, often leading to feelings of isolation or neglect for patients. While robots cannot fully replicate human empathy, they can integrate interactive features to enhance patients' emotional well-being. PARO, a therapeutic robot designed as a baby harp seal, exemplifies this approach. Equipped with advanced sensory technology, PARO can respond to touch, sound, and environmental cues, mimicking the behavior of a live animal. These features allow PARO to foster engagement and reduce loneliness in various healthcare settings, particularly for elderly patients with dementia. Studies have shown that interacting with PARO can improve mood, decrease stress, and enhance social interaction among patients in nursing homes (Jøranson et al., 2015; Moyle et al., 2018).

Technical Difficulties

Remote caregiving systems rely heavily on internet connectivity, device functionality, and other technological components, making them vulnerable to failures. Robots equipped with offline functionality can address this issue by continuing to provide essential care services during network outages. Additionally, built-in diagnostics and repair capabilities can help mitigate technical difficulties and ensure consistent system performance.

Robots equipped with cameras, sensors, AI, and NLP technologies present a promising solution to the limitations of current remote caregiving systems. They can assist with various tasks, enhance communication, manage emergencies, provide companionship, and ensure consistent care even in the face of technical challenges. However, transitioning to robot-supported caregiving introduces new challenges, including ethical considerations, cost barriers, and the need for widespread technological literacy, which require careful and ongoing evaluation (Papadopoulos et al., 2020).

ADDRESSING THE LIMITATIONS OF ROBOT-SUPPORTED REMOTE CAREGIVING SYSTEMS

Incorporating robots into remote patient care systems has the potential to create comprehensive healthcare models that significantly enhance patient monitoring and care. However, addressing the challenges of integrating robotics into caregiving systems requires technological innovation and thoughtful policy-making. Before deploying robots in caregiving, it is essential to critically evaluate the characteristics of such systems to determine whether the perceived drawbacks represent legitimate disadvantages that could undermine their effectiveness. Once identified, strategies must be devised to mitigate these issues, ensuring that this advanced technology improves rather than detracts from care quality.

Lack of Personal Interaction

The absence of personal interaction in robotic caregiving settings is a notable limitation, as effective caregiving often requires a human touch that robots cannot yet fully replicate. However, advancements in AI and affective computing offer promising solutions. Researchers in this field are developing systems capable of recognizing, interpreting, and responding to human emotions, which may lead to more empathetic and responsive robotic caregivers (Abdollahi et al., 2023).

Furthermore, trust plays a crucial role in caregiving relationships. Interestingly, humans often trust machines more than other people because robots, unlike humans, do not betray, act against instructions, or exhibit dishonesty. While genuine human relationships are vital, robots' predictable behavior and reliability can foster a sense of security. As robots become increasingly capable of mimicking human emotions and expressions, they may provide a form of humanlike care that enhances trust and emotional comfort for patients (Papadopoulos et al., 2020).

Cost and Accessibility

The high cost of robotic caregivers is a significant barrier to widespread adoption. However, technological advancements are expected to lower manufacturing expenses, making robots more affordable over time. Government subsidies, insurance coverage, and partnerships with community organizations or telecommunication companies could also improve access to these systems. Additionally, subscription services for caregiving robots offer a practical solution by reducing financial burdens through fixed monthly fees, including maintenance and upgrades, ensuring budget predictability (Eggleston et al., 2021).

Robotic caregivers also provide consistent quality of care, as they can be programmed to perform standardized tasks and updated with new software, reducing variability in service. This contrasts with the skills and expertise of human caregivers, which can vary widely and potentially lead to additional costs in finding suitable personnel. Furthermore, robots are available 24/7, eliminating the need for shift changes, breaks, or replacements, thereby ensuring uninterrupted care. The scalability of robotic services further enhances their utility, allowing flexibility to adjust care levels without the logistical challenges of recruiting or training human staff (Abdi et al., 2018).

Technological Limitations

Technological limitations currently constrain robots' functionality, but ongoing advancements are expected to enhance their capabilities. Improvements in machine learning algorithms could enable robots to handle unexpected situations more effectively. Regular software updates and proactive maintenance will also ensure that robots remain functional and adaptable, allowing them to meet a broader range of caregiving needs over time.

Dependence on Infrastructure

Robotic caregiving systems face critical limitations due to their reliance on robust infrastructure, including stable internet connectivity and reliable power sources. While alternative solutions like satellite internet services and portable power sources can help extend connectivity and power to remote or underserved areas, a more robust and sustainable approach involves equipping these systems with on-device AI. On-device AI addresses the challenge of unreliable networks by enabling robots to operate independently without constant internet connectivity. Additionally, using renewable energy sources such as solar power and harnessing Energy Storage Systems provides a sustainable and reliable energy supply. This integrated approach ensures that robotic caregiving systems remain operational even in remote areas, reducing dependence on external infrastructure while maintaining high efficiency and reliability.

Incorporating robots into remote patient care systems presents an opportunity to enhance healthcare models by improving monitoring and care delivery. However, the challenges associated with personal interaction, cost, accessibility, technological limitations, and infrastructure dependency must be carefully addressed. Advancements in AI and affective computing may mitigate the lack of personal interaction by creating robots that can recognize and respond to human emotions, fostering trust and emotional well-being. Cost barriers can be overcome through technological progress, government support, and innovative service models such as rentals. Addressing technological and infrastructure limitations through regular updates and alternative connectivity solutions will ensure that robotic systems are effective, reliable, and accessible. By thoroughly evaluating and addressing these limitations, robotic caregiving systems can be optimized to enhance the quality of care and support provided to patients.

FOUR COMPONENTS OF ROBOT-SUPPORTED REMOTE CAREGIVING SYSTEMS

In the realm of healthcare and caregiving, the integration of technology offers immense potential to enhance the quality, accessibility, and efficiency of care provided to individuals in need. An ideal holistic remote caregiving system requires the seamless integration of four essential components: android-based caregiving robots, advanced wearable biosensors, telemedicine centers, and dedicated urgent response teams, each contributing to a comprehensive solution designed to address the multifaceted needs of individuals, particularly those in remote or underserved regions (Ramasamy et al., 2022).

Android-based caregiving robots serve as the cornerstone of this system, offering personalized assistance and companionship while performing tasks ranging from basic household chores to more complex healthcare-related functions, with AI enabling them to adapt to individual needs and improve the overall caregiving experience (Loza-Matovelle et al., 2019). Advanced wearable biosensors complement these efforts by continuously monitoring the health status of individuals and collecting real-time physiological data such as heart rate, oxygen saturation, and glucose levels, thereby enabling proactive health management, preventing crises, and improving the management of chronic conditions (Zhang et al., 2021).

Meanwhile, telemedicine centers, equipped with cutting-edge technology, facilitate virtual consultations, diagnoses, and treatments, serving as the communication hub between caregivers, patients, and healthcare providers to ensure seamless access to medical expertise without the need for physical travel (Hashiguchi, 2020). Finally, dedicated urgent response teams act as a critical link between remote patients and emergency healthcare services, providing immediate care during emergencies and ensuring timely interventions when robotic systems or telemedicine support prove insufficient, thereby addressing life-threatening situations promptly and effectively (Unitek EMT, 2023).

Together, these four components form an integrated and comprehensive caregiving system capable of significantly improving the accessibility, quality, and efficiency of remote caregiving, transforming it from a theoretical concept into a practical, scalable reality that brings meaningful care to individuals regardless of their location (Miranda et al., 2023) (Fig. 1).

ANDROID-BASED CAREGIVING ROBOTS

Developing a caregiving robot based on an android shape (Tesla, 2023) is not merely an aesthetic choice but also a deliberate and logical decision grounded in human interaction needs, functional requirements, social acceptance, and cultural considerations.

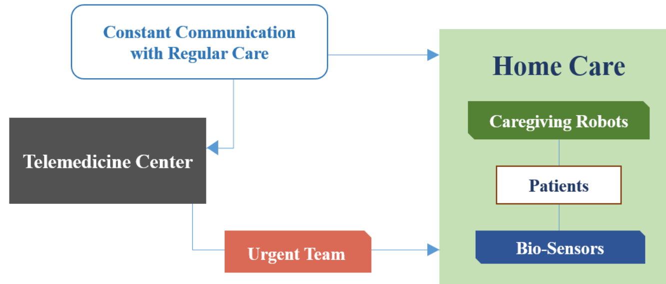

Fig. 1. Four components of robot-supported remote caregiving systems. This diagram depicts a coordinated remote healthcare model in which four interconnected components are telemedicine centers, urgent response teams, caregiving robots, and biosensors. The system supports continuous patient monitoring, timely emergency interventions, and seamless communication between home-based patients and medical professionals, thereby enabling comprehensive robot-supported care.

Functional Mimicry

The humanlike shape of android robots enables them to use tools, open doors, and perform other tasks in a manner similar to human caregivers. This design facilitates seamless integration into human-centered environments, such as homes and hospitals, without requiring significant modifications to the existing infrastructure. Moreover, android robots can be customized to meet specific patient needs and perform specialized caregiving tasks based on individual preferences and requirements (Mukai et al., 2008).

Complex Task Handling

Equipped with two arms, hands, and the ability to display facial expressions, android robots can handle complex tasks, including lifting, personal grooming, and conveying empathy through facial gestures. These capabilities are crucial for providing personal care, especially in sensitive or intimate scenarios. However, developers must carefully address the "uncanny valley" phenomenon to ensure that the robot's appearance and behavior remain comforting rather than unsettling (MacDorman & Ishiguro, 2006).

Humanlike Interaction Capability

The resemblance of an android robot to the human form can make interactions more intuitive and comfortable for patients (Hille et al., 2023). This familiarity helps reduce anxiety and fosters a stronger emotional connection between the robot and the patient, which is particularly beneficial in long-term care settings where trust and companionship are critical.

Social Acceptance

The humanlike appearance of android robots enhances their social acceptance, particularly among individuals unaccustomed to interacting with robots (MacDorman & Ishiguro, 2006). An android shape is often perceived as less intimidating and more approachable than other robotic forms, which can help build trust, encourage cooperation, and ease the adoption of robotic assistance in caregiving environments (MacDorman & Ishiguro, 2006).

In conclusion, the development of caregiving robots with android shapes marks a significant advancement in the integration of technology with human care (Mukai et al., 2008; MacDorman & Ishiguro, 2006). By combining functional mimicry with the ability to handle complex tasks, android robots provide a practical solution to many caregiving challenges in diverse settings (Mukai et al., 2008). Their humanlike appearance not only simplifies integration into human-centered environments but also improves social acceptance and emotional connectivity with patients (MacDorman & Ishiguro, 2006). While the challenges posed by the uncanny valley must be carefully managed, the overall benefits of android-shaped caregiving robots, ranging from improving patient care to easing the burden on human caregivers and advancing robotic capabilities, are undeniable (MacDorman & Ishiguro, 2006). This innovative approach highlights the importance of designing robots that are not only functional but also culturally sensitive and socially compatible with the humans they are intended to serve (Mukai et al., 2008).

BIOSENSORS BASED ON WEARABLE DEVICE TECHNOLOGY

Wearable biosensors represent a revolutionary advancement in healthcare, particularly within robot-supported caregiving systems. These devices are transforming the delivery of healthcare services, especially in home-based care settings, by enabling continuous, personalized, and proactive health monitoring (Kim et al., 2019). The integration of these technologies offers significant potential to enhance patient outcomes, reduce healthcare costs, and increase accessibility and convenience.

Continuous Monitoring Capability

Wearable devices equipped with biosensors can continuously monitor a wide range of vital signs and physiological parameters. These include heart rate, blood pressure, body temperature, and even more complex biomarkers found in bodily fluids such as sweat or interstitial fluid (Sempionatto et al., 2021; Tehrani et al., 2022). This real-time tracking generates valuable data, allowing both patients and healthcare providers, including caregiving robots, to detect potential health issues before they escalate into critical problems.

Early Intervention and Personalized Care

By identifying abnormalities at an early stage, wearable biosensors facilitate prompt interventions, often preventing conditions from worsening. This proactive approach enables more effective treatment and reduces the likelihood of hospitalization (Gao et al., 2016; Tehrani et al., 2022). Moreover, these devices can be customized to address the specific needs and conditions of individual patients, enabling tailored monitoring and care plans. Advances such as wearable microneedle arrays and epidermal patches allow the continuous and simultaneous monitoring of multiple biomarkers in interstitial fluid and bodily surfaces (Sempionatto et al., 2021; Tehrani et al., 2022). The data collected by these devices informs treatment decisions that consider a patient's unique physiology and medical history, thus improving the precision and efficacy of care (Sempionatto et al., 2021; Tehrani et al., 2022).

Compliance and Medication Adherence

Wearable devices also support medication management by reminding patients about their schedules and monitoring adherence to prescribed treatments. This capability is especially critical for managing chronic conditions effectively and ensuring optimal therapeutic outcomes (Hoogenbosch et al., 2018; Morrissey et al., 2018). These devices can significantly improve patient compliance with treatment regimens by providing real-time feedback and alerts.

Patient Empowerment and Data Integration

By granting patients access to their health data, wearable devices encourage active participation in health management. Empowered patients are more likely to adopt healthier lifestyles and achieve better outcomes, fostering a sense of ownership over their well-being (Haddadi et al., 2015). Furthermore, the information collected by wearable devices can be seamlessly integrated into electronic health records, providing healthcare providers with a comprehensive and longitudinal view of a patient's health. This integration is vital for long-term care management and facilitates collaboration among different healthcare providers to deliver coordinated care (Haddadi et al., 2015).

Challenges and Future Prospects

While the potential benefits of wearable biosensors are immense, their implementation requires careful attention to several factors. These include optimizing device design for comfort and usability, ensuring data security and privacy, and integrating these technologies with existing healthcare systems (Kaur et al., 2022; Liu et al., 2018). Additionally, the accuracy and reliability of these devices must be continuously improved to ensure their effectiveness in clinical settings (Liu et al., 2018). Looking ahead, the future of wearable biosensors in healthcare is promising. Advancements in materials science, such as the development of flexible and stretchable electronics, are enabling the creation of more comfortable and unobtrusive devices (Bariya et al., 2018).

TELEMEDICINE CENTERS

The practical implementation of robot-supported remote caregiving systems hinges on establishing a telemedicine center that functions as the central hub for coordination, communication, and data management. As the linchpin of these systems, telemedicine centers enable the delivery of comprehensive and efficient healthcare services by bridging the gap between advanced robotics and patient care. This section outlines the key functions and requirements of a telemedicine center, emphasizing its role in ensuring personalized, efficient, and cost-effective caregiving.

Key Functions

A telemedicine center must perform several vital functions to support robot-assisted caregiving systems:

Classification of Care Levels

By categorizing patients into different grades based on their specific needs, telemedicine centers can deliver more efficient and individualized care. This classification determines the level of technological intervention required, including the functionalities that caregiving robots must provide for each patient.

Remote Monitoring

Data collected by caregiving robots and biosensors, such as vital signs, movement patterns, or changes in daily routines, is transmitted to the telemedicine center for real-time analysis, enabling early detection of health issues.

Two-Way Communication

Real-time communication between healthcare providers and patients is facilitated through the robot's interface, ensuring seamless interaction and continuous support for patients.

Remote Control and Intervention

Healthcare professionals can remotely control robots to perform specific actions or adjustments as needed, providing immediate assistance without requiring physical presence.

Data Analysis and Reporting

Patient data is processed to identify health trends, potential risks, and necessary interventions, supporting proactive and preventive healthcare management.

Emergency Response

Protocols are in place to dispatch emergency services based on incoming data or during consultations, ensuring rapid and timely intervention in critical situations.

Software Maintenance and Learning

Telemedicine centers are responsible for overseeing software updates, troubleshooting technical issues, and analyzing data from robot-patient interactions to refine care protocols and improve system performance.

Training and Support

Patients and healthcare staff receive training on how to interact with and effectively utilize robots, ensuring the optimal functionality and benefits of the caregiving system.

Essential Requirements

To support these functions, telemedicine centers must meet specific requirements to ensure continuous, high-quality care:

Reliable Connectivity

Stable and high-speed internet connections are essential for real-time data transmission and communication.

Interoperability

Systems must be compatible with various devices and platforms, adhering to universal data standards and using open APIs, application programming interfaces, to enable seamless integration and scalability.

Qualified Personnel

Healthcare professionals must be trained in both medical procedures and the technical aspects of robotic systems.

User-Friendly Interfaces

The systems must be intuitive and easy to use for healthcare providers and patients alike.

Backup Systems

Robust backup systems, including emergency power supplies and redundant data storage, ensure uninterrupted operations during outages or failures.

Regular Training and Updates

Continuous staff training and periodic protocol updates are necessary to keep pace with technological advancements.

Physical Infrastructure

Adequate server capacity, multiple communication channels (e.g., video conferencing, instant messaging), and emergency power systems form the backbone of telemedicine centers, ensuring reliable service delivery.

Data Security and Privacy

Ensuring the security and privacy of sensitive patient information is paramount in telemedicine centers. Strong encryption methods, such as advanced encryption standards and secure socket layer protocols, must be employed alongside strict adherence to healthcare regulations. Additionally, blockchain technology can be leveraged to enhance data transmission security by providing a decentralized and tamper-proof ledger for managing patient information, ensuring transparency, and preventing unauthorized access. On-device AI in robotics further strengthens privacy by processing sensitive data locally on the robot itself, reducing the need for data transmission to external servers and minimizing exposure to potential breaches. This dual-layer approach not only protects patient data but also builds trust in the caregiving system by prioritizing privacy and compliance with regulatory standards.

Scalability

The infrastructure must be designed to handle increasing data and communication demands as robot-supported caregiving expands.

Regulatory Compliance

The center must adhere to all relevant local and national regulations governing telemedicine and patient care.

Economic Efficiency

Telemedicine centers provide significant economic advantages by centralizing operations and optimizing resources, including equipment, infrastructure, and medical expertise. This centralization reduces redundancies and minimizes administrative overhead (Rosa & Fleming, 2023). Additionally, the automation of routine tasks enables healthcare professionals to concentrate on critical responsibilities, thereby improving efficiency and potentially reducing labor costs (Sayani et al., 2019).

As robot-supported caregiving systems scale, the cost per unit of care delivery decreases, creating economies of scale. Although initial investments may be high, the long-term cost savings for healthcare institutions and patients make these systems financially sustainable (Rosa & Fleming, 2023). Centralized systems also reduce operational inefficiencies, further driving down costs and enhancing accessibility (Sayani et al., 2019).

In conclusion, telemedicine centers are the cornerstone of robot-supported remote caregiving systems, integrating essential functions such as patient classification, remote monitoring, communication, data analysis, emergency response, and software maintenance. To support these capabilities, centers must meet stringent requirements for connectivity, interoperability, qualified personnel, data security, scalability, and infrastructure. By optimizing resources and leveraging economies of scale, these systems offer a cost-effective and scalable solution to modern healthcare challenges (Rosa & Fleming, 2023; Sayani et al., 2019).

URGENT CARE TEAMS

In robot-supported remote caregiving, advanced technologies enable constant monitoring and data transmission, but they face limitations when immediate, hands-on medical intervention is required during emergencies. While robots provide efficiency and precision, human judgment and intuition are irreplaceable in unpredictable situations. Furthermore, the assurance that rapid human responses are available during crises offers immeasurable psychological comfort to patients and their loved ones, making urgent care teams a critical component of such caregiving systems.

Composition of Urgent Care Teams

Medical Experts

Urgent care teams include emergency physicians and paramedics equipped with essential medical instruments and medications to stabilize or treat patients immediately. These teams can also utilize stretchers or ambulances for patient transport, reducing physical fatigue and ensuring comprehensive medical support.

Technical Personnel

Given the integration of robots in caregiving, the team includes technical experts experienced in troubleshooting or interpreting issues with robotic systems to ensure seamless coordination and optimal system functionality.

Urban Air Mobility (UAM) Operators

UAM operators play a pivotal role in controlling advanced aerial systems, ensuring timely and secure transport of medical supplies, personnel, or even patients to and from critical locations.

Roles of the Urgent Care Team and Urban Air Mobility (UAM) Systems

Rapid Response

Time is critical in emergencies, and UAM systems provide a solution by bypassing transportation barriers such as traffic or difficult terrain, ensuring faster response times to reach patients in need.

Initial Aid Via UAM Systems

Before the full care team arrives, UAM systems can deliver essential first-aid supplies or relay visual data to the telemedicine center, enabling healthcare professionals to assess the situation remotely and prepare for effective intervention.

Collaboration with On-Site Robots

Upon arrival, the urgent care team collaborates with caregiving robots, utilizing their diagnostic data and tools to deliver precise and immediate care. This integration bridges the gap between robotic efficiency and human expertise.

Real-Time Data Collection

Advanced sensors in UAM systems provide real-time updates, enhancing situational awareness for both telemedicine center staff and the urgent care team. This continuous data flow supports accurate decision-making and intervention.

Evacuation Facilitation

UAM systems equipped for patient transport can evacuate individuals to medical facilities when ground transportation is impractical, ensuring timely access to advanced medical care.

Manned-Unmanned Teaming (MUM-T)

MUM-T integrates manned systems, such as aircraft, with unmanned systems, such as unmanned air vehicles (UAV), to achieve mission objectives collaboratively (Yi, 2016). In emergencies, UAVs can autonomously transport additional supplies, exchange sensor data, and provide logistical support while coordinating seamlessly with manned aircraft. This strategic approach enhances operational flexibility, accelerates response times, and ensures efficient supply chains in healthcare scenarios.

A Synergized Approach to Emergency Response

In the context of robot-supported caregiving, the integration of human expertise with cutting-edge technology offers a comprehensive approach to emergency response. Robots excel in monitoring and data transmission, but human intuition and immediate intervention are essential during crises. The composition of urgent care teams, comprising medical experts, technical personnel, and UAM operators, ensures a rapid and effective response. Leveraging UAM systems for swift transportation and initial aid, combined with man and MUM-T strategies for coordinated logistics, significantly enhances the efficiency and capabilities of these teams.

This synergy between human and robotic systems, supported by advanced UAM technologies and MUM-T frameworks, accelerates emergency response times while providing psychological reassurance to patients and their families. Ultimately, this integrated approach exemplifies the potential of combining human medical expertise with advanced technology to improve patient care and emergency outcomes in robot-supported caregiving environments.

KEY CONSIDERATIONS FOR ROBOT-SUPPORTED CAREGIVING SYSTEMS

Robot-supported caregiving systems have the potential to revolutionize patient support and management, offering enhanced quality of life, improved efficiency in care delivery, and valuable support for healthcare professionals. These systems are designed to assist individuals in their daily lives, particularly those requiring continuous care, while addressing their medical, emotional, and social needs. However, integrating advanced technology into the profoundly personal realm of caregiving introduces significant ethical, practical, and technological challenges. Several critical considerations must be addressed to ensure these systems deliver genuine benefits without compromising human values.

Needs and Preferences

The design and development of robot-supported caregiving systems must prioritize care recipients' specific needs and preferences. This includes accommodating their medical requirements, assisting with daily routines, and respecting personal care preferences to create a system that aligns with their individual lifestyles and promotes well-being.

Integration with Existing Healthcare Systems

Seamless integration with existing healthcare infrastructure, such as electronic medical record systems, healthcare providers, and other related platforms, is essential to ensure continuity of care and effective collaboration among stakeholders.

Cost Effectiveness

To maximize accessibility, caregiving systems must be designed to deliver high-quality care without being prohibitively expensive, particularly for long-term use. Cost-effectiveness ensures that the benefits of such systems can reach a broader population while reducing the financial burden on individuals and healthcare institutions.

Customization and Scalability

The ability to customize systems to meet individual needs and scale them to accommodate varying levels of care is crucial. Whether addressing the needs of a single patient or expanding the system for broader healthcare applications, scalability, and adaptability are vital for ensuring long-term utility.

Emotional Interaction

For systems that interact directly with care recipients, the ability to recognize and respond to emotional cues is essential. Humanlike interactions foster trust, reduce feelings of isolation, and enhance the emotional well-being of patients, making this a critical consideration for effective caregiving.

Cultural Sensitivity

Caregiving systems must be designed with cultural norms and values in mind to ensure they are respectful and appropriate for diverse populations. Cultural sensitivity enhances acceptance and usability, fostering greater trust among users from various backgrounds.

Public Acceptance

Gaining public acceptance is essential for the widespread adoption of robot-supported caregiving systems. This can be achieved through public education campaigns that highlight the benefits, address concerns about safety and privacy, and emphasize the human-centric nature of these technologies.

Environmental Considerations

The environmental impact of caregiving systems, including energy consumption and the materials used in their production, must be considered. Sustainable practices in design, manufacturing, and operation are essential to minimize ecological footprints and ensure long-term viability.

Integrating robotic systems into healthcare represents a transformative step forward in meeting the diverse needs of individuals requiring care. By addressing considerations such as individual needs and preferences, integration with existing healthcare systems, cost-effectiveness, customization, emotional interaction, cultural sensitivity, public acceptance, and environmental sustainability, these technologies can be deployed in a manner that is both humane and sustainable.

As we embrace this technological revolution, it is imperative to strike a careful balance between innovation and ethics, ensuring that caregiving systems address practical challenges while enriching the lives of those they serve. By doing so, robot-supported caregiving can not only improve care delivery but also foster a deeper connection between technology and humanity, ultimately advancing healthcare in a meaningful and responsible way.

THE NEAR FUTURE

In an era where technology is becoming indispensable in healthcare, integrating robot-supported caregiving systems represents a transformative opportunity to enhance the accessibility, quality, and efficiency of care. These systems, meticulously designed to address individuals' specific needs and preferences, aim to bridge gaps in healthcare delivery through advanced robotics, telemedicine, and wearable biosensors. However, the journey toward widespread adoption requires careful navigation of ethical considerations, cultural sensitivities, environmental impacts, and societal acceptance. By addressing these complexities, technological advancements can meet practical needs and enrich the human experience, fostering a more inclusive, efficient, and compassionate healthcare landscape.

If robots are successfully integrated into caregiving services, further advancements are likely, such as incorporating domestic functions to actively assist patients and adding features akin to assistants or butlers. Specialized nursing robots may also emerge, designed to cater to highly specific medical and personal care requirements. As future generations grow up alongside these robots, their presence will likely be perceived as natural and indispensable, much like how smartphones are viewed today, as though robots have always been integral to caregiving.

In our aging society, deploying robot-supported caregiving systems stands out as a groundbreaking solution with profound socioeconomic implications. These systems alleviate the societal burden of elderly care while offering significant economic benefits. As the demographic shift toward an older population accelerates, the urgent need for innovative solutions becomes increasingly clear, underscoring the importance of safeguarding the well-being of older individuals while ensuring the efficient use of societal resources. From an economic perspective, further research is essential to unlock the full potential of these systems. This includes exploring direct and indirect cost savings, such as reductions in healthcare infrastructure strain, decreased reliance on traditional caregiving resources, and relief on families' personal finances. Additionally, understanding the economic feasibility of scaling these technologies across diverse socioeconomic groups is critical to ensuring equitable access and widespread adoption.

The long-term integration of robot-assisted care into national healthcare systems demands thorough investigation. This includes examining potential shifts in employment patterns within the caregiving industry and assessing the broader economic impacts of improved elderly health outcomes. Comparative research on the cost-effectiveness of robot-assisted systems versus conventional care methods will provide valuable insights for policymakers, healthcare providers, and investors, guiding future strategies for sustainable implementation. By delving into the economic, societal, and practical implications of robot-supported caregiving systems, we can pave the way for a more resilient and inclusive approach to elderly care.

These systems have the potential to redefine caregiving by offering personalized, efficient, and scalable solutions that address the challenges posed by an aging population. Balancing innovation with ethics will be pivotal as we embrace this technological revolution. By prioritizing human values while leveraging advanced technologies, we can create a future where caregiving systems not only meet the practical demands of aging societies but also enhance the quality of life for individuals and communities. In doing so, we contribute to building a more sustainable, compassionate, and forward-thinking healthcare framework that adapts to the evolving needs of our global population.

"Nothing impossible!
The moment just has not yet come."

REFERENCES

Abdi, J., Al-Hindawi, A., Ng, T., & Vizcaychipi, M. P. (2018). Scoping review on the use of socially assistive robot technology in elderly care. *BMJ Open*, *8*(2), e018815.

Abdollahi, H., Mahoor, M. H., Zandie, R., Siewierski, J., & Qualls, S. H. (2023). Artificial emotional intelligence in socially assistive robots for older adults: A pilot study. *IEEE Transactions on Affective Computing*, *14*(3), 2020-2032.

Almathami, H. K. Y., Win, K. T., & Vlahu-Gjorgievska, E. (2020). Barriers and facilitators that influence telemedicine-based, real-time, online consultation at patients' homes: Systematic literature review. *Journal of Medical Internet Research*, *22*(2), e16407.

Ansah, J. P., & Chiu, C. T. (2023). Projecting the chronic disease burden among the adult population in the United States using a multi-state population model. *Frontiers in Public Health*, *10*, 1082183.

Babaei, S., & Taleghani, F. (2019). Compassionate care challenges and barriers in clinical nurses: A qualitative study. *Iranian Journal of Nursing and Midwifery Research*, *24*(3), 213-219.

Bariya, M., Nyein, H. Y. Y, & Javey, A. (2018). Wearable sweat sensors. *Nature Electronics*, *1*(3), 160-171.

Bokolo, A. J. (2021). Exploring the adoption of telemedicine and virtual software for care of outpatients during and after COVID-19 pandemic. *Irish Journal of Medical Science*, *190*(1), 1-10.

Buhtz, C., Paulicke, D., Hirt, J., Schwarz, K., Stoevesandt, D., Meyer, G., & Jahn, P. (2018). Robotic systems for care at home: A scoping review. *Zeitschrift für Evidenz, Fortbildung und Qualität im Gesundheitswesen*, *137*, 1-8.

Campanella, P., Lovato, E., Marone, C., Fallacara, L., Mancuso, A., Ricciardi, W., & Specchia, M. L. (2016). The impact of electronic health records on healthcare quality: A systematic review and meta-analysis. *European Journal of Public Health*, *26*(1), 60-64.

Carr, D., & Utz, R. L. (2020). Families in later life: A decade in review. *Journal of Marriage and Family*, *82*(1), 346-363.

Chapman, S. A., Wagner, L., & Bates, T. (2023). *Rural America faces major shortage of personal care aides*. https://healthforce.ucsf.edu/news/rural-america-faces-major-shortage-personal-care-aides

Chi, N. C., & Demiris, G. (2015). A systematic review of telehealth tools and interventions to support family caregivers. *Journal of Telemedicine and Telecare*, *21*(1), 37-44.

Crimmins, E. M. (2015). Lifespan and healthspan: Past, present, and promise. *The Gerontologist*, *55*(6), 901-911.

Dorsey, E. R., & Topol, E. J. (2020). Telemedicine 2020 and the next decade. *The Lancet*, *395*(10227), 859.

Duffy, L. V., Evans, R., Bennett, V., Hady, J. M., & Palaniappan, P. (2023). Therapeutic relational connection in telehealth: Concept analysis. *Journal of Medical Internet Research*, 25(1), e43303.

Eggleston, K., Lee, Y. S., & Iizuka, T. (2021). *Robots and labor in the service sector: Evidence from nursing homes* (Working Paper No. 28322). National Bureau of Economic Research (NBER).

Eze, N. D., Mateus, C., & Hashiguchi, T. C. O. (2020). Telemedicine in the OECD: An umbrella review of clinical and cost-effectiveness, patient experience and implementation. *PLOS ONE*, *15*(8), e0237585.

Gao, W., Emaminejad, S., Nyein, H. Y. Y., Challa, S., Chen, K., Peck, A., Fahad, H. M., Ota, H., Shiraki, H., Kiriya, D., Lien, D. H., Brooks, G. A., Davis, R. W., & Javey, A. (2016). Fully integrated wearable sensor arrays for multiplexed in situ perspiration analysis. *Nature*, *529*(7587), 509-514.

Grand View Research. (2023). *Home healthcare market size, share & trends analysis report by component (equipment, services), by indication (cardiovascular disorder & hypertension, diabetes & kidney disorders), by region, and segment forecasts, 2024–2030*. https://www.grandviewresearch.

com/industry-analysis/home-healthcare-industry

Haddadi, H., Ofli, F., Mejova, Y., Weber, I., & Srivastava, J. (2015). *360-degree quantified self*. 2015 International Conference on Healthcare Informatics (pp. 587-592). Dallas, TX.

Hashiguchi, T. O. (2020). *Bringing health care to the patient: An overview of the use of telemedicine in OECD countries* (OECD Health Working Papers No. 116). OECD.

Hille, N., Bürvenich, B., Carros, F., Manavi, M., Wieching, R., Matsumoto, Y., & Wulf, V. (2023). The effects of Android robots displaying emotion on humans: Interactions between older adults and Android robots. *arXiv preprint arXiv:2303.13624*.

Hoogenbosch, B., Postma, J., de Man-van Ginkel, J. M., Tiemessen, N. A., van Delden, J. J., & van Os-Medendorp, H. (2018). Use and the users of a patient portal: Cross-sectional study. *Journal of Medical Internet Research*, *20*(9), e262.

IBISWorld. (2023). *Home care providers in the US - Market research report (2015–2030)*. https://www.ibisworld.com/united-states/market-research-reports/home-care-providers-industry/

Jøranson, N., Pedersen, I., Mork Rokstad, A. M., & Ihlebæk, C. (2015). Effects on symptoms of agitation and depression in persons with dementia participating in robot-assisted activity: A cluster-randomized controlled trial. *Journal of the American Medical Directors Association*, *16*(10), 867-873.

Karimi Moghaddam, Z., Rostami, M., Zeraatchi, A., Bytamar, J. M., Omid, S., & Zenozian, S. (2023). Caregiving burden, depression, and anxiety among family caregivers of patients with cancer: An investigation of patient and caregiver factors. *Frontiers in Psychology*, *14*, 1059605.

Katz, B. (2017). *2,000-Year-old texts reveal the first emperor of China's quest for eternal life*. https://www.smithsonianmag.com/smart-news/2000-year-old-texts-reveal-first-emperor-chinas-quest-eternal-life-180967671/

Kaur, R., Shahrestani, S., & Ruan, C. (2022). Privacy and security of wearable sensors in healthcare: An exploratory literature analysis. *Communications of International Proceedings*, *2022*(33), 4032222.

Kichloo, A., Albosta, M., Dettloff, K., Wani, F., El-Amir, Z., Singh, J., Aljadah, M., Chakinala, R. C., Kanugula, A. K., Solanki, S., & Chugh, S. (2020). Telemedicine, the current COVID-19 pandemic and the future: A narrative review and perspectives moving forward in the USA. *Family Medicine and Community Health*, *8*(3), e000530.

Kim, J., Campbell, A. S., de Ávila, B. E. F., & Wang, J. (2019). Wearable biosensors for healthcare monitoring. *Nature Biotechnology*, *37*(4), 389-406.

Kruse, C. S., Stein, A., Thomas, H., & Kaur, H. (2018). The use of electronic health records to support population health: A systematic review of the literature. *Journal of Medical Systems*, *42*(11), 214.

Lam, K., Lu, A. D., Shi, Y., & Covinsky, K. E. (2020). Assessing telemedicine unreadiness among older adults in the United States during the COVID-19 pandemic. *JAMA Internal Medicine*, *180*(10), 1389-1391.

Lee, H. J., Lee, H. K., & Kim, Y. R. (2022). The impact of caregivers on nosocomial transmission during a COVID-19 outbreak in a community-based hospital in South Korea. *PLOS ONE*, *17*(11), e0277816.

Liu, Y., Wang, H., Zhao, W., Zhang, M., Qin, H., & Xie, Y. (2018). Flexible, stretchable sensors for wearable health monitoring: Sensing mechanisms, materials, fabrication strategies and features. *Sensors*, *18*(2), 645.

Loza-Matovelle, D., Verdugo, A., Zalama, E., & Gómez-García-Bermejo, J. (2019). An architecture for the integration of robots and sensors for the care of the elderly in an ambient assisted living environment. *Robotics*, *8*(3), 76.

MacDorman, K. F., & Ishiguro, H. (2006). The uncanny advantage of using androids in cognitive and social science research. *Interaction Studies: Social Behaviour and Communication in Biological and Artificial Systems*, *7*(3), 297-337.

Miranda, R., Oliveira, M. D., Nicola, P., Baptista, F. M., & Albuquerque, I. (2023). Towards a framework for implementing remote patient monitoring from an integrated care perspective: A scoping review. *International Journal of Health Policy and Management*, *12*(1), 7299.

Monaghesh, E., & Hajizadeh, A. (2020). The role of telehealth during COVID-19 outbreak: A systematic review based on current evidence. *BMC Public Health*, *20*(1), 1193.

Morrissey, E. C., Casey, M., Glynn, L. G., Walsh, J. C., & Molloy, G. J. (2018). Smartphone apps for improving medication adherence in hypertension: Patients' perspectives. *Patient Preference and Adherence*, *12*, 813-822.

Moyle, W., Jones, C., Murfield, J., Thalib, L., Beattie, E., Shum, D., O'Dwyer, S., Mervin, M. C., & Draper, B. (2018). Effect of a robotic seal on the motor activity and sleep patterns of older people with dementia, as measured by wearable technology: A cluster-randomised controlled trial. *Maturitas*, *110*, 10-17.

Mueller, S. M., Winkelmann, C., & Grunwald, M. (2023). *Human touch in healthcare: Textbook for therapy, care and medicine*. Springer.

Mukai, T., Onishi, M., Odashima, T., Hirano, S., & Luo, Z. (2008). Development of the tactile sensor system of a human-interactive robot "RI-MAN". *IEEE Transactions on Robotics*, *24*(2), 505-512.

National Alliance for Caregiving, & AARP. (2020). *Caregiving in the U.S. 2020*. AARP Public Policy Institute. https://www.caregiving.org/caregiving-in-the-us-2020/

Olshansky, S. J., Goldman, D. P., Zheng, Y., & Rowe, J. W. (2009). Aging in America in the twenty-first century: Demographic forecasts from the MacArthur Foundation research network on an aging society. *The Milbank Quarterly*, *87*(4), 842-862.

Papadopoulos, I., Koulouglioti, C., Lazzarino, R., & Ali, S. (2020). Enablers and barriers to the implementation of socially assistive humanoid robots in health and social care: A systematic review. *BMJ Open*, *10*(1), e033096.

Partridge, L., Deelen, J., & Eline Slagboom, P. (2018). Facing up to the global challenges of ageing. *Nature*, *561*, 45-56.

Pillemer, K., Burnes, D., Riffin, C., & Lachs, M. S. (2016). Elder abuse: Global situation, risk factors, and prevention strategies. *The Gerontologist*, *56*(Suppl 2), S194-S205.

Piras, E. M., & Miele, F. (2019). On digital intimacy: Redefining provider–patient relationships in remote monitoring. *Sociology of Health* & *Illness*, *41*(Suppl 1), S116-S131.

Pristavec, T. (2019). The caregiving dyad: Do caregivers' appraisals of caregiving matter for care recipients' health? *Archives of Gerontology and Geriatrics*, *82*, 50-60.

Ramasamy, L. K., Khan, F., Shah, M., Prasad, B. V. V. S., Iwendi, C., & Biamba, C. (2022). Secure smart wearable computing through artificial intelligence-enabled Internet of things and cyber-physical systems for health monitoring. *Sensors*, *22*(3), 1076.

Reinhard, S. C., Feinberg, L. F., Houser, A., Choula, R., & Evans, M. (2019). *Valuing the invaluable: 2019 Update: Charting a path forward*. AARP Public Policy Institute.

Rosa, P. M., & Fleming, T. (2023). The benefits of telemedicine on the economy. *Trends in Telemedicine* & *E-health*, *4*(5), 1-9.

Sayani, S., Muzammil, M., Saleh, K., Muqeet, A., Zaidi, F., & Shaikh, T. (2019). Addressing cost and time barriers in chronic disease management through telemedicine: An exploratory research in select low- and middle-income countries. *Therapeutic Advances in Chronic Disease*, *10*, 12040622319891587.

Schulz, R., & Eden, J. (2016). *Families caring for an aging America*. The National Academies Press.

Schulz, R., Czaja, S. J., Lustig, A., Zdaniuk, B., Martire, L. M., & Perdomo, D. (2009). Improving the quality of life of caregivers of persons with spinal cord injury: A randomized controlled trial. *Rehabilitation Psychology*, *54*(1), 1-15.

Sempionatto, J. R., Lin, M., Yin, L., De la Paz, E., Pei, K., Sonsa-Ard, T., de Loyola Silva, A. N., Khorshed, A. A., Zhang, F., Tostado, N., Xu, S., & Wang, J. (2021). An epidermal patch for the simultaneous monitoring of haemodynamic and metabolic biomarkers. *Nature Biomedical Engineering*, *5*(7), 737-748.

Tehrani, F., Teymourian, H., Wuerstle, B., Kavner, J., Patel, R., Furmidge, A., Aghavali, R., Hosseini-Toudeshki, H., Brown, C., Zhang, F., Mahato, K., Li, Z., Barfidokht, A., Yin, L., Warren, P., Huang, N., Patel, Z., Mercier, P. P., & Wang, J. (2022). An integrated wearable microneedle array for the continuous monitoring of multiple biomarkers in interstitial fluid. *Nature Biomedical Engineering*, *6*(11), 1214-1224.

Tesla. (2023). *Tesla bot update*. https://www.youtube.com/watch?v=XiQkeWOFwmk

Tsui, K. M., Yanco, H. A., Feil-Seifer, D. J., & Matarić, M. J. (2008). Survey of domain-specific performance measures in assistive robotic technology. *Proceedings of the 2008 Performance Metrics for Intelligent Systems Workshop* (pp. 116-123). New York, NJ.

Unitek EMT. (2023). *Telemedicine in emergency medical services*. https://www.unitekemt.com/blog/telemedicine-in-emergency-medical-services/

Vespa, J., Medina, L., & Armstrong, D. M. (2020). *Demographic turning points for the United States: Population projections for 2020 to 2060* (Current Population Reports, P25-1144). U.S. Census Bureau.

Weller, C., Almeida, B., Cohen, M., & Stone, R. (2020). *Making care work pay: How paying at least a living wage would benefit care recipients, workers, and communities*. https://leadingage.org/sites/default/files/Making%20Care%20Work%20Pay%20Report.pdf

Wolff, J. L., Spillman, B. C., Freedman, V. A., & Kasper, J. D. (2016). A national profile of family and unpaid caregivers who assist older adults with health care activities. *JAMA Internal Medicine*, *176*(3), 372-379.

Yi, H. (2016). *Manned-unmanned teaming: An analysis of UAVs and their interoperability with manned aircraft*. https://api.semanticscholar.org/CorpusID:21708806

Zhang, S., Zeng, J., Wang, C., Feng, L., Song, Z., Zhao, W., Wang, Q., & Liu, C. (2021). The application of wearable glucose sensors in point-of-care testing. *Frontiers in Bioengineering and Biotechnology*, *9*, 774210.

Zhang, Z., Brazil, J., Ozkaynak, M., & Desanto, K. (2020). Evaluative research of technologies for prehospital communication and coordination: A systematic review. *Journal of Medical Systems*, *44*(5), 100.