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Digital health for aging populations

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Growing life expectancy poses important societal challenges, placing an increasing burden on ever more strained health systems. Digital technologies offer tremendous potential for shifting from traditional medical routines to remote medicine and transforming our ability to manage health and independence in aging populations. In this Perspective, we summarize the current progress toward, and challenges and future opportunities of, harnessing digital technologies for effective geriatric care. Special attention is given to the role of wearables in assisting older adults to monitor their health and maintain independence at home. Challenges to the widespread future use of digital technologies in this population will be discussed, along with a vision for how such technologies will shape the future of healthy aging.

The world's older population continues to grow remarkably fast, with humans aged 65 years or above projected to rise from 10% in 2022 to 16% in 2050 (ref. 1). Such rapidly increasing life expectancy presents major health challenges and is expected to impose substantial socio-economic burdens. As people live longer, they are more prone to having non-communicable diseases (for example, diabetes, kidney failure, arthritis and Alzheimer's or Parkinson's disease), which require continuous monitoring and management. Older adults experience a progressive decline in their physical and cognitive skills and are likely to experience several pathological conditions simultaneously as well as critical events such as falls or strokes (Fig. 1a). The increasing geriatric population (coupled with the decreasing caregiver workforce) puts substantial pressure on healthcare systems globally regarding operational costs and resources. A primary societal goal is to support healthy aging while maintaining older adults' autonomy and safety at home.

Traditional health assessments relying on in-clinic visits, face-to-face contact with the doctor and nurse and annual laboratory testing are inconvenient and costly and suffer from delayed analytical results and potentially late diagnosis. Accordingly, such a traditional approach cannot offer a continuous and longitudinal assessment of the patient and is limited to applications for which infrequent tests are sufficient; hence, it does not meet the rapidly growing healthcare demands of the fast-growing aging population. The application of digital technologies to assist clinical practice can address these increasing demands by offering convenient, continuous remote medical care to older patients and holds considerable promise to transform geriatric care.

In particular, wearable digital technologies are expected to provide healthcare professionals with continuous access to the health status of older adults and offer unique opportunities for effective remote care[2,3]. Wearables can support older adults in remotely tracking chronic health conditions or ongoing treatments and monitoring for safety concerns and can do so without disrupting daily activities. For example, wearable platforms can continuously and non-invasively capture biometric and biomolecular data, which is not feasible by traditional health assessment. They can generate instantaneous alarms in cases of emergencies, such as stroke, seizure or fall, to allow timely medical interventions. Such tools are also expected to reduce geographical inequalities by providing older adults living in rural areas with improved access to healthcare services.

The demand for providing healthcare at a distance (that is, telemedicine or telehealth) has increased sharply during the COVID-19 pandemic. While intermittent in-clinic visits will remain an essential part of healthcare services, we anticipate an increasing involvement of wearable devices in this process. In this Perspective, we describe the main types of wearable and non-wearable technologies that hold promise for healthy aging and geriatric care. We discuss the challenges of translating this technology into broad clinical use, and we outline our view for a future in which such technologies are embedded in the healthcare landscape.

Technologies for healthy aging

Wearable sensors, capable of real-time on-body monitoring of various aspects of the wearer's health or behavior, have garnered enormous

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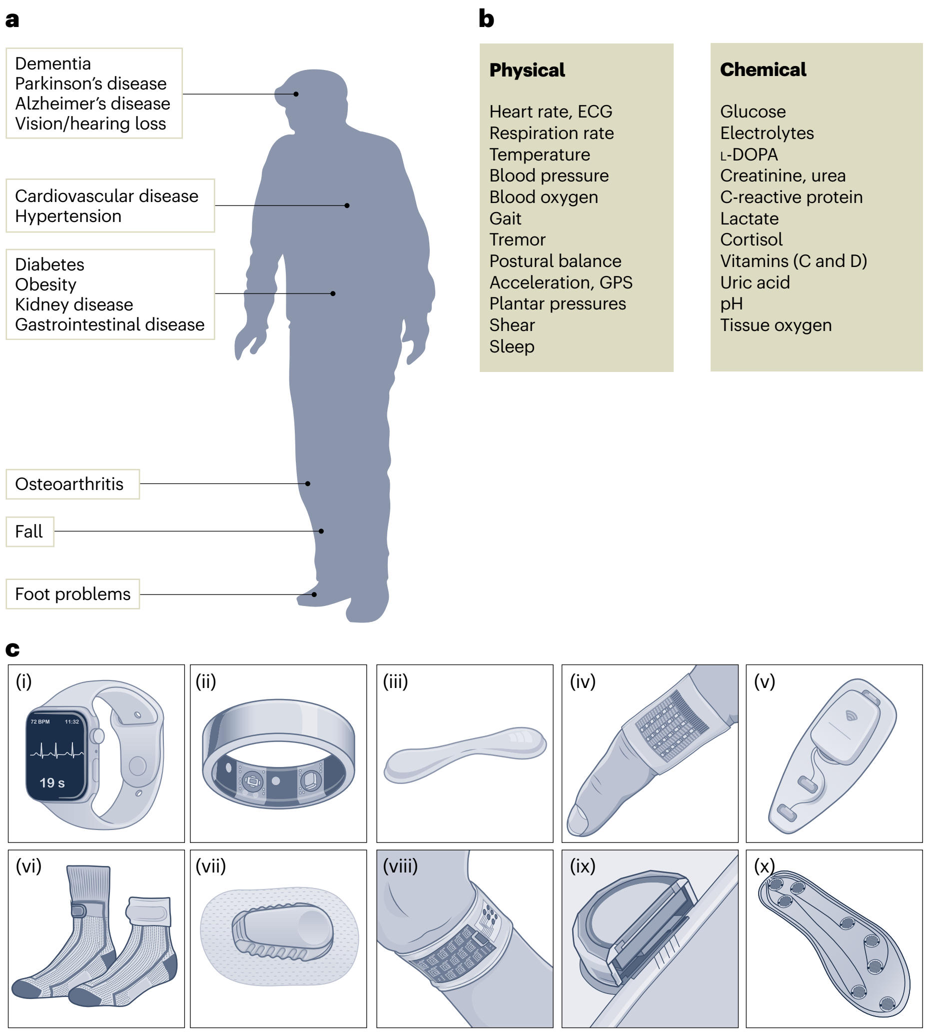

Fig. 1 | The landscape of current wearable devices for health monitoring in older adults. a, Common age-related medical conditions for the geriatric population. **b**, Key physical and chemical signals that reflect the health conditions of older adults and that can currently be measured by wearable devices. In the future, it may be possible to measure others (such as amyloid and tau). **c**, Common body-worn sensing devices, mounted on different accessories, clothing or skin. GPS, global positioning system. (i), Apple watch (adapted from ref. 22). (ii), Oura ring (adapted from ref. 23). (iii), Philips VitalPatch (adapted from ref. 24). (iv), Wearable ultrasound patch (adapted from ref. 25). (v), Mobile Cardiac Outpatient Telemetry ECG sensor (adapted from ref. 26). (vi), Sensoria Fitness Smart Socks (adapted from ref. 27). (vii), Dexcom CGM (adapted from ref. 28). (viii), Integrated wearable sensor array (adapted from ref. 15). (ix), Wearable microneedle array (adapted from ref. 29). (x), Orpyx Insoles plantar pressure sensor (adapted from ref. 30).

attention over the past couple of decades owing to their diverse applications (Fig. 1b)[4,5]. Wearable sensors have evolved rapidly since the emergence of the internet of things and mobile devices, from early trackers of the user's mobility and vital signs to current advanced, multi-modal sensing devices, capable of generating valuable molecular data that were impossible to obtain a few years ago[6]. Current and emerging digital monitoring devices can be broadly grouped into four categories: wearable physical sensors, wearable chemical sensors, hybrid and multi-parameter wearable sensing platforms and non-wearable sensors.

Wearable physical sensors. Most commercial wearable devices rely on physical sensors that measure physical signals of the human body continuously and longitudinally over prolonged periods. These include continuous measurements of basic vital signs, heart rate, electrocardiogram (ECG), respiration rate, body temperature, oxygen saturation or blood pressure[7–9]. Physical wearable sensors also monitor mobility and other activity-related signals (including steps) using miniaturized motion sensors, such as accelerometers or gyroscopes. Such wearable devices can detect fall events or assess the gait disorders of patients with Parkinson's disease; for example, an ongoing, randomized trial involving 200 older adults will evaluate the effectiveness of an Apple watch in detecting falls (NCT04304495)[10]. Continuous and remote monitoring of vital signs can trigger warnings of adverse events and deteriorating conditions in older adults, including the early onset of cardiovascular, neurological and pulmonary diseases. For example, abnormal respiration rates can predict respiratory failure, elevated body temperature can indicate an infection, and abnormal ECG patterns can alert for cardiac arrest. Indeed, physical wearable sensing devices have long been used to monitor cardiovascular diseases since the initial recording of cardiac heart rate and ECG signals in the 1960s. Modern epidermal physical sensors can now enable remote monitoring of older adults in their homes for a wide range of key vital signs, performing virtually much of the traditional office-based physical examination. For example, such real-time sensing devices have been useful for detecting abnormal physiological events, such as the onset of COVID-19 (ref. 11).

Wearable chemical sensors. While current wearable devices, such as smartwatches, track mobility and vital signs, substantial efforts are being devoted to develop wearable platforms for monitoring health parameters at the molecular level[4,12–14]. Introducing such non-invasive chemical sensors, capturing rich molecular data from the human body in real time, addresses a major gap in wearable sensor technology. The use of wearable chemical sensors offers continuous non-invasive tracking of the dynamically changing chemical composition of various biofluids, such as sweat, tears, saliva and interstitial fluid and hence provides extremely useful molecular-level insights into the wearer's health status. Such rich temporal molecular information is not available from wearable physical sensors.

Different strategies, based on electrochemical and optical measurements, have thus been explored for creating a lab-on-the-wrist platform, performing many common hospital tests of key chemical biomarkers in a non-invasive continuous manner. These include continuous monitoring of dynamically changing glucose levels in patients with diabetes, potassium ions and the stress hormone cortisol in individuals with cardiac disease or the Parkinson's disease drug L-DOPA (also known as levodopa)[4]. Multiplexed wearable sensor arrays offer the ability to monitor a myriad of molecular markers simultaneously and hence can lead to a better diagnostic picture of the wearer's health[15].

Hybrid and multi-parameter wearable sensing platforms. Recently developed hybrid wearable devices, simultaneously tracking chemical biomarkers and physical vital signs (such as blood pressure or heart rate) using single multi-modal epidermal patches, offer considerable promise for providing continuous and comprehensive healthcare monitoring and for alerting older adults and their caregivers to the occurrence of a variety of abnormal physiological changes[16,17]. Simultaneous tracking of vital signs and chemical biomarkers using a single wearable device greatly simplifies monitoring for the user, which could enhance compliance. This new generation of hybrid wearable sensors can provide rich longitudinal information to offer continuous home monitoring of chronic diseases, ranging from diabetes and cardiovascular diseases to dementia and arthritis[18–21]. While wearable physical sensors collect their information by contacting the skin directly, wearable chemical sensors capture their biomarker data by contacting different biofluids. Different body-worn flexible-form factors, designed to conform to the curvature of the skin and other organs, are thus being employed for a plethora of different healthcare-monitoring applications.

These sensors can be mounted onto smartwatches, elastic wristbands, rings, skin patches, microneedles, socks, shoes, insoles and glasses; embedded into clothing; or placed directly on the skin at different body locations (Fig. 1c)[15,22–30]. These body-worn platforms aim to continuously monitor changes of a wide range of indicators without causing discomfort or affecting users' daily activity. The convenience of these wearable platforms is likely to result in improved compliance, which can lead to enhanced detection of abnormalities. The Oura Ring and VitalPatch systems (Fig. 1c) are examples of recently introduced commercial, multi-parameter monitoring platforms that offer considerable promise for remote geriatric care. The Oura Ring uses multiple sensors embedded on the inner ring surface to simultaneously track skin temperature, respiration rate, blood oxygen, heart rate, heart rate variability and activity levels[23]. Similarly, the VitalPatch offers remote, continuous physiological monitoring of key vital signs, including skin temperature and respiratory and heart rates, along with physical activity[24,31]. These and similar multi-sensor wearable platforms have the potential to enable early detection of deterioration or avoidable complications[32].

Advances in miniaturization and fabrication techniques have allowed the integration of multiple sensing modalities and numerous sensing elements into very small footprints (~0.5-inch diameter) of a single wearable platform. Such smart wearable systems commonly have high processing power and are paired with other devices, particularly smartphones and tablets, to collect and transmit their data, thus remotely providing a continuous flow of rich medical data to the cloud (where the system data are stored and processed) and healthcare providers. Coupling with advanced communication and information technologies, wearable sensing technologies have paved the way for a new era of cost-effective remote healthcare services for monitoring older adults in their home settings. Pending their large-scale validation (against gold-standard clinical protocols, for example, NCT04306588, NCT05334680, NCT05245097), these sensing technologies are expected to become an important integral part of future diagnostic tools, leading to improved health outcomes for older adults.

Non-wearable sensors. While wearable sensors have become increasingly popular for collecting health information directly from the body, there is also a growing interest in developing non-wearable sensors, based on smart home digital systems, to monitor the behavior, posture and movement of older adults[33,34]. These sensors can analyze data and alert caregivers or healthcare professionals of any anomalies, thereby promoting the health and safety of older adults in their homes. For example, a pending clinical trial was designed to use the Kinect camera (a device with depth-sensing capability) as a sensor for evaluating the mobility and gait of patients with Parkinson's disease in their homes for better disease management (NCT05211687). In addition, non-wearable mobile chemical sensors, such as L-Dopa meters and common diabetes test strips, can help older adults manage their corresponding diseases and health at home. However, while such disposable sensors commonly rely on repeated blood testing, they cannot provide the continuous readout and rich molecular data common to advanced wearable devices.

Challenges to clinical translation

While digital technologies promise to revolutionize geriatric care, their practical implementation is facing major challenges. These include limited digital literacy skills, data privacy and security threats and limited device performance. While some of these challenges (for example, sensor performance and reliability) are not unique to the geriatric population, other challenges are more specific to older adults. Owing to greater disparity in their utilization of digital technologies and their specific health needs, older adults require substantially greater assistance in relation to digital technologies and data security than younger populations. Overcoming these challenges is critical to the widespread use of digital technology in geriatric healthcare.

Designing with older adults in mind

A recent study revealed that older adults generally have high adherence to using a wearable watch and reported little to no difficulties during the process[35]. Nevertheless, despite their clear benefits, age remains a major barrier to the acceptability of digital devices[36,37]. Many older adults prefer personal contact with health professionals, have minimal digital technology experience and struggle to use telehealth independently[38]. Those with digital literacy and visual impairments may have trouble using common mobile devices with numerous buttons, tiny text and poor color contrast. Expanding digital health services to the geriatric population will thus require simpler, user-tailored mobile devices with fewer buttons, larger text and improved color contrast. Devices need to be user centered so that individuals with a range of other pre-existing health conditions, such as impaired hearing or fragile skin, can still use and benefit from these devices. The lifetime, size and weight of the device should also be taken into consideration. Overall, a better understanding of the technical barriers that older adults face when using digital technologies will enable designers to tailor future devices to their needs. Engaging with older adults and seeking their input on design and operation of these digital devices would be the best way to understand user needs and achieve this goal.

There is a trend to move from active sensors (which require user interaction) to passive sensors (which operate without user interaction). One notable example is how the monitoring of glucose has evolved from requiring finger pricks several times a day to now being free of both finger pricks and calibration. This approach, if extended to other applications, could help older adults reduce their need to interact with devices while still providing timely and accurate feedback. Future wearable devices will likely be designed to reduce the burden of interaction and the complexity of the devices, to improve adherence. In addition, passive sensors collecting and analyzing data without user intervention would potentially reduce interference from subjective factors, such as anxiety, to obtain more accurate data.

Data processing and security

While digital health tools have been rapidly developed to continuously capture an enormous amount of multi-sensory data, the healthcare system has not kept up with processing and securing these data. Current systems cannot efficiently cope with the exponential growth of data or the extraction of large volumes of valuable information produced by wearable sensors, and have difficulty analyzing it effectively. Meeting the challenge posed by such a tremendous volume of dynamic data collected continuously from multiple sources requires a multidisciplinary approach to big data processing and analysis. This will involve leveraging modern data-analysis approaches, such as machine learning or artificial intelligence techniques for efficient data fusion and mining toward recognizing trends, making decisions, speeding up diagnostics to facilitate timely interventions, predicting disease onset and identifying risk of early health decline[13,39,40]. Advanced data processing will be used to fuse the rich data collected from the wearable sensors and from other electronic surveillance devices and to translate them to practical health care decisions. Establishing the inherent connections between age-related disease traits and the biomarker signals obtained with wearable sensors will also require intermittent testing in the clinic to provide a more holistic picture of the patient's health[37,41].

In addition to the slow processing of big data, there are major concerns about data privacy and security when dealing with healthcare services and personal data. The landscape of security and privacy risks has been evolving as fast as digital technologies themselves, creating an urgent need to secure digital devices against major threats through a multilayered security approach. Privacy concerns can negatively influence the adoption and use of digital health technology, and mobile devices are particularly vulnerable. A specific safety concern is the risk of remote hacking and control of medical devices, such as insulin pumps or pacemakers, that may put patients at risk (for example, by triggering a lethal insulin overdose). It should be noted that data processing and security pose a greater challenge for older adults than for the rest of the population, for example, due to lower digital literacy or cognitive aging[42]. Strict regulation, consistent societal support and outreach to older adults should improve their use and trust of digital healthcare while ensuring privacy and security.

Performance gaps and challenges

Realizing the true potential of digital sensing devices and their broad adoption requires addressing key technological gaps. In particular, as the performance of wearable devices impacts healthcare decision making, it is critical to assess and validate their accuracy in large-scale trials involving older adults. Achieving widespread acceptance of wearable chemical sensors thus requires reliable analytical performance, similar to that of laboratory-based analytical techniques. Despite substantial recent advances, wearable chemical sensors still face major challenges associated with their limited stability, accuracy and narrow scope[4]. The limited stability of wearable chemical sensors reflects their susceptibility to biofouling and to degradation of the bioreceptor (that is, the molecule that senses the analyte) in uncontrolled conditions, such as temperature, humidity and motion, that can all affect the biorecognition and sensing processes and hence the reliability and stability of wearable sensors. Improvements in the stability and accuracy of body-worn chemical sensors thus require proper attention to the choice and immobilization of bioreceptors and to coverage with appropriate protective coatings for protection against surface-biofouling effects. As the scope of such wearable chemical sensors is often limited by the irreversible nature of common laboratory-based bioaffinity assays, new on-body assays based on reversible recognition events must be explored to continuously monitor a broad range of biomarkers. As a result, wearable chemical sensing platforms have experienced greater commercialization challenges than those sensing physical vital signs.

Widespread acceptance of wearable chemical sensors for future diagnostics and remote geriatric care will require large-scale clinical trials involving older adults to validate their accuracy against gold-standard blood-based laboratory assays. Certain wearable devices can perform high-quality measurements comparable to those of traditional regulated medical instruments[21]. For example, continuous glucose-monitoring (CGM) systems have reported high accuracy compared to glucose values in the hospital laboratory[43]. Similarly, recent studies have demonstrated that vital sign data collected from wearable devices can give more consistent and precise heart rate measurements than measurements made in the clinic[41]. Continuous improvements of wearable devices are expected to fill the performance gap and make these sensors ready to transform geriatric care.

Other considerations

The accessibility and cost of devices and services associated with digital healthcare should not be overlooked, as the economic burden poses additional financial challenges to the geriatric population, particularly in low–middle-income countries. Several lessons from previous successful digital health implementations by other populations, for example, the evolution of glucose-monitoring devices in people with diabetes, could be used to guide a wider use of wearable sensors by older adults (Box 1). These lessons relate to the importance

BOX 1

Lessons from diabetes

Diabetes has a strong correlation with age, with an estimated more than 25% of adults aged 65 years or older having the condition[62]. Mobile and wearable sensor technologies (from early glucose strips to current CGM devices) have played a major role in the management of diabetes for nearly three decades[12]. The latest wearable CGM technology has been proven to be extremely useful for reducing risks of hypoglycemia and hyperglycemia[63]. The application of CGM for delivering precise insulin doses in a closed-loop manner (that is, entirely automated) is rapidly advancing. The extensive historical and technological lessons from using such digital technologies for diabetes care are currently guiding the development of wearable platforms for monitoring the progression and treatment of various other diseases and for improving patient care. The knowledge gained in developing the artificial pancreas is paving the way to the creation of similar autonomous, closed-loop, 'sense–act' wearable systems for supporting corrective therapeutic action toward personalized therapy and the management of different chronic diseases. The management of diabetes itself is expected to improve by translating the lessons from glucose monitoring to decentralized and on-body measurements of other major diabetes biomarkers, particularly ketone and insulin. The extensive lessons from the management of diabetes offer extremely useful guidance on how to develop wearable devices for older adults to facilitate their health management.

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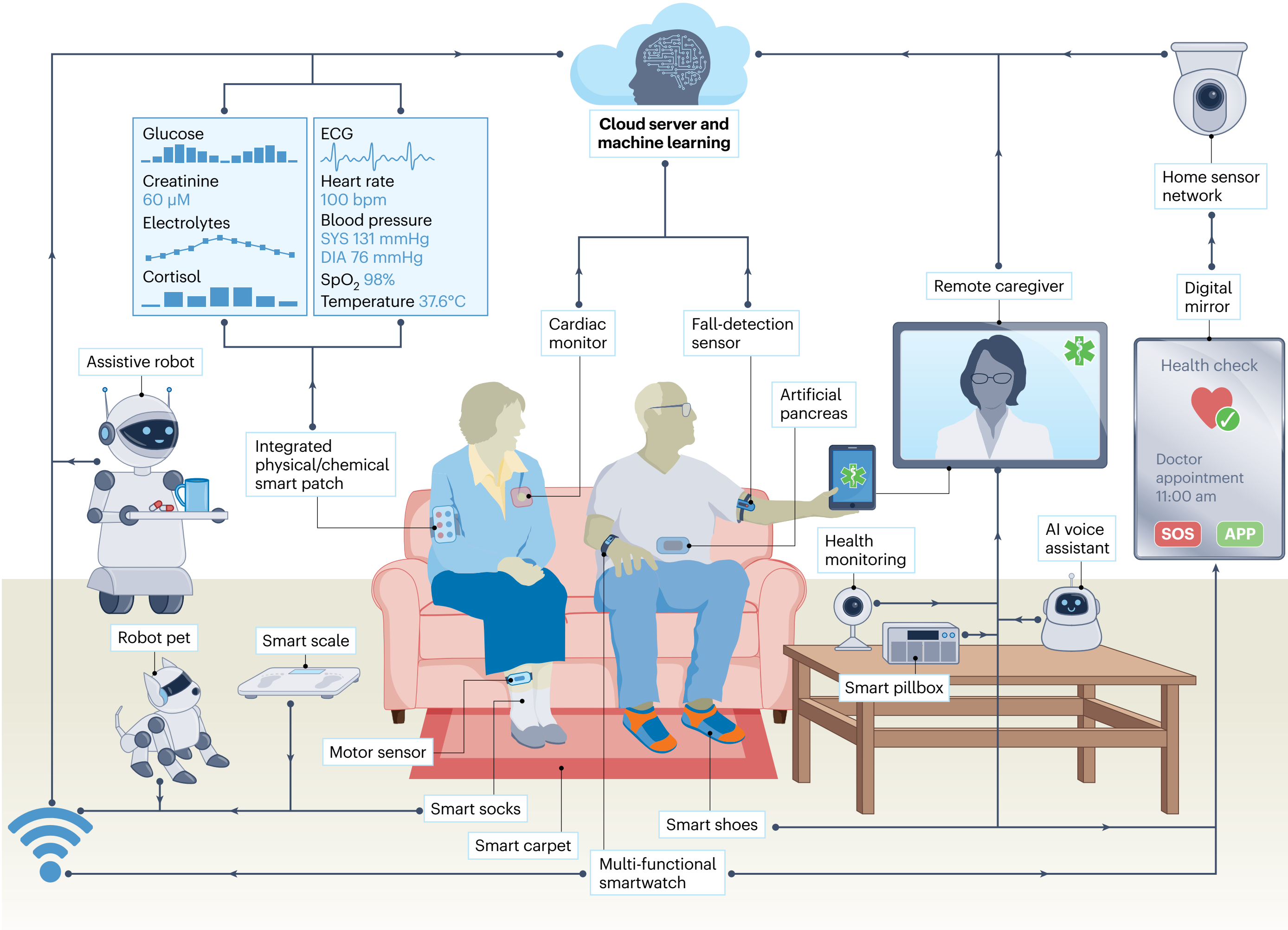

Fig. 2 | The future of geriatric healthcare in the home setting. A vision of future home-centered geriatric care, powered by digital technologies and devices. A network of internet-connected sensors on the body and distributed around the home, monitors the health conditions of older adults and transmits rich dynamic data to cloud servers. The data are then analyzed by machine learning algorithms to coordinate with the remote caregiver and with autonomous wearable therapeutic devices toward optimal health care. Such care is supported by virtual visits with the physician, voice-controlled personal assistants and social and assistive robots. AI, artificial intelligence; DIA, diastolic; SpO_2, oxygen saturation; SYS, systolic.

of user-centered design in the devices, improving data processing and security, rigorous validation from evidence-based practice, providing additional training and support and lowering the cost for better financial sustainability.

What is next?

Smart homes for older adults

Digital health technology is spreading rapidly, with the aging population becoming a major target group for this technology. The unique capabilities of wearable sensors are expected to be coupled with telehealth platforms, leading to a paradigm shift in geriatric healthcare. Multidisciplinary collaboration will be required to realize the full potential of digital technology in all aspects of geriatric care. Such efforts will lead to smart homes, with an extended surveillance and communication system, that will help older residents live healthily and independently in their own familiar environment.

We envision that such smart homes for older adults will rely on a fully integrated home monitoring system network, combining a variety of body-worn sensing devices and electronic surveillance devices within a wireless communication network and a cloud analytics platform (Fig. 2). The resulting system will continuously monitor the health, activities and well being of the residents and be interfaced with big data processing and alert systems to inform caregivers remotely about abnormal changes. Such remote monitoring will be tailored to meet the specific health needs of residents, for example, based on the level of frailty and presence of chronic conditions such as diabetes, heart disease or kidney disease.

In addition to next-generation skin-worn patches, which will seamlessly integrate different chemical and physical sensing modalities on a single epidermal device, motion sensors (distributed around the house and/or worn on the body) will detect movement in certain locations. Foot-worn sensors, such as smart socks, insoles, shoes or carpet, will monitor gait, balance, foot problems (for example, associated with diabetes) and frailty[44]. The continuous remote home surveillance system will be supported by a variety of digital devices distributed around the house, including smart mirrors, scales and pillboxes. For example, digital mirrors will collect data from distributed motion sensors, identify a fall event and alert emergency services[45]. These will also monitor other health indicators by assessing changes in appearance and can also be used for visual displays (for example, appointment or medication reminders), analogous to the audio–visual displays of commercial consumer electronic devices. Voice-controlled intelligent personal assistants, such as Amazon Echo or Google Home, will also support continuous monitoring and help to detect emergency situations (for example, falls), providing personalized medication reminders and alerts as well as social and cognitive stimulation[46]. The next generation of these consumer devices is expected to be better tailored to geriatric healthcare needs. Other parts of the smart home, such as the kitchen or bathroom, will contribute to the surveillance of older adults' health, daily activity and diet, using digital systems such as smart refrigerators (that track stored food or medicine) or smart toilets (that analyze urine or feces)[47–49].

We envisage that various types of home robots will support geriatric care in the future. For example, researchers have found that social robots, such as pet robots, offer companionship and can reduce social isolation and depression[50]. We anticipate that these will have a positive effect on the lives of people with Alzheimer's disease and dementia while also encouraging older adults to be more active. More advanced assistive robots will perform useful tasks to improve medical supervision (for example, delivering medication and/or diagnostic devices at regular intervals, detecting falls) and enhance the autonomy of older adults. Eventually, we expect nurse-like humanoid assistive robots to provide 'tender loving care' along with medical support[51].

Beyond their own homes, other living scenarios for older adults, such as assisted living facilities, should benefit in similar ways from the development of digital health. By contrast, for hospital at-home and skilled nursing facility settings, due to the greater number (and complexity) of medical conditions and interventions, wearable sensors are expected to provide an assistive role, along with trained health workers, in monitoring the health of older adults. Older adults living in such facilities tend to have multiple comorbidities, hence requiring careful testing of the functions and reliability of any wearable device before its application. Nevertheless, implementing digital health in these settings could conceivably alleviate staff shortages and reduce costs. In all cases, human participation will remain critical in the implementation of digital health monitoring to ensure proper training of users and carers as well as appropriate interpretation and response to alerts and data readouts.

Telemonitoring for remote geriatric care

In the context of healthy aging, the goal of telemonitoring is to enable older adults to stay safely and comfortably in their home setting, under constant medical supervision through video-based services. Such virtual visits with the physician or nurse will be transformed from the current followups and prescription renewals to provide more advanced care delivery, assessing changes in health parameters and monitoring chronic diseases. These video visits will be enhanced by Internet-connected wearable devices that capture data remotely (for example, heart rate, blood pressure) and forward these data to clinicians. Indeed, all key vital signs measured during the traditional office-based physical examination can now be measured remotely during such virtual visits. Engaging older adults in such routine telehealth services will require training and user-tailored devices to support uptake of video-based consultations. Improved network coverage at affordable rates is also critical for efficient telemedicine activities, especially in rural areas.

Rich cloud-based data from wearable and home-based sensors will use powerful computational techniques to mine useful information, identifying major trends and patterns and making accurate predictions. Such big data-fusion algorithms will support corrective medical intervention and guide 'closed-loop' timely interventions toward personalized therapy and optimal therapeutic outcome. For example, autonomous 'sense-and-act' wearable platforms will tailor the delivery of insulin or L-Dopa in connection with optimal management of diabetes or Parkinson's disease, respectively.

Future wearable chemical monitoring for older adults

Potentially revolutionary sensing strategies could be a transformative technology for wearable technologies and hold considerable promise for supporting the well being of older adults. While current wearable devices are limited to measurements around the skin surface, new non-invasive wearable sensing strategies are currently being developed for probing deep-tissue signals. For example, wearable ultrasonic devices have recently been used for monitoring blood pressure and for direct assessment of cardiac function[52,53]. Such sensing strategies will offer important real-time insights into the physiological status of internal organs or tissues, with their deep-tissue signals correlating with various disease states or predicting the onset of symptoms.

Wearable chemical sensors capable of providing continuous molecular-level information are still at the early stage of development. The scope of current devices is narrow because they rely primarily on enzymatic and ion-recognition processes. While early efforts have focused on biomarkers for assessing performance, recent activity has shifted to monitoring drugs or disease biomarkers relevant to geriatric health[54]. However, the practical implementation is still facing major challenges, and progress toward clinical translation has been slow (except for commercial CGM for diabetes management that still requires needle insertion below the skin surface)[54]. Owing to the irreversible nature of common antibody- or DNA-based affinity assays, new on-body assays based on reversible recognition events must be explored to continuously monitor a wider range of biomarkers. Recent efforts have addressed this challenge by engineering artificial biomimetic receptors with tailored binding affinity and properties that enable reversible recognition processes and continuous label-free assays. New receptors, such as DNA aptamers[55,56] or molecularly imprinted polymers, can be used for on-body molecular measurements for a wide range of chemical markers[57,58]. Such new receptors integrated in wearable switch sensors have shown high reversibility for continuous label-free on-body monitoring of new important biomarkers including nutrients and metabolites[59–61]. In addition, the biocompatibility of the sensors needs to be improved further. It needs to rely on advanced materials, such as biopolymers and low-toxic sensing materials, owing to the fragile skin of older adults and sensitive ulcer areas (for example, diabetes foot ulcers, bedsores).

Concluding remarks

The rapid growth of the geriatric population across the world is surpassing society's ability to meet the healthcare needs of its older adults. Digital technologies offer considerable promise for addressing these needs and transforming many aspects of geriatric care. Such technologies are rapidly changing how older adults access care and interact with the healthcare system, but their inappropriate use could have negative consequences on physical and mental health. Therefore, providing proper training to both the user and the caregiver is important. Furthermore, the cost of digital care, particularly in mid- and low-income countries, needs to be considered to ensure its accessibility and affordability. Digital devices need to be included in health insurance systems with the help of governments and regulators to make them widely available to the public, and improving integration and performance of devices will require lowering the cost of research and production. Achieving these goals requires partnering with healthcare providers, offering more educational assistance for older adults and continuous engagement with policymakers.

By collecting rich physiological and activity-related personal data continuously and non-invasively, wearable devices have opened tremendous opportunities for tracking and improving the well being of adults at different stages of aging. We expect the ongoing innovations in digital technology to be translated in the near future into timely and effective interventions for improving the quality of geriatric care and successful, healthy aging.

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Additional information

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