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Communicative Development and Diffusion of Humanoid AI Robots for the Post-Pandemic Health Care System

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Abstract

As humanoid robot technology, anthropomorphized by artificial intelligence (AI), has rapidly advanced to introduce more human-resembling automated robots that can communicate, interact, and work like humans, we have begun to expect active interactions with Humanoid AI Robots (HAIRs) in the near future. Coupled with the HAIR technology development, the COVID-19 pandemic triggered our interest in using health care robots with many substantial advantages that overcome critical human vulnerabilities against the strong infectious COVID-19 virus. Recognizing the tremendous potential for the active application of HAIRs, this article explores feasible ways to implement HAIRs in health care and patient services and suggests recommendations for strategically developing and diffusing autonomous HAIRs in health care facilities. While discussing the integration of HAIRs into health care, this article points out some important ethical concerns that should be addressed for implementing HAIRs for health care services.

Keywords: humanoid AI robots, machine-learning, new normal in health care, post-pandemic world, human-machine communication

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Humanoid robot technology, anthropomorphized by artificial intelligence (AI), is rapidly advancing to introduce more human-resembling automated robots that can communicate, interact, and work like humans. Although humanoid robots have been implemented in many societal sectors to provide diverse services, such as providing information at airports, assisting human workers at companies, and interacting with patients at health care facilities, the current humanoid robots typically still look, speak, and move like machines, not fully resembling the ways that humans communicate. However, in the (near) future, we expect active interactions with humanoid robots that really look, speak, and move very similarly to humans with better information storage, processing, and capacity for (machine-) learning. With this expectation, as the number of people who see and communicate with humanoid robots increases and robots are located in more places where people frequently visit, it is expected that the public will begin perceiving humanoid robots more positively (Stroessner & Benitez, 2019; Van Pinxteren, 2019).

We anticipate rapid development and implementation of humanoid AI robots (HAIRs) that have a great potential to contribute to advancing health care services in many ways, from diagnosis, treatment recommendations, and administrative activities to patient engagement and adherence (Davenport & Kalakota, 2019). Nowadays, HAIRs with friendly social skills and machine-learning abilities are already delivering a broad range of physical and mental health care services to patients, such as monitoring and responding to emerging health risks, performing robotic surgeries, dispensing needed medications, providing therapeutic counseling and companionship, as well as helping to overcome cognitive challenges for patients with certain health conditions (Kaiser et al., 2020; Kyrarini et al., 2021). As the trend for using robots for health care services expands, we anticipate that more advanced AI robots, HAIRs, will be widely applied to many areas of health care services (Holland et al., 2021; Konijn & Hoorn, 2020).

Coupled with the AI robot technology development, the COVID-19 pandemic triggered growing interest in using health care robots with many substantial advantages that overcome critical human vulnerabilities against the strong infectious virus (Kaiser et al., 2020; Singh et al., 2021). For example, since the coronavirus cannot harm machines, robots do not pose significant risks as carriers of viral infection that can damage the human biological system, nor can robots be infected by the virus. Therefore, under a pandemic situation and public health risks caused by infectious diseases, robots can function as normal within health care settings without the biological concerns of contagion, as opposed to human health care providers. Recognizing the tremendous potential for the active application of humanoid AI-based robot in health care, this article encourages careful consideration of the ways that HAIRs can be widely used for health care and patient services, suggesting recommendations for strategically developing and diffusing HAIRs for use in health care facilities.

We define humanoid AI robots by clarifying the two primary terms, humanoid and AI. *Humanoid* means human-like appearance and function in face, body, ways of moving, speaking, and interacting. *AI* (artificial intelligence) endows robots with autonomy in learning, developing creativity, decision-making/judgment, and adapting to different situations. Based on these definitions, this study examines the use of HAIRs as robots that look, speak, and move exactly like a human, are able to autonomously communicate with patients and make decisions, and take adaptive actions to accomplish set goals in the health care system. We also provide recommendations and rationale for developing, implementing, and diffusing health care HAIRs to promote health and well-being.

Demands for Health Care *Humanoid* AI Robots

Providing effective health care to address major health care problems is not easy. It is often very complex, demanding a great deal of information to guide effective disease detection, diagnosis, treatment, and follow-up. There is much that must be known about the nature of specific health care concerns to accurately diagnose and treat these problems. Health care providers must be well-informed about patients' individual health histories, their unique and emerging symptoms, as well as their health care needs, expectations, and priorities, so they can use this information to develop and administer effective treatment plans for each patient.

Health care providers must be aware of the latest and best available evidence-based treatments for different conditions and should be able to deliver these different treatments. Once a treatment strategy is implemented, health care providers must carefully monitor patients' responses to treatments to determine how well treatment regimens are working, or if the treatments are leading to other problems for patients. It is unreasonable to assume that health care providers can know about, understand, apply, and keep track of all these factors when delivering complex care to patients.

The information demands of health care become stronger and more complicated during challenging pandemics often due to limited information about the disease or virus itself; how it spreads; the ways it influences biological processes; the physical, mental, social effects it has on patients; and what the best forms of prevention and treatment are. These complexities challenge the cognitive information-processing and decision-making capacities of health care providers to keep up with a vast and expanding body of scientific literature, to know about and master different health treatment modalities, to recognize unique consumer health factors and predispositions, and to take all this information into consideration for delivering effective care.

However, the vast and instant digital information storage and processing capacities that are available in computerized humanoid robots can provide tremendous assistance to health care providers for managing the complexities of health care delivery. In addition, robots are relentless in monitoring and caring for patients without rest, meals, or comfort breaks, as long as sources of energy are continuously supplied. Robots can maintain rapt attention over time to gathering and analyzing information, delivering and managing care, and communicating with humans. In addition (as mentioned earlier), during pandemics, robots do not experience the risks of contagion (spreading or contracting infection) to which human caregivers are heir. Due to these unique abilities and merits, AI robots that have the ability to produce rapid evidence-based decisions in certain health or medical situations and even look and communicate the same as humans could not only assist human health care providers but could also take the role of autonomous health care providers in addressing complex health care challenges.

Care must be taken to design and implement robotic health care delivery systems to be adaptive to addressing the unique communication demands of different human participants within the health care system (Johanson et al., 2020; Yasuhara, 2021). The robots must be designed to gather and make sense (decoding) of messages from patients, both the physiological data that are often provided automatically from lab tests and monitoring devices and from patient written and oral messages about their concerns, requests, and recollections. Moreover, the HAIRs must be designed to accurately decode a vast variety of information from communication with patients, and also be able to understand information requests and messages provided to them by health care professionals and support staff. This will take a great deal of careful communication decoding skills to enable health care robots to serve human patients effectively with their interpretation competencies.

HAIRs in health care also must be designed to send meaningful and sensitive messages (encoding skills) to patients in their communication with humans (Kreps, 2014). Not only do the messages robots send to humans need to be understandable to different health care consumers and providers, but the messages to humans also need to actively engage humans with interesting, relevant, and relationally sensitive communication using a powerful relationally reciprocal communication strategy referred to as immediacy (Kreps & Neuhauser, 2013). Immediacy describes sharing messages that encourage relational closeness and leads to enjoyable and involving communication. It promotes active communication participation and fosters message exchange, message attention/exposure, and relationship development (Kreps, 2012). HAIRs must be programmed to adapt the messages they share to meet unique and individual human concerns, interests, backgrounds, and communication orientations (literacy levels, language use, message/channel preferences, and more) so their interactions with individuals will be well received, understood, and enjoyable for the humans (Kreps, 2012, 2014).

Decoding and encoding processes must work in unison for HAIRs to be effective communicators, so their responses to humans are appropriate to the messages humans send to the robot. If a patient asks a robot: When do I need to take my medicine? The robot must be able to provide an appropriate and accurate response. Similarly, when a patient expresses a strong emotion, such as fear, the robot must be able to provide a response that acknowledges and appropriately addresses that emotion. This is how HAIRs in health care can communicatively help patients while determining the best response to specific messages from both human patients and health care providers (Kreps & Neuhauser, 2013). The more natural and effective the interpersonal message exchanges are between health care robots and humans, the more effective these robots will be in interacting to provide needed health information, service, and support (Krist et al., 2016).

Current Use of Humanoid AI Robots and Its Ethical and Social Implications

Health care robotics has been at the center of many efforts to improve health care delivery over the past decade with the rapid development in robot technologies (Cresswell et al., 2018). Particularly, AI that has evolved over the past 65 years has transformed the practice of medicine and the direction of its future (Andreu-Perez et al., 2017). Recently, AI robots have greatly improved health care delivery in terms of enhancing medical diagnosis, treatments, and performance in diverse health care fields, such as psychiatry (Loh, 2018), surgery (Davenport & Kalakota, 2019), remote medical consultation (Marius, 2019), and many other areas of application. Furthermore, as more advanced technology emerges, HAIRs are expected to help promote health care that is safe, excellent, and competent (Cresswell et al., 2018).

The Integration of Humanoid AI Robots in Health Care Settings

HAIRs are now applied to a wide range of health care fields—delivering medicine, screening patients, surveillance, and cleaning and disinfecting medical equipment and hospitals (Khan et al., 2021; Merkusheva, 2020; Tavakoli et al., 2020). Specifically, from the human-machine communication (alternatively, Human-Robot Interaction, HRI) perspective, Khan and colleagues (2021) divided robot technology into the following five categories: telerobot, collaborative robot, autonomous robot, social robot, and wearable robot. Human-operated telerobots can be deployed in health care settings from a distance through wireless network technology. Collaborative robots are designed to augment human-robot interaction. They are also used in the health care industry under careful manual supervision. Autonomous robots (or intelligent machines) are capable of undertaking tasks and making decisions independently with no external control. Social robots, especially in a humanoid structure, are designed to communicate and interact with humans and their surrounding environment. Wearable robots are an assistive robotic technology that utilizes wearable electronic devices to augment human motor functions (Kapeller et al., 2020) and assist clinical decision-making (Khan et al., 2021). For broad applications of robots in health care, Khan and colleagues (2020) classified health care robot utilization into the following 12 categories: receptionist robot, nurse robots, ambulance robot, telemedicine robot, hospital serving robot, cleaning robot, spraying/disinfestation robot, surgical robot, radiologist robot, rehabilitation robot, food robot, and outdoor delivery robot. As shown in these broad applications of robots in health care, HAIRs are now transforming and augmenting health care delivery by performing complex surgical procedures with great precision (Mayo Clinic, 2021), providing nursing care (Hamstra, 2018), helping senior living residents (Kourtney, 2021), disinfecting hospital rooms (Henry Ford Health System, 2020), and providing therapeutic companionship care services (Medical Futurist, 2018).

AI robot technologies in health care settings pose remarkable advantages and considerable limitations simultaneously. While AI robots are beneficial to health care, given their capability to automate health care services, there are some concerns about patient safety and the quality of health care services (Gkegkes et al., 2017). Moreover, from a patient perspective, the issue of cost-effectiveness raises difficulties in accessibility to robot-based medical services as well as overcoming cultural barriers in communicating with robots. AI robots in health care organizations have been advancing in their abilities to facilitate coordination of patient care as Gombolay et al. (2018) view "a robotic assistant may be able to safely and effectively assist with patient care" (p. 1300). However, the integration of HAIRs into health care demands improvement in knowledge and education; responsiveness to people's attitudes, ethics, and human values; and the ability to engage in working practices, leadership, governance, regulations, communication, and physical integration processes (Pekkarinen et al., 2020).

With the rapid advancement and massive investment in AI robotics and its applications, health care organizations are increasingly turning to humanoid robot technologies for improving patient satisfaction in their services and health care quality. The use of HAIRs offers multiple opportunities to improve health care delivery by automating hospital tasks and medical practices (Cresswell et al., 2018).

Opportunities and Challenges Revealed From the Experience of the COVID-19 Pandemic

With the advent of the COVID-19 pandemic, significant efforts have been underway to deploy robots to automatize SARS-CoV-2 testing, perform and support health care and hospital functions, public safety, and people's daily lives in their work and private places (Cresswell et al., 2020; Wang & Wang, 2021). In response to the rapid spread of the infectious disease, the use of robotics technologies can tackle the COVID-19 pandemic more effectively in various ways. For example, robotic applications can support and increase the speed and accuracy of identifying COVID-19 cases (Naseem et al., 2020) and can offer contact-free alternatives to addressing a highly contagious disease like the COVID-19. More substantially, robotic applications can help prevent the transmission of the virus between patients and health care providers. Robotic technology and artificial intelligence can be integrated for surgical procedures and to accurately position patients for radiological imaging, minimizing physical contact between patients and health care providers, and thus further reducing transmission risks (Hussain et al., 2021; Naseem et al., 2020; Zemmar et al., 2020). In addition, robotic cleaners and automated facial recognition technology for COVID-19 contact tracing have been used to slow down the spread of the pandemic (Wang & Wang, 2021).

The COVID-19 pandemic has resulted in an onslaught of AI robots being used for a variety of applications that include improving sanitation and performing fast diagnostic tests under social distancing guidelines, while reducing personal interactions (Zhao et al., 2021). Various intelligent robots have been deployed on the front line to reduce transmission of the virus by carrying out functions of monitoring patients and public places, disinfection, serving and delivering food and other heavy items, food preparation, and telepresence (Wang & Wang, 2021). Additionally, AI can also provide and speed up the provision of documents, medication, food, medical supplies, and other essential items to patients isolated in quarantine and thus help to decrease the chances of spreading the infection by reducing inter-personal contact (Bogue, 2020; Céspedes et al., 2021; Zhao et al., 2021). As rightly postulated by Zemmar and colleagues (2020), "AI, machine learning and robotic technology may well be the next quantum leap" (p. 571). As shown in many places with diverse functions, advanced intelligent robots can not only aid in mitigating the spread of the coronavirus, but also reduce the workload of health care providers by performing many routine tasks (Bogue, 2020; Brunda et al., 2020).

However, Cresswell and colleagues (2020) underscored concerns that limit the implementation of patient-facing intelligent robots, such as high costs associated with deploying and managing these robots and the risk of possible adverse effects these robots may have on health care staff, work practices, and patient interactions. Exemplifying SARs-CoV-2 testing that only can take one sample at a time, but cost much more than other means, they argued that deploying these robots does not substantially increase the number of COVID tests conducted on patients. This study also pointed out that robots with too human-like features may be considered a threat to human patients since the services given by HAIRs could be perceived as rather being less personal and interactive because of the discrepancy in their traditional expectation between robots with some level of mechanical moves and communication and human health care providers. Although the integration of AI-based robots into health care can create tremendous opportunities for patient care as well as for provider and hospital support, ethical concerns have also been raised about implementing these technologies for health care services.

Ethical and Social Concerns and Implications

Increasing efforts are underway to investigate the use of HAIRs as personalized social companions with audio, visual, and movement capabilities to deliver various health treatments through friendly and effective interactions (Scoglio et al., 2019). Cresswell and colleagues (2018) conducted a qualitative study to explore the role of robotics in health care contexts. They interviewed 21 stakeholders with varied backgrounds—academics, engineers, system developers, users of robots in health care settings, suppliers, strategists, and visionaries/futurists. The findings revealed some major barriers that need to be addressed to maximize the benefits of robotic applications, especially for HAIRs. First, concerns among professionals and patients about HAIR technology were attributed to a combination of negative publicity about robots, lack of acceptance of robots, lack of contact with robots, and the perceived threat that robots may outperform or transcend human performance. Second, the appearance of humanoids, either being too robotic or too human, is another issue to consider. For example, being too robot-like demarcates humans from robots, while being too human-like can inflate expectations regarding robot engagement and trust. Another concern is related to several legal and ethical challenges pertaining to using robots in health settings. For example, a dearth of clear and liable regulations on consumer and product safety associated with robot use, the emotional attachment to robots, and under what circumstances health care providers should be mandated to use robot applications were all cited.

Wangmo and colleagues (2019) conducted a multi-site study to explore and assess ethical concerns surrounding the use of Intelligent Assistive Technologies (IATs), specifically in dementia care. They interviewed 20 professional stakeholders—researchers and health professionals—about their perceptions regarding the development and use of IATs in elderly and dementia care. The findings revealed four ethical concerns, including challenges associated with decision-making about the use of IATs for older adults with dementia because of their compromised ability to provide informed consent; concerns surrounding data ownership and sharing as the use of IATs involves sharing of personal data; questions of social inequality because not everyone who needs IATs will be able to afford them because of the relatively high price of IATs; and the importance of human contact as IATs should be complementary and not substitute human contact and empathy when caring for people with dementia. These concerns and challenges seem to be more pronounced for HAIRs because their close resemblance with humans might not be realistically convincing and rather arousing an unsettling feeling among people, also known as the “uncanny valley” phenomenon (Mori et al., 2012). Although increasing efforts have been made to integrate and optimize autonomous applications such as HAIRs into health care settings, these efforts are presented with “specific sociotechnical challenges because social and technical dimensions are progressively, visibly, and disruptively interconnected” (Cresswell et al., 2018, p. 8).

Respect for and safeguarding patient autonomy is another area of concern when applying embodied AI, especially in health care practices. How can AI applications evaluate a patient's full understanding of the information provided? What should be done in cases when patients, such as children, patients with intellectual disabilities, dementia, and severe schizophrenia, cannot provide consent? Related to these issues, prior to approving embodied AI devices for clinical use, it will be critically important to perform a rigorous risk assessment and regulatory oversight to mitigate possible harm resulting from therapeutic encounters as well as malfunctioning robots (Fiske et al., 2019). In addition, there is a need for clear standards on issues related to information privacy, maintaining confidentiality, and securing data collected by assistive robots and intelligent virtual agents due to a lack of guidance on the development of HAIRs.

Recommendations for Development and Diffusion of Fully Autonomous Humanoid Robots for Health Care Services

Along with this fast growth of humanoid robot production, it is necessary for us to proactively prepare for the post-pandemic world with such advanced AI technologies. Humanoid robot developers like Hanson Robotics plan to produce and place a significantly increasing number of humanoid robots in the coming years (Hennessy, 2021). In this creation of a new normal with humanoid robots, this article proactively points out some important suggestions for designing and diffusing humanoid health care robots from the communication perspective.

For the preparation of a new world with advanced AI technology, the communication standpoint provides important recommendations not only for practical development and implementation of AI machines but also for adopting a cognitive frame that demands a paradigm shift. A shift of paradigm refers to changing the worldview; in other words, how we see the world. In the past, AI machines were considered devices that each user or individual could control and modify like other mechanical tools. Therefore, although people frequently communicated with AI machines in their everyday lives, the machines were regarded as mechanical objects. However, as artificial intelligence technology develops with machine-learning ability, AI machines are increasingly seen as communication partners or co-workers with their own ethos like humans (Coleman, 2018). Because of the machine-learning ability that keeps evolving and updating communication data, AI machines are able to become increasingly autonomous and capable of being decision-making communicators. For example, HAIRs have been evolved to autonomously learn and follow human partners' communication attributes (e.g., vocal tones, volumes, accents, etc.), different emotional states (e.g., happy, sad, angry, etc.), and different topics raised during conversations with humans. As a result, AI machines practice communication that is based on the results of analyzing data obtained through communication with humans, enabling them to communicate like real humans and providing a natural communication experience as they communicate with real humans.

In health care facilities where human patients need special care and demand careful and considerate communication, the ways that AI machines communicate are critically important especially to create mutual trust between patients or customers and health care providers. Specifically, how health care HAIRs look, move, and speak are important factors when developing humanoid robots for health care services and implementing them in health care facilities. First, in terms of outlook, a number of studies have demonstrated the effectiveness of using machine-looking AI robots implemented in several health care facilities, especially for promoting patient engagement and adherence (e.g., Park, 2019; Purtill, 2019). Taking this one step forward from the present to the future, can human-looking AI robots facilitate communication with patients in hospitals and health care facilities even more effectively?

Kim (2019) conducted a survey to investigate the US public's trust in humanoid robot doctors that humans would have in the (near) future. In that study, humanoid robot doctors were supposed to look and speak exactly like human doctors. The result of this study showed not much difference between consumer trust in humanoid robot doctors and human doctors. The same type of study was conducted in South Korea and produced very similar results (Kim & Kim, 2021). DiSalvo and colleagues (2002) examined whether facial features of a robot would affect the human perception of robots and found that the dimensions of the head and facial features greatly influence the perception of humanness and favorability among participants. This implies that HAIRs' appearance is likely to affect people's perception of robots when people receive health care services by HAIRs. Therefore, more studies on the issues of facial features and body shape are needed for developing HAIRs for health care services.

In addition to physical features, Pelau and colleagues (2021) found that the ability of robots to express empathy in communication with humans was an essential factor in promoting trust in these machines. This indicates that communication with HAIRs is more than information sharing. Related to this, we have to consider both verbal and nonverbal communication elements in developing HAIRs. Conventionally, verbal communication is understood as the use of language, while nonverbal communication is all other elements that facilitate communication between interlocutors. In developing HAIRs for a health care purpose, these two communication elements should be well considered to increase the adoption of HAIRs. First, in terms of verbal communication, the ability to accurately understand humans' use of language for sharing information can be improved through AI's machine-learning ability as they communicate with more humans. Coupled with verbal communication, nonverbal elements of communication should be also examined with formative research about how humans perceive different nonverbal cues. This work can guide the implementation of HAIRs to increase trust in communication with HAIRs. A number of studies have been conducted to accumulate knowledge about how AI robot's paralinguistic nonverbal cues, such as tone (e.g., Moridis & Economides, 2012), pitch (e.g., Edwards et al., 2019; Niculescu et al., 2013), and gendered voice (e.g., Crowelly et al., 2009), as well as kinesic cues such as gestures (e.g., Kose-Bagci et al., 2009), and other body movements (e.g., Coleman, 2018), affect their communication with humans. Such studies should be continued in different communication settings and with different groups of human communication partners to provide more communication data for developing HAIRs.

In addition to the designing elements in developing more effective AI humanoid robots, what accelerates the diffusion of AI humanoid robots in our health care system? Based on the theory of diffusion of innovations (DOI), diffusion can be facilitated and accelerated not only by the notable attributes of innovation, but also with purposive dissemination strategies (Kim & Dearing, 2014). While the attributes of innovation are directly related to innate functionality and design elements of innovations, purposive strategies focus more on how to control the target population's perception of the innovations that developers or diffusion agencies aim to sell or disseminate. Particularly, in order to design a diffusion strategy targeting a large group of potential adopters, DOI suggests harnessing a small group, called opinion leaders who have a great influence on the target population's communication network to promote adoption (Rogers, 2003). Therefore, identifying the opinion leaders is very important to design a purposive diffusion strategy. If we apply this communication strategy to a larger unit of analysis from individuals to organizations (or systems), which sector in our health care system can be an opinion-leading sector that needs the assistance of HAIRs and also has great visibility to show its advantages and effectiveness of implementing HAIRs?

Early studies of AI robots in health care showed some mixed perceptions about implementing them for direct caring activities (e.g., Göransson et al., 2008). However, more recent studies began to present and highlight social dimensions of communication as a positive aspect of implementing HAIRs in health care (e.g., Coeckelbergh, 2010; Göransson et al., 2008; Kim, 2019). Empirically, countries with a large elderly population are likely to consider the implementation of robots positively (Gnambs & Appel, 2019). For example, many European countries with a higher demand for elderly care have been found to consider the use of autonomous AI robots favorably to care for the elderly (Greve, 2016). In fact, AI mobile robots have been implemented in many nursing homes and elderly health care facilities in many countries in Europe, Asia, and North America (e.g., Girling, 2021; Greve, 2016; Purtill, 2019). Most importantly, it has been reported that the elderly in nursing homes favor AI robots' assistance, and they often develop personal relationships with their health care robots (Purtill, 2019). Based on this empirical evidence, it is recommended that health care HAIR developers focus first on elderly people's communication and then other health care demands in expanding the applications of robots broadly.

A current feature of the diffusion of innovation is that diffusion occurs not solely by an individual's active choice of adoption, but also by a passive or external demand with the desire to be connected with others. For example, regardless of an individual's favorability, smartphone use has become necessary for communicating with others in modern society, which illustrates a forced diffusion of this communication technology. Although an individual may have been reluctant to use a smartphone, it is increasingly more likely that smartphones have become an important part of that person's life due to the external demand to use this new communication medium (Fullwood et al., 2017). This exemplifies, in DOI, how an innovation can diffuse from an implementation stage (initial use of an adopted innovation) to a confirmation stage (an innovation becoming part of an adopter's life) (Rogers, 2003). This feature of the forced diffusion of innovation by certain external demands demonstrates that a previous perception of innovation can be replaced by an intended perception that is designed by utilizing a purposive diffusion strategy. Therefore, the favorability of HAIRs in health care can be purposively developed by increasing the visibility of HAIRs and the frequency of communication with robots in health care settings over time. Theoretically, from the DOI perspective, a purposive increase of trialability—giving people chances to try this innovation—could greatly help improve people's perception of HAIRs implemented in health care facilities.

For the future development and diffusion of HAIRs in health care, the COVID-19 pandemic created a unique social environment. Because of many limitations of human labor in all health care areas, which are caused by the deadly infectious virus, many health care organizations have desperately sought opportunities to use AI robots to provide alternative health care services (Landi, 2020). Coupled with the demand from the field, researchers and governments have discussed developing and implementing robotized pandemic responses for future pandemics since the beginning of the COVID-19 pandemic (Barfoot et al., 2020).

The COVID-19 pandemic also brought a change in people's lifestyles. As the pandemic period has prolonged, a self-quarantined lifestyle has been routinized as the new normal globally. This transformed personal lifestyle is replacing human communication partners with AI machines (Röösli et al., 2021), which notably increases human experience with AI machines. As a result, an increasing number of individuals feel connected with their AI communication partners (e.g., chatbots, AI devices, etc.). Related to this new normal, many studies highlight the important role of AI machines, particularly in mental health (Cheng & Jiang, 2020; D'Alfonso, 2020), which will hasten the time when we see HAIRs in hospitals, rehabilitation centers, nursing homes, and other health care facilities.

Conclusion

This article discussed HAIRs in health care fields, focusing on how the humanoid attributes of the robots could make a difference in our health care system. In fact, many areas of our health care system are now adopting diverse HAIRs, including nursing (Pepito et al., 2020), rehabilitative care (Tanioka, 2019), mental health care facilities (Miller & Polson, 2019), and other health care settings. As the adoption of HAIRs increases along with the development of related technologies, it is expected that the implementation of robots is likely to be broad and diverse within the health care system. Based on this anticipation, this article proactively suggested several directions for developing advanced HAIRs from a communication perspective.

Current research on HAIRs raises more questions than it provides answers: How effectively can HAIRs replace human health care professionals, and are humans really able to share their physical and mental health problems with HAIRs openly? What would be the role of human health care professionals if communication with HAIRs becomes the norm in society? Will health care consumers disclose their private health information more comfortably with human or robotic health care practitioners? More broadly, if HAIRs become the prevalent communication partners in our daily lives, how will this influence human identity?

Communication with HAIRs in our daily lives as well as within health care facilities still sounds like a dream for most people around the world. However, if we do not proactively and openly prepare for the coming robotic future despite experiencing the rapid diffusion of human-machine communication, we will not be well-prepared to maximize the effective use of this new health communication modality. A couple of hundred years ago, people read *Frankenstein* as a fictionalized novel. With the state-of-the-art HAIR technology, the story might become a reality if we blindly create artificial humans and breathe life into embodied HAIRs. Therefore, it is important that researchers should examine the pros and cons of this new technology health care modality, proactively identify the best directions for further technology development, and monitor the use of HAIRs in every sector of our society. Research on the effective use of HAIRs can contribute to building a foundation for cultivating a desirable digital technology future in health care that is one of the most critical sectors for dealing with life and death in human lives.

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