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Review Article

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Human-Robot Interaction and Social Robot: The Emerging Field of Healthcare Robotics and Current and Future Perspectives for Spinal Care

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Recent advances in robotics technology and artificial intelligence (AI) have sparked increased interest in humanoid robots that resemble humans and social robots capable of interacting socially. Alongside this trend, a new field of robot research called human-robot interaction (HRI) is gaining prominence. The aim of this review paper is to introduce the fundamental concepts of HRI and social robots, examine their current applications in the medical field, and discuss the current and future prospects of HRI and social robots in spinal care. HRI is an interdisciplinary field where robotics, AI, social sciences, design, and various disciplines collaborate organically to develop robots that successfully interact with humans as the ultimate goal. While social robots are not yet widely deployed in clinical environments, ongoing HRI research encompasses various areas such as nursing and caregiving support, social and emotional assistance, rehabilitation and cognitive enhancement for the elderly, medical information provision and education, as well as patient monitoring and data collection. Although still in its early stages, research related to spinal care includes studies on robotic support for rehabilitation exercises, assistance in gait training, and questionnaire-based assessments for spinal pain. Future applications of social robots in spinal care will require diverse HRI research efforts and active involvement from spinal specialists.

Keywords: Human-robot interaction, Robotics, Social robot, Healthcare, Spinal care

INTRODUCTION

Since the advent of the Fourth Industrial Revolution, technologies such as artificial intelligence (AI), the Internet of Things, and big data have been advancing as core technologies across various industries.[1] In addition, AI robots are rapidly emerging as key players that will lead the era of the Fourth Industrial Revolution in the future. Already, robots are actively utilized not only in industrial settings but also in the field of healthcare, where surgical robots and others are actively used in real clinical environments.[2,3]

Until recently, industrial robots have performed tasks in separated spaces from humans for safety reasons. However, with the development of robots that share workspace with humans and engage in social communication, such as social robots, the importance of the academic field known as human-robot interaction (HRI) is gradually increasing.[4] HRI in the medical field is still relatively unfamiliar, but within this domain, the subfield of physical HRI has already been applied in the development of surgical robots.[2,3] Recently, there has been a growing interest in social robots, such as care and nursing robots, which support the emotions and treatment of the elderly or patients.[5] With

this increasing interest, it is expected that HRI will play a crucial role in the future development of healthcare robots.[2]

The aim of this review paper is to introduce the fundamental concept of HRI and social robot, and its present application in healthcare areas. Ultimately, it discusses the current and future perspectives of HRI and social robot in spinal care.

THE CONCEPTS OF HRI AND SOCIAL ROBOT

Social robots refer to robots designed for the purpose of human-social interaction and communication. The initial development in this field took place in the 1990s at the MIT Media Lab, where the world's first social robot, KISMET, was created. KISMET was a robot capable of expressing emotions in response to humans, and its facial expressions were developed by integrating theories from various fields, including psychology, evolutionary biology, and child development.[6]

In 2014, SoftBank introduced the humanoid robot Pepper, which became one of the most widely distributed commercial social robots.[7] Pepper is equipped with facial recognition capabilities to read emotions and engage in interactions. It can perform various tasks and provide information through direct interaction via a touchscreen. Pepper has been utilized in diverse fields, including the healthcare sector, where it has been employed in patient treatment (Fig. 1).[8]

In 2022, the humanoid robot Ameca showcased remarkable advancements in technology, expressing natural movements and a variety of facial expressions that make it difficult to distinguish from human interactions. Additionally, it demonstrated a high level of conversational ability.[9] Furthermore, with the recent emergence of advanced conversational AI chatbots like chat generative pre-trained transformer (ChatGPT), the potential for the utilization of social robots has increased even further. ChatGPT engages in natural conversations with users, not only responding to questions on various topics but also understanding nuances of emotions and language, providing a richer conversational experience.[10]

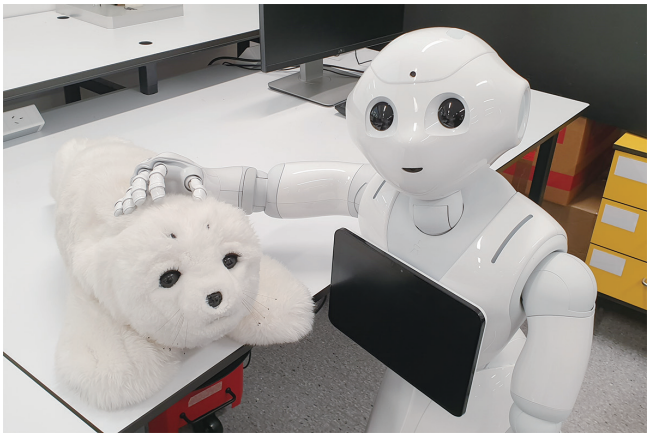

Fig. 1. Two well-known examples of social robots are the humanoid robot Pepper (right) and the animal-shaped robot Paro (left).

Alongside these technological advancements, social robots are being utilized in various fields such as homes, entertainment, education, healthcare, and more.[11] Consequently, HRI is gaining significant attention as a crucial academic discipline.

HRI is a relatively new area that studies the interactions between humans and robots. However, the concept of HRI has already been present in novels and movies contemplating various issues that can arise in the relationship between humans and robots. For instance, The Three Laws of Robotics in Isaac Asimov's novels encompass crucial principles related to safety, ethical philosophy, and other issues when robots interact with humans. Each principle emphasizes that the actions and interactions of robots should occur safely and ethically in relationships with humans.[12]

The definition of HRI is interpreted in various ways. From some perspectives, HRI has been understood as a subset of robot technology related to AI and robotics. However, the recent concept of HRI encompasses research in all academic fields related to the interaction between humans and robots. This includes interdisciplinary research that goes beyond engineering fields like robotics and AI, delving into psychology to explore how humans perceive and interact with robots, design to enhance the user experience of robots, and even philosophical reflections on the existence and ethics of robots.[2,4,13]

HRI can be broadly divided into 2 subfields, namely, physical HRI and social HRI.[4,14] Physical HRI primarily focuses on understanding and enhancing various aspects that arise in environments where robots physically interact and collaborate with humans. In the field, research primarily focuses on aspects such as robot control, motion planning, user convenience, and safety. For instance, research on haptic technology falls under this category.[15] Additionally, healthcare robots like surgical robots, exoskeleton robots, and transport robots serve as examples of physical HRI.[2,16] On the other hand, social HRI research focuses on exploring the technology and theories that enable robots to effectively communicate and collaborate with humans in social situations. The research areas and content within social HRI are diverse, but they can be generally outlined as follows.[4]

1. Development of Perception, Recognition, and Expression Technologies for Robots to Interact With Humans

This is the most fundamental research area in HRI, encompassing robotics and AI technologies. In this field, various perception technologies, including face recognition, expression recognition, gesture recognition, object recognition, human following, and speech recognition, are developed. Additionally, technologies for situation awareness, deducing user intentions, emotional states, personality, are developed.[17] This includes the development of expressive capabilities using arms and body movements, as well as technologies for language-based communication and emotional expression.

2. Research on Human Psychology and Perception Regarding Robots

This field explores the complex interactions between humans and robots, studying how psychological and social factors influence the perception, interaction, and formation of relationships with robot entities. In particular, it focuses on research related to the anthropomorphism of robots, trust, empathy, ethical and social implications, as well as the emotional and cognitive aspects of HRI.[4] The psychological foundation of HRI contributes to robots communicating more effectively with humans and creating a positive user experience. This field is primarily led by social scientists, particularly psychologists, and has gained emphasis recently with the emergence of the term "robot psychology."[18]

3. Design of Robots Capable of Interaction With Humans

HRI design encompasses not only the appearance of the robot but also the unseen user experience design, including aspects of psychology, interaction, service, and character. It involves designing intelligence to mimic ethical decision-making or behaviors like humans by examining and observing human traits and behavior patterns. Additionally, it includes designing practical usage scenarios and interactions that align with the robot's purpose through user research. Service design to meet customer requirements to succeed in the commercial market is also part of this.[5,19]

However, HRI is not performed individually in each field but is an interdisciplinary field where engineering, social sciences, design, and various disciplines collaborate organically to develop robots that successfully interact with humans as the ultimate goal. Especially in specific fields like healthcare, not only medical knowledge but also, and the essential involvement of healthcare professionals such as doctors and nurses are required for user-centered HRI design, clinical research, verification (Fig. 2).

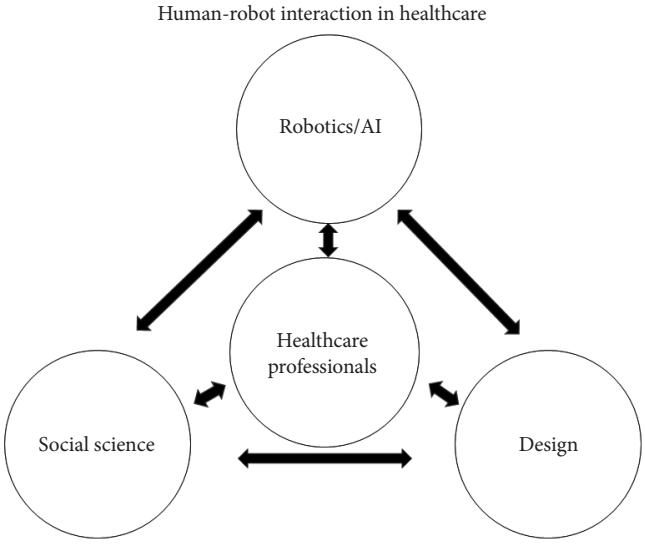

Fig. 2. Human-robot interaction (HRI), an interdisciplinary field, merges engineering, social sciences, and design to create robots that interact effectively with humans. In healthcare, medical professionals is essential for user-centered design and research in HRI. AI, artificial intelligence.

The interdisciplinary collaboration of HRI can be processed as follow. First, teams collaborate to determine the robot's requirements based on its intended use, such as assisting with daily activities, providing companionship, and monitoring patients in a healthcare setting. Second, Engineers build prototypes based on these requirements. Psychologists or healthcare professionals then test these prototypes with real users to observe interactions and gather data on the robot's effectiveness and user satisfaction. Third, based on feedback from testing, designers and engineers iteratively refine the robot's design and functionality. Psychologists or healthcare specialists provide insights on how changes might affect user interaction and emotional response. Fourth, once the robot is finalized, it is deployed in real-world settings. Continuous evaluation helps to gather long-term data on its performance and impact, informing future improvements. A representative example of interdisciplinary collaboration in healthcare is the PARO therapeutic robot. This interdisciplinary approach addresses both technical challenges and human factors, ensuring robots are functional, engaging, and supportive, thus fostering innovation and higher user satisfaction.[20,21]

THE EMERGENCE OF SOCIAL ROBOT AND HRI IN HEALTHCARE

In the field of healthcare, there is currently a growing interest

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in surgical robots and rehabilitation robots, following the success of the da Vinci surgical robot. Remote surgery or navigation-based surgical robots, as well as rehabilitation robots designed for physical rehabilitation, are actively being utilized in clinical settings.[2,3]

On the other hand, while social robots are not yet widely deployed in actual clinical settings, some robots have been commercialized and implemented, with ongoing related research being conducted.[22] In healthcare, the key roles performed by social robots include the following.

1. Nursing and Care Assistance

Social robots can be utilized to provide care to patients and support various activities in daily life. They can be particularly helpful for elderly or patients living alone. Robots can perform various roles such as medication administration, meal assistance, basic medical monitoring, and more.[11]

2. Social and Emotional Support

When patients experience stress, anxiety, or depression, robots can respond to these emotions by listening and providing words of comfort or calming actions to stabilize the patient's emotions.[23]

3. Rehabilitation and Cognitive Enhancement in the Elderly

Healthcare robots can support physical rehabilitation or activities aimed at enhancing the cognitive abilities of the elderly. For example, as part of physical therapy, robots can engage in exercises with patients, or through brain training games, they can improve the cognitive abilities of the elderly.[24]

4. Medical Information Provision and Education

Social robots can provide medical information to patients and conduct medical education. Robots assist in delivering information and education on medication management, disease prevention, and healthy lifestyles.[2]

5. Patient Monitoring and Data Collection

Social robots can monitor the health status of patients and collect necessary data. For instance, robots can measure a patient's heart rate, blood pressure, body temperature, etc., and transmit this information to healthcare professionals, enabling real-time tracking of the patient's health status.[25]

Various HRI research is being conducted for healthcare social robots.[2,4] As a prominent example, HRI research have been conducted on utilizing various social robots for the therapeutic purpose of children with autism spectrum disorder (ASD) effectively.[26] Representatively, the interaction with NAO robot has been reported to have positive effects on enhancing social skills, emotion recognition, and conversational abilities in children with ASD.[27] Recently, there has been research aimed at enhancing the assessment, monitoring, and treatment of children with ASD by integrating ChatGPT with social robots like Pepper to enable real-time dialogue solutions.[28]

As another example, there is HRI research aimed at cognitive rehabilitation for dementia patients. In 2009, the representative animal-shaped social robot, PARO, received approval from the U.S. Food and Drug Administration as a neurological therapeutic device. Through clinical trials, PARO has been proven effective in reducing stress, alleviating depression and anxiety, mitigating dementia-related behavioral and psychological symptoms, and enhancing communication abilities among dementia patients (Fig. 1).[29] The recent meta-analysis investigates the impact of social robots on depression and loneliness among older adults in care facilities. The study reviewed multiple randomized controlled trials and found that social robots significantly reduce depression and loneliness in this population. The analysis underscores the potential of social robots as effective non-pharmacological interventions to enhance mental health and social well-being in long-term care settings.[30]

Telepresence robots are the most prominent robots in the healthcare field. They can play roles in the medical field such as telemedicine and counseling, monitoring chronic conditions, providing education and specialized counseling for healthcare professionals, and facilitating social interaction for long-term care or isolated patients.[31] Especially during the coronavirus disease 2019 (COVID-19) pandemic, telepresence robots garnered significant attention for remote medical care for isolated patients and emotional support in quarantine situations. During the COVID-19 pandemic, a study in British Columbia, Canada, explored the use of telepresence robots (Double 3) by residents, families, and staff in long-term care homes. Through interviews and focus groups, 5 key themes emerged: staying connected, regaining autonomy, reducing caregiver burden, addressing environmental and technical challenges, and managing scheduling issues. Overall, the study found that telepresence robots facilitated social connection maintenance between residents and families despite pandemic restrictions.[32] In the field of HRI, researches have been made to develop user-friendly interfaces with a focus on user experience for healthcare providers, patients, and caregivers.[33] Examples of the representative social robots and HRI applied in healthcare, along with notable re-

Table 1. The representative social robots and their applications in healthcare

Name	Company/Institute	Application	Key features	Reference
PARO	Intelligent System	Therapy for dementia patients	Interactive communication, responsive to touch	Shibata and Coughlin[29]
Pepper	SoftBank Robotics	Patient engagement and support	Speech recognition, facial recognition, interactive screen	Pandey and Gelin[7]
Moxi	Diligent Robotics	Assisting nurses with routine tasks	Autonomous navigation, item delivery, task automation	Kyrarini et al.[43]
NAO	SoftBank Robotics	Autism therapy and education	Voice interaction, gesture recognition, programmable	Tapus et al.[27]
Jibo	Jibo, Inc.	Patient companionship and engagement	Voice recognition, expressive movements	Jeong[44]
Buddy	Blue Frog Robotics	Elderly care and social interaction	Home automation control, telepresence	Milliez[45]
Kaspar	University of Hertfordshire	Autism therapy and social skills development	Human-like appearance, customizable responses	Robins et al.[46]
ElliQ	Intuition Robotics	Elderly companionship and wellness	Cognitive stimulation, health monitoring	Pratt et al.[47]
Temi	Temi	Telehealth and patient interaction	Autonomous navigation, voice assistant, telepresence	Yoo et al.[48]
QTrobot	LuxAI	Autism therapy and special education	Emotion recognition, interactive games	Horstmann et al.[49]

search and commercialization cases, are summarized in Table 1.

THE CURRENT AND FUTURE PERSPECTIVES OF HRI AND SOCIAL ROBOT IN THE SPINAL CARE

Recently, surgical robots are also emerging as a key keyword in spinal surgery. In spinal surgery, robots are primarily focused on navigation-based pedicle screw guiding.[34] There is also significant interest in providing walking assistance for patients with spinal cord injury through exoskeletons or robot-assisted physical rehabilitation therapy.[2] However, clinical applications of social robots for spinal patients are rare. Nevertheless, socially assistive robotics technology has the potential to offer a range of medical services, encompassing care, monitoring, remote rehabilitation, and emotional support, for patients with spinal disorders. The following are the examples of current and future application of social robots and HRI research relevant to the spinal care (Fig. 3).

Typically, these social robots can be applied in rehabilitation exercises, gait training, and walking guidance for spinal patients. Vircikova and Sincak[35] applied the NAO humanoid robot as a trainer for the rehabilitation and prevention of scoliosis in pediatric hospitals and elementary schools. In the study, children freely engaged with a robot to develop a relationship prior exercise and imitated the rehabilitation exercise. The study showed the potential of humanoids robot to enhance children to exercise in an entertaining and effective way. Cespedes et al.[36] applied social robot as a collaborator agent to promote patient engagement and performance during the gait rehabilitation therapy. In the experiments, patients who used social robots showed an improvement of 18.44% in thoracic curvature and 32.23% in cervical curvature compared to the control group. The study showed the practicality of incorporating a social robot into gait rehabilitation programs as a supplementary component. In particular, walking exercise assists spinal patients in early recovery after surgery (ERAS) and contributes to the restoration of spinal flexibility and strength. The social robot can encourage the walking exercise by a supportive and social interaction with patients. At the same time, it offers assistance in various forms, including physical support and monitoring of gait during their walking activities. Piezzo and Suzuki[37] conducted a study on utilizing the Pepper robot as a walking trainer for elderly individuals. The HRI was designed to motivate them to walk more while simultaneously providing assistance, including physical support and gait monitoring. In the study, older individuals indicated a preference for the robot to walk in front of them rather than alongside. They expressed high acceptability in terms of interest, trust, and usefulness for robot as a walking trainer.

Measurement of pain severity and patient-reported outcome measures (PROMs) is essential and requires continuous moni-

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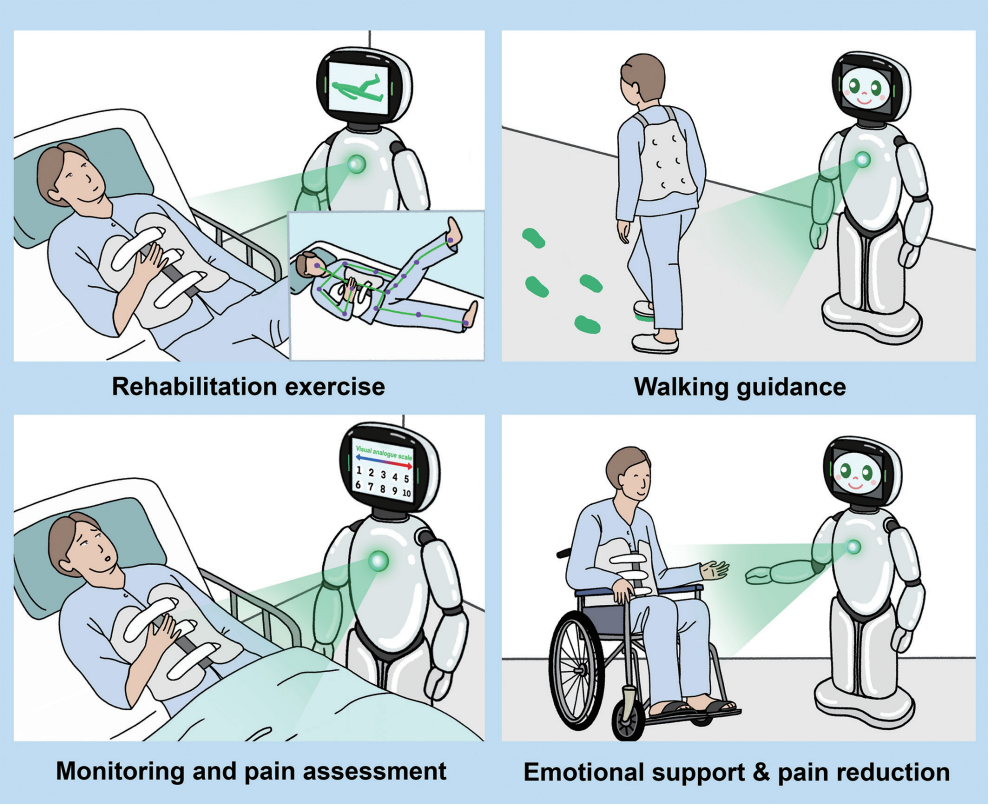

Fig. 3. The examples of current and future application of social robots and human-robot interaction research relevant to the spinal care.

toring in spinal patients. Such monitoring tasks can be undertaken by social robots as part of their duties. Boumans et al.[38] explored the feasibility of a social robot to gather PROM from elderly patients. The design of the robot dialogue included a personalized welcome, PROM-related inquiries, confirmation requests, expressive statements, utilization of a support screen displaying answer options, and accompanying robot gestures. The results showed that the effective and successful gathering of PROM data from older individuals can be accomplished through a social robot. Nam et al.[39] designed a spoken dialogue system (SDS) for use in clinical assistant robots within the ward, aimed at assessing spinal pain through conversations with inpatients. The SDS systematically asked questions and recognized responses through voice dialogue to automatically record and monitor information such as the location, pattern, intensity of pain, psychological status related to pain, and the quality of sleep for both pre- and postoperative spinal surgery patients. The SDS demonstrated satisfactory results in terms of user satisfaction and performance accuracy for doctors, nurses, and patients. Importantly, social robot can be effectively applied in the collection of PROMs such as visual analogue scale, Oswestry Disability Index, 36-item Short Form health survey, which are crucial for the evaluation and monitoring of spinal patients. Social robots can be applied to acquire basic medical history information from newly admitted spinal patients through conversation (Fig. 4).

Prior studies have indicated that interaction with PARO or humanoid robots reduces clinical pain among pediatric patients, cancer patients, and children undergoing medical procedures. Human-robot social touching has been reported to positively impact the reduction of pain perception.[40] Geva et al.[40] evaluated the effect of touching the social robot PARO on mild and strong pain ratings and on stress perception in 60 healthy young participants. When touching the robot, mild pain ratings decreased only in the social interactive group, while strong pain ratings decreased similarly in both the interactive and non-interactive group. While there are currently no specific instances of its application to alleviating pain in spinal patients, it appears to be applicable in reducing spinal pain among pediatric and elderly patients.

As mentioned earlier, the application of social robots for spinal patients and research in HRI are still in very early stages. However, the rapid advancement of robotics technology and AI

Fig. 4. A desktop telepresence robot Dasom K conducting pain assessment.

in recent years is bringing the clinical application of social robots for supporting spinal patients to a practically feasible level. Specifically, various contents for ERAS of spinal patients can be integrated into social robots and applied. Effective social interaction with patients is crucial for social robots to be helpful in spinal care. This necessitates consideration not only of relevant robotics and AI technologies but also the psychological aspects of patients experiencing spinal pain. In particular, various HRI research efforts are needed, taking into account medical knowledge and user-centered HRI design from spinal specialists. Future HRI research and development of social robot in healthcare and spinal care is expected to explore diverse applications further. Future advancements in AI could enable social robots to provide highly personalized care, adapting their interactions based on individual patient needs and preferences. With advancements in telepresence technology, robots could facilitate remote healthcare delivery, allowing doctors to interact with patients and monitor their health from a distance. Future HRI research will focus on enhancing the long-term engagement of

Table 2. Summary of key roles and future perspectives of social robots and human-robot interaction in healthcare and spinal care

Category	Key roles	Future perspectives
General healthcare		
Emotional support	To provide companionship and emotional support to patients	Enhanced emotional intelligence for better patient interaction and support.
Cognitive therapy	Aid in cognitive training and therapy for patients with dementia or cognitive impairments	Development of personalized therapy programs based on AI and patient data.
Engagement	To increase social interaction among elderly and isolated individuals and improve social interaction skill in children with autism	Advanced adaptive learning algorithms to tailor interactions based on individual progress.
Rehabilitation	To guide patients through exercises and physically assist patients with limited mobility	To assist patients with a broader range of physical tasks such as mobility exercises, daily activities.
Education	Education on medication management, disease prevention, and healthy lifestyles	Tailored educational programs that meet the specific needs and preferences of individual patients and elderly users.
Monitoring	To provide health monitoring and medication reminders	Enhanced remote monitoring capabilities and integration with telehealth services.
Spinal care		
Rehabilitation	Future development of robots to assist with spinal rehabilitation exercises and therapy	Personalized rehabilitation plans using AI to track and adapt to patient progress.
Pain management	Potential use of robots to administer and monitor pain management techniques	Development of smart systems for real-time pain assessment and automated pain relief methods.
ERAS	Future robots to aid in the recovery process after spinal surgeries	Advanced monitoring and support systems to facilitate faster recovery and reduce complications.
Psychological support	Psychological support and motivation during long-term spinal care	AI-driven emotional support tailored to the specific psychological needs of spinal care patients.

AI, artificial intelligence; ERAS, early recovery after surgery.

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social robots, ensuring that they can effectively serve as companions and caregivers over extended periods. The key roles and future prospects of HRI and social robots in healthcare and spinal care are summarized in Table 2.

LIMITATION OF SOCIAL ROBOT AND HRI IN HEALTHCARE

HRI in healthcare holds the potential to provide effective medical services, but it still faces several limitations. Firstly, the healthcare environment is highly complex and diverse, leading to technical challenges in enabling robots to adapt to all situations and perform various tasks. Additionally, the emotional intelligence of robots faces challenges in accurately understanding and responding to the emotional states of patients.[41] Secondly, ethical concerns arise regarding potential compromises to privacy in the collection and processing of health information and patient data. When robots participate in decision-making within clinical situations, the delineation of authority between the robot and healthcare professionals may become ambiguous. there is a need for ethical regulations to define the boundaries of the robot's authority and distinguish it from the authority of healthcare professionals.[22] Thirdly, safety is a fundamental concern in HRI, as emphasized in the 3 laws of robotics. Safety issues are particularly critical when robots physically interact with vulnerable patients, posing a risk of safety concerns during such interactions. In medical situations where rapid responses are crucial, robots may have limitations in appropriately addressing sudden changes or emergencies.[2] Lastly, the development, maintenance, and upgrades of robot technology entail high costs, potentially posing financial challenges for healthcare institutions or patients. Integrating robots into healthcare systems involves not only technical challenges but also complexities related to education and training.[42]

Overcoming these limitations requires ongoing technological advancements, effective regulations and policies, and user-centric HRI research and education.

CONCLUSION

This review paper introduces the concept of HRI and social robots, emphasizing their growing significance, especially in current and future perspectives for spinal care. HRI is an emerging research field where engineering, social sciences, design, and various disciplines collaborate organically to develop robots that successfully interact with humans. While the application of social robots and HRI in spinal care is still in its early stages, the rapid progress in robotics technology and AI is making their clinical use increasingly feasible. Social robots hold promise in various aspects of spinal care, including rehabilitation, gait training, pain management, and patient monitoring.

NOTES

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