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Review Article

Considerations on Standardization in Smart Hospitals

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Smart hospitals involve the use of recent ICT (information and communications technology) technologies to improve healthcare access, efficiency, and effectiveness. Standardization in smart hospital technologies is crucial for interoperability, scalability, policy formulation, quality control, and maintenance. This study reviewed relevant international standards for smart hospitals and the organizations that develop them. Specific attention was paid to robotics in smart hospitals and the potential for standardization in this area. The study used online resources and existing standards to analyze technologies, standards, and practices in smart hospitals. Key technologies of smart hospitals were identified. Relevant standards from ISO (International Organization for Standardization) and IEC (International Electrotechnical Commission) were mapped to each core technology. Korea's leadership in smart hospital technology were highlighted. Approaches for standardizing smart hospitals were proposed. Finally, potential new international standard items for robotics in smart hospitals were identified and categorized by function: sampling, remote operation, delivery, disinfection, and movement tracking/contact tracing. Standardization in smart hospital technologies is crucial for ensuring interoperability, scalability, ethical use of artificial intelligence, and quality control. Implementing international standards in smart hospitals is expected to benefit individuals, healthcare institutions, nations, and industry by improving healthcare access, quality, and competitiveness.

Keywords: Smart hospital; ISO; IEC; Healthcare; Standardization; Robotics; Artificial intelligence; Internet of things; Big data; Standards developing organization

INTRODUCTION

The concept for a smart hospital is not clearly established [1,2]; however, the term in general refers to hospitals that involve the use of recent information and communication technology (ICT) innovations to healthcare services. Specifically, the smart hospital typically employs optimized and automated processes within an ICT environment, particularly leveraging robotics [3-5], ultra-connected networks using 5G [6,7], cloud computing [8,9] and big data [10,11], artificial intelligence (AI) [12,13], and integrated healthcare Internet of things (IoT) [13-15]. This integration facilitates various aspects of healthcare, including assessment, treatment, services, and integrated care. The innovation aims at improving healthcare access, efficiency, and effectiveness.

To enhance the efficiency and quality of healthcare of smart hospitals and the delivery of associated healthcare services, standardization in smart hospital technologies is crucial: First, it ensures interoperability, allowing different systems and devices to communicate seamlessly. This interoperability is important for the integration of patient data across various platforms, ensuring that healthcare providers have comprehensive and real-time access to patient information. Standardization also plays a key role in the scalability of smart hospital solutions. Standardized protocols and interfaces enable easier adoption of new technologies across different hospitals and health systems, facilitat-

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ing the streamlined dissemination of innovative healthcare solutions. This scalability is particularly important for public health management, as it ensures that advancements in healthcare technology are not confined to elite institutions but are accessible across the healthcare spectrum, thereby democratizing advanced healthcare. From a policy perspective, standardization is vital in formulating regulations that govern the use of smart hospital technologies. These regulations are necessary to protect patient privacy, ensure data security, and maintain ethical standards in the use of AI and other advanced technologies in healthcare. By establishing clear standards, policymakers can provide a framework for responsible innovation, balancing the need for technological advancement with the imperative to protect patient rights and public health. Furthermore, standardization aids in quality control and maintenance of healthcare services. It establishes benchmarks for performance, safety, and reliability of smart hospital technologies used in hospitals. Adhering to these standards helps in minimizing errors and inconsistencies in patient care, thus enhancing the overall quality and safety of healthcare services.

This study conducts a thorough review of the pertinent international standards applicable to smart hospitals and standards developing organizations (SDOs) that develop standards related to smart hospital technologies. This study places a special focus on the potential standardization items for robotics utilized in smart hospitals, underlining the significance of standardizing such technologies to uphold the highest levels of operational excellence and patient care.

METHODS

This study aimed to explore smart hospital technologies, and standardization organizations and technical committees that are relevant to the smart hospital and its core technologies. Our methodology comprised a multi-faceted approach to identify, categorize, and analyze the relevant technologies, standards, and practices in smart hospitals with special focus on robotics in smart hospitals.

We commenced by identifying a comprehensive list of technologies currently employed in smart hospitals. This process involved mostly a literature review of industry and technical reports [16,17] and investigation of global standardization organizations (International Organization for Standardization [ISO], International Electrotechnical Commission [IEC], and Institute of Electrical and Electronics Engineers [IEEE]) and their committees relevant to smart hospital technologies. To search international standards, we used online standard search interface for ISO and IEC (Online Browsing Platform, https://www.iso.org/obp/ui) to search technical committees using keywords "smart hospital," "digital hospital," "artificial intelligence," "cloud computing," "big data," "high-speed network," "Internet of things," "IoT," "robotics," "augmented reality," "virtual reality," and "mixed reality." A group of five researchers were involved in reviewing the scopes, publications, and standards published to understand their roles and contributions to smart hospital standardization. Our study also included a thorough review of existing standards applicable to smart hospitals. The group assessed these standards for their scope, applicability, and relevance to the technologies identified. This review helped in understanding the current standardization landscape and identifying gaps where new standards may be necessary. Building on the insights gained, we identified standardization approaches suitable for smart hospitals (Figure 1) and established the prelimi-

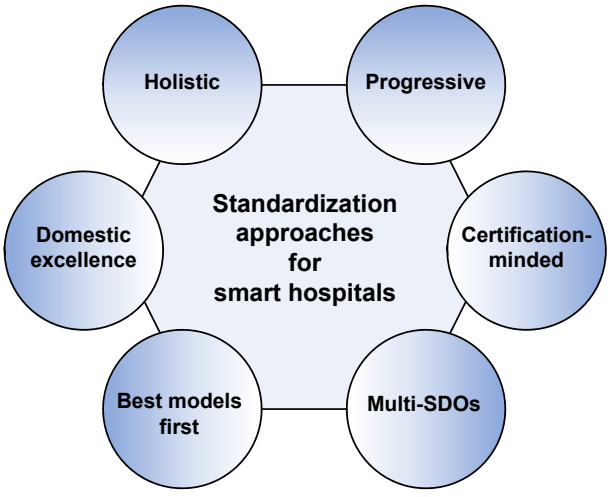

Figure 1. Standardization approaches. SDOs, standards developing organizations.

nary standard items for one of core technologies of smart hospitals—robotics, particularly the standard items developed by the Pandemic Prevention Robotics Project Group.

The Pandemic Prevention Robotics Project was conducted from July 2020 to June 2024 for 4 years. The Group used ICT-based robot technologies to develop pandemic response robots. The goal of the Group was to develop three types of robot ICT convergence life quarantine solutions: (1) for intensive healthcare sites, (2) for temporary healthcare facilities, and (3) for daily quarantine spaces to solve and improve problems with customized quarantine systems for each type.

A survey was conducted in the nursing team of the negative pressured isolation ward of a university hospital to identify their tasks which could be helped and replaced by robotic technologies as shown in Table 1. The survey identified the following areas in which robotics can replace tasks: aspiration care, medication administration, blood sampling, hygiene care, enteral nutrition, postmortem care, and medication replacement/exchange.

The Group then developed the following robots and related technologies:

1. Specimen extraction robot system

This system is image-based automatic sampling planning technology and intelligent target (nasopharynx) contact recognition technology. The robot, designed for non-contact nasal specimen collection, ensures the safety of the test subjects by preventing excessive force during swab insertion and automates the sample collection process, thus enhancing the sample handling capacity of healthcare institutions.

2. Delivery robot system

This system is designed to deliver essentials like food, daily supplies, and medicines to patients, and collect trash or healthcare waste, transporting them to designated locations. Main components of the system include a non-contact material transport and delivery robot platform, autonomous driving modules, and a modular manipulator for item delivery and collection.

3. Disinfection robot system

This system is designed to work for multi-use facilities and living spaces and includes object identification and disinfection control algorithms, and high-output, large-area

Table 1. Robotics for nursing tasks

Variable	General patients	Critically-ill patients
Nurse	Ward nurses	Intensive care unit nurses
Main tasks	- Vital signs measurement - Measurement of intake and excretion - Medication (oral and injection) - Blood glucose measurement sample collection - Assistance during mealtime - Aid in taking X-ray - Environmental cleanup	- Includes all the tasks of ward nurse - Parameter setting of various treatment equipment (ventilator, infusion pump and others) - 1-hour interval vital signs, intake, and excretion measurement - 2-hour interval repositioning and aspiration (suction of sputum and others) - Continuous intravenous medication for vital sign stabilization and sedation - Blood sample collection for point-of-care testing at 1- or 2-hour intervals - Hygiene nursing (oral care and bed bathing)
Difficulties encountered	- Wearing protective clothing when performing all nursing care - Even a simple task requires putting on and taking off protective equipment - More than 5 times of sample surface disinfection and packaging steps required for transportation after sample collection (requiring about 10 minutes or longer) - No work related to emptying the contaminated waste bins	- Includes all difficulties faced by ward nurses - In the event of a change in the patient's vital signs, protective equipment should be worn to control medication injected - Protective clothing should be worn even for simple task such ventilator adjustment - For a deceased patient, about 12 persons are involved to take care of the body (sealing and transporting the body and cleaning the environment, etc.
Potential tasks replaced by robots	- Empty contaminated waste bins - Clean up the environment such as floor cleaning - Vital signs, degree of dyspnea, pain, and amount of intake/excretion are directly entered into the robot by the patient. - Delivery of oral medications according to the time of administration - Meal delivery - Specimen transport - Transporting goods - Assistance when changing protective clothing	- Includes robot technology proposed for tasks done by ward nurses - Parameter control of various treatment equipment (mostly button or touch screen controlled) - Drug replacement/exchange

ultraviolet-C–LEDs (light-emitting diodes) for disinfection.

4. Real-time monitoring and remote operation of treatment equipment

This system aims to reduce the number of times healthcare staff need to enter isolation wards, prevent cross-infection within the ward, and contribute to emergency response. It focuses on equipment such as ventilators, hemodialysis machines, and extracorporeal membrane oxygenation devices.

5. Movement tracking

The primary objective was to develop an accurate AI-based path tracking source technology using deep learning methodologies. This was to trace the movements of confirmed cases and their close contacts quickly and accurately. The technology includes automatic path tracking technology using multi-view CCTVs (closed-circuit televisions) and sensors.

While developing these robotics technologies, the Group realized that standardization of research artifacts was the critical element that would determine the applicability of the research and development (R&D) results. The robotics standard items proposed in the paper are the end results of such consideration by the Pandemic Prevention Robotics Project.

RESULTS

1. Technologies for smart hospitals

A smart hospital is the result of streamlined organization of various technological elements, and Figure 2 below shows the key technologies that form the technical backbone of the smart hospital.

1) Internet of things

IoT, or the Internet of things, is a network where various objects communicate and exchange information. Its core technologies include the internet, wireless communication, RFID (radio frequency identification), and sensor network technologies. When IoT is merged with cloud computing and AI, it leads to the development of innovative service models, broadening the range of connected devices. In the context of smart hospitals, IoT technology is important for improving clinical effectiveness, patient experience, and the efficiency of hospital operations.

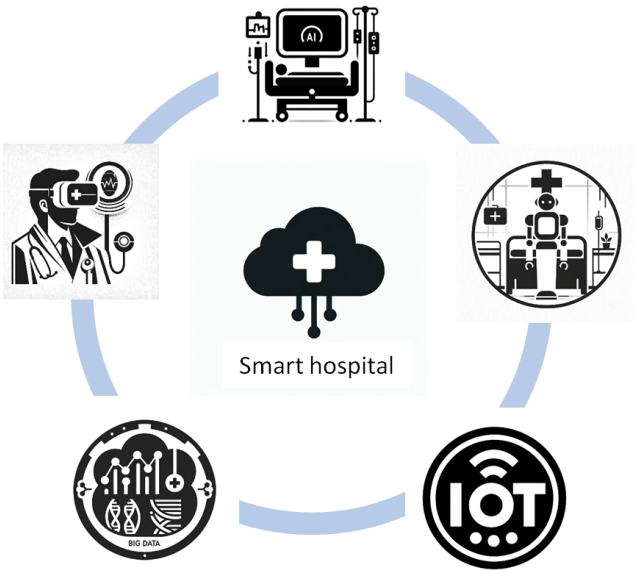

Figure 2. Key technologies of smart hospitals.

2) Artificial intelligence

AI-based healthcare services use AI's core functions like learning and reasoning to diagnose and predict diseases, with healthcare organizations adopting these services for enhanced patient care. Advancements in AI, particularly in healthcare image analysis using deep learning and electronic health record data, are improving the accuracy and timeliness of disease diagnosis and treatment. Moreover, the use of AI in smart hospitals automates administrative tasks, optimizing budgets and staffing efficiency, minimizing equipment downtime, ensuring timely healthcare supply procurement, and enhancing patient communication through virtual assistants.

3) Robotics

Robots are increasingly central to healthcare services, aiding in surgery, rehabilitation, nursing, and logistics management. Robotic systems enhance the precision in manag-

ing and delivering medications, meals, and other necessities. Additionally, robotic process automation, powered by AI, boosts administrative efficiency in hospitals, ensuring time and cost savings and reliable work processing.

4) High speed network

Advanced communication networks such as 5G and Wi-Fi 6 are revolutionizing healthcare by enabling personalized smart healthcare solutions through the integration of wearable technology, machine learning, and big data. These high-speed networks facilitate cutting-edge healthcare services, including remote surgery with minimal latency, real-time vital sign monitoring, AI-based diagnostics, and virtual hospital visits, significantly improving healthcare access and quality.

5) Cloud and big data

Cloud computing enhances healthcare services quality by offering flexible access to healthcare data and scalable storage, integrating vast health information systems for real-time data streaming, and improving interoperability among various healthcare systems and applications for efficient patient care. Concurrently, big data analytics are vital for predicting clinical outcomes and optimizing patient care, enabling early disease diagnosis and prevention, and improving healthcare supply chain management and service personalization, thereby driving innovative improvements in both healthcare service quality and operational efficiency.

6) Extended reality (VR/AR/MR)

Augmented reality (AR), virtual reality (VR), and mixed reality (MR) are transformative technologies in smart hospitals, enhancing healthcare through surgical simulations, patient education, disease diagnosis, and telehealth collaboration. These technologies (AR/VR/MR) are instrumental in improving healthcare training, aiding in preoperative planning for complex surgeries, and enhancing patient care and rehabilitation through immersive experiences. Furthermore, MR facilitates remote expert consultation in surgeries, while AR improves patient engagement with their treatment.

2. Standard development organization for smart hospitals

A smart hospital is an integrated model that merges science and technology. Central to this model is the development of advanced systems that exhibit functions typically realized in robotics and autonomous systems. Furthermore, this model integrates an array of specialized technologies such as signal processing technology, AI, and a wide range of application-specific technologies. The integration of these diverse technologies enables the creation and execution of sophisticated, interconnected systems specifically designed for the healthcare sector.

There exists a multitude of standards that may play a role in the operation and management of smart hospitals. However, many of these guidelines and standards were not originally developed with smart hospitals specifically in mind. They often have originated from broader domains such as information technology, data security, healthcare quality, and healthcare device regulations. This means that while they are applicable and crucial to the functioning of smart hospitals, they might not fully address the unique complexities and nuances specific to these technologically advanced healthcare facilities. This gap underscores the need for the development of tailored standards that can more effectively cater to the distinct requirements of smart hospitals, ensuring a higher level of precision and relevance in their application.

1) International Organization for Standardization

ISO is a global body that develops and publishes a wide range of standards with its technical committees comprising domain experts who create standards in specific subject areas. The technical committee, ISO/technical committee 299 (robotics), has provided a robotics glossary, performance, and operation criteria for service robots, specialized standards for navigation and waist support robots, modularization requirements, as well as safety and application guidelines for the industry.

2) International Electrotechnical Commission

ISO/IEC joint technical committee (JTC) 1, a collaboration between IEC and ISO for information technology

standards, has a subcommittee, ISO/IEC JTC 1/SC 42 (artificial intelligence). The latter published a standard, ISO/IEC 23053 (framework for artificial intelligence systems using machine learning). And ISO/IEC JTC 1/SC 38 (cloud computing and distributed platforms) published a technical report, ISO/IEC technical report 23188 (cloud computing: edge computing landscape). Also, IEC/technical committee 129 (robotics for electricity generation, transmission, and distribution systems) addresses standardization of inspection robots that be used in the air, underwater, sub-surface and in difficult terrains. IEC/technical committee 47 established key sensor standards.

3) Institute of Electrical and Electronics Engineers

IEEE is engaged in standardization efforts in robotics, covering areas like robot navigation and ethical aspects of autonomous robots.

The IEEE Robotics and Automation Society's Standing Committee for Standards Activities collaborates with various stakeholders spanning researchers, industry, and other SDOs to identify standardization needs in robotics. Key standards include the IEEE Standard Ontologies for Robotics and Automation (IEEE 1872-2015) that cover essential terms, definitions, attributes, relationships, and others, facilitating task-based reasoning and communication. The IEEE Standard for Autonomous Robotics (AuR) Ontology (IEEE 1872.2-2021) extends IEEE 1872-2015 for AuRs by defining additional ontologies. The IEEE Standard for Robot Map Data Representation for Navigation (IEEE 1873-2015) includes models and formats for two-dimensional metric and topological maps. The IEEE Ontological Standard for Ethically Driven Robotics and Automation Systems (IEEE 7007-2021) sets out ontologies at various abstraction levels, providing the necessary definitions and concepts for ethically driven robots and automation systems. New standardization areas in human-robot interactions are also being explored in interaction terminology, interaction design, and measurement of robot agility.

The Engineering Medicine and Biology Society Standards Committee focuses on healthcare robots, setting a standard for classification, terminologies, and definitions for healthcare robots.

3. Technical committees of ISO and IEC for smart hospitals

Table 2 presents representative technical committees and sub-committees of ISO and IEC that are engaged in standardization efforts pertinent to foundational technologies of smart hospitals.

Table 3 shows samples of relevant standards from ISO and IEC for each core technology in smart hospitals.

4. Smart hospitals and technologies in Korea

Korea is a leader in smart hospital technology, which is a result of a concerted effort by the government and major corporations. The government plan to establish 18 smart hospitals by 2025 [18]. Korea Health Industry Development Institute (KHIDI) fosters smart hospital for the realization of future smart healthcare. KHIDI also provides a smart healthcare service model and organic connection & proliferation among healthcare institutions. Supporting this transformation, major hospitals in Korea have shown significant digital maturity. Large enterprises, such as Samsung and Hyundai, funded hospitals and are increasingly investing in the healthcare and digital technology sectors. This shift has brought the value of Korea's digital health market to significant heights, with a recorded value of £4.4 billion as of the end of 2020 [19]. A study revealed that close to 90.5% of hospitals in Korea have implemented electronic medical records (EMR) systems, with 42 tertiary hospitals maintaining a 100% EMR implementation rate since 2015 [20]. These developments collectively underline Korea's status as a global frontrunner in smart hospital technology, setting a benchmark for healthcare innovation worldwide. Notably, Newsweek announced the world's best smart hospitals 2024 for hospitals leading the way in electronic functionalities, telemedicine, digital imaging, AI, and robotics [21]. Most of the selected Korean hospitals (14 in total) have stood out in AI and digital imaging. These hospitals significantly enhance patient care and healthcare staff efficiency through AI-based real-time biometric monitoring, EMR data integration, and preemptive alert systems, addressing man-

Table 2. TC/SC of ISO and IEC for smart hospitals

Technology category	TC/SC	Title
High-speed network	ISO/IEC JTC 1/SC 6	Telecommunications and information exchange between systems
	ISO/IEC JTC 1/SC 32	Data management and interchange
	ISO/IEC JTC 1/SC 25	Interconnection of information technology equipment
	ISO/IEC JTC 1/SC 27	Information security, cybersecurity, and privacy protection
	ISO/IEC JTC 1/SC 39	Sustainability, IT, and data centers
	ISO/IEC JTC 1/SC 40	IT service management and IT governance
IoT	ISO/IEC JTC 1/SC 38	Cloud computing and distributed platforms
	ISO/IEC JTC 1/SC 39	Sustainability, IT, and data centers
	ISO/IEC JTC 1/SC 40	IT service management and IT governance
	ISO/IEC JTC 1/SC 41	Internet of things and digital twin
	ISO/IEC JTC 1/SC 43	Brain-computer interfaces
Artificial intelligence	ISO/IEC JTC 1/SC 31	Automatic identification and data capture techniques
	ISO/IEC JTC 1/SC 42	Artificial intelligence
	ISO/IEC JTC 1/SC 43	Brain-computer interfaces
	ISO/TC 184/SC 5	Interoperability, integration, and architectures for enterprise systems and automation applications
	IEC/TC 62	Healthcare equipment, software, and systems
	IEC/TC 72	Automatic electrical controls
	IEC/TC 79	Alarm and electronic security systems
	IEC/TC 47	Semiconductor devices
Robotics	ISO/TC 299	Robotics
	IEC/TC 129	Robotics for electricity generation, transmission, and distribution systems
Extended reality	ISO/IEC JTC1/SC 24	Computer graphics, image processing, and environmental data representation
Cloud and big data	ISO/IEC JTC1/SC38	Cloud computing and distributed platforms
	ISO/IEC JTC1/SC 42	Artificial intelligence
UV radiation for germicidal purposes	IEC/TC 34	Lighting

TC, technical committee; SC, subcommittee; ISO, International Organization for Standardization; IEC, International Electrotechnical Commission; JTC, joint technical committee; IT, information technology; IoT, Internet of Things; UV, ultraviolet.

power shortages and reducing potential healthcare errors.

The successful domestic implementation of smart hospital technologies establishes a strong foundation for global expansion, offering a competitive edge in international markets due to the demonstrated efficiency and operational improvements, with leading innovations in medicine delivery/dispensing robots, smart infection control, AI-based fall and pressure sore management, smart outpatient services, and intelligent workflow management (logistics automation and delivery robots), and healthcare information systems. Table 4 shows examples of international ventures of Korean smart hospitals.

5. Standardization approaches for smart hospitals

Innovation serves as the primary driver of growth and prosperity of an economy and standards ensure performance and safety of products and services [22] and define communication interfaces, safety features, and evaluation metrics [23].

One daunting task facing decision makers in industry and policy is to employ standardization judiciously and effectively to bolster innovation, considering the longstanding perception that standards and innovation are inherently contradictory.

While standards may occasionally impede innovation by solidifying inefficient technologies, thus increasing resistance to change, they typically foster innovation by encapsulating technological expertise, establishing a foundation for the development of new technologies [24].

Figure 1 shows basic approaches to be taken when developing standards for smart hospitals. (1) Standardization efforts should take holistic approaches rather than one that

Table 3. Relevant standards for smart hospitals

Core technologies	Related standards	
	ID	Title
High-speed network	ISO/TR 11636:2009	Health informatics: dynamic on-demand virtual private network for health information infrastructure
	ISO/IEC 27002:2022	Information security, cybersecurity, and privacy protection: information security controls
	ISO 27799:2016	Health informatics: information security management in health using ISO/IEC 27002
IoT	ISO/IEC 20924:2021	Information technology: Internet of things (IoT): vocabulary
	ISO/IEC 21823-1:2019	Internet of things (IoT): interoperability for IoT systems—part 1: framework
	ISO/IEC 21823-2:2020	Internet of things (IoT): interoperability for IoT systems—part 2: transport interoperability
	ISO/IEC 30147:2021	Information technology: Internet of things: methodology for trustworthiness of IoT system/service
	ISO/IEC 30161-1:2020	Internet of things (IoT): requirements of IoT data exchange platform for various IoT services—part 1: general requirements and architecture
	ISO/IEC TR 22417:2017	Information technology: Internet of things (IoT) use cases
	ISO/IEC 30165:2021	Internet of things (IoT): real-time IoT framework
	ISO/IEC 30141:2018	Internet of things (IoT): reference architecture
	ISO/IEC 30179:2023	Internet of things (IoT): overview and general requirements of IoT system for ecological environment monitoring
Artificial intelligence	ISO/IEC AWI TR 18988	Artificial intelligence: application of AI technologies in health informatics
	ISO/IEC TR 24030:2021	Information technology: artificial intelligence (AI): use cases
	ISO/IEC TR 24368:2022	Information technology: artificial intelligence: overview of ethical and societal concerns
	ISO/IEC 22989:2022	Information technology: artificial intelligence: artificial intelligence concepts and terminology
	ISO/IEC 24668:2022	Information technology: artificial intelligence: process management framework for big data analytics
	ISO/IEC 23053:2022	Framework for artificial intelligence (AI) systems using machine learning (ML)
Robotics	ISO 8373:2021	Robots and robotic devices: vocabulary
	ISO 13482:2014	Robots and robotic devices: safety requirements for personal care robots
	IEC 80601-2-77:2019	Healthcare electrical equipment—part 2-77: particular requirements for the basic safety and essential performance of robotically assisted surgical equipment
	ISO/TR 23482, part 1 and 2	Robotics: application of ISO 13482
	ISO 19649:2017	Mobile robots: vocabulary
	ISO 9787:2013	Robots and robotic devices: coordinate systems and motion nomenclatures
	ISO/TS 15066:2016	Robots and robotic devices: collaborative robots
	ISO 10218:2011, parts 1 and 2	Robots and robotic devices: safety requirements for industrial robots
	ISO 13482:2014	Robots and robotic devices: safety requirements for personal care robots
	ISO 9409, parts 1, 2	Manipulating industrial robots: mechanical interfaces
	ISO 18646, all parts	Robotics: performance criteria and related test methods for service robots
	ISO 22166-1:2021	Robotics: modularity for service robots—part 1: general requirements
Extended reality	ISO/IEC 23488:2022	Information technology: computer graphics, image processing and environment data representation: object/environmental representation for image-based rendering in virtual/mixed and augmented reality (VR/MAR)
	ISO/IEC 18038:2020	Information technology: computer graphics, image processing and environmental representation: sensor representation in mixed and augmented reality
	ISO/IEC 18039:2019	Information technology: computer graphics, image processing and environmental data representation: mixed and augmented reality (MAR) reference model
	ISO/IEC 3721:2023	Information technology: computer graphics, image processing and environmental data representation: information model for mixed and augmented reality content: core objects and attributes
Cloud and big data	ISO/TS 23535:2022	Health informatics: requirements for customer-oriented health cloud service agreements
	ISO/IEC TR 20547, all parts	Information technology: big data reference architecture
	ISO/IEC 19941:2017	Cloud computing: interoperability and portability
	ISO/IEC TS 23167:2020	Cloud computing: common technologies and techniques
	ISO/IEC 23751:2022	Cloud computing and distributed platforms: data sharing agreement (DSA) framework
	ISO/IEC TR 20547, parts 1, 2, 3, 5	Information technology: big data reference architecture
UV radiation for germicidal purposes	IEC PAS 63313:2021	Position statement on germicidal UV-C irradiation: UV-C safety guidelines

ISO, International Organization for Standardization; TR, technical report; IEC, International Electrotechnical Commission; AWI, approved work item; TS, technical specification; UV, ultraviolet; PAS, publicly available specification.

Table 4. International ventures of Korean smart hospitals by the Korea Health Industry Development Institute

Leading technologies	Leading hospitals	Countries
Pharmaceuticals delivery robots & intelligent authentication	Keimyung University Dongsan Healthcare Center	Japan
Smart infection control	Yongin Severance Hospital	Singapore, Saudi Arabia
Healthcare information systems	National Health Insurance Service Ilsan Hospital	Saudi Arabia, UAE, Thailand
Artificial intelligence-based fall and pressure sore management	Kangwon National University Hospital	Japan, Australia, etc.
Smart outpatient services	Hallym University Sacred Heart Hospital	Switzerland, Denmark, Sweden
Intelligent workflows	Samsung Healthcare Center	France, Germany, Finland, Vietnam, Singapore, Saudi Arabia, New Zealand

focuses on individual technical components necessary for operation of smart hospitals. (2) Standardization should start from the existing R&D outcome, such as the Smart Hospital Pilot Project and Pandemic Prevention Robotics Project, and progressively build other standards on them. (3) Standardization efforts should be directed towards those areas in which Korea has technical excellence such as AI and robotics. (4) Standardization efforts should consider global certification. (5) Standardization efforts should focus primarily on the best models proven domestically and internationally. (6) Standardization should be multi-SDOs such as ISO and IEC.

6. Potential standard items in robotics

The Pandemic Prevention Robotics Project conducted research on the development of a "Pandemic Response Robot & ICT Integrated Prevention Control System" utilizing ICT foundations and robotic technologies.

The Project developed three types of robots integrated with ICT: (1) intensive for healthcare care settings, (2) for living treatment facilities, and (3) for everyday pandemic prevention spaces. The primary areas of development include (1) specimen collection robots, (2) delivery robots, (3) disinfection robots, (4) remote operation systems, and (5) movement tracking technology development. The Project has identified the following potential international standard items for robotics in smart hospitals.

1) Sampling robots

The 15 new international standardization items for sampling robots encompass a comprehensive framework designed for optimizing robotic functionality in the smart hospital, as shown in Table 5.

2) Remote operation

A sample of new international standardization items for tele-ICU in Table 6 emphasizes the development and evaluation of kiosk-based remote monitoring solutions in intensive care environments.

3) Delivery robots

The six new standardization items in Table 7 for delivery robots include a range of guidelines and requirements aimed at enhancing their functionality and safety, particularly in contexts where infection prevention is crucial.

4) Disinfection robots

The nine new standardization items in Table 8 for disinfection robots provide a comprehensive framework for their design, functionality, safety, and effectiveness.

5) Movement tracking/contact tracing

The six new standardization items in Table 9 for movement tracking or contact tracing focus on tracking/tracing and identification technologies, especially in high-risk and multi-purpose facilities.

CONCLUSION

The development of smart hospitals aligned with international standards and obtaining international accreditation is anticipated to have a profound and multifaceted impact on individuals, healthcare institutions, nations, and industry. Over the long term, the streamlined functioning of

Table 5. Potential new standard items for sampling robots

No.	Potential new standard items
1	Sampling robot: vision guidance-based sampling robot's swap insertion location path planning and control technology - Utilizing vision guidance for precise swab insertion path planning and control in sample collection
2	Sampling robot: built-in control system and control framework - A built-in system and framework for efficient robot control
3	Sampling robot: device for interfacing of 3-axis force sensor and digital data processing - Incorporating a 3-axis for sensor and digital processing for enhanced interaction and accuracy
4	Sampling robot: requirements for manufacturing/operation/management/maintenance (quality control) - Establishing standards for manufacturing, operation, management, and maintenance to ensure quality control
5	Sampling robot: subject-adaptive specimen extraction end-effector - Developing subject-adaptive end-effectors for efficient specimen collection
6	Sampling robot: stability/reliability evaluation framework of precision control technology - Standardizing the stability and reliability of precision control technologies
7	Sampling robot: single master/multi slave functional or performance evaluation requirements - Standardizing evaluation criteria for a single-master-multi-slave system regarding functional or performance aspects
8	Sampling robot: real-time control performance evaluation of control system - Standard for evaluation methods for robots' real-time control system
9	Sampling robot: workflow/work process for collaboration with humans (healthcare staff) - Standard for workflows and processes for effective collaboration with healthcare staff
10	Sampling robot: multi/multi-axis control system control/communication structure - Standard for control and communication structure for multi/multi-axis control systems
11	Sampling robot: remote control API - Standardized set of APIs for remote operation of robots
12	Sample collection robots: guidelines for users - Guidelines for users of sampling robots
13	Sample collection robots: guidelines for managers - Guidelines for managers overseeing sampling robots
14	Sample collection robots: auto capsulation/capping requirements - Standard for auto capsulation and capping processes
15	Sample collection robot: verification of deep learning-based colocation recognition algorithm - Verification standard for effectiveness of deep learning-based colocation recognition algorithms in sampling robots

API, application programming interface.

Table 6. Potential new standard items for tele-ICU

No.	Potential new standard items
1	Tele-ICU: functional requirements of the system for remote monitoring of patient status based on kiosks - Standard that defines the necessary system functionalities for remote monitoring of patient status using kiosk-based technologies. It focuses on the critical capabilities that these systems must possess to ensure accurate and real-time monitoring of patients in ICU settings
2	Tele-ICU: performance evaluation requirements for kiosk-based remote operation - Standard that establishes the criteria for assessing the performance of remote operations conducted via kiosks
3	Tele-ICU: kiosk user interface considerations - Standard that emphasizes user interface design in kiosk systems. It addresses the need for standardized interfaces that are intuitive, user-friendly, and conducive to efficient interaction between users and the tele-ICU system
4	Tele-ICU: compatibility requirements for single-master-multi-slave systems - Standard that specifies the compatibility requirements for tele-ICU systems functioning within a single-master-multi-slave framework. It ensures that the system can seamlessly integrate and operate across multiple devices or modules, which is essential for flexibility and scalability in intensive care environments.

ICU, intensive care unit.

the healthcare delivery system will contribute to improved population health and bolster the healthcare industry's global competitiveness.

AI will boost treatment efficacy and safety through intelligent diagnostic systems. Remote collaboration systems in smart hospitals and operating rooms will raise healthcare service standards. Smart hospitals will empower patients to manage their health and access personalized services anytime, anywhere. This will aid in early disease detection, enhance health management, and secure personal health

Table 7. Potential new standard items for delivery robots

No.	Potential new standard items
1	Delivery robots: safe operating guidelines for infection prevention - Standard that specifies the operating protocols that delivery robots should adhere to for preventing the spread of infections. It includes procedures for sanitization, contactless operations, and safe navigation
2	Delivery robots: mobile-operated robot platforms for delivery and collection - Standard that outlines the capabilities and functionalities required for robots that are operated via mobile platforms
3	Delivery robots: high-speed controllers and control algorithms for the operation of modular robotic arms with multi-degrees of freedom - Standard that specifies controllers and algorithms essential for the operation of modular robotic arms with multiple degrees of freedom
4	Delivery robots: system integration and services for management and control of multiple robots - Standard that covers the integration and service requirements necessary for the coordinated management and control of multiple delivery robots. It ensures that systems are capable of handling simultaneous operations, data synchronization, and efficient task allocation among different robots
5	Delivery robots: functional requirements for lunch box service in contaminated areas - Standard that specifies the functional requirements for robots designated for delivering lunch boxes in areas that are contaminated or have a high risk of contamination. It includes design considerations for contamination prevention, packaging safety, and maintaining food quality
6	Delivery robots: visual-based control for the delivery and collection of goods - Standard that specifies visual-based control systems for delivery robots. It specifies the requirements for visual sensors and processing capabilities that enable the robot to accurately navigate, identify, and handle goods during delivery and collection

Table 8. Potential new standard items for disinfection robots

No.	Potential new standard items
1	Disinfection robots: object identification algorithm - Standard that outlines algorithms required for disinfection robots to accurately identify objects in their environment that need disinfection, ensuring targeted and efficient cleaning
2	Disinfection robots: work design and control algorithms - Standard that outlines the necessary design and control algorithms for disinfection robots to operate effectively and autonomously within predefined parameters
3	Disinfection robots: high-power, large-area UV-C-LED performance requirements - Standard that specifies the performance requirements for high-power, large-area UV-C-LEDs used in disinfection robots
4	Disinfection robots: UV-C-LED self-diagnosis operation sequence - Standard that specifies a self-diagnosis sequence in UV-C-LEDs, ensuring the LEDs are functioning correctly and maintaining the effectiveness of the disinfection process
5	Disinfection robots: requirements for manufacturing/operation/management/maintenance or disposal - Standards that cover the comprehensive requirements for the manufacturing, operation, management, maintenance, and disposal of disinfection robots
6	Disinfection robots: measurement techniques for disinfection effects - Standard that specifies techniques to measure disinfection effects, providing a standard for evaluating the effectiveness of disinfection process
7	Disinfection robots: risk and safety assessment of UV-C-based disinfection according to IEC 62471 - Standard that outlines a risk and safety assessment for UV-C-based disinfection, in compliance with IEC 62471
8	Disinfection robots: communication with the central control system for multimodal remote control - Standard that specifies communication between disinfection robots and the central control system, enabling efficient remote control and coordination of multimodal operation
9	Disinfection robots: contamination measurement for proper disinfection - Standard that specifies methods for measuring contamination levels, which is crucial for determining required intensity and duration of disinfection

UV, ultraviolet; LED, light-emitting diode; IEC, International Electrotechnical Commission.

Table 9. Potential new standard items for movement tracking/contact tracing

No.	Potential new standard items
1	Movement tracking: CCTV-based person tracking and re-ID in high-risk/multi-purpose facilities - Standard that specifies CCTV-based tracking of individuals and re-identifying them in high-risk or multi-purpose facilities
2	Movement tracking: three-dimensional movement tracking in high-risk/multi-purpose facilities - Standard that specifies three-dimensional tracking of movements in high-risk and multi-purpose facilities
3	Movement tracking: Beacon-based person re-ID in high-risk/multi-purpose facilities - Standard that specifies Beacon-based re-ID of persons in high-risk, multi-purpose facilities
4	Movement tracking: information on confirmed cases in hospitals and movement data - Standard that specifies requirements for collecting and managing data related to the movements of confirmed cases within hospitals, to ensure precise tracking for infection control and management purposes
5	Movement tracking: training data set and validation data set - Standard that specifies requirements for training and validation data sets for movement tracking
6	Movement tracking: detection and tracking with multi-targeting multi-cameras - Standard that specifies simultaneous detection and tracking of movement using multi-targeting, multi-cameras

CCTV, closed-circuit television; ID, identification.

data, leading to more precise treatments. International accreditation of smart hospitals boosts service quality and global competitiveness. This certification increases the credibility of healthcare institutions and attracts international patients, improving national healthcare quality and global reputation. International standardization in smart hospital technologies drives innovation and increases exports of competitive technologies. This provides domestic smart hospitals and technologies global competitiveness, stimulates job creation, and fosters industrial growth, benefiting the nation overall. In conclusion, the establishment of internationally standardized smart hospitals is expected to generate a multidimensional positive impact, paving the way for the evolution of a sustainable healthcare system both domestically and internationally.

Conflicts of Interest

No potential conflict of interest relevant to this article was reported.

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