# Healthcare 4.0 digital technologies impact on quality of care: A systematic literature review

Dounia Marbouh
Research Associate
Department of Industrial and Systems Engineering
Khalifa University, Abu Dhabi, UAE
E-mail: marbdounia@gmail.com

Vikas Swarnakar
Post Doctoral Fellow
Department of Industrial and Systems Engineering
Khalifa University, Abu Dhabi, UAE
E-mail: vikas.swarnakar@ku.ac.ae

Mecit Can Emre Simsekler
Associate Professor of Industrial and Systems Engineering
Department of Industrial and Systems Engineering
Khalifa University, Abu Dhabi, UAE
E-mail: emre.simsekler@ku.ac.ae

Jiju Antony
Professor of Industrial and Systems Engineering
Department of Industrial and Systems Engineering
Khalifa University, Abu Dhabi, UAE
E-mail: jiju.antony@ku.ac.ae

Fabiane Letícia Lizarelli
Associate Professor
Federal University of Sao Carlos, UFSCar, Department of Production Engineering, Sao Carlos, SP, Brazil
E-mail: fabiane@dep.ufscar.br

Raja Jayaraman
Associate Professor of Industrial and Systems Engineering
Department of Industrial and Systems Engineering
Khalifa University, Abu Dhabi, UAE
E-mail: raja.jayaraman@ku.ac.ae

Jose Arturo Garza-Reyes
Professor of Operations Management
College of Business, Law and Social Sciences
Derby Business School
University of Derby, England, UK
E-mail: J.Reyes@derby.ac.uk

Alireza Shokri
Reader of Operations and Supply Chain Management

Newcastle Business School
Northumbria University, Newcastle, England, UK
E-mail: alireza.shokri@northumbria.ac.uk

Elizabeth Cudney
Professor of Data Analytics
John E. Simon School of Business
Maryville University, St. Louis, MO, USA
E-mail: ecudney@maryville.edu

Samer Ellahham
Clinical Professor
Heart and Vascular Institute and Quality and Patient Safety Institute,
Cleveland Clinic Abu Dhabi, Abu Dhabi, United Arab Emirates
E-mail: ellahas@clevelandclinicabudhabi.ae

**Abstract**

The healthcare industry is transforming into Healthcare 4.0 (H4.0), an era characterized by smart and connected healthcare systems. This study presents a conceptual framework that classifies H4.0 digital technologies into information and communication technology bundles within the healthcare value chain. It also identifies barriers and evaluates digital technologies' impact on quality measures through a systematic literature review and meta-analysis approach following the PRISMA protocol. The analysis reveals that digital technologies in the healthcare sector traditionally consist of sensing-communication and processing-actuation technologies. The findings highlight the significant influence of H4.0 digital technologies on three quality measures: patient safety, patient experience/satisfaction, and clinical effectiveness. While these technologies offer potential benefits, they pose challenges for patients and clinicians, including intellectual property and significance concerns, especially in North America. The proposed framework addresses these issues and enables stakeholders to prioritize, review, and analyze H4.0 digital technologies to enhance patient safety, experience, and clinical effectiveness. This research contributes to the existing literature by being the first comprehensive analysis of the impact of H4.0 technologies on the quality of care. The framework provided in this study offers valuable guidance for stakeholders in selecting appropriate technologies to improve patient outcomes and support the healthcare value chain.

**Keywords:** Industry 4.0; healthcare 4.0; digital health; quality measures; quality; clinical effectiveness

## Introduction

The Fourth Industrial Revolution, also known as Industry 4.0 (I4.0), refers to the trend towards automation and data exchange in industry, supported by modern digital technologies such as the Internet of Things (IoT), Robotic Process Automation (RPA), augmented reality (AR), fog computing, artificial intelligence (AI), and blockchain technology (Tortorella et al., 2020; Jamkhaneh et al., 2022). I4.0 has transformed several industries into a new paradigm–smart, cyberized, and sustainable, and produced substantial improvements in quality and satisfaction (Sakr & Elgammal, 2016). I4.0 has also revolutionized all sectors, including healthcare, moving it away from the traditional "one-size-fits-all" healthcare management approach towards real-time personalized monitoring and therapeutic care (Ramori et al., 2021). Such revolutionary changes brought about a significant impact on healthcare (Hundal et al., 2021). Healthcare delivery started to embrace these technological innovations and reached a new era of change, referred to as Healthcare 4.0 or H4.0 (Thuemmler & Bai, 2017). Healthcare continuously introduces various diagnoses and treatment options and generates and reports extensive data. The data collection requires installing considerable wired and wireless equipment, sensors, and devices in hospitals, clinics, homes, pharmacies, and many other care environments (Antony et al., 2022).

H4.0 can improve the ability to diagnose accurately, enhance healthcare delivery for patients, and empower patients to have more control over and make better-informed decisions about their health (Arden et al., 2021). The concept also offers numerous opportunities to facilitate prevention, early diagnosis of life-threatening diseases, and managing chronic conditions outside traditional healthcare settings (Awad et al., 2021). The recent COVID-19 pandemic has also highlighted the critical importance of digital technologies in healthcare (Kumar & Pumera, 2021; Marbouh et al., 2020), with many people relying on the Internet and digital devices for access to medical services, diagnosis, and treatments.

Healthcare systems gradually recognize that adopting H4.0 technologies can streamline the patient pathway, from identifying symptoms to treatment and long-term support (Jamkhaneh et al., 2022). This paradigm shift has the potential to widen access to healthcare provision, reduce costs, and provide services tailored to individual needs (Al Muammar et al., 2017). These technologies allow medical care to percolate in traditional clinical settings, homes, workplaces, and travel locations. In this manner, participatory medicine lessens the burden on physical healthcare establishments while providing patients care that integrates with their daily lives. These technologies can empower patients to self-advocate, gain control over their care, and make better-informed decisions about their health (Awad et al., 2021).

These technological developments have generated numerous opportunities to improve the quality of care and offer a chance to move beyond the traditional scope of healthcare engineering, such as process improvement and technology implementation. However, using these technologies to improve quality measures is complex, with challenges as several barriers hinder their full effective implementation (Ramori et al., 2021). There are many systematic reviews articles available to date that discuss the application of I4.0 technologies in the healthcare sector or systematic literature review (SLR) on H4.0 (Narkhede et al., 2020; Vassolo et al., 2021; Sisodia & Jindal, 2021; Alloghani et al., 2022; Sibanda et al., 2022; Ahsan & Siddique, 2022a; Jose et al., 2022; Sood et al., 2022). Few systematic literature reviews exist that relate to the impact of I4.0 applications on the healthcare sector (Mustapha et al., 2021; Sony et al., 2022; Mwanza et al., 2023). There is a lack of SLR studies focusing on H4.0 on quality measures, or no studies currently exist concerning H4.0 and quality measures relationship. Hence, there is a need for conducting a thorough review of the literature in the field of H.40 to identify its impact on quality care in a healthcare setting to guide stakeholders and propose future research directions.

Quality in healthcare is one of the most frequently quoted health policy principles, which is currently high on policymakers' agendas. Measuring the quality of care is essential for various stakeholders within healthcare systems as it builds the basis for numerous quality assurance and improvement strategies (Busse et al., 2019). Quality performance measures are the instruments that assist in measuring/quantifying healthcare processes, results, patient perceptions, systems, and organizational structure related to the ability to offer high-quality healthcare and facilitate achieving quality goals in the healthcare sector (CMS, 2022; Ramori et al., 2021). According to the World Health Organization (WHO), clinical effectiveness, patient safety, and patient-centeredness/experience/satisfaction have become universally accepted core care quality measures (WHO, 2018; National Health Services, 2011). However, other measures exist for quality other than those mentioned previously; these include attributes such as appropriateness, timeliness, efficiency, access, and equity (Ferreira et al., 2020). This research aims to identify different bundles of digitalized information and communication technologies used in the healthcare value chain and discuss the impacts of H4.0 on key quality measures and its opportunities and challenges. Locating, retrieving, and reading the literature is time-consuming for academicians (Thomas, 2018). Therefore, to achieve the aims of the present study and provide healthcare providers and academics with valuable insights into the impact of H4.0 technologies on quality measures, this research undertook a comprehensive review of the existing literature. Hence, this paper conducted an SLR to locate relevant existing studies based on prior formulated research questions to evaluate and synthesize their contributions. Therefore, this study attempts to answer the following research questions through a comprehensive SLR:

Q1. What are the different bundles of digitalized information and communication technologies used in the healthcare value chain?

Q2. What are the barriers to H4.0 digital technologies and their implementation challenges?

Q3. How do H4.0 digital technologies impact quality measures such as patient safety, patient experience/satisfaction, and clinical effectiveness?

The rest of this article is structured as follows. Section 2 presents the methodology, including the review process and selection of relevant studies. Section 3 presents the results by discussing the descriptive analysis of studies and the analysis of findings. Section 4 discusses the paper's conclusions and generates insights for practitioners and managers on implementing H4.0 digital technologies to improve patient safety, experience, and clinical effectiveness. Finally, section 5 presents the study's limitations and opportunities for future research.

## Theoretical background

### *Existing literature review studies on H4.0*

Before starting a literature review, it is vital to examine the current literature reviews in the area to gain an overview of existing H4.0 articles and to guarantee the absence of literature reviews focusing on H4.0 technologies' impact on care quality. Table 1 shows the objectives of prior H4.0 literature review studies that differ from the objectives of the present study.

Mwanza et al. (2023) reviewed the impact of I4.0 on the healthcare systems of low- and middle-income countries. The analysis reveals a significant bias toward mobile health and telemedicine technology adoption, with notable research gaps in the usage of additive manufacturing, augmented reality, simulation, and digital twin technologies. Jose et al. (2022) examined the previous research on the competency criteria for implementing H4.0 technology.

The findings indicate that the literature frequently discusses the competencies required for implementing H4.0 in non-clinical deployments of I4.0 applications. Sood et al. (2022) presented a scientometric study of the literature on using artificial intelligence and I4.0 in the healthcare industry in the context of COVID-19. The findings reveal that China has created the most research outputs, even though India is the most collaborative country in this subject. Ahsan and Siddique (2022a) examined the influence of I4.0 on healthcare systems.

The outcomes observed that healthcare and I4.0 merged and matured together during COVID-19, addressing concerns such as data security, resource allocation, and data openness. Sony et al. (2022) investigated the effect of medical cyber-physical systems (MCPS) on the quality of healthcare service delivery. The results reveal that MCPS positively impacts all healthcare service delivery dimensions. Sibanda et al. (2022) examined the current implementation status of I4.0 technology in maternity healthcare. Findings show that most of the research focuses on providing solutions for low- to medium-income countries and focuses more on four technologies: the Internet of Things, cloud computing, big data analytics, and Artificial intelligence. Alloghani et al. (2022) reviewed studies that deal with theoretical or analytical research for data mining applications in the healthcare environment. Vassolo et al. (2021) examined past research on evaluating H4.0 technologies in hospitals and identified the most frequent investment methodologies employed. This study found that the most popular investment techniques center on a single technology, cost analysis, and single decision-maker engagement, which outnumber H4.0 technology value considerations, bundle analysis, and multiple decision-maker involvement. Mustapha et al. (2021) reviewed the impact of I4.0 on the healthcare environment. The study's findings suggest that I4.0 is improving healthcare standards. Sisodia and Jindal (2021) reviewed the literature on I4.0 design principles applied in the health sector. The findings highlight the criteria employed in the fundamental research directions and any current gaps in this field. Narkhede et al. (2020) reviewed the literature on cloud computing applications in the healthcare sector. We identified twelve significant difficulties for retail sectors that operated as operational bottlenecks and proposed using I4.0 technology to address them.

Table 1 shows the existing SLR on the application of I4.0 technologies in the healthcare sector. Only a few SLRs exist that examine the impact of I4.0 applications on the healthcare sector (Mustapha et al., 2021; Sony et al., 2022; Mwanza et al., 2023). Further, no SLR studies focused on H4.0 technologies' impact on quality measures. Thus, this study fills the gap and supports industries by providing a conceptual framework to classify H4.0 digital technologies into bundles of information and communication technologies used in the healthcare value chain and examine their impact on quality measures.

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**Research Methodology**

Considerable literature exists in numerous databases and journals regarding digital health technologies. This body of knowledge, however, is not easily accessible to healthcare providers and managers. Furthermore, finding, extracting, and reading literature requires considerable academic time (Thomas et al., 2004). Thus, to meet this study's goals and offer practitioners and academics relevant insights into the practical implications of the impact of H4.0 technologies on quality measure studies and the future research agenda, a thorough evaluation of the current literature in the concerned field was conducted. This research used an SLR for the following reasons. First, an SLR varies from typical literature reviews in that it employs a more reproducible, scientific, and transparent approach to search and analyze the literature (Tranfield, 2003; Sangwa & Sangwan, 2018b). Second, it provides more transparent and specific guidelines to aid researchers in doing the literature review and presenting the results, as well as a more in-depth discussion of how to analyze the literature (Hu et al., 2015). Third, it reduces bias and mistakes by providing high-quality evidence and an audit trail of the reviewers' judgments, methods, and findings (Tranfield, 2003). Fourth, studies demonstrated that an SLR is adequate for comprehensive, in-depth evaluations (Alkhoraif et al., 2019). Finally, the current study's authors were inspired to perform an SLR by the recent growth in academic interest in SLR studies in digitalized healthcare (Narkhede et al., 2020). The present study adopted the SLR methodology suggested by Tranfield 2003 and detailed the steps in the following sections.

*Planning the Review*

In this stage, the research team formed a panel of four academic experts consisting of experts in healthcare and I4.0. Motivated by the justified rationale of the review, the panel members determined the review protocol at their first meeting. Specifically, the panel clarified the research questions and research objectives. The quality measures for this study were limited to patient safety, patient experience/satisfaction, and clinical effectiveness. According to the WHO (2018), these measures are the key and core dimensions of quality of care.

Database selection and keyword identification are critical to a comprehensive and unbiased review (Caiado et al., 2020). This study selected the following databases: Scopus, Web of Science (WoS), and PubMed. The study considered these three databases due to their comprehensive coverage of peer-reviewed journal articles, review papers, books, conference proceedings, and short surveys. Further, the databases contain different subject areas, including medicine, biochemistry, scientific, social science, engineering, healthcare, economics, science, biology, management, and accounting, among other areas (Zulfiquar et al., 2017; Vassolo et al., 2021; Mwanza et al., 2023). However, these databases captured all the relevant scientific articles sufficient to perform an SLR (Ahsan & Siddique, 2022a; Mwanza et al., 2023). Many researchers and practitioners rely only on Scopus and Web of Science databases for extracting the articles and conduct the SLR (Ahsan & Siddique, 2022b; Ahsan & Siddique, 2022c; Mustapha et al., 2021).

Further, the research limited the search to keywords using the two axes of digital health technologies and quality measures. The following keywords were applied to search the literature: Industry 4.0, hospital 4.0, healthcare 4.0, digital health, patient safety, medical risk, adverse event, medical error, patient experience, patient satisfaction, quality of care, clinical effectiveness, clinical care, and effective care. The keyword search used the Boolean expressions “AND” and “OR”.

*Conducting the Review*

The review team applied the search strings in the three selected databases in the second stage. This initial search resulted in 534 related articles. Then, the search results were screened and examined for their fit with the targeted study objectives, focusing on the title, abstract, and keywords. Literature screening is one of the rigorous processes to refine the extracted articles from the selected databases. The review team used the inclusion and exclusion criteria to refine the articles found during the initial search. This article followed the guidelines and strategy for inclusion and inclusion criteria similar to other SLR articles published in high-ranking journals in the healthcare field (Vassolo et al., 2021; Ahsan & Siddique, 2022a; Mwanza et al., 2023). Considering the inclusion criteria, the review team selected only articles in the selected databases, academic journals, original research articles focusing on patient safety, satisfaction/experience, and quality of care, and articles published in English. The review team excluded those articles published before 2010, articles not included from non-academic databases, grey literature, books, book chapters, conference papers, letter notes, meeting abstracts, editorials, comments, technical reports, and theses. In addition, the review team excluded articles focused on providers (hospitals) rather than patients (customers), review articles, and articles published in non-English language articles. While there is debate about when I4.0 began, predominant research shows that it was in approximately 2010 (Fadilurrahman et al., 2021), which is the reason for including the literature from 2010 in this study. Figure 1 describes including and excluding articles during the evaluation and selection of studies, following the preferred reporting items for systematic reviews and meta-analysis (PRISMA) protocol.

<<<<<<<<<<Insert Figure 1 Here>>>>>>>>>>

The review team members individually read the full text of the articles and excluded those which focused on the impacts on providers rather than patients. Each reviewer recorded rejected articles. The review team checked the process of article search and selection. Concurrently, the research team discussed the results. The research team resolved disputes over including and excluding studies during team meetings. The review team checked the list in a meeting, and there was consent to remove 232 articles.

On the other hand, the reviewers selected those that fulfilled the eligibility criteria for investigation and content assessment. The focus of the searches was limited to articles published in the H4.0 literature and included adequate detail on quality measures. Thus, the final sample included 35 relevant articles listed in Table 2.

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The quality of the articles included in the sample was ensured by evaluating the fit between the research methodology and research questions formulated for the study. The research team also created an Excel spreadsheet that gathered general information from the sample articles. The information included the title, year of publication, journal title, authors, paper type, geographical research area, primary objective, technology discussed, main results, and other features that covered the impacts of H4.0 technologies on quality measures and their implementation barriers.

*Reporting and Dissemination*

The prime objective of this phase is presenting the report, followed by suggestions and translating this into practice (Tranfield, 2003). The "current map" presents the gathered articles and an in-depth look at the practical consequences of the impact of H4.0 technologies on quality measures studies. The future research agenda is offered based on the Excel spreadsheets generated during the second stage. This phase provides a transparent background of the major concerns for researchers, practitioners, and academics.

## Results and Findings

*Descriptive analysis of the reviewed articles*

An analysis of the journals indicates that 26 different journals published the 35 reviewed articles. Figure 2 presents the reviewed articles in the academic journals considered. Out of 35 sample articles, the Journal of Medical Internet Research published six articles, JMIR mHealth and uHealth journals published five articles, and the remaining 24 journals each published one. Further, Journals related to medicine and health published most of the sample articles (56.4%). These journals include the Journal of Medical Internet Research, JMIR mHealth, uHealth, JMIR Dermatol, JMIR Cardio, JMIR Diabetes, and Journal of Allergy and Clinical Immunology.

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Regarding the diachronic evolution of H4.0 technologies publication, Figure 3 shows that published articles increased from 2016 to 2021. The results show that researchers published two articles in 2016, four in 2019, 11 in 2020, and a high publication (18) appeared in 2021. The analysis reveals that researchers did not publish any articles before 2016, and no authors showed interest in this topic in 2017 and 2018. Specifically, the authors published 17.1% of the articles before the end of 2019, while more than three quarters (82.8%) appeared in print between 2020 and 2021; in other words, within the last few years. This diachronic increase verifies the academic community's continuous interest in studying I4.0 implementation in the healthcare sector.

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Figures 4 and 5 show that the authors from 14 countries on six continents conducted the research. Further, the authors conducted most of the research in North America (39%) and Europe (35%). Finally, the countries with the highest H4.0 studies were the USA, Germany, Brazil, Canada, Italy, and China.

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<<<<<<<<<<Insert Figure 5 Here>>>>>>>>>>

Figure 6 shows the different H4.0 technologies the hospitals adopted in their healthcare value chain. The analysis observed that in the majority of the literature (23%), healthcare organizations adopted mHealth apps (23%) to solve their problems and improve service quality, reduce efforts, make effective use of resources, and satisfy the patients. Similarly, 14% of articles mentioned using a remote patient monitoring system, and 11% applied general H4.0 technology (i.e., no specific mention of the H4.0 technology). Further, it is also worth noting that Biomedical digital sensors (9%), IoT (9%), secure messaging (6%), the patient portal (6%), and machine/deep learning (6%) were among the commonly discussed technologies discussed in the sample articles. The literature also highlights the minimum adoption of other H.40 technologies in hospitals, including fog computing (3%), augmented reality (3%), blockchain (3%), VR (3%), IVR (3%), and EHR (3%).

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*Findings Analysis*

This section presents the findings of the SLR analysis by synthesizing knowledge about the 35 selected articles. Table 3 summarizes the most commonly cited H4.0 technologies in the literature. Following the suggestions of Aceto, Persico, and Pescapé (2018) and Tortorella et al. (2020), the H4.0 technologies separate into two principal bundles, including sensing-communication and processing-actuation bundles. The Sensing–Communication bundle combines six H4.0 technologies, including digital sensors, remote patient monitoring, blockchain, IoT, messaging, and mHealth apps. In these technologies, digital sensors mainly focus on providing means for data acquisition from patients and equipment. Once data and information are acquired, they should be transmitted. Information availability allows real-time and remote monitoring of processes, patients, materials, and equipment.

Remote patient technology can facilitate information monitoring. Blockchain creates an efficient, safe, and transparent platform to communicate data across global healthcare (Hasselgren et al., 2021). It can also help save money, time, resources, and support in healthcare development. IoT enables the interconnection between people, materials, and equipment, favoring the agile exchange of information in the hospital. Due to such enhanced interconnection, there is a constant generation of large amounts of diversified data, which establishes the need for proper storing and organizing/synthesizing data into useful information. Cloud computing and AI provide the means for that, contributing to a successful hospital communication process.

Furthermore, secure messaging allows doctors and nurses to interact and collaborate in real time with essential care team members through their mobile devices via a secure network (Mishra et al., 2019). Secure messaging improves clinical workflows and protects patient privacy, increasing the company's overall care and safety. Finally, healthcare organizations utilize the mHealth app to gather health data, deliver public healthcare information, remotely monitor patients, make medical diagnoses, access health records, and aid in disease prevention and management (Vaghefi & Tulu, 2019).

The second bundle included technologies that may change or process data and move or control a system, mechanism, or software based on such information (Tortorella et al., 2020a; Teng et al., 2020). These technologies include machine/deep learning, augmented reality/simulation, virtual reality, and fog computing. The second bundle is processing–actuation. In healthcare, machine learning can create better diagnostic tools for analyzing medical pictures (Ahmad et al., 2018). A machine learning algorithm, for example, may be used in medical imaging (such as X-rays or MRI scans) to seek patterns that suggest a specific condition using pattern recognition.

Similarly, Augmented Reality can simplify various clinical practices, including accurate vein visualization, operating room preparation, medical training, dental practice, real-time access to patient data, 3D medical imaging, and precise symptom detection (Fingent, 2023). VR simulations assist doctors in better understanding what their patients are experiencing. Finally, fog computing helps healthcare organizations monitor patients suffering from chronic illnesses by ensuring that data is captured and processed efficiently (Kim et al., 2019).

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Incorporating these digital technologies and design principles into healthcare originated the concept of H4.0. The H4.0 approach is driven by digital technology adoption, requiring vital changes in healthcare organizations in both technical and social aspects. The introduction of H4.0 also raised the level of interconnectivity and automation in hospitals, enabling patient care and administrative processes to become more effective. However, several barriers and challenges hinder a successful H4.0 implementation. For instance, Boillat and Rivas (2021) stated that managing, maintaining, and designing medical devices, applications, and systems for various healthcare settings are challenging tasks that hinder a successful H4.0 implementation in hospitals. Tortorella et al. (2020b) highlighted that several technical challenges, such as internet coverage, system failures, usability, scalability, portal-related problems, patient appointments, and inability to print results, highly affect the H4.0 implementation process within the healthcare sector or hospitals. Meyer (2020) and Khan et al. (2020) discussed digital illiteracy, poor engagement with technology, and preference for in-person attendance as barriers to adopting H4.0 in hospitals. Similarly, patients with weak eyesight find difficulties in using digital technologies is one of the common barriers that affect H4.0 implementation in the healthcare sector. Table 4 summarizes the list of barriers and challenges extracted from the literature.

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Table 5 summarizes the numerous impacts that H4.0 technologies can have on quality measures in a healthcare setting from the literature. This summary comprises two main sections. The first section includes the sensing-communication bundle comprising digital sensors, mHealth apps, remote patient monitoring/telehealth, IoT, and messaging services. The second section discusses the processing-actuation bundle that comprises fog computing, deep learning/machine learning, and virtual reality/augmented reality. The findings summarized in Table 5 clarify that there is a difference in the impact of H4.0 technologies on those three quality measures. Based on the inference provided in Table 5, we can understand the impact of H4.0 on quality measures in the following manner. For instance, from the category of Sensing–

Communication Bundle, digital sensors have an impact on patient safety because they can help to limit the number of missed elements (Boillat & Rivas, 2021) and helps to identify modifiable risk factors for cognitive frailty (Razjouyan et al., 2020).

Further, it also impacts patient experience/satisfaction because digital sensors can help reduce the frequent domiciliary or in-hospital visits, which gives some mental and financial relaxation to patients and their dependents (Donati et al., 2019). Digital sensors can significantly impact clinical effectiveness because they can help to digitalize the process and share information within the stipulated time (Donati et al., 2019). Digital sensors also improve the identification of high-risk individuals (Razjouyan et al., 2020), guarantee a better quality of care (Boillat & Rivas, 2021), Optimize the chronic patient management processes (Donati et al., 2019) and enable the care team to remotely assign personalized care plans and monitor distance patients' health status (Donati et al., 2019). Table 5 provides a detailed discussion of the impact of several other H4.0 technologies on quality measures.

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**Discussion and Implications**

This study reviewed the impact of H4.0 technologies on key quality measures and discussed their opportunities and challenges. This research suggests two significant findings. First, H4.0 technologies can have a significant impact on quality. For instance, the sensing-communication bundle greatly influences all quality measures. Within this bundle, digital sensors and mHealth apps significantly impacted clinical effectiveness rather than other technologies (i.e., remote patient monitoring, IoT, and messaging). The findings summarized in Table 5 highlight how adopting digital technologies can help digitalize healthcare processes and share clinical information without time and distance barriers (Donati et al., 2019). Digital technologies also improve the identification of high-risk individuals (Razjouyan et al., 2020) and ensure a better quality of care (Boillat & Rivas, 2021), which optimizes chronic patient management processes (Donati et al., 2019). Finally, digital technologies enable remote assign personalized care plans and monitor distance patients' health status (Donati et al., 2019). Whereas adopting mHealth apps can decrease anxiety and pain catastrophizing (Bhatia et al., 2021) and improve subjective well-being and anxiety over time (Montgomery et al., 2021). mHealth apps help share data and risk patterns with the provider to create new, more refined care practices (Jongsma et al., 2020), improve usual care when compared with routine care alone (Khan et al., 2020), and provide access to information, communication, and continuous support (Holden et al., 2020). Thus, this bundle proved very useful in enabling the care team to remotely assign personalized care plans and monitor distance patients' health status.

The second bundle had the most significant impact on patient safety and clinical effectiveness, whereas minimal impact on patient satisfaction. The research noted little influence on patient satisfaction measures after adopting H4.0 technologies of the second bundle based on the inference summarized in Table 5. The present study findings are similar to those of Damery et al. (2021) and Jongsma et al. (2020), in which the patients said they did not see a significant improvement in the quality of care and preferred conventional care delivery. Therefore, while technologies such as remote patient monitoring (RPM) can save time/money for patients and reduce the chances of getting an infection in a health facility, they can also make patients unsatisfied with the care quality as the engagement can be poor (Hamad et al., 2021). However, the finding suggests that their barriers explain the little impact on patient satisfaction with these technologies. As shown in Table 4, H4.0 technologies bring about several technical and social challenges for patients. For instance, most of the authors reported several technical challenges such as "lack of usability, quality of image, internet coverage, lack of system interoperability, internet and system failures, device malfunctions, scalability" (Tortorella et al., 2020b; Kelley et al., 2020; Hasselgren et al., 2021; Mishara et al., 2019).

Similarly, several studies highlight social barriers such as digital illiteracy, poor engagement with technology, preference for in-person attendance, smartphone ownership, and dislike of remote follow-up (Budhwani et al., 2021; Damery et al., 2021; Meyer, 2020). These barriers affect H4.0 technologies implementation in healthcare organizations (Budhwani et al., 2021; Mishara et al., 2019; Kumari et al., 2018). Although, the H4.0 technology interaction with H4.0 barriers is relevant for improving H4.0 implementation. Hence, it is vital to concurrently consider H4.0 technologies and barriers to understand their impact on hospitals. Therefore, removing these barriers can help implement H4.0 technologies in the healthcare sector. Therefore, healthcare managers should focus on these barriers before implementing H4.0 in hospitals or anywhere within the healthcare environment.

Thus, this research provides a conceptual framework for classifying H4.0 digital technologies and examines their impact on quality measures. By addressing barriers and offering valuable insights, this study contributes to the understanding and adoption of H4.0 technologies to improve patient safety, experience, and clinical effectiveness in the healthcare industry.

*Implications*

The consensus is that quality health services worldwide should be effective, safe, and people-centered. In addition, health services must be timely, equitable, integrated, and efficient to realize the benefits of quality healthcare. Digital technologies play an essential role in recording and transmitting patient data. This study sought to classify H4.0 digital technologies affecting healthcare quality by grouping them under two bundles. This study also provides a framework for selecting emerging H4.0 technologies. The framework provides a structure for adopting and selecting digital technologies in healthcare facilities to meet quality standards while understanding their challenges. There are significant managerial implications associated with the results. First, the findings of this study will provide information about digitalized information and communication technologies used in the healthcare sector, which will help managers understand the existing technologies and their importance. Second, the outcomes provide explicit knowledge about the barriers and challenges of H4.0 technologies adoption in the healthcare environment, which motivates organizations for digital transformation and guides managers to grasp the challenges. Third, it will give the idea to healthcare managers understand the real impact of H4.0 technologies on quality measures. These findings will help managers to choose the right H4.0 technologies for implementation in their organization based on the problem or issue facing them. With the outcome of the present study, organizational managers can choose the right technology and save a lot of time and resources from the complicated selection process. The selection of the right H4.0 technology to solve the real industrial problem is challenging as this technology is nascent and unfamiliar to people. Therefore, the present study's findings work as a solution approach or roadmap for healthcare managers to select the right technology. This roadmap will help prepare healthcare organizations to embrace digital transformation and motivate academicians to develop a structured roadmap for H4.0 adoption. Further, the findings support the need to create a systematic framework for H4.0 technologies, and parallel, it opens a new path for researchers to work on it and fulfill the gap.

## Conclusions, Limitations, and Future Research

The extensive integration of new digital technologies into healthcare organizations is associated with new opportunities and applications that lead to better patient safety, patient satisfaction, and clinical effectiveness. Hospitals' interactions with patients and stakeholders also benefit from the envisioned quality measures improvements. Nevertheless, the implications of H4.0 adoption still need to be better investigated. This study aimed to provide a conceptual framework for classifying H4.0 digital technologies influencing healthcare quality measures. Findings showed that H4.0 technologies could greatly influence quality metrics and bring several challenges to patients and clinicians. Also, the proposed framework can assist stakeholders in selecting H4.0 digital technologies to prioritize, review, and analyze appropriate technologies to improve and support patient safety, experience, and clinical effectiveness.

This study has some limitations that fall into four main categories. The first limitation is that this study sought to analyze the diversity of H4.0 in the literature published in the healthcare sector. However, this study only captured articles that discussed diverse H4.0 technologies focused on patients (customers) rather than providers (hospitals). The second limitation is that this study attempted to identify the impact of H4.0 technologies on healthcare quality measures. The present review analyzed the impact only on patient safety, patient experience/satisfaction, and clinical effectiveness. Additional literature analysis could investigate other quality measures (e.g., equity, efficiency, timeliness). The third limitation is that studies on H4.0 implementation primarily focus on the early stages, reporting isolated applications in specific departments or processes. This limitation suggests that the extension of H4.0 implementation and its maturity level may vary significantly across hospitals, influencing perceptions of the subject.

Moreover, the fourth limitation is that the current review only discussed examining sample articles using descriptive analysis. Studies could also examine the literature using categorical analysis. Therefore, future research should focus on empirical studies through survey and interview data collection instruments for further detailed analysis of the provided framework.

Further research in this field can examine healthcare services' various technical, social, economic, and even environmental factors and their value chain to provide a sustainable framework for selecting digital technologies. Future studies can also examine and analyze the proposed framework in the particular services of specialized hospitals and compare it with the findings of this study conducted in general and teaching hospitals. Using new technologies in complex healthcare systems may cause unwanted changes that future studies should evaluate.

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Table 1. Objectives of existing SLR on H4.0

| Reference | Objective |
|---|---|
| Mwanza et al. (2023) | This review assesses the effect of I4.0 on the healthcare systems of low- and middle-income countries. |
| Jose et al. (2022) | The goal of this study is to analyze prior studies on the competencies needed to deploy H4.0 technologies. |
| Sood et al. (2022) | This article gives a scientometric examination of the literature on the use of I4.0 technology in the healthcare industry in the context of COVID-19. |
| Ahsan and Siddique (2022a) | This study examines how I4.0 will affect healthcare systems. |
| Sony et al. (2022) | This study's objective is to evaluate the effect of MCPS on the standard of healthcare service delivery. |
| Sibanda et al. (2022) | This study examines the current status of using I4.0 technologies in maternity healthcare. |
| Alloghani et al. (2022) | This study focuses on articles that discuss theoretical or analytical work for the use of data mining in healthcare analytics. |
| Vassolo et al. (2021) | This study attempts to identify the most prevalent investment methodologies employed and assess prior research on the evaluation of H4.0 technologies in hospitals. |
| Mustapha et al. (2021) | This research intends to examine how I4.0 will affect the healthcare system. |
| Sisodia and Jindal (2021) | This study presents a meta-analytic approach for interpreting, integrating, and critically analyzing I4.0 design principles used in the healthcare industry. |
| Narkhede et al. (2020) | This research intends to present a systematic literature evaluation of cloud computing in healthcare's capabilities, usages, and other difficulties across nations over a time frame. |

Table 2. Article information

| **Paper Title** | **Year** | **Country** | **Main Technology** |
|---|---|---|---|
| It is in the box! Improving the usability and benefits of surgical safety checklists – A feasibility study | 2021 | USA | Hand gesture sensor |
| Evaluating the experiences of new and existing teledermatology patients during the COVID-19 pandemic: Cross-sectional survey study | 2021 | USA | Tele-dermatology |
| The effects of a digital mental health intervention in adults with cardiovascular disease risk factors: Analysis of real-world user data | 2021 | USA | mHealth app (Happify) |
| Differences in secure messaging, self-management, and glycemic control between rural and urban patients: Secondary data analysis | 2021 | USA | Secure messaging in a web-based patient portal |
| Asthma on the move: How mobile apps remediate risk for disease management | 2016 | USA | mHealth app |
| Health-related quality of life improvements in systemic lupus erythematosus derived from a digital therapeutic plus tele-health coaching intervention: Randomized controlled pilot trial | 2020 | USA | mHealth app |
| Toward using wearables to remotely monitor cognitive frailty in community-living older adults: An observational study | 2020 | USA | Chest-worn sensor |
| Use of digital health kits to reduce readmission after cardiac surgery | 2016 | USA | Web-based digital health kits (DHK) |
| Usability and feasibility of consumer-facing technology to reduce unsafe medication use by older adults | 2020 | USA | mHealth app |
| COVID-19 pandemic accelerates need to improve online patient engagement practices to enhance patient experience | 2020 | USA | Hospital website |
| Qualitative and quantitative analysis of patient's perceptions of the patient portal experience with open notes | 2019 | USA | Patient portal |
| User engagement and clinical impact of the manage my pain app in patients with chronic pain: A real-world, multi-site trial | 2021 | Canada | mHealth app (MMP) |
| Delivering mental healthcare virtually during the COVID-19 pandemic: Qualitative evaluation of provider experiences in a scaled context | 2021 | Canada | Telehealth (Zoom) |
| Exploring how virtual primary care visits affect the patient burden of treatment | 2020 | Canada | Telehealth (video) |

| | | | |
|---|---|---|---|
| Measuring the effect of healthcare 4.0 implementation on hospitals' performance | 2020 | Brazil | H4.0 |
| Impacts of healthcare 4.0 digital technologies on the resilience of hospitals | 2021 | Brazil | H4.0 |
| Information and communication technologies in emergency care services for patients with COVID-19: A multi-national study | 2021 | Brazil | ICTs |
| Digital technologies: An exploratory study of their role in the resilience of healthcare services | 2021 | Brazil | H4.0 |
| Why #wearenotwaiting-motivations and self-reported outcomes among users of open-source automated insulin delivery systems: Multi-national survey | 2021 | Germany | Automated insulin delivery (AID) system |
| Measuring atopic dermatitis disease severity: The potential for electronic tools to benefit clinical care | 2021 | Germany | mHealth technology |
| Using postmarket surveillance to assess safety-related events in a digital rehabilitation app (Kaia App): Observational study | 2021 | Germany | mHealth app (Kaia App) |
| Postmarketing safety monitoring after influenza vaccination using a mobile health app: Prospective longitudinal feasibility study | 2021 | Germany | mHealth app (SafeVac) |
| Wound image quality from a mobile health tool for home-based chronic wound management with real-time quality feedback: Randomized feasibility study | 2021 | Switzerland | mHealth app |
| User experiences with and recommendations for mobile health technology for hypertensive disorders of pregnancy: Mixed methods study | 2020 | Netherlands | mHealth technology |
| Remote consultations versus standard face-to-face appointments for liver transplant patients in routine hospital care: Feasibility randomized controlled trial of myvideoclinic | 2021 | UK | Telehealth (videoconferencing software) |
| Effects of an innovative telerehabilitation intervention for People with Parkinson's Disease on quality of life, motor, and non-motor abilities | 2020 | Italy | Virtual reality (VR) |
| Design, implementation, and metrological characterization of a wearable integrated AR-BCI hands-free system for health 4.0 monitoring | 2021 | Italy | Augmented reality (AR) |
| A telemedicine service system exploiting BT/BLE wireless sensors for remote management of chronic patients | 2019 | Italy | Wireless sensors |
| BeyondSilos, a telehealth-enhanced integrated care model in the domiciliary setting for older patients: Observational prospective cohort study for effectiveness and cost-effectiveness assessments | 2020 | Spain | Telehealth (BeyondSilos platform) |

| | | | |
|---|---|---|---|
| Blockchain for increased trust in virtual health care: Proof-of-concept study | 2021 | Norway | Blockchain technology |
| Fog computing for healthcare 4.0 environment: Opportunities and challenges | 2019 | India | Fog computing |
| Automatic medical code assignment via deep learning approach for intelligent healthcare | 2020 | China | Deep learning |
| Recommendation system using feature extraction and pattern recognition in clinical care systems | 2019 | China | N/A |
| An interactive voice response software to improve the quality of life of people living with HIV in Uganda: Randomized controlled trial | 2021 | Uganda | Interactive voice response (IVR) |
| Digital health tools and patients with drug use disorders: Qualitative patient experience study of the electronic case-finding and help assessment tool (eCHAT) | 2020 | Australia | eChat |

Table 3. Bundles of H4.0 technologies in the literature

| **Bundles** | **Technology** | **References** |
|---|---|---|
| **Sensing–Communication** | Digital sensors | Boillat and Rivas (2020)<br>Razjouyan et al. (2020)<br>Donati et al. (2019) |
| | Remote patient monitoring | Hamad et al. (2021)<br>Budhwani et al. (2021)<br>Kelley et al. (2020)<br>Damery et al. (2021)<br>Piera-Jiménez et al. (2020) |
| | Blockchain technology | Hasselgren et al. (2021) |
| | IoT | Braune et al. (2021)<br>McElroy et al. (2016) |
| | Messaging | Choy et al. (2020)<br>Meyer (2020)<br>Mishra et al. (2019)<br>Robinson et al. (2021) |
| | mHealth apps | Bhatia et al. (2021)<br>Montgomery et al. (2021)<br>Kenner (2016)<br>Zhang et al. (2021)<br>Holden et al. (2020)<br>Jain et al. (2021)<br>Nguyen et al. (2021)<br>Maintz et al. (2021)<br>Khan et al. (2020)<br>Jongsma et al. (2020) |
| **Processing–Actuation** | Machine/deep learning | Bhatti et al. (2019)<br>Teng et al. (2020) |
| | Augmented reality | Arpaia et al. (2021) |
| | Virtual reality | Isernia et al. (2020) |
| | Fog computing | Kumari et al. (2018) |

Table 4. Consolidation of H4.0 implementation barriers and challenges

| References | H4.0 Implementation Challenges | Description |
|---|---|---|
| Boillat and Rivas (2021) | Medical device management | Managing, maintaining, and designing medical devices, applications, and systems to fit various healthcare settings can be challenging. |
| Tortorella et al. (2020b), Kelley et al. (2020), Hasselgren et al. (2021), Mishara et al. (2019), Robinson et al. (2021), Zhang et al. (2021), Maintz et al. (2021), Teng et al. (2020), Isernia et al. (2020), Kumari et al. (2018), Byonanebye et al. (2021) | Technical issues<br>• Internet coverage<br>• Quality of image<br>• Lack of system interoperability<br>• Lack of usability<br>• Internet and system failures<br>• Device malfunctions<br>• Scalability | Technical issues were noted such as issues with the portal, appointments, and the inability to print results. |
| Choy et al. (2020), Kumari et al. (2018) | Privacy and data security | Patients identified privacy breaches and data security as more significant concerns than the cost of healthcare. |
| Tortorella et al. (2020b), Budhwani et al. (2021), Damery et al. (2021), Meyer (2020), Khan et al. (2020) | Social barriers<br>• Digital illiteracy<br>• Poor engagement with technology<br>• Preference for in-person attendance<br>• Smartphone ownership<br>• Remote follow-up dislike | Patients with specific characteristics (e.g., past trauma history, older age, not speaking English as a first language) had more difficulties accessing and navigating the video visit technology and registration processes. |
| Choy et al. (2020) | Physical disabilities of patients | Patients with weak eyesight, for instance, find it hard to use digital technologies. |
| Hasselgren et al. (2021), Jongsma et al. (2020) | Cost<br>• The initial investment for technology implementation<br>• High transaction fees (blockchain) | Varying healthcare regulations and accrediting organizations impose different requirements on hospitals that invest significant efforts to achieve compliance. Such actions are usually capital consuming. |
| Meyer (2020) | Regulations<br>• Regulatory changes<br>• Different regulations across geographies | Patients claimed that the regulations regarding using some digital technologies could be confusing and vary from place to place. |

Table 5. Summary of H4.0 technologies impact on quality measures

| Sensing–Communication Bundle | | | | |
|---|---|---|---|---|
| | **H4.0 Technologies** | **Patient Safety** | **Patient Experience/ Satisfaction** | **Clinical Effectiveness** |
| **Biomedical/Digital Sensors** | Hand gesture sensors (Boillat and Rivas, 2021)<br>Chest-worn sensors (Razjouyan et al., 2020)<br>Wireless sensors (Donati et al., 2019) | • Limit the number of missed elements (Boillat and Rivas, 2021)<br>• Identify modifiable risk factors for cognitive frailty (Razjouyan et al., 2020) | • Reduce the frequent domiciliary or in-hospital visits (Donati et al., 2019) | • Complete digitalizing of processes and sharing clinical information without the time and distance barriers (Donati et al., 2019)<br>• Improve identification of high-risk individuals who develop cognitive frailty or associated adverse health outcomes (e.g., dementia) (Razjouyan et al., 2020)<br>• Ensure going through all the elements guarantees better quality of care (Boillat and Rivas, 2021)<br>• Optimize the chronic patient management processes (Donati et al., 2019)<br>• Enable the care team to remotely assign personalized care plans and monitor distance patients' health status (Donati et al., 2019) |
| **mHealth Apps** | MMP (Bhatia et al., 2021)<br>Happify (Montgomery et al., 2021)<br>mAsthma (Kenner, 2016)<br>Wound Management (Zhang et al., 2021)<br>Brain Buddy (Holden et al., 2020)<br>Kaia App (Jain et al., 2021)<br>SafeVac (Nguyen et al., 2021) | • Highlight overlooked components of disease, risk, and care (Bhatia et al., 2021)<br>• Routine medication use and doctor visits (Montgomery et al., 2021)<br>• Track medical performance (Kenner, 2016)<br>• Improve patient literacy (Zhang et al., 2021)<br>• Stay better informed about medications that may be unsafe (Holden et al., 2020)<br>• Report adverse events (Jain et al., 2021)<br>• Allow feedback which can improve safety (Nguyen et al., 2021) | • Enhance the connectivity between patients and their HCPs (Bhatia et al., 2021)<br>• The apps resulted in positive health outcomes, impacting patients' experiences (Montgomery et al., 2021)<br>• Reduce unnecessary travel to the clinics (Kenner, 2016) | • Decrease in anxiety and pain catastrophizing (Bhatia et al., 2021)<br>• The users experienced significant improvement in subjective well-being and anxiety over time (Montgomery et al., 2021)<br>• Share data and risk patterns with the provider to create new, more refined care practices (Kenner, 2016)<br>• Meaningful improvements when added to usual care, compared with routine care alone (Zhang et al., 2021)<br>• JIT information access, efficient and effective communication channels, and continuous support (Holden et al., 2020) |
| | Tele-dermatology (Hamad et al., 2021)<br>Zoom meetings (Budhwani et al., 2021) | • Easy access to primary care through timely appointments with no booking required (Hamad et al., 2021) | • Reduce time and money (Hamad et al., 2021)<br>• Easier routine follow-up (Damery et al., 2021) | • Virtual visits appeared to improve access to primary care through timely appointments with no booking required and reducing the risk of infection by not |

| | | | | |
|---|---|---|---|---|
| **Remote Patient Monitoring** | Videoconferencing software (Kelley et al., 2020; Damery et al., 2021)<br>Telehealth platform (Piera-Jiménez et al., 2020) | • Reduce the risk of infection by not going to a healthcare facility (Budhwani et al., 2021) | | going to a healthcare facility. (Hamad et al., 2021)<br>• Routine medication use and doctor visits (Damery et al., 2021)<br>• Track medical performance, and improve patient literacy (Piera-Jiménez et al., 2020) |
| **IoT** | Automated insulin delivery (AID) system (Braune et al., 2021)<br>Digital Health Kits (DHK) (McElroy et al., 2016) | • Improving management of diabetes-related complications and increasing safety by avoiding hypoglycemia (McElroy et al. 2016; Braune et al. 2021) | • Positive improved sleep quality thanks to technology (McElroy et al., 2016; Braune et al., 2021) | • Highlight the unmet needs of people with chronic diseases (Braune et al., 2021). |
| **Messaging** | Patient portal (Mishra et al., 2019)<br>eChat (Choy et al., 2020)<br>Hospital website (Meyer, 2020) | • Improve understanding (education) and refresh the memory of patients (Mishra et al., 2019; Choy et al., 2020; Meyer, 2020) | • Communicate the situation more effectively (Mishra et al., 2019; Choy et al., 2020; Meyer, 2020)<br>• Reduce experiences of stigma (Mishra et al., 2019; Meyer, 2020) | • Improve self-care thanks to medication adherence (Mishra et al., 2019; Meyer, 2020)<br>• Engage more with healthcare providers (Mishra et al., 2019; Choy et al., 2020) |
| **Processing–Actuation** | | | | |
| **Fog Computing** | Fog computing (Kumari et al., 2018) | • Assist doctors in making smart decisions during an emergency (Kumari et al., 2018) | • Patients can manage current and historical medical history/bills using a mobile application or a web interface which makes their overall experience positive (Kumari et al., 2018) | • Increased collaboration between stakeholders as FC allows patients and medical practitioners to access the data anytime, anywhere (Kumari et al., 2018) |
| **Machine/Deep Learning** | Feature extraction and pattern recognition (Bhatti et al., 2019)<br>Automatic medical code assignment via DL (Teng et al., 2020) | • The system helps providers detect some rare diseases (Bhatti et al., 2019)<br>• Highlight issues in a real-time environment (Bhatti et al., 2019)<br>• Assist management and providers in analyzing the drastic change in chronic diseases (Teng et al., 2020) | N/A | • Improve the quality of health monitoring, disease-trend modeling, and early intervention with evidence-based medical treatment (Bhatti et al., 2019)<br>• Identify causes of diseases (Bhatti et al., 2019)<br>• Establish diagnoses (Teng et al., 2020)<br>• Detect side effects of beneficial treatments (Teng et al., 2020)<br>• Monitor clinical outcomes (Teng et al., 2020) |
| **Augmented and Virtual Reality** | Augmented reality (AR) (Arpaia et al., 2021)<br>Virtual reality (VR) (Isernia et al., 2020) | • Reduce the number of times the operator has to shift attention from the patient to the equipment, thus, fewer medical errors (Arpaia et al., 2021)<br>• Decrease incidents of falling (Isernia et al., 2020) | N/A | • Patients had a positive global cognitive level, memory, positive affect, and mental health results (Isernia et al., 2020; Arpaia et al., 2021) |

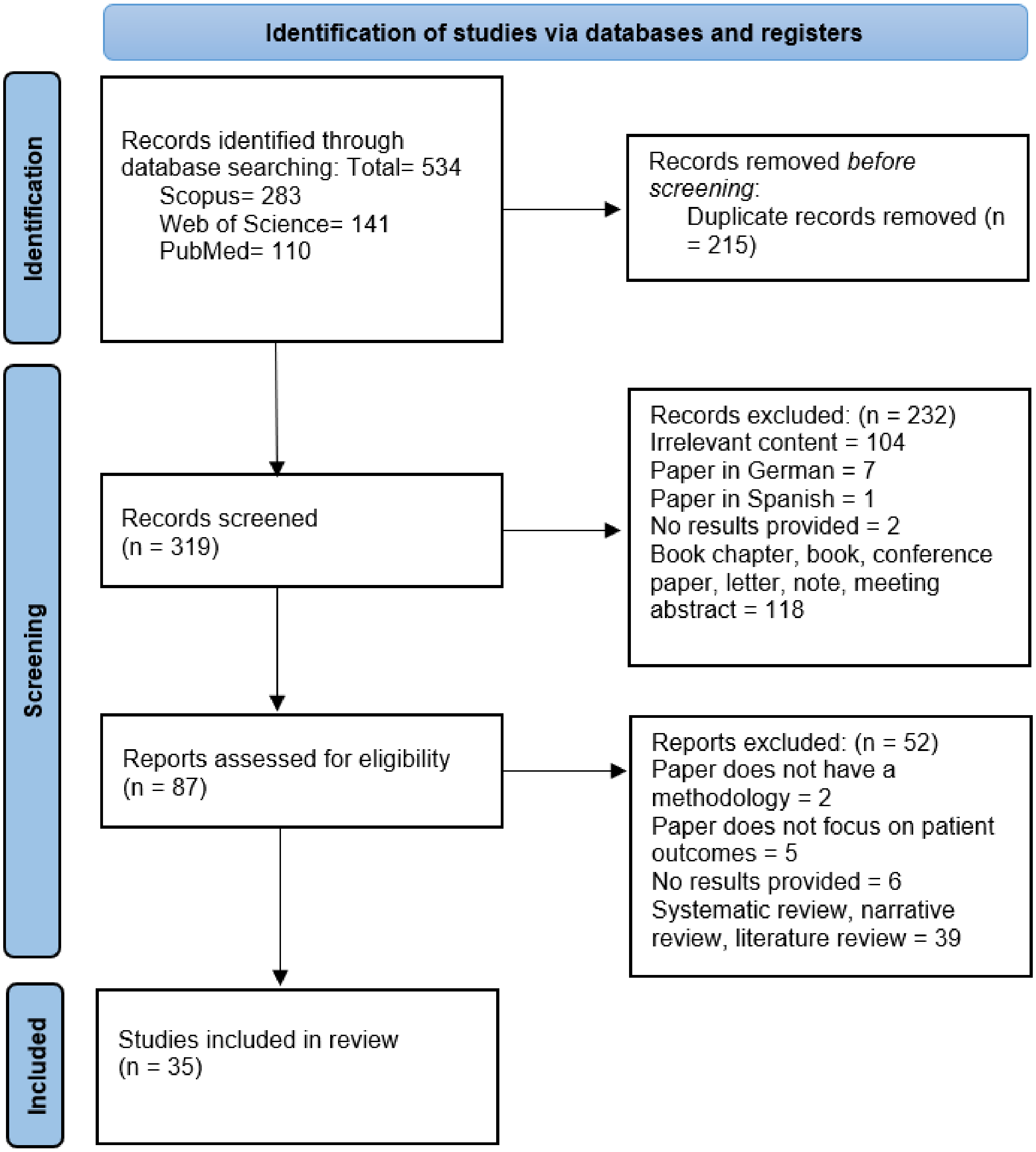



Figure 1. Flowchart of the research methodology

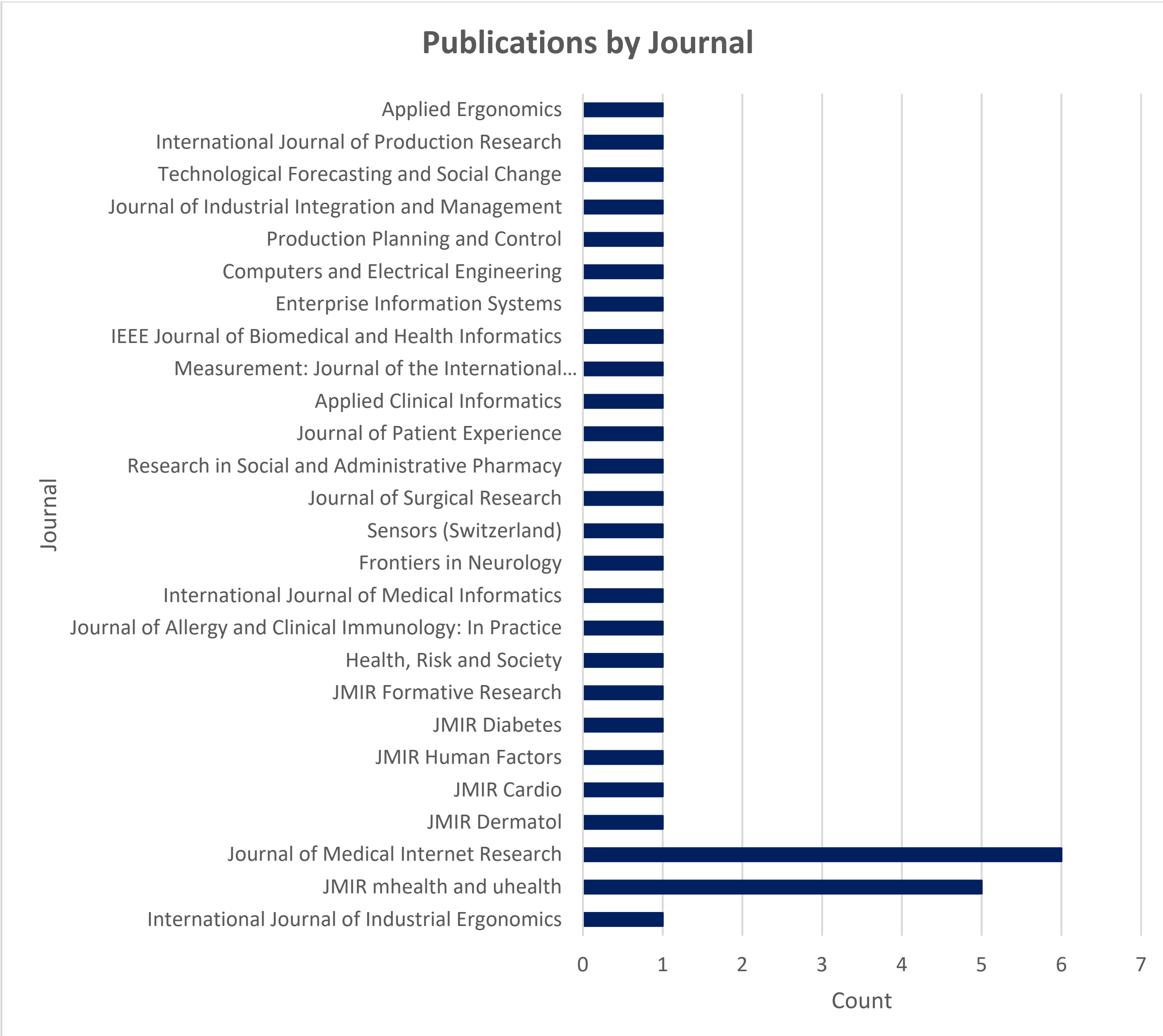



Figure 2. Publications by journal

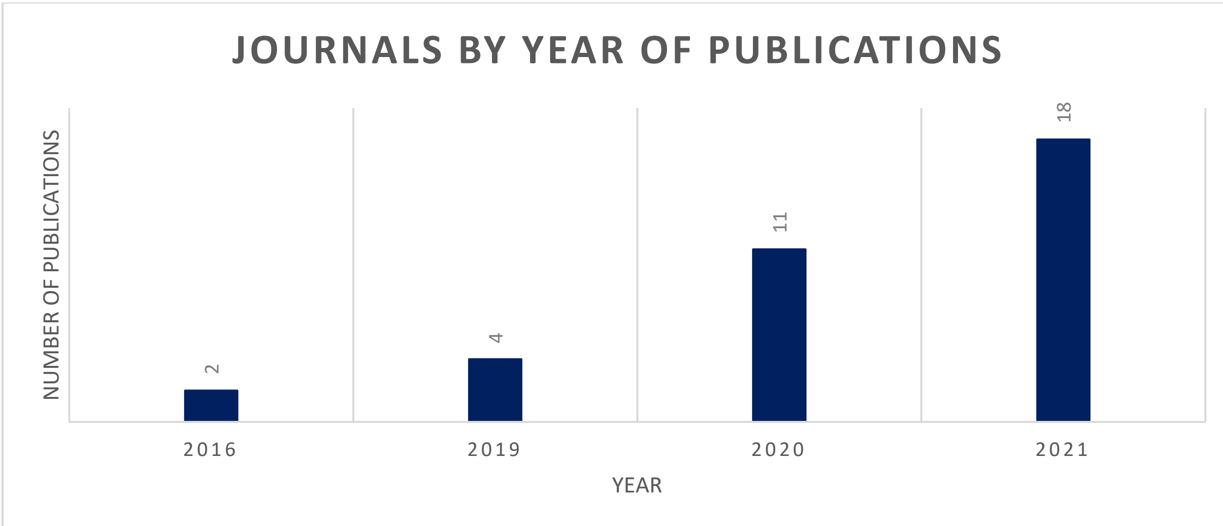
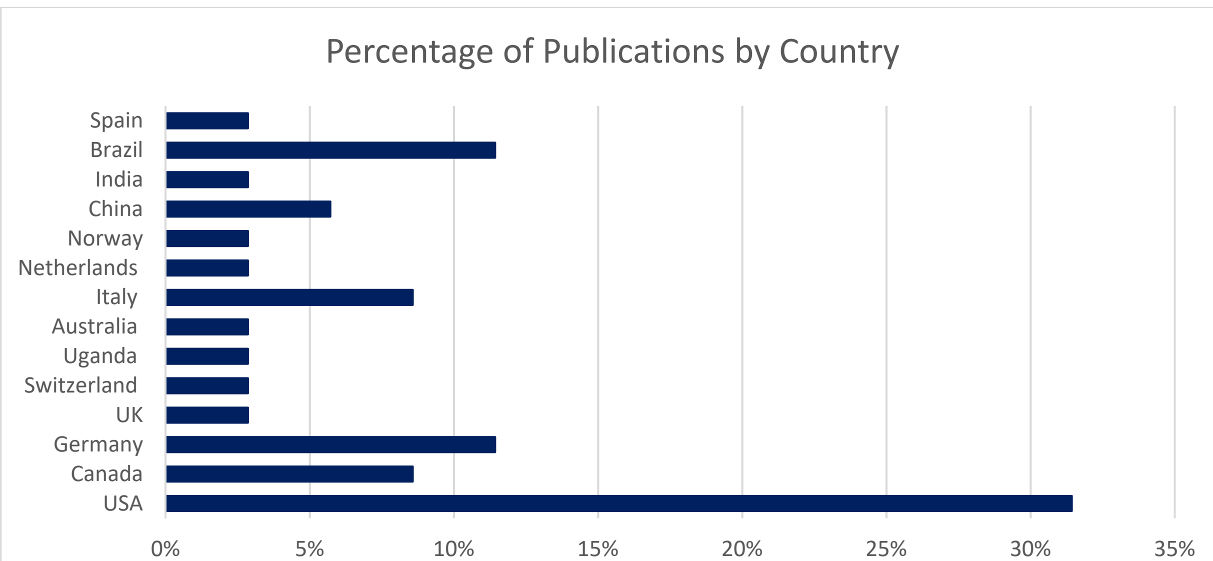



Figure 3. Articles by publication year




| | USA | Canada | Germany | UK | Switzerland | Uganda | Australia | Italy | Netherlands | Norway | China | India | Brazil | Spain |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| % | 31% | 9% | 11% | 3% | 3% | 3% | 3% | 9% | 3% | 3% | 6% | 3% | 11% | 3% |

Figure 4. Articles by country of study

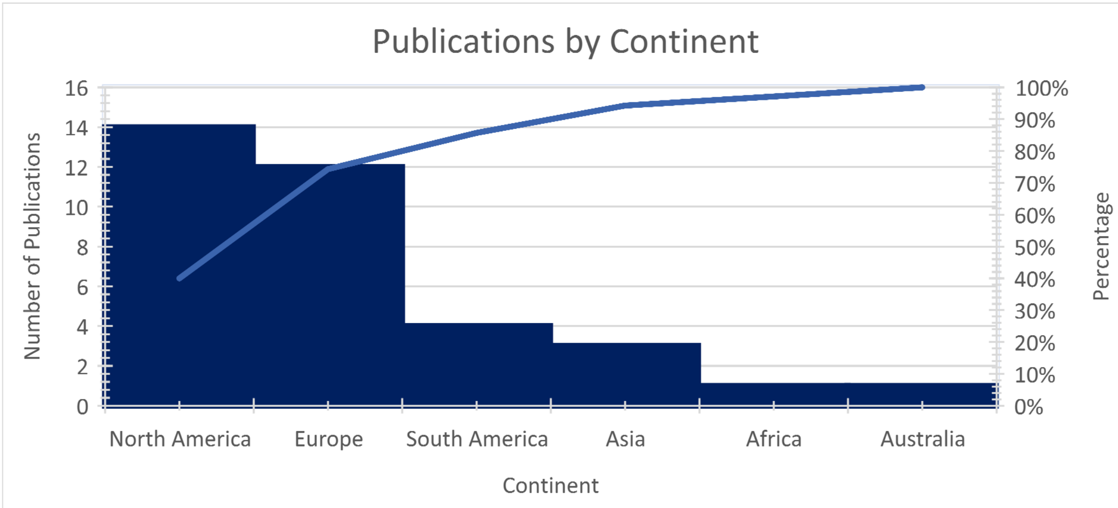



Figure 5. Geographic research areas

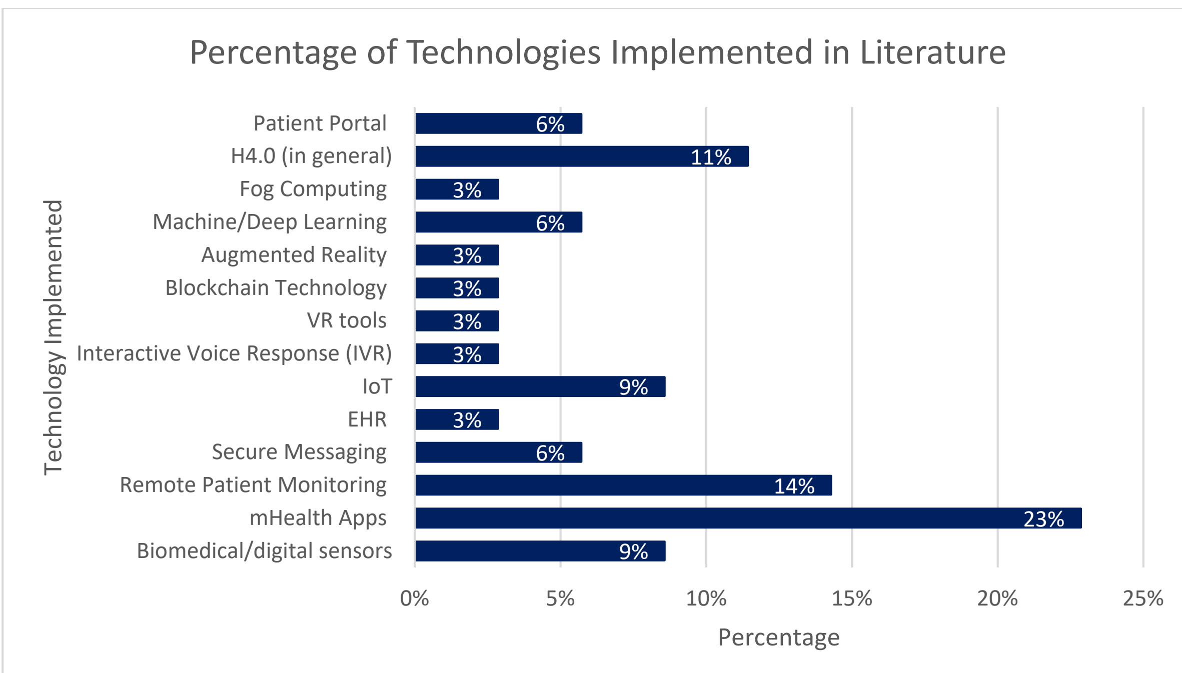



Figure 6. H4.0 technologies discussed in the selected articles