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Review Article

Smart hospitals worldwide: a systematic review

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ABSTRACT

The term "Smart hospital" is a highly comprehensive concept and it has not received the attention it deserves among researchers, as it is more than using a smart tool in a hospital. This study was designed to conduct a review of smart hospitals. In this systematic review, 808 studies were identified using keywords through searches on PubMed, Science Direct, Embase, Scopus and IEEE databases. After applying the inclusion and exclusion criteria (705 based on abstracts and titles and 35 after reading full texts) and removing duplicates (43), 25 studies were included in this review. Geographically, of the majority of the articles were from Asia (60%). The highest number of publications was observed in 2012 and 2020. A multidisciplinary team was involved in 72% of the research, and 68% were conducted in more than one research center. Most articles have been published in Q1 quality journals (48%), and high-income countries accounted for the largest percentage (56). Notably, 32% of these studies focused on patient care. RFID technology was the most used technology, featured in 66.67% of the studies, which primarily centered on the implementation of smart hospitals. It should be noted that development or implementation of a smart device in a hospital should not be equated with the implementation of a smart hospital and it is far beyond that.

Keywords:
Smart Hospital
Digital Hospital
Smart Device
Smart Health

Introduction

Nowadays, digital technologies and systems have profoundly influenced various aspects of our daily lives. Without them, everything would seem out of place in modern society (Bucci et al., 2019; He and Li 2019; Hoehe and Thibaut 2022; Krick et al., 2019). The field of healthcare and medicine is one area which has witnessed significant development through the use of digital tools (Howarth et al., 2018; Mathews et al., 2019; Mitchell and Kan). For instance, smart tools play a vital role in the diagnosis and treatment of various diseases (Holzinger et al., 2015; Ricciardi, 2019). Therefore, the development of such technologies and awareness, training, and attitude of medical staff and patients towards smart technologies have given rise to a new concept called "smart hospital" (Ilyashenko et al., 2018).

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The term "Digital hospital" was firstly introduced with the aim of transitioning paper-based systems and patient files into electronic health records (EHR) (Serbanati, 2020). Later, in 2007, the triple concept of care, health and cost, was developed, emphasizing the improvement of care and health outcomes while reducing costs in healthcare organizations (Berwick et al., 2008). With the growing acceptance of EHR among the healthcare society, a substantial volume of clinical and financial data was generated, leading to the developments in clinical research, better decision-making for managers, and highlighting the need for technological maturity in that era (Nordo et al., 2019). With the approval of The Health Information Technology for Economic and Clinical Health (HITECH) Act in 2009 exponentially increased the use of EHR (Nordo et al., 2019; Redhead, 2009) Eventually, the term "digital" evolved into "smart", marking the beginning of efforts to develop smart hospitals, leading to numerous research studies and operational projects in this field (Ilyashenko et al., 2018).

One of the essential prerequisites for developing a smart hospital is the creation and optimization of clinical and administrative processes, accompanied by the design and utilization of innovative technologies and equipment. These conditions cannot be met without interconnected assets (Bygstad and Øvrelid 2020; Rizwan 2017; Thakare and Khire, 2014; Vecchia et al., 2012). In this regard, Big Data plays a vital role in smart hospitals since vast amounts of data are automatically generated continuously. The efficient use of this Big Data can result in improved care and enhanced functionality (Moro Visconti and Morea, 2020). Smart Hospitals have revolutionized healthcare service delivery by maximizing efficiency, enhancing care quality, improve existing processes and obtain better patient satisfaction (Garg, 2021; Holzinger et al., 2015; Moro Visconti and Martiniello, 2019)

According to World Health Organization (WHO), the healthcare sector will face a shortage of over 18 million healthcare professionals with insufficient skills in the next decade (Ghebreyesus, 2020). With limited space and human resources resulting in long, high-stress work hours, increasing the number of medical staff is not a sustainable solution to meet the over-increasing needs for healthcare services (Manyisa and van Aswegen, 2017). In addition, the ability of smart hospitals to simplify workflow and better manage patients' health can address these challenges and rectify current deficiencies (Fischer et al., 2020). Moreover, the use of emerging sciences such as AI[1] is essential in the development of smart hospitals (Liu et al., 2018).

Despite the advantages of AI and automation, their implementation has been slow in several fields, including healthcare (Tian et al., 2019). However, it is undeniable technological maturity is inevitable, and the increasing use of novel technologies in healthcare is predictable in the near future (Risling, 2017).

Smart hospitals can not only result in improved service provision and quality within hospitals, but can also play a significant role in larger ecosystems, such as smart cities, in providing healthcare services (Oueida et al., 2019). Many believe that the concept of "Smart Hospital" simply involves the use of smart tools in a hospital setting. However, it is much more comprehensive. Smart hospital is a dynamic, digitalized environment at its core, driven by AI and incorporating a multitude of integrated technological innovations, all aimed at delivering maximum and real-time benefits to all connected individuals (De Almeida et al., 2020; Ilin et al., 2018; Moro Visconti and Morea, 2020; Tabatabaei et al., 2021). Therefore, recognizing the significance of smart hospitals and considering them as this comprehensive concept, we aim to provide a review of research conducted in this area.

Material and Methods

In this systematic review, articles published before 2021 were considered and the York standard framework, proposed by Arksey and O'Malley, were employed to structure the study (Arksey and O'Malley, 2005). The steps in this research align with the five phases outlined by York, which encompass:

1. Identification of study questions
2. Identification of relevant resources
3. Careful review of the resources
4. Data analysis.

Gathering, summarizing and reporting the results.

Each step will be explained in the following sections.

Identification of study questions

In this study, three main aspects of smart hospitals including general information, design and economic as-

1. Artificial Intelligence

pects were investigated. Questions for each aspect were defined though formation of a focus group consisting of medical informatics experts, comprising three faculty members and two Ph.D. students (table 1).

Identification of relevant studies

The search team (SMT, NS, MR and MT) developed a comprehensive search strategy to identify and retrieve articles aligned with our research goals and within the parameters set by our inclusion and exclusion criteria.

The inclusion criteria included articles in English language published before 2021, irrespective of article affiliations.

The exclusion criteria included review articles, conference papers, letters to editor, books, white papers and articles with inaccessible full texts.

Search Strategy

It is necessary to determine concepts and keywords for a search strategy (Peters et al., 2015). To this end, keywords were selected in the field of smart hospitals based on research goals. Keywords employed in our search included "smart hospital", "intelligent hospital", and "digital hospital".

The search team (SMT, NS, MR and MT) used these keywords to formulate the following search strategy for title/abstract fields: ("smart hospital" OR "digital hospital" OR "intelligent hospital"). The publication years of the articles were set to any articles published before 2021. Finally, electronic literature search was conducted on PubMed, Science Direct, Embase, Scopus and IEEE databases.

Study Type

Retrieved articles were categorized based on their type of study through the formation of a focus group and divided into three main categories including implementation, architecture and survey studies. Implementation articles pertained to the deployment of specific products within smart hospitals; architecture articles offered frameworks for smart hospital development and survey articles conducted qualitative studies involving users and stakeholders of smart hospitals, often through interviews or written questionnaires. Notably, the majority of the published articles during the studied period fell into the implementation category (60%), followed by architecture articles (36%), with survey articles comprising only 4% of the total publications.

Selection of studies

The research method which is presented as a diagram in figure 1, shows the step-by-step process used to select articles.

Following the search, a total of 808 articles (85 PubMed, 131 from Science Direct, 115 from Embase articles, 410 from Scopus, and 72 from IEEE) were retrieved. After removing duplicates (43 articles), 765 articles remained. The search team (NS, MR and MT) then screened these articles based on our inclusion and exclusion criteria. during this phase, 705 articles were removed after reviewing the title and abstract. While the full texts were investigated for 60 remaining articles. After careful evaluation, 35 articles were extracted, of which 25 were included in the final study.

Data analysis

Two researchers (NS, MR and MT) independently extracted relevant data from the retrieved articles, based on study questions and study goals. The extracted data were then compared, and to assess the agreement be-

TABLE 1: Study questions and corresponding smart hospital

Aspects	Questions
General Information	What is the distribution of existing articles based on publication year?
	What is the distribution of existing articles based on geographical location?
	What is the quality of the journals publishing these articles?
	What information is available about the specialized teams in these articles?
Economics	What is the distribution of the articles based on development index of the publishing countries?
	What is the distribution of the articles based on the GDP of the publishing countries?
Design	What is the distribution of the articles based on their goals?
	What are the technologies used in these articles?
	What is the distribution of the articles based on the type of study?

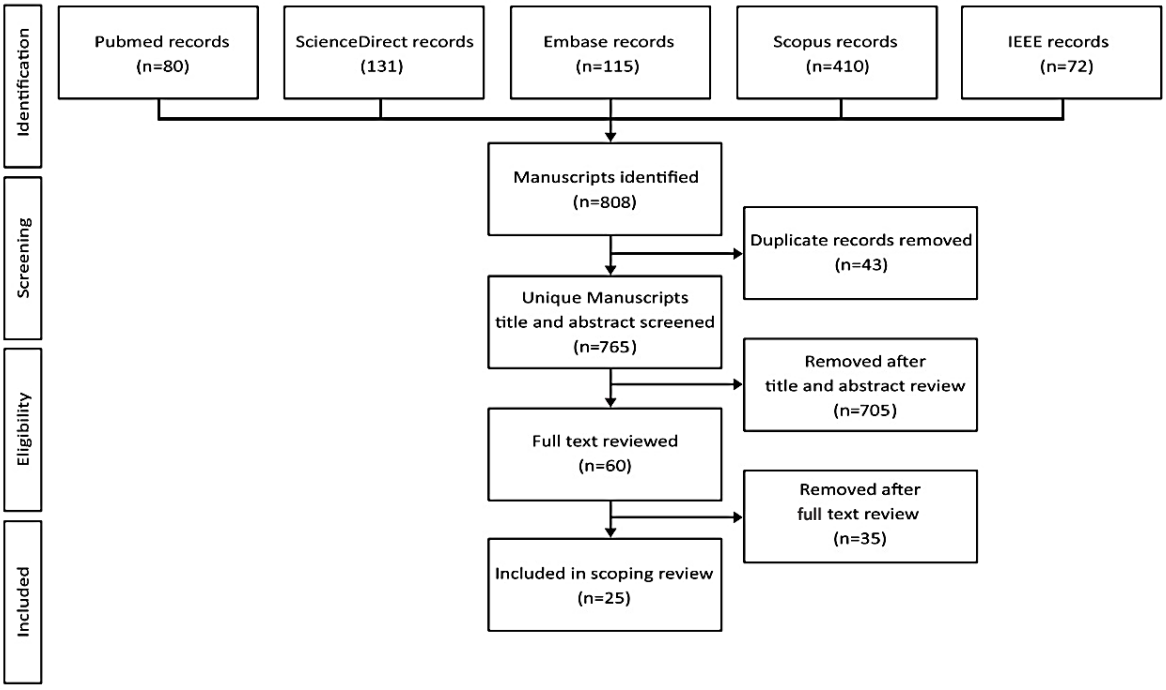

FIGURE 1. The preferred reporting items for systematic reviews and meta-analyses diagram of the search methodology

tween the two researchers, Kappa coefficient was used which equaled 0.86. In case of disagreement, a third researcher (SMT) was consulted. The final dataset was prepared after thorough evaluation by the team members, incorporating suggestions and comments.

Gathering, summarization and reporting of results

A table was used to collect data extracted from the articles. Each row represented an individual article, while columns indicated the variables. Then, the table was filled with the collected Data.

Frequency analysis, a common method for analyzing data sets, was used to analyze the data based on each variable in our study. The results were presented using various graphs.

Results

The results obtained from this study were categorized into three aspects as presented in table 1: general information, economics and design. Statistically significant results were further categorized based on publication year, geographical location, journal quality, specialized teams, study goals, study technology, and study type.

Geographical Location

The geographical distribution of published articles is presented in figure 2. Asia accounts for the highest number of publications at 60%, followed by Europe at 24%. Interestingly, no articles from Africa were included in the study.

Publication Year

Figure 3 shows the distribution of articles by their publication year. Articles related to smart hospitals were published from 2010 onwards, with notable peaks in 2012 and 2020. Notably, no articles in 2013 and 2016 were retrieved according to our search strategy.

Specialized team

After evaluating the retrieved studies, various disciplines were observed among the authors. A majority of 72% of the studies, involved multidisciplinary teams, while the remaining 28% did not. Furthermore, the results indicated that multicenter studies, conducted by more than one research center, constitute 68% of the retrieved studies, while single center studies comprise 32% (Figure 4).

Journal

48% of the retrieved articles were published in Q1 journals, while 16% appeared in Q2 and Q3 journals. Articles published in Q4 journals accounted for 12%,

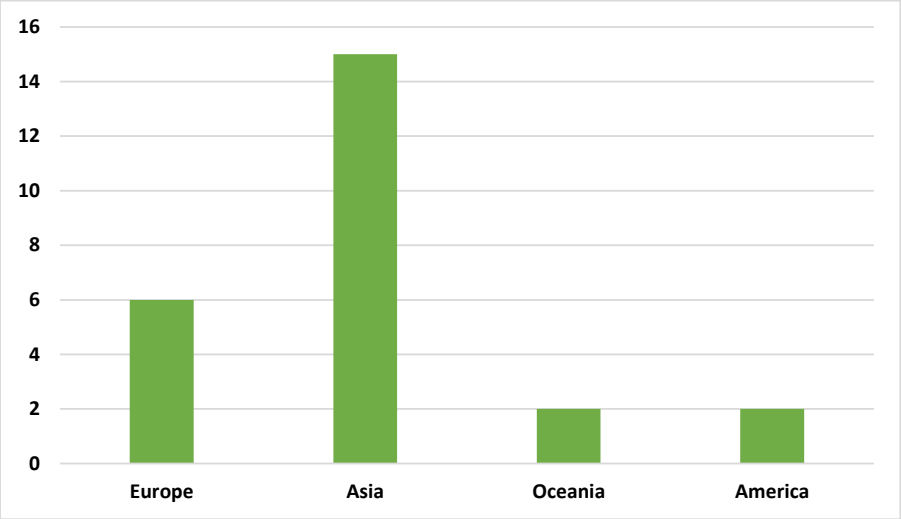

FIGURE 2. Frequency distribution of studies based on their geographical location

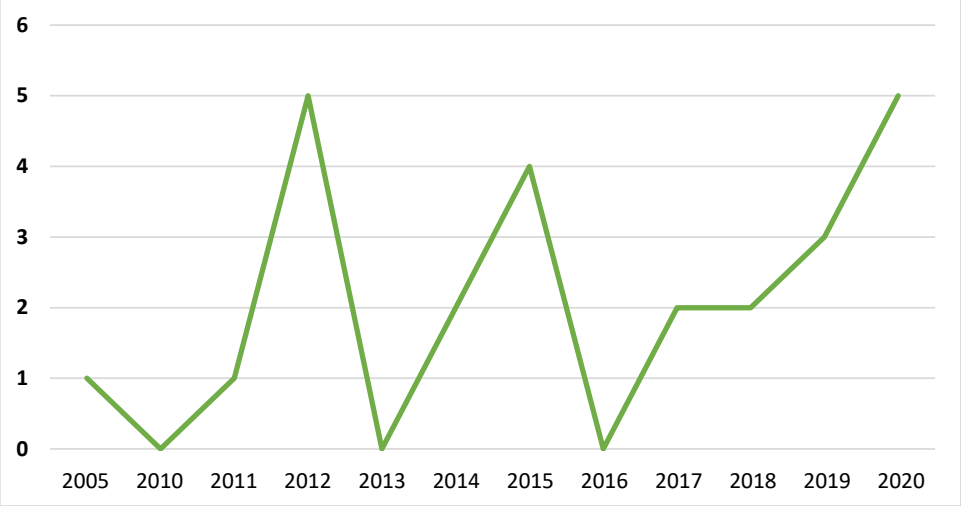

FIGURE 3. Frequency distribution of studies by publication year

and 8% were published in journals not indexed in ISI. Figure 5 shows the distribution of articles based on their journal quality and development level of their countries.

Distribution of articles based on country development and GDP

Investigating the published articles based on the level of development as well as GDP of the source countries revealed that both developing and developed countries contributed nearly equally to the published articles (50%). These countries were also divided into three groups of high-, upper middle- and lower middle-income based on their reported GDP. According to this categorization, 56% were conducted in high-income countries, 36% in upper middle-income countries, and only two articles were published in a lower middle-income country.

Goal

Evaluating the retrieved papers showed a wide variety of study goals. These goals were grouped into three main categories: patient care, resource management, and framework (Figure 6).

As can be seen in figure 6, 32% of the studies were conducted with the goal of patient care, 20% with the goal of resource management, and 12% with the goal of framework. Furthermore, studies with combined patient care and framework aims made up 8% of the studies

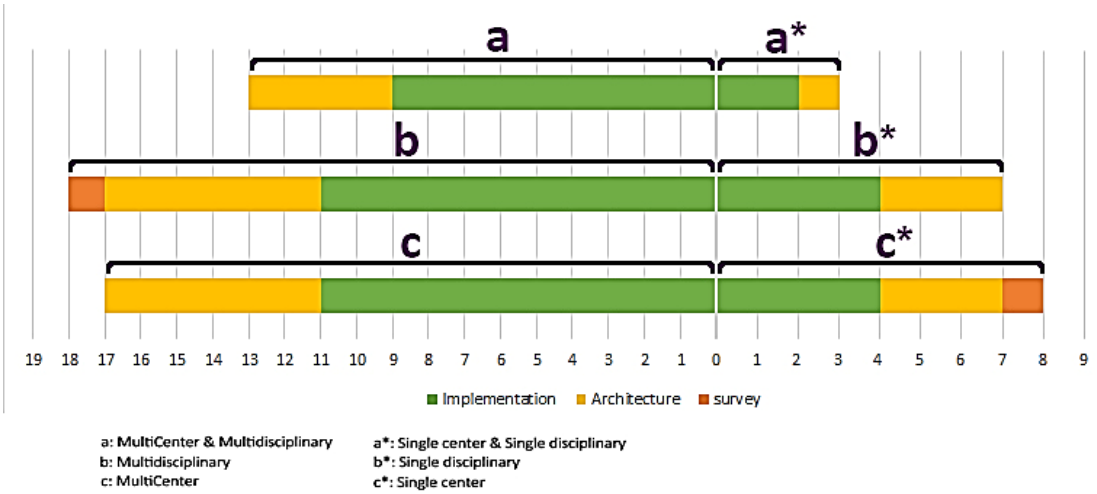

FIGURE 4. Frequency distribution of studies based on their specialized team

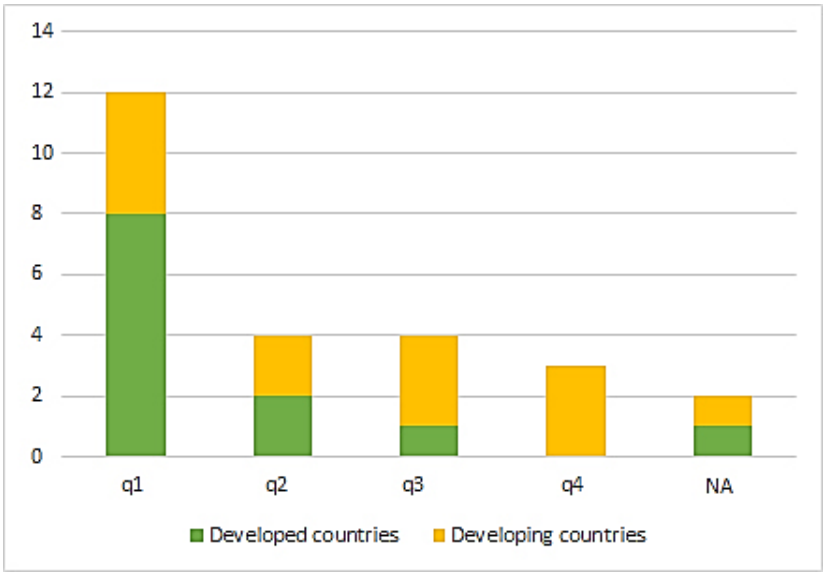

FIGURE 5. Frequency distribution of articles based on journal quality and country development level

while the rest has the combined goal of patient care and resource management (28%).

Used Technologies

Evaluating retrieved articles indicated that 24 out of 25 articles (96%) incorporated different technologies (table 2). These technologies were employed to make a section, room or device within hospital settings.

Main Findings

A smart hospital is a complex concept for which numerous definitions have been suggested to date. However, one certain part of all these definitions is that a smart hospital contains a wide variety of smart interconnected nodes which minimizes human intervention (De Almeida et al., 2020; Kharbanda et al., 2017; Moro Visconti and Morea, 2020; Peters et al., 2015). According to our investigations, the majority of the investigated articles had used the term "smart hospital" due to its appeal, despite merely implementing a smart tool in a limited portion of the hospital environment. This observation raises concerns, as the concept encompasses far more than these implementations. It can be due to lack of medical informatics or similar specialists in the research teams. Although the field of smart hospitals is currently attractive to journals, researchers must remember that such studies represent only a fraction of what constitutes a smart hospital. According to our results, the trend toward smart hospitals has been significant, especially in Asia. This is more interesting when we know that the

TABLE 2: Technologies used in various studies

Technology	2005	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
RFID[1]		1	2 1#	-	1*	1@ 1+ 1$	-	1	-	-	-
Augmented reality		-	-	-	-	-	-	-	-	-	1
Nano-chip		-	-	-	-	-	-	-	-	-	1
sensor		-	1 1#	-	1	1 1@	-	-	1	2	-
IOT [2]		-	1#	-	-	1+ 1$	-	1	1	-	2
ZigBee		-	-	-	1*	1+	-	-	-	-	-
Wi-Fi	1	-	1	-	-	-	-	-	-	-	-
None		-	-	-	-	-	-	-	-	1	1

[1]Radio-frequency identification:

[2] IOT: Internet of things

Similar articles are marked with "*", "+", "#", "$" and "@" signs

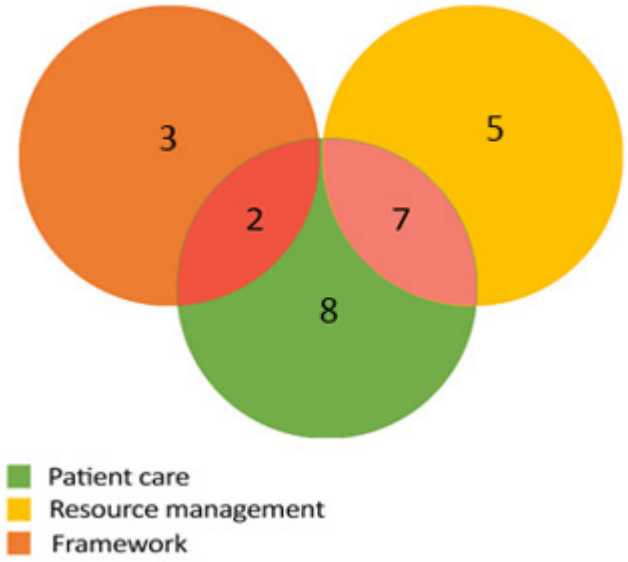

FIGURE 6. Frequency distribution of articles based on Study Goal

number of articles published in Asia on this topic exceeds that in Europe and the United States. However, the quality of journals in Europe and the United States surpassed those in Asia. In developed countries, the majority of studies focused on implementing smart tools, which require substantial financial investments. The emphasis of retrieved studies was mainly on resource management and patient care. We aimed to identify the shared aspects of the published studies by answering several study questions. To this end, we suggested to use three categories of general information, design and economics and identified research questions for each of these categories.

General Information

After analyzing 18 retrieved articles, contrary to our expectations for higher number of published articles related to smart hospitals in Europe and the United States, the results indicated that Asian countries, especially those in East Asian had conducted a larger number of

research studies on this topic. This fact, of course, can be explained somewhat through the vast geographical area of the Asia continent in compared to that of Europe and the United States. The majority of studies on development of smart tools have used RFID and sensors. Based on our search strategies, no studies on the topic of smart hospitals were retrieved in years 2013 and 2016.

Economics

Researchers in developed countries predominantly published their articles on smart hospitals in Q1 and Q2 journals. In contrast, the results indicated that although developing countries had published a larger number of articles, the majority of these appeared in Q3, Q4, and other journals. This difference in journal quality may be attributed to the significant resource requirements for conducting studies in the field of smart hospitals (Uslu et al., 2020). While most studies predict a high return on investment, the initial investment can be challenging in developing countries with limited budgets and other competing priorities.

Design

The results indicated that the majority of retrieved articles focused on resource management and patient care, as these aspects are typically considered high-priority areas in healthcare systems. Furthermore, investigating the technologies used in different studies revealed a stronger emphasis t on the use of RFID and sensors as smart tools in hospitals, possibly due to the delineation and prioritization of various levels to transform hospitals into smart environments.

According to the results, most studies focused on the utilization and implementation of smart tools within hospitals. A number of studies also discussed the necessary architectural components of smart hospitals, while only one study investigated the attitudes of stakeholders. Since most studies explored the implementation of a single smart tool, it appears that these types of articles are easier to publish, especially when the evaluation of the implemented tool is conducted within the same study. This shows a trend toward the implementation of smart tools among researchers and high attractiveness of this topic to journals.

Based on our results, the majority of studies were conducted by researchers with specialties in computer engineering. Furthermore, the implementation of smart tools in hospital settings was mostly carried out by researchers with diverse specialties, working within multidisciplinary teams. This underscores that the implementation of such tools in smart hospitals necessitates the involvement of specialists from various disciplines (Kharbanda et al., 2017).

Comparison to other studies

To the best of our knowledge, this is the first systematic review in the field of smart hospitals that comprehensively adopts the concept of a smart hospital.

Limitations

This study included several limitations. The primary limitation is the absence of meta-analysis due to a lack of sufficient details obtained from the selected studies. Secondly, the study exclusively included English articles, potentially excluding valuable research in other languages. Lastly, due to limited access to search engines in Iran, the search was restricted to databases such as Science Direct, PubMed, Scopus, and Embase. Expanding the search to include other databases might yield additional results.

Conclusion

The concept of a smart hospital is a complex and vast concept, requiring years of collaboration among multidisciplinary teams and adherence to various medical standards. Although this concept has yet to reach its ideal maturity, the rapid advancements in technology make the future of healthcare services seem reachable. It's essential to differentiate between implementing smart tools in hospitals and achieving the status of a smart hospital. Moreover, since implementation of smart hospital requires a great deal of investment and has a lengthy return on investment duration, therefore, it is expected that academic researchers with limited budgets are only able to develop and implement smart tools in hospital settings. As a result, development of a smart hospital is only possible by large and credible companies. For example, companies like HUAWEI CLOUD and Alcatel-Lucent have made claims regarding implementation of smart hospitals. Alcatel-Lucent's most significant service involves tracking patients' precise locations to provide timely, high-quality care. HUAWEI, on the other hand, has used Huawei cloud platform to create the triple structure of Communication collaboration, Big Data

and AI within smart hospital settings. The communication infrastructure for these smart hospitals employees various technologies, including Wi-Fi, optic fibers, 5G internet, microwave communication, and eLTE technology. Therefore, it is expected that successful experiences in the field of smart hospitals can serve as a catalyst for substantial changes in operational attitudes and execution methods.

Conflict of interest

All authors confirm that there are no competing interests to declare.

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Ethics approval

This study has the ethical approval from Mashhad University of Medical Sciences (ID: IR.MUMS.MEDICAL.REC.1400.118).

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