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Identifying the Knowledge Structure and Trends of Nursing Informatics

A Text Network Analysis

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With the advent of the information age and technological development, the importance of digital health technologies has increased. Subsequently, nursing informatics has been developed to enhance the effectiveness of healthcare information management and communication. This study aimed to identify the nursing informatics knowledge structure and research trends through quantitative analysis using text network analysis. Here, we analyzed 14 225 studies published by 2020. The knowledge structure of nursing informatics and changes therein were clarified by identifying and analyzing the core keywords, topics, and changes in the topics of related studies over time. We identified "patient," "health," "system," and "information" as core keywords connecting other keywords. Over time, the networks between "information," "communication," and "technology" strengthened, and "patient safety" and "quality" have recently emerged as research keywords. This change indicates an increase in the importance of nursing education on technology. Similar changes appeared in the topic analysis, showing an increased proportion of research related to system and technology and nursing education. These results can broaden a systematic understanding of nursing informatics research. Furthermore, given these findings, the importance of nursing informatics on patient safety and nursing education—based on the development of systems and technology—can be expected to continue growing.

KEY WORDS: Nursing informatics, Knowledge structure, Text network analysis, Topic analysis, Patient safety

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With the 21st century being the information age, the importance of digitalization has been emphasized in all spheres of life.[1] Similarly, digital health technologies, which use computing platforms, connectivity, software, and sensors for health, are emerging in healthcare.[2] Indeed, the World Health Organization presented the "Global Strategy on Digital Health 2020–2025," with the goal of strengthening the healthcare system through the application of digital health technologies to patients, healthcare professionals, and the industry.[3] Digital health encompasses broad categories, such as mobile health, health information technology (IT), wearable devices, telehealth and telemedicine, and personalized medicine. Therefore, digitalization and the use of information are central to such strategies. Health informatics, the basis for these digital technologies, is the scientific discipline concerned with the cognitive, information processing, and communication tasks of healthcare practice, education, and research, including the information science and technology needed to support these tasks.[4,5] To address the set objectives and provide better healthcare, it has evolved to applying and exploring the uses of relatively new instruments such as electronic computers and microcomputers.[6] In addition, big data science is now one of the foremost research topics in health informatics.[7]

Health informatics arose from its predecessor, the science of medical informatics,[8–10] which originated in 1974.[6] Although the two disciplines share many concepts and the terms are often interchangeable, health informatics is all-embracing, and medical and nursing informatics can be viewed as its subsets.[6] Over the last three decades, health IT has been penetrating the healthcare sector.[11]

Specifically, nursing informatics is the specialty that integrates nursing science with multiple information management and analytical sciences to identify, define, manage, and communicate data, information, knowledge, and wisdom in nursing practice.[12] Nursing informatics enhances decision-making in all direct and indirect nursing roles through the collection, extraction, aggregation, analysis, and interpretation of standardized data, using emerging data science principles and methods.[13]

Through nursing records, nurses share patient care plans and information and communicate with colleagues, all of which contribute to the quality and continuity of care. The rapid adoption of electronic health record (EHR) systems

provides a growing opportunity to expand our knowledge about nursing practices using nursing data in EHRs.[14] Moreover, nursing information systems have a significant impact on service safety and quality in healthcare centers. Previous studies have demonstrated the role of these systems in reducing adverse drug events and interactions.[15–19] Documentation in healthcare serves to provide an accurate record of the patient's status and needs at a point in time.[20]

In today's dynamic health systems, technology plays an important role in both education and nursing work. The increase in nursing informatics shows that nurses are being automatically integrated into IT[21]; therefore, they should be able to utilize it successfully to improve the quality of care outcomes. Thus, highlighting the appropriate IT educational needs of nurses is necessary. To take advantage of IT to enhance nursing outcomes and healthcare quality, an educational arrangement that equips nurses at different levels to implement IT instruments in all aspects of their profession and integrates them with the ever-increasing pace of technological advances is recommended.[21,22]

The six core competencies of nurses according to the Quality and Safety Education for Nurses[23] project launched in the United States in 2005 by the Quality and Safety Education for Nurses Institute are "patient-centered nursing," "teamwork and collaboration," "evidence-based practice," "quality improvement and safety," and "informatics." As such, nursing informatics is regarded as a very important nursing competency. In addition, the advent of the electronic era has given rise to mobile health and digital health in the medical field. With the ongoing COVID-19 pandemic in particular, information and communication technologies (ICTs) in healthcare have developed rapidly as their importance has proliferated. To fight the pandemic, nursing informaticists aiming to enhance nursing education, clinical practice, and policy are collaborating with colleagues to contribute to and lead research and digital health initiatives.[24]

Clearly identifying changing trends will both further solidify nursing informatics as an academic field and identify the necessary future research directions when we consider trends in nursing informatics research have changed due to technological developments.[25] For this purpose, systematic reviews and meta-analyses are commonly used to review previous research on a specific topic. However, these methods cannot reveal the overall flow of trends or the structure in sufficient detail.[26] Therefore, social network analysis, a valuable analytic and predictable method for extensive amounts of data, is mainly used to examine the contextual meanings of words and their relationships.[27–29] Recently, various fields have been actively studying research trends using texts collected through specific documents or papers. Text network analysis (TNA) extracts useful information from text data using natural language processing techniques, which can be divided into document summaries, information retrieval, and trend analysis. It is particularly helpful for research topic exploration and research planning.[30]

The importance and utility of nursing informatics have increased gradually.[25] It is important to ascertain the knowledge structure of nursing informatics and understand the research trends that connect data into meaningful information as this develops wisdom in nursing practice.[12] The objectives of this study were to identify the knowledge structure and research trends on nursing informatics by conducting TNA on related research papers, from the earliest to the most recent studies, and to suggest directions for future research.

METHODS

This is a quantitative content analysis study to explore the knowledge structure and research topics on nursing informatics by constructing a text network based on the co-occurrence rate of keywords in published literature using text network analysis.

Data Search and Collection

The PubMed, EMBASE, and CINAHL (Cumulative Index to Nursing and Allied Health Literature) databases were used to search for nursing informatics literature published up until October 2020. In total, 9607 (PubMed), 5177 (EMBASE), and 4971 (CINAHL) studies were identified through a search using the keyword "nursing informatics" with the MeSH terms and related terms applied to the titles or abstracts (Supplemental Digital Content 1, http://links.lww.com/CIN/A171). After excluding duplications and articles without an abstract or peer review, 14 225 studies were identified. The article exclusion process is summarized in Supplemental Digital Content 2 (http://links.lww.com/CIN/A172). We identified vital information from these 14 225 studies using citation information from the databases and organized the information using a predefined Excel form (Supplemental Digital Content 3, http://links.lww.com/CIN/A173).

Data Standardization

This program does recognize capital- and non–capital-letter words as different terms and general terms (eg, introduction, purpose, methods, results, etc) are not useful for analysis. Therefore, two researchers created a dictionary containing the relevant keywords for the analysis, which comprised a thesaurus, defined words, and exception lists. We used the deletion function to remove non–content-bearing concepts, such as conjunctions and articles from the text, and used the stemming function to convert each concept into its related morphemes, from which 42 641 keywords remained.

Developing Keyword Networks

Among the 42 641 keywords filtered through the dictionary, we cut the frequency by more than 50, resulting in 1306

high-frequency and therefore core keywords. We then transformed the obtained 2-mode network (with the rows of papers and the columns of keywords) into a 1-mode network, which formed a word-to-word network that developed text networks with a weight higher than 10% of a total of 73 838 networks. This clarified the structural feature of the network.

Keyword Analysis and Visualization

We analyzed frequency, degree centrality, closeness centrality, and betweenness centrality, which are keyword quantification values. By obtaining the quantification values, we could compare the degree to which each keyword acts as a central word and/or bridging word. The frequency of a keyword refers to the number of times it occurs in all the included studies. Degree centrality measures how many connections the nodes have; thus, it measures the level of influence and co-occurrences of keywords.[31] Betweenness centrality measures a mediation level in a network.[31] Closeness centrality estimates the level of efficiency and convenience of connections between node of focus and the other nodes by measuring one node's sum distance to the other.[31]

For the knowledge structure, we visualized the network structure, node, and connectivity strength to be included in the sociogram using major keywords with high frequency and degree centrality. The network data and their analysis results were graphically visualized using the NetMiner version 4.4.3 (Cyram Inc, Seongnam, Korea), a program widely used for text network analysis in various disciplines.

We generated separate networks by segmenting the entire period into (1) a period from the first year to 1990 (because there were fewer studies in this period than in other periods) and (2) 10-year intervals thereafter to map nursing informatics research trends over time. We analyzed each period to obtain data on frequency, degree centrality, closeness centrality, and betweenness centrality. In addition, we visualized the knowledge structure of nursing informatics in each period and identified the changes over time.

Topic Analysis

Topic modeling is an unsupervised method of natural language processing that allows researchers to analyze vast amounts of nonnumeric data, such as text data, and to aggregate and understand these data.[32] We performed topic modeling to analyze the numerous text data available on nursing informatics and to understand the research topic. We used the latent Dirichlet allocation (LDA) analysis, whose algorithm is the most popular and frequently used among other topic modeling methods.[33,34] It finds hidden topics in documents and within entire document sets and uncovers the ratio of topics for each document and the probability of each word being included in each topic. Because it is challenging to identify the optimal number of topics in LDA modeling,[34] we analyzed varying numbers of topics with $\alpha = .1$ and $\beta = .01$ using the standard method of Bayesian statistics.[34]

RESULTS

Keywords That Emerged in Nursing Informatics Research

The obtained nursing informatics knowledge structure revealed that "health," "system," "information," and "patient"

FIGURE 1. The knowledge structure of nursing informatics.

were highly correlated with other keywords (Figure 1). These four keywords appeared to play central roles in the network and served as interchanges and bridges. "Information," "technology," and "communication" showed strong connections with "computer" and "device." Therefore, this group of keywords forms the "information system" keyword group, which includes "electronic health records (EHRs)" and "documentation." "Health" showed a strong connection with "student" and "education," which form the "student practice and education program" group. In addition, "patient" showed a strong connection with many other keywords, such as "hospital," "data," "medication," and "physician."

Table 1 presents the top 30 keywords by frequency, degree centrality, closeness centrality, and betweenness centrality indices, which were calculated from the main keywords extracted from nursing informatics studies. "Patient," "data," "health," "system," and "technology" showed high frequency and centrality (Table 1), implying that they appear regularly in research alongside a large number of other keywords. Keywords with high betweenness centrality are those with a high connectivity of research subdomains, thus acting as bridges between other nodes.[35]

Trends in Nursing Informatics Research by Time

Figure 2 shows the number of studies for each period, which increased more than 20 times from 333 (19741990) to 7542 (2011 to October 2020). Figure 3 depicts the knowledge structures of each period and the changes over time, whereas Table 2 presents the top 30 keywords by degree centrality for each period.

Prior to 1990, unlike in other periods, nursing informatics studies focused on data, systems, computers, and patients. During this time, the "system," "computer," "technology," and "program" keyword networks were strong. From 1991 to 2000, studies focused more on patients, information, systems, health, and data, and many such studies were centered on systems and computers. The network of "data," "databases," and "quality control" showed up from this period,

Table 1. Top 30 Keywords That Emerged in the Nursing Informatics Studies

Rank	Frequency	Degree Centrality	Closeness Centrality	Betweenness Centrality
1	patient	Patient	Patient	patient
2	data	Data	Data	data
3	health	Health	Health	health
4	system	System	System	technology
5	student	technology	Technology	system
6	practice	information	Information	student
7	technology	practice	Practice	information
8	information	student	Student	practice
9	hospital	hospital	Physician	hospital
10	physician	physician	Hospital	program
11	home	process	Management	physician
12	education	management	process	skill
13	program	education	education	process
14	quality	program	program	quality
15	process	knowledge	knowledge	knowledge
16	knowledge	Home	quality	home
17	participant	development	home	management
18	model	Quality	development	education
19	experience	Skill	communication	medication
20	development	communication	assessment	development
21	management	healthcare worker	experience	model
22	communication	assessment	healthcare worker	communication
23	skill	experience	skill	experience
24	assessment	healthcare	model	child
25	healthcare	Model	healthcare	resource
26	medication	medication	training	assessment
27	training	training	medication	counseling
28	healthcare worker	implementation	participant	simulation
29	implementation	participant	strategy	risk
30	strategy	strategy	implementation	healthcare worker

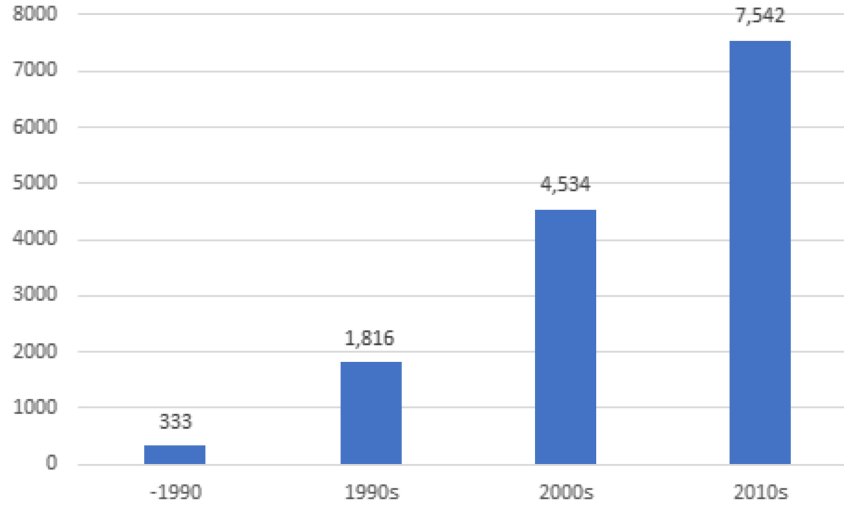

FIGURE 2. Number of research articles for each period.

and system-related "decision making," "process development," and "hospital" emerged as research topics. From 2001 to 2010, keeping central keywords constant, "data" and "safety improvement" were linked, and a number of studies focused on information and technology. Further, "EHR," "decision making," and "medication errors" related to systems emerged in the research, and studies on informatics competency surfaced. Finally, the 2011 to 2020 period saw a rise in research on "quality," "safety," and "decision making," which were centered on data, and "information," "communication," and "technology" networks became stronger. The centrality of "EHR" increased, and studies related to "system," "implementation," and "development" were carried out. Moreover, simulation, experience, and perception studies related to students surfaced.

Topic Modeling of Nursing Informatics Research

Latent Dirichlet allocation analysis was performed on varying numbers of topics (K = 2, 3, 4, 5, 6, 8, 10) to identify the number of topics. In the case of K = 2 and 3, it was difficult to derive meaningful content because they included too few topics. Because K = 10 included a large number of topics, there was a problem of overlapping between the topics. After the researchers discussed the LDA analysis results, K = 5 topics with no overlapping meanings between groups were finally identified (Table 3). Topic 1, the subject-related research group, includes the keywords "patient," "child," "family," "health," and "participant." Topic 2 includes "hospital," "patient," "medication," and "resident," which form the hospital-based research group. Topic 3 is a mediator topic group consisting of research related to "system" and "technology." This group contains the keywords "system," "technology," "information," "data," and "health." Topic 4, the data-centered research group, includes keywords such as "data," "information," "quality," and "database." Topic 5, the nursing education research group, includes "student," "education," "program," "practice," "skill," and "simulation." We also analyzed the topics by period and uncovered changes in the proportions of each topic group by time (Figure 4).

DISCUSSION

This study analyzed nursing informatics literature to understand its knowledge structure and trends and suggest directions for future research on the topic. In this study, the knowledge structure and research trends were identified using TNA, a methodology that derives the centrality of keywords and the strength between keywords as quantitative results from texts and builds a qualitatively meaningful network. It is a useful methodology to derive and visualize the relationship between keywords. Two researchers—nursing informatics professionals who have prior experience performing TNA research—conducted all steps of the TNA in this study and went through a review and discussion process with a TNA expert. In addition, to understand the research topic in nursing informatics, we performed topic modeling using LDA analysis, whose algorithm is the most popular and frequently used among other topic modeling methods. Because subjectivity is involved in the interpretation of these qualitative analysis results, the results were analyzed through discussions with nursing informatics experts and text network analysis methodologists. Thus, this study followed a rigorous methodology.

The study found that "patient," "health," "system," and "information" are the central keywords of the nursing informatics knowledge structure. Keywords with a high centrality of intermediation indicate the influence of the keyword on the trend and formation of the entire network by connecting various other keywords.[36] In addition, "technology"

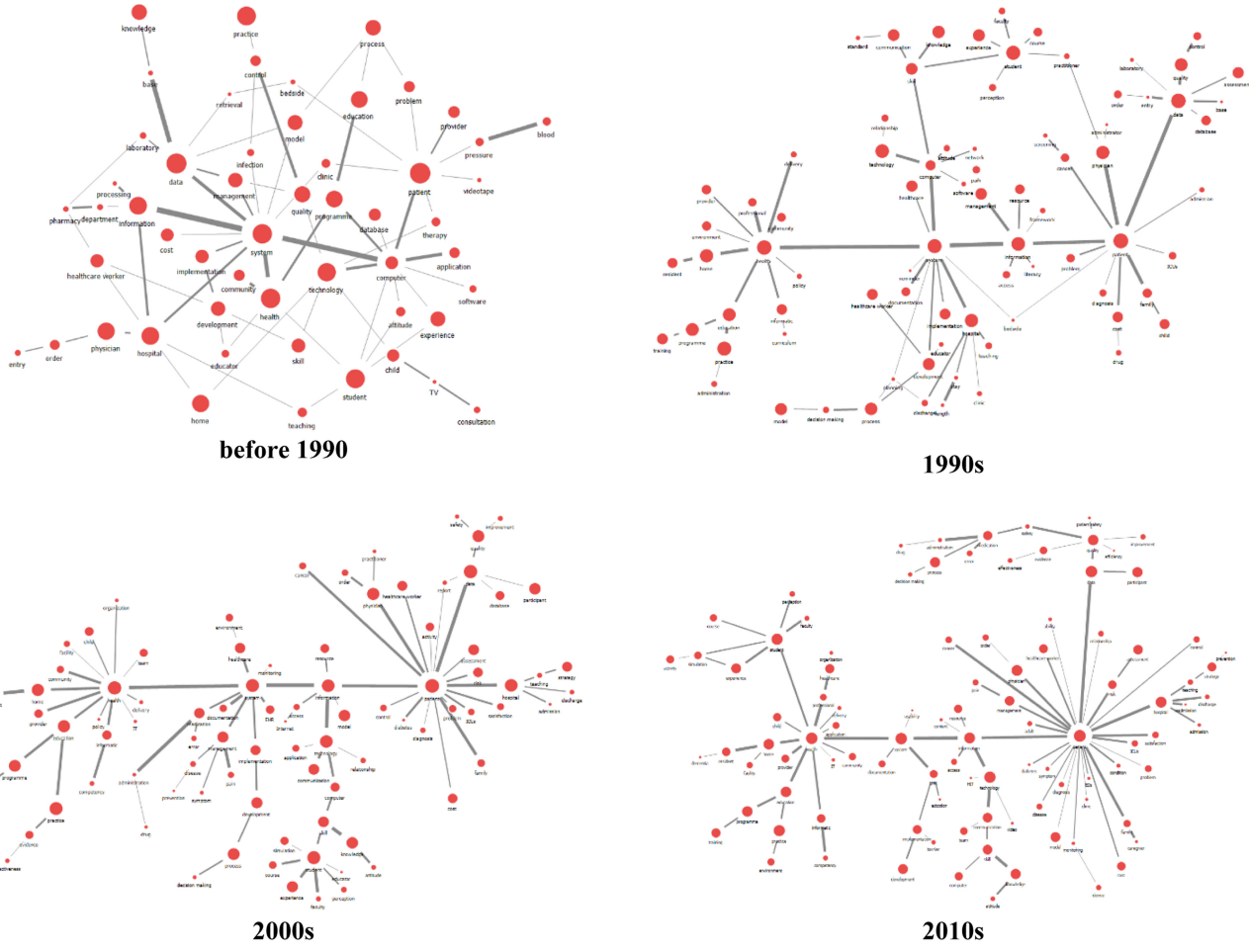

FIGURE 3. Knowledge structures of nursing informatics by time.

is strongly connected with "information," forming the ICT research group related to computers and devices. This connection suggests a group of machine and computer-related research that led to the development of informatics.[4] In the research group including the keyword "system," "EHR" and "documentation" were connected to "development," "implementation," and "healthcare." This group reflects data digitalization in healthcare settings as a result of system developments.[3] A connection between the keywords "health," "student," and "education" reveals that current technological advances and digitalization are bringing about important changes in education and that nursing education is no exception.[21] The keyword "data," which ranks second highest in degree centrality, is strongly connected with "patient" and falls within the same group as "quality," "database," and "safety." This emphasizes the importance of nursing quality and safety issues in nursing informatics.[37]

Moreover, changes in the knowledge structure over time are noticeable. A cohesive research group did not appear until 1990 because most of the keywords were connected to each other. In this period, "system," "technology," and "program" were strongly linked and centered on "computer." This is because computers were invented and rapidly updated in this period.[4] Over time, cohesive groups formed around the central keywords "patient," "health," "system," and "information." From 1991 to 2000, numerous studies centered on systems and computers emerged. From 2001 to 2010, "quality improvement" and "safety" emerged as keywords and showed a strong connection with "data." Since the 2000s, interest in patient safety and quality of care has increased worldwide,[37] indicating an increase in data-related nursing informatics research. In 1999, the Institute of Medicine also released a report for improving patient safety, focusing on working systems and the design of a safer health system.[38] This report showed how data and nursing informatics could contribute to patient safety; it also increased people's attention on safety issues in hospitals. Lastly, from 2011 to 2020, a network including "information," "communication," and "technology" became stronger, and simulation centered on "student" emerged. It is evident that the recent rapid ICT developments[4]

Table 2. Top 30 Degree Centrality Keywords by Time

Degree Centrality	≤1990	1990s	2000s	2010s
1	system	patient	patient	patient
2	patient	health	health	data
3	computer	data	system	health
4	health	system	data	technology
5	data	information	information	system
6	technology	practice	practice	student
7	hospital	technology	student	practice
8	development	computer	technology	information
9	program	development	physician	hospital
10	student	hospital	education	physician
11	information	student	process	home
12	control	physician	hospital	Knowledge
13	management	program	program	Education
14	physician	quality	development	Process
15	education	knowledge	home	quality
16	quality	skill	quality	management
17	base	education	knowledge	program
18	healthcare worker	management	management	communication
19	knowledge	home	healthcare worker	healthcare
20	practice	model	experience	development
21	process	process	skill	assessment
22	application	assessment	assessment	medication
23	consultation	cost	communication	skill
24	cost	child	computer	implementation
25	laboratory	control	medication	participant
26	model	informatics	implementation	experience
27	pharmacy	communication	model	risk
28	retrieval	decision making	training	healthcare worker
29	skill	experience	healthcare	training
30	teaching	family	informatics	model

and increase in technology applications, such as simulations in education, are reflected in the research.[21] This strengthened connection indicates the increased importance of education in ICTs and technology.

Using LDA topic analysis, this study identifies topics in nursing informatics. Here, five potential topics are generated by topic analysis. Topic 1 (3170 studies) consists of subject-related studies, and various researches[39,40] presented lots of

Table 3. Proportion and Keywords of Each Topic Group

Topic Groups (n, %)	Keywords (Weight)
Topic 1: subject-related research (2661)	patient (0.077), health (0.03), child (0.02), home (0.019), family (0.018), cancer (0.017), participant (0.017), pain (0.015), technology (0.013), physician (0.013)
Topic 2: Hospital-based research (2516)	patient (0.083), hospital (0.032), medication (0.024), home (0.023), data (0.021), resident (0.018), risk (0.016), cost (0.014), physician (0.012), error (0.012)
Topic 3: System and technology research (3699)	system (0.05), technology (0.033), information (0.031), health (0.03), practice (0.022), hospital (0.022), data (0.019), patient (0.018), communication (0.016)
Topic 4: Data-centered research (2165)	data (0.07), practice (0.03), information (0.026), system (0.023), health (0.023), quality (0.022), process (0.021), database (0.02), model (0.018), evidence (0.016)
Topic 5: Research on nursing education (3184)	student (0.093), education (0.042), program (0.031), sill (0.03), technology (0.025), simulation (0.022), knowledge (0.021), course (0.019), experience (0.019)

n = number of documents on each topic.

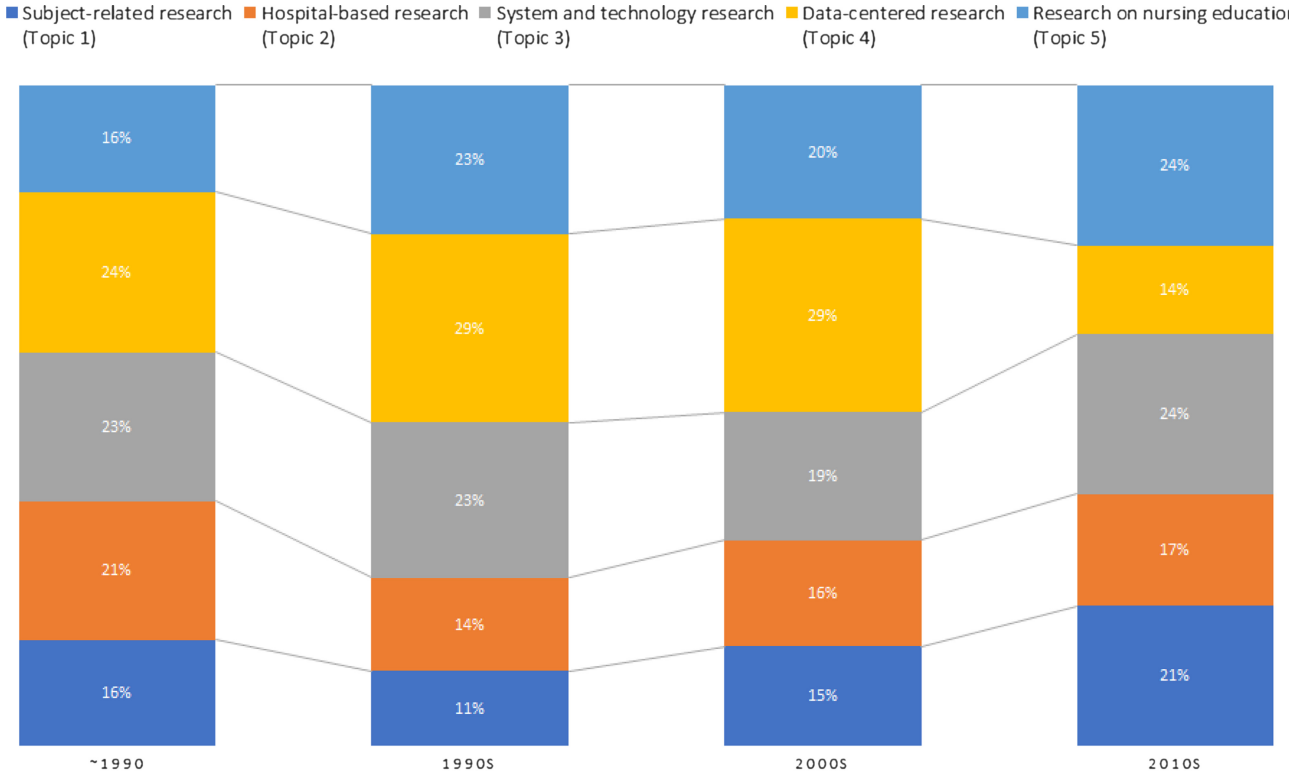

FIGURE 4. Trends of topic group proportions by time.

subjects such as patient, child, and family in nursing informatics. For the hospital-based research group (topic 2, 2555 studies), many studies focused on medical costs or medication errors.[41,42] Topic 3 (2884 studies) comprised system and technology–related research. In order to focus on the system and technology, many researchers develop the system and technologies concerning information, practice, and data.[43,44] For topic 4 (2361 studies), there are specific studies that consist of improving quality and safety using information and system to provide evidence.[45] This shows that many studies have been conducted on information system development and quality improvement using nursing informatics data. Lastly, for topic 5 (3255 studies), research on nursing education using technologies such as simulation and virtual reality has been conducted.[46–48]

Changes in the proportions of each topic show which theme has become more popular and vice versa. The proportion of topic 3 has been maintained over time, whereas that of topic 5 has increased steadily as the emphasis on the importance of education on technology intensified. This change is also evidenced by the knowledge structure shift. Because nursing informatics has become more important, and its application in education has increased, the proportion of topic 5 has also increased.[21] This change shows the increased importance of nursing education on technology. With such a change, topic 1 has grown to include not only "patient," "child," and "family," but also "cancer" and "physician." Conversely, as nursing informatics has been utilized to address education, patient safety, quality of care, and electronic health issues, interest in data itself has decreased. Therefore, the proportion of topic 4 decreased, especially over the last 10 years.

This study may have been restricted by a methodological limitation, particularly pertaining to TNA. Text network analysis is limited in that researchers using this method are more likely to rely on their knowledge, experience, and insights while analyzing data and understanding its meaning. However, in this study, it was possible to identify the important semantic context of the analysis results through a data-based inductive approach that excludes the subjectivity of the researcher. Nevertheless, the study may still be limited by having included only texts extracted and collected from the titles and abstracts of published articles and by having excluded keywords with low frequency and low centrality. Therefore, careful consideration of evidence and rationality should be exercised when interpreting and generalizing these results.

This study is the first to draw a quantitative analysis of nursing informatics research via text network analysis and qualitatively determine its knowledge structure and research

topics simultaneously. The knowledge structure identified in this study can broaden a systematic understanding of nursing informatics research. Nursing informatics experts may also gain important insights to improve nursing informatics education and application of ICT technology, in future studies.

CONCLUSION

This study examined the nursing informatics research using TNA to broaden and deepen our understanding of the knowledge structure and trend changes of nursing informatics over time. The knowledge structure of nursing informatics is formed around networks centered on "patient," "health," "system," and "information." With the increase in research on nursing informatics, studies related to systems and technology have also increased over time. Information and communication technologies have strengthened the connections within the literature, and patient safety, care quality, and nursing informatics education have become important research themes. Moreover, this study showed that big data, patient safety, and quality of care have become more important, with the number of these keywords having increased. This is in line with a survey of nurses with experience in nursing informatics that identified big data science and patient-centered issues (eg, patient safety or engagement) as top research priorities.[24] Accordingly, we propose further research on patient safety, quality of care, and nursing education based on big data and ICTs corresponding to its development. Ultimately, these can make a positive contribution to the recognition of the nursing informatics research field and the application of technology in nursing education, as well as to understand quality of care and patient safety issues.

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