Research Regarding the Clinical Decision Support Systems: A Bibliometric Analysis

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Abstract

Aim: This study aimed to analyze the research activity of Clinical Decision Support Systems (CDSS) for the last two decade via a bibliometric analysis. *Material and Method:* The search was carried out using the keyword ("clinical decision support system") in the "topic" selection mode. Documents published between 2000 and 2021 were retrieved from the Web of Science (WoS) database. Bibliometric analysis was performed to assess the quality and quantity of the documents, co-authorship analysis based on countries was employed to analyze the worldwide collaboration pattern in each time-interval, namely 2000-2009, 2010-2019 and 2020-2021. *Results:* United States of America (USA) ranked first as the most productive country in each time-interval. United Kingdom (UK), USA and China were first-in-line in terms of total citations in each time-interval, respectively. Medical Informatics dominated as the most common research category being listed in top-three in each time-interval. No statistically significant difference was observed between these time-intervals in terms of the number of publications (p=0.433). "Clinical decision support system" was marked as the most frequent authors' keyword over the years. *Conclusion:* The usage of CDSSs is expected to prevail more in almost every clinical branch in the next years. Hence, this current study is considered a guide for upcoming and ongoing CDSS research.

Keywords: Clinical decision support system; Bibliometric analysis; Healthcare; Technology; Health-informatics

Introduction

Clinical Decision Support Systems (CDSS) is a computer-based program created to provide necessary information to clinicians and other healthcare professionals for qualified healthcare and clinical decision-making process [1]. Necessary information covers all range of evidence-based clinical guidelines with a focus on patient-care. CDSS also can be defined as health-information technology aimed to aid decision-makers by utilizing information technologies, medical records and documents of patients. In this respect, CDSS researches require the collaboration of multidisciplinary fields such as engineering, medicine, computer sciences etc. Therefore, CDSS can be considered as a combination of multidisciplinary areas. Starting to have been used in 1980s, CDSSs have been observed to expeditious and remarkable progress. Besides clinical workflow, integration of Electronic Health Record (EHR) data later in the timeline has caused substantial popularity to the CDSS [2]. Numerous decision support systems have been developed over the years and they are currently in use, CDSS for managing hypertension in primary care [3], for prevention of venous

thromboembolism [4], for patients in clinical-care units to enable preventive preparations and reduce complications [5], to name a few.

Bibliometric analysis is a statistical method that aims to assess the quality and quantity of documents in the area in question [6]. This method also demonstrates the research evolution and the changes in the field of interest within the study period [7]. In addition, it detects popular research areas and the gaps that need more research for the specific area within a specified time interval [8]. Furthermore, bibliometric analysis guides policy-makers as a decision-making tool and research managers to utilize as a reliable resource for distributing grants for international collaborations [9].

Numerous bibliometric analyses have been produced in a wide range of areas, such as life sciences [10-13], natural sciences [14-15] as well as health sciences[16-19]. Furthermore, this analysis has gained much attention in medical sciences [20-23], even many bibliometric analyses in various clinical fields with a focus on the COVID-19 pandemic has been produced in such a short time, considering the outbreak has been in our lives for approximately 2 years [24-26]. However, taking into account that the CDSSs are in use for almost four decades, their rapid progress did not seem to reflect on bibliometric researches. To date, few bibliometric studies have been published with a focus on the CDSS and Decision Support System (DSS) topics [1, 27]. Both of these studies cover specific time-intervals and summarize the key developments regarding CDSS and DSS research activity in these particular time-spans. Farooq et al. revealed the interdisciplinary nature of the CDSS and revealed the key results such as highly cited authors, most productive countries, universities with the most citation bursts, most active journals and subject categories for the 2005-2016 time-interval [1]. On the other hand, the similar key results as Farooq et al's [1] were presented by Minhas and Potdar for 2000-2016 time-span in DSS research in construction area [27]. Moreover, the ongoing pandemic period gave an opportunity to researchers to evaluate its effect on field in question, which is CDSS in this current study. The current study aimed to determined as analyzing the CDSS research activity and progress over the last two decades, which is a wider time-interval compared to other bibliometric analyses focusing on CDSS research, assessing the evolution in detail at three-different time-intervals, evaluating the possible COVID-19 pandemic effect on the publications of CDSS, based on the documents that were published between 2000 and 2021.

Material and Method

Web of Sciences (WoS) website (www.webofknowlege.com) was used for retrieving the data due to its comprehensiveness among databases. The search was carried out using the keyword ("clinical decision support system") in the "topic" selection mode. The results were filtered to include journals in Science Citation Index Expanded (SCIE) category, publications in English and articles as research type. The .txt documents that had full records and cited references were downloaded from the WoS website. The search was started and completed on March 28, 2021, and publications between January 2000 and March 2021 were retrieved. The years used for this research were partitioned into three different periods to analyze papers published during 2000-2009, 2010-2019 and papers published during 2020-2021(until March 28th) in more detail. The main reason for this partitioning is to better evaluate the progression of CDSS over the last two decades or to better analyze the COVID-19 pandemic effect on CDSS documents. The number of publications of 2020-2021 (until March 28th) were not included to group comparisons since these publication numbers reflect only the first 1.5 year of the 2020-2029 decade, it is thought unreasonable to compare the 10-year research outputs with an almost 2-year research activity. Furthermore, since the year of 2021 is not complete, only the descriptive statistics for SCP were given for this time-interval.

Statistical Analysis

Biblioshiny interface of the bibliometrix R package (www.bibliometrix.org) [28] and VOSviewer software (v.1.6.16) were used for all the analyses. Frequency (n) and percentages (%) were given as basic descriptive statistics for categorical variables, while mean±standard deviation, median,

minimum and maximum values were reported for numerical ones. Mann-Whitney U Test was utilized for comparing single country publications (SCP) in different time-intervals, as well as in terms of income classification of countries. Income classifications were retrieved from https://data.worldbank.org/ website. Co-authorship analysis and corresponding graphics were obtained by VOSWiever, while biblioshiny application of bibliometrix package were applied for the remaining analyses. Two-sided p<0.05 was taken as a statistical significance level in all analyses.

Results

A total of 58, 373 and 96 papers with CDSS topic were published during time intervals 2000-2009, 2010-2019 and 2020-2021, respectively. These number of publications were retrieved and analyzed in this present study. The number of publications along with the average total citations of publications per year for each time-interval were demonstrated in Figure 1.

Number of publications and average of total citations for 2000-2009 and 2010-2019 were depicted in the following figure (Figure 1). On the other hand, mean of total citations per year was calculated as 1.523 for papers published in 2020.
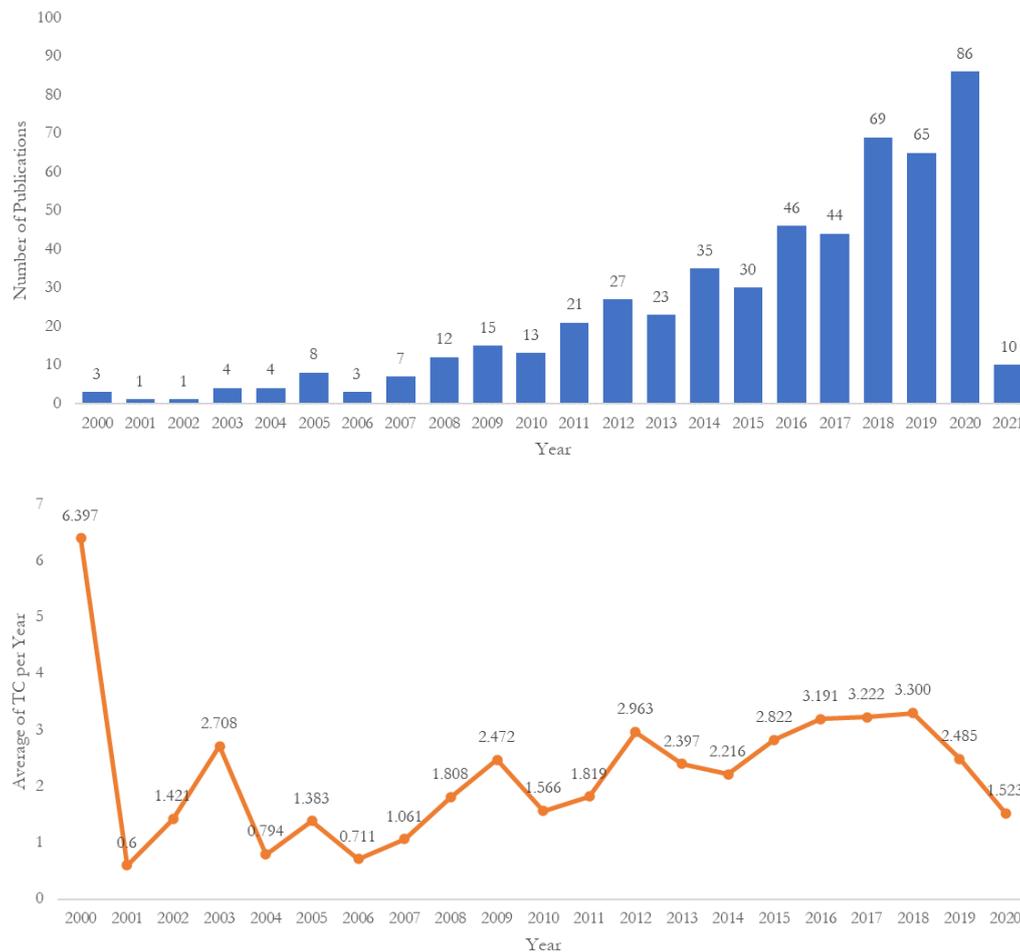

Figure 1. Number of publications and average of total citations (TC) per year for years between 2000 and 2020

Between 2000 and 2009, mean of 2.44 papers with standard deviation of 2.955 were produced (median, minimum and maximum statistics were 2, 0 and 12, respectively) whereas mean and standard deviation statistics of the documents were calculated as 5.56 and 9.664 (median, minimum and maximum statistics were 2, 0 and 58, respectively) in 2010-2019 time interval. No statistically

significant difference was found between these time-intervals in terms of the number of publications (p=0.433). Moreover, no statistical significant difference were found in terms of income level in each time-span (Table 1).

Table 1. SCP comparisons for each time-interval in terms of income classification

Income Classification	2000-2009			2010-2019		
	Mean ± SD	Median [Min – Max]	p-value	Mean ± SD	Median [Min – Max]	p-value
High-income	2.79±3.286	2 [0 – 12]	0.327	6.45±11.230	2 [0 – 58]	0.373
Middle-income	1.25±0.5	1 [1 – 12]		3.94±5.848	1 [0 – 21]	

SD = standard deviation

Most productive countries regarding publications on CDSS were listed in Table 2. In all three-time intervals, USA ranked first with 13 (12 SCP and 1 MCP), 64 (58 SCP and 6 MCP) and 16 papers (13 SCP and 3 MCP) in aforementioned time-intervals, respectively (Table 2).

Table 2. Most productive countries in terms of CDSS research

2000-2009				2010-2019				2020-2021 (until March 28th)			
Country	Articles	SCP	MCP	Country	Articles	SCP	MCP	Country	Articles	SCP	MCP
USA	13	12	1	USA	64	58	6	USA	16	13	3
UK	9	8	1	CHINA	41	21	20	CHINA	14	9	5
CANADA	7	2	5	KOREA	27	16	11	KOREA	10	6	4
SWEDEN	4	3	1	NETHERLANDS	21	18	3	INDIA	8	7	1
FRANCE	3	2	1	SPAIN	21	14	7	GERMANY	6	5	1
GERMANY	3	2	1	INDIA	20	14	6	NETHERLANDS	6	3	3
ISRAEL	3	3	0	GERMANY	19	13	6	ITALY	4	3	1
SPAIN	3	2	1	CANADA	16	9	7	SPAIN	4	2	2
CHINA	2	1	1	UK	15	8	7	TURKEY	4	4	0
INDIA	2	2	0	AUSTRALIA	13	12	1	UK	3	3	0

*: SCP: Single Country Publications, **MCP:** Multiple Country Publications

On the other hand, United Kingdom, USA and China were observed to be first in-line in terms of total citations in 2000-2009; 2010-2019 and 2020 and the first 3-months of 2021. In addition, France (2000-2009 and 2010-2019) and South Africa were listed in first place in terms of AAC metric with 84.3, 27.7 and 15 citations per article, respectively (Table 3).

Table 3. Most cited countries in terms of CDSS research

2000-2009			2010-2019			2020-2021 (until March 28th)		
Country	TC	AAC	Country	TC	AAC	Country	TC	AAC
USA	236	18.2	INDIA	346	17.30	SOUTH AFRICA	15	15
INDIA	67	33.5	NETHERLANDS	201	9.57	GREECE	5	5
SWEDEN	153	38.2	KOREA	315	11.67	TURKEY	15	3.75
UK	408	45.3	USA	1097	17.14	CHINA	36	2.571
FRANCE	253	84.3	CHINA	636	15.51	USA	29	1.812
NORWAY	60	60	AUSTRALIA	160	12.31	IRAN	3	1.5
GERMANY	66	22	UK	192	12.80	ITALY	5	1.25
CANADA	144	20.6	FRANCE	277	27.70	KOREA	12	1.2
KOREA	69	69	SPAIN	263	12.52	NETHERLANDS	6	1
NETHERLANDS	66	33	GERMANY	184	9.68	GERMANY	4	0.667

TC: Total Citations, AAC: Average Article Citations

Clinical Decision Support System (CDSS) publications were categorized into different research areas over the years in terms of WoS category. The top three category can be listed as healthcare sciences services (n=14, 24.138%), medical informatics (n=12, 20.690%) and computer science artificial intelligence (n=10, 17.241%) for 2000-2009 period; they were medical informatics (n=98, 26.064%), healthcare sciences services (n=50, 13.298%) and computer science artificial intelligence (n=45, 11.968%) between 2010 and 2019. Furthermore, medical informatics (n=20, 20.833%), computer science artificial intelligence (n=13, 13.542%) and Engineering, Electrical & Electronic (n=11, 11.458%) were listed as top-three WoS category in 2020 and 2021 (until March 28th). In most active journals' aspect, Expert System with Applications, Computer Methods and Programs in Biomedicine and IEEE Access were found as the leading journals in 2000-2009, 2010-2019 and 2020-2021 (until March 28th), respectively. Journal list is given in the following table (Table 4).

Co-authorship analysis based on countries was performed and illustrated in Figure 2. It is revealed that there were 2, 4 and 4 clusters in each time-interval; namely 2000-2009, 2010-2019 and 2020-2021(until March 28th), respectively (Figure 2).

Figure 2a. Co-authorship analysis for 2000-2009 time-interval *Cluster 1: England, France, USA. Cluster 2: Canada, Poland*

Table 4. Most active journals in CDSS research

| 2000-2009		2010-2019		2020-2021 (until March 28th)	
Sources	Articles	Sources	Articles	Sources	Articles
EXPERT SYSTEMS WITH APPLICATIONS	4	COMPUTER METHODS AND PROGRAMS IN BIOMEDICINE	14	IEEE ACCESS	7
ARTIFICIAL INTELLIGENCE IN MEDICINE	3	ARTIFICIAL INTELLIGENCE IN MEDICINE	12	PLOS ONE	4
DECISION SUPPORT SYSTEMS	2	JOURNAL OF MEDICAL SYSTEMS	12	BMC MEDICAL INFORMATICS AND DECISION MAKING	3
DISEASE MANAGEMENT & HEALTH OUTCOMES	2	EXPERT SYSTEMS WITH APPLICATIONS	11	JOURNAL OF MEDICAL INTERNET RESEARCH	3
EUROPEAN JOURNAL OF CLINICAL PHARMACOLOGY	2	INTERNATIONAL JOURNAL OF MEDICAL INFORMATICS	10	APPLIED SCIENCES-BASEL	2
INTERNATIONAL JOURNAL OF MEDICAL INFORMATICS	2	BMC MEDICAL INFORMATICS AND DECISION MAKING	9	ARTIFICIAL INTELLIGENCE IN MEDICINE	2
METHODS OF INFORMATION IN MEDICINE	2	IEEE JOURNAL OF BIOMEDICAL AND HEALTH INFORMATICS	9	BMJ OPEN	2
ACADEMIC MEDICINE	1	APPLIED CLINICAL INFORMATICS	7	COMPUTER METHODS AND PROGRAMS IN BIOMEDICINE	2
ADVANCES IN CHRONIC KIDNEY DISEASE	1	PLOS ONE	7	HEALTH INFORMATICS JOURNAL	2
AMERICAN JOURNAL OF HEALTH-SYSTEM PHARMACY	1	COMPUTERS IN BIOLOGY AND MEDICINE	6	JMIR MEDICAL INFORMATICS	2
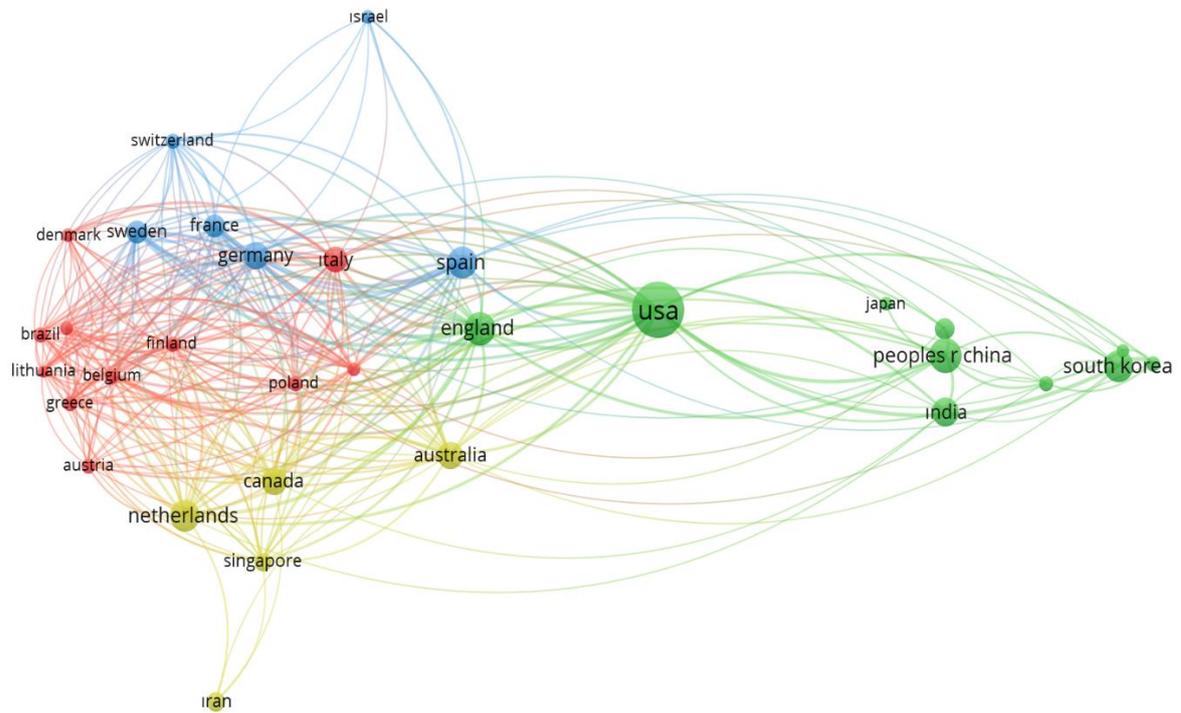
Figure 2b. Co-authorship analysis for 2010-2019 time-interval. *Cluster 1: Austria, Belgium, Brazil, Denmark, Finland, Greece, Italy, Lithuania, Poland, Scotland, Turkey. Cluster 2: Egypt, England, India, Japan, Pakistan, China, Saudi Arabia, South Korea, Taiwan, USA. Cluster 3: France, Germany, Israel, Spain, Sweden, Switzerland. Cluster 4: Australia, Canada, Iran, Netherlands, Singapore.*

Figure 2c. Co-authorship analysis for 2020-2021 (until March 28th) time interval. *Cluster 1: England, Netherlands, China. Cluster 2: South Korea, Spain, USA. Cluster 3: India, Taiwan, Turkey. Cluster 4: Germany, Italy.*

On the other hand, most frequent keywords lightly change over the years, this change was demonstrated with 3-different word cloud graphs, each one for each interval (Figure 3a-3b and 3c).

Figure 3a. Most frequent authors' keywords for 2000-2009 time-interval

Figure 3b. Most frequent authors' keywords for 2010-2019 time-interval

Figure 3c. Most frequent authors' keywords for 2020-2021 (until March 28th) time-interval

Graphs suggested that "clinical decision support system" was the authors' most common keyword for each time-interval, with 15 and 100 and 30 counts, respectively. Furthermore, "machine learning" was observed to be the second most-common keyword in the last time-interval, followed by "artificial intelligence", while "expert systems" seemed common between 2000 and 2009, after "clinical decision support system", "clinical decision support systems" and "clinical decision support system (cdss)". "Machine learning" and "artificial intelligence" were the most common keywords of authors after the "clinical decision support system" between 2010 and 2019. In overall, the frequency of keywords "machine learning" and "artificial intelligence" were observed to increase within the study-period.

Discussion

Results for this current study revealed that the USA is in the lead in terms of the total number of publications in all-three time-intervals, while country profiles were observed to change in terms of total citations, USA, India and South-Africa were listed first in line in 2000-2009, 2010-2019 and between 2020 and 2021 (until March 28th), respectively. USA's predominance in number of publications lane may mainly be attributed to high number of researchers in USA and high level of research funds given in this country compared to other countries. Moreover, contribution to worldwide collaboration of USA might play an important role WoS-based research categories were observed to change over the years, but this change was only observed in the lines. 2000-2009 and 2010-2019 first three research categories were the same, with a different ranking. Most of the CDSS were observed to be developed in healthcare sciences services areas between 2000 and 2009 time-interval, while majority of the CDSS were developed in medical-informatics-related areas from 2010 to 2019. Current research on CDSS was found to be centered more on engineering-related fields, as a result, the Engineering, Electrical & Electronic WoS category was listed first for 2020-2021(until March 28th). In general, WoS categories of research areas were converted from healthcare sciences services to Engineering, Electrical & Electronic, indicating more engineering-centered DSS were being developed currently. These results also imply that the collaboration trend of clinical and engineering fields is increasing. An almost similar pattern was observed in terms of the most popular journals for CDSS; that is, Expert System with Applications in Engineering category, Computer Methods and Programs in Biomedicine in Health Informatics sub-category and IEEE Access in Enginerring as well as Materials Science category were listed as leading journals for each time-interval, respectively. On the other hand, even though anayzing the possible COVID-19 pandemic effects on CDSS studies was one of the aims of this study, no remarkable effect could be detected in this regard.

The reason could be the inclusion of such a short-time interval for COVID-19 effect, that is, possible effects on CDSS research could not be captured due to shortness of time-interval, taking into account that this outbreak has emerged in the late 2019, and be declared as a pandemic in March 2020 by World Health Organization (WHO); very first publications could be published in the midst of 2020 at best, therefore a 10-year time-interval would be more appropriate to investigate this possible pandemic effect on CDSS papers.

Results of this study revealed that most productive and most cited countries such as USA and UK are developed, high-income countries with a high level of welfare. Therefore, publications that require international collaboration and a high level of research funds are generally produced in such countries. Furthermore, CDSS are described as the enhancer of adherence to clinical guidelines, cost-effective through clinical interventions and improver of the quality of the clinical documentation [29]. Hence, the increasing level of global collaboration and a higher level of research funds will display its properties more clearly in each clinical specialty. As such, this current bibliometric study is expected to be seen as a guideline for both ongoing and upcoming CDSS research since within its scope, the useful information about current CDSS research trend, which can be thought as the pre-report for the future CDSS studies, are presented.

Despite the fact that there are numerous bibliometric analyses in the literature related to medical researches, to date, only a few analysis have been published pertaining to CDSS studies. USA was also mentioned as the most productive county in 2005-2016 time-span by Farooq et al. (2017) [1]. Furthermore, similarly, healthcare sciences & services followed by medical informatics WoS categories were listed as most common research areas within the study period in Farooq et al. (2017)'s study [1]. However, in contrast to our results, Journal of the American Medical Association was indicated as the most central journal both in terms of number of publications and number of citations. The contrast could be stem from either the difference of the search strategy or usage of other databases.

On the other hand, Minhas and Potdar's study revealed that USA as well as China were described as the most influental contributers to DSS research in construction area between 2000 and 2016 [27], moreover they indicated Lithuania as having the most ranked authors in this field. Even though USA was found as the most active contributor both in Minhas and Potdar's and this current study, it's not comparable since the research fields of these studies are different.

Some limitations for this current study should be taken into account. First, only papers written in English language were included, therefore documents of other languages were not analyzed. Second, publications from WoS database were retrieved and for comprehensiveness other databases such as PubMed and Scopus were excluded. Third, only SCIE indexed publications were included in this study. Moreover, a limited discussion could be made for this current research due to the inadequate number of bibliometric papers in the CDSS field.

This study provides an all-inclusive bibliometric analysis on CDSS, based on the publications between 2000 and 2020. It is considered a unique bibliometric study on CDSS, taking into account the various analysis and visual materials including group-comparisons, explanatory co-authorship graphs based on countries to investigate international collaboration, informative word-cloud graphs based on authors' keywords to identify most-frequent ones for each time-interval. Moreover, this current study covers a wider time-interval compared to other bibliometric analyses with a focus on CDSS. Furthermore, this broader study period was partitioned into 3-different time-interval, namely 2000-2009, 2010-2019 and 2020-2021 (until March 28th). Needless to point out, this broader and fragmented time interval provides the opportunity to better assess the progression on CDSS documents and to better investigate the changes during the study period. Also, it is noteworthy to mention that inclusion of over 20 years of research output and partitioning-based detailed evaluation were not applied to the analysis of research activity of CDSS. Hence, this current study could also be thought of the first study for these aforementioned properties.

This current study represents a detailed visual and bibliometric research on the CDSS area. Besides its multidisciplinary environment, several components such as increasing worldwide collaboration and extended research fund opportunities will help improve CDSS developments in each clinical specialty. As a result, their usage is expected to be more popular in the following years.

List of abbreviations

CDSS: Clinical Decision Support Systems
USA: United States of America
UK: United Kingdom
SCP: Single Country Publications
MCP: Multiple Country Publications
AAC: Average Article Citation
TC: Total Citations
WHO: World Health Organization
DSS: Decision Support System
EHR: Electronic Health Record

Conflict of Interest

The author declares no conflict of interest.

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