Clinical Decision Support Systems (CDSSs): State of the art Review of Literature

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Abstract

Introduction: One of the major advances in medical practice and healthcare is to incorporate decision support systems (DSS) in such practices to assist healthcare staff. The present study aimed to make a general understanding framework about the state of the art of the clinical decision support systems (CDSS).
Methods: The design of this was a systematic review. According to the research keywords (decision, decision-making, clinical decision, clinical decision-making, decision support, decision support system, clinical decision support system), Persian and English papers and scientific literature in scientific data bases include Simorgh, MagIran, and SID for Persian, as well as Science Direct, Google Scholar, Google Patent, Wikipedia, PubMed, Sage, and Springer for English resources were searched. At the end, among 1247 papers, 27 papers were selected regarding the inclusion criteria. Delphi method was implemented to construct the final format of the results report. The method of the data analysis were librarian and content analysis.
Results: Two main definitions of CDSS, 13 popular CDSSs, major aims of usage, practical and theoretical benefits, principal methods of decision support, three major classifications, medical/clinical data mining, EBM, and efficacy of CDSS have been evaluated and discussed.
Conclusion: The usage of CDSS in clinical and healthcare settings is increasing. It has been shown that the incorporation of CDSS can significantly improve health outcome indices. However, authorities shall establish standards and quality control systems to evaluate and integrate development and implementation procedures of CDSS. In addition, future studies would better compare alike CDSS to evaluate competitive advantages and concurrent validity of various CDSSs.

Keywords: Decision Support Systems (DSS), Clinical Decision Support Systems (CDSS), Multiple-criteria Decision Analysis (MCDA), Multiple-criteria Decision Making (MCDM), Medical/Clinical Data Mining, Evidence-Based medicine (EBM), Systematic Review, Delphi Method.

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Submission Date: 10/09/2015
Accepted Date: 28/11/2015

Introduction

Human beings take decision all day long in mostly every action of her/his life. It is believed that optimum decision-making is an art. Studies suggest that most people act much weaker than expected [1]. It could be said that all actions and affairs of human in any domain of life are the results of decision-making processes. Nowadays, deciding is a process which is related to problem-solving and therefore, decision-making is known as a problem-solving action. In other words, mentally, a problem occurs when the desired situation of the person appears that is different with the current situation. In such an occasion, individual primarily tries to change the current situation or condition in her/his mind, and then, willing to change the surrounding environment in order to achieve the desired goals [2].

Considering the need to take a suitable decision in a proper time, the presence of a system to provide people with aid in decision-making is of high value. Systems which do not only provide information, but also participate in even simple decision-making activities of any organization, are known as Decision Support Systems (DSS) [3]. DSS is a computer-based system of information processing which is mainly developed to support organizational and enterprise affairs. Today authors believe that DSS could be told to any system that can support decision-making processes. In other words, DDSs are information systems which support organization, institutional, and/or enterprise activities that are in some way related to decision-making. DSSs are especially important when the situation is rapidly changing and anticipation and determination of future situations/conditions are hardly possible [4].

Medical errors are one of the major problems in public health and are considered as threats to patients' security. Patients' security has a great role in healthcare. Authors have suggested the use of information technology advances as a suitable strategy to improve the quality of healthcare services and patients' health. One of the most important and applicable information systems are clinical decision support systems (CDSS). In fact, one brilliant domain of the implementation of DSS is clinical decision-making [5].

The domain of health is nowadays a wide area of information which is actually demanding for professional consultation and support, especially with every-day change and extension of medical knowledge in different aspects of healthcare system. These aspects include: diagnosis, medication, treatment, and follow-up in all three phases of primary, secondary, and tertiary prevention. Clinical decision support system (CDSS) is an interactive software which is developed on the basis of expert systems in order to assist and support the decision-making of physicians, health-care staff, and other personnel involved in broader domains of health-care systems. It could be noted that CDSS relates to health observations with health knowledge to improve health-care decisions which are taken by health-care professionals. CDSS is the manifestation of the application of artificial intelligence in the public as well as private health-care systems [6].

CDSSs are considered as active systems of knowledge which are using two or more classification orders to generate case-specific medical suggestions for patients. This means that CDSS is indeed a DSS which focuses on knowledge management in health-care affairs to reach a medical advice according to few available issues [7]. The main goal of designing current CDSSs is to assist physicians as well as other clinical professionals in some point in professional care systems. Therefore, the clinical experts and staff shall be in an active interaction with CDSS to use its capabilities to reach an optimum diagnosis, analysis, etc., according to patients' data.

Previous instructions and theories of CDSS was based on using it to provide diagnosis with clinician. Formerly, clinicians gave information to CDSS and awaited CDSS to take the correct decision, and the clinician solely acted according to CDSS outputs. Modern methodology in using CDSS compels clinicians and healthcare staff to interact with CDSS and simultaneously uses both knowledge to better analyze patients' information and reach a more correct diagnosis and more accurate healthcare services, comparing to the time of using just of these two. CDSS Usually classifies and provides clinicians and healthcare staff with suggestions and/or a set of desired outputs, and then clinicians and healthcare staff formally choose between useful information and reject incorrect suggestions from the system [8].

CDSSs are not designed to substitute physicians, and healthcare staff are just considered as an aid to medical sciences professionals, healthcare services, healthcare staff, diagnosis, and treatment. These systems facilitate the process of specific diagnosis, prescription, medication, and healthcare and also reduces the need to consult with experts and hence, significantly reduces the healthcare system expenses and increases the accuracy of healthcare services [9].

Therefore, the use of information technology in the form of CDSS would surely help and assist physicians and healthcare staff, as well of healthcare managers and policy makers to correctly and timely decide. Nowadays diverse domains of healthcare system utilizes CDSS to improve their services and reduce the medical error rates. The present review paper aims to make a better understanding of CDSS, its bases, and its benefits to healthcare domain.

Methods

2.1. Design

The design of the present study was a systematic review. Systematic review aims at providing a detailed abstract of literature about study question(s). It is noteworthy that, in systematic reviews, each inspected literature has its own different methodology and might be qualitative/quantitative, descriptive/experimental, etc. [10], which shall be incorporated in the specific framework of the given systematic review. All systematic reviews have objective and determined approaches to synthesize results with the core aim of maximum reduction of biases. While some may do statistical analyses, most systematic reviews (include current study) are based on qualitative evaluations according to the standards of collection, analysis, and reporting gathered evidence [11].

2.2. Data sources

In order to fulfill the aims of the current systematic review, several academic and scientific search engines were used. These search engines included PubMed, Sciencedirect, Google Scholar, Kolwer, and Google Patent, for English, as well as Simorgh, MagIran, and SID for Persian resources.

2.3. Sample

The population of the study was comprised of all the published papers in English and Persian about clinical decision support systems (CDSS) which were totally about 1247 in different scientific search engines (with exact "clinical decision support" phrase either in the title or keyword of the published paper). The process of sampling consisted of increasing inclusion criteria to reduce the amount of references including publication date (between January 1, 2005 and June 1, 2015), having exact phrase of "clinical decision support system" in keywords, and exclusion of irrelevant papers, reduced the papers to 253. In the next step, the abstracts were reviewed, so that 49 full-text papers remained. The final sample comprised of 17 full-text papers which were completely inspected (Diagram 1).

2.4. Procedure

In the study procedure, the key words of the research (decision, decision-making, clinical decision, clinical decision-making, decision support, decision support system, clinical decision support system) were used in Persian and English to find related papers and scientific literature in scientific data bases.

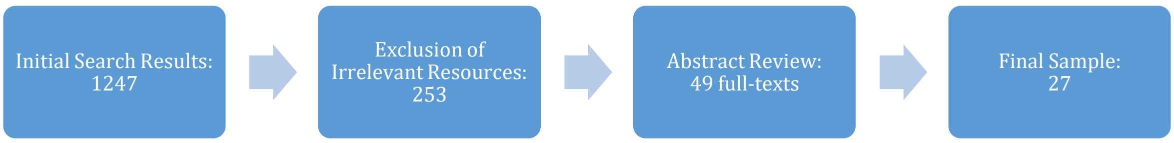

Diagram 1. Sampling process in the study

The priority was with the review papers. The inclusion criteria were publication date (between Jan, 1, 1995 and July, 1, 2015), subjective relevance to specified parts of the study, relevance to study aims, relevance to study keywords, being published by academic sources, and the level of relevance which was determined by scientific search engines.

2.5. Analysis

After primary resource collections, the Delphi method was implemented to increase the validity of the results and decreased the probable latent biases. The Delphi method is mainly used to explore innovative and confident ideas in order to collect and classify knowledge in some area of knowledge from its experts. This method is mostly used in exploratory qualitative research with the use of various opinions from different experts about new ideas or complex problems by administrating several surveys and controlled feedbacks [12, 13]. Delphi method is a dialectical process of confrontation of thesis and antithesis, and finally construction of synthesis, which is the newly formed consensus. The underlying dialectical logic of Delphi methods ensures the multidimensionality of the results and aims to construct new theoretical points of view. It helps to increase the level of novelty and creativity in the phase of exploration of new ideas and is mostly addressed as a novel inspiring method. [14].

It has also been applied to determine and develop possible alternatives, exploring or exposing assumptions that leads to different judgments, generating consensus, and educating the respondents [15]. All typical Delphi methods comprise three major stages. The first stage is the selection of the participants and is very important, because it is directly related to the quality of the generated results. At the second stage, the actual Delphi rounds are implemented. The number of rounds ranges from two to ten. Each round needs to have an objective, around which the content of the survey must be built. The final stage is the analysis of the results and the final written consensus. The stage also includes reflecting on the experiences gained from the Delphi process and applying the results and the experience in practice [16].

According to the benefits of the Delphi method and its implementation, authors decided to use this methodology to maximize the optimum issues of concern in reviewing the field of CDSS. This was to ensure that biases of authors would not result in ignoring or overemphasizing some domains of CDSS. The present study applied the form of classical Delphi with five features including anonymity, iteration, controlled feedback, statistical group response and stability in responses among those with expertise on a specific issue. The participants in this type of Delphi have expertise and give opinions to arrive at stability in responses on specific issues [17]. In the current study, in order to administrate the Delphi method, six experts were chosen: three PhD of industrial engineering with at least five years of expertise in DSS (to suggest the technical issues of CDSS in general), and three healthcare experts with at least a background of five years dealing with CDSS (to suggest the specific implementations and objectives of CDSS in healthcare systems). The main question of the study (what are the essential issues in the domain of CDSS?) was sent to them and were asked to reply in written forms. Their answers were collected and unified in a checklist. This checklist was sent to experts and they were asked to write down their ideas and any modification. This procedure was repeated three times until all experts had no modification in their own checklist in round four. Therefore, the Delphi procedure was terminated by participants after three dialectical stages (Table 1).

Following data collection, the most related resources were chosen and devoted according to domains, which were determined by the Delphi method previously. The method of data analysis were librarian and content analysis, as well as frequent considerations of various papers to certain issues.

2.6. Ethics

The ethical aspects of the study was comprised of two parts. The first ethical issue was respecting the copyrights of the authors of resources including papers, books, book chapters, manuscripts, dissertations, etc., which was directly done in the present study. The second part of study ethics included anonymity and confidentiality of the participants of the Delphi method. The identity of all these experts kept anonymous. All the procedure and aims of the study were fully described to all them and they filled out a written consent in which they fully understood the terms of participation. The results of the Delphi method administration and the study were sent to the aforementioned experts as part of mutual partnership**.**

Table 1. Results of Delphi method

Round	suggested topics
Round 1	Definition of decision, definition of DSS, definition of CDSS, design of CDSS, algorithms of CDSS, aims of CDSS, benefits of CDSS, classification of CDSS, types of CDSS, CDSS softwares, applications of CDSS, history of CDSS, advances in CDSS, statistical comparisons of CDSS usage, differences of CDSS in developed vs. developing countries, CDSS in tough situations, portable CDSS, level of access in CDSS, methods of CDSS computations, degree of specifity, CDSS in different sectors of healthcare system, management of CDSS, biases in CDSS, racial and gender differences in CDSS, integration of therapeutic technologies with CDSS, limitations of CDSS
Round 2	Definition of CDSS, Scopes of CDSS usage, pros and cons of CDSS, applications of CDSS, methods of analysis in CDSS, types and classes of CDSS, evidence-based (EBM) and CDSS, data mining in CDSS, domains of coverage by CDSS, medical errors in CDSS, software development of CDSS, general and specific CDSS, CDSS basic needs, CDSS benefits of healthcare system, degree of specifity in CDSS, management of healthcare system and CDSS.
Round 3	Definition of CDSSs, popular CDSSs, aims of application CDSS, benefits of CDSS, methods of decision support in CDSS, classification of CDSSs, Medical/clinical data mining, evidence-based medicine (EBM), reduction of medical error, facilitation of quality of healthcare.

Results

3.1. Definition of CDSS

There are various definitions of CDSS. The major issues of definition are emphasizing on the consideration of CDSS as an active knowledge system which uses two or more classifications of the data of patients to generate case-specific medical suggestions. This shows that CDSS is, in fact, a DSS concentrating on the use of knowledge management in medical affairs to reach a medical advice by concluding different types of current options and information [7].

CDSS is an analytical instrument which assists therapists to decide better about their patients by transforming row clinical data to useful information. CDSS is indeed a software which provides a healthcare system with information for secure care. These information includes standards and evidence-based instructions, actions and protocols, regulations and suggestions for care, medicine reference and instruments to calculate suitable proportions, future for connection to library, digital reference books, and/or internet references [5].

3. 2. Popular CDSSs

Numerous clinical decision support systems are being mass produced in the market and sold day to day. In addition, many researchers have developed CDSS according to their research aims [18]. Table 3 presents the popular CDSSs in clinical and healthcare systems. Indeed, there are many CDSSs up to date, however, a few of them are being used widely. This list only emphasizes on the inclusive CDSSs by the time of framing the study.

3.3. The aim of the implementation and application of CDSS

The main goal in designing and developing the current CDSSs is to assist physicians and clinical professionals in any given point of professional healthcare system. CDSS is mostly designed to help healthcare staff to decide in semi-structured problems, support instead of substitution of clinical judgments, and completion of effectiveness of decision-making instead of its efficacy [19].

Any knowledge and information management system in the form of DSS is far beyond organizational information architecture which is the main reason of development and implementation of CDSS in healthcare systems and networks. It appears that in the era of information technology, any healthcare system shall be equipped with CDSS to satisfy the need to best, fastest, and most confident medical information in all the three phases of prevention [20].

According to recent review of literature in Iran, major domains of the implementation of CDSS are disease trend management (15.15%), healthcare and treatment (27.27%), prescription (27.27%), assessment and evaluation (27.27%), and prevention (12.12%) [21].

3.4. Benefits of CDSS

All systems shall be cost-effective in order to be eligible to being incorporated to the management systems. If all pros and cons of CDSS, were simply quantifiable, then it would be possible to justify their usage. Whenever pros exceed cons, the system is justified to get implemented. The problem is that most advantages of the application of CDSS are intangible. With accurate assessments, it would be possible to evaluate the performance and advantages of using DSS. Some important benefits of using decision-support systems in clinical settings are derived from reviews as follows [22]:

1. Saving time
2. Saving expenses
3. Better understanding of clinical situations
4. Ability to perform unprecedented analyses
5. Better use of resources
6. Ability to respond fast to unexpected situations
7. Extension of examined options
8. Extension of available options
9. Make new viewpoints
10. Provide new learning
11. Development and facilitation of inter-professionals communication
12. Provide control
13. Improve decisions
14. Facilitate teamwork in medical staff
15. Facilitate clinical group decision-making

Some authors have divided the benefits of CDSS into three domains [21]:

1. Improvement of quality of healthcare and improvement of patients' safety by reducing prescription errors and drug side-effects, as well as direct following of evidence-based clinical instructions.
2. Increase of effectiveness/cost ration by faster process of orders, reduction of medical test repetition, reduction in drug side-effects, changing drug consumption pattern, and changing drugs with generic ones in order to retrenchment the healthcare costs.
3. Improvement of medical and professional knowledge by ease of access to scientific resources, presentation of reminders, and providing useful and critical information to desirable decision-making with minimum errors.

3.5. Methods of decision support in CDSSs

There are various methods and techniques to decision support. Nowadays, decision support mainly focuses on decision support systems. In other words, common sense of the current era, identifies decision support synonymous to DSS in its general and wide meaning. Yet, most of the DSS and CDSS implement multiple-criteria decision support techniques. Multiple-criteria decision-making (MCDM), also known as multiple-criteria decision analysis (MCDA), is a subset of operation research which exclusively deals with studying different qualitative and quantitative criteria in any given situation of deciding. All domains of personal and social life, whether general or specific, usually have different and conflicting criteria which are needed to be inspected and evaluated before taking any decision. One of the mostly important and considered criteria is the cost or price of any decision. Another controversial and conflicting domain of decision-making is criteria for quality evaluation. Human everyday life is full of deciding points which are done unconsciously.

Table 2. Popular CDSSs

CDSS	manufacturer	Usage Period	Algorithms	layout	Application fields	website
CADUCEUS	Pittsburg University, Pittsburg, PA, USA.	1970's and 1980's	Knowledge-based, Dissociative reasoning	Have separate computer system	Diagnosis of internal diseases, Educational application.	---
Clinical Rules	Digitalis Rx, Amsterdam, Netherlands	Now active	Knowledge-based, Knowledge management, Clinical Rules Engine, G standard MFB, Andere protocollen	Online	Medicine prescription, consumption monitoring.	http://www.clinicalrules.nl/en
DiagnosisPro (Free)	MedTech USA, Inc.‹Los Angeles, CA, USA.	Now active	Knowledge-based	Online, computer software, touch phone applet	Diagnosis and differential diagnosis of more than 11 thousand diseases and 30 thousand medical conditions.	http://en.diagnosispro.com/
DxMate (Free)	Infermedica Sp. Warsaw, Poland.	Now active	Knowledge-based	Online	Diagnosis of more than 500 medical condition.	https://dxmate.com/
Dxplain (Free one-month evaluation version)	Massachusets General Hosptial, Boston, MA, USA	Now active	Knowledge-based, pseudo-probabilistic algorithm, Bayesian logic,	Online, computer software	Diagnosis and differential diagnosis of internal diseases, educational application.	http://www.lcs.mgh.harvard.edu/projects/dxplain.html
ESAGIL (Free)	Esagil Institute, New York, NY, USA.	Now active	Knowledge-based, dissociative reasoning,	Online	Diagnosis of diseases according to signs and symptoms, blood and urine test.	http://esagil.org/
ISABEL	Isabel Healthcare Inc. Ann Arbor, MI, USA.	Now active	Knowledge-based, query string, HL-7, XML, API	Online	Diagnosis of all medical diseases, medicine prescription.	http://www.isabelhealthcare.com/home/default
INTERNIST-I/QMR	Pittsburg University, Pittsburg, PA, USA.	1970's and 1980's	Dialog system, pattern recognition, ranking algorithm,	Have separate computer system	Diagnosis of internal diseases, educational application.	---
Litmusdx	Litmusdx Company, Kolkata, India	Active now	Knowledge-based	Online	Diagnosis and differential diagnosis of 11 thousand diseases, presentation of 300 therapeutic protocols, presentation of 50 thousand medicines,200 thousand medicine usage cautions, medical test interpretations, medical files.	www.litmusdx.com
MYCIN	Stanford University, CA, USA.	1970's and 1980's	Knowledge-based, Bayesian networks, graphical models, decision trees	Have separate computer system	Bacteria identification, blood infections identification, medicine prescription, blood clot diseases, educational application.	---
Prescriptor	Digitalis Rx Company, Amsterdam, Netherlands	Now active	Knowledge-based, Knowledge management, matrix models	Online	Medicine prescription, Online access to medical files	http://ww.prescriptor.nl/en www.digitalis.nl
RODIA	Warsaw Medical University, Warsaw, Ploand.	Now active	Non-knowledge-based, Pattern identification, telemedicine, calibration, linear and angular measurement, phantom calibration	Online	Medical imaging, diagnosis, orthopedic problems, monitoring the bone-fracture remedial	w.glinkowski@parser.com.pl
SimulConsult (Free and Purchase versions)	SimulConsult Inc., Chestnut Hill, MA, USA.	Now active	Knowledge-based, Bayesian inference engine, bioinformatics genome annotation, statistical pattern-matching approach	Online	Diagnosis of 5300 diseases especially genetic and neurological.	http://www.simulconsult.com/

People, whether ordinary or experts, usually implement multiple-criteria probes in their routines implicitly and might be satisfied with the decisions which are made heuristically. On the other hand, when the capital volume and/or value is high, or when the human life matters, accurate and correct structuring of the problem and explicit evaluation of various criteria becomes important [23]. Knowing that in healthcare systems, any medical error could be lethal and if any of these heuristic decisions fail, patient's health might be in harm or death threats might occur.

CDSS uses widely MCDM methods to solve problems of decision-making. MCDM practically deals with structuring, deciding, and planning in multiple-criteria domains and its goal is supporting deciders confronting such situations. Usually, there is not just one optimum solution to such problems and deciders' preferences shall be considered to discriminate between options. Problem-solving in decision process has various interpretations. This problem-solving could be finding and choosing the best alternatives from a set of options. In another approach, problem-solving means to select a small set of good alternatives, or grouping of alternatives to sets with different preferences. Some other problem-solving is to find all influential or non-influential alternatives [24]. Different models and methods have been developed to solve problems of MCDM (whether evaluation, or design) that have advanced mathematical bases and complex calculations. Today, with the use of high-speed computers, all these calculations are done automatically. Famous methods include AHP, ANP, ELECTRE, ELECTRE-II, ELECTRE-III, DRSA, ARIM, ER, GP, GRA, MAUT, MAGIQ, NFSDSS, MAVT, IPV, WPM, EA, VA, PROMETHEE, TOPSIS, PAPRIKA, MACBETH, SIR Method, and NATA [e.g., 25, 26, 27, 28].

3.6. Classification of CDSS

Most of the time, CDSSs could be divided into two distinctive groups [29]:

1. **Knowledge-based CDSS:** Like all expert systems, most of CDSSs have three parts of knowledge base, inference engine, and mechanism to communicate. Knowledge base includes rules, regulations, and connection of interpreted data which often in the form of "if-then" rules. Inference engine synthesizes existing rules of knowledge base with patient's data. Communication mechanism enables systems to show the results to operators and also enables operators to present inputs to system
2. **Non-Knowledge-based CDSS:** Those CDSSs which do not use knowledge-base, implement some kind of artificial intelligence named machine learning that allows computer learn from past experience and/or detecting figures from clinical data. Usually non-knowledge-based CDSSs are designed and developed on the basis of artificial neural networks and/or genetic algorithms.

Another classification, divides CDSSs into seven groups of data-access systems, data-analysis systems, future prediction data-analysis systems, computational-models-based systems, presentation-based systems, optimization-models-based systems, and suggestive-models-based systems [16].

In a recent research, authors have reviewed CDSS papers and classified them according to their methodologies as follows [30]:

1. **Machine learning:** This class represents methodologies which implement algorithms that enable systems to learn from data. Such methods have an initial training phase to find trends in data sets of the given data base. Then, the system would be able to analyze new data with the same parameters and suggests predictions. This group includes artificial neural networks (ANNs), support vector machines (SVM), and logistic regression.
2. **Knowledge representation:** These methods concern the representation of knowledge and facts which are attained from clinical expertise to generate and produce a language of description which is comprehensible by machines (computers). This system uses automatic reasoning languages. This group contains ontology-based systems, guide-line-based systems, and fuzzy logic systems.
3. **Information visualization (IV):** These methods are using visualization algorithms to encode abstract concepts and information. Such systems enable operators to visually inspect their decision's outcomes.
4. **Text mining:** These methods to some extent use the logic of content analysis to provide essential information from unstructured texts by implementing machine learning, linguistic, and statistical strategies. This group comprise information retrieval (IR), and natural language processing (NLP).
5. **Multi-purpose:** These techniques integrate various features, options, attributes, and characteristics of existing domains and categories to assist the decision making process. This group includes decision trees (DTs), and Bayesian logic.

3.7. Medical/clinical data mining in CDSS

Medical/clinical data mining is a domain of science devoted to finding implicit and unknown figures and trends in wide ranges of data and information (usually data warehouses) which are often hidden from healthcare experts' view. This includes medical sciences professionals. Because of the huge amounts of data and limits of cognitive processing in the human brain, there shall be aids and instruments to assist experts and healthcare professionals finding these trends and classify and sort them in order to reduce medical errors. There are several methods to cluster and classify medical/clinical data which are implemented in CDSS. Using these methods have often resulted in surprising improvements in clinical decision-making. No CDSS shall be substituted to physicians decisions, however, these aids can help clinical decision-making especially in critical and vital situations [31].

There are various algorithms of medical/clinical data mining, which has been shown to be effective in real world. These algorithms could be implemented in separate software environments (like, WEKA, and IBM SPSS Modeler) and results imported to CDSS, or designed as a part within CDSS software engine. Accuracy, sensitivity and specify are three important features of the evaluation of results in medical/clinical data mining [32].

State-of-the-art literature cannot specify which algorithm is the best for data mining of medical/clinical data and using in CDSS. Because, each method is designed for satisfying special criteria in methodology, aim of study, variables and etc., therefore, the comparison would be hard to conduct. Within the known models, some of them are famous and popular in medical/clinical data mining and are recommended to get used in medical/clinical data mining, and decision support which include decision three, Bayesian networks, decision tree with naive Bayes, artificial neural network networks (ANN), support vector machines (SVMs), and logistic regression. There are different reports about the effect size and prediction potential of these methods, which is stemmed from high levels of sensitivity of data mining to data bases and data warehouses. Authors have suggested that the first step in data mining is getting confidence about the existing data in data pool, existence of required and suited variables [33].

3.8. CDSS and evidence-based medicine (EBM)

Recent advances in medical sciences have emerged new fields of practice. Everyday all around the world, there are many new announcements of new medical and treatment methods as well as publication of new researches and findings. These aspects result in evidence-based medicine (EBM) which considers the correct and wise use of best evidence to take clinical decisions in healthcare systems for any specific patient. This approach is widespread and even managerial decisions in healthcare systems take advantage of best evidence for the evaluation of clinical practice [34, 35].

There are several reasons to implement EBM including medical errors and mortality as well as death cases. Following these medical errors, physicians' knowledge is not being updated after their graduation, existence of questions without answer in time of patients' treatment, inability to sound judgment of information to separate valid from invalid information, prolonged duration of information reception by physicians, and using different treatments for a same disease [36-38]. The main obstacle which results in aforementioned reasons comprise having limited time to update knowledge [39], information sources are mostly out-of date, and irregularity of scientific texts [40].

EBM is provided by CDSS which shall comprise reference data bank, case-specific concepts and information, clinical and executive data warehouse, internet-based health and medical information system, and an integrated user interface which supports clinical decision support for the healthcare staff. CDSS bridges between medical data and medical knowledge by combining patient's data, physician's individual clinical knowledge, and evidence. Such CDSS can connect to information banks and digital libraries, and therefore, automatically combines clinical data and knowledge-based information, such as patients' profiles, biomedical papers, and real data banks [41].

Implementation and application of EBM via CDSS have shown to be beneficial. Authors have found that EBM retrenches 12% in medicine prescription, prevents overlapping, and physicians who administered it have 30% more income than those who didn't [34]. CDSS, ideally, tries to connect medical profiles of patients to a central data warehouse of healthcare systems. Such connections facilitates the diagnosis, ease of access to scientific evidence, determining the approved therapeutic practices, and group clinical decision-makings in order to support logical and rational flow of information in private and public health sectors. Therefore, provided information of CDSS could be available to physicians in suited and a useful way, in the proper time and place; the underlying reason of EBM [41,42].

3.9. CDSS efficacy in healthcare systems

State-of-the-art advances of information technology as well as improvements of capabilities of individuals in using IT products, have resulted in a global desire and tendency to accept and incorporate CDSS within healthcare settings both in public and private sectors. Today, operationalization of CDSS have grown much and like all other innovations, it shall be assessed and evaluated before wide and global use of such systems. Recently, it has been revealed that CDSS can reduce the time of making patients' files, paper works, medical errors, while increases the time of medical examination and direct contact with patients and facilitation of accessibility of patients necessary data, whether personal data or therapeutic suggestions [43].

In a brilliant work, authors have systematically reviewed CDSS-related published papers between 1980 and 2010 which comprised 122839 patients. This study divided CDSSs into four groups of diagnostic systems (16%), automatic alarm systems for prevention (12%), disease management systems (37%) , and medicine prescription and drug usage control (35%). investigated two main domains [44]:

1. **Improvement of quality of healthcare by using CDSS:** Among the studies, 78% reported various levels of improvement of quality of healthcare. In Medicine prescription and drug usage control systems, there were no reported improvement in patients' treatment quality. Among those who did not report significant improvement of quality of healthcare, there were some positive improvements in clinical trends; the time of healthcare significantly reduced, and nurses' follow-ups on course of treatment facilitated.
2. **Medical error reduction by using CDSS:** Study results revealed that 85% of studies about benefits of

CDSS have reported significant reduction in medical errors.

4. Discussion and conclusion

Up to now, many studies have devoted to CDSS implementation in clinical courses and trends which their quantity and quality are increasing fast. A review study on conducted researches on CDSS between 1990 and 2007 found that CDSSs could play a significant role on the improvement of healthcare systems and improved physicians performance [45]. In general, the findings of the present study shows that CDSS can suggest case-specific diagnostic and treatment alternatives by integration and evaluation of patient's information. Moreover, via the facilitation of communication among healthcare providers and making connections between medical knowledge and physicians' expertise, CDSS can play a great role in the reduction of medical errors as well as unnecessary diagnostic-therapeutic actions. Authors have found that CDSS, when being designed user-friendly, could be used more preferably by physicians. Especially in the form of dashboard, CDSS can be more popular for healthcare staff as well as being beneficial in care processes and patients' improved quality of healthcare service [46].

The study evaluated 27 papers, mostly reviews, to fulfill the aims. This paper covered definitions of CDSS, popular CDSSs, aim of usage, benefits, methods of decision support, classifications, medical/clinical data mining, EBM, and efficacy of CDSS in state of the art healthcare system papers. Maybe the most fundamental problem of studies, generally in the DSS domain and especially on CDSS, is the lack of comparisons between various decision support systems. Papers have presented pros and cons and/or evaluated the capabilities of only one system, and usually analyses are wide and thorough. Nevertheless, such systems neither have been compared to other alike systems, nor even compared to a basic standard of decision support. Another limitation of the study was lack of coverage of all relevant studies. Due to the inclusion criteria of just two languages of Persian and English, it could be said that there could possibly be papers in other languages.

It shall be mentioned that there has not been established/reported a global standard and/or organization to provide supervision on either development or application of CDSS in healthcare systems, yet. Therefore, although there are a wide range of CDSSs in the market, there is a great need to provide some instructions and quality control systems to evaluate the CDSS development and application, so that both healthcare staff and patients be ensured to receive safer health care services.

It would be plausible for future researches to make head-to-head comparisons between different alike CDSSs to evaluate their capabilities and make some ranks about their applications, potentials, strengths, and coverage areas. In addition, it appears that it would be better to establish two lines of development of CDSS: one for general purpose CDSSs which could be used by all healthcare sectors as a binding and comprehensive system, and one for domaining-specific CDSSs which are applicable in some strict and distinctive areas, even as specific as one-for-profession in healthcare systems.

Another issue of concern would be in program, design and development. All available CDSSs are following strict and rigid algorithms to decide which would not be applicable to all cases and problems. It would be a great advancement to include an input panel to determine the format of problem and available data and their related most suited algorithms of analysis. Therefore, both healthcare staff and patients would be ensured to have the most fit method to inspect the situation and assist the clinical decision making given the specific situation.

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