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Big Data Visualization in Cardiology–A Systematic Review and Future Directions

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ABSTRACT The digital transformations and use of healthcare information system, electronic medical records, wearable technology, and smart devices are increasing with the passage of time. A variety of sources of big data in healthcare are available, such as biometric data, registration data, electronic health record, medical imaging, patient reported data, biomarker data, clinical data, and administrative data. Visualization of data is a key tool for producing images, diagrams, or animations to convey messages from the viewed insight. The role of cardiology in healthcare is obvious for living and life. The function of heart is the control of blood supply to the entire parts of the body. Recent speedy growth in healthcare and the development of computation in the field of cardiology enable researchers and practitioners to mine and visualize new insights from patient data. The role of visualization is to capture the important information from the data and to visualize it for the easiness of doctors and practitioners. To help the doctors and practitioners, the proposed study presents a detailed report of the existing literature on visualization of data in the field of cardiology. This report will support the doctors and practitioners in decision-making process and to make it easier. This detailed study will eventually summarize the results of the existing literature published related to visualization of data in the cardiology. This research uses the systematic literature protocol and the data was collected from the studies published during the year 2009 to 2018 (10 years). The proposed study selected 53 primary studies from different repositories according to the defined exclusion, inclusion, and quality criteria. The proposed study focused mainly on the research work been done on visualization of big data in the field of cardiology, presented a summary of the techniques used for visualization of data in cardiology, and highlight the benefits of visualizations in cardiology. The current research summarizes and organizes the available literature in the form of published materials related to big data visualization in cardiology. The proposed research will help the researchers to view the available research studies on the subject of medical big data in cardiology and then can ultimately be used as evidence in future research. The results of the proposed research show that there is an increase in articles published yearly wise and several studies exist related to medical big data in cardiology. The derivations from the studies are presented in the paper.

INDEX TERMS Big data, medical big data, visualization, healthcare, cardiology, systematic literature review.

I. INTRODUCTION

Medical information system (IS) has massive data with the increase of digital transformations and the use of healthcare IS system, electronic record, uses of wearable devices and handheld. Devices such as remote sensor and wearable technologies continuously produce abundant heterogeneous structured and unstructured data. According to IDC [1], in late 2011, about 1.8 ZB of data was created as of that year. Worldwide, electronic data of approximately 1.2 ZB (10^{21}) are generated per year by different sources [2]. By 2020, data is expected to 40 ZB, as per IDC [3]. A huge bulk of data is

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generated in the field of healthcare especially in cardiology. Thus, effective management techniques and tools are required to handle big data in the field.

Visualization of data is a key tool for producing images, diagrams, or animations to convey a message from the viewed insight. The role of cardiology in healthcare is obvious for living and life. The function of the heart is to control the blood supply to the entire parts of the body. Recent speedy growth in healthcare and the development of computation in the field of cardiology enable researchers and practitioners to mine and visualize the new insights from patient data. Different algorithms are used for the detection of diseases like diagnosis gallbladder stone with using medical big data from Internet of Things [4], Parkinson's Disease [5], analytical method for diseases prediction [6]. B. Li, et al. shared their experiences from China's Xiangya medical big data. The goal of the project is the establishment of policies for data sharing, personal privacy, security, and availability of information, cooperation among agencies, and establishing a large data centre [7].

The role of visualization is to capture the important information from the data and visualize it for the easiness of the doctors and practitioners. Data visualization is about how to show the data to the right people at right time, in order to facilitate them to gain insights most efficiently. Data visualization let you interact with data and goes beyond analysis. Visualization of data keeps audience eye on the screen and gets them to take interest in it. Visualization of data has several benefits, like, effective way to communicate an abstract and concrete message, revolutionary methods of technical drawing for engineering and scientific purpose. Visualization of information is ''the graphical presentation of abstract data'' which ''attempts to reduce the time and the mental effort users need to analyze large datasets'' [8]

The proposed study presents a detailed report of the existing literature on the visualization of data in the field of cardiology to help the doctors and practitioners. This detailed study will eventually summarize the results of the existing literature published related to visualization of data in the cardiology. This research uses the systematic literature review (SLR) protocol as presented by Kitchenham et al. [9]. The data was collected from the studies published during the year January 2009 to September 2018. The current study focused on the systematic literature review of medical big data in cardiology and identified a total of 53 studies that were selected based on the defined inclusion/exclusion, and quality criteria. The following are the main contributions of the proposed research work:

- To highlight the research work been done from January 2009 till September 2018 (10 years) in the field of visualization of big data in cardiology
- To present a brief summary of the techniques used for visualization of data in cardiology
- To highlight the benefits of visualizations in field of cardiology

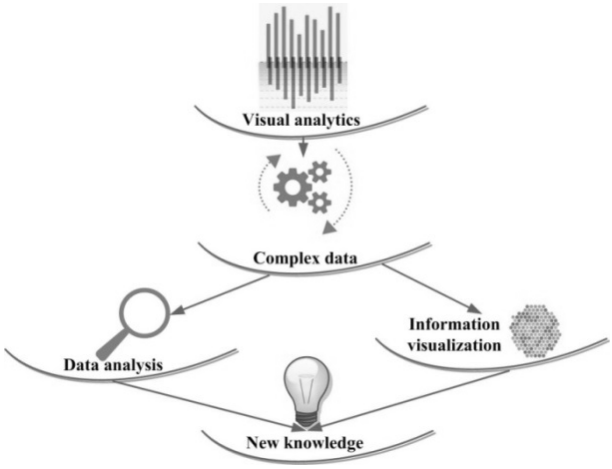

FIGURE 1. Effective insights in data.

The organization of the paper is as follows; Section 2 shows the detail process of the research based on the guidelines to conduct SLR. Results and discussions along with the answers of the research questions are briefly presented in Section 3. The limitations and conclusion of the present research work is given in Section 4.

II. RESEARCH METHOD

Visualization of data gives an exclusive insight into the dataset. Diverse approaches are used for the visualization of data, such as tables, figures, and charts [10]. Tables are normally used when the data is having a small number of data points. The table shows the amounts and labels in a structured and organized way with the facilitation of sorting and filtering the data. The charts are used to map the dimension of data and to visualize the properties of geometric shapes [10]. To meet the user expectations, the tool for big data visualization should give the following features [11]:

- Ability to process different types of incoming data
- Ability to apply different filtered to justify the results
- Ability to cooperate with the dataset during the analysis
- Ability to communicate with other tools to exchange data
- Ability to provide options of collaboration for users

Figure 1 shows to find more effective insights in data [10].

Different SLRs have been carried out for different studies published in diverse areas [12] and it is confirmed as a way to analyze and examine a problem area objectively. The applications of visualization in the field of medical are obvious especially in the area of cardiology. The reason of using systematic literature review is to systematically discover, assess, and deduce all of the accessible and published materials associated to the pre-defined questions of the research to give complete information to the community of research [12]. The protocol implemented for carrying out the SLR [9], the activities are categorized into three key phases which consist of; development of the protocol, conducting the SLR, and the reporting. A proper way of an SLR is followed which

makes the process more objective and repeatable. Following the formal process will play an essential responsibility in the appreciation of the primary nature of the conclusion presented by the study. The formal process of conducting the SLR and the steps involved, define the review protocol, define search strategies, document search strategies, inclusion and exclusion criteria, quality criteria assessment and qualitative meta-analysis [12]. Figure 2 shows the phases of the protocol developed and followed for conducting of the SLR.

The following sub-sections briefly describe the research method and the SLR Protocol.

A. RESEARCH QUESTIONS

The following are the key research questions identified for conducting the proposed study:

RQ 1. What research has been done since January 2009 till September 2018 in the field of visualization of big data in cardiology?

RQ 2. What techniques are used for visualization of data in cardiology?

RQ 3. What are the benefits of visualizations in cardiology?

B. SEARCH STRATEGY

A well-formulated search process devises it promising to thoroughly execute the resources available in order to identify all the associated existing studies which meet the defined search criteria. SLR is an essential and formal search process of conducting a systematic literature review to search each individual source. To maintain the standard of SLR and conduct this study a proper search process has been done to identify the related materials which are published in the given well-reputed libraries. The proposed study uses five keywords related to the medical big data in cardiology based on the research questions were searched in these libraries. The following are the libraries that were used for the search process of the defined keywords for the related studies to the proposed research;

a. PubMed
b. ScienceDirect
c. SpringerLink
d. Taylor and Francis Online
e. Wiley Online Library

C. SEARCH STRING

Initially, the authors decided to choose the libraries and appropriate keywords related to the present research. The scope of the searched terms was defined to be in the range of the current research. The keywords defined which include (''Cardiology'') AND (''Visualizing medical big data'' ''OR'' data visualization ''OR'' big data visualization ''OR'' medical data visualization''. The information and detail received from the sources based on the keywords were then used as a channel for the development and validation of the key search terms. These keywords were then modified, as different sources have the different syntax of the searching process. The detail of the searched term and the articles obtained are shown in figure 2. The information collected from different sources includes journal articles, books chapters, books, conference proceedings, and other online materials available. The final list of articles obtained is shown in table 3. While the initial, filtered by title, filtered by abstract and filtered by content is given in figure 2. Figure 3 shows the steps involved in the search process.

TABLE 1. Inclusion criteria.

- The paper published in the year January 2009-September 2018.
- The contents of the article is available
- The article is written in English
- The paper gives details about the use and application of big data in the cardiology
- The paper provides background which is required to answer the defined research questions.
- The article exists in the above databases

TABLE 2. Exclusion criteria.

- The papers not in the range of January 2009-September 2018
- Several versions of the paper
- Not associated with the defined research questions
- Not in English

D. PUBLICATION INCLUSION AND EXCLUSION CRITERIA

During the search process, a large number of articles including journal publications, books, conference, workshops, and many other published materials were found. All the mentioned libraries were manually searched using the pre-defined keywords. The required references and bibliographic information were managed by using the Endnote reference manager software [13]. The bibliographic information included in the Endnote library contains author name, article title, conference/journal name, publishing year, and page numbering of a specific article. The detail of the overall search process according to the defined keywords in the given libraries is shown in figure 2. This includes the initial search, inclusion and exclusion, filtered by title, by abstract and by full content. The authors decided to include the paper with the following inclusion criteria shown in Table 1.

The authors decided to exclude the papers with the following exclusion criteria shown in Table 2.

Figure 4 shows the initial results obtained from searching process of the proposed research.

The study selection process in the proposed research was performed in different stages. Initially, the articles titles were reviewed by the authors based on the defined criteria of inclusion and exclusion. The papers which are not relevant were excluded based on the exclusion criteria. After that, the articles were filtered by reading the abstract and as a

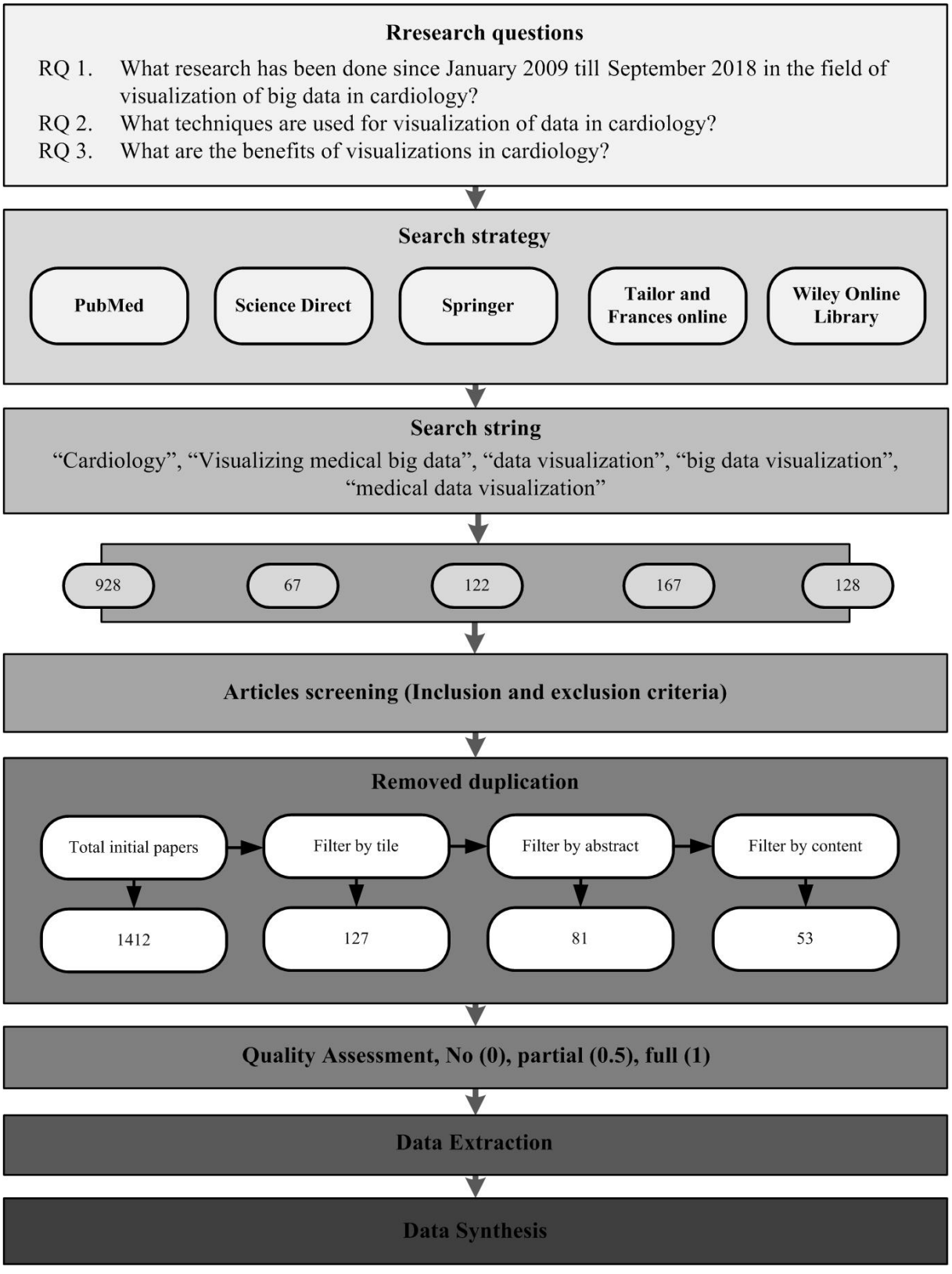

FIGURE 2. Phases of the protocol designed and followed to conduct the SLR.

TABLE 3. Details of the selected papers.

S.No	*Citation*	*Title*	*Year*
1	[15]	Experiences of building a medical data acquisition system based on twolevel modelling	2018
2	[16]	Future Direction for Using Artificial Intelligence to Predict and Manage Hypertension	2018
3	[17]	A probabilistic data-driven framework for scoring the preoperative recipient-donor heart transplant survival	2018
4	[18]	Mining Neuroscience Data for Social Campaign Evaluation	2018
5	[19]	A composite visualization method for electrophysiology-morphous merging of human heart	2017
6	[20]	Big Data in Cardiology	2017
7	[21]	A Survey of Visualization for Live Cell Imaging	2017
8	[22]	A Survey on Multimodal Medical Data Visualization	2017
9	[23]	Big Data, Health Informatics, and the Future of Cardiovascular Medicine	2017
10	[24]	Sculpting the future of medical data visualization	2017
11	[25]	Google Glass in medicine – The man with a computer on face	2016
12	[26]	Integration of electro-anatomical and imaging data of the left ventricle: An evaluation framework	2016
13	[27]	Data Visualization Principles	2016
14	[28]	7 - Mobile Health Technologies and Applications	2016
15	[29]	Big Data for cardiology: novel discovery?	2016
16	[30]	A web-based data visualization tool for the MIMIC-II database	2016
17	[31]	Connecting the Dots: From Big Data to Healthy Heart	2016
18	[32]	Implementation of a Web Portal for Diabetes Patients Using Open Source Data Visualization Libraries	2016
19	[33]	Use of smart phone technology in cardiology	2016
20	[34]	Health Analytics	2016
21	[35]	Feast for the Eyes: An Introduction to Data Visualization	2016
22	[36]	Big Data and paediatric cardiovascular disease in the era of transparency in healthcare	2016
23	[37]	Intelligent Techniques in Medical Volume Visualization	2015
24	[38]	Data visualization: Science on the map, Easy-to-use mapping tools give researchers the power to create beautiful visualizations of geographic data	2015
25	[39]	Harnessing the Heart of Big Data	2015
26	[40]	Web-Pacs in Imaging Medical: A Teaching and Visualization Tool in Clinical Trial	2015
27	[41]	Applying a Big Data Approach to Biomarker Discovery Running Before We Walk?	2015
28	[42]	A Unified Framework for Data Visualization and Coclustering	2015
29	[43]	4-D OCT in Developmental Cardiology	2015
30	[44]	Selected Issues of Visualisation of Fuzziness in Cardiac Imaging Data	2015
31	[45]	Visualizing Cardiovascular Magnetic Resonance (CMR) imagery: Challenges and opportunities	2014
32	[46]	Applying Open Source Data Visualization Tools to Standard Based Medical Data	2014
33	[47]	Evaluation Study for a Multi-User Oriented Medical Data Visualization Method	2014
34	[48]	Kinect-based Gesture Recognition in Volumetric Visualisation of Heart from Cardiac Magnetic Resonance (CMR) Imaging	2014
35	[49]	Accessing and Representing Knowledge in the Medical Field: Visual and Lexical Modalities	2014
36	[50]	Big Data Implications for Industry	2013
37	[51]	Big-Data Visualization	2013
38	[52]	Ischemic heart disease detection using selected machine learning methods	2013
39	[53]	Data visualization and evaluation	2013
40	[54]	Improved data visualization techniques for analyzing macromolecule structural changes	2012
41	[55]	Visual Data Mining of Coexpression Data to Set Research Priorities in Cardiac Development Research	2012
42	[56]	Visualization and Surface Rendering Based on Medical Image	2012
43	[57]	Standard Based Multiclient Medical Data Visualization	2012

TABLE 3. *(Continued.)* **Details of the selected papers.**

44	[58]	Thomas M. Deserno (ed): Biomedical Image Processing	2012
45	[59]	Integrative GenomicsViewer (IGV): high-performance genomics data visualization and exploration	2012
46	[60]	Data visualization in the neurosciences: overcoming the curse of dimensionality	2012
47	[61]	What is visualisation?	2011
48	[62]	Cardiac 4D Ultrasound Imaging	2011
49	[63]	Intelligent visualization and exploration of time-oriented data of multiple patients	2010
50	[64]	Development and evaluation of a compartmental picture archiving and communications system model for integration and visualization of multidisciplinary biomedical data to facilitate student learning in an integrative health clinic	2010
51	[65]	3D segmentation of coronary arteries based on advanced mathematical morphology techniques	2010
52	[66]	Biomedical Visualization	2009
53	[67]	Medical Data Visualization: Toward Integrated Clinical Workstations	2009

TABLE 4. **Year-wise division of selected papers.**

2018	2017	2016	2015	2014	2013	2012	2011	2010	2009
		[36]	[44]	[49]	[53]	[60]	[62]	[65]	[67]
		[35]	[43]	[48]	[52]	[59]	[61]	[64]	[66]
		[34]	[42]	[47]	[51]	[58]		[63]	
		[33]	[41]	[46]	[50]	[57]			
		[32]	[40]	[45]		[56]			
		[31]	[39]			[55]			
	[24]	[30]	[38]			[54]			
	[23]	[29]	[37]						
[18]	[22]	[28]							
[17]	[21]	[27]							
[16]	[20]	[26]							
[15]	[19]	[25]							

result, several irrelevant papers were excluded which were not according to the defined questions. Furthermore, the criteria of inclusion and exclusion were defined and are shown in section 2.4.

Table 3 shows the list of the selected papers based on the inclusion criteria. The process selected only the most relevant papers, clearly assessed based on the given inclusion and exclusion criteria [14]. The list of papers selected with their title, and citations is given in Table 3.

According to the tendency shown in table 4, there is year-wise rise in the research and papers, spotting the gaining significance and applications of in the field. Figure 5 presents the number of papers in the selected year range.

E. QUALITY ASSESSMENT

The quality assessment (QA) process plays an important role in the SLR protocol. QA of the included papers was performed after the process of selecting papers. All the included articles were reviewed by the authors and the quality assessment of the papers with respect to each defined research

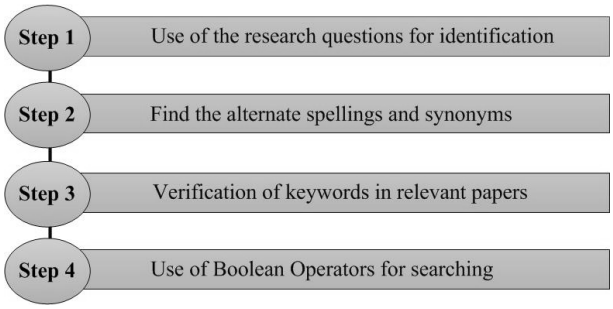

FIGURE 3. **Steps of the search process.**

question was evaluated. In proposed study the Quality Criteria (QR) was defined for each research question and is given below:

QR1. The paper provides the description of the research questions defined.

QR2. The paper provides the work been done from January 2009 till September 2018 in the field of visualization of big data in cardiology.

QR3. The paper gives details of the techniques used for visualization of data in cardiology.

QR4. The paper describes the benefits of visualizations in cardiology.

In the list of included papers, each paper was reviewed and analyzed manually by the authors. Weights to each paper were assigned according to the review and quality assessment against above-mentioned criteria. Weights were assigned in the manner of 1 for a question completely explained in the paper, 0.5 for question somewhat explained and 0 for paper when does not provide any detail concerning the defined question.

To quantify this evaluation for more analysis, the total score assigned to each paper shows the relevancy of paper with the present research. All the assigned values of the three research questions are added for each paper. Further details to show the quality evaluation of the selected papers is shown in figure 6.

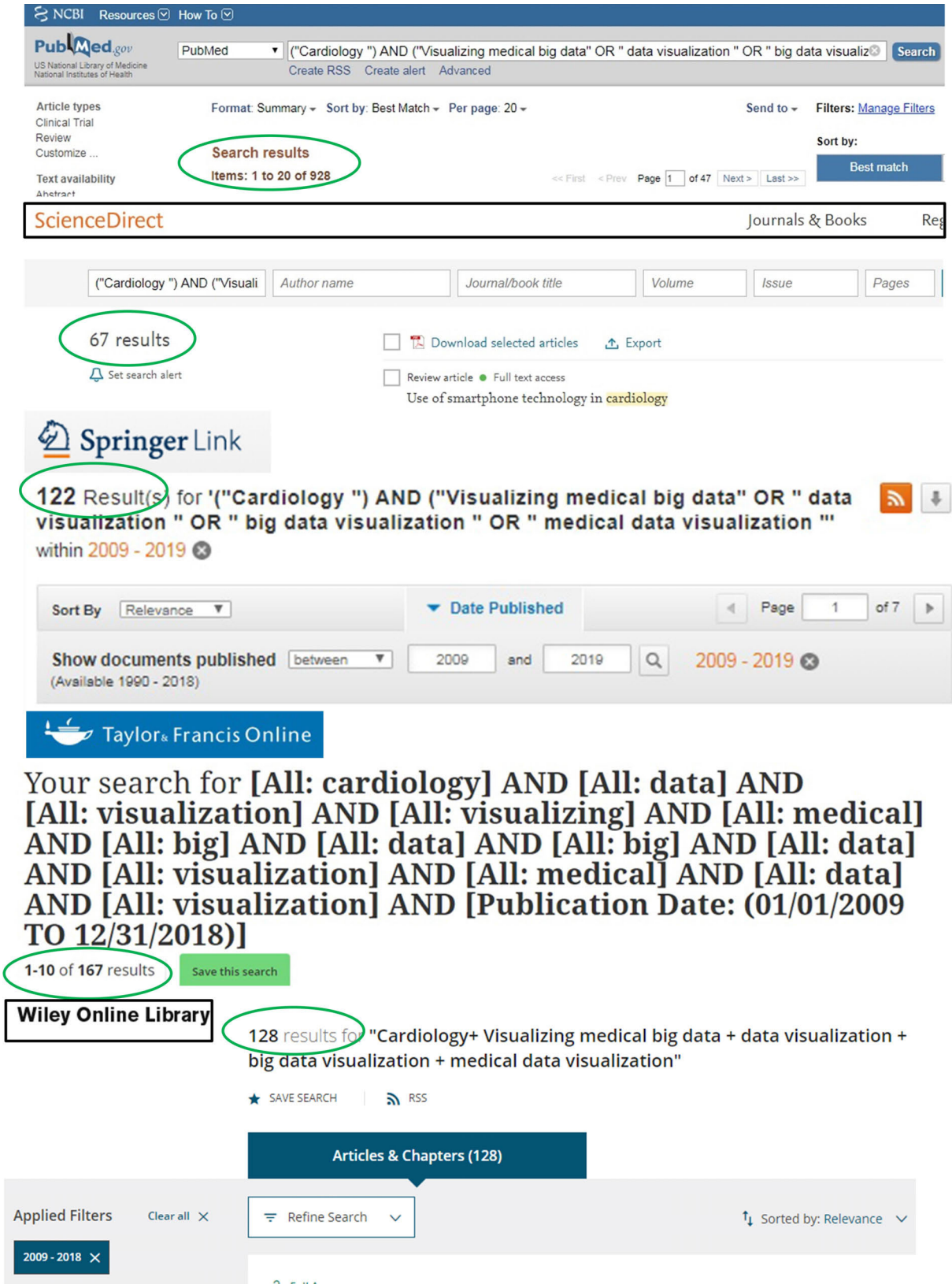

FIGURE 4. Initial results obtained from the searching process for the proposed research.

TABLE 5. Description of the answer for the questions defined in the proposed study.

Citation	*Method*	*Description*	*RQ1*	*RQ2*	*RQ3*
[15]	Data acquirement system for medical based on the modelling of two level	The proposed system in the study investigates, implement and improve the approach of two-level modelling and describe the practices of creating a system of integrated data acquisition for the four universities associated with hospitals. The study designed acquisition system for medical data where medical experts can describe the metadata for their personal specialties through the use of visual tool.	✔		
[16]	Application of Artificial Intelligence for Prediction and Management of Hypertension	The paper aims the application of artificial intelligence in predicting the risk factors and its management for hypertension and highlights the advances of AI in the medical field. Furthermore, the future directions of AI in the field of medical were also studied	✔		
[17]	A framework based on probabilistic data-driven approach for scoring the preoperative recipient-donor heart transplant survival	The authors proposed a Bayesian Belief Network consist of four phases. The data is pre-processed in the first two phases and generate a candidate set of predictors. Medical relevant variables are added in the third phase and finally, the Bayesian Belief Network model is applied.	✔		✔
[18]	Mining Neuroscience Data for Social Campaign Evaluation	The paper presented a study by which the collected data using the techniques of cognitive neuroscience can be characterized for obtaining valuable insights for researchers to derive conclusions	✔		
[19]	Electrophysiology-morphous merging of human heart based on composite visualization method	The paper presented cardiac electrical excitation propagation model based on the data of human cardia cross-sectional to discover the activities of cardiac electrical. After that, visualization method of biophysical is applied for the biophysical integration of cardiac anatomy and properties of electrophysiological, which provide the equivalent position, spatial relationship and the complete process in 3D space with the background of structure of anatomical for presenting the detail of activity of biophysical electrophysiological	✔	✔	✔
[20]	Big Data in Cardiology	The paper aims the three promising big data applications in cardiovascular care, with 'proof of concept' challenges to be met if the promising data is to be realized	✔	✔	✔
[21]	Visualization for Live Cell Imaging- a survey	The paper presented a survey on the methods of live cell imaging visualization and accomplished a qualitative analysis structure of methods of visualization which include the abstract task, domain and data characterization, and defining interaction design and visual encoding. The future gaps with the current research are also presented	✔	✔	✔
[22]	Multimodal Medical Data Visualization-Survey	The authors presented an overview of the techniques used for multimodal medical data visualization and analyze the challenges arises from it and how it is aimed to solve by recent works	✔	✔	✔
[23]	Cardiovascular medicine big data, health informatics, and future	The paper presented a report on cardiovascular medicine big data, health informatics and future	✔	✔	✔
[24]	Sculpting the future of medical data visualization	The paper presents the study on sculpting the future of data visualization in medical	✔	✔	✔
[25]	Google Glass in medicine – The man with a computer on face	The applications of Google glass in medicines are described	✔		
[26]	Integration of electro-anatomical and imaging data of the left ventricle: An evaluation framework	The authors presented an approach based on a) A framework for the assessment of the accuracy of EAM and imaging integration strategies b) New methodology of planar disk representation	✔	✔	✔
[27]	Data Visualization Principles	The study focuses on the assessment of hedge funds from the perception of investment consultant and investor who recommending fund investors	✔	✔	
[28]	7 - Mobile Health Technologies and Applications	The study focuses on the mobile health technologies in which the physician can certainly access the lab results, and other medical information of patients and in the same way the patient can check their status of disease remotely by using the mobile devices	✔	✔	
[29]	Big Data for cardiology: novel discovery?	The study determined the promising datasets for discovery of science, the impact on the methods used in science in general and specifically in cardiology.	✔	✔	✔
[30]	Tool for the MIMIC-II database- A web-based data visualization	The study objective is a) to create an interactive and b) data visualization tool based on web MIMIC-II *1)* Furthermore, the study mainly offered two features of explores and compare. The first feature facilitates the patient cohort within MIMIC-II and visualized the distribution of various variables including administrative, clinical and demographic within the selected cohort. The second feature facilitates the users in selection of two patient cohorts and compare visually with other variables	✔	✔	
[31]	Connecting the Dots: From Big Data to Healthy Heart	The authors described different sources of big data in cardiology the discussed the potentials of making the best use of data driven knowledge production models	✔	✔	✔
[32]	Open source data visualization libraries implementation of web portal for diabetes patients	A web portal is implemented for better communication of diabetes patients with doctors for the process of diagnosis and treatment of diabetes. Medical data is presented on the portal based on open source libraries.	✔	✔	
[33]	Use of smart phone technology in cardiology	The study discusses the details of different applications of smart-phone based technologies in cardiology	✔	✔	
[34]	Health Analytics	The chapter discusses the analysis, visualization, and mining of healthcare data and determines the way in which data can be efficiently managed which further enhance the organization ability to produce revenue, control risk, and cost.	✔		
[35]	Feast for the Eyes: An Introduction to Data Visualization	The authors presented a study on the current use of data visualization, discussed the potential issues, benefits, and libraries applications	✔	✔	

TABLE 5. ***(Continued.)*** **Details of the selected papers.**

[36]	Paediatric cardiovascular disease in the era of transparency in healthcare using big data	The study presented a review on big data analytics impact in paediatric cardiovascular disease and its probable issues of transparency in delivery of care	✔	✔	✔
[37]	Medical volume visualization using intelligent techniques	The applications of using algorithms and intelligent techniques visualization of medical big data are discussed. the paper also discusses the available toolkits and software for medical volume visualization	✔	✔	✔
[38]	Data visualization: Science on the map	A tool box for data visualization	✔	✔	
[39]	Harnessing the Heart of Big Data	The paper discussed; • report on big data science research • Promise of data science to help investigations of cardiovascular • Challenges and opportunities	✔	✔	✔
[40]	A teaching and visualization tool in clinical trial based on web-pacs in imaging medical	The study presented an information system in clinical centres of diagnosis medical images. A novel teaching and visualization tool is provided for the support of clinical web-pacs including various research centres and hospital	✔	✔	
[41]	Application of big data approach to discovery of biomarker running before we walk?	Applications of big data in biomarker discovery	✔	✔	
[42]	A unified framework for visualization and coclustering data	The authors proposed a theoretical framework for visualization of data based on iterative procedure by using two similarity matrices.	✔	✔	✔
[43]	4-D OCT in Developmental Cardiology	The chapter focuses on the various available solutions and give details of the of context in the assessment of 4-DOCT imaging for cardiovascular system in the past several years	✔	✔	✔
[44]	Visualisation of fuzziness in cardiac imaging data- selected issues	The chapter proposed visualization of fuzzy numbers in 1, 2, and more dimension space and is based on ScpovPlot3D templates for POVRay	✔	✔	✔
[45]	Visualizing cardiovascular MRI- challenges and opportunities	The research presented an overview of the available related work of visualization technique and focussed on the issues of visualizing imagery resulting from 2D myocardial tagging in CMR	✔	✔	✔
[46]	Applications of open source data visualization tools to standard based medical data	The authors used the libraries of Java Script to create the presentation of data for standard medical data focusing the development of Open Source Tools.	✔	✔	✔
[47]	Assessing multi-user oriented medical data visualization method	The proposed study is based on the parameter for good assessment practices in informatics of health and identified different stages with detail descriptions. The proposed concept of the evaluation was used for medical data visualization method	✔	✔	
[48]	Kinect-based gesture recognition in volumetric visualization of heart from CMR imaging	The study aims to propose a virtual human heart from medical imaging data with integration of interactive interface using visual 3D holographic, haptic and sonic feedback.	✔	✔	✔
[49]	Representing and accessing knowledge in the field of medical with visual and lexical modalities	The chapter describes the details of representing and accessing knowledge in the field of medical with visual and lexical modalities	✔	✔	
[50]	Implications of big data for industry	The chapter provides details of big data propositions for industry	✔	✔	✔
[51]	Big-Data Visualization	Present the editorial on big data visualization	✔	✔	✔
[52]	Applications of machine learning methods in ischemic heart disease detection	Support vector machine and Osuna are used to detect the ischemic disease of heart. The algorithm principal component analysis (PCA) is also used.	✔	✔	✔
[53]	Data visualization and evaluation	The chapter describes the basics of data visualization, outlined the development of data visualization, and provide some examples of how the visualization of data been used in assessment to support aid understanding, collect data, analyze, and communication to stakeholders. Further, it highlights future trends in the visualization of data. Limitations are also given.	✔	✔	✔
[54]	Analyzing macromolecule structural changes with the help of improved data visualization techniques	The paper suggests three approaches for visualization of data as techniques for analyzing macromolecule structural changes. Firstly, the relationship of UV CD spectra and protein secondary structure, intrinsic fluorescence spectra and protein tertiary structure changes, and light scattering measurements and quaternary structure to assign direct protein structural meaning to colors are used. In the second and third approach the use of color all together are eliminated by using radar, charts, and Chernoff faces	✔	✔	
[55]	Visual data mining of Coexpression data to set research priorities in cardiac development research	The paper describe the use of StarNet , a web based visualizing tool available at "http://vanburenlab.medicine.tamhsc.edu/starnet2.html", for mining coexpression data The StarNet also provide a tool to support the comparison of networks drawn from two different datasets	✔	✔	✔
[56]	Medical image visualization and surface rendering	Defined a method to describes the boundary conditions, identified by the new method have the same parameter space if the given three surface patches can be converted into the same form through parameter transformation.	✔	✔	✔
[57]	Standard based multiclient medical data visualization	The study is based on ISO 13606 data model for specifying the requirements on data visualization method in medical. The method suggested permit separating medical knowledge from visualizing knowledge. The XML schema was used for visual concept to allocate multi-client generic data presentation	✔	✔	✔
[58]	Thomas M. Deserno (ed): Biomedical Image Processing	The book gives detail of the a) image formation, b) image enhancement, c) feature extraction and selection, d) segmentation, e) classification and measurements, f) image data visualization, g) image manipulation and integration, and h) valuation and customizing	✔	✔	✔
[59]	High-performance genomics data visualization and exploration with integrative GenomicsViewer	The authors presented an integrative genomics viewer which views huge heterogeneous data sets with high performance. The IGV focuses on the integrative nature of genomics studies, which hold up both array-based and next-generation sequencing data, and the integration of phenotypic and clinical data. Further, the IGV supports local and remote data sets and is having the ability to visualize the data optimally with high performance. The IGV is freely available on http://www.broadinstitute.org/igv, under a GNU LGPL open-source license	✔	✔	✔

TABLE 5. *(Continued.)* **Details of the selected papers.**

[60]	Neurosciences data visualization: overcoming the curse of dimensionality	The paper determined the available practices in visualization of data and given the details of developments in design choices which expose the data rather to hide it	✔	✔	✔
[61]	What is visualisation?	The paper highlights that the existing practices of information visualization are based on two principles, the first one is reduction and the second is spatial variables. The paper further, discusses a more advanced visualization method called direct visualization. The method creates new visual representations from the real visual media object	✔	✔	✔
[62]	Cardiac 4D Ultrasound Imaging	Overview of the technological developments for volumetric imaging of the heart beat with the help of ultrasound is given	✔		✔
[63]	Intelligent visualization and exploration of time-oriented data of multiple patients	The paper presented an approach for visualizing the Time-Oriented Records system, which is the integration of intelligent temporal analysis and techniques of information visualization. The proposed system including tool for retrieval, exploration, visualization, and analysis of raw time-oriented data and derived concepts of various records of patients	✔	✔	
[64]	Integration and visualization of multidisciplinary biomedical data to facilitate student learning in an integrative health clinic for development and evaluation of a compartmental picture archiving and communications system model for	The study assessed the satisfaction of nursing students with a compartmental representation archiving and communication system for automatic object-oriented integration and biomedical data visualization. The sample size was used for 63 students of nursing. The results showed that multi-disciplinary visualization of data features provides a technology-improved learning that can help nursing students in organizing and representing knowledge	✔	✔	✔
[65]	Applications of advanced mathematical morphology techniques in 3D segmentation of coronary arteries	The study proposed a mathematical morphological technique and presents an automatic algorithms for segmentation of coronary artery from 3D X-ray data sequences of a cardiac cycle	✔		✔
[66]	Biomedical Visualization	The chapter described an overview of the approaches used for scientific visualization research to tackle the needs of biomedical applications	✔	✔	✔
[67]	Visualization of medical data: toward integrated clinical workstations	The chapter gives detail of the work related to the medical big data visualization, spotlighting the issues associate to navigation and present by illustrating imaging and other disciplines of display and integration methods. Various algorithms are covered by the study	✔	✔	✔

F. DATA EXTRACTION

The relevant data were extracted from each of the included paper based on the review, assessment, and defined research questions. The significant data extracted is shown in different figures and tables and are briefly given as follows;

- Table 3 shows all of the finally selected papers, with their titles, reference, and year of publication.
- Table 4 provide year-wise breakup of publications selected in which the number of publications is mentioned against each year
- Figure 5 shows the number of publications for the proposed research from 2009 – 2018. In the figure the high number of papers are published in the year 2016 which shows that more research work have been done in this year.
- Table 5. Shows the answers of the research questions defined in section 2.1. This table shows show the details of each question and their answer with brief descriptions.

G. DATA SYNTHESIS

The process of data synthesis was done by the primary reviewer with the support of secondary reviewer. As a result, the data extraction phase presented in Section 2.7, a list of factors from the sample of 53 papers was created. The primary reviewer read these in order to obtain a list of categories to organize the success factors. Figure 2 shows the research questions, keyword terms, search process, inclusion and exclusion, and the filtering process based on the keywords for articles. Separate folders were maintained for all of the above-mentioned libraries and a total of 1412 titles were found. At the start, each folder of the library was checked manually and all of the articles were properly named by their titles. The paper duplications were removed by checking the title of papers in each folder. The initial process of selection and filtering was performed manually for all of the libraries by titles and 127 articles were obtained. These articles obtained were then scrutinized manually by abstract, and a total of 81 articles were included. Finally, these articles were again filtered manually by contents and a total of 53 articles were selected. The process of exclusion and inclusion was very tricky as each of the paper was checked manually. These 53 papers along with their citations management process were done in the Endnote library. The process of making the

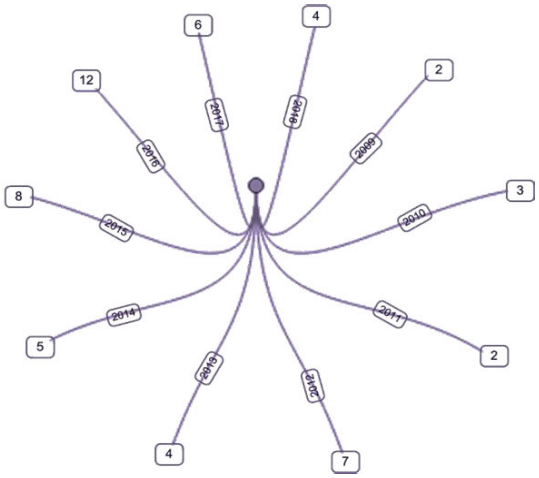

FIGURE 5. Number of publications for the proposed research from 2009 – 2018.

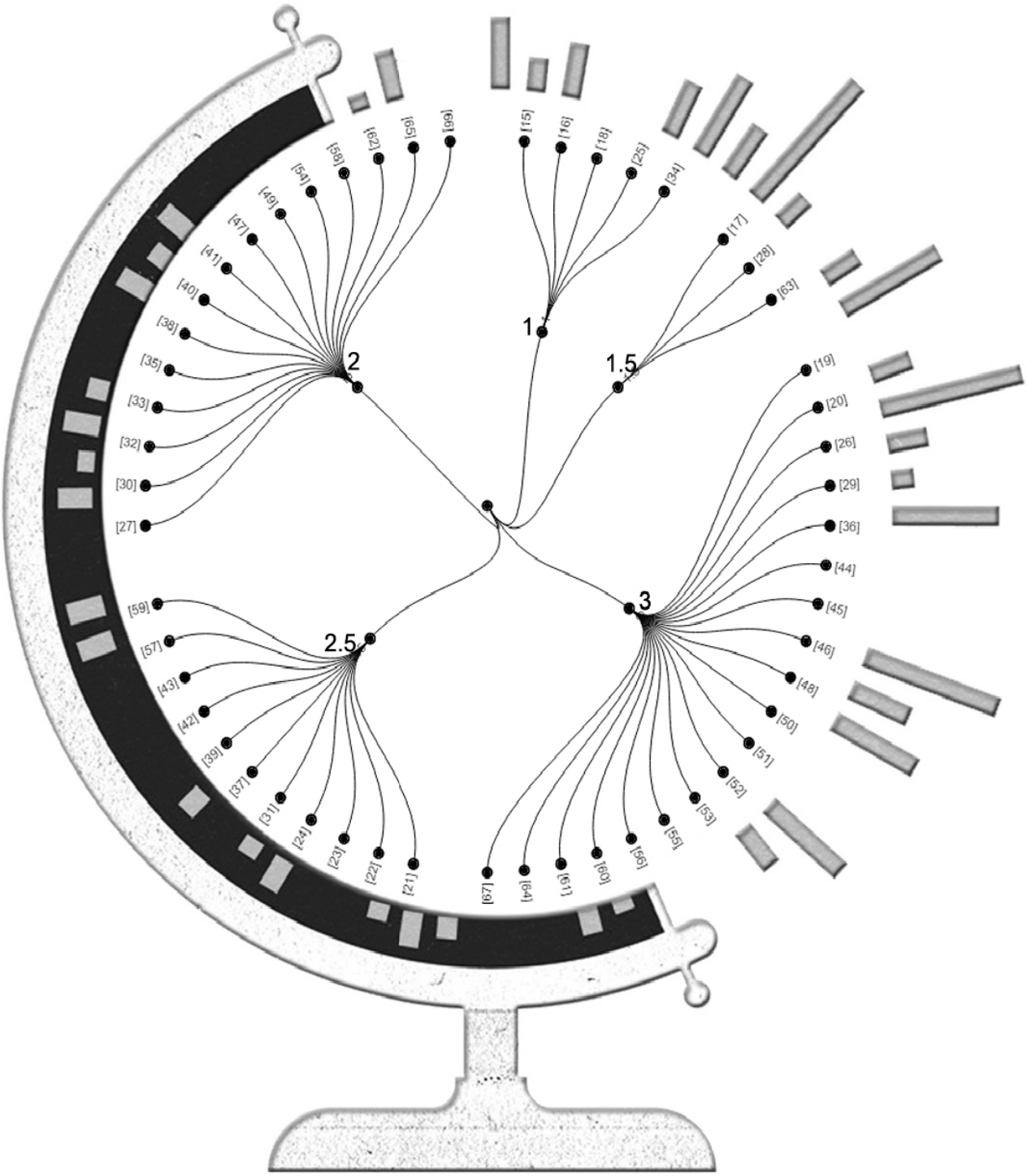

FIGURE 6. Quality assessment of the selected papers.

references was done manually as mostly when downloading a citation from the internet then some of the information's are missing. For example, this information may be in the form of author name, year, the title of the article, place of publishing, page no. and so on. The selected articles were then used for the defined research questions in the proposed literature review process protocol.

III. RESULTS AND DISCUSSIONS

SLR is an established protocol used to systematically study a specific research [68]–[71]. The current research is an endeavor to study visualization of medical big data in cardiology. This section briefly describes the answers of the research questions defined below:

1.1 What research has been done since January 2009 till September 2018 in the field of visualization of big data in cardiology?
1.2 What techniques are used for visualization of data in cardiology?
1.3 What are the benefits of visualizations in cardiology?

Table 5 shows the description of answers for the questions defined in section 2.1.

IV. CONCLUSION

The first limitation of the proposed research is the proposed study is limited to big data visualization in cardiology and maybe some papers are skipped. The second limitation of the proposed research is that the search process was performed in five most commonly referenced libraries and skipped the rest of the libraries. The reason was to focus on only high-quality peer-reviewed conference and journals papers. It was decided by the authors to pass up keyword searching in googlescholar, as it provides access to all the papers, and the other reason was to save from duplicate entries. There is a probability that a paper might have been skipped to discuss about the ideas associated to big data in cardiology, but not uses the term at all.

Visualization of data plays an important role in creating images, diagrams, or animations to communicate a message from the insight viewed. As the digital transformations and the use of healthcare medical information system, electronic medical record, wearable, and smart devices and handheld are increasing with the passage of time. Recent prompt development in healthcare, especially, in the field of cardiology enables researchers and practitioners to visualize the insights from patient data. Visualization of data is to capture the important information from the data and plot it for the easiness of the doctors and practitioners. To help the doctors and practitioners, the proposed studies presents a detailed study report of the existing literature on the visualization of data in the field of cardiology.

The proposed research uses SLR protocol and the data was collected from the research published from January 2009 to September 2018. Initially, a total of 1412 titles were found. Separate folders were maintained for the libraries. Each folder of the library was checked manually and all of the articles were properly named by their titles. The duplication of these publications was done by checking the titles in each folder. The inclusion and exclusion process were performed manually for all of the libraries by the titles and 127 articles were included. These 127 articles were then reviewed manually by abstract, and 81 articles were included. Finally, these 81 articles were reviewed by contents and 53 articles were selected. The process of exclusion and inclusion was very tricky as each of the paper was checked manually. These 53 papers along with their references were managed in the Endnote library.

This research summarizes and organizes the existing literature in the form of published materials related to big data visualization in cardiology. The proposed research will help the researchers to view the available research studies on the subject of medical big data in cardiology and then can ultimately be used as evidence in future research. The results of the proposed research show that there is an increase in articles yearly wise and several studies exist related to medical big data visualization in cardiology.

Limitations of the study-

- The first limitation of this research was to only carried out search in five of the widely referenced libraries.
- It was also decided to avoid keyword searching in Google Scholar, as it provides access to all the papers, and to save from the trouble of duplicate entries. Secondly, the search was performed using a limited set of keywords mainly ''medical big data in cardiology'' to get only related results, as there is quite a lot of research published in the area.
- There is a chance that a paper might have been skipped which talks about the idea related to medical big data in cardiology but not uses the term at all.

Future scope of the work-in future, we trying to establish a detailed report of the advanced techniques used in the analysis of medical big data in healthcare in general while specific in cardiology. This will help the practitioners to easily support decision making in healthcare.

CONFLICT OF INTEREST

The authors declare that no conflict of interest exits regarding this publication.

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