International Research Journal of Advanced Engineering and Science
ISSN (Online): 2455-9024

Embedded Engines of Telemedicine: A Systematic Review

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Abstract—*Telemedicine is emerging as a critical component of the healthcare crisis solution. Some of the most challenging problems of our current healthcare system such as access to care, cost effective delivery, and distribution of limited providers can be impacted significantly through the technology called telemedicine. This telemedicine needs some engines put in place to run it. Presented in this paper is a systematic review of some technologies that fueled telemedicine; they are digital imaging devices, electronic health records (EHRs), and clinical decision support systems (CDSSs) among others. This paper intensifies further research in the field of telemedicine.*

Keywords— *Telemedicine, Healthcare, Electronic Health Records, Artificial Intelligence, Machine Learning, and Clinical Decision Support Systems.*

I. INTRODUCTION

Telemedicine can change the current paradigm of care and allow for improved access and improved health outcomes in cost effective ways. This telemedicine has the potential to transform the way medical care is provided in many areas of the country. The term telehealth on the other hand, is often used interchangeably with telemedicine, but doesn't necessarily involve clinical services. It can include patient education or mobile health apps that engage patients in their care, for instance. Telemedicine isn't a separate medical specialty, but can be deployed by a variety of medical providers and specialties (Fig 1.1). For instance, dermatology and radiology are medical specialties that tap into telemedicine technologies, including digital imaging and high-bandwidth communication, to remotely view patient medical images-such as photos of skin lesions or CT scans-for diagnosis and treatment recommendations. Telemed technology can also be used to monitor patients with chronic conditions, enhance nursing call centers, and provide remote consultations for patients in rural areas or off-hours. While Medicare has been slower to change reimbursement policies to accommodate telemedicine care, private insurers and state Medicaid payers have been more progressive in covering many services in some countries, and that's pushing more doctors and hospitals to provide them. When it comes to monitoring patients with chronic conditions, mobile and home-based devices that connect via the web to clinicians increase the likelihood that patients experiencing problems will be spotted early. Clinical systems that remotely collect patient readings can generate alerts to physicians or nurse case managers indicating that prompt intervention is needed to prevent complications or a serious emergency situation from developing. These could range from a diabetic patient with irregular glucose readings or sudden weight gain in a heart failure patient, for example. So, this paper is expected to intensify further the research interest in telemedicine so that access to care, cost effective care delivery, and distribution of limited care providers can be impacted significantly through the technology called telemedicine as seen in Fig. 1.2.

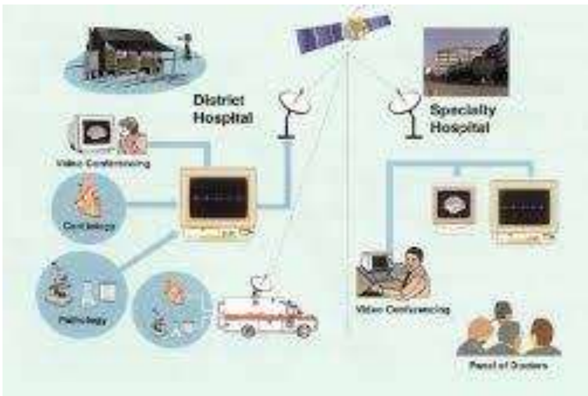

Fig. 1.1. Concept of telemedicine.

Fig. 1.2. Telemedicine linking remote hospitals.

II. LITERATURE REVIEW

In the work of Gerald-Mark Breen and Jonathan Matusitz [1], it was said the origin or introduction of telemedicine, that is, distant medical assistance through communication and technology could be traced back to the time during which electronic devices emerged in the public eye [2]. Telemedicine is defined as the use of advanced communication technologies, within the context of clinical health, that deliver care across considerable physical distance [3-7]. As such, it enables and ensures the delivery of tele-healthcare to specifically benefit medical patients [2], [8-9]. Such communication technologies encompass a variety of advanced, computerized equipment, allowing physicians, nurses, and other similar health professionals to provide complex healthcare thousands of miles away from the location of service [10], [2], [11]. Besides, not only is telemedicine a system that can be practiced in a diversity of medical settings, but it can also assist and hasten communication (i.e., correspondence, dialogue, and interchange) between medical practitioners and their patients. It does so between locations of clinical practice in order to provide relief and/or guidance [12], [5]. As the medical field has so progressively harnessed and exploded with innovative, complex technological devices for healthcare delivery, telemedicine now even includes hundreds of reliable, internet-based medical sites that provide an enormous amount of information about diseases, treatments, pharmaceuticals, and images of pathology [13]. These types of services are known as a form of telemedicine called e-health [3], [5]. Some of the primary e-health applications validate how telemedicine has, to a great extent, culminated into an invaluable mine of resources accessible via any computer (i.e., PC and laptop computers, etc.) linked to the internet [4], [13]. Tele-health is a tool for access. It can be asynchronous (store and forward) or synchronous (interactive). Technology needed includes: patient exam camera, digital electronic stethoscope, fiber-optic horoscope, fiber-optic ophthalmoscope, digital camera, document camera, intra-oral camera, laser caries detector, clinical video (Polycom, Vcom), and clinical exam rooms. In regards to transmission spectrum, telemedicine needs to have good quality (ISDN and LAN) while maintaining secure lines as shown in Fig. 2.1

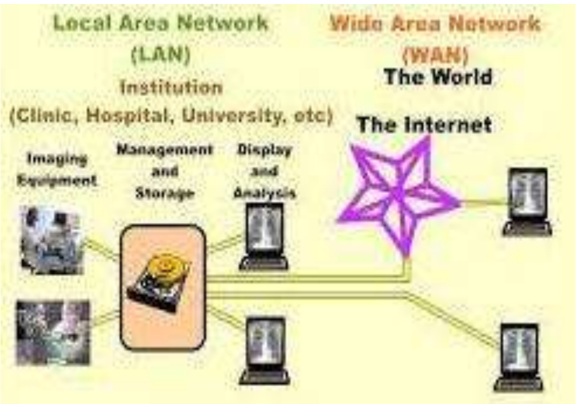

Fig. 2.1. Digital image networks.

III. ENGINES OF TELEMEDICINE

Telemedicine is composed of so many devices that enable medical attention at a distance; these devices are ranked in importance as they serve different purposes. Some of the engines that fuel telemedicine are discussed in the subsequent sub headings.

A. Clinical Decision Support Systems (CDSSs)

CDSS was defined as any software designed to directly aid in clinical decision making in which characteristics of individual patients are matched to a computerized knowledge base for the purpose of generating patient-specific assessments or recommendations that are then presented to clinicians for consideration. There are two main types of CDSS. [14]: (1) Knowledge-based and (2) Non-knowledge-based. An example of how a clinical decision support system might be used by a clinician is a specific type of CDSS, the DDSS (diagnosis decision support systems). A DDSS requests some of the patients' data, and in response, proposes a set of appropriate diagnoses. The doctor then takes the output of the DDSS and determines which diagnoses might be relevant and which are not [14], and if necessary orders further tests to narrow down the diagnosis. Another example of a CDSS would be a case-based reasoning (CBR) system [15]. A CBR system might use previous case data to help determine the appropriate amount of beams and the optimal beam angles for use in radiotherapy for brain cancer patients; medical physicists and oncologists would then review the recommended treatment plan to determine its viability [16]. Another important classification of a CDSS is based on the timing of its use. Doctors use these systems at point of care to help them as they are dealing with a patient, with the timing of use being either pre-diagnosis, during diagnosis, or post diagnosis. Pre-diagnosis CDSSs are used to help the physician prepare the diagnoses. CDSSs used during diagnosis help review and filter the physician's preliminary diagnostic choices to improve their final results. Post-diagnosis CDSSs are used to mine data to derive connections between patients and their past medical history and clinical research to predict future events [14]. It has been claimed that decision support will begin to replace clinicians in common tasks in the future [17]. Another approach, used by the National Health Service in England, is to use a DDSS (either, in the past, operated by the patient, or, today, by a phone operative who is not medically-trained) to triage medical conditions out of hours by suggesting a suitable next step to the patient (e.g. call an ambulance, or see a general practitioner on the next working day). The suggestion, which may be disregarded by either the patient or the phone operative if common sense or caution suggests otherwise, is based on the known information and an implicit conclusion about what the worst-case diagnosis is likely to be (which is not always revealed to the patient, because it might well be incorrect and is not based on a medically-trained person's opinion - it is only used for initial triage purposes).

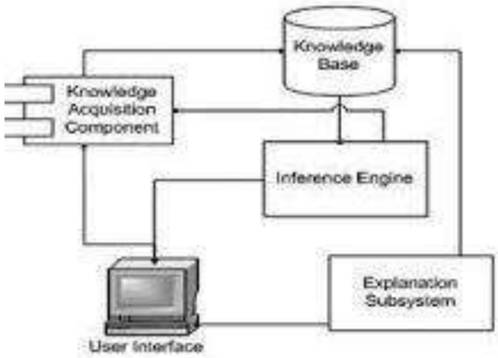

Fig. 3.1. Components of CDSSs.

As shown in Fig. 3.1, most knowledge-based CDSSs consist of three parts: (1) the knowledge base (2) an inference engine and (3) a mechanism to communicate. The knowledge base contains the rules and associations of compiled data which most often take the form of IF-THEN rules (Fig. 3.2). If this was a system for determining drug interactions, then a rule might be that IF drug X is taken AND drug Y is taken THEN alert user. Using another interface, an advanced user could edit the knowledge base to keep it up to date with new drugs. The inference engine combines the rules from the knowledge base with the patient's data. The communication mechanism allows the system to show the results to the user as well as have input into the system [14].

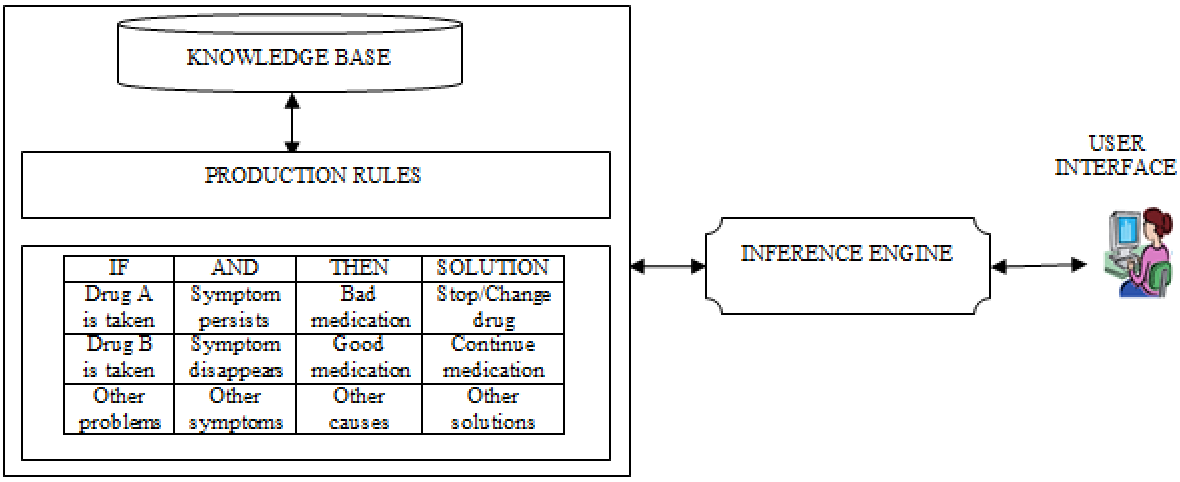

Fig. 3.2. CDSS components with production rules.

CDSS that do not use a knowledge base use a form of artificial intelligence called machine learning [18], which allows computers to learn from past experiences and/or find patterns in clinical data. This eliminates the need for writing rules and for expert input. However, since systems based on machine learning cannot explain the reasons for their conclusions (they are so-called "black boxes", because no meaningful information about how they work can be discerned by human inspection), most clinicians do not use them directly for diagnoses, for reliability and accountability reasons [14]. Nevertheless, they can be useful as post-diagnostic systems, for suggesting patterns for clinicians to look into in more depth. Three types of non-knowledge-based systems are: (1) support vector machines, (2) artificial neural networks and (3) genetic algorithms [19]. Artificial neural networks use nodes and weighted connections between them to analyze the patterns found in patient data to derive associations between symptoms and a diagnosis. Genetic algorithms are based on simplified evolutionary processes using directed selection to achieve optimal CDSS results. The selection algorithms evaluate components of random sets of solutions to a problem. The solutions that come out on top are then recombined and mutated and run through the process again. This happens over and over until the proper solution is discovered. They are functionally similar to neural networks in that they are also "black boxes" that attempt to derive knowledge from patient data. Non-knowledge-based networks often focus on a narrow list of symptoms, such as symptoms for a single disease, as opposed to the knowledge based approach which cover the diagnosis of many different diseases [14].

B. Electronic Health Records (EHRs)

Implementing electronic health records (EHRs) was an inevitable challenge. The reasons behind this challenge are that it is a relatively uncharted area, and there are many issues and complications during the implementation phase of an EHR. However, challenges in implementing EHR have received some attention, but less is known about the process of transitioning from legacy EHR to newer systems [20]. With all of that said, electronic health records are the way of the future for healthcare industry. They are a way to capture and utilize real-time data to provide high-quality patient care, ensuring efficiency and effective use of time and resources. For instance, because we are now in an era of widespread, almost excessive, diagnosis of psychiatric illness and subsequent pharmaceutical treatment for the management of these conditions, such patients, as well as individuals who suspect they might have a mental malady, can use electronic health services to obtain information on many psychological conditions or treatments [21]. In other words, many of their psychological questions can be answered with the information provided on e-health web sites. Incorporating EHR and CDSS together into the process of medicine has the potential to change the way medicine has been taught and practiced [22]. It has been said that "the highest level of EHR is a CDSS" [23]. Since "clinical decision support systems (CDSSs) are computer systems designed to impact clinician decision making about individual patients at the point in time that these decisions are made" [22], it is clear that it would be beneficial to have a fully integrated CDSS and EHR. Even though the benefits can be seen, to fully implement a CDSS that is integrated with an EHR has historically required significant planning by the healthcare facility/organization, in order for the purpose of the CDSS to be successful and effective. The success and effectiveness can be measured by the increase in patient care being delivered and reduced adverse events occurring. In addition to this, there would be a saving of time and resources, and benefits in terms of autonomy and financial benefits to the healthcare facility/organization [24]. A successful CDSS/EHR integration will allow the provision of best practice, high quality care to the patient, which is the ultimate goal of healthcare. Errors have always occurred in healthcare, so trying to minimize them as much as possible is important in order to provide quality patient care. Three areas that can be addressed with the implementation of CDSS and EHR are: (1) medication prescription errors (2) adverse drug events (3) other medical errors. CDSS will be most beneficial in the future when healthcare facilities are "100% electronic" in terms of real-time patient information, thus simplifying the number of modifications that have to occur to ensure that all the systems are up to date with each other.

IV. Discussions

The evidence of the effectiveness of CDSS is mixed. A 2014 systematic review did not find a benefit in terms of risk of death when the CDSS was combined with the electronic health record [25]. There may be some benefits, however, in terms of other outcomes [25]. A 2005 systematic review concluded that CDSS improved practitioner performance in 64% of the studies. The CDSS improved patient outcomes in 13% of the studies. Sustainable CDSS features associated with improved practitioner performance include automatic electronic prompts rather than requiring user activation of the system. Both the number and the methodological quality of studies of CDSS increased from 1973 through 2004 [26]. Another 2005 systematic review found... "Decision support systems significantly improved clinical practice in 68% of trials." The CDSS features associated with success include the following [27]: (1) the CDSS is integrated into the clinical workflow rather than as a separate log-in or screen (2) the CDSS is electronic rather than paper-based templates (3) the CDSS provides decision support at the time and location of care rather than prior to or after the patient encounter (4) the CDSS provides recommendations for care, not just assessments. However, other systematic reviews are less optimistic about the effects of CDSS, with one from 2011 stating "There is a large gap between the postulated and empirically demonstrated benefits of CDSS and other electronic health technologies their cost-effectiveness has yet to be demonstrated" [28]. A 5-year evaluation of the effectiveness of a CDSS in implementing rational treatment of bacterial infections was published in 2014; according to the authors, it was the first long term study of a CDSS [29]. The main purpose of modern CDSS is to assist clinicians at the point of care [14]. This means that clinicians interact with a CDSS to help to analyze, and reach a diagnosis based on, patient data. In the early days, CDSS were conceived of as being used to literally make decisions for the clinician. The clinician would input the information and wait for the CDSS to output the "right" choice and the clinician would simply act on that output. However, the modern methodology of using CDSS to assist means that the clinician interacts with the CDSS, utilizing both their own knowledge and the CDSS, to make a better analysis of the patient's data than either human or CDSS could make on their own. Typically, a CDSS makes suggestions for the clinician to look through, and the clinician is expected to pick out useful information from the presented results and discount erroneous CDSS suggestions. Implementing CDSS and EHR in telemedicine healthcare settings incurs challenges; none more important than maintaining efficiency and safety during rollout [30], but in order for the implementation process to be effective, an understanding of the technologies users' perspectives is key to the success of their implementation projects [31]. In addition to this, adoption needs to be actively fostered through a bottom-up, clinical-needs-first approach [32]. The main areas of concern with moving into a fully integrated EHR/CDSS are [33]: (1) privacy (2) confidentiality (3) user friendliness (4) document accuracy and completeness (5) integration (6) uniformity (7) acceptance and (8) alert desensitization as well as the key aspects of data entry that need to be addressed when implementing a CDSS to avoid potential adverse events from occurring. These aspects include whether (1) correct data is being used (2) all the data has been entered into the system (3) current best practice is being followed and (4) the data is evidence-based. Although, service oriented architecture has been proposed as a technical means to address some of these limitations [34].

V. Conclusion

This paper has been able to systematically review telemedicine and its engines especially CDSS and EHR. Since "clinical decision support systems (CDSSs) are computer systems designed to impact clinician decision making about individual patients at the point in time that these decisions are made", it is clear that it would be beneficial to have a fully integrated CDSS and EHR for an effective telemedicine. Even though the benefits can be seen, to fully implement a CDSS that is integrated with an EHR has historically required significant planning by the healthcare facility/organization, in order for the purpose of the CDSS to be successful and effective. The success and effectiveness can be measured by the increase in patient care being delivered and reduced adverse events occurring. In addition to this, there would be a saving of time and resources, and benefits in terms of autonomy and financial benefits to the healthcare facility/organization. This paper has also intensified further research in the field of telemedicine.

References

[1] Breen, G.M. and Matusitz, J. An Evolutionary Examination of Telemedicine: A Health and Computer-Mediated Communication Perspective. US National Library of Medicine, National Institutes of Health, Soc Work Public Health. 25(1): 59–71, 2010 Jan.

[2] Turner, J.W. Telemedicine: Expanding healthcare into virtual environments. In: Thompson, T.L., Dorsey, A.M., Miller, K.I., Parrott, R., editors. Handbook of health communication. pp. 515–535, 2003.

[3] Breen, G.M. and Matusitz, J. An interpersonal examination of telemedicine: Applying relevant communication theories. eHealth International Journal. 3(1):18–23, 2007.

Rotimi-Williams Bello and Firstman Noah Otobo, "Embedded engines of telemedicine: A systematic review," *International Research Journal of Advanced Engineering and Science*, Volume 3, Issue 2, pp. 367-371, 2018.

[4] Latifi, R. Current principles and practices of telemedicine and e-health: Studies in health technology and informatics (Volume 131) Fairfax, VA: IOS Press; 2008.

[5] Matusitz, J. and Breen, G.M. Telemedicine: Its effects on health communication. Health Communication. 21(1):73–83, 2007. [PubMed]

[6] Mort, M., May, C.R. and Williams, T. Remote doctors and absent patients: Acting at a distance in telemedicine? Science, Technology, and Human Values. 28(2):274–296, 2003.

[7] Turner, J.W., Thomas, R.J. and Reinsch, N.L. Willingness to try a new communication technology: Perpetual factors and task situations in a health care context. Journal of Business Communication. 41(1):5–26, 2004.

[8] Whitten, P., Doolittle, G. and Mackert, M. Telehospice in Michigan: Use and patient acceptance. American Journal of Hospice and Palliative Medicine. 21(3):191–195, 2004. [PubMed]

[9] Wootton, R. Telemedicine. British Medical Journal. 323:557–560, 2001. [PubMed]

[10] Eysenbach, G. What is e-health? Journal of Medical Internet Research. 3(2):e20, 2001. [PubMed]

[11] Whitten, P., Davenport Sypher, B. and Patterson, J.D. Transcending the technology of telemedicine: An analysis of telemedicine in North Carolina. Health Communication. 12(2):109–135, 2000 [PubMed]

[12] Ausseresses, A. Telecommunications requirements for telemedicine. Journal of Medical Systems. 19(2):143–151, 1995. [PubMed]

[13] Oudshoorn, N. Diagnosis at a distance: the invisible work of patients and healthcare professionals in cardiac telemonitoring technology. Sociology of Health & Illness. 30(2): p272–288, 2008. [PubMed]

[14] Berner, Eta S., ed. Clinical Decision Support Systems. New York, NY: Springer, 2007.

[15] Begum, Shahina; Ahmed, Mobyen Uddin; Funk, Peter; Xiong, Ning and Folke, Mia. "Case-based reasoning systems in the health sciences: a survey of recent trends and developments". IEEE Transactions on Systems, Man, and Cybernetics, Part C (Applications and Reviews). 41 (4): 421–434, July 2011.

[16] Khussainova, Gulmira; Petrovic, Sanja and Jagannathan, Rupa. "Retrieval with clustering in a case-based reasoning system for radiotherapy treatment planning". Journal of Physics: Conference Series. 616 (1): 012013, 2015.

[17] Khosla, Vinod. "Technology will replace 80% of what doctors do". CNN. 4 December 2012. Archived from the original on 28 March 2013. Retrieved 25 April 2013.

[18] Tanveer, Syeda-Mahmood. The Role of Machine Learning in Clinical Decision Support". Plenary talk: SPIE Newsroom. March 2015.

[19] Wagholikar, Kavishwar; V. Sundararajan and Ashok Deshpande. "Modeling Paradigms for Medical Diagnostic Decision Support: A Survey and Future Directions". Journal of Medical Systems. Journal of Medical Systems. 36: 3029–3049, 2012.

[20] Zandieh, Stephanie O.; Kahyun, Yoon-Flannery; Gilad, J. Kuperman; Daniel, J. Langsam; Daniel, Hyman and Rainu, Kaushal. "Challenges to EHR Implementation in Electronic- Versus Paper-based Office Practices". Journal of Global Information Management: 755-761, 2008.

[21] Nelson, E., Barnard, M. and Cain, S. Feasibility of telemedicine intervention for childhood depression. Counseling & Psychotherapy Research. 6(3):125–129, 2006.

[22] Berner, Eta S. and Tonya, J. La Lande. "1". Clinical Decision Support Systems: Theory and Practice (2 ed.). New York: Springer Science and Business Media. pp. 3–22, 2007.

[23] Rothman, Brian; Joan, C. Leonard and Michael, M. Vigoda. "Future of electronic health records: implications for decision support". Mount Sinai Journal of Medicine. 79 (6): 757–768, 2012.

[24] Sambasivan, Murali; Pouyan, Esmaeilzadeh; Naresh, Kumar and Hossein, Nezakati. "Intention to adopt clinical decision support systems in a developing country: effect of Physician's perceived professional autonomy, involvement and belief: a cross-sectional study". BMC Medical Informatics and Decision Making. 12: 142–150, 2012.

[25] Moja, L.; Kwag, K.H.; Lytras, T.; Bertizzolo, L.; Brandt, L.; Pecoraro, V.; Rigon, G.; Vaona, A.; Ruggiero, F.; Mangia, M.; Iorio, A.; Kunnamo, I. and Bonovas, S. "Effectiveness of computerized decision support systems linked to electronic health records: a systematic review and meta-analysis". American Journal of Public Health. 104 (12): e12–22, December 2014.

[26] Garg, A.X., Adhikari, N.K., McDonald, H., Rosas-Arellano, M.P., Devereaux, P.J., Beyene, J. et al. "Effects of computerized clinical decision support systems on practitioner performance and patient outcomes: a systematic review". JAMA. 293 (10): 1223–38, 2005.

[27] Kensaku, Kawamoto; Caitlin, A. Houlihan; E. Andrew Balas and David F. Lobach. "Improving clinical practice using clinical decision support systems: a systematic review of trials to identify features critical to success". BMJ. 330 (7494): 765, 2005.

[28] Black, A.D.; Car, J.; Pagliari, C.; Anandan, C.; Cresswell, K.; Bokun, T.; McKinstry, B.; Procter, R.; Majeed, A. and Sheikh, A. "The impact of ehealth on the quality and safety of health care: A systematic overview". PLoS Medicine. 8 (1): e1000387, 18 January 2011.

[29] Nachtigall, I.; Tafelski, S.; Deja, M.; Halle, E.; Grebe, M. C.; Tamarkin, A.; Rothbart, A.; Unrig, A.; Meyer, E.; Musial-Bright, L.; Wernecke, K. D. and Spies, C. "Long-term effect of computer-assisted decision support for antibiotic treatment in critically ill patients: a prospective 'before/after' cohort study". BMJ Open. 4 (12): e005370, 22 December 2014.

[30] Spellman Kennebeck, Stephanie; Nathan, Timm; Michael, K. Farrell and S. Andrew Spooner. "Impact of electronic health record implementation on patient flow metrics in a pediatric emergency department". Journal of the American Medical Informatics Association. 19: 443–447, 2012.

[31] McGinn, Carrie A.; Marie-Pierre, Gagnon; Nicola, Shaw; Claude, Sicotte; Luc, Mathieu; Yvan, Leduc; Sonya, Grenier; Julie, Duplantie; Anis, B. Abdeljelil and France Légaré. "Users' perspectives of key factors to implementing electronic health records in Canada: a Delphi study". BMC Medical Informatics and Decision Making. 12: 105–118, 2012.

[32] Rozenblum, Ronen; Yeona, Jang; Eyal, Zimlichman; Claudia, Salzberg; Melissa, Tamblyn; David, Buckeridge; Alan, Forster; David W. Bates and Robyn, Tamblyn. "A qualitative study of Canada's experience with the implementation of electronic health information technology". Canadian Medical Association Journal: 281–288, 2011.

[33] Berner, Eta S. and Tonya, J.La Lande. "4". Clinical Decision Support Systems: Theory and Practice (2 ed.). New York: Springer Science and Business Media. pp. 64–98, 2007.

[34] Loya, S. R.; Kawamoto, K.; Chatwin, C. and Huser, V. "Service oriented architecture for clinical decision support: A systematic review and future directions". Journal of Medical Systems. 38 (12): 140, 2014.