Status of AI-enabled Clinical Decision Support Systems Clinical Implementations in China

Mengting Ji
Shanghai Jiao Tong University School of Medicine
Xiaoyun Chen
China Digital Medicine Press, Beijing
Georgi Z. Genchev
Bulgarian Institute for Genomics and Precision Medicine, Sofia
Ting Xu
Shanghai Jiao Tong University School of Medicine
Mingyue Wei
Children's Hospital of Shanghai
Guangjun Yu (gjyu@shchildren.com.cn)
Shanghai Children's Hospital

Research

Keywords: Artificial Intelligence, Clinical Decision Support Systems, Clinical Implementation, Survey, AI+CDSSs, AI-enabled Clinical Decision Support Systems

Posted Date: January 31st, 2020

DOI: https://doi.org/10.21203/rs.2.22387/v1

Abstract

Background

AI-enabled Clinical Decision Support Systems (AI+CDSSs) were heralded to contribute greatly to the advancement of healthcare services. At present, there is an increased availability of monetary funds and technical expertise invested in projects and proposals targeting the building and implementation of such systems. Therefore, in this context of large funds and technical devotion, understanding the actual system implementation status in clinical practice is imperative. The objective of this research was to understand: 1) the current clinical implementations of AI+CDSSs in Chinese hospitals and 2) concerns regarding AI+CDSSs current and future implementations.

Methods

A survey supported by the *China Digital Medicine* journal was performed. We employed stratified cluster sampling and investigated tertiary hospitals from 6 provinces and province-level cities. Descriptive analysis, two-sided Fisher exact test, and Mann-Whitney *U*-test were utilized for analysis.

Results

Responses were collected from 160 respondents. The analyzable response rate was 86.96%. Thirty-eight of the surveyed hospitals (23.75%) had implemented AI+CDSSs. There were statistical differences on grade, scales, and medical volume between the two groups of hospitals (implemented vs. not-implemented AI+CDSSs, $p<0.05$). On the 5-point Likert scale, 81.58% (31/38) of respondents rated their overall satisfaction with the systems as 3 to 4. The three most-common concerns were *system functions improvement and integration into the clinical process, data quality and data sharing mechanism improvement*, and *methodological bias*.

Conclusions

While AI+CDSSs were not yet wide-spread in Chinese clinical settings, clinical professionals recognize the potential benefits and challenges regarding in-hospital AI+CDSSs.

Contributions To The Literature

- Breakthrough emergence of AI and launch of AI-enabled applications draw attention, but often the status of their clinical implementation is less studied. Studies investigating the implementation status of AI+CDSSs in Chinese hospitals are scarce, and our work helps address this knowledge gap.
- AI+CDSSs are yet to become widespread in Chinese hospitals and implemented are often not evaluated as most satisfactory. We explored the three most-common concerns and challenges which accompany the implementation of AI+CDSSs in China.
- Findings of this work's China-specific analysis can help alleviate the concerns and challenges of developing and implementing a well-received AI+CDSSs.

Background

Since its birth in 1950s, artificial intelligence (AI) has been used to solve medical problems in the fields of medical management, clinical decision support, patient monitoring, and health intervention (1). In the 1970s, there was a wave of development of initial AI-enabled applications in the medical field, such as the MYCIN (an expert system for advising physicians regarding selection of appropriate antimicrobial therapy (2)) and the Quick Medical Reference (QMR) (a diagnostic decision-support system for internists (3)). After the "cold winter" during which interest in AI waned in the 1980s, in recent years AI has experienced an era of explosive growth and in the 21st century has advanced to a new stage of accelerated development fueled by an enormous increase in computing power and an even larger increase in data, in combination with improved AI methodologies. Many countries including U.S., China, Japan, India, France, UK, Germany, and others(4, 5) have raised the development of AI to a level of government strategy, and recently, especially since 2016, a number of relevant policies have been issued to advance country-specific AI priorities. AI is widely seen as having a great potential to improve efficiency across many sectors, and healthcare is seen as one of the major and most important domains to be revolutionized by AI (6, 7). From health-care industry perspective, AI-related initiatives have received increased funding and investor interest. For example, by 2017, there were already 131 AI-focused healthcare companies in China, which attracted over CNY 18 billion in investments (8).

There is no single, universally agreed definition of AI. Broadly speaking, AI can be regarded as the emulation of human intelligence, which enables machines to learn from existing knowledge, adjust outputs, perform human-like tasks, and discover new knowledge (9). AI is generally classified into two types: 1) narrow (weak) AI which typically focuses on a specific task, or works within a narrow set of parameters; and 2) general (strong) AI which can learn to perform a multitude of tasks, or even refer to a sentient machine with elements of mind and consciousness. Narrow AI is widely applied in the healthcare field and uses computer algorithms to uncover relevant information from source data and to assist clinical decision-making (10) in order to have a positive impact on individuals, families, communities, and society as a whole(9).

Clinical Decision Support Systems (CDSSs) are software programs designed to utilize massive data, medical knowledge, and analysis engines with the goal to generate patient-specific assessments and recommendations to health professionals and to assist clinical decision-making through human-computer interaction (11, 12). Such systems provide services ranging from reminders to complex risk-prediction algorithms (13). AI-enabled Clinical Decision Support Systems (AI+CDSSs), represent a narrow AI application (14), and refer to CDSSs that include an intelligent (AI) component. The basic design approach to AI+CDSSs is to combine the knowledge reasoning techniques of AI and the basic function models of CDSS (15). These system apply numerical, logical, and intelligent techniques in order to find out suitable solutions to medical problems as well as assist clinical decisions, and provide intelligent behavioral patterns with the ability to learn new clinical knowledge (16). Based on this, AI+CDSSs can outperform the traditional CDSSs and act as systems that support and improve the decision-making process by converting the raw medically-related data, documents, and expert practice into a set of sophisticated algorithm inputs. AI+CDSSs approaches are believed to: 1) aid physicians in their diagnostic efficiency; 2) improve clinical decisions accuracy and effectiveness, 3) reduce medical errors, 4) improve patient safety, and 5) decrease costs (15). In recognition of the advances, integration, and benefits of information technology in medicine, the FDA released its “Digital Health Innovation Action Plan” (17) in July 2017 to foster innovation in medically-focused digital devices and systems. Subsequently, FDA-approved AI+CDSSs products that are used for monitoring, early warning, or diagnostic assistance have emerged, and have been deployed to various medical facilities worldwide.

In this work we examine the implementation of AI+CDSS systems from the perspective of real-world practice in China. AI+CDSSs for triage or screening, diagnostic assistance, images interpretation, etc. have already been deployed and tested in some Chinese hospitals, however, many unanswered questions regarding the implementation status of AI+CDSSs in clinical practice still remain. With the goal to understand: 1) the current clinical implementations of AI+CDSSs, and 2) concerns regarding AI+CDSSs current and future implementations, we performed a web-based survey of Chinese hospitals’ information technology (IT) department personnel combined with statistical analysis. Specifically, we focus to uncover the percentage of hospitals that have deployed and tested such systems; and within hospitals which have tested and deployed such systems – the current perspectives about the system and key issues and concerns that should be solved in system upgrade iterations or new deployments. To the best of our knowledge, this is the first such report, which provides a unique China-focused perspective, and helps address the knowledge gap regarding the AI+CDSSs status in China.

Methods

A web-based survey was initiated to understand: 1) the current clinical implementations of AI+CDSSs in Chinese hospitals and 2) concerns regarding AI+CDSSs current and future implementations. This study was informed by the Checklist for Reporting Results of Internet E-Surveys (CHERRIES) (18).

Survey questionnaire development and pre-testing

Before fielding the questionnaire, the appropriateness, usability, and technical functionality of the electronic questionnaire were tested through semi-structured interviews and a pilot survey (19). Investigators asked a pilot interviewee group, which included two health management experts, two medical informatics experts, and five prospective respondents, whether they understood the questions and whether they interpreted each included question as intended by the investigator. The pilot group members judged the appropriateness of each question, including whether to accept the original question, to revise the question while keeping the original meaning, to remove the question, or to write a new question. Sentence structure, wording, and layout of the questionnaire were modified according to the feedback of the pilot interviews. The modified version was tested on an additional pilot sample of five members of the target population. It took about 5 to 15 minutes by the respondents of the pilot test group to complete the maximum 30-item questionnaire (including adaptive questions which only conditionally displayed based on responses).

Survey methodology and sample size calculation

We employed stratified cluster sampling, which is a feasible method considering the research goals and target population. We randomly assigned groups (provinces) from the Eastern area, Midlands, and Western area of China, and then surveyed tertiary hospitals within the groups. The areas were defined as follows: Eastern area (Shanghai, Guangdong), Midlands (Henan), and Western area (Qinghai, Chongqing, Yunnan). According to the figures released by the statistical information center of the National Health Commission of the People's Republic of China, there are 2619 tertiary hospitals in China (June 2019). Hereby, the sample size was calculated as 184. Response rate of at least 70% is desirable for external validity(20).

AI+CDSSs stratification

To understand the details of actual AI+CDSSs practice in Chinese tertiary hospitals, we divided the AI+CDSSs into three types based on clinical diagnosis procedure stage: pre-diagnosis AI+CDSSs, diagnosis AI+CDSSs, and post-diagnosis AI+CDSSs. Pre-diagnostic AI+CDSSs are defined as software tools that are generally adopted in the process of previewing and preliminary checking, focused on medical history collection, risk factors screening, and ordering inspections and laboratory tests needed for diagnosis. Diagnostic AI+CDSSs are defined as triage or screening tools, which are used to assist clinicians in performing clinical diagnosis and detection by comprehensive assessment of patient information, including clinical phenotype, molecular genetics, reference knowledge, and other related data. Post-diagnostic AI+CDSSs are defined as systems that present recommended treatments to the clinician to select, alert for abnormal laboratory values, monitor medication safety, predict the possible health-related problems reflecting patient conditions and existing knowledge bases, generate and execute individual discharge plans and other post-diagnostic activities.

AI+CDSSs system development lifecycle staging

Following the nomenclature of the canonical System Development Life Cycle (21), we defined the implementation phase of AI+CDSSs as consisting of clinical testing and deployment stages. Therefore, systems either in the clinical testing or deployment stage were regarded as being implemented in the specific hospital's clinical practice.

Survey format and respondents

This electronic questionnaire consisted of five parts: 1) cover letter, 2) questions about respondents demographics, 3) questions about basic information of the surveyed hospitals, 4) questions about the status of clinical implementations of AI+CDSSs, and 5) questions about the respondents' concerns on AI+CDSSs current and future implementations. All questions were presented in a single scrolling webpage on a website used for e-survey. Respondents were IT department directors or key personnel familiar with AI+CDSS development and clinical implementation of their hospitals.

Survey deployment

This cross-sectional, web-based survey was initiated in August and was closed in October, 2019. It was assisted by the *China Digital Medicine* ([illegible]) journal (ISSN 673-7571) which is a science and technology academic journal based in Beijing, China, focused on reflecting the development of digital medicine domestically and globally. The journal has liaison offices across China and with the assistance of the local liaison offices in different provinces, we were able to outreach to hospitals, and carry out the survey in the areas described above. At the start of the survey, we contacted the leaders of the liaison offices from the assigned provinces, stating the objective of the study, target respondents, and the length of time of the survey. This was a voluntary survey. The liaison individuals transmitted the electronic questionnaire link to the target respondents.

Survey quality control measures

We preset the logical relationship between questions and designated required questions in the electronic questionnaire. Therefore, logical consistency and completeness checks were ensured before the questionnaire was submitted by the responders. Before submitting respondents can review or change their answers. Furthermore, we asked the liaisons to send online notifications at least three times at regular intervals in order to improve the response rate. Three duplicate questionnaires were removed by considering the IP address and the name of hospital. Investigators verified the three duplicates: two of the duplicates were due to repeated submission, and one duplicate was a resubmission of a pilot test questionnaire.

Calculations and statistical analysis

Based on the survey results, we calculated summary statistics for the respondents (age, gender, professional titles, educational background). We also calculated summary statistics for the responding hospitals (area, grade, beds, number of medical doctors and nurses, number of patients). We also described the current situation of actual implementation of AI+CDSSs in the hospital's clinical practice, the respondents' satisfaction with their AI+CDSSs, and the responders' opinion regarding the priority of concerns to be solved in the future development of AI+CDSSs.

We used chi-square test, two-sided Fisher exact test, or Mann-Whitney *U* test to compare background variables of surveyed hospitals between groups where AI+CDSSs were or were not implemented. Statistical significance was determined as $p<0.05$. Statistical calculation was performed by SPSS (IBM Corp. Released 2011, IBM SPSS Statistics for Windows, Version 20.0. Armonk, NY: IBM Corp.).

Results

Geographical and demographics characteristics

The survey's analyzable response rate was 86.96%. Survey responses were collected from a total of 160 respondents from 160 hospitals located in 6 provinces across China. Geographical distribution of responding hospitals is shown on *Table 1*, 73.13% were grade A tertiary hospitals. The majority of respondents (88.13%) were between 31 to 50 years of age, male (81.25%), with undergraduate or master's degree (88.13%), and intermediate or senior work titles (85.00%) (*Figure 1*).

Overall AI+CDSSs implementations

Less than a quarter of the surveyed hospitals (38/160, 23.75%) had deployed or tested an AI+CDSSs. There were significant statistical differences on hospital scale and volume (including hospital grade, actual opening beds, number of doctors and nurses, annual quantity of outpatient, surgery, and discharged patients) (p- value see *Table 1*) between the two groups of hospitals which had or had not an AI+CDSSs implemented.

AI+CDSSs implementations details

Diagnostic AI+CDSSs were implemented in 20.00% (32/160) of the surveyed hospitals *(Figure 2)*. The main functions of diagnostic AI+CDSSs in clinical practice were image interpretation (84.38%), diagnostic assistance (46.88%), and pathological typing assistance (12.50%) (*Figure 3*). Compared with diagnostic AI+CDSSs, the number of pre-diagnosis AI+CDSSs implemented in surveyed hospitals was lower (28, 17.50%). The main functions of pre-diagnostic AI+CDSSs were triage previewing (64.29%), risk factors screening (60.71%), suggestions for examinations or laboratory tests (57.14%), and history collection and recording (35.71%). The lowest implementation rate of the three types of AI+CDSSs was for the post-diagnostic systems -10.00% (16/160). The main functions of this type of system in clinical application were urgent values warnings/alerts (81.25%), drug therapy management (50.00%), treatment recommendations (43.75%), and follow-up service (37.50%) (*Figure 3*). Over half of the respondents reported that their AI+CDSSs were not embedded in multi-disciplinary consultation systems or remote consultation systems, regardless if the system was used for pre-diagnosis (18/28, 64.29%), diagnosis (25/32, 78.13%), or post-diagnosis (9/16, 56.25%) (*Figure 4*).

Attitude towards deployed AI+CDSSs

The general attitude toward AI+CDSSs among the respondents was positive. On the 5-point Likert scale, 81.58% (31/38) of respondents rated their overall satisfaction as 3 or 4. No statistical difference was observed on overall satisfaction between groups of the three different types of AI+CDSSs (p>0.05) (*Table 2*). Over half of the respondents considered that AI+CDSSs were beneficial for improving clinical quality (60.71%-68.75%), clinical efficiency (50.00%-71.43%), and the decision-making ability of hospital clinicians (62.50%-71.88%) (*Table 3*).

Concerns regarding AI+CDSSs

We explored a total of 6 major concerns (*Table 4*) and their resolution priority. Respondents were asked to select which three concerns should be solved as an urgent need or in future implantations. The most common concern was *system functions improvement and integration into the clinical process*. Majority of the respondents (131/160, 81.88%) considered that this was the top-priority concern to be solved in existing or future implementation of AI+CDSSs. The next concern selected by over three- quarters of the respondents was regarding *data quality and data sharing mechanism improvement* (124/160, 77.50%). The third concern selected by over one-third of the respondents (70/160, 43.75%) was *methodological bias, including explainability, transparency, adaptability of algorithms* (*Table 4*).

Discussion

Overview

Breakthrough emergence of new technologies and launch of new software products draw attention and publicity, but often the status of their clinical application is less studied. There are global studies(22) about AI+CDSSs implementations, and healthcare professionals' attitudes and experiences of AI application in healthcare delivery. Studies investigating the implementation status of AI+CDSSs in clinical practice from Chinese perspective are scarce, and our work helps address this existing knowledge gap.

Our study found that AI+CDSSs are yet to become widespread in clinical practice in Chinese tertiary hospitals. Current systems were rarely embedded in multi-disciplinary or remote consultation systems and one of the most successfully executed functions of AI+CDSSs was imaging, followed by the previewing triage and risk factors screening. Our finding is consistent with a previous prediction that AI could foremost enter widespread use in medical imaging services (23, 24). Chinese hospitals which have clinically tested or deployed AI+CDSSs tend to have higher grade, larger scale (actual opening beds, number of doctors and nurses) and bigger medical volume (quantity of outpatients, surgery, and discharged patients). A feasible explanation to this fact is that such hospitals may have larger capital investments into AI+CDSSs construction in order to meet their large needs and clinical workload.

Concerns and challenges

The implementation of AI+CDSSs in Chinese clinical practice are not yet widespread and implemented are often not evaluated as most satisfactory. Some underlying issues and constraints were already acknowledged in prior work (25, 26). In our study we explored the prioritized concerns and challenges which accompany the implementation of AI+CDSSs in China. Herein we discuss: 1) system functions improvement and integration into the clinical process, 2) data quality and data sharing mechanism improvement, and 3) methodological bias, e.g. explainability, transparency, adaptability of algorithms, which were identified as the three most important areas for the surveyed group.

The top challenge for current and future implementation of AI+CDSSs identified in the survey is *system functions improvement and integration into the clinical process*. Our interpretation of this result is that the AI+CDSSs in Chinese hospitals, similarly to systems explored in other studies(27, 28), may suffer from a mismatch between users' requirements/needs and system functions thus making the absence of translating users' requirements into system function design and clinical pathway integration is one of the major obstacles faced by AI+CDSSs implementation. Another challenge related to the implementation of AI+CDSSs highlighted by our analysis is the *data quality and data sharing mechanism improvement*. This is a common global problem where the lack high quality and available data creates a barrier for practitioners to receive the “right information” (26) from an AI+CDSSs system. The link between data quality and value can be illustrated by the *Garbage In, Garbage Out* (GIGO) phenomenon; data quality is also a prerequisite to data sharing. The third major concern about implementations of AI+CDSSs in Chinese hospitals is regarding algorithm bias, *e.g.* transparency, adaptability, and explainability. The lack of methodological transparency inherent in machine learning methods (“black-box”) can impair user trust in the outputs produced by an AI+CDSS (29). This is a phenomenon is distinctive in the healthcare field(22) where medical practitioners are less likely to adopt AI in clinical practice if they don’t trust the technology or understand how it was used to support process of care or patient outcomes (30).

Perspectives

What can an AI+CDSS do and where will it work best, what are the clinicians’ needs to deliver the best health care, and how to maximize the success of an AI+CDSS implementation in Chinese hospitals? While not an exhaustive recommendation set, the following key behaviors, informed by previous and this work’s China-specific analysis, can help alleviate the concerns and challenges of developing and implementing a usable and well-received AI+CDSSs.

- Perform comprehensive requirements definition involving all stakeholders (medical professionals, hospital administration, payers, government agencies, and patient groups) to ensure that system functionality addresses the clinicians’ perception of greatest need and value for intelligent decision support.
- Design the functions of AI+CDSSs in light of the multifaceted and complex workflow of the specific hospital setting where it is to be deployed in order to generate the right recommendations to the right person at the right time and location.
- Develop and implement data standards, data quality measures, and data sharing mechanisms. Technology and user rules should be combined to improve data-focused procedures such as storage, governance, patient record portability and security.
- Ensure end-user training on system functionality and logic takes place among clinicians to explain how AI+CDSSs suggestions were reached in ways that are understandable to clinical users and reduce the ‘black-box’ perception.

Limitations of the study

There are two limitations in our study: non-response bias control and the the quantitative study design. Firstly, the non-response bias of this survey was not controlled and analyzed. In the implementation stage, the electronic questionnaires were received efficiently in the Midlands region (Henan), and the planned sample size was achieved. Comparatively, the response efficiency was lower in the Eastern and Western area. Therefore, investigators assigned more than one province in the Eastern (Shanghai, Guangdong) and Western area (Qinghai, Chongqing, Yunnan). In the data analysis stage, the impact of non-respondent bias was not analyzed due to the fact that detailed information of non-respondent subjects and their hospitals was unavailable. This non-response bias may have some possible adverse influence on the representativeness of the survey results. The actual effect remains uncertain and can be identified by performing a large-scale census.

Secondly, a quantitative study may not be sufficient to fully understand AI+CDSSs experience in actual practice. Indeed focusing only on technologies and ignoring the role of human nature can lead to omitting further explanations (31). Considering the socio-technical nature of this topic, a mixed study with qualitative and quantitative methods may provide additional understanding of this complex phenomena and is under consideration in our future work.

Conclusions

In this work, we aimed to explore the gap between the excitement about the potential of AI+CDSSs and their actual implementation in Chinese tertiary hospitals. While AI+CDSSs were not yet wide-spread in Chinese clinical settings, hospital professionals recognize the potential benefits and challenges regarding in-hospital AI+CDSSs.

Abbreviations

AI: Artificial Intelligence; CDSSs: Clinical Decision Support Systems; AI+CDSSs: AI-enabled CDSSs

Declarations

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Availability of data and materials

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Competing interests

The authors declare that they have no competing interests.

Funding

This work was supported by the “2019 China Medical AI Development Research Project” of the National Institute of Hospital Administration, the “Doctoral Innovation Fund in Shanghai Jiao Tong University

School of Medicine 2019 [BXJ201906]"; and the "Shanghai Municipal Education Commission-Gaoyuan Nursing Grant Support [Hlgy1906dxk]".

Authors' contributions

All authors contributed to conception and design of the work, or acquisition of data, or analysis and interpretation of data; and drafting or revising the article. All authors have approved the submitted version; and have agreed both to be personally accountable for the author's own contributions and to ensure that questions related to the accuracy or integrity of any part of the work, even ones in which the author was not personally involved, are appropriately investigated, resolved, and the resolution documented in the literature.

Acknowledgements

The authors thank Xianzhong Lu, Qingbin Wu, Jian Lu, Yun Shi, Haibo Zhang for survey assistance.

References

1. Reddy S, Fox J, Purohit MP. Artificial intelligence-enabled healthcare delivery. J R Soc Med. 2019;112(1):22-8.
2. Shortliffe EH, Davis R, Axline SG, Buchanan BG, Green CC, Cohen SN. Computer-based consultations in clinical therapeutics: explanation and rule acquisition capabilities of the MYCIN system. Comput Biomed Res. 1975;8(4):303-20.
3. Lemaire JB, Schaefer JP, Martin LA, Faris P, Ainslie MD, Hull RD. Effectiveness of the Quick Medical Reference as a diagnostic tool. CMAJ. 1999;161(6):725-8.
4. NSTC. National Artificial Intelligence Research And Development Strategic Plan 2016 [cited 2019 Dec. 18th]. Available from: https://www.nitrd.gov/PUBS/national_ai_rd_strategic_plan.pdf.
5. Hall DW, Pesenti J. Growing the artificial intelligence industry in the UK 2017 [cited 2019 Dec. 18th]. Available from: https://www.gov.uk/government/publications/growing-the-artificial-intelligence-industry-in-the-uk.
6. Hartskamp M, Consoli S, Verhaegh W, Petković M, Stolpe A. Artificial Intelligence in Clinical Health Care Applications: Viewpoint. Interactive Journal of Medical Research. 2019;8(2):e12100.
7. CBInsights. Healthcare Remains The Hottest AI Category For Deals 2017 [cited 2019 Dec.01]. Available from: https://www.cbinsights.com/research/artificial-intelligence-healthcare-startups-investors/.
8. EOIntelligence. AI Innovation of Healthcare Industry in China 2017 [cited 2019 Dec. 14th]. Available from: https://www.iyiou.com/intelligence/report561.html.
9. Ream M, Woods T, Joshi I, Day L. Accelerating Artificial Intelligence in health and care: results from a state of the nation survey. NHS; 2018.

10. He J, Baxter SL, Xu J, Xu J, Zhou X, Zhang K. The practical implementation of artificial intelligence technologies in medicine. Nat Med. 2019;25(1):30-6.
11. Sim I, Gorman P, Greenes RA, Haynes RB, Kaplan B, Lehmann H, et al. Clinical decision support systems for the practice of evidence-based medicine Journal of the American Medical Informatics Association Jamia. 2001;8(6):527-34.
12. Haynes RB, Wilczynski NL. Effects of computerized clinical decision support systems on practitioner performance and patient outcomes: Methods of a decision-makerresearcher partnership systematic review. Implementation Science. 2010(5):12.
13. Grout RW, Cheng ER, Carroll AE, Bauer NS, Downs SM. A six-year repeated evaluation of computerized clinical decision support system user acceptability. Int J Med Inform. 2018;112:74-81.
14. Daniel G, Silcox C, Sharma I, Wright MB. Current State and Near-Term Priorities for AI-Enabled Diagnostic Support Software in Health Care US: Duke-Margolis Center for Health Policy; 2019 [updated June 6; cited 2019 Nov. 9th]. Available from: https://healthpolicy.duke.edu/publications/current-state-and-near-term-priorities-ai-enabled-diagnostic-support-software-health.
15. Salem H, Attiya G, El-Fishawy N. A Survey of Multi-Agent based Intelligent Decision Support System for Medical Classification Problems. International Journal of Computer Applications. 2015;123(10):20-5.
16. Aljaaf AJ, Al-Jumeily D, Hussain AJ, Fergus P, Al-Jumaily M, Abdel-Aziz K. Toward an Optimal Use of Artificial Intelligence Techniques within a Clinical Decision Support System. Science and Information Conference; London, UK2015. p. 548-54.
17. FDA. Digital Health Innovation Action Plan 2017 [cited 2019 Nov. 9th]. Available from: https://www.fda.gov/media/106331/download.
18. Eysenbach G. Improving the Quality of Web Surveys: The Checklist for Reporting Results of Internet E-Surveys (CHERRIES). J Med Internet Res. 2004;6(3).
19. Kelly K, Clark B, Brown V, Sitzia J. Good practice in the conduct and reporting of survey research. Int J Qual Health Care. 2003;15(3):261-6.
20. Burns KE, Duffett M, Kho ME, Meade MO, Adhikari NK, Sinuff T, et al. A guide for the design and conduct of self-administered surveys of clinicians. CMAJ. 2008;179(3):245-52.
21. Rastogi V. Software Development Life Cycle ModelsComparison, Consequences. International Journal of Computer Science and Information Technologies. 2015;6(1):168-72.
22. Shinners L, Aggar C, Grace S, Smith S. Exploring healthcare professionals' understanding and experiences of artificial intelligence technology use in the delivery of healthcare: An integrative review. Health Informatics J. 2019:1-12.
23. Obermeyer Z, Emanuel EJ. Predicting the Future - Big Data, Machine Learning, and Clinical Medicine. N Engl J Med. 2016;375(13):1216-9.
24. Lewis SJ, Gandomkar Z, Brennan PC. Artificial Intelligence in medical imaging practice: looking to the future. J Med Radiat Sci. 2019;66(4):292-5.

25. Liberati EG, Ruggiero F, Galuppo L, Gorli M, Gonzalez-Lorenzo M, Maraldi M, et al. What hinders the uptake of computerized decision support systems in hospitals? A qualitative study and framework for implementation. Implementation science : IS. 2017;12(1):113.
26. Borum C. Barriers for Hospital-Based Nurse Practitioners Utilizing Clinical Decision Support Systems: A Systematic Review. Comput Inform Nurs. 2018;36(4):177-82.
27. Vermeulen J, Verwey R, Hochstenbach LM, van der Weegen S, Man YP, de Witte LP. Experiences of multidisciplinary development team members during user-centered design of telecare products and services: a qualitative study. J Med Internet Res. 2014;16(5):e124.
28. Baslymana M, Almoaber B, Amyot D, Bouattane EM. Using Goals and Indicators for Activity-based Process Integration in Healthcare. Procedia Computer Science. 2017(113):318–25.
29. Howard J. Artificial intelligence: Implications for the future of work. Am J Ind Med. 2019;62(11):917-26.
30. Fan W, Liu J, Zhu S, Pardalos PM. Investigating the impacting factors for the healthcare professionals to adopt artificial intelligence-based medical diagnosis support system (AIMDSS). Ann Oper Res. 2018.
31. Chon A, Marie-Claude B, Iris J, Richard W. Enriching our theoretical repertoire: the role of evolutionary psychology in technology acceptance. European Journal of Information Systems. 2013;22(1):56-75.

Tables

Table 1 Information of the respondents' hospitals, stratified by AI+CDSSs implementation

Information of Scale [a]		Total N(%)	Deployment or Testing n(%)	No Implementation n(%)	*p*
Total		160(100.00)	38(23.75)	122(76.25)	/
Area	Eastern (Shanghai, Guangdong)	60(37.50)	19(50.00)	41(33.61)	>0.05*
	Midlands (Henan)	66(41.25)	12(31.58)	54(44.26)	
	Western (Qinghai, Chongqing, Yunnan)	34(21.25)	7(18.42)	27(22.13)	
Grade#	Grade A	117(73.13)	34(89.48)	83(68.03)	<0.01**
	Grade B	15(9.37)	2(5.26)	13(10.66)	
	Grade C	28(17.50)	2(5.26)	26(21.31)	
Actual opening beds	<500	27(16.88)	1(2.63)	26(21.31)	<0.001**
	500-999	32(20.00)	2(5.26)	30(24.59)	
	1000-1499	37(23.13)	5(13.16)	32(26.23)	
	1500-1999	21(13.13)	10(26.32)	11(9.02)	
	≥2000	43(26.88)	20(52.63)	23(18.85)	
Number of doctors	<100	10(6.25)	0(0.00)	10(8.20)	<0.001**
	100-199	20(12.50)	1(2.63)	19(15.57)	
	200-499	41(25.63)	3(7.89)	38(31.15)	
	500-999	53(33.13)	14(36.84)	39(31.97)	
	≥1000	36(22.50)	20(52.63)	16(13.11)	
Number of nurses	<500	44(27.50)	2(5.26)	42(34.43)	<0.001**
	500-999	53(33.12)	8(21.05)	45(36.88)	
	1000-1499	27(16.88)	10(26.32)	17(13.93)	
	1500-1999	15(9.38)	7(18.42)	8(6.56)	
	≥2000	21(13.12)	11(28.95)	10(8.20)	
Outpatient quantity	<100k	16(10.00)	0(0.00)	16(13.11)	<0.001**
	100-500k	37(23.12)	3(7.89)	34(27.87)	
	500k-1m	36(22.50)	5(13.16)	31(25.41)	
	1-2m	31(19.38)	8(21.05)	23(18.85)	
	>2m	40(25.00)	22(57.89)	18(14.75)	
Surgery quantity	<10k	53(33.12)	4(10.53)	49(40.16)	<0.001**
	10-20k	23(14.38)	3(7.89)	20(16.39)	
	20-50k	37(23.13)	7(18.42)	30(24.59)	
	50-100k	30(18.75)	14(36.84)	16(13.11)	
	>100k	17(10.62)	10(26.32)	7(5.74)	
Discharged patients' quantity	<20k	32(20.00)	1(2.63)	31(25.41)	<0.001**
	20-50k	40(25.00)	4(10.53)	36(29.51)	
	50-100k	49(30.62)	15(39.47)	34(27.87)	
	100-200k	27(16.88)	12(31.58)	15(12.30)	
	>200k	12(7.50)	6(15.79)	6(4.92)	

Note:

[a] All data were hospital statistics in 2018.

Tertiary hospitals in China are officially rated as class A, class B and class C.

* Fisher's exact test.

**Mann-Whitney *U*-test.

Table 2 Respondents' overall satisfaction with AI+CDSSs

Score#	Overall satisfaction n (%)	Pre-diagnostic AI+CDSSs n (%)	Diagnostic AI+CDSSs n (%)	Post-diagnostic AI+CDSSs n (%)	*p*
	N=38	N=28	N=32	N=16	>0.05*
5	1(2.63)	1(3.57)	1(3.13)	2(12.50)	
4	13(34.21)	9(23.68)	12(37.50)	4(25.00)	
3	18(47.37)	15(53.57)	17(53.13)	9(56.25)	
2	5(13.16)	3(10.71)	2(6.25)	0(0.00)	
1	1(2.63)	0(0.00)	0(0.00)	1(6.25)	

Note:

Overall satisfaction with AI+CDSSs on a 5-point Likert scale, from 1 being “not at all satisfied” to 5 being “very satisfied”.

*Mann-Whitney *U* test.

Table 3 Positive influence of AI+CDSSs on clinical process

Clinical influence	Pre-diagnostic AI+CDSSs n (%)	Diagnostic AI+CDSSs n (%)	Post-diagnostic AI+CDSSs n (%)
Improvement of clinical quality	17（60.71）	20（62.50）	11（68.75）
Enhancement of clinical efficiency	20（71.43）	17（53.13）	8（50.00）
Promotion of the “Hierarchical diagnosis and treatment” *	14（50.00）	8（25.00）	8（50.00）
Improvement of decision-making ability of clinicians	20（71.43）	23（71.88）	10（62.50）
Reduction of medical costs	11（39.28）	8（25.00）	8（50.00）
Improvement of patients’ satisfaction	14（50.00）	7（21.88）	8（50.00）
None	0（0.00）	2（6.25）	1（6.25）

Note:

*Hierarchical diagnosis and treatment：One of the medical system reforms in China which was aimed to allocate medical resources properly and to promote the equalization of basic medical services. Shanghai is the first pilot area. The main content of this reform is: 1) encouraging patients with common diseases to visit community health centers first, 2) redirect referral patients with chronic diseases or in recovery stage from tertiary hospitals to community health centers, 3) establishment of cooperation mechanism of different grades of hospitals to make full use of medical resources.

Table 4 Respondents’ opinion on priority of concerns to be solved in the current and future implementations of AI+CDSSs

Concerns	N	%
System functions improvement and integration into the clinical process	131	81.88
Data quality and data sharing mechanism improvement	124	77.50
Methodological bias, *e.g.* explainability, transparency, adaptability of algorithms	70	43.75
Mechanisms of social security, *e.g.* industry standards, laws and regulations, assessment and supervision, ethics	43	26.88
Costs of information systems	38	23.75
Interdisciplinary talents	29	18.13

Figures

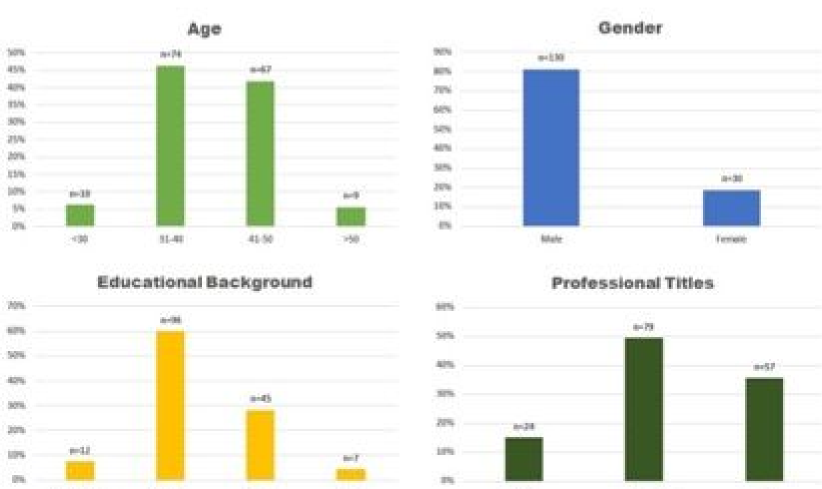

Figure 1

Characteristics of the study respondents (N=160)

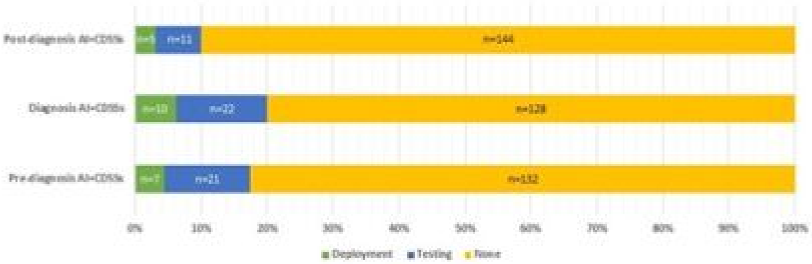

Figure 2

Clinical implementation of AI-enabled CDSSs

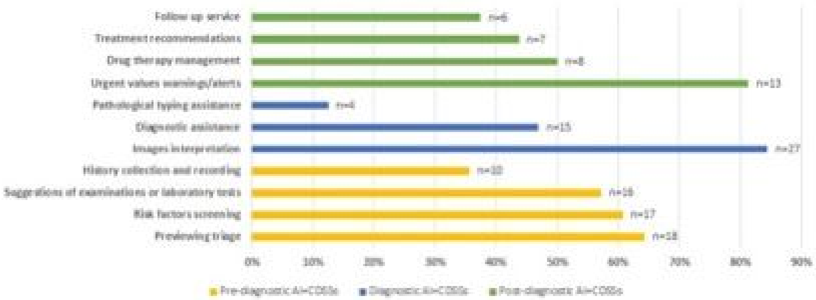

Figure 3

Main functions of AI+CDSSs realized in clinical practice in respondents’ hospitals

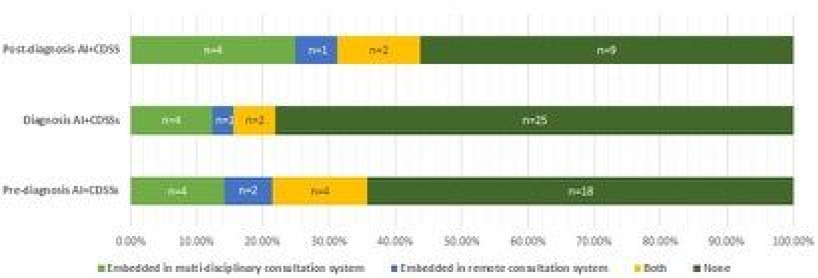

Figure 4

AI+CDSSs embedded in consultation systems