Advances in Clinical Decision Support Systems: Contributions from the 2022 Literature

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Summary

Objective: To summarize significant research contributions published in 2022 in the field of clinical decision support (CDS) systems and select the best papers for the Decision Support section of the International Medical Informatics Association (IMIA) Yearbook 2023.

Methods: A renewed search query for identifying CDS scholarship was developed using Medical Subject Headings (MeSH) terms and related keywords. The query was executed in PubMed in January 2023. The search results were reviewed in three stages by two reviewers: title-based triaging, followed by abstract screening, and then full text review. The resulting articles were sent for external review to identify best paper candidates.

Results: A total of 1,939 articles related to CDS were retrieved. Of these, 11 articles were selected as candidates for best papers. The general themes of the final three best papers are (1) reducing documentation burden through in-line guidance for clinical notes, (2) clinician engagement for continuous improvement of CDS, and (3) mitigating healthcare-related carbon emissions using scalable and accessible CDS, respectively.

Conclusion: The field of clinical decision support remains highly active and dynamic, with innovative contributions to a range of clinical domains from primary to acute care. Interoperability issues, documentation burden, clinician acceptance, and the need for effective integration into existing healthcare workflows are among the prominent challenges and areas of interest faced by CDS implementation efforts.

1   Introduction

Clinical decision support (CDS) systems are at the forefront of the digital revolution in biomedicine. With their potential to make care safer, more efficient, and less costly they are emerging as powerful tools for clinicians in making evidence-based and informed decisions. This manuscript represents the synopsis for the Decision Support section of the 2023 International Medical Informatics Association (IMIA) Yearbook. Our synopsis supplements the review paper on the impact of CDS on health disparities and digital divide, authored by Douthit *et al.* [1]. The aim of this synopsis is to summarize significant research in the CDS domain and to select the best papers published in this field in the year 2022.

2   Methods

Following the principles outlined in the paper by Lamy et al. [2], the literature review process for the Yearbook's CDS synopsis is expected to be systematic and standardized including specific data sources, search strategies, and selection criteria. First, we reached out to Borbolla and Colicchio (the authors of the CDS synopsis for the 2022 IMIA Yearbook [3]) and discovered that the actual query used for the prior synopsis had been lost. However, salient terms were described in the 2022 CDS synopsis [3]. For Medical Subject Headings (MeSH), the terms "Decision Support Systems, Clinical", "Expert systems" AND "Medical Order Entry Systems" were used. Borbolla and Colicchio also used terms such as "Clinical Decision Support", "Medication Alert Systems", "Computerized Provider Order Entry System" in the narrative search. Since prior queries were not available, we were forced to develop a new search strategy based on Lamy et al. recommendations [2] and a related systematic review by Ostropolets *et al.* [4].

We are including the actual query (see Table 1) to support future Yearbook contributors. Similar to prior synopsis, we searched for relevant papers in PubMed® using the newly developed search strategy. We included journal articles published in 2022 in English that had a series of keywords either in the MeSH terms or in the paper's title or abstract. For the MeSH terms, we considered, "Clinical Decision Support", "Expert systems", Medical Order Entry Systems", "Decision Support Techniques", and "Decision Support Systems, Management". For the abstracts and title search, we used the terms, "Best Practice Alert", "Clinical Decision Support", "Decision Support Techniques", "Decision Support Systems", "Expert systems", "Medication Alert Systems", and "Computerized Provider Order Entry System". The final query is shown in Table 1.

We reviewed the query results in three stages: title only review, followed by abstract review, and then full text review as described below. We chose to first triage using a title only review because the query returned 5.75 times more results than in 2022 (see *Results* section for more details). At this stage, we were blinded to country of origin, institution, or authors. We included any articles that were selected for further review by at least one of

Table 1 Search Strategy for CDS Literature Review.

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2022[DP] NOT pubstatusaheadofprint AND
(journal article[PT]) AND
English[LA] AND
(
(Clinical Decision Support[MeSH Terms]) OR (Expert systems[Mesh]) OR (Medical Order Entry Systems[Mesh]) OR
(Decision Support Techniques[MeSH Terms]) or (Decision Support Systems, Management [MeSH Terms]) OR
"Best Practice Alert"[title/abstract] OR
"Clinical Decision Support"[title/abstract] OR
"Decision Support Techniques"[title/abstract] OR
"Decision Support Systems"[title/abstract] OR
"Expert systems"[title/abstract] OR
"Medication Alert Systems"[title/abstract] OR
"Computerized Provider Order Entry System" [title/abstract]
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us (CUL and VS). Following the title only review, we proceeded to screen the remaining articles using their abstracts. We individually examined the full text of all remaining articles and conducted a conference call to discuss each article that was selected by at least one of us. Through consensus, we identified the candidate best papers. The full IMIA Yearbook editorial board determined the finalists.

3 Results

The search query resulted in 1,939 unique references, which was significantly more than in 2022, where 337 references were found. After the title review, 111 references were included by either section editor (CUL and VS). While both editors agreed on 12 articles, VS had included an additional 23 articles, and CUL incorporated an additional 76 articles.

After screening the abstracts, 19 articles were identified with five selected by both editors. After full text review, 11 best paper candidates were selected in a consensus conference call (Table 2). Of these, three papers were published in the Journal of the American Medical Informatics Association, two each in BMC Health Services Research and Applied Clinical Informatics, and one each in BMC Medical Informatics and Decision Making, eBioMedicine, JMIR Perioperative Medicine, and Open Forum Infectious Diseases.

We provide further analyses of the 11 best paper candidates using the Donabedian's structure-process-outcomes model [5]. After external review of best paper candidates, the IMIA Yearbook editorial committee finally selected three candidates as the best papers (Table 3) making the most significant contributions in the field of clinical decision support for 2022. A summary of the best papers can be found in the appendix of this synopsis.

4 Discussion and Outlook

The eleven best paper candidates are analyzed using a range of structural, process, and outcome characteristics. Structural aspects include the type of CDS and clinical setting where the CDS was deployed or studied. Six studies included domain-specific systems such as an electronic alert to notify prescribers about inappropriate red blood cell and platelet transfusion [6]; a patient-specific CDS report for disease prevention and surveillance in the primary care setting [7]; a non-interruptive alert in anesthesia to reduce fresh gas flow when a predefined threshold was exceeded [8]; a real-time text message alert when antimicrobial therapy was inappropriate (*i.e.*, an antimicrobial agent–pathogen mismatch with a positive blood culture result) [9]; a guideline-based CDS for maternal health [10]; and a microRNA-based thyroid molecular

classifier test for a precision endocrinology [11]. Clinical settings for implementation or investigation of CDS systems included critical care, primary care, hematology and oncology, anesthesiology, pediatrics, and infectious diseases.

In terms of process characteristics, we primarily analyzed the nature of CDS evaluation (*e.g.*, prospective *vs.* retrospective studies; multisite *vs.* single-site studies; provider-facing *vs.* patient-facing CDS; early-stage *vs.* effectiveness studies). Most studies were single-site, retrospective in nature, and focused on provider-facing CDS. Two out of the 11 best paper candidates [7,12] had a patient-facing application. Lobach *et al.* explored the integration of a patient engagement application (for monitoring and managing COVID-19 symptoms) into the electronic health record using Health Level 7 (HL7) Fast Health Interoperability Resources (FHIR) standards, including contemporary services such as CDS Hooks [12]. Wu *et al.* conducted an implementation effectiveness trial for examining the clinical impact of patient-oriented and provider-facing CDS report for health risk assessment [7]. Notably, one study demonstrated the scalability and transferability of a CDS system to reduce anesthetic gas waste [8], innovatively linking informatics solutions to environmental impact.

Four studies [13–16] were focused broadly on evaluating the effect of CDS on clinician-related outcomes and problems (*e.g.*, documentation burden, alert fatigue, adherence to CDS recommendations). All of these studies were largely focused on rule-based CDS. None of the 11 selected papers had artificial intelligence and/or machine learning models as the basis for decision support. However, we predict that, in 2023, there will be a renewed and moderate attention to evaluation of expert systems for clinical decision support.

Table 2 Best paper candidates for the Clinical Decision Support Section.

PMID	Title	First Author	Journal	DOI
36581868	Effectiveness of clinical decision support in controlling inappropriate red blood cell and platelet transfusions, speciality specific responses and behavioural change	Atia J	BMC Med Inform Decis Mak	10.1186/s12911-022-02045-8
36567357	Effects of computerized decision support on maternal and neonatal health-worker performance in the context of combined implementation with performance-based incentivisation in Upper East Region, Ghana: a qualitative study of professional perspectives	Aninanya GA	BMC Health Serv Res	10.1186/s12913-022-08940-0
36516969	Integrating a Patient Engagement App into an Electronic Health Record-Enabled Workflow Using Interoperability Standards	Lobach DF	Appl Clin Inform	10.1055/s-0042-1758736
*36480254	An Accessible Clinical Decision Support System to Curtail Anesthetic Greenhouse Gases in a Large Health Network: Implementation Study	Ramaswamy P	JMIR Perioper Med	10.2196/40831
36474257	Implementation-effectiveness trial of systematic family health history based risk assessment and impact on clinical disease prevention and surveillance activities	Wu RR	BMC Health Serv Res	10.1186/s12913-022-08879-2
36320200	Using a Knowledge-Based Clinical Decision Support System to Reduce the Time to Appropriate Antimicrobial Therapy in Hospitalized Patients With Bloodstream Infections: A Single-Center Observational Study	Chen CS	Open Forum Infect Dis	10.1093/ofid/ofac522
36264258	Distinct components of alert fatigue in physicians' responses to a noninterruptive clinical decision support alert	Murad DA	J Am Med Inform Assoc	10.1093/jamia/ocac191
36228116	Clinician adherence to pharmacogenomics prescribing recommendations in clinical decision support alerts	Nguyen JQ	J Am Med Inform Assoc	10.1093/jamia/ocac187
*36044925	Disappearing Help Text: Implementing a Note-Based Tool for In-Line Clinical Decision Support and Note Bloat Reduction	Chong AZ	Appl Clin Inform	10.1055/a-1934-8323
35785619	Clinical decision support analysis of a microRNA-based thyroid molecular classifier: A real-world, prospective and multicentre validation study	Santos MT	EBioMedicine	10.1016/j.ebiom.2022.104137
*35244165	Clinician collaboration to improve clinical decision support: the Clickbusters initiative	McCoy AB	J Am Med Inform Assoc	10.1093/jamia/ocac027

*Best paper finalist

Table 3 Selection of best papers for the 2023 IMIA Yearbook of Medical Informatics for the section Decision Support. The articles are listed in alphabetical order by the first author's surname.

Section
Decision Support
▪ Chong Z, Lee B, Hollenbach K, Kuelbs CL. Disappearing Help Text: Implementing a Note-Based Tool for In-Line Clinical Decision Support and Note Bloat Reduction. Appl Clin Inform 2022 Oct;13(5):1033-9. doi:10.1055/a-1934-8323.
▪ McCoy AB, Russo EM, Johnson KB, Addison B, Patel N, Wanderer JP, Mize DE, Jackson JG, Reese TJ, Littlejohn S, Patterson L, French T, Preston D, Rosenbury A, Valdez C, Nelson SC, Aher CV, Alrifai MW, Andrews J, Cobb C, Horst SN, Johnson DP, Knake LA, Lewis AA, Parks L, Parr SK, Patel P, Patterson BL, Smith CM, Suszter KD, Turer RW, Wilcox LJ, Wright AP, Wright A. Clinician collaboration to improve clinical decision support: the Clickbusters initiative. J Am Med Inform Assoc 2022;29(6): 1050-9. doi:10.1093/jamia/ocac027.
▪ Ramaswamy P, Shah A, Kothari R, Schloemerkemper N, Methangkool E, Aleck A,Shapiro A, Dayal R, Young C, Spinner J, Deibler C, Wang K, Robinowitz D, Gandhi S. An Accessible Clinical Decision Support System to Curtail Anesthetic Greenhouse Gases in a Large Health Network: Implementation Study. JMIR Perioper Med 2022;5(1): e40831. doi:10.2196/40831.

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1. Douthit BJ, McCo, A., Nelson SD. The Impact of Clinical Decision Support on Health Disparities and the Digital Divide. Yearb Med Inform 2023:169-78. doi: 10.1055/s-0043-1768722.
2. Lamy J-B, Séroussi B, Griffon N, Kerdelhué G, Jaulent M-C, Bouaud J. Toward a formalization of the process to select IMIA Yearbook best papers. Methods Inf Med 2015; 54:135-44. doi:10.3414/ME14-01-0031.
3. Borbolla D, Colicchio TK. Clinical Decision Support Systems: Contributions from 2021. Yearb Med Inform 2022;31:199–201. doi:10.1055/s-0042-1742528.
4. Ostropolets A, Zhang L, Hripcsak G. A scoping review of clinical decision support tools that generate new knowledge to support decision making in real time. J Am Med Inform Assoc 2020;27:1968–76. doi:10.1093/jamia/ocaa200.
5. Donabedian A. The quality of care. How can it be assessed? JAMA 1988 260:1743–8. doi:10.1001/jama.260.12.1743.
6. Atia J, Evison F, Gallier S, Pettler S, Garrick M, Ball S, et al. Effectiveness of clinical decision

support in controlling inappropriate red blood cell and platelet transfusions, speciality specific responses and behavioural change. BMC Med Inform Decis Mak 2022;22:342. doi:10.1186/s12911-022-02045-8.

7. Wu RR, Myers RA, Neuner J, McCarty C, Haller IV, Harry M, et al. Implementation-effectiveness trial of systematic family health history based risk assessment and impact on clinical disease prevention and surveillance activities. BMC Health Serv Res 2022;22:1486. doi:10.1186/s12913-022-08879-2.

8. Ramaswamy P, Shah A, Kothari R, Schloemerkemper N, Methangkool E, Aleck A, et al. An Accessible Clinical Decision Support System to Curtail Anesthetic Greenhouse Gases in a Large Health Network: Implementation Study. JMIR Perioper Med 2022;5:e40831. doi:10.2196/40831.

9. Chen C-S, Huang T-S, Lee SS-J, Chien F-C, Yan C-H, Li S-S, et al. Using a Knowledge-Based Clinical Decision Support System to Reduce the Time to Appropriate Antimicrobial Therapy in Hospitalized Patients With Bloodstream Infections: A Single-Center Observational Study. Open Forum Infect Dis 2022;9:ofac522. doi:10.1093/ofid/ofac522.

10. Aninanya GA, Williams JE, Williams A, Otupiri E, Howard N. Effects of computerized decision support on maternal and neonatal health-worker performance in the context of combined implementation with performance-based incentivisation in Upper East Region, Ghana: a qualitative study of professional perspectives. BMC Health Serv Res 2022;22:1581. doi:10.1186/s12913-022-08940-0.

11. Santos MT, Rodrigues BM, Shizukuda S, Oliveira AF, Oliveira M, Alves Figueiredo DL, et al. Clinical decision support analysis of a microRNA-based thyroid molecular classifier: A real-world, prospective and multicentre validation study. EBioMedicine 2022;82:104137. doi:10.1016/j.ebiom.2022.104137.

12. Lobach DF, Boxwala A, Kashyap N, Heaney-Huls K, Chiao AB, Rafter T, et al. Integrating a Patient Engagement App into an Electronic Health Record-Enabled Workflow Using Interoperability Standards. Appl Clin Inform 2022;13:1163–71. doi:10.1055/s-0042-1758736.

13. McCoy AB, Russo EM, Johnson KB, Addison B, Patel N, Wanderer JP, et al. Clinician collaboration to improve clinical decision support: the Clickbusters initiative. J Am Med Inform Assoc 2022;29:1050–9. doi:10.1093/jamia/ocac027.

14. Nguyen JQ, Crews KR, Moore BT, Kornegay NM, Baker DK, Hasan M, et al. Clinician adherence to pharmacogenomics prescribing recommendations in clinical decision support alerts. J Am Med Inform Assoc 2022;30:132–8. doi:10.1093/jamia/ocac187.

15. Murad DA, Tsugawa Y, Elashoff DA, Baldwin KM, Bell DS. Distinct components of alert fatigue in physicians' responses to a noninterruptive clinical decision support alert. J Am Med Inform Assoc 2023;30:64–72. doi:10.1093/jamia/ocac191.

16. Chong AZ, Lee B, Hollenbach K, Kuelbs CL. Disappearing Help Text: Implementing a Note-Based Tool for In-Line Clinical Decision Support and Note Bloat Reduction. Appl Clin Inform 2022;13:1033–9. doi:10.1055/a-1934-8323.

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Appendix: Content Summaries of Selected Best Papers for the 2023 IMIA Yearbook, Decision Support Section

McCoy AB, Russo EM, Johnson KB, Addison B, Patel N, Wanderer JP, Mize DE, Jackson JG, Reese TJ, Littlejohn S, Patterson L, French T, Preston D, Rosenbury A, Valdez C, Nelson SC, Aher CV, Alrifai MW, Andrews J, Cobb C, Horst SN, Johnson DP, Knake LA, Lewis AA, Parks L, Parr SK, Patel P, Patterson BL, Smith CM, Suszter KD, Turer RW, Wilcox LJ, Wright AP, Wright A

Clinician collaboration to improve clinical decision support: the Clickbusters initiative

The objective of the Clickbusters initiative, a single site study implemented at Vanderbilt University Medical Center (VUMC), was to optimize clinical decision support (CDS) alerts to enhance safety and care quality and to reduce clinician burnout. The authors developed a 10-step "clickbusting" process that included a training program, CDS alert inventory, oversight process, and incentives for participants. Two rounds of the Clickbusters program were conducted over a span of three months each and included a total of 24 participants who analyzed a total of 84 CDS alerts, leading to a modest reduction in the number of weekly alert firings. Additionally, the initiative increased engagement and participation of a diverse range of users in evaluation and optimization of CDS alerts, resulting in a culture of continuous improvement and enhancement of clinical content within electronic health record systems.

Ramaswamy P, Shah A, Kothari R, Schloemerkemper N, Methangkool E, Aleck A, Shapiro A, Dayal R, Young C, Spinner J, Deibler C, Wang K, Robinowitz D, Gandhi S

An Accessible Clinical Decision Support System to Curtail Anesthetic Greenhouse Gases in a Large Health Network: Implementation Study

This work addresses the environmental impact of inhaled anesthetics in healthcare facilities and presents a real-time clinical decision support (CDS) system aimed at reducing anesthetic gas waste. The study focuses on the implementation of the Fresh Gas Flow (FGF) CDS toolkit developed at the University of California San Francisco (UCSF) and its subsequent adoption at other medical campuses within the University of California Health network. The FGF CDS system was designed to alert anesthesia professionals when FGF rates exceeded 0.7 L per minute for common volatile anesthetics. The implementation process involved documentation and assembly of an informational toolkit to aid integration of the CDS system at other healthcare institutions. Educational and outreach presentations were utilized to disseminate information about the safety and environmental sustainability of low FGF use before implementation. The FGF CDS system was successfully deployed at five University of California Health network campuses, including four independent institutions. Each campus made modifications to the CDS tool to suit their specific needs, highlighting the adaptability of the technology and implementation framework described in the toolkit. The toolkit encompassed sustainability-focused education for anesthesia professionals, hardware integration, software build of the CDS system, and data reporting of measured outcomes. Overall, the implementation and transferability of the FGF CDS system using the toolkit demonstrated a reduction in anesthetic gas waste, leading to environmental and financial benefits.

Chong AZ, Lee B, Hollenbach K, Kuelbs CL

Disappearing Help Text: Implementing a Note-Based Tool for In-Line Clinical Decision Support and Note Bloat Reduction

This work sought to address the challenges of lengthy notes and poor note readability in electronic health records (EHRs) by creating an unobtrusive clinical decision support (CDS) tool named "disappearing help text." The tool was designed to provide in-line decision support on best documentation practices, note bloat reduction, billing compliance, and provider workflow enhancement of note templates in a pediatric hospital medicine setting. The authors implemented this tool in the EHR system and evaluated its impact on note quality, note length, and usage of automatic import of information from other parts of the EHR into notes. The study found that the median progress note length decreased by 18.7% and the median admission note length decreased by 6.4% after help text implementation. The authors also observed a decrease in the average number of coding queries sent to attendings and high pass rates on internal billing compliance audits. Overall, the study suggests that the "disappearing help text" tool can be an effective solution to the challenges of lengthy notes and poor note readability in EHRs, while also decreasing provider stress and burnout due to documentation burden.