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The Role of Clinical Decision Support Systems in Optimizing Anemia Management: A Systematic Review

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ABSTRACT

Background: One of the most potential methods to close the gap between the evidence and practice is through the use of Clinical Decision Support Systems (CDSS) for the patient suggestions for anemia identification and treatment. This study aims to identify, synthesize, and map systematic review of the effectiveness of Clinical Decision Support Systems (CDSS) for optimal anemia management.

Methods: This systematical assessment adhered to PRISMA regulations to investigate how efficient CDSS are in the management of anemia through the optimization of various healthcare settings. Numerous databased were navigated from May 2021 to December 2025 to find relevant studies. Study included 9 studies (randomized controlled trials, quasi, experimental, and observational studies) that met the criteria for inclusion.

Results: A total of 3517 articles were identified; following screening, 241 reviews underwent full-text screening, and 9 articles met the inclusion criteria and were included in this review. The analyzed studies revealed that CDSS involve in reflexive algorithms, guideline, based order sets, and AI models, have the potential to greatly raise the proper management of anemia, related laboratory test requests, lower the redundant testing and expenses, and increase the diagnostic accuracy.

Conclusion: CDSS is effective in achieving efficient anemia management through the provision of support for evidence, based decision making, facilitation of test appropriateness, and reduction in resource utilization. Integrating CDSS into a workflow is effortless and choosing strategies that will result in proper engagement of clinicians in appropriate anemia management.

KEYWORDS: Anemia, Artificial Intelligence, CDSS, Clinical Decision Support Systems, Diagnostic Accuracy, Management.

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INTRODUCTION

Anemia is the most common hematological disorder that affects the population in both developing and developed countries. Anemia adversely affects patient´s quality of life and is a condition associated with higher morbidity and mortality (Rodriguez-Borja et al., 2021). Furthermore, it is a common problem in primary care and generally constitutes an important challenge to health-care systems in terms of diagnosis and management (Garcia-Casal et al., 2023).

CDSS integrated with electronic health records represent a novel means for clinical practice to closely follow research findings by providing patient, specific recommendations in real time (Solomon et al., 2023). Such systems may, on their own, collect laboratory trends, past diagnoses, medications, and comorbidities, thus enabling the computer to anemia screening, etiologic work, up, iron deficit estimation, and individualized treatment planning (Miller et al., 2023). By making

it possible for complex decision pathways to be standardized and by prompting guideline concordant threshold adherence, CDSS can eventually lead to a decrease in the diagnostic delay, the ordering of inappropriate tests, and in the occurrence of transfusions that could be avoided, thus resulting in better patient outcomes and anemia management becoming less costly (Atia et al., 2022).

Recent research highlights that anemia interventions guided by CDSS can have a substantial positive impact both the processes of care and the clinical outcomes of the patients most at risk. In populations undergoing hemodialysis, the implementation of computerized anemia management systems as part of the regular workflow has been linked to the improvement of hemoglobin targets, the reduction of the failure rates of anemia management, and, eventually, the decrease of the risk of hospitalization when clinicians follow the system recommendations (Yang et al., 2023).In the same way, human, centered CDSS prototypes for iron deficiency anemia in children with inflammatory bowel disease and preoperative anemia decision tools have revealed that the proper design of alerts and the alignment of the workflow with the interface can lead to better screening, completion of diagnostics, and increased adherence to treatment algorithms based on the evidence (Miller et al., 2023).

The imprecision clinical decision support systems have in detecting anemia, as revealed by the Miller et al., 2023 study, is quite interesting. The study further suggests that this performance significantly depends on the system's design features, the environment where it is implemented, and the involvement of the end, users. Looking at the broader picture of CDSS evaluations, one can derive from the evidence that the effectiveness of the system depends largely on how well it is integrated with the order entry, the extent to which it promotes specific recommended actions, the degree to which it minimizes the extra data entry, and its alignment with the local workflows (Olakotan, and Mohd Yusof, 2021).Additionally, the new artificial, intelligencepowered tools and shareable digital care pathways for anemia put a greater emphasis on the necessity of comprehending how different technical approaches, different levels of automation, and different clinical settings can influence the performance, safety, and equity of anemia care (Olawade et al., 2025).

BACKGROUND

Anemia is a significant global public health challenge that has a complicated and multi, cause factor origin, which includes the lack of nutrients, chronic inflammation, infections, inherited blood disorders, and the reproductive biology of women (Mildon et al., 2023). The worldwide figures based on the Global Burden of Disease Study 2021 reveal that approximately one, fourth of the global population is anemic, and the most considerable prevalence and years lived with disability i.e., women of reproductive age, children under five, and the people from low and middleincome countries (Dongarwar, 2023). Anemia has been hanging as a major public health problem which mainly targets young children, pregnant and postpartum women, and menstruating adolescent girls and women. The global situation is such that it has been predicted that 40% of all children aged 6-59 months, 37% of pregnant women and 30% of women 15-49 years of age will be affected by anemia (Who, 2025).

Anemia evaluation and treatment from a clinical view are very complicated due to the fact that they need the doctor to interpret a variety of laboratory indices, clinical comorbidities, and contextual factors in order to figure out whether it is iron deficiency anemia, anemia of inflammation, renal anemia, or the other causes (Williams et al., 2023). In a hectic real, world environment, clinicians might find it difficult to always implement detailed diagnostic algorithms and guideline, recommended treatment thresholds, which in turn may result in incorrectly identifying the type of anemia, instances of iron therapy and erythropoiesis, stimulating agents being both under, used and over, used as well as wrongly decided transfusions (Patel et al., 2020; Iolascon et al., 2024). The difficulties here are the reasons for the existing discrepancies between the recommendations based on the evidence and the real practices, thus, giving further support to the need for informatics solutions as a means of facilitating more uniform and timely decision, making in anemia care (Mildon et al., 2023).

Clinical decision support systems (CDSS) and other artificial intelligence (AI) based tools have been identified as viable options to strategically implement complex anemia management pathways through electronic health records and other digital platforms (Ohara et al., 2021). One example is the rule, based decision support system for iron deficiency anemia and AI, supported anemia control systems like the Artificial Intelligence Supported Anemia Control System (AISACS) that have shown positive effects on hemoglobin stability, erythropoiesis, stimulating agent dosing, and the achievement of guideline, recommended hemoglobin targets in patients with chronic kidney disease on hemodialysis (Brier, Gaweda, and Aronoff, 2022).Additionally, the overall impact of such systems on medication management has been investigated. The results suggest that properly designed CDSS can improve prescribing quality, diminish medication, related incidents, and foster the enhancement of certain patient outcomes, thus indicating the potential utility of analogous methods when specifically directed towards blood disorders (Taheri Moghadam et al., 2021).

More recently, machine, learning and deep, learning models of the most advanced kind have been developed as components of CDSS to support screening, diagnosis, and treatment of anemia based on clinical and laboratory data that are routinely collected. Some of the examples are automated anemia classification systems that have been constructed on supervised

learning, an attention, based architecture such as the GRU, attention "GAM" model for optimizing anemia management and transfusion alerts in chronic dialysis, as well as predictive models for transfusion needs in diverse hospital populations (Olawade et al., 2025). These AI, powered CDSS strategies have exhibited impressive effectiveness in predicting hemoglobin trajectories, issuing recommendations for erythropoiesis, stimulating agent and iron dosages, and identifying patients who are at a high risk of anemia, which indicates that they may be able to support the judgment of clinicians and contribute to the safety and the efficiency of anemia management (Ramzan et al., 2024).

METHODS

Aims

This review is meant to systematically assess just how much Clinical Decision Support Systems (CDSS) can be helpful in managing anemia properly in various healthcare settings. The main emphasis is put on scenarios where the use of CDSS tools is recommended to clinicians for aiding them in diagnosis, picking up the right treatments, monitoring, and follow, up care of anemic patients. The extra purposes are to depict the operational components, the ways of integration, and the frameworks of implementation of these CDSS and to figure out which system parameters and features (like alert types, recommendation specificity, integration with electronic health records) are most strongly correlated with improvements in clinical process measures (such as guideline adherence, appropriate testing, and correct prescription rates) and patient outcomes (including hemoglobin level enhancement, anemia correction rates, and reduced complications).

Design

A comprehensive review was made with reference to the guidelines and the data capture template given in the newest version of the Cochrane Handbook for Systematic Reviews of Interventions (6.0). According to Page et al. (2021) the PRISMA statement served as the main framework for this evaluation and it was recorded in PROSPERO with the ID: CRD42021262081. We want to answer the following question: Are Clinical Decision Support Systems (CDSS) able to improve the effectiveness and quality of anemia management in hospitals?

Search methods

A search for pertinent literature was performed from May 2021 to December 2025 using the outlined keywords on PubMed, Scopus, Cochrane Library, Web of Science, CINAHL, and ProQuest: Just type in " "clinical decision support systems", "CDSS", "decision support", "anemia", "anemia", "management", "treatment", and "diagnosis". to find that information. Language filters were limited to English. The reference lists of all the included studies and the relevant systematic reviews were checked to obtain more publications. Besides that, grey literature sources like clinical trial registries (ClinicalTrials.gov) and conference proceedings were also consulted. A comprehensive search strategy was developed with the help of a specialized health informatics librarian. The complete search strategy for PubMed is shown in **Table 1.**

Table 1: Literature search strategy

Database	Date Searched	Results	Query
PubMed	8/15/2025	663	(“clinical decision support systems” OR “CDSS” OR “decision support”) AND (“anemia” OR “anemia”) AND (management OR treatment OR diagnosis) Filters: full text free – Human Languages: English.
Web of Science	15/12/2025	3829	(“clinical decision support systems” OR “CDSS”) AND anemia AND (management OR treatment OR diagnosis) Filters: full text free – Human Languages: English.
Embase	16/12/2025	2059	Search (clinical decision support systems OR CDSS OR decision support) AND (anemia OR anaemia) AND TS=(management OR diagnosis) Filters: full text free – Human Languages: English.
Cochrane Library	18/12/2025	819	Search (clinical decision support systems OR decision support) in Title/Abstract/Keywords AND (anemia OR anaemia) Filters: full text free – Human Languages: English.
CINAHL	18/12/2025	36	Search (“Decision Support Systems, Clinical”) AND (“Anemia+”) AND (management OR treatment OR diagnosis) Filters: full text free – Human Languages: English.

Inclusion criteria and study selection

This systematic review identified relevant studies based on the following criteria pertaining to study design, population, intervention, and outcomes:

Inclusion Criteria:
Study Design: Randomized Controlled Trials (RCTs), Human-centered design (HCD), retrospective, and prospective studies.
Population: Patients of any age or gender with a diagnosis of anemia (of any etiology) managed in a clinical setting (primary, secondary, or tertiary care).
Intervention: Implementation or use of a Clinical Decision Support System (CDSS) specifically designed to aid in anemia management. Eligible CDSS interventions included, but were not limited to:

- Systems provide diagnostic suggestions or alerts for anemia.
- Tools offering recommendations for laboratory testing or interpretation.
- Systems guiding treatment selection (e.g., iron supplementation, erythropoiesis-stimulating agents).
- Alerts for medication dosing, drug interactions, or follow-up scheduling.
- Integrated management algorithms for specific anemias.
- Comparator: Usual care (without CDSS) or an alternative CDSS/decision aid.

Outcomes: Primary outcomes included measures of clinical process improvement (e.g., adherence to management guidelines, appropriate test ordering, correct treatment initiation) and patient health outcomes (e.g., improvement in hemoglobin levels, time to anemia correction, reduction in complication rates). Secondary outcomes included user acceptance, system usability, and cost-effectiveness metrics.

Exclusion Criteria:
Studies were excluded if they were review articles, editorials, commentaries, or protocols; or were published in a language other than English. Studies where the CDSS intervention was not the primary component of the management strategy were also excluded.

Search outcomes
Three authors (1, 3, and 7) independently extracted data based on the inclusion and exclusion criteria, then verifying and comparing their findings. The gathered data was compiled utilizing Microsoft Excel (version 16.0).

The subsequent criteria were employed to gather data from each study: authors' names, country, participants, sample size, intervention/control groups, follow-up time, measurement instruments, and outcomes. The data extraction form was standardized. The articles employed in this assessment were systematically organized and handled with Rayyan software.

With this approach, 7406 articles were located (Fig. 1) In the initial step, we evaluated each article's abstract and title to weed out duplicates and ones that didn't align with our study's purpose. The remaining 240 publications were culled for 231 reasons: 102 for a lack of data, 13 for not being applicable to a home setting, 110 for inconsistent phenomena of interest, and 6 for not being relevant to a patient group. Hence, nine articles were considered for this evaluation.

Quality appraisal and data extraction
Lockwood et al. (2020) employed the Joanna Briggs Institute's critical analysis tools for quality assessment. We selected these resources because the checklists provide comprehensive guidance on responding to each question. This instrument can enhance nursing research due to its superior evaluative capabilities and comparative analysis with analogous tools (Jbi-global-wiki, 2024).

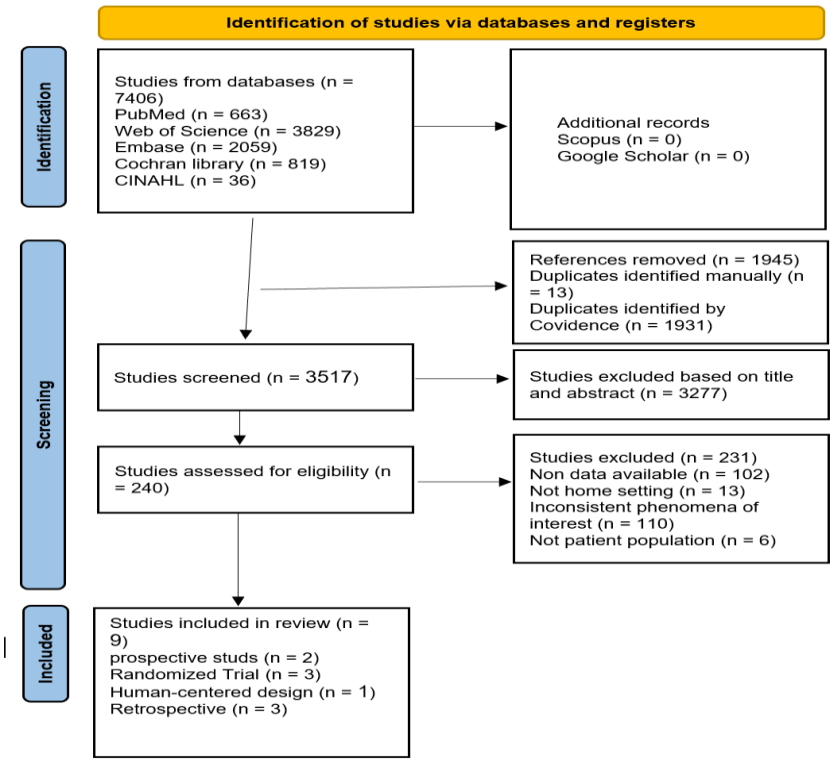

Fig. 1 PRISMA article selection flowchart

Synthesis

The data extracted from the included studies were organized into Table 2 (Review Matrix), which summarizes the following elements for each intervention: authors, aim of the study, target population and clinical setting, study design, duration, type of clinical decision support system, anemia-related outcomes, and main findings. Although the studies addressed broadly similar aspects of anemia management and often targeted comparable clinical decisions (diagnostic work-up, iron/ESA therapy, or transfusion practice), there was substantial heterogeneity in populations, CDSS architectures, implementation strategies, and outcome measures. This variability made a pooled meta-analysis inappropriate, and therefore the effects of clinical decision support systems on anemia management are presented in a narrative format.

RESULTS

After the selection procedure, nine studies were identified, which outlined the criteria for inclusion in this review: Four trials of clinical decision support systems (CDSS) in primary care or hospital settings focused on laboratory test ordering or general clinical recommendations. Three studies examined the use of anemiaspecific CDSS or AI tools in preoperative, nephrology, or inflammatory bowel disease (IBD) settings. One study implemented a patient blood management (PBM) program with a CDSS in a resourceconstrained environment. One observational study examined the quality of life related to anemia in myelodysplastic syndrome (MDS) patients (RodriguezBorja et al., 2021; Delvaux et al., 2020; Moja et al., 2019; Duarte et al., 2022; Haring et al., 2023; Kang et al., 2024; Yang et al., 2023; Mignanelli et al., 2023; Miller et al., 2023).

They cover a wide range of clinical settings and include studies done in primary care practices, internal medicine wards, hematology/oncology services, hemodialysis units, perioperative services, and pediatric gastroenterology clinics (Delvaux et al., 2020; Moja et al., 2019; Yang et al., 2023; Mignanelli et al., 2023; Miller et al., 2023).

Table2: Literature Review Matrix

Author (Year) / Country	Purpose	Participants	Design	Duration	Control Intervention	Intervention	Outcomes	Findings
Rodriguez-Borja et al. (2021) / Spain	To implement a computerized Decision Support System (DSS) with reflexive algorithms and automatic interpretative reports for anaemia diagnosis in primary care patients, measure its impact on test ordering and cost savings, and assess its clinical usefulness for establishing proper treatments.	Primary care patients from a catchment area of approximately 360,000 people in Valencia, Spain. The study analyzed data from 1994 "Anaemia Suspicion" studies, 10,026 "Microcytic Anaemia Follow Up" studies, and 745 "Normo/Macrocytic Anaemia Follow Up" studies, resulting in 240 positive anaemia cases determined.	Prospective cohort study with a pre-post intervention design.	2 years (January 2018 to December 2019), divided into a 6-month pre-intervention phase (January-June 2018) and a 6-month post-intervention phase (July-December 2019) following one year of algorithm implementation.	Usual care or "Phase PRE" (pre-intervention phase) where general practitioners often ordered "every possible anaemia related test" using a non-sequential "shotgun" approach.	Implementation of a "Decision Support System" via the laboratory information system (LIMS) and computer physician order entry (CPOE). This included new clinical profiles for anaemia diagnosis, reflexive algorithms (activating >20 rules) to add further tests based on laboratory results, and automatic generation of interpretative reports (always reviewed by two staff pathologists).	Demand for specific anaemia-related tests (total iron, transferrin, ferritin, folate, vitamin B12, and the three clinical profiles), laboratory costs associated with these tests, consultation rate of laboratory reports by GPs, and rate of proper treatment establishment based on interpretive reports.	Facilitated enhancements in patient outcomes by providing counsel on specific clinical cases. Furthermore, it significantly diminished the frequency of excessive test requests and laboratory expenses.
Delvaux et al. (2020) / Belgium	To evaluate the effects of an intervention that integrated a clinical decision support service into a computerized physician order	280 general practitioners (GPs) from 72 primary care practices and 9683 patients aged ">=" 18 years with a laboratory test order for at least one of 17 indications.	Pragmatic, cluster randomized, open label, controlled clinical trial.	7 months (December 2017 to June 2018)	GPs ordered laboratory tests as usual through a computerized physician order entry (CPOE), recording indications but without receiving	A Clinical Decision Support System (CDSS) integrated into a computerized physician order entry (CPOE) in the form of evidence-based	Primary outcome: Proportion of appropriate tests over the total number of ordered tests and inappropriately not-requested tests. Secondary	A Clinical Decision Support System (CDSS) utilizing order sets, integrated within the Computerized Physician Order Entry (CPOE),

Author (Year) / Country	Purpose	Participants	Design	Duration	Control Intervention	Intervention	Outcomes	Findings
	entry (CPOE) on the appropriateness and volume of laboratory test ordering, and on diagnostic error in primary care.				suggestions from a Clinical Decision Support System (CDSS).	order sets that suggested appropriate tests based on the indication provided by the general physician.	outcomes: Diagnostic error, test volume, and cascade activities.	enhanced appropriateness and reduced the volume of laboratory test orders without elevating diagnostic errors.
Moja et al. (2019) / Italy	To assess the effectiveness of a computerized clinical decision support system (CDSS) that preappraises evidence and provides health professionals with actionable, patient-specific recommendations at the point of care.	6480 patients (3242 to CDSS and 3238 to control) admitted to internal medicine wards of a large Italian general hospital. Mean age was 70.5 (17.3) years, and 54.5% were men.	Open-label, parallel-group, randomized clinical trial.	14 months (November 1, 2015, to December 31, 2016) for data collection. Data analyzed between February 1 and July 31, 2018.	Reminders were generated but not shown to physicians. Therapeutic-specific and diagnosis-specific links to full-text guidelines were available, representing modestly enhanced usual care.	Evidence-Based Medicine Electronic Decision Support (EBMEDS), a commercial CDSS integrated into the hospital electronic health records, displayed patient-specific recommendations (reminders) to physicians.	Primary outcome: resolution rate (rate at which medical problems identified by CDSS were addressed by a change in practice). Secondary outcomes: length of hospital stay, in-hospital all-cause mortality, mortality at 30 and 90 days after discharge, and in-hospital morbidity for VTE-related causes.	An worldwide commercial CDSS intervention had a modest impact on routine practice in a general hospital, however the change did not statistically significantly improve patient outcomes.
Duarte et al. (2022) / Brazil	To assess the feasibility and effectiveness of an adapted Clinical Decision Support (CDS) system for low-income countries and to evaluate the implementation of a Patient Blood	Patients from a 200-bed tertiary hospital in Brazil requiring blood transfusions. The study analyzed 3,607 transfusion requests (7,833 blood units) in the pre-intervention period and 4,555 transfusion requests (9,790 blood units,	Prospective study comparing outcomes before (pre-PBM era) and after (post-PBM era) the implementation of a Patient Blood Management	Pre-intervention period: January 2018 to January 2019. Intervention period: February 2019 to May 2020 (16 months).	Standard practice involving mandatory transfusion request data entry into blood bank software without systematic pre-transfusion auditing.	Implementation of a Patient Blood Management (PBM) program, including an institution-validated blood transfusion guideline integrated into blood bank software,	Red blood cell (RBC), fresh frozen plasma (FFP), and platelet unit transfusions; transfusion of a single unit of red blood cells; Red Blood Cell Adequacy Index (RAI); product acquisition-related	The PBM programs, which encompass electronic transfusion guidelines and pretransfusion medical auditing, were linked to enhanced transfusion practices and

Author (Year) / Country	Purpose	Participants	Design	Duration	Control Intervention	Intervention	Outcomes	Findings
	Management (PBM) program using this CDS system.	3,131 RBC units) in the intervention period.	program.			concurrent pre-transfusion physician analysis for inadequate requests, and discussion with prescribing physicians.	costs.	decreased product purchase costs.
Haring et al. (2023) / Israel	To study the Quality of Life (QoL) at various degrees of anemia in lower-risk Myelodysplastic Syndromes (MDS) patients, compare it with non-MDS controls, and assess QoL at MDS diagnosis versus 1 year later, focusing on the correlation with hemoglobin (Hb) levels.	127 lower-risk Myelodysplastic Syndromes (LR-MDS) patients (mean age 74.9 years, range 36-91) categorized by Hb levels (normal, mild, moderate, severe, very severe anemia). A control group of 141 non-MDS patients (aged > 60 years) admitted to a hospital department was also included.	Retrospective, real-world, non-interventional study using data from the Israel National MDS Registry. QoL data collected at presentation and every 6 months.	1 year follow-up (QoL surveys filled every 6 months).	No specific intervention; served as a comparison group for QoL scores (non-MDS patients admitted to a hospital department).	Not applicable; this was an observational, non-interventional study. Changes in Hb levels observed were likely due to existing treatments, not a study intervention.	Quality of Life (QoL) assessed by EQ-5D questionnaire (parameters: mobility, self-care, daily activities, pain/discomfort, anxiety/depression) and Visual Analogue Scale (VAS) (general health status). Hemoglobin (Hb) level was also measured.	The suboptimal quality of life in MDS-anemia is non-linear, indicating the presence of other factors affecting quality of life.The significant decline in quality of life with hemoglobin levels below 9 g/dL raises questions regarding the transfusion hemoglobin threshold.The quality of life in anemic MDS patients may differ from that of non-MDS patients.Elevating hemoglobin levels, however advised, does not ensure an

Author (Year) / Country	Purpose	Participants	Design	Duration	Control Intervention	Intervention	Outcomes	Findings
								enhancement in quality of life.
Kang et al. (2024) / Republic of Korea	To optimize anemia management in patients undergoing hemodialysis using an AI model (GAM) for Hb level prediction, ESA dose recommendation, and red blood cell transfusion alerts.	252 patients aged ">= 18 years" undergoing hemodialysis. Data collected from Kangwon National University Hospital (2017-2022).	Retrospective observational study that developed and validated a Gated Recurrent Unit-Attention-Based Module (GAM) AI model.	Data collected over approximately 6 years (2017-2022).	Comparison with traditional machine learning models (linear regression, XGBoost, multilayer perceptron), other deep learning models (LSTM, GRU architectures), and clinical experts for ESA dose recommendations.	A Gated Recurrent Unit-Attention-based Module (GAM) artificial intelligence model designed for (1) predicting Hb levels, (2) recommending ESA doses (more, similar, less), and (3) providing red blood cell transfusion alerts (necessary, non-necessary).	Hb level prediction (measured by R-squared, MSE, RMSE, MAE), ESA dose recommendation (classified into 'more', 'similar', 'less' and measured by Precision, Recall, F1-score, Accuracy), and transfusion alert (classified into 'necessary', 'non-necessary' and measured by Precision, Recall, F1-score, Accuracy).	The GAM model attained an R-squared value of 0.60 for predicting Hb levels, surpassing conventional machine learning and other deep learning methods. For ESA dose recommendation, GAM attained an overall accuracy of 0.78, markedly surpassing the baseline. For transfusion alarms, GAM attained an overall accuracy of 0.99, with a recall of 0.98 for 'required' transfusions, demonstrating proficient recognition of essential circumstances. The model demonstrates potential for optimizing ESA dosages and

Author (Year) / Country	Purpose	Participants	Design	Duration	Control Intervention	Intervention	Outcomes	Findings
								delivering prompt transfusion alerts in patients with end-stage kidney disease (ESKD).
Yang et al. (2023) / Taiwan	To investigate whether physician compliance was an intermediate variable between the CDSS and the management outcomes of renal anemia.	717 eligible patients on hemodialysis (mean age 62.9, SD 11.6 years; male n=430, 59.9%).	Retrospective Electronic Health Record Observational Study. Data divided into pre-CDSS (2016-2018) and post-CDSS (2020) phases. Random intercept mixed models were used for comparison.	4 years (2016 to 2020) for data collection; pre-CDSS phase (2016-2018), post-CDSS phase (2020).	The 'pre-CDSS phase' (2016-2018) without the computerized clinical decision support system.	Implementation of a rule-based Computerized Clinical Decision Support System (CDSS) for the management of renal anemia and iron supplements, which provides recommended doses of ESA and iron supplements for physicians' consideration (implemented in 2019).	Absolute hemoglobin (Hb) level, on-target rate (Hb 10-12 g/dL), failure rate (Hb <10 g/dL), weekly ESA dosage, ESA prescription change rate, and CDSS concordance rate (physician compliance).	Physician compliance served as a significant intermediary element influencing the efficacy of the Clinical Decision Support System (CDSS). The Clinical Decision Support System diminished failure rates in anemia care by enhancing physician adherence.The study underscores the necessity of enhancing physician adherence in the design and execution of Clinical Decision Support Systems (CDSSs) to elevate patient outcomes.
Mignanelli et al. (2023) /	To evaluate anesthesiologists' baseline	763 French-speaking anesthesiologists	Randomized controlled web-based survey	Survey completion time (mean 10.2	Anesthesiologists answering the survey questions	Anesthesiologists answering the survey questions	Correct response rate to survey questions, total	Management options for optimizing

Author (Year) / Country	Purpose	Participants	Design	Duration	Control Intervention	Intervention	Outcomes	Findings
France	knowledge of preoperative anemia optimization and to determine the impact of real-time clinical decision support on anemia management.	(senior physicians, fellows, and residents) who fully completed the survey, out of 1123 enrolled.	study with simulated case vignettes.	minutes for decision support group, 7.8 minutes for control group). Recruitment occurred over at least 2 months.	without any real-time clinical decision support or cognitive aid.	with real-time clinical decision support (cognitive assistance providing current recommendations on anemia management, visible if an error was made, allowing participants to change their answer).	score out of 12, and mean duration of response.	preoperative anemia are inadequately understood and implemented by anesthesiologists in routine practice, despite their clinical significance. Nonetheless, using a decision support tool can substantially enhance patient care by alerting practitioners to current recommendations.
Miller et al. (2023) / USA	To use human-centered design (HCD) methods to evaluate baseline care practices and inform the iterative design of a Clinical Decision Support System (CDSS) called the IBD Anemia Diagnosis Tool (IADx) for improving iron deficiency anemia (IDA)	Six clinicians (providers) participated in total across two rounds of testing (3 per round). Participants included attendings, fellows, and a nurse practitioner, recruited via email using purposive sampling.	Human-centered design (HCD) approach including semi-structured interviews for process mapping, iterative prototyping, and simulation-based usability evaluation. Evaluation methods included a 'Think Aloud'	Not reported for the overall study duration. The prototype design involved eight 30-minute design sessions, and usability evaluation was conducted in two rounds.	No formal control group was used in this HCD and usability evaluation study. The intervention was designed to improve upon existing baseline care practices for anemia screening and treatment in children with IBD.	The IBD Anemia Diagnosis Tool (IADx), a Clinical Decision Support System (CDSS) embedded in an Electronic Health Record (EHR). It involved an interruptive alert with a linked order set, preselected laboratory and iron orders, patient instructions,	Usability (measured by System Usability Scale (SUS) scores, task completion, perceived difficulty rates), user feedback on usability dimensions (visibility, workflow, content, understandability, practical usefulness, medical usefulness, navigation), and alignment with	Providers favored an interruptive alert, possibly due to the minimal probability of noticing a non-interruptive advisory.Elevated levels of demand for the automation of information collecting and processing, coupled with reduced automation in decision selection and action, may be

Author (Year) / Country	Purpose	Participants	Design	Duration	Control Intervention	Intervention	Outcomes	Findings
	care in children with inflammatory bowel disease (IBD).		technique, direct observation of task difficulty, System Usability Scale (SUS) surveys, and semi-structured interviews. The study involved two rounds of iterative redesign.			laboratory trends, normal ranges, auto-calculation of intravenous (IV) iron treatment dose, and iron prescription data.	human factors principles.	applicable to other Clinical Decision Support Systems (CDSS) intended for chronic disease management.This emphasizes how CDSSs can enhance rather than supplant provider cognitive efforts.

Significance of CDSSs in promoting diagnostic accuracy

The research into the different CDSS interventions revealed that the use of a structured, guideline, driven system can actually help to improve the diagnostic accuracy of anemia by not only directing the appropriate selection of tests but also helping with the interpretation while at the same time, the system is designed in such a way that it is hardly possible for a missed diagnosis to occur (Delvaux et al., 2020; RodriguezBorja et al., 2021). In the ELMO trial, doctors were able to use CDSS, supported order sets to cut down on the number of inappropriate and unnecessary laboratory tests without the risk of diagnostic error being increased, thus, the more focused testing did not lead to the loss of diagnoses or delayed diagnoses (Delvaux et al., 2020). Likewise, the reflexive algorithm system set up by RodriguezBorja et al. not only facilitates the addition of targeted followup assays but also allows the generation of expertvalidated interpretive comments, thus enabling the accurate etiologic classification of anemia while at the same time, greatly reducing the overrequest of ironrelated tests (RodriguezBorja et al., 2021).

The future AI-based models also demonstrate the possibility of sophisticated AI algorithms to aid in accurate diagnosis of anemia and distinguish between subtypes, with high accuracy, sensitivity, and precision, in case of properly curated hematological data, being trained (Kang et al., 2024). Simultaneously, it has also been demonstrated that anemia management in hemodialysis units, guided by a CDSS, can lead to a lower rate of failure in reaching target hemoglobin ranges, and physician concordance mediates the relationship between CDSS recommendations and a positive change in anemia management, thus supporting the role of decision support, accurate interpretation, and clinical-correct dosing decision making (Yang et al., 2023).

Characteristics of CDSS and AI interventions

Most interventions consisted of electronic CDSS modules integrated into computerized physician order entry (CPOE) or electronic health records (EHR), delivering evidence-based order sets, automated reflex algorithms, reminders, and context-specific interpretive comments (Rodriguez-Borja et al., 2021; Delvaux et al., 2020; Moja et al., 2019). In primary care, Delvaux et al. implemented the ELMO order-set-based CDSS, which suggested appropriate laboratory tests for specific clinical indications, whereas Rodriguez-Borja et al. embedded reflexive algorithms in the laboratory information system to automatically perform follow-up anemia tests and generate hematologist-validated interpretive comments for “Anaemia Suspicion” profiles (Rodriguez-Borja et al., 2021; Delvaux et al., 2020). In a hospital internal-medicine setting, Moja et al. evaluated the EBMEDS CDSS, which produced patient-specific reminders derived from pre-appraised guideline evidence for medications and comorbidities, including anemia-related issues (Moja et al., 2019).

Other interventions focused on different anemia, related decisions or scenarios. Mignanelli et al. (2023) evaluated a real, time decision support module in perioperative anemia management by anesthesiologists randomly being provided or not provided brief guideline, based recommendations when responding to simulated clinical vignettes (Mignanelli et al., 2023). The study by Yang et al. (2023) described a CDSS integrated with a hemodialysis EHR, which suggested the adjustment of erythropoiesis, stimulating agent (ESA) doses and hemoglobin (Hb) targets (10-12 g/dL) for patients with end, stage kidney disease. Then, they measured the physicians' compliance with those recommendations (Yang et al., 2023). Miller et al. (2023) employed human, centered design to develop the IBD Anemia Diagnosis Tool (IADx) by documenting current workflows and designing a prototype that automated data aggregation (e.g., labs, iron studies) while keeping ordering and treatment as the clinicians (Miller et al., 2023).

Besides that, Duarte et al. (2022) described the initiation of a PBM program based on the use of a CDSS adapted to a low-income environment, which ordered transfusions and anemia-related interventions, and Kang et al. created an AI model that optimized anemia management in hemodialysis and claimed that the structured approach to Hb and ESA dosing was more efficient than the traditional ones (Duarte et al., 2022; Kang et al., 2024). Haring et al. (2023) provided contextual evidence by showing that MDS-related anemia severely affects health related to quality of life, and that any change in Hb did not equally correlate with a similar change in patient-reported outcome (Haring et al., 2023).

Effects on test ordering, appropriateness, and costs

Primary care CDSS trials have consistently shown that decision support can lead to more appropriate ordering of laboratory panels while also cutting down on unnecessary testing and related activities, all without an increase in diagnostic errors (Delvaux et al., 2020). In the ELMO cluster randomized trial, the proportion of appropriate tests per panel increased by 0.21 (95% CI 0.160-.26) in the intervention arm, and general practitioners ordered approximately seven fewer tests per panel than the control group, with no statistically significant increase in possible diagnostic errors (Delvaux et al., 2020). A later analysis revealed that CDSS assisted testing led to fewer downstream activities such as additional imaging, referrals, and treatment changes, which suggests that more targeted test ordering may be a means of avoiding the cascade of unnecessary activities (Delvaux et al., 2020).

The reflex algorithm system described by Rodriguez-Borja et al. (2021) also had a significant influence on test utilization and costs (Rodriguez-Borja et al., 2021). In an analysis of nearly 2, 000 "Anaemia Suspicion" requests and more than 10, 000 follow-up profiles, only around 12% of the initial suspicion profiles turned out to be positive for anemia, however, the automatic rules resulted in very significant reductions in ferritin, transferrin, total iron, folate, and vitamin B12 lab requests, thus the cost of these tests was estimated to be reduced by 40% (Rodriguez-Borja et al., 2021). Among other things, it was reported in the study that appropriate treatment was set up in 88% of the anemic patients, which therefore confirms the idea that reflexive testing together with interpretive comments were sufficient for accurate diagnosis and management (Rodriguez-Borja et al., 2021).

DISCUSSION

Overall, the evidence suggests that both CDSS and AI tools can make the diagnostic work-ups of anemia more appropriate and efficient; reduce unjustified laboratory use; and enhance the knowledge of clinicians, especially in the primary care and

perioperative areas (Rodriguez-Borja et al., 2021; Delvaux et al., 2020; Mignanelli et al., 2023). It seems that the use of reflex algorithms and guideline-driven order sets integrated in CPOE and LIMS is particularly effective in preventing shotgun anemia testing, and consequently in maintaining the accuracy of the diagnostic process as well as in prompting the timely treatment choice, which is exceptionally pertinent to resource-limited systems (Rodriguez-Borja et al., 2021; Delvaux et al., 2020).

Nevertheless, the specialty-care and hospital experiments also highlight the fact that the better processes do not necessarily lead to significant, quantifiable mortality or other hard-end point improvements, especially when clinician interactions with CDSS are inefficient (Moja et al., 2019; Yang et al., 2023). Such elements as alert fatigue, irrelevance of some of the reminders, and lack of integration into the workflow can decrease the compliance with the CDSS recommendations and thus diminish the influence on patient outcomes, which is also consistent across the wider range of CDSS literature (Moja et al., 2019; Yang et al., 2023). The fact that the relationship between the use of CDSS and anemia control is entirely mediated by physician compliance, as found by Yang et al. (2023), indicates strongly that the involvement of the organization in supporting the use of such algorithms via training, feedback, and local champions is of equal significance to the technical functionality of the algorithms in question (Yang et al., 2023).

According to the perioperative and human-focused design investigations, the usability, context, and preferences of clinicians play a crucial role in designing the effectiveness of CDSS (Mignanelli et al., 2023; Miller et al., 2023). In simulated perioperative situations, brief, context-specific prompts that comply with the existing anemia guidelines can quickly enhance the quality of decisions made, whereas systems that assist in data collection and interpretation, but leave decision-making to human operators can be more favorable to clinicians (IADx, 2023; Miller et al., 2023). These results endorse the adoption of hybrid, shared-control CDSS models, which integrate both automation and clinician control, which could contribute to better levels of trust, minimize alert fatigue, and increase uptake over time (Miller et al., 2023).

Implications for nursing

The results denote the central position of nurses as frontline users and co-designers of CDSSs and AI solutions to anemia, especially in an environment where they organise laboratory testing, patient education, and follow-up of abnormal findings (Miller et al., 2023; Delvaux et al., 2020). Since the unnecessary tests are minimized, and the diagnostic error rate does not rise with the implementation of the CDSS-guided order sets and reflex algorithms, nurses working in primary care and in the outpatient clinics can utilize the systems to simplify the work-up of anemia, prioritize the high-value tests, and provide patients with the rationale of why more focused tests are necessary, which ultimately results in better efficiency and patient comprehension (Delvaux et al., 2020; Rodriguez-Borja et al., 2021).

In expert care, like hemodialysis and perioperative clinics, nurses have a central role in tracking the trends of hemoglobin levels, iron and ESA treatment, and the preparation of patients for surgical operations, which makes them the primary user of the CDSS recommendations and non-adherence or alert fatigue of prescribers (Yang et al., 2023; Mignanelli et al., 2023). The participation of nurses in the design and implementation of the CDSS, including workflow mapping, usability testing, and feedback loops, can contribute to the enhancement of the system acceptability, decrease the interruptive burden, and make sure that alerts support instead of hinder the provision of holistic and patient-centered anemia care (Miller et al., 2023).

Limitations

The findings presented in this systematic review are limited in a number of ways, which should be taken into account when interpreting them. The studies included were few (only nine in total), and done in dissimilar clinical settings, with various populations, CDSS designs, and outcome measure, hence making it impossible to perform a meta-analysis and restricting the power of pooled explanations. The majority of interventions were assessed in high-income or well-resourced settings with the few representations of low- and middle-income settings which decrease the applicability of the findings to the health systems with resource constraints. Some of them involved quasi-experimental or observational designs, were vulnerable to bias, or did not provide complete information on implementation procedures and user adoption, among other reasons, which made it challenging to pinpoint the effects to the CDSS interventions. Moreover, inconsistencies in reporting about the results of usability, cost-effectiveness, and long-term sustainability limited the possibility of determining the extent to which such systems are acceptable, scalable, and durable in the common practice. Lastly, the search period might not fully reflect the changes in artificial-intelligence based tools and more recent CDSS platforms and thus the review might be underrepresenting the contribution of the latest technologies or their capabilities.

CONCLUSION

To sum up, this systematic review of evidence suggests that Clinical Decision Support Systems have the potential to optimize anemia management by three main ways: improving adherence to evidence, based recommendations, regulating laboratory test ordering, and guiding treatment decisions more appropriately in a variety of clinical settings. Several studies showed that CDSS interventions, especially when closely linked to electronic health records and order entry workflows, led to better hemoglobin target achievement, less unnecessary testing, and more efficient use of therapies and transfusions.Yet, the advantages were not consistent, and the performance of CDSS was highly influenced by factors like system design, alert logic, workflow integration, local context, and clinician engagement, thus pointing towards the necessity of human, centered design and strong implementation strategies. There has to be a focus in future research on quality trials and implementation studies that assess usability, cost, effectiveness, equity, and long, term sustainability. Moreover, they should investigate the use of advanced AI, enabled decision support that is specific to different anemia etiologies and healthcare settings.

Authors' contributions
Naif, and Norah collaborated on the study title and protocol, Abeer completed the search strategy, reviewed by Rahaf, Hanan, and Rawan handled screening, quality appraisal, and data extraction, supervised by Naif, Shaimaa drafted the manuscript, with input from Bandar, Norah. All authors approved the final manuscript.

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Availability of data and materials
The data that supports the results and findings of this systematic review can be found in either the main paper. Any other data from the current study are available from the corresponding author upon reasonable request.

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Competing interests
The authors declare no competing interests.

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