Laboratory Test Ordering in Inpatient Hospitals: A Scoping Review on the Effects and Features of Clinical Decision Support Systems

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Abstract

Background: Studies have revealed inappropriate laboratory testing as a source of waste. This review was aimed to evaluate the effects and features of CDSSs on physicians' appropriate laboratory test ordering in inpatient hospitals.

Method: Medline through PubMed, SCOPUS, Web of Science, and Cochrane were queried without any time period restriction. The outcomes were categorized based on test-related, physician-related, and patient-related. The primary outcome measures were the number and cost of laboratory test ordered.

Result: Sixteen studies met the inclusion criteria. Most studies were conducted based on a quasi-experimental design. The results showed improvement in laboratory test-related outcomes (e.g. proportion and cost of tests) and also physician-related outcomes (e.g. guideline adherence and orders cancellation). Patient-related outcomes (e.g. length of stay and mortality rate) were not well investigated in the included studies. Also, the evidence about applying CDSS as a decision aid for interpreting laboratory results was rare.

Conclusion: CDSSs increase appropriate test ordering in hospitals through eliminating redundant test orders and enhancing evidence-based practice. Appropriate testing and cost saving were both affected by the CDSSs. However the evidence is limited about the effects of laboratory test CDSSs on patient-related outcomes.

Background

Laboratory tests results have an important impact on patients care, as they affect many of physicians' decisions including admission, drug orders, and discharge as well as motoring and managing the vast majority of diseases. However, studies indicate that diagnostic tests are being used inappropriately as a meta-analysis result showed that almost 20% of laboratory tests are over-utilized and 45% are under-utilized [1]. A study has indicated that only 1–5% of chemistry tests and 1–3% of hematology tests have led to an action; action in this study meant any alternation from what would have been done without the test result [2]. Moreover, in one study about 70% of residents reported that they are ordering unnecessary daily laboratory tests [3].

Inappropriate test ordering can increase risk of false positive results and medical errors [4]. Overutilization can potentially cause patient discomfort including phlebotomy-induced anemia [5]. Underutilization can also result in delayed or missed diagnosis. Studies found that a vast majority of claims both in outpatients and emergency department belongs to missed diagnosis which resulted in death or serious harm to patients [6, 7]. Overcrowded diagnostic services, increased length of stay (LOS), and waste of valuable healthcare resources are amongst other consequences of inappropriate testing [8–10]. Conversely it imposes a lot of costs to healthcare as 3% of health care expenditures in the USA belong to laboratory testing [11–13].

Information technology [IT] has provided some solutions to decrease inappropriate laboratory tests ordering. Some of these technologies are electronic medical record (EMR) [14], electronic health record (EHR) [15], computerized physician order entry (CPOE) [16], and clinical decision support systems (CDSS) [17]. Among all technologies CDSS has more potential to support physicians when deciding about ordering a test or interpreting the results. However, studies have shown inconsistent results about the impact of CDSSs on physicians' performance and patients outcomes [18, 19]. Thus there is a need for a scoping review on the effects of CDSSs on ordering appropriate laboratory tests.

Studies evaluating the impact of CDSSs on diagnostic testing showed no improvement in clinical outcome but small positive improvement on physicians behavior regarding diagnostic test ordering [20, 21]. There are two similar systematic reviews focusing on laboratory test ordering specifically. The first is Maillet et al. (2018) study [22] which addressed the IT impact on laboratory tests ordering process in primary healthcare. This study did not focus on the effectiveness of CDSSs rather it focused on all specific IT interventions. It also included the studies conducted in primary healthcare. The second systematic review by Delvaux et al. (2017) [23] included the studies conducted in diverse healthcare settings (i.e. primary healthcare, hospital outpatient, and hospital inpatient). They found that CDSSs had little or no effect on clinical outcomes but some effects on physician compliance rate. Including all studies conducted in inpatient hospitals aiming at improving laboratory testing process as the primary objective, without considering study designs, might produce different results. Thus, the goal of current study was to conduct a scoping review on the effects and features of CDSSs on physicians' appropriate laboratory tests ordering in inpatient hospitals.

Method

Research question

Do CCDSSs improve practitioners' appropriate laboratory test ordering in hospitals?

Search Strategy And Study Selection

A search strategy was developed using keywords, MeSH terms, and major subject headings to identify published papers in the literature and adaptations were made for each database. Four databases were queried: Medline (through PubMed), SCOPUS, Web of Science, and Cochrane. We considered studies published till 21 January 2020 without any time limitation. The search strategy consisted of a combination keywords and Mesh terms related to clinical laboratory services (laboratory test utilization), CDSSs, and hospitals. The search strategy is presented as supplementary (supplementary A).

After removing duplicates, two authors (SZ and MS), working independently, selected the papers based on eligibility criteria. Titles and abstracts were screened for inclusion. The full text of potentially relevant papers was obtained, and the inclusion and exclusion criteria were considered. The reference lists of

the identified papers were also searched to include any other paper missed during the electronic searches. Authors resolved disagreements through discussion and consensus, and any remaining disagreements were resolved by another author (EN).

Study Selection Criteria

Inclusion criteria

Type of studies

A variety of evaluation study designs were included: randomized controlled trials (RCTs), non-randomized controlled clinical trials (CCTs), prospective observational studies, before-after, and interrupted time series (ITS).

Type of population

The study populations in the included studies were laboratory tests, physicians ordering laboratory tests, or the patients for whom laboratory tests were ordered.

Types of interventions

Studies using CDSSs as an intervention to improve laboratory test ordering as the primary aim were included. In current study a CDSS is considered as a health Information Technology system designed for providing assistance to physicians and other healthcare providers with decision-making tasks. CDSSs can ease access to data required to make decisions, provide reminders and alarms while a patient encounter, assist in recognizing a diagnosis and in entering appropriate orders, and alert healthcare providers when new patterns in patient data are observed [22, 24]. In studies with multifaceted interventions, the effects of CDSS intervention were considered independently and in cases which it was not possible to separate the CDSS impact, studies were excluded.

Type of outcomes

Outcome measures include: diagnostic yield and diagnostic detection rate, the number and cost of laboratory test ordered, laboratory turnaround time (TAT), STAT tests, guideline adherence for laboratory test ordering, physicians knowledge and attitude toward laboratory testing, patients outcome (e.g. patients safety, readmissions, death, length of stay and disposition). These outcomes were categorized based on test-related, physician-related, and patient-related groups. Test-related outcomes were proportion of tests, cost of tests, test intervals, number of STAT request, and laboratory TATs. Physician-related outcomes include diagnostic yield and diagnostic detection rate, adherence or order cancellation after the reminders (or overriding the reminders), and physicians knowledge and attitude. Patient-related outcomes were patients' complications, patients' disposition, length of stay (LOS), and mortality rate.

Exclusion criteria

Exclusion criteria were studies published in any language rather than English, conducted in outpatient or primary care settings, used interventions rather than CDSS, conducted in an unreal clinical environment or based on a scenario (in a simulated setting i.e. for test of a system). Moreover, all retrospective studies were excluded.

Quality Assessment

One study was RCT [28], one case-control [39], and the others (n = 14) were quasi experimental studies (appendix B). Most of the included studies (n = 11, 68.7%) were of intermediate quality, the remaining were of good quality. The main limitations of the included studies were not being blinded (93.7% had not blinded assessors) and lack of a clear specified description of inclusion and exclusion criteria (43.7%). The results are presented as a supplementary (supplementary B).

Quality assessments of the CDSSs are presented in Table 2. Almost all CDSSs were integrated with CPOEs (93.7%), providing real-time feedback (93.7%) without any recommended action (100%). Most CDSS classifications of the studies (43.7%) are in C category which required the ordering clinician to justify why they were overriding the provided decision support recommendation (see Table 2 legend). Four studies (25%) were integrated with and automated through EHR. Eight studies (50%) reported that they tested CDS before implementation. Only two studies (12.5%) reported user training about the intervention; in other cases the provided educations were about the targeted tests indication or similar things. Other characteristics, barriers, and facilitators affecting implementation of CDSS were: role of order sets, “adjustment” period, stakeholder and champion leaders engagement, appropriate environment, ease of repeating targeted tests, testing options constrains, paradoxical prompting generated by CDSS, and daily orders which would not trigger the audits.

Table 2
Quality assessment of the CDSSs

Author	CDSS design				Data entry source		Implementation characteristic		
	Is it integrated with CPOE?	Does it give real time feedback at point of care?	Does the CDS suggest a recommended course of action?	CDSS Classification*	Is it automated through EHR?	Does clinical staff enter data specifically for intervention?	Was it pilot tested or used an iterative process of development/ implementation?	Was there any user training/clinician education?	Are the author also th develo and pa of the group f the CD
Bates et al. (28)	Yes	Yes	No	C	Yes	No	NM**	NM	Yes
BoonFalleur et al. (31)	No	No	No	B	No	No	Yes	NM	NM
Bridges et al. (34)	Yes	Yes	No	B	NM	No	Yes	NM	No
Dalal et al. (35)	Yes	Yes	No	D	Yes	No	Yes	Yes	Yes
Eaton at al. (36)	Yes	Yes	No	B	No	NM	No	NM	NM
Gottheil et al. (30)	Yes	Yes	No	C	NM	No	Yes	NM	Yes
Klatte at al. (37)	Yes	Yes	No	D	Yes	Yes	Yes	NM	NM
Levick at al. (38)	Yes	Yes	No	B	No	No	NM	NM	Yes
Lippi at al. (32)	Yes	Yes	No	B	NM	No	NM	NM	Yes
Nicholson at al. (39)	Yes	Yes	No	C	NM	Yes	NM	NM	Yes
Niès at al. (33)	Yes	Yes	No	C	Yes	No	Yes	NM	Yes
Quan et al. (40)	Yes	Yes	No	D	NM	No	NM	NM	NM

Author	CDSS design				Data entry source		Implementation characteristic		
	Is it integrated with CPOE?	Does it give real time feedback at point of care?	Does the CDS suggest a recommended course of action?	CDSS Classification*	Is it automated through EHR?	Does clinical staff enter data specifically for intervention?	Was it pilot tested or used an iterative process of development/ implementation?	Was there any user training/clinician education?	Are the author also th develo and pa of the group f the CD
Procop at al. (41)	Yes	Yes	No	D	NM	No	Yes	Yes	No
Rosenbloom at al. (42)	Yes	Yes	No	C	NM	Yes	NM	NM	Yes
Rudolf at al. (43)	Yes	Yes	No	C	NM	Yes	NM	NM	NM
Samuelson et al. (44)	Yes	Yes	No	C	NM	Yes	NM	NM	NM
Sum Yes	15	15	0	A: 0	4	5	8	2	8
No	1	1	16	B: 5	3	10	1	0	2
NM	0	0	0	C: 7	9	1	7	14	6
				D: 4					

*Intervention Classification: “A” interventions provided information only; “B” interventions presented information on appropriateness or guidelines specifically often as a pop-up or alert. Some of these interventions also recommended alternative interventions, but did not include any barrier for the clinician to order th were similar to “B” interventions, but required the ordering clinician to justify with free text why they were overriding the decision support recommendation tha “soft stop”). “D” interventions included a “hard stop,” meaning the intervention prevented the clinician from ordering a test contrary to the CDS determination discussion with or permission obtained from another clinician or pathologist.

** Not Mentioned

CDSS interventions were mostly in the form of a reminder about duplicate tests in a specific timeframe, rule-bases providing knowledge about when it is appropriate to order the specified test, or predefined appropriateness criteria physicians had to determine before ordering the tests. These interventions support physicians’ informed decision-making in the first step of testing process when they are deciding about ordering a test.

Table 2: **Quality assessment of the CDSSs**

Data Extraction

We designed a form to extract data from each of the included studies. For each study the following data were extracted: study design, sample size, intervention description, and results. One author (SZ) extracted data which were subsequently reviewed and confirmed by another reviewer (EN).

Data analysis

A narrative synthesis was used to describe and compare the designs and the results of included studies. We categorized studies based on different features of CDSSs, outcome category, and effects of CDSSs. The effect of interventions were reported based on statistically significant positive, positive without statistical argument, no effect (not statistically significant), negative without statistical argument, or statistically significant negative [27]. Meta-analysis was not performed due to the variety of outcomes and results.

Results

Study selection (Fig. 1)

The literature search identified 2784 records, as well as two additional papers [28, 29] identified through other sources (snowball-search), 739 of which were duplicates. The papers were screened for eligibility by title and abstract, resulting in 74 potential papers for the full-text review. During the full-text reviewing 58 papers were excluded. Finally, 16 studies were deemed eligible for inclusion.

Figure 1: PRISMA flow diagram of the study selection

Characteristics Of The Included Studies

A substantial number of the included studies were performed during the recent decade. Overall, 81.2% of the included studies were published after 2010 and, of these, 69.2% were published after 2015. Most of the included studies were conducted in the United States (n = 12, 75%); and one was conducted in each of the following countries: Canada [30], United Kingdom [31], Italy [32], and France [33].

Table 1**) Characteristics of the included studies**

Table 1
Characteristics of the included studies

Authors, publication, year, Country	Study design	Study duration	Setting	Population	Sample size	Intervention description	Conclusion
Bates et al., 1999, The USA (28)	RCT	4 months	A tertiary care hospital	Inpatients at the hospital	CG: 5886 patients IG:5700 patients	CPOE reminder: In the intervention group, if a test had previously been ordered within its test-specific interval, the physician received a reminder that the test had been performed recently or was pending; the result was showed if available. For the control group, duplication was determined in exactly the same way, but there was no reminder.	Delivering reminders about orders for apparently redundant laboratory tests were effective. However, since many tests were conducted without corresponding computer orders and many orders were not screened for duplication overall effect was limited.
Boon-Falleur et al., 1995, The United Kingdom (31)	Before-after	6 months	A pediatric liver disease unit	Patients with liver transplant	Before: 42 patients After: 175 patients	A rule-based expert system allows static and dynamic requesting rules to be defined for different clinical classifications of patients. The static rules allow the definition of "baseline" proposals within a precise time schedule. Dynamic rules allow the system to react to results of previously ordered tests. The attending physician may accept or amend the system's proposals by adding or removing requests to the proposed schedule.	The clinicians' perspective was that the system would increase the total benefits in clinical resources use, improve the management of laboratory data, and save time for doing laboratory ancillary tasks.
Bridges et al., 2014, The USA (34)	Before-after	6 months	A tertiary care hospital	Patient admitted to the department of medicine	Before: 674 patients After: 692 patients	The intervention consisted of displaying a computerized alert informing that the clinician is ordering a recently ordered test.	Computerized alerts may be effective in reducing redundant laboratory tests and enhancing efficiency of healthcare system.
Dalal et al., 2017, The USA (35)	Before-after	6 months	A teaching hospital	All TSH, T3, and T4 ordered in Department of Medicine	Before: 2611 tests After: 2454 tests	A clinical algorithm for CDS and Hard Stops were incorporated into the EMR to decline ordering freeT3 or freeT4 without an abnormal TSH, also certain exceptions were predefined. In addition, if the TSH was abnormal a reflex rule was triggered and could automatically order freeT3 and freeT4.	By a clinical decision support about when to order TFTs, they observed a decrease in the number of unnecessary tests ordered.
Eaton et al., 2018, The USA (36)	Time-series	30 months	Hospital	Inpatient population admitted to general medicine service	Before: 14193 patients After: 13751 patients	Educational guide, nonintrusive ordering message, and noon conference. Appropriate indications for selected tests were incorporated into text accompanying the laboratory orders in hospital's HER. Physicians could ignore the text and proceed with the order.	Nonintrusive CDSS do not have significant effect on utilization of laboratory test.
Gottheil et al., 2016, Canada (30)	Time series	12 months	A tertiary care hospital	Erythrocyte Sedimentation Rate orders	Not mentioned	Educational content and CDSS: a series of appropriateness criteria for Erythrocyte Sedimentation Rate was incorporated into CDSS.	Their quality improvement initiative could reduce inappropriate Erythrocyte Sedimentation Rate testing by computerized CDS.

CDSS: Clinical Decision Support System; CG: Control Group; CPOE: Computerized Physician Order Entry; ED: Emergency Department; IG: Intervention Group; RCT: Randomized control trial; TFT: Thyroid Function Test; TSH: Thyroid Stimulation Hormone.

Authors, publication, year, Country	Study design	Study duration	Setting	Population	Sample size	Intervention description	Conclusion
Klatte et al., 2016, The USA (37)	Time series	12 months	A tertiary hospital, a 53-bed satellite facility	Specimens from children ≤ 12 months	485 specimens	Educational intervention, an evidence-based algorithm for appropriate clostridium difficile ordering, and CPOE requiring clinicians to mandatory complete 2 extra fields. nondiarrheal stool were automatically declined by laboratory, unless in cases with severe ileus or toxic megacolon.	Their CDSS intervention resulted in a sustained drop in the number of specimens tested, which saved laboratory and patient cost significantly. They observed no sustained change in clinicians' ordering practices in spite of multiple educational efforts.
Levick et al., 2013, The USA (38)	Time series	6 months	Three not-for-profit hospitals	Patients with B-Type Natriuric Peptide test	41306 patients	CPOE with embedded CDS: The CDS intervention is an expert rule that searches the system for a B-Type natriuric peptide lab value for the patient. An advisory alert was indicated to the ordering clinician if there was a value for the test and it was within the current hospital stay.	Using CDSS alerts has the potential for improving care, but should be used judiciously and in the appropriate environment.
Lippi et al., 2015, Italy (32)	Before-after	6 months	A teaching hospital	A variety of tests requests including C reactive protein, TSH, ferritin, brain natriuretic peptide, etc	3539 test requests	CDSS: an electronic alert is automatically triggered by a potentially inappropriate test request. The alert contains a detailed explanation of the specific rule for appropriateness of the test.	A CDSS alert may be effective to decrease the inappropriateness of laboratory test orders, generate significant cost saving and educate physicians to use laboratory resources more efficiently.
Nicholson et al., 2017, The USA (39)	Before-after non-equivalent control group	26 months	A tertiary-care pediatric hospital	Children < 36 months of age	Before: 141 patients After: 55 patients	An alert advising against ordering C. difficile tests in infants and young children based on the American Academy of Pediatrics recommendations. Physicians could override it optionally.	The average monthly testing rate for C. difficile for children < 35 months old decreased without complication after the use of a CPOE alert in those who tested positive for C.difficile.
Niès et al., 2010, France (33)	Time series	36 months	A university teaching hospital	Patients with hepatitis B antigen test	Before: 2888 patients After: 1572 patients	CDSS: The alert is triggered when one of the targeted serological tests for hepatitis B virus is selected to be ordered. The Serology-CDSS stores a record of its execution each time a physician selects a viral serology test order. An alert is displayed if the most recent result of the targeted laboratory test for the patient is less than 90 days old.	After CDSS implementation an immediately decrease was observed in the proportion of unnecessarily duplicate tests. CDSS alerts could also improve compliance rate.
Quan et al., 2019, The USA (40)	Before-after	24 months	An academic hospital	Patients with C. difficile infection test	Before: 284 tests After: 268 tests	Clinicians were required to verify the determined criteria for appropriate ordering of C. difficile infection test. A warning email was sent to the physicians ordering the test without appropriate approval.	The protocol increased appropriate testing as well as decreasing hospital-onset standardized infection ratio of C. difficile infection.

CDSS: Clinical Decision Support System; CG: Control Group; CPOE: Computerized Physician Order Entry; ED: Emergency Department; IG: Intervention Group; RCT: Randomized control trial; TFT: Thyroid Function Test; TSH: Thyroid Stimulation Hormone.

Authors, publication, year, Country	Study design	Study duration	Setting	Population	Sample size	Intervention description	Conclusion
Procop et al., 2014, The USA (41)	Time series	24 months	The Cleveland Clinic	more than 1000 tests of all patients	Not mentioned	CDSS: This tool informs the provider that the test being ordered is a duplicate. It also block unnecessary duplicate test orders during the computerized physician order entry	Real-time interaction between the laboratory and the physician through CDS tools could decrease duplicate orders. It saves healthcare costs and should also increase patient satisfaction and well-being.
Rosenbloom et al., 2005, The USA (42)	Time series	5 years	An academic inpatient tertiary care facility	Clinicians at a university hospital	194,192 patients	The CDSS exhorted users to discontinue unnecessary tests recurring more than 72 hours into the future 2) Education regarding appropriate indications for testing. 3) CDS and CPOE systems targeted only magnesium ordering, displayed recent results, limited testing to one instance per order, summarized indications for testing, and required users to select an indication	A clinical decision support intervention intended to regulate testing increased test order rates as an unintended result of decision support.
Rudolf et al., 2017, The USA (43)	Time series	36 months	A tertiary care teaching hospital	Laboratory tests	61644 laboratory test ordes	Alert in the CPOE system: the alert appeared in the CPOE each time an order with frequency greater than one occurrence was selected. The justification for the order was also captured by the CPOE, as providers were required to select one of three approved indications for the daily laboratory test or manually enter another indication.	Our experience suggests auditing and continued feedback are additional crucial components to changing ordering behavior. Curtailing daily orders alone may not be a sufficient strategy to reduce in-laboratory costs
Samuelson at al., 2015, The USA (44)	Before-after	16 months	Two academic medical hospitals	Patients evaluated for heparin-induced thrombocytopenia	Before: 265 patients After: 146 patients	CDSS: A decision-support tool required providers to calculate the 4Ts (heparin-induced thrombocytopenia risk) score prior to ordering laboratory-based tests for anti-PF4/heparin antibody enzyme-linked immunosorbent assay testing	Our study demonstrates that a clinical decision support tool embedded within the electronic ordering process can decrease unnecessary testing for heparin-induced thrombocytopenia.

CDSS: Clinical Decision Support System; CG: Control Group; CPOE: Computerized Physician Order Entry; ED: Emergency Department; IG: Intervention Group; RCT: Randomized control trial; TFT: Thyroid Function Test; TSH: Thyroid Stimulation Hormone.

Effects Of Cdsss On Outcomes (table)

Table 3
) Effects of CDSS interventions on laboratory testing outcomes

Outcome		Positive		No effect	Negative
Category	subcategory	Statistically Significant Demonstrated			Statistically Significant Demonstrated
Test-related	Proportion of tests	(28), (34), (35), (36), (32), (39), (33), (40), (42)*, (44)	(31), (36), (30), (37), (38), (41)	(31), (36), (43)	(42)*
	Cost of tests	(34)	(28), (30), (37), (38), (32), (41)		
	Test intervals	(28)			
	Number of STAT request		(31)		
Physician-related	Guideline adherence		(31), (33)		
	Orders cancellation after the reminders		(28)		
Patient-related	Patient complication			(28), (39), (41)	
	Patient disposition	(34)			
	LOS			(34)	
	Mortality rate	(34)			

*This study used three different CDSS intervention; two of which had positive impact and one of which had negative impact

The included studies had mostly investigated laboratory test-related outcomes. Generally, CDSS interventions showed positive effects on all outcomes.

Laboratory Test-related Outcomes

Appropriate testing and cost saving were both affected by the CDSSs and it is consistent with a similar systematic review on outpatient setting [22]. It is also consistent with a narrative review by Bindraban et al. [48] which showed nearly all interventions in educational, CPOE, and audit and feedback category caused reduction in test order volume. Roshanov et al. systematic review [20] also indicated that those systems aimed at reducing test ordering rate had positive impact. However the results are inconsistent with Delvaux and colleague systematic review. They found that CDSSs designed to change laboratory testing behavior for diabetes, HIV, and anticoagulation had little or no influence on clinical outcome. Our study included studies aimed at improving laboratory testing process as the primary aim. However most studies included by Delvaux et al., as mentioned in Introduction section, had different objective for instance computer-aided dosing and further they evaluated its impact on diagnostic testing. Thus it seems CDSSs specifically designed to affect laboratory tests are more influential. Eaton et al. [36] showed that CDSSs might be effective for some tests and ineffective for some others. There was only one study [42] that found a negative impact in magnesium ordering attributed to CDSS. The CDSS was supposed to regulate magnesium ordering; they developed a CDSS in a way that three tests (i.e. magnesium, calcium, and phosphorus) could be ordered from one user interface of CPOE. This may have caused an unintentional prompt to order these tests together without original plan. Decreasing cost of tests was approved in several studies [28, 30, 32, 34, 37, 38, 41]. But it is important to mention that quality of the studies were fair and results were not analyzed statistically. Thus the conclusion about cost reduction sounds difficult. Even it is stated that the reported cost reduction is an underestimation of true cost savings since they only assessed consumables costs, and associated resources (i.e. equipment, personnel, test tubes, etc.) should be included in the calculation.

Physician-related Outcomes

Physician-related outcomes were reported in three included studies [28, 31, 33]. In these studies compliance was measured based on the proportion of cancelled orders after the provision of the reminders and showed positive effect. A systematic review by Delvaux et al. [23] also demonstrated a positive impact in compliance with recommendations made by CDSSs. Roshanov et al. [20] also concluded that CDSSs had positive impact on physicians' diagnostic test ordering behaviors. However they believed that the contributing factors resulting in success or failure are unclear. Main et al. found that if they consider the result of both primary and secondary outcome then CDSSs is effective on physicians' behaviors.

Patient-related Outcomes

The results also indicated that the evidence pertaining to the effects of CDSSs on patient-related outcomes is limited. Overall, CDSSs may make little or no difference to patient outcomes including patient complications, patient disposition, or mortality rate [28, 34, 39, 41]. For instance in Bates et al. [28], study three of the eight urinalysis cancelled tests displayed a few red blood cells, while the previous specimen had been negative. It is inferred from these findings that cancelling the orders due to a CDSS suggestion, probably lead to no adverse event to patients. Bridges et al. [34] study showed that patients with duplicate

tests had higher mortality rate than those without duplicate tests; they also had a worse disposition after discharge, indicating those with redundant tests were generally sicker. Thus, less mortality rate cannot be only attributed to CDSS effect and needs more investigation. Patient experience like decreased phlebotomy and other possible improved outcomes like decreased risk for false-positive test results should be investigated in future studies.

Discussion

Generally, the studies were mostly of moderate methodological quality with only one RCT out of the 16 included studies, and most studies being conducted after 2015. The majority of included studies were addressing the CDSSs effect on laboratory test-related outcomes. The results showed improvement in laboratory test-related and physician-related outcomes. Patient-related outcomes were not well investigated in the included studies.

Most studies were conducted after 2015 suggesting a new research agenda in health information technology. It also indicates that attentions to resource utilization for appropriate utilizing laboratory tests have been increased recently. It might also be attributed to limited resources as well as increased cost of healthcare. Healthcare resource utilization and costs by different diseases shows a high economic burden highlighting need for taking some actions for decreasing costs [45–47]. The results of this review showed that CDSSs have the ability to improve laboratory tests utilization in some cases including hepatitis B virus, Clostridium Difficile, magnesium, B-Type natriuric peptide, TFT, ESR, and heparin-induced thrombocytopenia tests.

Strengths And Limitations

A comprehensive search strategy, without any time period restriction, was performed to find the maximum number of relevant studies. To avoid missing any important findings, a variety of interventional study designs were included. We assessed the effects of CDSSs not only on proportion of test orders and associated costs but also on physician-related and patient-related clinical outcomes.

A limitation of this review is that due to exclusion of non-English language papers and conference proceedings, some relevant studies might have been missed. Another limitation is the exclusive focus on studies on reducing unnecessary testing as the main outcome. Most studies conducted in this field were performed using a quasi-experimental design making the conclusion about the impacts difficult due to possible biases.

Implication

Applying a clinical algorithm and hard stop alerts for preventing specified tests would result in more reduction in tests volume. CDSSs should be evaluated for specific laboratory tests to make sure only effective alerts would be displayed [36]. Nonetheless, allowing overrides may be effective for clinicians' acceptance of the system. Nonintrusive alerts should be evaluated to make sure only effective alerts continue to be displayed so as to prevent rising alert fatigue [36]. Alert fatigue causes both important and non-important alerts to be overridden by clinicians. Thus, considering a balance between system flexibility and hard-stop alerts is important in designing a CDSS. It is suggested that the intervention must be sustainable through providing awareness to the changes, which will bring about better compliance. Impact on physician-related outcomes can be promoted over time, since physicians possibly experience an "adjustment" period at the beginning of the intervention so they need time to become familiar with the intervention [34]. Although physicians' attitude and requirements are important factors contributing in more acceptances and perceived usefulness of CDSS, less attention has been paid to them. It has been shown that simple static rules had higher compliance rates than complicated dynamic rules [31]. CDSSs design should not allow two or more tests to be ordered from a single interface, because it may contribute in unintentional prompt to order those tests together and increase tests ordering.

Future Research Directions

Since most studies were conducted after 2015, indicating a new research agenda, there is a need for more studies investigating effective information technology-based approaches to manage health resources utilization. Moreover, considering the majority of the studies were performed using a quasi-experimental design, there is an essential need for further studies with more robust study designs. Also, to make sure about the effects of CDSSs on test interval, STAT tests, and TAT, further studies are needed. According to the lack of evidence on potential negative effects resulting from the cancellation of the tests based on CDSS recommendations, future research should evaluate these effects, especially potential harm to patients. Although some physicians need guidance when interpreting some tests [49, 50] and CDSSs have the potential to aid them, according to our review there was no physician aid for interpreting the result; new research can investigate the effects of CDSSs as a physician aid for interpreting the laboratory tests results.

Conclusion

Current scoping review indicate that CDSSs increase appropriate test ordering through eliminating redundant test orders and enhancing evidence-based practice in hospitals. The literatures showed that CDSSs have the potential to affect on cost savings. However evidence is limited about the impact of cancelling order tests on patient health and needs further studies.

Abbreviations

CDSS
Clinical Decision support system
EMR
Electronic Medical Record
HER
Electronic Health Record

CPOE
Computerized Physician Order Entry
TAT
Turnaround Time
RCT
Randomized Controlled Trials
CCT
Controlled Clinical Trials
ITS
Interrupted Time Series
ED
Emergency Department
IG
Intervention Group
TFT
Thyroid Function Test
TSH
Thyroid Stimulation Hormone
C. difficile
Clostridium difficile

Declarations

Ethics approval and consent to participate

The study is approved by the ethics review board of the Vice-chancellor for Research Affairs of KaUMS (IR.KAUMS.NUHEPM.REC.1398.005). **Consent to participations is not applicable.**

Consent for publication

Not applicable.

Availability of data and material

All data are available in the submission.

Competing interest

The authors declare that there are no conflicts of interest

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Authors' contribution

EN and ZM directed the study. SZ MS contributed in reading the articles for relevance and disagreements were solved by EN. SZ extracted the information of the included studies. SZ and EN have drafted the manuscript. All the authors have read and approve the manuscript.

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Figures

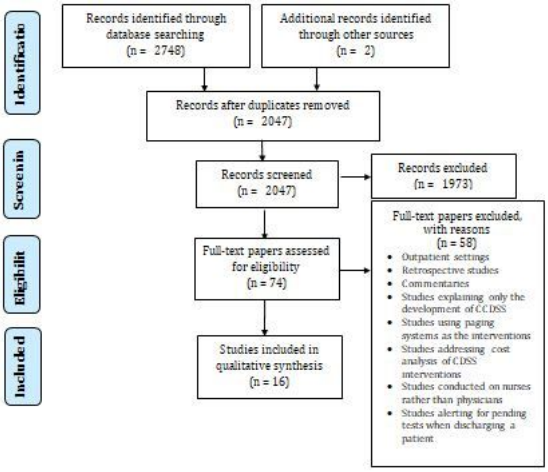

Figure 1

PRISMA flow diagram of the study selection

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