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Reducing Test Utilization in Hospital Settings: A Narrative Review

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Background: Studies addressing the appropriateness of laboratory testing have revealed approximately 20% overutilization. We conducted a narrative review to (1) describe current interventions aimed at reducing unnecessary laboratory testing, specifically in hospital settings, and (2) provide estimates of their efficacy in reducing test order volume and improving patient-related clinical outcomes.

Methods: The PubMed, Embase, Scopus, Web of Science, and Canadian Agency for Drugs and Technologies in Health-Health Technology Assessment databases were searched for studies describing the effects of interventions aimed at reducing unnecessary laboratory tests. Data on test order volume and clinical outcomes were extracted by one reviewer, while uncertainties were discussed with two other reviewers. Because of the heterogeneity of interventions and outcomes, no meta-analysis was performed.

Results: Eighty-four studies were included. Interventions were categorized into educational, (computerized) provider order entry [(C)POE], audit and feedback, or other interventions. Nearly all studies reported a reduction in test order volume. Only 15 assessed sustainability up to two years. Patient-related clinical outcomes were reported in 45 studies, two of which found negative effects.

Conclusions: Interventions from all categories have the potential to reduce unnecessary laboratory testing, although long-term sustainability is questionable. Owing to the heterogeneity of the interventions studied, it is difficult to conclude which approach was most successful, and for which tests. Most studies had methodological limitations, such as the absence of a control arm. Therefore, well-designed, controlled trials using clearly described interventions and relevant clinical outcomes are needed.

Key Words: Laboratory utilization, Laboratory testing, Unnecessary laboratory utilization, Unnecessary laboratory testing, Reduction, Intervention

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INTRODUCTION

Over the past decades, Western countries have witnessed a marked rise in healthcare expenditure, with annual growth rates exceeding the rise in gross domestic product [1]. The constantly expanding field of diagnostics has contributed to this exponential growth in curative health-care costs. Rapid increases have been seen in the volumes and costs of different types of diagnostics, with absolute test volumes doubling every five to ten years in the United States, the United Kingdom, and Canada [2].

Laboratory testing represents the largest volume of medical activity and is considered to influence more than 70% of deci-

sion making in medical practice [2, 3]. In 2015, Kobewka *et al* [4] reviewed numerous international studies to conclude that a considerable proportion of performed (laboratory) tests were unnecessary. Another review addressing the appropriateness of diagnostic laboratory testing reported a mean rate of overutilization of approximately 20% [5]. Statistically, laboratory test results will deviate from normal in 5% of healthy individuals [6]. Besides the financial impact, overutilization increases the number of false-positive results, leading to more, sometimes invasive and potentially harmful tests. In addition, excessive blood draw can result in iatrogenic anemia [7, 8]. Moreover, excessive testing can lead to less patient-friendly practices. Therefore, a reduction in unnecessary laboratory testing is often targeted with the aim of improving patient safety and reducing healthcare expenditure. Such a reduction does not lead to adverse patient outcomes and might even reduce the length of hospital stay and the need for red cell transfusion [8-12].

Interventions to reduce unnecessary laboratory testing, such as educational sessions or posters, pop-up reminders upon test ordering through an electronic ordering system, modification of paper order forms, or providing clinicians insight into their ordering patterns, have been implemented and studied in different clinical settings in many countries [4, 13]. Although a few reviews examine the efficacy of these interventions in different settings [4, 13], no recent review has considered a hospital setting. Therefore, this review aims to describe the different types of interventions implemented to reduce unnecessary laboratory testing in hospital settings as well as the overall efficacy of these interventions and their impact on patient-related clinical outcomes.

METHODS

1. Data sources and search strategy

We initially searched the PubMed, Embase, and Canadian Agency for Drugs and Technologies in Health-Health Technology Assessment (CADTH HTA) databases from inception through July 2016 for potentially relevant articles describing interventions to reduce unnecessary laboratory testing in hospital settings. We combined synonyms of the following terms: laboratory test, reduction, and intervention. Supplemental Data S1 provides an overview of all search terms used. Highly relevant papers found in this initial screening of titles and abstracts were selected and subjected to backward reference checking in Scopus. Of the papers retrieved in this round, a selection was checked backwards and forwards for references in Scopus and Web of Science. Our search was not exhaustive, as the aim of our effort was not to report and compare exact estimates of effectiveness, but merely to describe published interventions and provide crude estimates of their effectiveness.

2. Study selection

We selected only hospital-based studies that reported an intervention to reduce unnecessary laboratory testing and presented data on changes in test order volumes. Only articles written in English or Dutch with full text available were included. We defined unnecessary laboratory tests as those with results that did not generate added value in clinical decision making, relying on the authors' judgment. Studies were excluded when only the influence of the intervention on costs was presented or when reduction in test order volumes was given only for a subset of all tests studied. We chose to exclude the latter to avoid over-optimism that might occur when selective results are presented.

3. Data extraction and quality assessment

For each report included, data on the type of intervention(s) carried out were extracted. The interventions were categorized as educational interventions, (computerized) provider order entry [(C)POE] interventions, audit and feedback interventions, and others, based in part on a subdivision previously used by Kobewka *et al* [4]. We extracted data on the reduction in test order volume, which was expressed as the percentage change in order volume of the targeted tests before and after the intervention.

Further, we assessed the study design and characteristics of the comparators used. To get an indication of the study size, the number of participating centers was recorded along with a measure of study population, such as number of visits and admissions and number of hospital days. We assessed the number of tests targeted and the reproducibility and sustainability of the interventions (i.e., reduction in test order volume up to 2 years post-intervention). In addition, we noted whether the studies provided data on patient-related (clinical) outcomes that might have been affected by the modification of laboratory utilization, such as hospital length of stay, number of intensive care unit (ICU) admissions, number of readmissions, and mortality.

Data were extracted by one reviewer (RB). Uncertainties in data extraction were discussed with two other reviewers (MB, PN) until consensus was reached. Because of the anticipated heterogeneity of the tests, studied interventions, and reported outcome measures, we did not perform a meta-analysis.

RESULTS

1. Search results

After backward reference checking of 20 relevant papers selected from our PubMed/Embase/CADTH HTA database search, we retrieved 603 unique papers. Of these, 61 papers met our inclusion criteria. A selection of these papers was checked for references backwards and forwards. Of the 891 papers retrieved in this search, 23 papers fulfilled our inclusion criteria. Fig. 1 illustrates our search algorithm.

2. Study characteristics and quality assessment

Table 1 lists characteristics of studies included (N=84) in terms of design, presence and similarity of a comparator group, study size, number of tests targeted, reproducibility of the intervention, sustainability of effects, and reported effect on clinical outcomes if investigated. A more detailed overview of the individual studies can be found in Supplemental Data Table S2.

1) Study design and characteristics of comparator

Of the five randomized controlled trials, randomization was performed at the patient level in two studies, at the provider level in two studies, and at the test level in one study (i.e., a test was randomized to be subject to the intervention or not). Of the non-randomized controlled trials included, six used (a subset of) other tests as a control arm (e.g., a CPOE intervention in which the intervention applied to a subset of tests and another subset was used as a comparator), six used another department within the same clinic, and in three studies, another clinic was used as the control arm.

For controlled trials, we assessed whether both the intervention group and the control group were comparable with regard to the providers subjected to the intervention as well as the patients for whom they provided. In before-after studies, we assessed whether both patient and provider groups before and after the intervention were comparable; as shown in Table 1, this was the case in only seven studies (8.3%).

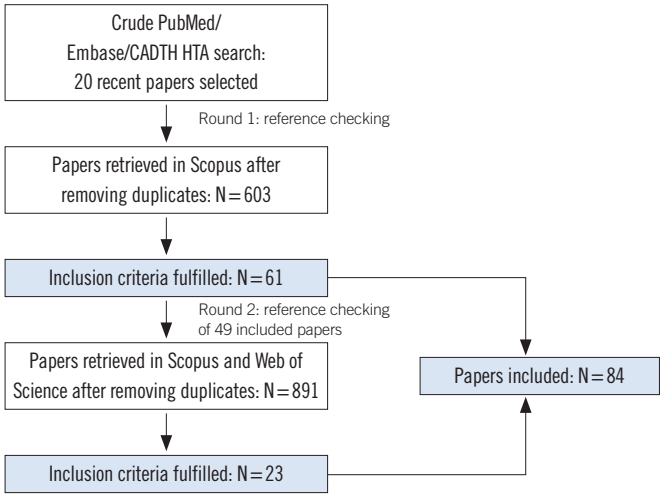

Fig. 1. Flowchart of the literature search algorithm used for identifying and selecting studies for inclusion in this review.
Abbrevations: CADTH HTA, Canadian Agency for Drugs and Technologies in Health-Health Technology Assessment.

Table 1. Characteristics of included studies

	N (%)
Study design	
Before after study	56.6 (66.7)
Retrospective audit	8 (9.5)
Randomized controlled trial	5 (6.0)
Non-randomized controlled trial	15 (17.8)
Similarity of patients and providers between comparison groups	
Both patients and providers comparable between both groups	7 (8.3)
Patients comparable, providers not comparable	1 (1.2)
Patients and providers not comparable	1 (1.2)
Patients comparable, no data on comparability of providers	21 (25.0)
Patients not comparable, no data on comparability of providers	3 (3.6)
Providers comparable, no data on comparability of patients	7 (8.3)
No data on comparability of either patients or providers	36 (42.9)
No comparator group	8 (9.5)
Number of centers included	78 (92.9)
Single center	6 (7.1)
Multiple centers	
Number of tests studied	
1	17 (20.2)
2–5	5 (6.0)
>5	53 (63.1)
Unclear	9 (10.7)
Reproducible intervention	
Yes	44 (52.4)
No	40 (47.6)
Sustainability assessed	
Yes	14 (16.7)
No	70 (83.3)
Data on clinical outcomes reported	
Yes	45 (53.6)
No	39 (46.4)

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2) Study population and tests

The numbers of visits and admissions analyzed ranged from 287 to 5,026,049. The number of hospital days analyzed ranged from 9,890 to 1,557,550. The majority of studies (93%) were single-center studies. In the majority of studies, more than five tests were targeted.

3) Reproducibility of the intervention

We assessed whether the interventions were described in sufficient detail to allow replication in another setting. This was the case in 44 studies, most of which (59%) reported (C)POE interventions. Information provided included the guidelines that were developed and screenshots of the modified order screen or form.

4) Sustainability

Only 15 studies (17.9%) investigated sustainability. All of these demonstrated a reduction in test order volume that was sustained for two or more years.

3. Interventions

Forty-four studies had an educational component, 49 had a (C)POE component, and 25 had an audit and feedback component. The majority of studies (55%) reported interventions in a single category. The remaining studies involved a combination of interventions from different categories. Table 2 shows the classification of studies by category of interventions used.

Table 2. Classification of interventions

	N (%)
Studies in which a single intervention was performed	46 (54.8)
Educational	9 (10.7)
(C)POE	33 (39.3)
Audit and feedback	0 (0)
Others	4 (4.8)
Studies in which combined interventions were performed	38 (45.2)
Educational & audit and feedback	15 (17.8)
Educational & (C)POE	4 (4.8)
Educational & others	3 (3.5)
Audit and feedback & (C)POE	1 (1.2)
(C)POE & others	2 (2.4)
Educational & (C)POE & Others	4 (4.8)
Educational & audit and feedback & others	4 (4.8)
Educational & audit and feedback & (C)POE	3 (3.5)
Educational & audit and feedback & (C)POE & others	2 (2.4)

Abbreviation: (C)POE, (computerized) provider order entry.

Table 3 provides an overview of the observed changes in test order volume in the individual studies included in this review. We classified all studies by category of intervention(s) used. A variety of outcomes are used to express the change in test order volume, e.g., "reduction in total number of tests," "reduction in the number of tests per patient per day," and "reduction in the number of tests per admission." For a more detailed description of the individual studies, see Supplemental Data Table S2.

1) Interventions with educational component

Out of 84 studies, nine implemented interventions that were exclusively educational. In 35 studies, interventions combining educational efforts with other approaches were implemented.

2) Interventions with (C)POE element

Thirty-three studies exclusively involved modifications in the (C)POE system. In 16 studies, these modifications were combined with other approaches. In seven studies, pop-up reminders were instated upon ordering a potentially redundant test, providing the opportunity to either cancel or continue the order ("soft stop"), which in some cases required justification. Five studies used a more rigorous approach by automatically rejecting orders that appeared to be redundant ("hard stop"), with or without a direct notification of the ordering provider. Another strategy used involved the unbundling or elimination of order panels or other modifications in order forms, e.g., by grouping tests by organ or disease, or displaying fee information. This strategy was used in 13 reports. A different approach was to limit the time window for order placement, with requests scheduled to be carried out beyond this time window being canceled, which was done in three studies.

3) Interventions with audit and feedback component

None of the studies included used audit and feedback methods solely. In 25 studies, audit and feedback methods, in which providers were presented with their ordering patterns, were combined with other interventions.

4) Other interventions

In three studies, test orders were reviewed for approval by a multidisciplinary team of specialists. In one study, the providers allowed to order tests were restricted.

4. Clinical patient outcomes

Possible effects of the reduction in laboratory test utilization on patient (clinical) outcomes were studied in slightly more than

Table 3. Test volume reduction by category of intervention(s)

Ref	Reduction in testing
Education	
[8]	8.7%*
[28]	32.7%†
[30]	22.4%‡
[32]	27.8%*
[33]	14.7%§
[18]	29.9%‡
[34]	57%‡
[35]	28.6% (I) vs 11.8% (C)‖
[36]	40.6% (I) vs 21.3% (C)†
(C)POE	
Soft stop	
[39]	46% (pre-I) vs 14% (post-I)¶
[41]	22.2–53.7% (I) vs 1.7–40.1% (C)‖
[43]	16.7%‡
[45]	21%‡
[46]	39.8%‡
[47]	19.5%‡
[49]	73% (I) vs 49% (C)**
Hard stop	
[19]	11.2%††
[16]	5.7%‡
[53]	96.6%**
[55]	12.4% (I) vs 0.3% (C)‡‡
[57]	0.56%‡
Soft stop vs hard stop	
[60]	92.3% (I) vs 43.6% (C)‡
Order form changes, display of fee	
[62]	44.2%†
[64]	3.9%†
[66]	25.5% (I) vs 1.3% (C)§§
[67]	18.6%‖‖
[69]	8.6% (I) vs 5.6% (C)*
[20]	17.3%‡‡
[71]	56.5%‡
[73]	54.3–52.5%+‖
[74]	19.1% (I) vs 40.6%+ (C)‡‡
[76]	18.5%‖
[77]	32.7%‡‡
[79]	4.5%¶¶
[80]	23.9%‡
Time limits on orders	
[81]	8.5%*
[83]	11.5%*
[85]	64.7%§
Combined (C)POE & Others	
[7]	33.3–48.5%*
[88]	18.0%†††
[90]	13.7%‡
[92]	55.2%†
Others	
[27]	38%‡
[29]	12%‡
[31]	15.9%‡
[15]	3.6%†
Education & Audit/Feedback	
[25]	5.1–7.0%§
[24]	25.5–42.2% (I) vs 3.7–22.4% (C)*
[3]	21%‡
[37]	29.8%‡
[10]	12.3–52.0% (I) vs 26.5–8.5%+ (C)‡‡
[38]	14.6% *
[40]	12%‡‡‡
[42]	48.6%‡
[44]	38.0–73.7%*
[9]	20.8%*
[11]	13.5%*
[48]	4.5%+†
[50]	41.5% (I) vs 10.0%+ (C)*
[51]	24–32%*
[52]	14%†
Education & (C)POE	
[54]	26.7% and 36.0%‡
[56]	61.5% and 100%‡‡
[58]	3.1–58.5% (I) vs 4.1–33.9%+*
[59]	41.9% and 44.8%‡
Education & Others	
[61]	20.7–56.3%*
[63]	7.5%*
[65]	69.5%‡
Audit/Feedback & (C)POE	
[68]	17%*
(C)POE & Others	
[70]	33.3–60%*
[72]	47.2%+§§§
Education, (C)POE & Others	
[75]	7.1–8.9%*
[21]	66%‡
[78]	80.9% (I) vs 11.8% (C)‡
[22]	34.5% (I) vs 10.1–14.8% (C)‖

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Table 3. Continued

Ref	Reduction in testing
Education, Audit/Feedback & Others	
[14]	5.7–30.4% (I) vs 1.2–8.8%+ (C)[§]
[82]	47.4%[‡]
[84]	11.5%[‡‡]
[86]	10.7% (I1) vs 52.3% (I2) vs 23.5% (I3)[‖]
Education, Audit/Feedback & (C)POE	
[87]	20%[‡]
[89]	95%[‖‖]
[91]	19.0% (I) vs 7.6% (C)[¶¶]
Education, Audit/Feedback, (C)POE & Others	
[93]	8%*
[94]	25.9%[‖]

*Number of target tests per (in)patient day; [†]Number of target tests per (in) patient; [‡]Total number of target tests; [§]Number of tests per day; [‖]Number of tests per admission, visit or discharge; [¶]Percentage of admissions in which test was performed; **Percentage of redundant orders cancelled; [††]Number of target tests per year; [‡‡]Number of tests per month; [§§]Monthly tests per patient day; [‖‖]Number of tests per 100 ED presentations; [¶¶]Fewer tests in intervention group compared to control group; ***Number of tests per day; [†††]Number of tests per week per hospitalization; [‡‡‡]Percentage of patients undergoing target test; [§§§]Number of tests per patient per visit; [‖‖‖]Percentage reduction in use of panel; [¶¶¶]Number of tests per 100 hospital days.
Abbreviations: Ref, reference; I, intervention group; C, control group; I1, intervention group 1; I2, intervention group 2; I3, intervention group 3.

half (54%) of all studies evaluated. Clinical outcomes were generally not or positively affected by most of the interventions studied. Negative effects on patient outcomes were reported in only two papers. In the report by Finegan *et al* [15], test selection was individualized by staff or resident anesthesiologists instead of according to surgery-specific clinical pathways by surgical staff. Significantly more complications and a higher mortality rate were found in the intervention group, although the internist reviewing the complications concluded in all cases that additional tests would not have affected these outcomes. In the report by Smit *et al* [16], an electronic gatekeeping system was implemented, automatically rejecting orders not meeting specific rules. Some restored tests were evaluated after previous rejection, and the negative effects on duration of hospital stay and conducting further diagnostics were noted.

DISCUSSION

We provided an overview of the nature and effectiveness of interventions aimed at reducing unnecessary laboratory utilization on the basis of 84 peer-reviewed studies that investigated educational, (C)POE, audit and feedback, and other interventions. Nearly all the studied interventions had the potential to reduce unnecessary laboratory utilization without affecting patient safety. In the majority of studies, reductions in unnecessary diagnostics were achieved, which was consistent with the previous findings [4, 13]. Study design, type of intervention, targeted tests, and reported outcomes were heterogeneous. The positive effects reported in nearly all studies and the insufficient detail in study descriptions make it difficult to replicate the studies or to identify the exact elements underlying success. Finally, sustainability of the effects was examined in only few studies. In nearly all studies, the authors concluded that their intervention was succesful; however, most studies merely reported a reduction in test order volume and no target for reduction was set at the outset, opening the way to considering the intervention succesful on the basis of any positive number. In addition, publication bias may be involved, in that mainly studies with positive outcomes are reported.

Although the interventions could be subdivided into three broad categories, the study designs, interventions, and tests targeted were rather heterogeneous. Moreover, the outcomes were reported in various ways (e.g., “reduction in total number of tests,” “number of tests per patient day,” “number of tests per patient,” “number of tests per day,” and “number of tests per month”). Therefore, we conclude that it is not possible to assess the individual effectiveness of different types of interventions.

A change in test utilization requires changes in provider awareness and behavior. Knowledge and attitude are concepts regularly targeted in acquiring and sustaining behavioral change [17]. Increase of knowledge is targeted through education. Attitude can be influenced through audit and feedback methods: knowing that one is being monitored may change one’s attitude towards testing, while feedback can also be a learning experience. (C)POE interventions focus directly on behavioral change, although they can contain educational elements as well. Because many interventions were not described in detail in the studies evaluated, it is difficult to identify which elements of an intervention led to success.

Although interventions from all categories seemed to be effective, most studies were relatively short and did not provide follow-up data to demonstrate the sustainability of the intervention. Another element to take into account when comparing interventions is adherence; in approximately half of the interventions, it was not clear to what extent care providers adhered to the interventions. Further, most studies did not use a control arm and had methodological limitations.

Many of the studies evaluated in this review focused on re-

ducing repeated monitoring tests or (accidental) duplicate requests instead of focusing on assessing whether certain tests were indeed indicated. Additionally, patient-related (clinical) outcomes were studied in only slightly more than half of the studies. These outcomes, such as mortality, length of hospital stay, and admission to the ICU, remained mostly unaffected, although they are crude and it is unclear to what extent these outcomes are linked to a reduction in laboratory testing. Further, studies might not have had sufficient power to demonstrate an effect on the reported clinical outcomes. Only a few studies have investigated consequences of reduced testing in terms of actually missing diagnosis [18-22]. This gives us the impression that reducing unnecessary testing has mostly focused on improvements in efficiency, without affecting patient outcomes.

1. Interventions with educational elements

Educational interventions provide an opportunity for a personal approach because physicians may be actively involved in the development and implementation of the intervention, e.g., through the development of guidelines. However, an element we did not often encounter in the studies we evaluated was to involve residents through educational sessions, flyers, e-mails, etc., which might further increase their commitment. A possible disadvantage to an educational approach is the amount of effort necessary to successfully carry out such an intervention. Here too, adherence might be a problem, as the extent to which care providers follow guidelines or algorithms, attend educational sessions, or read educational e-mails is often not clear.

2. Interventions with (C)POE elements

Most studies described in this review contain elements of changes in (C)POE systems. A major advantage of this type of intervention is the relatively little effort needed to carry out such an approach. While determining which modifications should be made in the order systems can be labor-intensive (e.g., how to modify order sets, how a new order form should be designed, and which time limits should be instated on which tests), once such modifications are implemented, no further action is needed. In general, provider adherence to these types of interventions is better than adherence to educational interventions since in most studies, all ordering providers receive the intervention upon ordering. Delvaux *et al* [23] recently published a systematic review on the effects of computerized clinical decision support systems on laboratory test ordering and noted that in the majority of studies, a positive effect was found in compliance with recommendations made by the order system.

3. Interventions with audit and feedback elements

In some studies, audits were performed to assess test order volume, while other studies also assessed test appropriateness. Providers were subsequently presented with data on their ordering patterns. The amount of effort this approach requires differs depending on the content and frequency of auditing and feedback. As was described in these studies, feedback can be provided about the entire study population or on an individual basis, with or without comparison to peers, and, in some cases, anonymously. The level of feedback might influence the extent of commitment [24, 25].

4. Comparison with the literature

In line with findings in other reviews on de-implementation, we found that most interventions were succesful [4, 13]. Because of the heterogeneity in the interventions studied and the outcomes reported, we found it difficult to compare effectiveness and to draw conclusions as to which intervention(s) is/are most successful. This difficulty was also encountered by Delvaux *et al* [23]. However, previous reviews stated that combined interventions appear to be more succesful than single interventions [4, 13].

Kobewka *et al* [4] reviewed 109 studies on interventions to reduce test utilization in both primary care facilities and hospital settings. In line with our findings, they found interventions from all categories to be successful. Further, they found that combined interventions were more effective than single interventions. To express median relative reduction, different outcome measures were combined. We found this approach questionable, even more so because the authors also found the effects of interventions to be different when these were expressed using a different outcome measure (e.g., Kumwilaisak *et al* [9] reported a 21% reduction in number of tests per patient per day, while the total number of tests decreased by 36% in the same study). Solomon *et al* [13] reviewed 49 studies on interventions aiming to improve physicians' testing practices and assessed methodological quality and efficacy of the interventions. Of 21 interventions using a single approach, 62% reported success, while 86% of 28 interventions using a combinatorial approach were successful.

5. Strengths and limitations

This review and the studies included have a number of strengths and limitations. A strength of this review is that it considered a variety of interventions and approaches to reduce unnecessary laboratory testing. In addition to assessing the reduction in test order volume, we were also interested in the effects of these interventions on patient-related clinical outcomes.

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A limitation is our exclusive focus on studies on reducing unnecessary testing in hospital settings, although we found that interventions carried out in primary care facilities were broadly similar to those we described [4, 26]. Further, we only included studies that reported a reduction in test order volume of all, not just a subset, of studied tests. In addition, we did not perform an exhaustive literature search; we concluded our search when we had, in our opinion, reached theoretical saturation and no new domains of interventions were found. Thus, we might have missed relevant articles. Finally, we did not assess the costs of development and implementation of interventions and the cost-benefit reducing laboratory testing yields.

6. Conclusions and implications for future research

In conclusion, there are various interventions to reduce unnecessary laboratory testing in the hospital setting. While the majority seems to be effective, the generalizability of the data is questionable and the data are not comparable. An important step in changing test-ordering behavior is changing the mindset of providers and for this purpose, even a few test items can be used to introduce the concepts related to unnecessary diagnostics. We do, however, believe that not all interventions are equally suitable in every setting and for every test targeted, e.g., instating time limits might be more suitable for tests that are (unnecessarily) ordered in high frequency, while education might be more suitable when aiming to reduce unnecessary arterial blood gas requests. Thus, investigators should consider the clinical setting, the providers, and the tests targeted when developing or implementing strategies for reduction. Reporting on interventions can be improved if articles share more details about the study design and intervention to allow replication. In addition, we recommend performing studies with relevant patient-related outcomes and the investigation of sustainability of the effect of interventions.

Authors' Disclosures of Potential Conflicts of Interest

No potential conflicts of interest relevant to this article were reported.

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Supplemental Data 1: Search terms

Search terms and combinations thereof used to find relevant articles describing interventions aimed at reducing unnecessary laboratory testing in the hospital setting in the PubMed, Embase, and Canadian Agency for Drugs and Technologies in Health-Health Technology Assessment databases

'laboratory test*' OR 'laboratory request*' OR 'laboratory order*' OR 'laboratory utilization', OR 'laboratory test utilization'

AND

'inappropriate' OR 'appropriate' OR 'reduce' OR 'reduction' OR 'improve' OR 'improving' OR 'improvement'

AND

'intervention*' OR 'strategy' OR 'strategies' OR 'education*' OR 'feedback'

Supplemental Data Table S2. Overview of individual studies

Ref	Interventions	Tests studied								Clin outcome	Adherence	Sustainability	Reproducibility
		All	Chem	Hem	Coag	Urine	TM	Endo	Other				
Education													
8	Presentations, discussions, flyers, email communication		X	X	X					Y	N	N	N
28	Team discussion during rounds		X							Y	N	N	Y
30	Implementation of a guideline		X							Y	N	N	Y
32	Range of educational efforts		X	X	X				X	Y	N	N	N
33	Implementation of standard operating protocols								X	N	N	N	N
18	Implementation of algorithm		X							Y	N	N	N
34	Implementation of guidelines		X							Y	N	N	N
35	Sessions on predictive value vs sessions on economic issues and cost control	X								Y	Y	N	N
36	Implementation of guideline and review of medical records vs no intervention		X	X						N	N	N	N
(C)POE													
Soft stop interventions													
39	Pop-up upon ordering second ionized test within 72 hours after normal test		X							Y	Y	Y	Y
41	Pop-up upon repeat order within specific time interval vs no intervention		X							Y	Y	N	Y
43	Pop-up upon ordering of potentially inappropriate test		X				X	X	X	N	Y	N	Y
45	Pop-up upon ordering if previous result within same hospital stay		X							N	Y	Y	Y
46	Pop-up if most recent result is less than 90 days old								X	Y	Y	N	Y
47	Pop-up upon potentially redundant ordering of test								X	N	Y	Y	Y
49	Pop-up upon ordering within time specific interval vs determination of redundancy and suppression of pop-up		X		X	X			X	Y	Y	N	N
Hard stop interventions													
19	Rejection if not ordered according to order frequency rule	X								Y	Y	Y	Y
16	Rejection if ordering within minimum retesting interval or if not meeting rules		X					X		Y	Y	N	Y
53	Pop-up upon ordering same-day duplicate test, rejection of unnecessary order	X								Y	Y	Y	Y
55	Rejection of order if previous result within 48 hours vs no intervention		X							N	Y	N	Y
57	Rejection of order if requested within certain time interval after previous test		X			X	X	X	X	N	Y	Y	Y
Hard stop vs soft stop interventions													
60	Blocking of tests deemed unnecessary more than once per day vs pop-up upon ordering of tests deemed unnecessary more than once per day	X								N	Y	N	Y

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Supplemental Data Table S2. Continued

Ref	Interventions	Tests studied								Clin outcome	Adherence	Sustainability	Reproducibility
		All	Chem	Hem	Coag	Urine	TM	Endo	Other				
Order form changes, display of fee													
62	Redesign of order form through re-categorization of target test		X							N	Y	N	Y
64	Revision of test panels, reducing the number from 171 to 60	X								N	Y	N	Y
66	Display of charge and turn-around-time upon ordering test vs no intervention								X	N	Y	N	Y
67	Limiting range of laboratory tests allowed to order by changing paper request form	X								N	Y	N	Y
69	Display of charge upon ordering vs no intervention		X	X	X	X	X	X	X	N	Y	N	Y
20	Redesign of order form: removing tickbox for target test, requiring written request						X			Y	Y	N	Y
71	Change in order form indicating appropriateness (overruling of recommendation by providing reason on sheet) and display of charge of tumor marker requests on order form						X			N	Y	Y	N
73	Display of charge on order form		X	X	X	X				Y	Y	N	Y
74	Redesign of order form displaying only boxes for clinical conditions instead of individual tests vs no intervention							X		N	N	Y	N
76	Unbundling and translocation of test panels, grouping tests, implementation of algorithms		X	X		X		X	X	N	Y	N	N
77	Elimination of predefined multitest panels		X							N	Y	N	N
79	Computerized display of charge upon ordering vs no intervention	X								Y	N	N	Y
80	Change in order form indicating appropriateness of request						X			N	Y	N	Y
Time limits on orders													
81	Elimination of ability to order daily recurrent tests		X	X	X					Y	Y	N	Y
83	Expiration of any laboratory order at 24 hours	X								N	Y	N	Y
85	Elimination of standing orders for laboratory studies	X								Y	N	N	N
Combined (C)POE & Others													
7	Time-limit on ordering, daily order set for appraisal of tests ordered daily, patient summary tab to permit rapid review of active orders		X	X	X					Y	Y	N	Y
88	Implementation of inpatient electronic health record with CPOE	X								Y	Y	N	N
90	Order form change through listing organs/diagnoses which directed to the test that could be requested, changing regulations for requests						X			N	Y	N	Y
92	Time-limit on ordering, display of previous test result upon ordering, display of testing guidelines		X							N	Y	Y	Y

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Supplemental Data Table S2. Continued

Ref	Interventions	Tests studied								Clin outcome	Adherence	Sustainability	Reproducibility
		All	Chem	Hem	Coag	Urine	TM	Endo	Other				
Others													
27	Review of microbiology send-out test requests								X	N	Y	N	Y
29	Review of reference test requests before approval								X	N	Y	N	Y
31	Review of reference test requests								X	N	Y	N	Y
15	Change of providers allowed to order tests, ordering individualized instead of through surgery-specific pathway	X								Y	Y	N	Y
Education & Audit/Feedback													
25	Information on charges, weekly feedback on mean volume and charges	X								N	N	N	Y
24	Presentations and flyers on high value care principles, pocket cards with charges, weekly feedback with peer comparison vs no intervention		X	X						Y	N	N	Y
3	Educational seminars on overutilization, weekly feedback reports on ordering habits		X	X	X				X	N	N	N	N
37	Implementation of guidelines, audit and feedback method not further specified		X							Y	N	N	N
10	Implementation of guidelines, lectures on use of laboratory tests, reminder letters, feedback on test use vs no intervention		X						X	N	N	Y	N
38	Emails with recommendations on laboratory ordering, monthly feedback		X	X						Y	N	N	N
40	Education regarding indications for target test ordering, physicians informed of results of previous audit on ordering behavior		X							N	N	N	N
42	Discussions of related literature, feedback on previous 3 years, feedback on first months after intervention		X							N	N	N	N
44	Guide with ordering rules and test costs, educational sessions, monthly feedback		X	X						Y	N	N	N
9	Implementation of ordering guidelines, monthly update on outcome	X								Y	Y	N	Y
11	Feedback on previous audit of appropriateness of testing, review of literature, discussion on strategies for reducing unnecessary testing		X	X						Y	Y	N	Y
48	Educational information, feedback on blood loss from phlebotomy	X								N	N	N	N
50	Implementation of guidelines, teaching sessions, monthly feedback on adherence and impact of guidelines vs no intervention		X							Y	Y	N	N
51	Teaching rounds, weekly review of cost data	X								Y	N	N	N
52	Discussing cost issues and unnecessary testing, feedback on ordering patterns relative to peers, implementation of guidelines		X	X	X	X				Y	N	N	Y

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Supplemental Data Table S2. Continued

Ref	Interventions	Tests studied								Clin outcome	Adherence	Sustainability	Reproducibility
		All	Chem	Hem	Coag	Urine	TM	Endo	Other				
Education & (C)POE													
54	Revision of protocols, lectures, omission of tests from standard panels, implementation of presets	X								N	Y	N	N
56	Alert upon ordering in specific patients, education through email								X	N	N	N	N
58	Implementation of guidelines, incorporation into admission templates on CPOE screen, educational sessions vs no intervention		X	X						Y	N	N	Y
59	Information campaign, clinical justification needed if more parameters ordered, implementation of algorithm							X	X	N	N	N	N
Education & Others													
61	Staff education, visual reminders, daily checklists		X	X	X					Y	N	N	N
63	Daily information for staff, reminders at bedside of test information and costs, incentive		X	X	X	X				Y	N	N	N
65	One day email discussions about utility and costs of CRP testing, no CRP day with gold coin penance if ordered		X							N	N	N	N
Audit/Feedback & (C)POE													
68	Implementation of computerized protocol management system, monthly summary of investigations used as basis for regular discussions		X							Y	Y	N	Y
(C)POE & Other													
70	Checklist enabling physicians to assess necessity for testing daily, restriction on scheduling tests to 24-hour interval		X	X	X					Y	N	N	N
72	Co-payment fee for nonemergent visits, reducing the number of eligible tests to order from the Emergency Department	X								N	Y	N	N
Education, (C)POE & Other													
75	Educational sessions, item on ICU checklist regarding routine blood tests, prompt in order system that compelled provider to specify indication for test		X	X						Y	N	N	Y
21	Implementation of guidelines, removal of tests from order set, pop-up warning upon ordering not according to specific rules, change of providers allowed to order tests		X							Y	N	N	Y
78	Implementation of protocol, rejection if request within 24 hours of previous request, consultant only requesting vs no intervention		X							N	N	N	N
22	Unbundling of panels, series of lectures on economic implications of excessive use of testing, supervision of ordering by senior physician vs no intervention	X								Y	N	Y	N

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Supplemental Data Table S2. Continued

Ref	Interventions	Tests studied								Clin outcome	Adherence	Sustainability	Reproducibility
		All	Chem	Hem	Coag	Urine	TM	Endo	Other				
Education, Audit/Feedback & Other													
14	30-minute discussion, pocket cards with charges, discussion of laboratory tests within rounds, incentive, monthly feedback of average and individual performance vs no intervention		X	X	X					Y	N	N	N
82	Implementation of guidelines, discouragement of use of panel, monthly feedback on ordering volume, financial incentive		X							Y	N	N	Y
84	Daily discussion of need for testing, daily coaching of resident, regular feedback on volume and costs, approval of superior needed for ordering daily tests	X								N	N	Y	N
86	One hour discussion, incentive, periodic feedback on performance in relation to testing goals vs one hour discussion, chart review sessions vs one hour discussion		X					X	X	Y	N	N	N
Education, Audit/Feedback & (C)POE													
87	Monthly discussions and feedback, unbundling panel	X								N	N	N	N
89	Educational sessions, feedback on results of previous audit, implementation of algorithm, replacement of four-component panel with two-component panel on order form				X					Y	N	Y	N
91	Restricting available emergency laboratory tests and allowed frequency of repeated orders, presentation on misuse of tests and restrictive strategy, feedback of results vs no intervention		X							Y	N	N	Y
Education, Audit/Feedback, (C)POE & Other													
93	Educational sessions and newsletters, quarterly feedback, elimination of standing daily orders, incentive		X	X	X					Y	N	Y	Y
94	Implementation of guidelines, educational campaign, feedback on individual provider level, removal of tests from quick-pick screen, pop-ups upon ordering specific tests, justification needed for requesting daily tests beyond 3 days, use of admission templates, discontinuing tests of limited usefulness	X								N	N	Y	N

Abbreviations: Clin, clinical; Ref, reference; Chem, chemistry; Hem, hematology; Coag, coagulation; TM, tumor markers; Endo, endocrinology; Y, yes; N, no.

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