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# Interventions to reduce repetitive ordering of low-value inpatient laboratory tests: a systematic review

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## ABSTRACT

**Background** Over-ordering of daily laboratory tests adversely affects patient care through hospital-acquired anaemia, patient discomfort, burden on front-line staff and unnecessary downstream testing. This remains a prevalent issue despite the 2013 Choosing Wisely recommendation to minimise unnecessary daily labs. We conducted a systematic review of the literature to identify interventions targeting unnecessary laboratory testing.

**Methods** We systematically searched MEDLINE, EMBASE, Cochrane Central and SCOPUS databases to identify interventions focused on reducing daily complete blood count, complete metabolic panel and basic metabolic panel labs. We defined interventions as 'effective' if a statistically significant reduction was attained and 'highly effective' if a reduction of ≥25% was attained.

**Results** The search yielded 5646 studies with 41 articles that met inclusion criteria. We grouped interventions into one or more categories: audit and feedback, cost display, education, electronic medical record (EMR) change, and policy change. Most interventions lasted less than a year and used a multipronged approach. All five strategies were effective in most studies with EMR change being the most commonly used independent strategy. EMR change and policy change were the strategies most frequently reported as effective. EMR change was the strategy most frequently reported as highly effective.

**Conclusion** Our analysis identified five categories of interventions targeting daily laboratory testing. All categories were effective in most studies, with EMR change being most frequently highly effective.

**PROSPERO registration number** CRD42021254076.

### WHAT IS ALREADY KNOWN ON THIS TOPIC

⇒ In 2013, Choosing Wisely recommended against performing complete blood count or basic chemistry tests in the face of clinical stability. Though many groups have attempted to follow this recommendation, existing literature is limited to small quality improvement projects and nonsystematic reviews.

### WHAT THIS STUDY ADDS

⇒ Our multidatabase search yielded over 5000 studies distilled down to 41 articles which we then systematically reviewed to categorise strategies for reducing unnecessary daily laboratory testing and identify the most highly effective interventions. All approaches demonstrated effectiveness with electronic medical record changes being the most commonly used independent strategy and the strategy most frequently categorised as highly effective.

### HOW THIS STUDY MIGHT AFFECT RESEARCH, PRACTICE OR POLICY

⇒ This study easily allows healthcare workers to identify high value care strategies applicable to their own institutions to reduce unnecessary daily laboratory testing.

## INTRODUCTION

One in every five inpatient laboratory tests ordered is unnecessary as it does not contribute to the advancement of patient care.[1] This high volume of repetitive lab testing is among the 4–5 billion tests that are performed within the USA each year, with approximately 200 billion dollars in annual healthcare spending attributed to excessive testing and treatment.[2 3] Moreover, unnecessary blood draws contribute to hospital-acquired anaemia, patient discomfort and excess downstream testing.[4 5] Drivers of inappropriate testing include defensive medicine and panel-based ordering.[1]

To help address and promote high value care, the Choosing Wisely Campaign recommended in 2013 against performing complete blood count (CBC) or basic chemistry tests 'in the face of clinical stability'.[6] Though many groups have attempted to follow this recommendation, there are limited synthesis and analysis of effective methods. One narrative review of 17 interventions suggests reduction in laboratory testing is best achieved through simultaneous interventions.[7] Our analysis builds on this review by seeking to categorise and identify the most highly effective interventions.

We performed a multidatabase systematic review to identify current methods for reducing unnecessary daily labs in the

inpatient setting and their effectiveness. This work can guide future interventions to reduce overall laboratory testing. This review focuses on interventions and outcomes specifically aimed at reducing the high volume of daily labs that do not contribute to the advancement of patient care.

## METHODS

### Systematic review registration

A protocol was developed and submitted to the International Prospective Register of Systematic Reviews (PROSPERO) on 10 May 2021 and registered on 10 June 2021 (registration number CRD42021254076).

### Inclusion and exclusion criteria

Studies evaluating interventions that aimed to reduce daily CBCs, comprehensive metabolic panel and BMPs (basic metabolic panel) in adult inpatient departments were included. Studies that focused on other tests such as coagulation or liver function tests, as per Choosing Wisely recommendations, were excluded.[6] All studies meeting the above criteria were included irrespective of year of publication and geographic location. Full text availability in English was required. Analyses of interventions in paediatric and intensive care unit populations were excluded. Cross-sectional studies without interventions were also excluded.

### Search strategy

We systematically searched MEDLINE, EMBASE, Cochrane Central and SCOPUS databases. Search terms included unnecessary lab testing, redundant labs, Choosing Wisely and high value care. Searches were performed before 14 April 2022. Search details can be seen in online supplemental file 1.

### Risk of bias

To identify risk of bias within the studies, the Newcastle-Ottawa Scale for Quality Assessment for cohort studies was used, which rated studies based on representativeness, ascertainment of exposure and outcomes, and comparability of groups and duration.[8] Studies could earn a total of eight points in eight separate categories (online supplemental table 1). A score of six or higher was considered good quality, five or less was considered fair quality and two or less was poor quality and thus high risk of bias.[8] Discrepancies were resolved by discussion between two reviewers (CB and BY).

### Study records

All database searches were extracted and uploaded to Covidence systematic review software (Veritas Health Innovation, Melbourne, Australia) for analysis of duplicates and further data management. Four reviewers (CB, BY, JDu and JYS) participated in the initial screen of studies. Each study was reviewed by a minimum of two reviewers with discrepancies reconciled jointly by two reviewers (CB and BY). Researchers (CB, BY, JDu, JYS, MSha, WZ and HL) systematically collected data on intervention method, primary outcome of reduction in labs ordered and cost reduction. Interventions were categorised as effective if a statistically significant reduction was attained and 'highly effective' if they achieved ≥25% reduction in primary outcome. The two groups were not mutually exclusive so interventions that were 'highly effective' were also classified as effective. Data were synthesised using general descriptive statistics.

## RESULTS

The systematic search yielded 5646 studies: 629 from Cochrane, 3380 from Embase, 1460 from Medline and 177 from SCOPUS, which were entered into Covidence. A total of 1384 duplicates were excluded. Of the remaining 4262 screened studies, 176 were advanced to full text screening, and ultimately 41 articles met all inclusion criteria.[9–49] Inter-rater reliability was moderate to substantial with a kappa statistic ranging from 0.40 between pairs of reviewers in the initial screening to 0.61 between final reviewers CB and BY.[50] Figure 1 demonstrates the Preferred Reporting Items for Systematic Reviews and Meta-Analyses flow diagram.

The study design and characteristics of these studies, including intervention types, are shown in online supplemental table 2. Of the 41 included papers, 35 were cohort studies, 4 were non-randomised control trials (RCTs)[30 34 35 48] and 2 were RCTs.[23 32] The majority of studies were published after 2014 (31 of 41). Most interventions took place in US academic hospitals and in a single healthcare setting. Assessment of risk of bias in the studies with the Newcastle-Ottawa Scale resulted in an average score of 7.8 out of 8, with scores ranging from 6 to 8, signifying high quality of studies. An intervention was considered successful if it resulted in a statistically significant reduction in lab ordering in comparison to a control period or group.

### Qualitative results

Interventions used to address laboratory overutilisation were grouped into five categories: audit and feedback, cost display, education, electronic medical record (EMR) change, and policy change. The most frequently used interventions were education (26 of 41 studies, 63.4%), followed by EMR change (19 of 41, 46.3%), audit and feedback (12 of 41, 29.3%), cost display (11 of 41, 26.8%) and policy change (10 of 41, 24.4%). Approaches included single interventions (14 of 41, 34.1%) and multiple interventions (27 of 41, 65.9%). Two of the included studies reported equivocal results in primary outcomes,[17 23] with the remainder reporting statistically significant reductions in daily labs ordered. Most studies (24 of 41, 58.5%) lasted less than 1 year.

### Audit and feedback

Audit and feedback was defined as an intervention that screened provider daily lab test ordering habits and provided reflective evaluation. This strategy was effective

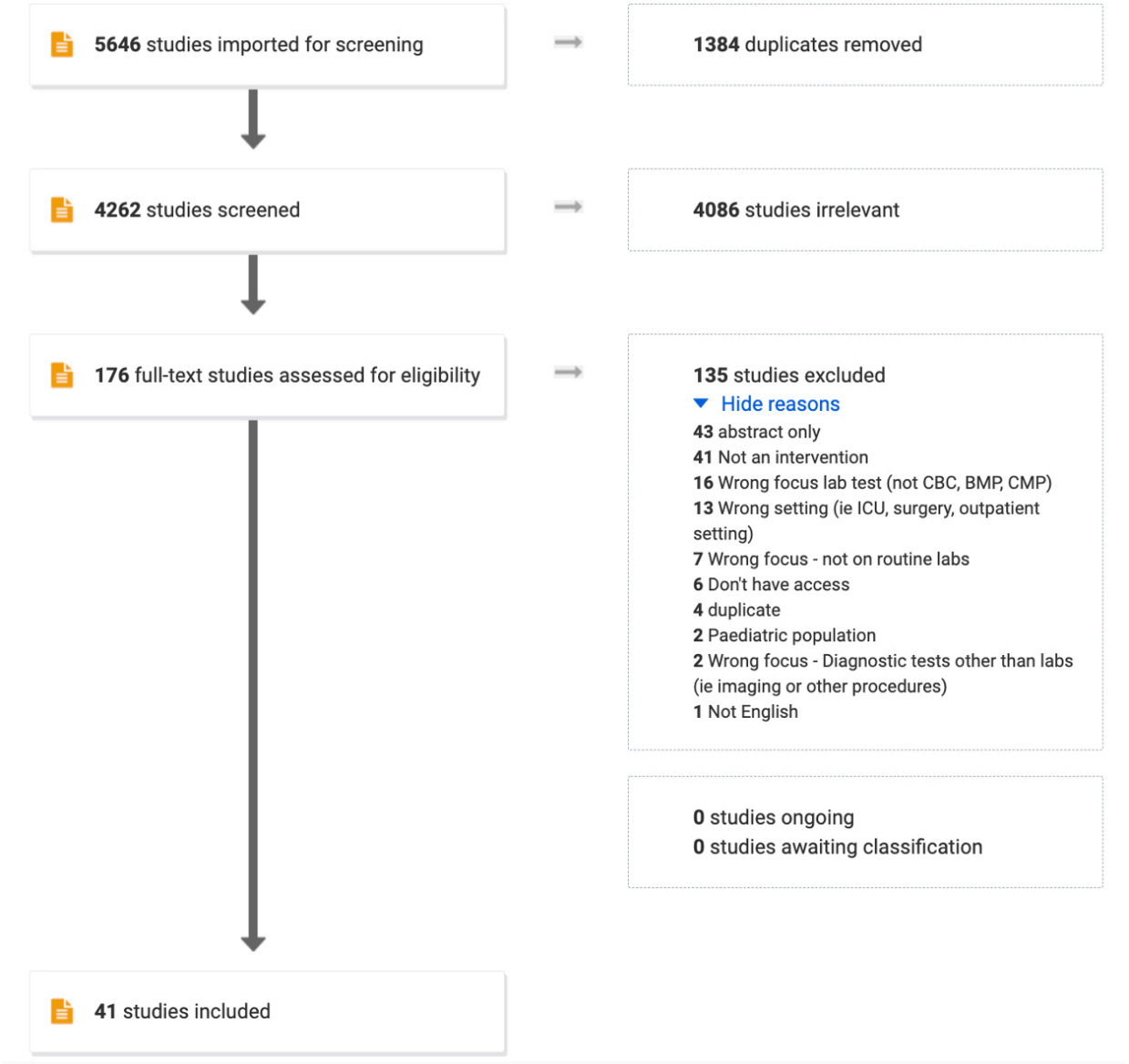


**Figure 1** Preferred Reporting Items for Systematic Reviews and Meta-Analyses flow diagram. BMP,basic metabolic panel; CBC, complete blood count; CMP, comprehensive metabolic panel; ICU, intensive care unit.

in 91.7% (11 of 12) and 'highly effective' in 8.3% (1 of 12) of the studies. Interventions provided feedback to frontline providers at weekly or monthly intervals. All 12 studies using audit and feedback as an intervention did so as a component of a combined intervention as opposed to an exclusive intervention. Corson *et al* incorporated audit and feedback with education via monthly emails and attributed their sustained success to a pre-existing culture of quality improvement in their facility.[27]

## Cost display

Cost display interventions provided laboratory test cost data to providers at the time of ordering. It was 'highly effective' in combination with education in 30% (3 of 10) of the studies. While only a single study used this approach exclusively, 22.0% (9 of 41) included cost display as a component of a multipronged intervention. Only one study, by Hirota *et al* used cost display alone. This study took place in Japan and juxtaposed standardised cases with and without cost display, resulting in significant cost savings and a reduction in labs ordered per patient.[40] Over half of the multi-intervention studies that included cost display used cost display coupled with education (7 of 10). Sommers *et al* did not find significant cost savings and included a qualitative approach to identify mitigators of the lack of impact.[23] They found that residents reported minimal cost-awareness education as well as systemic barriers to reduction in laboratory testing, including fear and attitudes of attendings.

## Education

Education was defined as any intervention that provided information to providers who ordered daily labs, excluding cost display, which was categorised separately. This intervention was effective in 42.3% (11 of 26) of studies and was highly effective in 19.2% (5 of 26) of studies. Education

was included as a component of combined interventions in 56% (23 of 41) of studies while only 7.3% (3 of 41) included this approach as their exclusive intervention. Of studies using education exclusively, 33.3% (1 of 3) were highly effective.[49] The most frequent combination was education coupled with policy change, which occurred in 34.6% (9 of 26) of included studies. Specific approaches to educational interventions varied significantly in their degree of proactivity. One study posted signs on physician computers outlining test-ordering recommendations.[45] Gupta *et al* developed lectures for residents and allotted time for resident teams to peer-review orders.[33] Meanwhile, Almeqdadi *et al* incorporated audit and feedback with biweekly discussions of repercussions of unnecessary daily labs and provided positive reinforcement incentives (such as food) for those who followed the suggested guidelines.[44] All three of these papers demonstrated successful reductions in laboratory test ordering.

### EMR change

EMR change was defined as interventions that targeted reduction in lab ordering through electronic means, such as directly restricting the frequency of ordering or implementing pop-up alerts. This strategy was effective in 100% of studies (19 of 19) and highly effective in 21% (4 of 19) of studies. Most single intervention studies used EMR change (10 of 14, 71.4%). Among these single intervention studies, 30% (3 of 10) were highly effective.[13 19 20] An additional 33% (9 of 27) of the multi-intervention studies included EMR change as a component of their combined interventions. EMR change interventions were associated with success in lab test reduction but were also met with negative feedback from affected providers. One study that exclusively used an EMR change to eliminate the ability to order daily recurring tests demonstrated success in reduction of less commonly tested labs, such as coagulation studies and hepatic function panels, but did not reduce CBCs or BMPs.[29] Importantly, 43% of surveyed providers reported negative experiences with this intervention and identified an increase in workload as a result of the EMR change.[29] Procop *et al* demonstrated the use of a demanding decision support tool that was more effective in reducing the number of duplicate tests ordered compared with a less stringent counterpart.[26] However, it is important to note that the 'Hard Stop' section of this study, which entailed a stricter protocol to limit lab orders, was less favoured by many physicians and was anticipated to cause a diversion of test ordering to downstream medical staff. In this vein, EMR changes that gave providers the power to override pop-ups resulted in more favourable feedback.[19]

### Policy change

Policy change was defined as any institutional modification, such as workflow change, implemented without adjusting the EMR. This strategy was effective in 100% of studies using this approach (9 of 9) and highly effective in 22% (2 of 9) of interventions. No studies exclusively used policy change, though it was incorporated in 22.0% (9 of 41) of included studies. Some examples of policy change included audit without feedback where auditors were required to use stricter guidelines in evaluating appropriateness of tests ordered and site-specific lab-ordering guidelines that required increasing provider justification for ordering labs in clinically stable patients.[22 36]

### Single intervention versus multiple interventions

Most studies (27 of 41) implemented a strategy that included multiple interventions. Of the 14 studies with single intervention approaches, all were effective at reducing unnecessary daily laboratory testing. EMR change was the most common exclusive intervention approach (nine studies), followed by education (three studies) and cost display (one study).

The most common intervention combinations included education with policy change (eight studies) and education with cost display (seven studies). Combinations of audit and feedback with education were seen in nine studies while audit and feedback with education and EMR change was reported in three studies. Interventions combining education, EMR change and policy change occurred in four studies. One large-scale, multifacility study demonstrated simultaneous interventions at four different hospitals that included components of audit and feedback, EMR change, and education, with success at three of the four hospitals.[43] The unsuccessful site had the least staffing with only a single resident who rotated during the period, as well as less investment in scrutinising lab ordering in the outpatient department. Nonetheless, this multimodal intervention received significant positive feedback regarding resident involvement in changing organisational culture.[43]

### Sustainability

Of the 24 studies that took place with a duration of 1 year or less, all but two demonstrated a significant change from preintervention to postintervention.[17 23] Most of the single intervention studies (8 of 14, 57.1%) had a duration of 1 year or less.[19 34 39 40 42 44 45 47]

All the studies (17 of 17) conducted over more than 1 year were successful in significantly decreasing the number of laboratory tests ordered.[18 20 21 24 25 28 29 31 33 35 37 38 41 43 46–48] The average length of these studies was 28.9 months. Eleven of the 19 studies lasting greater than 1 year used multiple interventions. The most common intervention for this group of studies was EMR change (5 of 19), followed by a combination of audit and feedback, education, and EMR change (4 of 19). Two studies demonstrated consistent and significant reduction in laboratory testing across multiple years. Konger *et al*, one of four studies with the longest duration of intervention (36 months), demonstrated significant sustainable reduction in laboratory testing across consecutive years of the study.[28] Similarly, Vidyarthi *et al* also demonstrated sustained decreases in total test volume across a 3-year interval.[25]

### Randomised controlled trials

Two randomised controlled trials were included. The trial by Wertheim *et al* examined a strategy of EMR change combined with education and policy change and reported a 9% reduction in aggregate labs.[32] The authors randomised medical teams comprised of residents and attendings to either intervention or control groups. The reduction was primarily driven by decreased ordering of BMP and CBC without differential; hepatic function panel, coagulation studies and other electrolytes were not affected. Sommers *et al* investigated education and cost display through a clustered RCT of 33 teams made up of 96 residents that entailed a 45 min educational session focused on reviewing a hospital bill for one of the resident's patients.[23] They aimed at reducing patient cost burden through reduction of unnecessary lab ordering. No significant difference in lab costs between the intervention and control groups was achieved.

## DISCUSSION

This systematic review identified 41 studies using five primary strategies for lab reduction: education, cost display, audit and feedback, EMR change, and policy change. All five strategies were effective in most studies. EMR change and policy change were the strategies most often reported to be effective. One-quarter of studies included were highly effective (defined as providing 25% or greater reduction in labs). When considering both sustainability and effectiveness of interventions, EMR change stood out in both dimensions. It was the strategy that was most often found to be highly effective when used as an exclusive intervention but was unfavourable among providers when strict limitations in ordering or unavoidable pop-up alerts were implemented. While other interventions such as cost display, education and policy change were similarly highly effective, they were primarily used in multifaceted interventions and less is known about their individual efficacy and sustainability. Our findings expand on previously noted trends.[7]

This systematic review adds to the prior literature review because it includes a larger number of studies, standardises components of analysis and introduces a benchmark to define the effectiveness of lab reduction across various interventions.[7] Identifying and categorising interventions into five strategies facilitates systemisation and comparison of the efficacy of such interventions, despite wide heterogeneity. This systematic review also comments on the reliability of studies including the risk of bias and unintended consequences for providers experiencing such interventions, such as dissatisfaction with overly stringent EMR changes.

Our findings suggest that institutions can develop impactful and sustainable models based on common organisational tools and mechanisms for improvement, such as EMR enhancements and hospital-based policy development. A supportive approach will be important in the implementation of any change. For example, new EMR requirements can contribute to burnout, but when done thoughtfully can provide highly effective and sustainable interventions.

This analysis has several limitations. Most importantly, only two of the identified studies were randomised controlled trials and most used pre–post analysis as opposed to a simultaneous control. One of the two randomised trials achieved a significant reduction in lab orders.[23 32] Though the low number of randomised trials precludes definitive conclusions, the non-randomised design of many of the published studies reflects the nature of most quality improvement initiatives and the consistency of results across the identified studies supports the primary conclusions. In addition, most studies were conducted within a single institution. Hospital leaders implementing EMR and policy changes across multiple sites will need to account for local differences, such as hospital culture and whether the same EMR is used. Additionally, most of the interventions lasted less than 1 year and none of the studies addressed turnover of house-staff as a factor in ordering practices, a key limitation for academic medical centres. The heterogeneous design of the studies and lack of primary data do not allow for a formal meta-analysis. Similarly, there is publication bias as interventions that were not successful were less likely to have been submitted or accepted for publication. Finally, while most studies demonstrated significantly reduced lab orders, successful interventions do not necessarily equate to reduced needle-sticks for patients, reduced cost, reduced phlebotomy labour or improved patient satisfaction.

Almost a decade has passed since the Choosing Wisely guidelines first recommended restricting daily lab ordering for clinically stable patients, yet this issue remains pervasive and challenging to address. This review identifies strategies that have the potential to reduce unnecessary laboratory testing when used alone or in combination and suggests that EMR change may be the most effective strategy.

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**Contributors** CB, BY, ST, AL, AD and MShy contributed to the design of the study. CB, BY, JDu and JYS participated in the initial screen of studies. BY, CB, JDu, JSY, MShy, WZ and HL systematically collected data. BY, CB and JDi performed analysis

of the results. BY, CB, AD, MShy, MSha, AL, ST contributed to the writing of the manuscript. BY is the designated gaurantor.

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**Competing interests** None declared.

**Patient and public involvement** Patients and/or the public were not involved in the design, or conduct, or reporting, or dissemination plans of this research.

**Patient consent for publication** Not applicable.

**Ethics approval** This study did not require institutional review board approval as it was limited to a systematic review of the literature.

**Provenance and peer review** Not commissioned; externally peer reviewed.

**Data availability statement** All data relevant to the study are included in the article or uploaded as online supplemental information.



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**Supplement: Search criteria for each database**

**Cochrane**

ID Search Hits

#1 ((Unnecessary test*)):ti,ab,kw

#2 MeSH descriptor: [Unnecessary Procedures] explode all trees 144

#3 ((Unnecessary lab*)):ti,ab,kw 481

#4 ((Low-value care)):ti,ab,kw 73

#5 (((Lab OR laboratory) NEAR/3 overutilization)):ti,ab,kw 1

#6 (((Lab OR laboratory) NEAR/3 burden)):ti,ab,kw 11

#7 (((Complete Metabolic Panel OR CMP) NEAR/3 unnecessary)):ti,ab,kw 3

#8 (((Complete Blood Count OR CBC) NEAR/3 unnecessary)):ti,ab,kw 37

#9 (((Basal Metabolic Panel OR BMP) NEAR/3 unnecessary)):ti,ab,kw 1

#10 ((Repetitive NEAR/3 lab*)):ti,ab,kw 4

#11 ((Redundant NEAR/3 lab*)):ti,ab,kw 2

#12 ((Unnecessary NEAR/3 laboratory)):ti,ab,kw 21

#13 ((Unnecessary NEAR/3 testing)):ti,ab,kw69

#14 ((Choosing wisely)):ti,ab,kw 72

#15 ((hospital*)):ti,ab,kw 201408

#16 ((inpatient*)):ti,ab,kw 20029

#17 ((emergency department* OR ED OR emergency room* OR ER)):ti,ab,kw 28352

#18 2-#14,49 1857

#19 {OR #15-#17} 226492

#20 #18 AND #19 with Publication Year from 2021 to 2022, in Trials 54

**Scopus Search**

( TITLE-ABS-KEY ( ( unnecessary AND test* ) OR ( unnecessary AND lab* ) OR "Low-value care" OR "choosing AND wisely" OR ( ( lab OR laboratory ) W/3 overutilization ) OR ( ( lab OR laboratory ) W/3 burden ) OR ( ( "Complete Metabolic Panel" OR cmp ) W/3 unnecessary ) OR ( ( "Complete Blood Count" OR cbc ) W/3 unnecessary ) OR ( ( "Basal Metabolic Panel" OR bmp ) W/3 unnecessary ) OR ( repetitive W/3 lab* ) OR ( redundant W/3 lab* ) OR ( unnecessary W/3 laboratory ) OR ( unnecessary W/3 testing ) ) AND TITLE-ABS-KEY ( hospital* OR inpatient* OR ( emergency AND department* ) OR ed OR ( emergency AND room* ) OR er ) )

**Embase Classic+Embase <1947 to 2021 May 06>**
1 (Unnecessary adj3 test*).mp. [mp=title, abstract, heading word, drug trade name, original title,
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device manufacturer, drug manufacturer, device trade name, keyword, floating subheading word,
candidate term word] 659
3 (Low-value care or Low-value test*).mp. 470
4 ((Lab or laboratory) adj3 overutilization).mp. 32
5 ((Lab or laboratory) adj3 burden).mp. 178
6 ((Complete Metabolic Panel or CMP) adj3 unnecessary).mp. [mp=title, abstract, heading word,
drug trade name, original title, device manufacturer, drug manufacturer, device trade name, keyword,
floating subheading word, candidate term word] 1
7 ((Complete Blood Count or CBC) adj3 unnecessary).mp. [mp=title, abstract, heading word, drug
trade name, original title, device manufacturer, drug manufacturer, device trade name, keyword, floating
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8 ((Basal Metabolic Panel or BMP) adj3 unnecessary).mp. [mp=title, abstract, heading word, drug
trade name, original title, device manufacturer, drug manufacturer, device trade name, keyword, floating
subheading word, candidate term word] 1
9 (Repetitive adj3 lab*).mp. [mp=title, abstract, heading word, drug trade name, original title, device
manufacturer, drug manufacturer, device trade name, keyword, floating subheading word, candidate term
word] 209
10 (Redundant adj3 lab*).mp. [mp=title, abstract, heading word, drug trade name, original title,
device manufacturer, drug manufacturer, device trade name, keyword, floating subheading word,
candidate term word] 79

11 (Lab* adj3 (frequent or frequency)).mp. [mp=title, abstract, heading word, drug trade name,
original title, device manufacturer, drug manufacturer, device trade name, keyword, floating subheading
word, candidate term word] 3164
12 (Unnecessary adj3 laboratory).mp. [mp=title, abstract, heading word, drug trade name, original
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candidate term word] 426
13 (Unnecessary adj3 testing).mp. [mp=title, abstract, heading word, drug trade name, original title,
device manufacturer, drug manufacturer, device trade name, keyword, floating subheading word,
candidate term word] 2314
14 choosing wisely.mp. 1628
15 hospitals/ or hospitals, community/ or hospitals, general/ or hospitals, group practice/ or hospitals,
high-volume/ or hospitals, low-volume/ or hospitals, private/ or hospitals, public/ or hospitals, rural/ or
hospitals, satellite/ or hospitals, special/ or hospitals, teaching/ or hospitals, urban/ or mobile health units/
or secondary care centers/ or tertiary care centers/ 622267
16 hospital*.mp. 2873573
17 Inpatients/ 163779
18 inpatient*.mp. 200089
19 exp Emergency Service, Hospital/ 6326
20 (emergency department* or ED or emergency room or ER).mp. 418819
21 1 or 2 or 3 or 4 or 5 or 6 or 7 or 8 or 9 or 10 or 11 or 12 or 13 or 14 10293
22 15 or 16 or 17 or 18 or 19 or 20 3209254
23 21 and 22 3280

**Ovid MEDLINE(R) and Epub Ahead of Print, In-Process, In-Data-Review & Other Non-Indexed
Citations and Daily <1946 to May 06, 2021>**
1 (Unnecessary adj3 test*).mp. [mp=title, abstract, original title, name of substance word, subject
heading word, floating sub-heading word, keyword heading word, organism supplementary concept word,

protocol supplementary concept word, rare disease supplementary concept word, unique identifier,
synonyms] 2476
2 (Unnecessary adj3 lab*).mp. [mp=title, abstract, original title, name of substance word, subject
heading word, floating sub-heading word, keyword heading word, organism supplementary concept word,
protocol supplementary concept word, rare disease supplementary concept word, unique identifier,
synonyms] 387
3 (Low-value care or Low-value test*).mp. 344

4 ((Lab or laboratory) adj3 overutilization).mp. 25
5 ((Lab or laboratory) adj3 burden).mp. 80
6 (Complete Metabolic Panel or CMP).mp. [mp=title, abstract, original title, name of substance
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concept word, protocol supplementary concept word, rare disease supplementary concept word, unique
identifier, synonyms] 4640
7 (Complete Blood Count or CBC).mp. [mp=title, abstract, original title, name of substance word,
subject heading word, floating sub-heading word, keyword heading word, organism supplementary
concept word, protocol supplementary concept word, rare disease supplementary concept word, unique
identifier, synonyms] 8869
8 (Basal Metabolic Panel or BMP).mp. [mp=title, abstract, original title, name of substance word,
subject heading word, floating sub-heading word, keyword heading word, organism supplementary
concept word, protocol supplementary concept word, rare disease supplementary concept word, unique
identifier, synonyms] 19931
9 (Repetitive adj3 lab*).mp. [mp=title, abstract, original title, name of substance word, subject
heading word, floating sub-heading word, keyword heading word, organism supplementary concept word,

protocol supplementary concept word, rare disease supplementary concept word, unique identifier,
synonyms] 172
10 (Redundant adj3 lab*).mp. [mp=title, abstract, original title, name of substance word, subject
heading word, floating sub-heading word, keyword heading word, organism supplementary concept word,
protocol supplementary concept word, rare disease supplementary concept word, unique identifier,
synonyms] 58
11 (Lab* adj3 (frequent or frequency)).mp. [mp=title, abstract, original title, name of substance word,
subject heading word, floating sub-heading word, keyword heading word, organism supplementary
concept word, protocol supplementary concept word, rare disease supplementary concept word, unique
identifier, synonyms] 1919
12 (Unnecessary adj3 laboratory).mp. [mp=title, abstract, original title, name of substance word,
subject heading word, floating sub-heading word, keyword heading word, organism supplementary
concept word, protocol supplementary concept word, rare disease supplementary concept word, unique
identifier, synonyms] 278
13 (Unnecessary adj3 testing).mp. [mp=title, abstract, original title, name of substance word, subject
heading word, floating sub-heading word, keyword heading word, organism supplementary concept word,
protocol supplementary concept word, rare disease supplementary concept word, unique identifier,
synonyms] 1245
14 choosing wisely.mp. 927
15 hospitals/ or hospitals, community/ or hospitals, general/ or hospitals, group practice/ or hospitals,
high-volume/ or hospitals, low-volume/ or hospitals, private/ or hospitals, public/ or hospitals, rural/ or
hospitals, satellite/ or hospitals, special/ or hospitals, teaching/ or hospitals, urban/ or mobile health units/
or secondary care centers/ or tertiary care centers/ 185811
16 hospital*.mp. 1690905

17 Inpatients/ 23645
18 inpatient*.mp. 126877
19 exp Emergency Service, Hospital/ 83902
20 (emergency department* or ED or emergency room or ER).mp. 264979
21 1 or 2 or 3 or 4 or 5 or 6 or 7 or 8 or 9 or 10 or 11 or 12 or 13 or 14 39349
22 15 or 16 or 17 or 18 or 19 or 20 1923086
23 21 and 22 3744
24 (Unnecessary adj3 test*).mp. [mp=title, abstract, original title, name of substance word, subject
heading word, floating sub-heading word, keyword heading word, organism supplementary concept word,
protocol supplementary concept word, rare disease supplementary concept word, unique identifier,
synonyms] 2476
25 (Unnecessary adj3 lab*).mp. [mp=title, abstract, original title, name of substance word, subject
heading word, floating sub-heading word, keyword heading word, organism supplementary concept word,
protocol supplementary concept word, rare disease supplementary concept word, unique identifier,
synonyms] 387
26 (Low-value care or Low-value test*).mp. 344
27 ((Lab or laboratory) adj3 overutilization).mp. 25
28 ((Lab or laboratory) adj3 burden).mp. 80
29 ((Complete Metabolic Panel or CMP) adj3 unnecessary).mp. [mp=title, abstract, original title,
name of substance word, subject heading word, floating sub-heading word, keyword heading word,
organism supplementary concept word, protocol supplementary concept word, rare disease
supplementary concept word, unique identifier, synonyms] 0
30 ((Complete Blood Count or CBC) adj3 unnecessary).mp. [mp=title, abstract, original title, name of
substance word, subject heading word, floating sub-heading word, keyword heading word, organism
supplementary concept word, protocol supplementary concept word, rare disease supplementary concept
word, unique identifier, synonyms] 1
31 ((Basal Metabolic Panel or BMP) adj3 unnecessary).mp. [mp=title, abstract, original title, name of

substance word, subject heading word, floating sub-heading word, keyword heading word, organism
supplementary concept word, protocol supplementary concept word, rare disease supplementary concept
word, unique identifier, synonyms] 1
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heading word, floating sub-heading word, keyword heading word, organism supplementary concept word,
protocol supplementary concept word, rare disease supplementary concept word, unique identifier,
synonyms] 172
33 (Redundant adj3 lab*).mp. [mp=title, abstract, original title, name of substance word, subject
heading word, floating sub-heading word, keyword heading word, organism supplementary concept word,
protocol supplementary concept word, rare disease supplementary concept word, unique identifier,
synonyms] 58
34 (Lab* adj3 (frequent or frequency)).mp. [mp=title, abstract, original title, name of substance word,
subject heading word, floating sub-heading word, keyword heading word, organism supplementary
concept word, protocol supplementary concept word, rare disease supplementary concept word, unique
identifier, synonyms] 1919
35 (Unnecessary adj3 laboratory).mp. [mp=title, abstract, original title, name of substance word,
subject heading word, floating sub-heading word, keyword heading word, organism supplementary
concept word, protocol supplementary concept word, rare disease supplementary concept word, unique
identifier, synonyms] 278
36 (Unnecessary adj3 testing).mp. [mp=title, abstract, original title, name of substance word, subject
heading word, floating sub-heading word, keyword heading word, organism supplementary concept word,
protocol supplementary concept word, rare disease supplementary concept word, unique identifier,
synonyms] 1245

37 choosing wisely.mp. 927
38 hospitals/ or hospitals, community/ or hospitals, general/ or hospitals, group practice/ or hospitals,
high-volume/ or hospitals, low-volume/ or hospitals, private/ or hospitals, public/ or hospitals, rural/ or
hospitals, satellite/ or hospitals, special/ or hospitals, teaching/ or hospitals, urban/ or mobile health units/
or secondary care centers/ or tertiary care centers/ 185811
39 hospital*.mp. 1690905
40 Inpatients/ 23645
41 inpatient*.mp. 126877
42 exp Emergency Service, Hospital/ 83902
43 (emergency department* or ED or emergency room or ER).mp. 264979
44 24 or 25 or 26 or 27 or 28 or 29 or 30 or 31 or 32 or 33 or 34 or 35 or 36 or 37 6049
45 38 or 39 or 40 or 41 or 42 or 43 1923086
46 44 and 45 1406

| Author | Year | Title | Representativeness of the Exposed Cohort | Selection of the non-exposed cohort | Ascertainment of exposure | Demonstration that outcome of interest was not present at start of study | Comparability of cohorts on the basis of the design or analysis | Assessment of outcome | Was follow-up long enough for outcomes to occur | Adequacy of follow up of cohorts | Total Score |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Thurm | 2021 | Reducing the number of unnecessary laboratory tests within hospital through the use of educational interventions | * | * | * | * | * | * | * | * | 8 |
| Fisher et al. | 2021 | Reducing inappropriate blood testing in haematology inpatients: A multicenter quality improvement project | * | * | * | * | * | * | * | * | 8 |
| Chin et al. | 2021 | A minimalist electronic health record-based intervention to reduce standing lab utilization | * | * | * | * | * | * | * | * | 8 |
| Basuita et al. | 2020 | Reducing Inappropriate Laboratory Testing in the Hospital Setting: How Low Can We Go? | * | * | * | * | | * | * | * | 7 |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Wiens et al. | 2020 | Signage as an intervention on a general medicine ward to reduce unnecessary testing | * | * | * | * | * | * | * | * | 8 |
| Almeqdadi et al. | 2019 | A Quality Improvement Project to Reduce Overutilization of Blood Tests in a Teaching Hospital | * | * | * | * | * | * | * | * | 8 |
| Bindraban et al. | 2019 | Association of a Multifaceted Intervention With Ordering of Unnecessary Laboratory Tests Among Caregivers in Internal Medicine Departments | * | * | * | * | * | * | * | * | 8 |
| Coberly et al. | 2019 | Evidence-Based Duplicate Order Alerts Promote Effective Test Utilization and Reduce Unnecessary Laboratory Testing | * | * | * | * | * | * | * | * | 7 |
| Erard et al. | 2019 | A multi-level strategy for a long-lasting reduction in unnecessary laboratory testing: A multicenter before and after study in a teaching hospital network | * | * | * | * | * | * | * | * | 8 |
| Hirota et al. | 2019 | The Effectiveness of Cost Reduction with Charge Displays on Test Ordering under the Health Insurance System in Japan: A Study Using Paper-based Simulated Cases for Residents and Clinical Fellows | * | * | | * | * | | * | * | 6 |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Lapic et al. | 2019 | Effectiveness of minimum retesting intervals in managing repetitive laboratory testing: Experience from a Croatian university hospital | * | | * | * | * | * | * | * | 7 |
| Shinwa het al | 2019 | "THINK" Before You Order: Multidisciplinary Initiative to Reduce Unnecessary Lab Testing | * | * | * | * | * | * | * | * | 8 |
| Faisal et al. | 2018 | Reducing the number of unnecessary routine laboratory tests through education of internal medicine residents | * | * | * | * | * | * | * | * | 8 |
| Bejjanki et al. | 2018 | The role of a best practice alert in the electronic medical record in reducing repetitive lab tests | * | * | * | * | * | * | * | * | 8 |
| Tsega et al. | 2018 | Bedside Assessment of the Necessity of Daily Lab Testing for Patients Nearing Discharge | * | * | * | * | * | * | * | * | 8 |
| Ambasta, Anshula | 2017 | Impact of an education and multilevel social comparison-based intervention bundle on use of routine blood tests in hospitalized patients at an academic tertiary care hospital: a controlled pre-intervention post-intervention study | * | | * | * | * | * | * | * | 7 |
| Bellodi et al. | 2017 | Economic and organizational impact of a clinical decision support | * | * | * | * | * | * | * | * | 8 |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | system on laboratory test ordering | | | | | | | | | |
| Gupta et al. | 2017 | Results of a Quality Improvement Project Aimed at Eliminating Healthcare Waste by Changing Medical Resident Test Ordering Behavior | * | * | | * | * | | * | * | 8 |
| McDonald et al. | 2017 | Mindfulness-Based Laboratory Reduction: Reducing Utilization Through Trainee-Led Daily 'Time Outs' | * | * | * | * | * | * | * | * | 8 |
| Melendez-Rosado et al. | 2017 | Reducing unnecessary testing: an intervention to improve resident ordering practices | * | * | * | * | * | * | * | * | 8 |
| Wertheim et al. | 2017 | An Educational and Administrative Intervention to Promote Rational Laboratory Test Ordering on an Academic General Medicine Service | * | * | * | * | * | * | * | * | 8 |
| Sadowski et al. | 2017 | High-Value, Cost-Conscious Care: Iterative Systems-Based Interventions to Reduce Unnecessary Laboratory Testing | * | * | * | * | * | * | * | * | 8 |
| Tawfik et al. | 2017 | House Officer-Driven Reduction in Laboratory Utilization | * | * | * | * | * | * | * | * | 8 |
| Iams et al. | 2016 | A Multidisciplinary Housestaff-Led Initiative to Safely Reduce Daily Laboratory Testing | * | * | * | * | * | * | * | * | 8 |
| Galovic et al. | 2016 | Minimum retesting intervals - application through electronic order forms on | * | * | * | * | * | * | * | * | 8 |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | common laboratory tests | | | | | | | | | |
| Iturrate et al. | 2016 | Optimize Your Electronic Medical Record to Increase Value: Reducing Laboratory Overutilization | * | * | * | * | * | * | * | * | 8 |
| Konger et al. | 2016 | Reduction in Unnecessary Clinical Laboratory Testing Through Utilization Management at a US Government Veterans Affairs Hospital | * | * | * | * | * | * | * | * | 8 |
| Corson et al. | 2015 | A multifaceted hospitalist quality improvement intervention: Decreased frequency of common labs | * | * | * | * | * | * | * | * | 8 |
| Procop et al. | 2015 | Reducing Duplicate Testing: A Comparison of Two Clinical Decision Support Tools | * | * | * | * | | * | * | * | 7 |
| Vidyarthi et al. | 2015 | Changing resident test ordering behavior: a multilevel intervention to decrease laboratory utilization at an academic medical center | * | * | * | * | * | * | * | * | 8 |
| Minerowicz et al. | 2015 | Impact of weekly feedback on test ordering patterns | * | * | * | * | * | * | * | * | 8 |
| Sommers et al. | 2012 | An educational intervention to improve cost-effective care among medicine housestaff: a randomized controlled trial | * | * | * | * | * | * | * | * | 8 |
| Vegting et al. | 2012 | How to save costs by reducing | * | * | * | * | * | * | * | * | 8 |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | unnecessary testing: lean thinking in clinical practice | | | | | | | | | |
| Waghol ikar et al. | 2011 | Observing effectiveness of pathology ordering controls in emergency departments | * | * | * | * | * | * | * | * | 8 |
| May et al. | 2006 | Reducing unnecessary inpatient laboratory testing in a teaching hospital | * | | * | * | | * | * | * | 6 |
| Miyakis et al. | 2006 | Factors contributing to inappropriate ordering of tests in an academic medical department and the effect of an educational feedback strategy | | * | * | * | * | * | * | * | 7 |
| Calder on-Margali t et al. | 2005 | An administrative intervention to improve the utilization of laboratory tests within a university hospital | * | * | * | * | * | * | * | * | 8 |
| Neilson et al. | 2004 | The impact of peer management on test-ordering behavior | * | * | * | * | * | * | * | * | 8 |
| Bates et al. | 1999 | A randomized trial of a computer-based intervention to reduce utilization of redundant laboratory tests | * | * | * | * | * | * | * | * | 8 |
| Gortma ker et al. | 1988 | A successful experiment to reduce unnecessary laboratory use in a community hospital | * | * | * | * | * | * | * | * | 8 |
| Grivell et al. | 1981 | Effect of feedback to clinical staff of information on | * | * | * | * | * | * | * | * | 8 |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | clinical biochemistry requesting patterns | | | | | | | | | |

**Supplement Table 1:** Newcastle Ottawa Scale

| Title | Author | Year | Journal | Total study duration (months) | Study Design | Intervention(s) tested | Description of Intervention | Summary data for each intervention group |
|---|---|---|---|---|---|---|---|---|
| Reducing the number of unnecessary laboratory tests within hospital through the use of educational interventions | Thurm | 2021 | Annals of Clinical Biochemistry | 1 month | Cohort study | Education | Combination of educational lectures and poster intended to incentivize physicians to evaluate whether blood testing was clinically indicated | 33% reduction (P<0.0001) in laboratory tests ordered and about $9,200 in savings. Statistically significant reduction at eight of the nine sites where the study was undertaken |
| Reducing inappropriate blood testing in haematology inpatients: A multicenter quality improvement project | Fisher et al. | 2021 | Clinical Medicine (London) | 48 months | Control trial (non-randomized) | Education + Policy change | Blood testing schedule (BTS) and education intervention designed by junior physicians with 3 PDSA cycles | 24.7% reduction in inappropriate tests with estimated cost savings of 38,000 Euros per year |
| A minimalist electronic health record-based intervention to reduce standing lab utilization | Chin et al. | 2021 | Postgrad Medical Journal | 24 months | Cohort study | EMR change | Providers required to specify number of laboratory tests in EMR instead of indefinite ordering | CBC with differential decreased by 9% (P<0.0001) on General Medicine service |
| Reducing Inappropriate Laboratory Testing in the Hospital Setting: How Low Can We Go? | Basuita et al. | 2020 | Journal of Clinical Outcomes Management | 24 months | Cohort study | Audit and feedback + Education + EMR change | Restrictions on computer ordering for laboratory tests, educating residents on appropriate laboratory ordering, and audit feedbacking to physicians | Number of labs per patient per days decreased from by 6.7% (1.19 to 1.11; P<0.0001). Average cost per case related to laboratory tests decreased by 6.2% ($17.24 to $16.17, totaling a cost savings of $26,851) |
| Signage as an intervention on a general medicine ward to reduce unnecessary testing | Wiens et al. | 2020 | Internal Medicine Journal | 6 months | Cohort study | Education | Placing signs describing safe indications for lab ordering on physician computers | Patients on Ward A received less tests compared to those on Ward B, the control ward (7.38 vs. 8.20; 10% reduction, P<0.01) and had less 'sign-specified tests' per day (6.43 vs. 7.15, 10% reduction), CBCs per day (0.80 vs 0.86), and 'Chem-7s' per day (0.87 vs. 0.96, 10% reduction). But not true when compared to historical Ward A control. Patients on Ward A were also less likely to get 1 or more CBC than ward B (36.1% vs. 42.5%; 15% reduction, P=0.04). Similar results when analyzing patients with LOS between 7-30 days. Savings equate to >$10,000 over the 6 months per ward |
| A Quality Improvement Project to Reduce Overutilization of Blood Tests in a Teaching Hospital | Almeqdadi et al. | 2019 | Journal of community Hospital Internal Medicine Perspectives | 6 months | Cohort study | Education | Educational intervention with food incentive/team competition | CBC index decreased by 7.05% from 1.56 (+/- 0.02) to 1.45 (+/- 0.03, P<0.001). BMP index decreased by 21.4% from 1.45 (+/-0.02) to 1.14 (+/- 0.03) (P<0.0001). No impact on hospital LOS or mortality |
| Association of a Multifaceted Intervention With Ordering of Unnecessary Laboratory Tests Among Caregivers in Internal Medicine Departments. | Bindraban et al. | 2019 | JAMA | 24 months | Cohort study | Audit and feedback + Education + EMR change | Education, heightened supervision, and EMR changes including time restrictions on reordering labs | Hospital 1 (−1.55; 95% CI, −1.98 to −1.11; P<0.001), hospital 3 (−0.74; 95% CI, −1.42 to −0.07; P=0.03), and hospital 4 (−2.18; 95% CI, −3.27 to −1.08; P<0.001) had statistically significant changes in slope for laboratory tests |
| Evidence-Based Duplicate Order Alerts Promote Effective | Coberly et al. | 2019 | American Journal of | 1 month | Cohort study | EMR change | EMR alerts for duplicate orders from 8 hours to custom time intervals based on evidence and focus group experience | 914 orders cancelled in 1 month because of tailored duplicate order alerts versus the baseline mean of 710 (22.3% reduction, 95% CI, 633-786) |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Test Utilization and Reduce Unnecessary Laboratory Testing | | | Clinical Pathology | | | | | and a predicted 552 (39.6% reduction, 95% CI, 475-628) when adjusted for number of inpatient discharges. Most canceled orders were CBCs (530 accepted alerts). This reduction is equivalent to 3,092 mL of blood not collected from patients per month |
| A multi-level strategy for a long-lasting reduction in unnecessary laboratory testing: A multicenter before and after study in a teaching hospital network | Erard et al. | 2019 | International Journal of Clinical Practice | 36 months | Cohort study | Audit and feedback + Education | Open access nonblinded database of order rates and educational component quarterly | 11% reduction of daily laboratory tests ordered per patient per day (P<0.0001). Also reduced blood volume per patient by approximately 7% (P<0.05), costs by 17% (P<0.01), and mean LOS by 3% (P<0.01) |
| The Effectiveness of Cost Reduction with Charge Displays on Test Ordering under the Health Insurance System in Japan: A Study Using Paper-based Simulated Cases for Residents and Clinical Fellows | Hirota et al. | 2019 | Internal Medicine | One session | Cohort study (Randomized) | Cost display | Provided standardized cases with and without costs of labs | Mean value of difference in number of tests and cost of tests between non-display and display group 4 and 2830-yen (P=0.002) |
| Effectiveness of minimum retesting intervals in managing repetitive laboratory testing: Experience from a Croatian university hospital | Lapic et al. | 2019 | Biochemical Medicine | 12 months | Cohort study | EMR change + Policy change | Implemented minimum retesting interval (MRI) unique to each laboratory test included with pop-up if test requested within MRI. Pop-up alert allows option to abort or override request with reasoning | Overall, 2.1% reduction in performed biochemistry tests with 432,429 biochemistry tests ordered and 9268 alerts canceled. 38,222 (Eur) annual reductions in charges with CBCs accounting for 17%. 6367 annual reductions in reagent cost-savings (Eur). Additionally, 90% of CBC alerts generated were ignored |
| "THINK" Before You Order: Multidisciplinary Initiative to Reduce Unnecessary Lab Testing | Shinwa et al. | 2019 | Journal for Healthcare Quality | 14 months | Cohort study | Education + EMR change + Policy change | Short, monthly educational initiative sessions to housestaff and hospitalists. A simple mnemonic, “THINK,” was created. Biweekly e-mails were sent and displayed a scorecard of the lab testing per each teaching team. Admission EMR order sets were adjusted to default to a single “next day's lab” order. A nurse-driven pathway facilitated discussion at time of discharge planning initiation | The intervention decreased the increasing baseline trend (post-intervention effect estimate −0.04 labs per patient day per month, P<0.05), which was not seen in the control unit. Estimated cost savings of $6,734 per month, a total of $94,269 |
| Reducing the number of unnecessary routine laboratory tests through education of internal medicine residents | Faisal et al. | 2018 | Postgrad Medical Journal | 1.8 months | Cohort study | Cost display + Education | Educational presentation explaining benefits of reducing the number of routine blood tests before the study. Additionally, resident reminders at beginning of IM rotations to reduce routine blood tests and to provide justification for ordered tests. Attending physicians were also educated and instructed to encourage minimization of | Median blood test count (CBC/CMP/BMP) decreased by 50% (4 to 2 tests per patient per day. Noted both a decrease in median LOS (4.9 to 3.9 days; 21% decrease) and in people requiring transfusions (2016: 6.1%, 2017: 2.9%). Median LOS reduced by 20.4% from 4.9 to 3.9 and 3.2% reduction in people requiring transfusions in the following year |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | unnecessary routine laboratory tests. Finally, displayed costs of different lab tests in resident areas | |
| The role of a best practice alert in the electronic medical record in reducing repetitive lab tests. | Bejjanki et al. | 2018 | Clinic economics and Outcomes Research | 18 months | Cohort study | EMR change | Best Practice Alert (BPA) implemented in the EMR as a pop-up for duplicate orders | 18% reduction in duplicate orders post exposure with 73,000 Euros in savings |
| Bedside Assessment of the Necessity of Daily Lab Testing for Patients Nearing Discharge | Tsega et al. | 2018 | Journal of Hospital Medicine | 12 months | Cohort study | Education + Policy change | Impelling hospitalists to identify stable patients and discontinue labs coupled with educational rounding discussions | 24-hour prior to discharge lab reduction of 15.5% from preintervention average of 50.1% to a postintervention average of 34.5%. Similarly, for 48-hour prior to discharge lab reduction of 20.5% from 75.6% to 55.1% |
| Impact of an education and multilevel social comparison-based intervention bundle on use of routine blood tests in hospitalized patients at an academic tertiary care hospital: a controlled pre-intervention post-intervention study | Ambasta, Anshula | 2017 | BMJ Quality and Safety | 30 months | Control trial (non-randomized) | Audit and feedback + Education | Provided individualized feedback that specifically included social comparison or lab ordering habits with subsequent education on safety and consequences of overordering | In intervention group, incidence ratio of ordering routine lab tests yielded 0.89 corresponding to an 11% reduction at the intervention site (CI 0.79 to 1.00; P=0.048) with cost savings of $68,877 (P=0.02) |
| Economic and organizational impact of a clinical decision support system on laboratory test ordering | Bellodi et al. | 2017 | BMC Medical Informatics and Decision Making | 6 months | Control trial (non-randomized) | EMR change | Implemented a clinical decision support (CDSS) system PROMETEO to measure effectiveness on lab and cost reduction | In the intervention group, 16-17% reduction of lab tests ordered and costs in cardiology and medicine wards compared to 14% reduction in labs, 20% reduction in costs for the cardiology wards, 4% increase in labs ordered, 2% increase in costs in medicine wards in the control group |
| Results of a Quality Improvement Project Aimed at Eliminating Healthcare Waste by Changing Medical Resident Test Ordering Behavior | Gupta et al. | 2017 | Journal of Clinical Medical Research | 21 months | Cohort study | Audit and Feedback + Education | Resident lectures highlighting judicious lab ordering, study team designed testing algorithm for CBC, BMP, CMP, and study team peer-groups to periodically assess progress of residents | Significant decreases in the number of PT/INR orders by 20.6%, followed by BMP orders by 12.4%, and CBC orders by 9.3%. The mortality rate increased slightly by 0.5% from 5.3% for the pre-intervention phase to 5.8% for the selected intervention phase |
| Mindfulness-Based Laboratory Reduction: Reducing Utilization Through Trainee-Led Daily 'Time Outs' | McDonald et al. | 2017 | American Journal of Medicine | 12 months | Cohort study | Education + EMR change + Policy change | Regular physician education combined with a forcing function along with a change in ordering culture was encouraged. Resident-led curriculum at monthly quality improvement rounds discussion intervention and harms of over testing. Additionally, lab ordering was restricted to 2 days. Finally, daily sign-out changed to include a “time out” for any required laboratory testing | 32% reduction in the number of per patient tests ordered. CBCs, and electrolyte panels performed per patient significantly decreased (P<0.001). Reduction of 9.6 tests per patient number of total tests (-7.0 to -12.2). The average cost per admitted patient decreased by 44% from $117 to $66 with estimated savings of $50,657 |
| Reducing unnecessary testing: an intervention to | Melendez-Rosado et al. | 2017 | Postgrad Medical Journal | 12 months | Cohort study | Cost display + Education | A short teaching session for internal medicine residents was held in December 2014, in which the quality improvement | 29.41% reduction in CBC with differentials (P<0.0001, SD=2.2) with no difference in mortality. But statistically significant decrease in readmission |

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| improve resident ordering practices | | | | | | | team presented the current literature encompassing laboratory ordering practices | rate (P=0.008) in the intervention group. The overall mean cost for all laboratory tests was US $632.40 per patient hospitalization, but no statistical difference occurred in the overall cost for all three months between the control and intervention groups (P=0.14) |
| An Educational and Administrative Intervention to Promote Rational Laboratory Test Ordering on an Academic General Medicine Service | Wertheim et al. | 2017 | American Journal of Medicine | 2 months | Control trial (Randomized) | Education + EMR change + Policy change | Educational intervention on first day of each block to review ordering guidelines. Ordering individuals were encouraged to not automatically order recurring daily labs. Also asked to include section in daily progress notes to track labs needed for following day | 9% decrease in aggregate laboratory utilization with rate ratio of 0.91 (P= 0.02; CI 0.84 – 0.98). This reduction appeared to be due to decreased BMP and constituent studies (Na, K, Cl, CO2, BUN, Cr, glucose) and CBC without differential |
| High-Value, Cost-Conscious Care: Iterative Systems-Based Interventions to Reduce Unnecessary Laboratory Testing | Sadowski et al. | 2017 | American Journal of Medicine | 24 months | Cohort study (randomized) | Cost display + EMR change | Changed EMR to adjust order sets by allowing labs to be drawn only one time at admission if not taken in the ED. Also display costs of lab tests next to order | Reduction in labs by 15.56% from 13829 to 11677 and total labs per day by 19.43% from 4.99 to 4.02 (P<0.001) for Intervention 1. Intervention 2 had no significant change in total labs, but reduced by 15.43% from 4.99 to 4.22 labs per patient per day (P<0.001) |
| House Officer-Driven Reduction in Laboratory Utilization | Tawfik et al. | 2017 | Southern Medicine Journal | 10 weeks | Cohort study | Cost display + Education | Posted cost of labs as well as lab ordering frequency weekly (as well as change from week prior). Also held educational conferences for residents | Mean lab tests for residents had a 7.01% reduction and decreased by 0.39 per patient per day (P<0.0001). Mean charge by residents decreased by $27 per patient per day. Mean lab tests by hospitalists decreased by 0.18 (nonsignificant) and mean charge by hospitalists decreased by $30 per patient per day (nonsignificant) |
| A Multidisciplinary Housestaff-Led Initiative to Safely Reduce Daily Laboratory Testing | Iams et al. | 2016 | Academic Medicine | 10 months | Control trial (non-randomized) | Cost display + Education | 20-minute oral presentation describing HVC principles and test ordering practices. Distributed pocket-size cards displaying lab test charges and educational flyer highlighting the Choosing Wisely recommendations supporting the initiative were distributed Weekly data feedback e-mails comparing their daily lab ordering rates and goals (20% daily BMP and CMP ordering goal on GM and surgical staff, 10% on hospitalist services) | Mean BMP tests per patient per day decreased by 28.3% (95% CI 0.17-0.29) for housestaff and 36.2% (95% CI 0.09-0.21) for hospitalists. CBCs decreased by 26.9% (95% CI 0.23-0.33) for housestaff, 35.5% (95% CI 0.03-0.13) for hospitalists. Lab-free days increased by an additional 4.1 percentage points (95% CI 2.1-6.1) for housestaff and 9.7 percentage points (95% CI 6.6-12.8) for hospitalists |
| Minimum retesting intervals - application through electronic order forms on common laboratory tests | Galovic et al. | 2016 | SIGNA VITAE | 1 month | Cohort study | EMR change | Notification in EMR system for inappropriate ordering based on preset criteria for minimal retesting intervals | 7% of all tests requested reduced (1,517 requests were cancelled), 37% of alerted tests and 36% of CBC's alerted were reduced |
| Optimize Your Electronic Medical Record to Increase Value: Reducing Laboratory Overutilization | Iturrate et al. | 2016 | American Journal of Medicine | 24 months | Cohort study (Randomized) | EMR change | Restrictions on repetitive daily labs in the EMR | 8.5% (P<0.001) to 20.9% (P <0.001) reduction in tests per patient per day with cost savings of $32,489 |

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| Reduction in Unnecessary Clinical Laboratory Testing Through Utilization Management at a US Government Veterans Affairs Hospital | Konger et al. | 2016 | American Journal of Clinical Pathology | 36 months | Cohort study | EMR change | Implementation of filters for ordering labs within the EMR | Year 1, year 2, and year 3 resulted in 5.07%, 12.37%, and 16.11% reduction in total labs ordered, respectively. Estimated projected savings of $469,162 over the 3-year intervention |
| A multifaceted hospitalist quality improvement intervention: Decreased frequency of common labs. | Corson et al. | 2015 | Journal Of Hospital Medicine | 7 months | Cohort study | Audit and feedback + Education | Monthly email describing educational component and transparent audit and feedback of lab ordering within hospitalist cohort | The number of labs ordered per patient decreased by 10.7% from 2.06 (SD of 1.40; P<0.01) per patient per day to 1.84. Nonsignificant changes in mortality and blood transfusion volume, LOS, and readmission rates. Hospital costs decreased from $16.19 per admission, totaling $151,682 |
| Reducing Duplicate Testing: A Comparison of Two Clinical Decision Support Tools | Procop et al. | 2015 | American Journal of Clinical Pathology | 12 months | Cohort study | Audit and feedback + EMR change + Policy change | EMR Smart Alert and Hard Stop alert that would block tests deemed to be unnecessary. Both alerts notified the ordering provider that the test ordered was a duplicate. The result from the previously ordered test was embedded in the alert screen, if available | The Hard Stop alert was significantly more effective than the Smart Alert (92.3% vs 42.6%, respectively; P<0.0001). $16.08 was saved per Hard Stop alert and $3.52 per Smart Alert |
| Changing resident test ordering behavior: a multilevel intervention to decrease laboratory utilization at an academic medical center | Vidyarthi et al. | 2015 | American Journal of Medical Quality | 36 months | Cohort study | Audit and feedback + Education + EMR change | System change, teaching, social marketing, academic detailing, incentive-based, audit and feedback | Year 1 (2009) actual test volume of 184,871, cost-savings of ($167,859.30), readmission rate or 12.16% and mortality of 2.24%. In year 1, CBC and CBC with differential decreased by 7.0% from 1.07 to 0.99 tests per inpatient day. Year 2 (2010) total test ordering decreased by 8.1% with actual test volume of 1,409,993 cost-savings of $931,942.50, readmission rate of 12.41% and mortality of 2.12%. Year 3 (2011) total test volume decreased by same 8% but unchanged from prior year with actual test volume of 1,411,262, cost-savings of $918,315.00, readmission rate of 1.92% and mortality of 2.07% |
| Impact of Weekly Feedback on Test Ordering Patterns | Minerowicz et al. | 2015 | American Journal of Managed Care | 18 months | Cohort study | Audit and feedback + Education | Educational session on laboratory utilization emphasizing consequences of overutilization on cost and safety. 5-minute refresher sessions with regular reminders and discussions of overall progress were included in monthly resident meetings. Weekly graphs reporting the total number of tests ordered per de-identifier and were grouped according to resident to allow comparison with peers in same level of training | Net reduction of 21% in tests ordered—an average of 941 tests per week |
| An educational intervention to improve cost-effective care among medicine housestaff: a randomized controlled trial | Sommers et al. | 2012 | Journal of the Association of American Medical Colleges; Academic Medicine | 2 months | Control trial (randomized) | Cost display + Education | Residents reviewed hospital bill of patients they cared for learn ordering effects on costs | No significant cost difference noted. No statistically significant outcomes except continued exposure to residents of concepts of cost-effectiveness in follow up survey (P=0.041) and higher readmission rates in the intervention group (P=0.01) |

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| How to save costs by reducing unnecessary testing: lean thinking in clinical practice | Vegting et al. | 2012 | European Journal of Internal Medicine | 12 months | Cohort study | Cost Display + Education + EMR change + Policy change | Supervising consultants advised to pay even more critical attention to lab ordering as to diagnostic ordering. Also unbundling of panel tests (clinicians instructed to follow national guidelines for Dutch physicians for lab ordering duration in specific chronic disease patients). Printing posters and pocket cards with pricing information of diagnostic tests as well as presentations of 6 weekly reports of ordered diagnostic tests | 230,000 euros savings in laboratory testing (P<0.02). No evident changes for mortality, hospital readmission, or HbA1c levels |
| Observing effectiveness of pathology ordering controls in emergency departments | Wagholikar et al. | 2011 | Studies in health technology and informatics | 9.2 Months (40 weeks) | Cohort study | Education + Policy change | "Traffic light system" pathology request form and Health Data Integration (HDI) to automatically analyze orders | "'Traffic Light System' and Pathology request form" led to 9.93% reduction in FBC tests from 42.3 to 38.1 tests per 100 patients (P=0.001) |
| Reducing unnecessary inpatient laboratory testing in a teaching hospital | May et al. | 2006 | American Journal of Clinical Pathology | 24 months | Cohort study | EMR change | Limiting Phlebotomy and Test Orders to 24 Hours on Previously Identified, Frequently Recurring Inpatient Laboratory Tests (multi-pronged approach) | 12% reduction in inpatient testing (72,639 tests) between fiscal year volume data from before (2002-2003) and after (2003-2004) |
| Factors contributing to inappropriate ordering of tests in an academic medical department and the effect of an educational feedback strategy | Miyakis et al. | 2006 | Postgrad Medical Journal | 6 months | Cohort study | Audit and feedback + Cost Display + Education | The medical staff was informed about their test-ordering behavior, cost awareness and the factors associated with overuse of diagnostic tests | The avoidable tests per patient per day significantly decreased by 21.40% from 2.01 to 1.58 tests per patient per day (P=0.002). However, containment of unnecessary ordering of tests gradually waned during the semester after the intervention |
| An administrative intervention to improve the utilization of laboratory tests within a university hospital | Calderon-Margalit et al. | 2005 | International Journal for Quality in Health Care | 12 months | Cohort study | Education + Policy change | Restricting test ordering in addition to educational intervention on detriments of repetitive lab testing | Average biochemistry ordering request reduced by 17.1% from 3 years prior to intervention (467,038 to 386,948; 95% CI: 16.8–17.5%). The average number of tests ordered per 100 hospital days reduced by 19% (591 to 479; 95% CI: 18.8–19.2%). Hematology tests reduced by 7.6% per 100 hospital days (P<0.009). All 12 tests (urea, albumin, electrolytes, bilirubin (total), glucose, amylase, uric acid, protein (total), AST, ALT, Cholesterol (total), creatinine also changed postintervention (P<0.009) |
| The impact of peer management on test-ordering behavior | Neilson et al. | 2004 | Annals of Internal Medicine | 24 months | Cohort study | EMR change | Modifying software for the care provider order entry (CPOE) system. A daily alert was initiated that asked providers whether they wanted to discontinue tests scheduled past 72 hours. Next, serum metabolic panel tests were unbundled (sodium, potassium, chloride, bicarbonate, glucose, blood urea nitrogen, and creatinine tests) | Voluntary reduction of testing after three days reduced metabolic panel component tests by 24% (P=0.02). Unbundling panel tests resulted in an additional 51% decrease for metabolic panel component tests (P<0.001). Incidence of patients with abnormal targeted blood chemistry levels after two days decreased post-intervention (P=0.02). Postintervention-adjusted coefficients of variation decreased for metabolic panel component estimates (P=0.03). Readmission rates, ICU transfers, hospital LOS, and mortality were unchanged |

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| A randomized trial of a computer-based intervention to reduce utilization of redundant laboratory tests | Bates et al. | 1999 | American Journal of Medicine | 4 months | Cohort study (randomized) | EMR change | Reminders were provided for previously performed or pending tests. Results were provided if available | In the intervention group, 69% (300/437) of tests were canceled. Of 137 overrides, 41% appeared justifiable. Less redundant tests were performed in the intervention group than the control group (51% in control group versus 27% in intervention group; P<0.0001) |
| A successful experiment to reduce unnecessary laboratory use in a community hospital | Gortmaker et al. | 1988 | Medical Care | 60 months | Cohort study | Audit and feedback + Education | Identification of personal ordering habits and educational meetings discussing consequences of overordering labs | 14% reduction (1.4 tests per patient per day) and 8% decrease in lab costs. There was a statistically significant decrease in CHEM profiles ordered during study and increase in alternatives |
| Effect of feedback to clinical staff of information on clinical biochemistry requesting patterns | Grivell et al. | 1981 | Clinical Chemistry | 12 months | Cohort study | Audit and feedback + Cost display | Audit and feedback every 4-weeks including histograms of number and costs of labs ordered | Monthly auditing and feedback did not decrease number of labs ordered |

**Supplementary Table 2:** Studies that met criteria for inclusion in the systematic review[9-49]