

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,kw	69
#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, device manufacturer, drug manufacturer, device trade name, keyword, floating subheading word, candidate term word] 4472
- 2 (Unnecessary 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] 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 subheading word, candidate term word] 5
- 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 title, device manufacturer, drug manufacturer, device trade name, keyword, floating subheading word, 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 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] 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

32 (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

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 et 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									
Wagholikar 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
Calderon-Margalit 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
Gortmaker 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									
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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 feedback 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

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

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	Vidyarathi 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)

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

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 review⁹⁻⁴⁹