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REVIEW

Electronic Health Record–Based Interventions for Improving Appropriate Diagnostic Imaging

A Systematic Review and Meta-analysis

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Background: One driver of increasing health care costs is the use of radiologic imaging procedures. More appropriate use could improve quality and reduce costs.

Purpose: To review interventions that use the computerized clinical decision-support (CCDS) capabilities of electronic health records to improve appropriate use of diagnostic radiologic test ordering.

Data Sources: English-language articles in PubMed from 1995 to September 2014 and searches in Web of Science and PubMed of citations related to key articles.

Study Selection: 23 studies, including 3 randomized trials, 7 time-series studies, and 13 pre–post studies that assessed the effect of CCDS on diagnostic radiologic test ordering in adults.

Data Extraction: 2 independent reviewers extracted data on functionality, study outcomes, and context and assessed the quality of included studies.

Data Synthesis: Thirteen studies provided moderate-level evidence that CCDS improves appropriateness (effect size, −0.49 [95% CI, −0.71 to −0.26]) and reduces use (effect size, −0.13 [CI, −0.23 to −0.04]). Interventions with a "hard stop" that prevents a clinician from overriding the CCDS without outside consultation, as well as interventions in integrated care delivery systems, may be more effective. Harms have rarely been assessed but include decreased ordering of appropriate tests and physician dissatisfaction.

Limitation: Potential for publication bias, insufficient reporting of harms, and poor description of context and implementation.

Conclusion: Computerized clinical decision support integrated with the electronic health record can improve appropriate use of diagnostic radiology by a moderate amount and decrease use by a small amount. Before widespread adoption can be recommended, more data are needed on potential harms.

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Concern that the costs of health care are increasing at unsustainable rates is widespread. One driver of cost is the increasing use of radiologic imaging procedures, particularly advanced imaging techniques, such as computed tomography (CT) and magnetic resonance imaging (MRI). For example, the use of CT scans in the emergency department (ED) increased by 330% from 1996 to 2007, a time when the rate of ED visits increased by only 11% (1). Other investigators reported a 3-fold increase in the likelihood of having CT or MRI during an ED visit between 1998 and 2007 (2).

The increases in imaging studies have led to closer scrutiny of their clinical value. In some cases, strong evidence shows that they provide no value or may even harm patients. For example, a meta-analysis of early lumbar imaging for patients with acute low back pain included 5 randomized, controlled trials in which patients were randomly assigned to receive or not receive early imaging in the form of a plain film, CT, or MRI. At 3 months, patients who had received imaging had no improvement in pain or function (3). In other situations, strong professional opinion considers certain tests to have little value, mainly because alternate tests are preferred or the probability of an abnormal image is exceedingly remote. When the American Board of Internal Medicine Foundation asked physician specialty groups to identify procedures or tests that they judged to have little value (the Choosing Wisely campaign), imaging tests, such as CT for minor head injury in the ED (American College of Emergency Physicians), imaging studies in patients with nonspecific low back pain (American College of Physicians), imaging for uncomplicated headache (American College of Radiology), CT angiography for patients with low clinical probability of pulmonary embolism and a negative D-dimer assay result (American College of Chest Physicians), and cardiac stress imaging in patients without high-risk markers for coronary artery disease (American College of Cardiology), were frequently cited.

The recognition that more appropriate use of imaging could improve quality and reduce costs has led to the development of interventions to encourage more appropriate radiology use. Some of these interventions have made use of the computerized clinical decision-support (CCDS) capabilities of electronic health records (EHRs). Given that adoption of EHRs is expanding, we undertook a systematic review and meta-analysis of EHR-based interventions to improve the appropriateness of diagnostic imaging. This work was performed for the Veterans Health Administration Choosing Wisely Workgroup. The key questions are as follows: What is the effectiveness of EHR-based interventions in reducing unnecessary or inappropriate diagnostic imaging, and does effectiveness vary in results by system? What are the harms or potential harms associated with EHR-based interventions used to reduce inappropriate imaging?

Key Summary Points

Computerized clinical decision support that is integrated in the physician order entry system of an electronic health record can help improve the appropriate ordering of diagnostic imaging studies.

Interventions that include a "hard stop" to prevent clinicians from ordering imaging tests classified as inappropriate and interventions in an integrated care delivery setting may improve effectiveness.

The potential harms of computerized clinical decision-support interventions have been rarely studied.

METHODS

This systematic review is reported according to Preferred Reporting Items for Systematic Reviews and Meta-Analyses guidelines (4). A formal protocol was developed and submitted to PROSPERO (CRD 42014007469). The protocol and preliminary results received input from a technical expert panel.

Data Sources and Searches

We began with a search of all studies included in 4 previous broad-based reviews of health information technology (IT) (5–8). These reviews were done using similar search strategies (between 1995 and 2013) and inclusion or exclusion criteria and were designed to identify all published hypothesis-testing studies of clinical health IT. Hypothesis-testing studies included randomized trials and controlled before-and-after, time-series, and pre–post studies. In the original reviews, these studies were further classified according to the health IT functionality. Recently published summary data showed that 417 of 1057 health IT studies published from 1995 to 2013 were classified as CCDS (8). These 417 titles and abstracts were searched for studies eligible for this review (for example, CCDS aimed at improving appropriateness of diagnostic imaging use). We next searched PubMed from 2011 to 10 September 2014 looking specifically at decision support for imaging and conducted Web of Science and PubMed searches of key references (see **Appendix Table 1**, available at www.annals.org).

We also reference-mined 3 potentially relevant systematic reviews on computerized physician order entry and medical imaging (9), CCDS for chronic disease management (10), and CCDS "with potential for inpatient cost reduction" (11).

Study Selection

All reference titles and abstracts were screened in duplicate. Full-text articles were then reviewed in duplicate, and all discrepancies were discussed with the group. Inclusion criteria began with the enrollment of an adult population. Studies aimed only at children were excluded. Studies with mixed populations were included. Interventions needed to be EHR-based and intended to reduce imaging for diagnostic purposes considered inappropriate or unnecessary on the basis of clinical guidelines. Because we judged increasing appropriate use to be conceptually related to decreasing inappropriate use, we also included studies measuring this outcome. Screening radiologic studies, such as interventions to increase the use of radiographic imaging (for example, mammography) for breast cancer screening, were excluded. Studies of systems running on personal digital assistants were excluded. Studies of Web-based interventions or computerized, stand-alone systems that we judged could be easily incorporated into the EHR were included. All comparison groups were included. Outcomes needed to be the rates of imaging procedures judged as appropriate or inappropriate on the basis of existing clinical guidelines or locally developed guidelines. Studies that targeted the use of imaging procedures stated as being overused and then reporting only data on use were also included. Studies in all settings were included. Country of origin was not an exclusion criterion.

Data Extraction and Quality Assessment

Data were extracted by 2 reviewers, and discrepancies were reconciled with the group. Articles had data abstracted on study design, time period, setting, imaging method, intervention, comparison, sample size, target of intervention, findings, IT design, data entry for intervention, and implementation characteristics. Interventions were classified regardless of whether they were integrated with computerized physician order entry, gave real-time feedback at the point of care, suggested a recommended cause of action, had a "stop" that had to be justified or overridden, were automated through the EHR, or required clinical staff to enter data specifically for the intervention. We assessed the development by means of iterative testing or pilot tests, clinician or user training, use of audit and feedback (or other internal incentives), and whether the authors of the study had also developed the intervention.

We assessed the quality of studies by their design (randomized vs. observational) and the degree to which they reported information about the intervention and implementation characteristics listed above.

Data Synthesis and Analysis

The effect of the intervention on appropriateness was the primary outcome. Studies measuring an increase in appropriateness were considered along with those measuring a decrease in inappropriate use. The effect on use was a secondary outcome. For studies presenting count data or for which a count could be calculated (from a percentage), an odds ratio and associated SE were calculated. For comparability, the log odds ratios and their SEs were converted into Cohen *d* effect sizes using Stata SE, version 10 (StataCorp) (12, 13). For studies presenting means and measures of variation, Cohen *d* effect sizes were calculated directly. For each study, we used the difference between the periods before and after intervention, the difference between the time-series projection of performance in the absence of the intervention and the actual performance during the intervention, or the difference between providers randomly assigned to the intervention or control, as appropriate to the study design and the available data. Results were converted to effect sizes for the analysis. Random-effects meta-analyses were conducted and results were pooled using the Hartung–Knapp–Sidik–Jonkman variance estimator (14).

After collecting data on the interventions, implementations, and settings but before extracting outcomes data, we developed 4 hypotheses about effectiveness of the intervention—1 in each category of intervention characteristics, settings, implementation, and target. First, interventions will vary in effectiveness according to the following rank order: interventions that present only information ("A" interventions), interventions that include a pop-up or reminder that the selected radiographic examination does not meet current guidelines ("B" interventions), interventions that require an active override for providers to continue to order a radiographic examination that is not supported by guidelines (that is, "soft stop") ("C" interventions), or interventions that forbid providers from ordering a radiographic examination that is not supported by guidelines unless or until consultation with a peer or an expert (that is, "hard stop") ("D" interventions). Second, interventions will be more effective in settings that are integrated networks of care (such as the U.S. Department of Veterans Affairs and Kaiser Permanente) than in other settings. Third, interventions will be more effective if they include other implementation components, such as audit and feedback and academic detailing. Fourth, interventions may vary by the radiographic method they target.

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RESULTS

Description of the Evidence

From all sources, we retrieved 1195 titles and identified 172 as potentially relevant. After review of these 172 titles, we identified 23 articles meeting inclusion criteria (**Appendix Figure 1**, available at www.annals.org).

Of the 23 articles included, 3 were randomized trials (15–17), 7 were time-series studies (18–24), and 13 were pre–post studies (25–37). Seven studies collected data before 2000 (15–17, 19, 20, 26, 35), and 7 included data collected within the past 5 years (2009 or later) (18, 21, 28–30, 32, 37). Ten interventions targeted what was sometimes called "high-cost imaging," which usually included CT and MRI and occasionally nuclear medicine tests (15, 18, 21, 23, 24, 30, 32–34, 36). Four interventions targeted pulmonary CT angiography (22, 27, 31, 37), 2 studies targeted chest radiography (16, 29), 3 studies targeted other types of radiologic studies (17, 20, 26), and 4 interventions targeted several types of radiologic studies (19, 25, 28, 35).

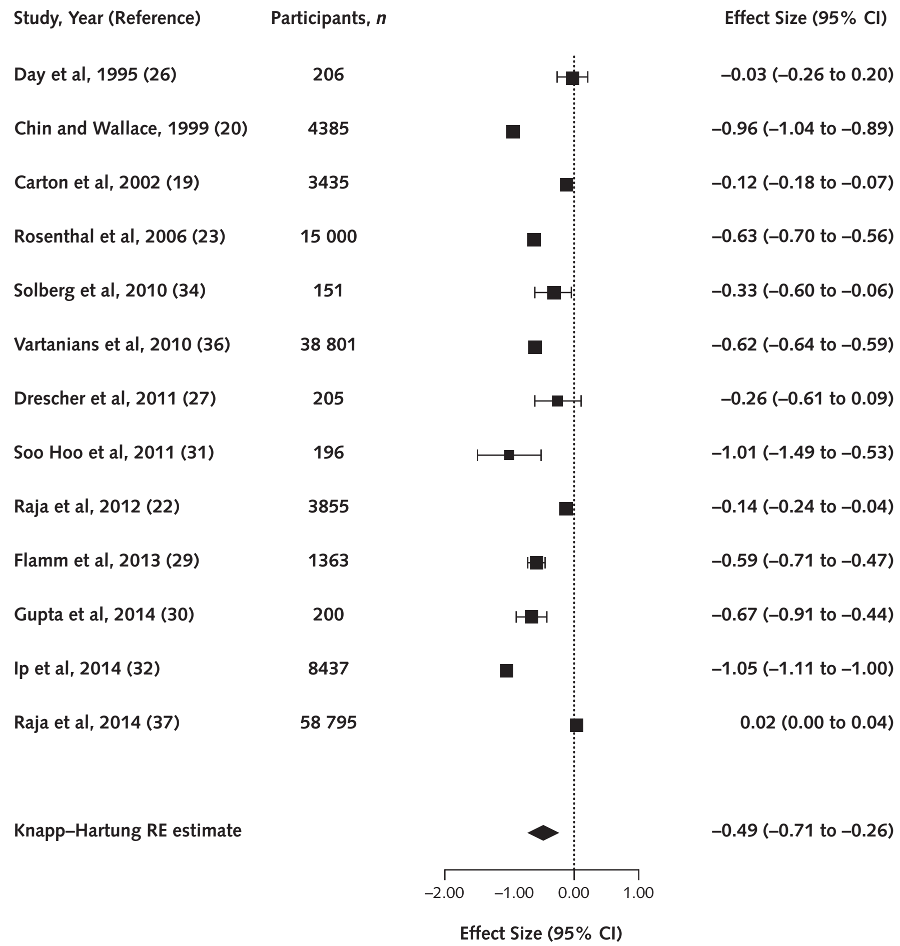
Studies were mostly single-institution implementations done at U.S. academic medical centers. Thirteen studies—just more than half of all studies—were from the "health IT leaders," meaning U.S. academic centers that have a long history of development, implementation, evaluation, and publication of health IT (15–17, 21–24, 30, 32, 35–37). Ten of these studies came from institutions affiliated with Harvard University (Cambridge, Massachusetts) (15, 17, 21–24, 30, 32, 36, 37). Three studies came from integrated health care delivery organizations: Kaiser Permanente (20), the U.S. Department of Veterans Affairs (31), and Virginia Mason (Seattle, Washington) (18).

In 5 studies, the intervention consisted only of display of information, such as the cost of tests or relevant guidelines (A interventions) (15, 16, 20, 28, 35). Nine studies displayed patient-specific information about whether the requested study was consistent with existing guidelines or appropriateness assessments for the specific clinical indication, or something similar (B interventions) (17, 22, 24, 26, 27, 29, 30, 34, 37). Four studies included what we characterized as a "soft stop," meaning that for radiology orders that the CCDS rated as inconsistent with guidelines or inappropriate, the provider needed to enter a reason why the CCDS advice was being overridden (C interventions) (19, 23, 25, 33). Five studies included a "hard stop," meaning that providers were prevented from ordering radiologic examinations that the CCDS classified as inappropriate without obtaining approval from some external person, such as a radiologist or senior clinician (D interventions) (18, 21, 31, 32, 36).

Nearly all interventions were integrated with computerized physician order entry, gave real-time feedback, and gave a recommended course of action. Only 1 study specifically indicated that the intervention was developed iteratively or pilot-tested (17); approximately one third of studies reported that clinician training was part of the implementation process (18, 22, 25–27); 5 reported including audit and feedback as part of the implementation (18, 21, 23, 25, 32); and 7 reported on other implementation characteristics, barriers, and facilitators (including having a culture of evidence-based medicine, a phased implementation, salaried physicians, and a risk contract with the payer of care) (18, 21, 24, 25, 27, 32, 34). The evidence tables present details of all 23 included studies (**Appendix Tables 2** and **3**, available at www.annals.org).

Two studies did not present data sufficient to include in our quantitative analysis (1 because it did not present comparative data without the intervention [25] and 1 because the outcome was an aggregate measure of many tests), and data specific to the radiologic targets were not presented (35). Of the remaining 21 studies, 13 reported an appropriateness outcome and 13 reported a use outcome (5 studies reported both) (**Appendix Table 4**, available at www.annals.org). Although the 2 outcomes were generally directionally consistent within a study, the effect size for appropri-

Figure 1. Effect of EHR-based interventions on the appropriateness of diagnostic radiologic test ordering.



EHR = electronic health record; RE = random effects.

ateness was much greater than for use in 3 studies (Appendix Figure 2, available at www.annals.org). In general, this is expected. Most radiologic examinations are not ordered for inappropriate reasons; thus, an intervention targeted at reducing inappropriate test ordering will have a larger effect on appropriateness than on use. However, these large differences in effect size between outcomes meant that we had to keep the studies separate for all analyses. For appropriateness outcomes, 5 studies reported only about increases in appropriate use, 4 reported only decreases in inappropriate use, 1 reported both increasing appropriateness and decreasing inappropriateness, and 4 (all of CT angiography) reported the change in yield as their measure of appropriateness or inappropriateness (Appendix Table 5, available at www.annals.org).

The Effectiveness of EHR-Based Interventions in Improving Appropriate Imaging

Thirteen studies contributed to each pooled analysis: 1 for appropriateness and 1 for use. Five studies contributed data to both. Our primary outcome was the effect on appropriateness. Figure 1 displays the results for individual studies reporting appropriateness. Ten of the 13 studies reported statistically significant benefits of the intervention, 1 reported a benefit that was not significant, and 2 studies reported no effect. The random-effects pooled estimate from all 13 studies was an effect size of −0.48 (95% CI, −0.71 to −0.26). This equates to a "moderate" effect, according to a conventional classification (38). Substantial heterogeneity is present, as indicated by the I^2 statistic of 99.5% and visual inspection of the plot. Neither the Begg nor Egger test indicated the presence of publication bias (P = 0.95 and 0.34, respectively).

As a clinical example of what constitutes a moderate-sized effect, consider the results of the study by Gupta and colleagues (30), which reported an effect size of 0.67 associated with implementation of the CCDS intervention. In clinical terms, this meant that before CCDS implementation, the percentage of head CT examinations ordered for appropriate reasons (guideline-adherent) in the ED for patients with mild traumatic brain injury was 49%. After implementation of the CCDS, this rate increased to 76.5%. As a second example, the study by Rosenthal and colleagues (23) reported an effect size of 0.63 associated with implementation of a CCDS, giving appropriateness scores for many radiologic procedures. Before the intervention, 6% of procedures were judged as being of low utility; after the intervention, this value decreased to 2%.

Figure 2 displays the results for the 13 studies reporting use outcomes. Six studies reported statistically significant benefits of the intervention, and 7 studies reported essentially no effect. The random-effects pooled estimate from all 13 studies was an effect size of 0.13 (CI, −0.23 to −0.04). This equates to a “small” effect, according to a conventional classification (38). Substantial heterogeneity is present (I^2 = 100%). Neither the Begg nor Egger test indicated the presence of publication bias (P = 0.39 and 0.26, respectively).

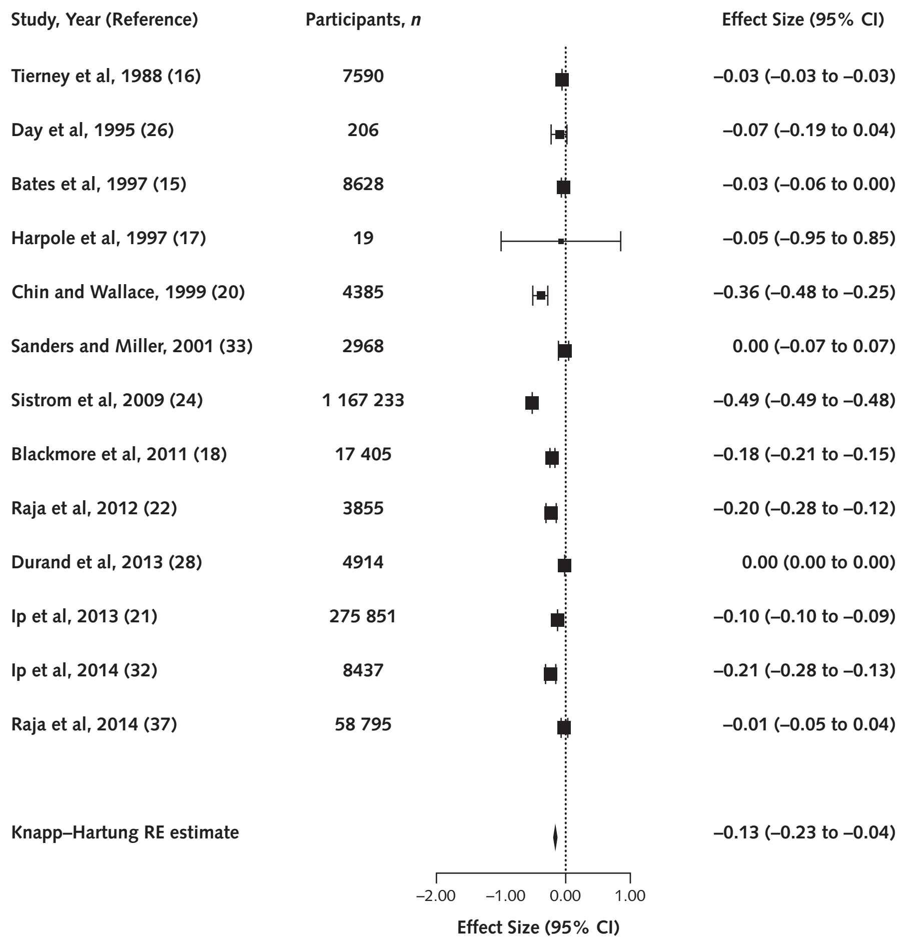
Effect of Intervention Characteristics, Setting, Implementation, and Target on Effectiveness

We explored 4 hypotheses about effectiveness: 1 each for characteristics of the intervention, the setting (integrated care delivery vs. other settings), the implementation process (the use of audit and feedback was the only implementation characteristic with sufficient data to support a stratified analysis), and the radiologic target of the intervention. We had insufficient studies to support robust pooled estimates of individual strata or to support multivariable analyses. Nevertheless, some patterns are apparent. Figure 3 presents a portion of the stratified results.

Regarding the classification of interventions as A, B, C, or D, all of the D studies reported moderate to large effects on appropriateness, and the other types of studies reported more variable effects. Chin and Wallace (20) was the only A study. This intervention displayed locally developed guidelines for appropriate ordering of upper gastrointestinal series at the time an order was placed. This study was also conducted in an integrated care delivery setting with a high baseline rate of inappropriate use (45%), which may explain these strikingly successful findings. Studies with B interventions provided more mixed results. Too few studies reached conclusions about C interventions.

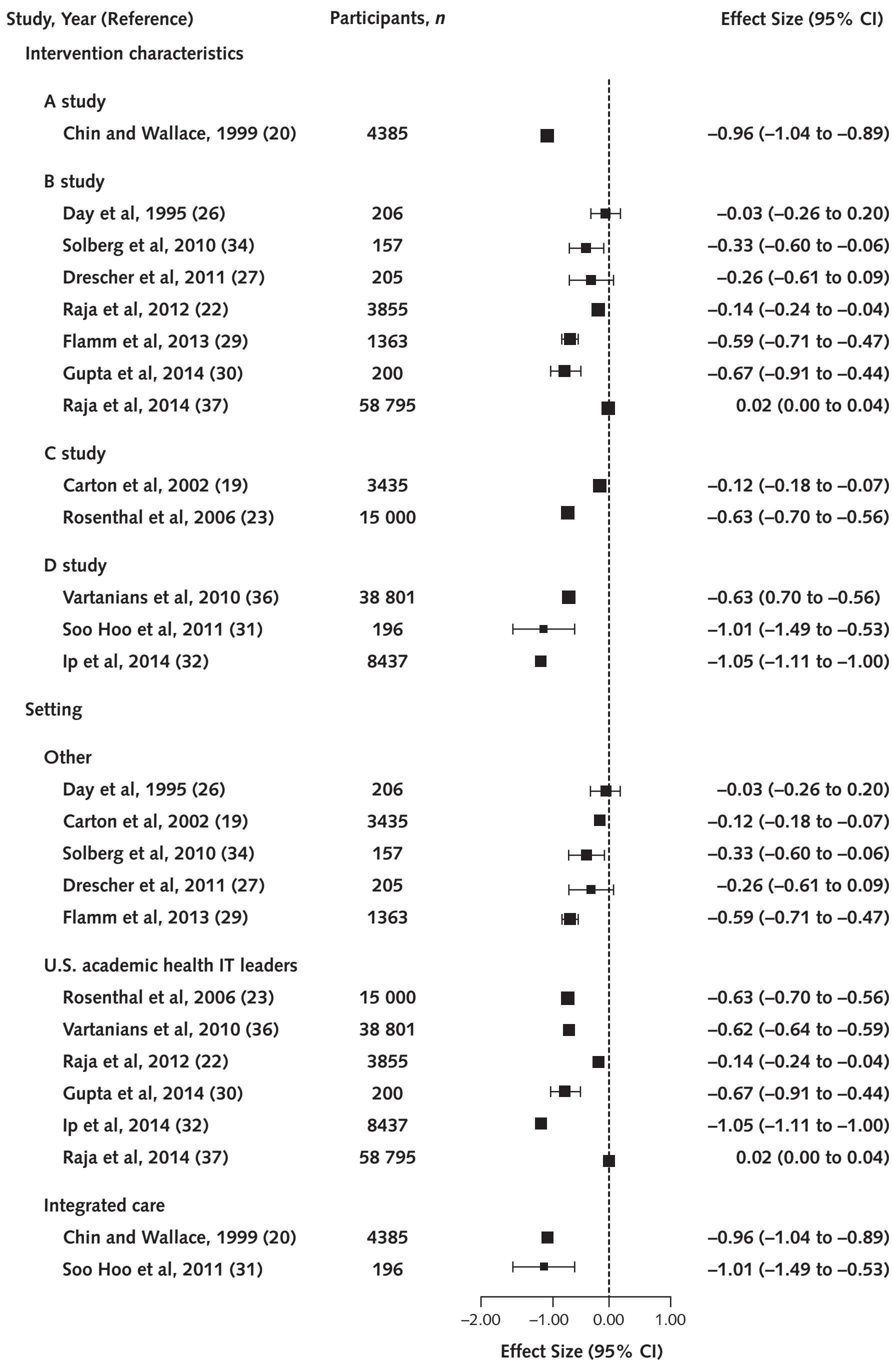
With respect to settings, the 2 studies conducted in integrated care settings both reported large effects on appropriateness. Studies conducted at facilities that are U.S. leaders in health IT and in other settings produced

Figure 2. Effect of EHR-based interventions on the use of diagnostic radiologic test ordering.



EHR = electronic health record; RE = random effects.

Figure 3. Effect of EHR-based interventions on the appropriateness of diagnostic radiologic test ordering, stratified by intervention type and setting.



EHR = electronic health record; IT = information technology.

more mixed results, although 4 of the 6 studies of appropriateness at the health IT leaders reported statistically significant benefits of the intervention.

With respect to implementation, only 2 appropriateness studies reported that audit and feedback were part of the implementation process (Appendix Figure 3, available at www.annals.org). Both studies reported moderate to large effects, but they were too few in number and we could not draw conclusions. No pattern of differential effectiveness is clearly apparent in the analysis on the basis of the radiologic target, although in a study of 1 intervention, a statistically significant effect was seen for CT and nuclear radiologic tests but not MRI (21), suggesting the possibility of a differential effect of interventions based on their target.

Two studies that otherwise met our inclusion criteria could not be included in the pooled analysis because they did not present sufficient data. In 1 study, a rural family medicine clinic in Canada made CCDS available to any interested physician. Most physicians were infrequent users of the system (use was voluntary). Among 904 diagnostic imaging studies ordered using the system, clinical guidelines applied to 58%. Of these, 29% were identified as inappropriate and an alternative diagnostic strategy was suggested; physicians followed the suggestion in 25% of these cases. This study could not be included in our pooled analysis because it did not present data from the preintervention period (25). The second study was a time-series study that displayed the costs for many outpatient diagnostic tests (such as urinalysis, complete blood count, and serum electrolytes) (35). Three radiologic tests relevant to this review were included: chest radiograph, head CT, and head MRI. This study could not be included in our pooled analysis because it did not report results separately for individual tests. The intervention's effect on the aggregate of all of these diagnostic tests was a statistically significant 14% reduction in use, which contrasts with 3 other studies of interventions that presented cost data, all of which reported no effect on use (15, 16, 28).

Harms

Four studies reported on harms associated with their interventions (17, 25, 27, 29). One study evaluating a decision-support tool to reduce unnecessary preoperative testing found an increase in the percentage of preoperative chest radiographies that were inappropriately not ordered with the intervention (29). Before the intervention, 1.9% of patients did not receive a chest radiograph when indicated compared with 9.3% after the intervention. Another study of a decision-support tool to reduce abdominal kidney, ureter, and bladder radiographies identified 12 such tests, out of a total of 255, that were done against the advice of the tool but yielded positive findings (17). Of these 12 radiographs, 6 were believed to have significantly influenced patient outcomes, making it unclear whether following the locally developed guidance could have endangered the patient. The 2 other studies reported on qualitative information from physician surveys, which primarily identified lack of interest in using the decision-support tools because of time constraints and perceived inefficiencies (25, 27).

DISCUSSION

The principal conclusions of this review and meta-analysis are, first, that 21 studies provided moderate-quality evidence that EHR-based interventions can change appropriate test ordering by a moderate amount and reduce overall use by a small amount and, second, that low-quality evidence supports that interventions including a "hard stop" and those done in an integrated care delivery setting may be more effective than interventions without a "hard stop" and implemented in different health care delivery settings. Audit and feedback may also increase the effectiveness of interventions, but data are too sparse to draw conclusions. In general, the target of the intervention does not seem to be related to effectiveness of interventions.

Heterogeneity in effectiveness is a prominent finding of our review. Our stratified analyses may have explained some of this heterogeneity, but the greater portion remains unexplained. It has been postulated that most heterogeneity in health IT evaluations is due to details of the context and implementation that go unreported in published studies. We expect the same to be true here.

The most important limitation to this review is the likely existence of publication bias. Although we did not detect any statistical evidence of publication bias, there must be more implementations of EHR-based interventions to improve appropriateness of radiologic test ordering than the 23 published studies we found. Our expectation is that many such interventions are done and never formally evaluated or published. How the results of these implementations differ from the published studies is unknown, but we expect that both effective and ineffective implementations have likely occurred and not been published. This lack of publication is a major impediment toward more rapid learning of how health IT can best be implemented. The second major limitation is the lack of reporting about possible harms. Strom and colleagues (39) reported that a CCDS intervention with a "hard stop" to help prevent drug–drug interactions probably contributed to delays in care for 4 patients, causing the local institutional review board to halt the study. Another study, excluded from our review because it assessed a pediatric population, surveyed physicians and found that most believed that CCDS was "a nuisance" and "not relevant to the complex or high risk patients they had to treat" (40). More assessments of the potential harms of CCDS interventions are needed. Another limitation is that key information on context and implementation are not reported in published studies. For example, only 1 study reported on pilot-testing the intervention, and only approximately one third of the studies reported on clinician training as part of the implementation. This lack of reporting of context and implementation, which is common to many studies of health IT (8), limits readers' ability to draw conclusions about effectiveness and may perpetuate the belief that these kinds of interventions can be developed separate from the workflow of practicing clinicians and then simply "turned on" with the expectation that clinicians will know how to use the intervention and use it correctly.

In summary, CCDS integrated with the EHR can improve appropriate use of diagnostic radiologic testing by a moderate amount. The use of a "hard stop" as part of the intervention and use in an integrated care delivery setting may increase effectiveness. There are few data on the potential harms of decision-support tools to reduce inappropriate radiologic test ordering. More data on potential harms are needed before widespread adoption can be recommended.

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Appendix Table 1. Search Strategy

Search 1

Database searched and time period covered: PubMed: 1 January 2011-10 September 2014
Language: English
Search strategy: Medical Informatics Applications[MeSH:NoExp] OR Decision Making, Computer-Assisted[MeSH:NoExp] OR Decision Support Techniques[MeSH:NoExp] OR Information Systems[MeSH:NoExp] OR Decision Support Systems, Clinical[MeSH] OR hospital Information Systems[MeSH:NoExp] OR Management Information Systems[MeSH:NoExp] OR Medical Order Entry Systems OR automatic data processing[majr] OR medical informatics[majr] OR public health informatics[majr] OR electronics, medical[majr] OR (computers[mh] OR computers, handheld OR microcomputers OR medical records systems, computerized OR computer systems OR software[mh] OR computer-based[tiab] OR computerize*[tiab] OR cpoe OR cdss OR paper chart* OR electronic chart* OR health information technolog* OR electronic medical record* OR emr OR computerized physician order entry OR computerized order entry OR computerize order entry OR electronic health record* OR ehr OR information technology OR e-health OR health information OR hospital information OR health informatic* OR medical informatic* OR Medical Order Entry System* OR information infrastructure* OR ehealth
AND
radiology department OR magnetic resonance imaging OR tomography, x-ray computed OR imaging[tiab] OR radiolog*[tiab] OR neuroradiolog*[tiab] OR tomograph*[tiab] OR x-ray[tiab]
AND
appropriat* OR inappropriat* OR unnecessary OR behavior
AND
test OR tests OR testing
AND
utilization OR utilize OR utilizing OR order* OR request*
Number of results: 630

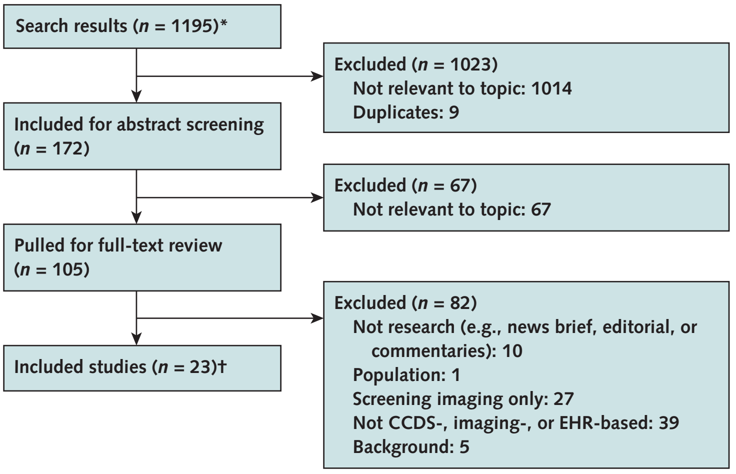
Search 2

Database searched and time period covered: Web of Science: 1 January 2011-10 September 2014
Language: English
Search strategy: Forward searched on the following articles:
Bates DW, Kuperman GJ, Jha A, Teich JM, Orav EJ, Ma'luf N, et al. Does the computerized display of charges affect inpatient ancillary test utilization? Arch Intern Med. 1997;157:2501-8. [PMID: 9385303]
Sanders DL, Miller RA. The effects on clinician ordering patterns of a computerized decision support system for neuroradiology imaging studies. Proc AMIA Symp. 2001:583-7. [PMID: 11825254]
Carton M, Auvert B, Guerini H, Boulard JC, Heautot JF, Landre MF, et al. Assessment of radiological referral practice and effect of computer-based guidelines on radiological requests in two emergency departments. Clin Radiol. 2002;57:123-8. [PMID: 11977945]
Vartanians VM, Sistrom CL, Weilburg JB, Rosenthal DI, Thrall JH. Increasing the appropriateness of outpatient imaging: effects of a barrier to ordering low-yield examinations. Radiology. 2010;255:842-9. [PMID: 20501721] doi:10.1148/radiol.10091228
Number of results after removing duplicates: 114

Search 3

Database searched and time period covered: PubMed: 1 January 2011-10 September 2014
Language: English
Search strategy: Related article searches on the following articles:
Bates DW, Kuperman GJ, Jha A, Teich JM, Orav EJ, Ma'luf N, et al. Does the computerized display of charges affect inpatient ancillary test utilization? Arch Intern Med. 1997;157:2501-8. [PMID: 9385303]
Sanders DL, Miller RA. The effects on clinician ordering patterns of a computerized decision support system for neuroradiology imaging studies. Proc AMIA Symp. 2001:583-7. [PMID: 11825254]
Carton M, Auvert B, Guerini H, Boulard JC, Heautot JF, Landre MF, et al. Assessment of radiological referral practice and effect of computer-based guidelines on radiological requests in two emergency departments. Clin Radiol. 2002;57:123-8. [PMID: 11977945]
Vartanians VM, Sistrom CL, Weilburg JB, Rosenthal DI, Thrall JH. Increasing the appropriateness of outpatient imaging: effects of a barrier to ordering low-yield examinations. Radiology. 2010;255:842-9. [PMID: 20501721] doi:10.1148/radiol.10091228
Number of results after removing duplicates: 49

Appendix Figure 1. Summary of evidence search and selection.



CCDS = computerized clinical decision support; EHR = electronic health record.
* Results from previous systematic reviews (*n* = 152), the Agency for Healthcare Research and Quality database (*n* = 226), the update searches (*n* = 793), and articles identified during reference mining (*n* = 24) were deduplicated to reach this number.
† Manuscript reference list includes additional references cited for background and methods plus Web sites relevant to key questions.

Appendix Table 2. Evidence Table of Study Characteristics

Author, Year	Study Design	Modality (Radiology)	Intervention	Comparison	Sample Size	Target	Finding
Bates, 1997[15]	RCT; April-October 1994; also evaluated historical data	35 most commonly ordered studies, including x-rays, US, CTs, VQ scan, and MRI brain/LS	Charges for the 35 most common radiologic tests were displayed at the time of electronic POE	POE without display of charge data	8728 intervention patients; 8653 control patients	Assess whether knowledge of cost (charges) can affect physician ordering behavior	Computerized display of cost information did not impact the number of radiologic tests ordered and performed (mean=$276 vs. $275; $P = 0.88$).
Blackmore, 2011[18]	Time series; January 2003-December 2009	Lumbar MRI, head MRI, head CT, sinus CT	Clinical decision support at the time of POE for 3 radiology procedures	Historical control, utilization rates from before and during the intervention	49,967	Decision support to lower utilization of lumbar MRI, head MRI, and sinus CT	Targeted use of decision support can decrease inappropriate utilization.
Carton, 2002[19]	Time series; June-November 1998	Radiology studies ordered in 2 EDs	Providers ordered radiology tests selected from a list of clinical contexts related to the exam and were alerted if the selected context did not conform to guidelines for the test	Notification that request did not meet guidelines	6869 radiology exam requests	Reduce unnecessary medical imaging	The display of recommendations reduced non–guideline-adherent requests by 20% relative at hospital A ($P = 0.02$) and 23% at hospital B ($P = 0.0001$) (19.4% to 15.6% and 39.9% to −90% and 30.0%, respectively. The 3 most commonly requested tests not conforming to guidelines were abdominal plain radiographs (76%), CXR (25%), and head CT (16%).
Chin, 1999[20]	Time series, descriptive quantitative; 1995	UGI studies, CXRs (but no data given to CXR)	Guidelines were displayed within electronic order at time of order entry	Web-based guideline publication	Not provided	Increase guideline-adherent ordering	UGI ordering that conformed to guidelines improved from 55% to 88% (once guidelines introduced at POE). Also decrease in orders from 10.6 per 1000 members to 5.6 per 1000 members. CXRs decreased by 20%.
Curry, 2011[25]	Pre-post; dates not stated	Radiology studies	Decision support during POE	None	904 orders	Clinical guideline acceptance through decision support during POE	Physicians supported the concept of decision support but were reluctant to change.
Day, 1995[26]	Pre-post; pre: May-November 1992, post: May-December 1993	Lumbosacral x-rays for back pain	ED charting system with guideline-based care recommendation	Usual care without computerized order entry; standalone	103 patients in pre period, 259 patients in intervention period (79% were treated using the CPOE/DSS intervention)	Improve appropriateness of care for LBP and reduce costs	There was no difference in the appropriateness of testing or cost-effectiveness of care.
Drescher, 2011[27]	Pre-post; dates not stated	CT angiography	Decision support calculating a Wells score for each order of CT angiography during POE	Historical preintervention	Pre: 205; post: 229	Increase the positive rate of CT angiography results	Decision support during POE lead to higher positive CT angiography results for PE. CT angiography positive rate increased from 8.3% pre to 12.7% post (difference, −4.4 percentage points [95% CI, −1.4 to 10.1 percentage points]).
Durand, 2013[28]	Pre-post; 2008-May 2010	10 most frequently ordered imaging tests: Intervention: AP CXR, AXR, CT head, renal US, vascular US; control: extremity US, PA/lateral CXR, CT abdomen with contrast, abdominal US, CT chest with contrast	Presented providers with cost information for 5 imaging studies	No-cost information for 5 different imaging studies	Number of tests ordered baseline: 34,776 intervention studies and 4914 control studies; number of tests ordered post intervention: 34,776 intervention studies and 4846 control studies	Reduce ordering of imaging studies	There was no significant difference in numbers of imaging studies ordered between the baseline and intervention periods.
Flamm, 2013[29]	Pre-post with historical controls; intervention 2009, control 2007	CXR	Web-based tool (PROP) that provides preoperative test recommendations based on inputted patient and procedure data	Patients referred for preoperative evaluation prior to PROP implementation	Intervention 1148; controls 1363	Improve preoperative guideline adherence and reduce unnecessary testing	For CXR, there were significantly fewer unnecessary preoperative x-rays performed in the intervention group (1.9% vs. 25.2%; $P < 0.001$). However, intervention patients were also more likely not to receive x-rays when clinically indicated (9.3% vs. 1.9%; $P < 0.001$).
Gupta, 2014[30]	Pre-post; August 2007-October 2009, December 2009-February 2012	Head CT	A CCDS for orders for mild head CT in traumatic brain injury that required clinicians to answer additional clinical questions	Web-based CPOE without CCDS	Random sample of 200 head CT examinations for mild traumatic brain injury in pre and post period	Adherence to evidence, head guidelines for use of head CT	Adherence to guidelines was 49% pre intervention and 76.5% post intervention.
Harpole, 1997[17]	Phase 1: Case series; 1 August-30 September 1995	KUB study	CPOE with pop-up message indicating that KUB study for a specific indication was low-yield or another view or modality (e.g., US) was more worthwhile	NA	190 patients; 380 KUB study orders	Reduce low-yield KUB study	Low-yield KUB studies were canceled in 3% of 258 orders. KUB study order was changed to other view or modality in 38% of 109 orders.

Continued on following page

Appendix Table 2–Continued

Author, Year	Study Design	Modality (Radiology)	Intervention	Comparison	Sample Size	Target	Finding
	Phase 2: RCT; 10 November 1995-21 March 1996	KUB study	CPOE with amended pop-up message further emphasizing that KUB study for a specific indication was low-yield or another view or modality (e.g., US) was more worthwhile	Original pop-up message from phase 1	491 patients; 864 KUB study orders	Reduce low-yield KUB study	Low-yield KUB studies were canceled in 4% of 283 orders. KUB study order was changed to other modality in 55% of 176 orders.
Ip, 2014[32]	Pre-post; 2007-2010	Lumbosacral MRI	Presentation of ACP/APS guidelines for MRI imaging in LBP and mandatory "near real-time" peer-to-peer telephonic consultation with a radiologist or internist when attempting to override the guidelines; audit-and-feedback of performance to individual provider	Existing EHR with CPOE but without guidelines or other interventions	21,445 primary care visits; 930 visits for LBP had MRI ordered	Reduce inappropriate use of MRI for back pain	Reduce use of LS MRI decreased from 5.3% of LBP-related primary care visits to 3.7% after implementation of the intervention. Guideline adherence rate increased from 78% to 98% with the intervention.
Ip, 2013[21]	Time series; 2004-2009	CT, MRI, and nuclear cardiology procedures	CCDS embedded in EHR that gives real-time feedback about appropriateness and regular peer-to-peer consultation to complete orders deemed uncertain or inappropriate	EHR before CCDS implementation	50,336 procedures	Reduce imaging utilization	After implementation, use of procedures decreased from 17.5 to 14.4 CTs per 1000 patient-months, from 10.7 to 11.1 MRIs per 1000 patient-months, and from 2.4 to 1.4 cardiac procedures per 1000 patient-months.
Raja, 2012[22]	Time series; October 2003-September 2007	CT pulmonary angiography	CCDS integrated into hospital CPOE system that required physicians to order a D-dimer and give a clinical suspicion of high, medium, or low	CPOE before the CCDS intervention	6838 patients	Reduce inappropriate CT pulmonary angiography in the ED	After CCDS implementation, the rate of CT pulmonary angiography decreased by 20%, from 26.4 to 21.1 examinations per 1000 patients. The proportion of positive CT angiograms increased after the intervention from 5.9% to 9.8%.
Raja, 2014[37]	Pre-post; 2009-2011	CT pulmonary angiography	CCDS integrated into CPOE that required mandatory data input for each unique clinical attribute of the Wells criteria and the D-dimer level; it required 9 mouse clicks	First-generation CCDS as described in reference 22	2423 patients	Appropriate use of CT pulmonary angiography in the ED	After the advanced CCDS implementation, appropriateness increased from 56.9% to 75.6%; however, use was constant and yield was relatively unchanged (10.4% pre vs. 10.4% post).
Rosenthal, 2006[23]	Time series; January 2002-December 2005	CT/MRI, nuclear cardiology exams	Computerized radiology order entry system that assigned a utility score to each ordered examination	Radiology order entry system without decision support	71,966 post decision-support tests	Reduce low-utility tests	The rate of low-utility examination declined from 6% to 2% across all examinations and all physician specialties. 19.4% of low-utility scores resulted in immediate cancellation.
Sanders, 2001[33]	Pre-post; pre: 30 September-4 December 2000, post: 5 December 2000-3 January 2001	Brain MRI, head CT	Implementation of WizOrder's DSS, which provides a recommended test (CT or MRI, contrast or noncontrast) based on ICD-9-CM codes and free-text indications	Preintervention paper-based guidelines	742 tests in pre period, 704 tests in post period	Appropriateness of neuroradiology imaging requests	Significant difference in the distribution of orders for each study type with a trend toward ordering the recommended tests in the postintervention period, with an increase in noncontract MRI being most prominent.
Sistrom, 2009[24]	Time series; 2000-2007	CT, MRI, US	Implementation of a Web-based radiology order entry system with decision support providing feedback on appropriateness based on provider-entered clinical information	Paper, facsimile, and telephone methods	100% sample of radiology tests by quarter, which were approximately 13,000 CTs, 9000 MRIs, and 11,000 Us each quarter	Growth rates of outpatient CT, MRI, and US volumes	CT and US volumes growth and growth rates decreased significantly after implementation of computerized order entry with decision support; MRI growth rate also decreased significantly from 3.0% to 0.25%, 2.2% to 0.9%, and 2.9% to 1.7%, respectively.
Solberg, 2010[34]	Pre-post; 2006-2007	CT, MRI of the head, MRI of the LS	Implementation of decision support that identified appropriateness criteria (in 3 categories: A, B, or C) for the imaging studies	EHR with no decision support	151 cases in pre period, 148 cases in post period; all randomly chosen	Reduce inappropriate imaging studies	Volume of completed test orders decreased by 36.5% for head CT and 20% for spine MRI but increased by 3.3% for head MRI. Only MRI of the head and spine showed an increase in meeting appropriateness criteria post implementation.
Soo Hoo, 2011[31]	Pre-post; December 2006-November 2008	CT pulmonary angiography	CCDS requiring physician-entered data to calculate a Wells score	CPOE without CCDS	196 examinations in the preintervention period, 261 CT examinations on 252 patients in the postintervention period	Increase the yield of positive examinations	After implementation of the intervention, the proportion of positive examinations increased from 3.1% to 16.5%.

Continued on following page

Appendix Table 2–Continued

Author, Year	Study Design	Modality (Radiology)	Intervention	Comparison	Sample Size	Target	Finding
Tierney, 1990[35]	Pre-post; January 1988; 14-week preintervention, 26-week intervention period, and 19-week postintervention period	CXR; abdominal sonography; CT scan (head); MRI (head)	Charge for test displayed at the time of test ordering at academic general internal medicine practice	Usual ordering without charge display	Preintervention period: 3362 patients in the control group and 3511 in the intervention group; intervention period: 4138 control and 4254 intervention; postintervention: 2806 control and 4461 intervention	Assess whether knowledge of cost (charges) can affect physician ordering behavior	No specific data on imaging modalities. Data pooled and displayed as cost for all tests, including blood, urine, EKG, and imaging studies. For both attendings and residents, there was a statistically significant reduction in test ordering and charges.
Tierney, 1988[16]	RCT; 24 March-30 September 1986	CXR as 1 of 8 intervention tests	Display of predicted probabilities of positive test abnormalities provided at the time of test ordering; academic general internal medicine practice for scheduled patients	Usual ordering without predicted probability display	7658 scheduled visits in intervention group; 7590 scheduled visits in control group; 487 CXRs	Reduction in ordering low-probability tests with resultant decrease in charges per visit	There was a nonsignificant 13.8% decrease in charges related to CXR ordering.
Vartanians, 2010[36]	Pre-post; pre: April-December 2006; post: April-December 2007	Outpatient CT/MRI and nuclear medicine examinations	Computerized radiology order entry system rule change that prevented nonclinician support staff from completing orders that received initial low-yield decision-support score (required order to be entered directly by clinician)	CPOE before the intervention	42,737 orders in control group and 76,238 orders in study group	Reduce number of low-yield imaging studies	Reduction in number of low-yield tests decreased: 2106 of 38,801 (5.43%) to 1261 of 65,765 (1.92%) ($P < 0.001$).

ACP = American College of Physicians; AP = anteroposterior; APS = American Pain Society; AXR = abdominal x-ray; CCDS = computerized clinical decision support; CPOE = computerized POE; CT = computed tomography; CXR = chest x-ray; DSS = decision-support system; ED = emergency department; EHR = electronic health record; EKG = electrocardiography; GI = gastrointestinal; ICD-9-CM = International Classification of Diseases, Ninth Revision, Clinical Modification; KUB = kidney, ureter, and bladder; LBP = low back pain; LS = lumbar spine; MRI = magnetic resonance imaging; NA = not available; PA = posteroanterior; PE = pulmonary embolism; POE = provider order entry; PROP = Preoperative Evaluation; RCT = randomized, controlled trial; UGI = upper gastrointestinal; US = ultrasonography; VQ = ventilation–perfusion.

Appendix Table 3. Evidence Table of IT Design and Implementation Characteristics

Author, Year	Setting	IT Design				Data Entry Source		Implementation Characteristics				
		Is It Integrated With CPOE?	Does It Give Real-Time Feedback at Point of Care?	Does the CCDS Suggest a Recommended Course of Action?	Intervention Classification*	Is It Automated Through EHR?†	Do Clinical Staff Enter Data Specifically for Intervention?	Was It Pilot-Tested, or Did It Use an Iterative Process of Development/ Implementation?	Was There Any User Training/Clinician Education?	Are the Authors Also the Developers and Part of the User Group for the CCDS?	Was There Use of Audit and Feedback (or Other Internal Incentive)?	Are There Any Other Implementation Components Not Already Discussed?
Bates, 1997[15]	Harvard-affiliated academic medical center	Yes	Yes	No	A	Yes	No	Not stated	Not stated	Yes	No	Not stated
Blackmore, 2011[18]	Integrated multidisciplinary health care network, Virginia Mason	Yes	Yes	Yes	D	No	Yes	Not stated	Yes	Not stated	Yes	Authors consider context of facility important for success; salaried physicians in an integrated health network reducing utilization was an important institutional goal. There is a culture of evidence-based medicine and local development of protocols.
Carton, 2002[19]	Two French teaching hospitals	No	Yes	Yes	C	No	Yes	Not stated	Not stated	Not stated	Not stated	Not stated
Chin, 1999[20]	Kaiser	Yes	Yes	Yes	A	Yes	No	Not stated	Not stated	Not stated	Not stated	No
Curry, 2011[25]	Rural Manitoba family medicine clinic	Yes	Yes	Yes	C	Yes	Yes	Not stated	Yes	No	Yes	Implemented at site indicating leadership interest in adoption
Day, 1995[26]	UCLA-affiliated academic medical center	No	Yes	Yes	B	No	Yes	No	Yes	Yes	No	No
Drescher, 2011[27]	VA	Yes	Yes	Yes	B	No	Yes	Not stated	Yes	Not stated	Not stated	Adherence by physicians in use of the CCDS was documented and varied widely.
Durand, 2013[28]	Johns Hopkins-affiliated academic medical center	Yes	No	No	A	Yes	No	No	No	Yes	No	No
Flamm, 2013[29]	Salzburg, Austria, hospital	No	Yes	Yes	B	No	Yes	No	No	No	No	No
Gupta, 2014[30]	Harvard-affiliated academic medical center	Yes	Yes	Yes	B	No	Yes	No	No	Unclear	No	No
Harpole, 1997[17]	Harvard-affiliated academic medical center	Yes	Yes	Yes	B	No	Yes	Yes; phase 1 led to phase 2	No	Probably	No	No
Ip, 2014[32]	Harvard-affiliated academic medical center	Yes	Yes	Yes	D	Yes	No	Not stated	Not stated	Not stated	Yes	Mandatory peer-to-peer telephone consult was needed to override an alert.
Ip, 2013[21]	Harvard-affiliated academic medical center	Yes	Yes	Yes	D	Yes	No	No	No	Yes	Yes	Academic detailing for high-utilization outlier physicians. A risk contract with the payer was an external stimulus.
Raja, 2012[22]	Harvard-affiliated academic medical center	Yes	Yes	Yes	B	No	Yes	No	Yes	Yes	No	No
Raja, 2014[37]	Harvard-affiliated academic medical center	Yes	Yes	Yes	B	No	Yes	No	No	Yes	No	Authors assessed fidelity of the entered information to the medical record; 83% concordance was found.
Rosenthal, 2006[23]	Harvard-affiliated academic medical center	Yes	Yes	Yes	C	No	No	No	No	Yes	Yes	No
Sanders, 2001[33]	Vanderbilt-affiliated academic medical center	Yes	Yes	Yes	C	No	Yes	No	No	Yes	No	No
Sistrom, 2009[24]	Harvard-affiliated academic medical center	Yes	Yes	Yes	B	No	Yes	No	No	Yes	No	Phased implementation of Web-based systems, but big-bang for decision support.
Solberg, 2010[34]	Large multispecialty group in Minneapolis-St. Paul	Yes	Yes	No	A	Yes	No	No	No	Not clear	No	No financial incentives
Soo Hoo, 2011[31]	VA	Yes	Yes	Yes	D	No	Yes	No	No	Yes	No	No
Tierney, 1990[35]	Regenstrief Health Center	Yes	Yes	Yes	A	Yes‡	No	No	No	Yes	No	No
Tierney, 1988[16]	Regenstrief Health Center	Yes	Yes	No	A	Yes‡	No	No	No	Yes	No	No
Vartanians, 2010[36]	Harvard-affiliated academic medical center	Yes	Yes	Yes	D	No	No	No	No	Yes	No	No

CCDS = computerized clinical decision support; CPOE = computerized provider order entry; EHR = electronic health record; IT = information technology; UCLA = University of California, Los Angeles; VA = Veterans Affairs.
* "A" indicates interventions provided information only. "B" indicates interventions presented information on appropriateness or guidelines specifically tailored to the individual patient, often as a pop-up or alert. Some of these interventions also recommended alternative interventions but did not include any barrier for the clinician to order the test. "C" indicates interventions in general that were similar to "B" interventions but required the ordering clinician to justify with free text why he or she was overriding the decision-support recommendation that a study was inappropriate (i.e., a "soft stop"). "D" indicates interventions that included a "hard stop," meaning the intervention prevented the clinician from ordering a test contrary to the CCDS determination of inappropriateness until additional discussion with or permission was obtained from another clinician or radiologist.
† For example, uses only data already being entered for clinical care.
‡ Integrated into an EHR precursor.

Appendix Table 4. Articles With Type of Outcome Presented

Author, Year	Appropriateness	Use
Bates, 1997[15]		X
Blackmore, 2011[18]		X
Carton, 2002[19]	X	
Chin, 1999[20]	X	X
Day, 1995[26]	X	X
Drescher, 2011[27]	X	
Durand, 2013[28]		X
Flamm, 2013[29]	X	
Gupta, 2014[30]	X	
Harpole, 1997[17]		X
Ip, 2014[32]	X	X
Ip, 2013[21]		X
Raja, 2012[22]	X	X
Raja, 2014[37]*	X	X
Rosenthal, 2006[23]	X	
Sanders, 2001[33]		X
Sistrom, 2009[24]		X
Solberg, 2010[34]	X	
Soo Hoo, 2011[31]	X	
Tierney, 1988[16]		X
Vartanians, 2010[36]	X	

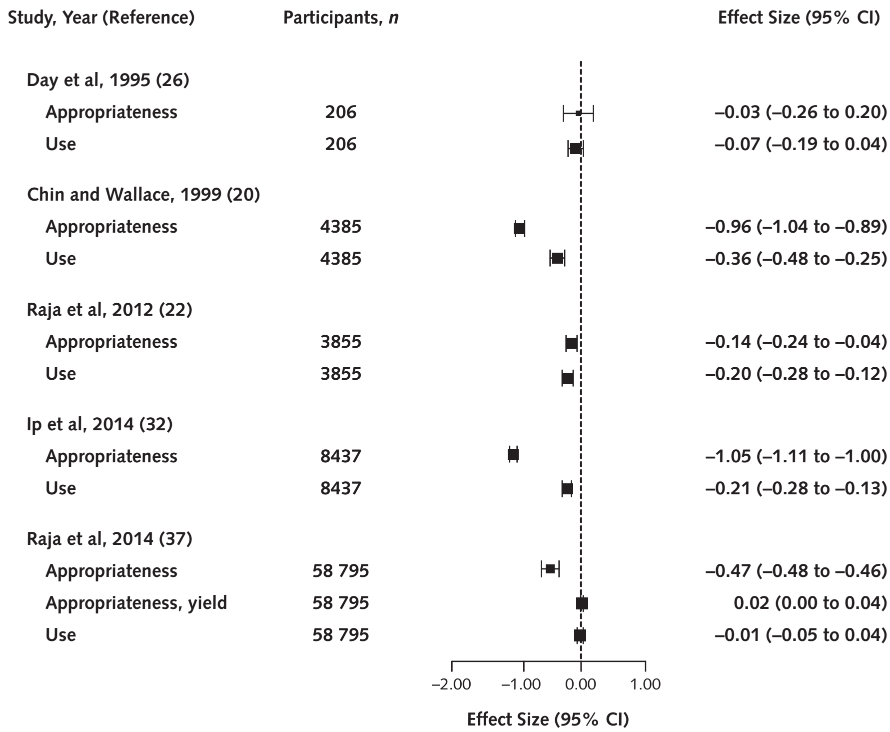
* This study reported both an appropriateness outcome, as in the proportion of radiologic tests ordered that met a national standard, and the percentage of positive yield of radiologic examinations. We included both here for comparison.

Appendix Table 5. Description of Outcomes Used as Measures of Appropriate or Inappropriate Use

Author, Year	Method of Reporting Outcome
Carton, 2002[19]	Percentage of radiologic examinations not in agreement with guidelines
Chin, 1999[20]	Percentage of UGI orders that conformed to a guideline
Day, 1995[26]	Was decision appropriate (according to guidelines)?
Drescher, 2011[27]	Percentage yield of positive CTA examinations
Flamm, 2013[29]	Numbers of radiology tests indicated or not indicated
Gupta, 2014[30]	Percentage of radiology ordering decisions adherent to guidelines
Ip, 2014[32]	Guideline adherence rate
Raja, 2012[22]	Yield of positive CTA examination
Raja, 2014[37]	Appropriateness of CTA ordering; yield of positive CTA examination
Rosenthal, 2006[23]	Change in rate of radiology orders judged as "low utility" according to appropriateness criteria
Solberg, 2010[34]	Proportion of radiology studies meeting "high utility" according to appropriateness criteria
Soo Hoo, 2011[31]	Yield of positive CTA examinations
Vartanians, 2010[36]	Percentage of examinations ordered judged to be of low-yield

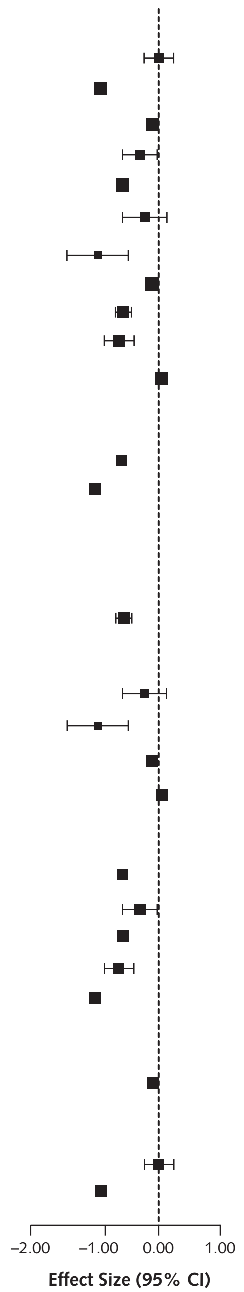
CTA = computed tomographic angiography; UGI = upper gastrointestinal.

Appendix Figure 2. Studies reporting both appropriateness and use outcomes.



Appendix Figure 3. Effect of EHR-based intervention on the appropriateness of diagnostic radiologic test ordering, stratified by implementation characteristic and target.

Study, Year (Reference)	Participants, *n*	Effect Size (95% CI)
Implementation characteristics		
No audit and feedback		
Day et al, 1995 (26)	206	–0.03 (–0.26 to 0.20)
Chin and Wallace, 1999 (20)	4385	–0.96 (–1.04 to –0.89)
Carton et al, 2002 (19)	3435	–0.12 (–0.18 to –0.07)
Solberg et al, 2010 (34)	157	–0.33 (–0.60 to –0.06)
Vartanians et al, 2010 (36)	38 801	–0.62 (–0.64 to –0.59)
Drescher et al, 2011 (27)	205	–0.26 (–0.61 to 0.09)
Soo Hoo et al, 2011 (31)	196	–1.01 (–1.49 to –0.53)
Raja et al, 2012 (22)	3855	–0.14 (–0.24 to –0.04)
Flamm et al, 2013 (29)	1363	–0.59 (–0.71 to –0.47)
Gupta et al, 2014 (30)	200	–0.67 (–0.91 to –0.44)
Raja et al, 2014 (35)	58 795	0.02 (0.00 to 0.04)
Audit and feedback		
Rosenthal et al, 2006 (23)	15 000	–0.63 (–0.70 to –0.56)
Ip et al, 2014 (32)	8437	–1.05 (–1.11 to –1.00)
Target		
Chest radiography		
Flamm et al, 2013 (29)	1363	–0.59 (–0.71 to –0.47)
CT		
Drescher et al, 2011 (27)	205	–0.26 (–0.61 to 0.09)
Soo Hoo et al, 2011 (31)	196	–1.01 (–1.49 to –0.53)
Raja et al, 2012 (22)	3855	–0.14 (–0.24 to –0.04)
Raja et al, 2014 (37)	58 795	0.02 (0.00 to 0.04)
High-cost imaging		
Rosenthal et al, 2006 (23)	15 000	–0.63 (–0.70 to –0.56)
Solberg et al 2010 (34)	157	–0.33 (–0.60 to –0.06)
Vartanians et al, 2010 (36)	38 801	–0.62 (–0.64 to –0.59)
Gupta et al, 2014 (30)	200	–0.67 (–0.91 to –0.44)
Ip et al, 2014 (32)	8437	–1.05 (–1.11 to –1.00)
Several		
Carton et al, 2002 (19)	3435	–0.12 (–0.18 to –0.07)
Other		
Day et al, 1995 (26)	206	–0.03 (–0.26 to 0.20)
Chin and Wallace, 1999 (20)	4385	–0.96 (–1.04 to –0.89)



CT = computed tomography; EHR = electronic health record.