Original Investigation

Training Physicians to Provide High-Value, Cost-Conscious Care
A Systematic Review

Lorette A. Stammen, MD; Renée E. Stalmeijer, MSc, PhD; Emma Paternotte, MD; Andrea Oudkerk Pool, MSc; Erik W. Driessen, MSc, PhD; Fedde Scheele, MD, PhD; Laurents P. S. Stassen, MD, PhD

IMPORTANCE Increasing health care expenditures are taxing the sustainability of the health care system. Physicians should be prepared to deliver high-value, cost-conscious care.

OBJECTIVE To understand the circumstances in which the delivery of high-value, cost-conscious care is learned, with a goal of informing development of effective educational interventions.

DATA SOURCES PubMed, EMBASE, ERIC, and Cochrane databases were searched from inception until September 5, 2015, to identify learners and cost-related topics.

STUDY SELECTION Studies were included on the basis of topic relevance, implementation of intervention, evaluation of intervention, educational components in intervention, and appropriate target group. There was no restriction on study design.

DATA EXTRACTION AND SYNTHESIS Data extraction was guided by a merged and modified version of a Best Evidence in Medical Education abstraction form and a Cochrane data coding sheet. Articles were analyzed using the realist review method, a narrative review technique that focuses on understanding the underlying mechanisms in interventions. Recurrent patterns were identified in the data through thematic analyses. Resulting themes were discussed within the research team until consensus was reached.

MAIN OUTCOMES AND MEASURES Main outcomes were factors that promote education in delivering high-value, cost-conscious care.

FINDINGS The initial search identified 2650 articles; 79 met the inclusion criteria, of which 14 were randomized clinical trials. The majority of the studies were conducted in North America (78.5%) using a pre-post interventional design (58.2%; at least 1619 participants); they focused on practicing physicians (36.7%; at least 3448 participants), resident physicians (6.3%; n = 516), and medical students (15.2%; n = 275). Among the 14 randomized clinical trials, 12 addressed knowledge transmission, 7 reflective practice, and 1 supportive environment; 10 (71%) concluded that the intervention was effective. The data analysis suggested that 3 factors aid successful learning: (1) effective transmission of knowledge, related, for example, to general health economics and prices of health services, to scientific evidence regarding guidelines and the benefits and harms of health care, and to patient preferences and personal values (67 articles); (2) facilitation of reflective practice, such as providing feedback or asking reflective questions regarding decisions related to laboratory ordering or prescribing to give trainees insight into their past and current behavior (56 articles); and (3) creation of a supportive environment in which the organization of the health care system, the presence of role models of delivering high-value, cost-conscious care, and a culture of high-value, cost-conscious care reinforce the desired training goals (27 articles).

CONCLUSIONS AND RELEVANCE Research on educating physicians to deliver high-value, cost-conscious care suggests that learning by practicing physicians, resident physicians, and medical students is promoted by combining specific knowledge transmission, reflective practice, and a supportive environment. These factors should be considered when educational interventions are being developed.

JAMA. 2015;314(22):2384-2400. doi:10.1001/jama.2015.16353

Editorial page 2359

JAMA Patient Page page 2462

Supplemental content at jama.com

CME Quiz at jamanetworkcme.com and CME Questions page 2408

Author Affiliations: Author affiliations are listed at the end of this article.

Corresponding Author: Lorette A. Stammen, MD, Department of Educational Development and Research, Faculty of Health, Medicine, and Life Sciences, Maastricht University, PO Box 616, 6200 MD Maastricht, the Netherlands (l.stammen@maastrichtuniversity.nl).

Increasing costs of health care are a cause of concern to patients, governments, health economists, and the medical profession around the world.[1-3] The United States has the highest health care expenses, with health care expenditures in 2015 approaching 18% of gross domestic product.[4] Leading physician associations, such as the American College of Physicians, the Alliance for Academic Internal Medicine, and the American Board of Internal Medicine, offer educational programs on providing high-value, cost-conscious care.[5,6]

High-value, cost-conscious care refers to care that aims to assess the benefits, harms, and costs of interventions and consequently to provide care that adds value.[7] Although in recent years the harms of increasing health care costs have been acknowledged, bending the cost curve has proved difficult.[8] Besides the increase in health care costs and its associated complications such as the accessibility and sustainability of health care, quality cannot always be established.[2,9] Interventions targeting physicians and their medical expertise are proposed as a means to reduce health care waste (care that is not beneficial to patients) while maintaining the quality of care.[2,7]

This review was conducted to gain understanding of how and under what circumstances educational interventions may help practicing physicians, resident physicians, and medical students deliver high-value, cost-conscious care. Insight into this learning process is necessary to develop programs that train physicians in providing such care.

Methods

This review was conducted and reported in accordance with the RAMESES publication standards for realist reviews.[10] Realist review is a systematic, theory-driven, interpretative, narrative technique developed to analyze heterogeneous evidence (qualitative and quantitative data and/or different outcome measures) to understand the underlying mechanisms of an intervention. Realist review gives priority to understanding what does or does not make an intervention effective over the outcome of the intervention. Included articles were analyzed by searching for information on contexts or settings in which the study was conducted, working mechanisms of the interventions, outcomes of the interventions, and program theories (ie, theories of how and why an intervention causes effect) that could explain effectiveness of the described interventions. The realist review method has a particular strength when designs like randomized clinical trials have produced inconsistent estimates of efficacy and there is no consensus on when, how, and with whom to use these interventions.[10]

Literature Search

The research team designed a strategy to search the PubMed, EMBASE, Education Resources Information center (ERIC), and Cochrane databases. Search terms were used to identify learners (*physicians*, *residents*, *medical students*, *medical education*) and topic (*cost awareness*, *cost consciousness*, *unnecessary procedures*). These were combined and searched with and without factors associated with cost containment (*cost-effectiveness*, *risk assessment*, *value-based care*, *shared decision-making*, *practice variation*, *stewardship of resources*). The search was conducted from the inception of each database until September 5, 2015.

Box. Final Inclusion Criteria[a]

- Article is about at least 1 of the following topics
  - Reducing volume of health care services
  - Reducing health care expenditures
  - Improving quality of care
  - Improving knowledge and/or attitude regarding costs of care
- Article describes an intervention implementation
- Intervention is evaluated
- Intervention contains educational component(s)
- Target group contains physicians, residents, and/or medical students

[a] To be included, articles had to meet all criteria described above.

Study Selection

After an initial search, titles and abstracts were screened by 3 independent researchers (L.A.S., A.O.P., and Inge Verheijen, Maastricht University) on the basis of inclusion criteria: abstract available, relevant topic, implementation of intervention, evaluation of intervention, educational components in intervention, and appropriate target group. Articles without an abstract were excluded from review. When title or abstract alone did not provide sufficient information, full-text review was done. Articles were assessed using an eligibility form based on the Best Evidence in Medical Education (BEME) abstraction form and a Cochrane data coding sheet (eAppendix 1 in the Supplement).[11,12] Articles that were found to be appropriate underwent further evaluation to determine if they met the final inclusion criteria (**Box**). If during full-text review articles did not meet all 5 inclusion criteria, they were excluded from further review. For a realist review, both qualitative and quantitative articles can be included and analyzed to create a broad range of potential empirical mechanisms of the interventions.[10]

Data Extraction and Synthesis

To abstract data from the selected articles in order to identify factors that may influence learning by practicing physicians, resident physicians, and medical students, 3 researchers used a merged and modified version of a Best Evidence in Medical Education (BEME) abstraction form and a Cochrane data coding sheet (eAppendix 2 in the Supplement).[11,12] Disagreements in the final phase of study selection were resolved by inviting other members of the research team to read articles in full. Data synthesis was guided by realist methodology: for each article, we identified program theories, context, mechanisms, and outcomes through a thematic analysis.[13] Recurrent patterns of context and outcome in the

Table 1. Characteristics of Included Studies[a]

Characteristics	No. (%)
Geographical setting	
North America	62 (78.5)
Asia	6 (7.6)
Europe	6 (7.6)
Oceania	4 (5.0)
Africa	1 (1.3)
Study designs	
Pre-post interventional (n>1619)	46 (58.2)
Quasi-experimental (n>616)	14 (17.7)
Randomized clinical trial (n>2149)	14 (17.7)
Mixed methods (n>349)	4 (5.1)
Qualitative (n=31)	1 (1.3)
Target group	
Practicing physicians	29 (36.7)
Physicians and other health care professionals	18 (22.6)
Combination of physicians, residents, and students	15 (19.0)
Resident physicians	12 (15.2)
Medical students	5 (6.3)
No. of participants	
Not reported	28 (35.4)
0-50	25 (31.7)
51-100	14 (17.7)
101-150	1 (1.3)
>150	11 (13.9)
Training factors	
Knowledge transmission, reflective practice, and supportive environment[b]	16 (20.3)
Knowledge transmission and reflective practice[c]	29 (36.7)
Knowledge transmission and supportive environment[35,36,44,50,51]	5 (6.3)
Reflective practice and supportive environment[39,74,77,78,91,92]	6 (7.6)
Knowledge transmission[d]	17 (21.5)
Reflective practice[21,40,66,67,73]	5 (6.3)
Supportive environment[87]	1 (1.3)

[a] Study designs and target groups are based on Best Evidence Medical Education Collaboration classification. Types of training factors in each study are counted based on which factor they represent in the Results section of the text. Twenty-eight included articles did not report the number of participants. Therefore, the minimum number of participants based on those who could be counted is reported.

[b] References 27, 32, 37, 41, 46, 55, 61, 64, 65, 69, 70, 71, 81-83, and 88.

[c] References 14-16, 22, 28-31, 34, 42-45, 47-49, 52, 53, 56, 57, 62, 63, 68, 72, 75, 76, 79, 80, 84, and 86.

[d] References 17-20, 23-26, 33, 38, 54, 58-60, 85, 89, and 90.

data were identified. Next, we sought to explain these patterns by their mechanism to gain understanding of how contexts, mechanisms, and outcomes are related. Both successes and failures can provide valuable information regarding context and mechanism.[10] The themes were discussed until consensus was reached within the research team. Particular attention was paid to discrepant examples to ensure that the analysis could account for their occurrence. Quality of the included articles was assessed based on the relevance and rigor of the articles.[10] Rigor was defined as to what extent the method used to generate that particular piece of data was credible (internal validity) and trustworthy (reliability) (high or low). Relevance was determined by assessing whether the article contributed to answering the research question (high or low). Assessments of rigor and relevance were conducted by 2 independent researchers (L.A.S. and A.O.P.) and were combined into 1 score: high (rigor high/relevance high), medium (rigor high/ relevance low or rigor low/relevance high), or low (rigor low/relevance low). The reviewers were not blinded to any portion of articles. Disagreement about study selection, data extraction, and data synthesis were resolved through consensus within the research team.

Results

Search Results and Selected Articles

The results of the review process are summarized in the eFigure in the Supplement. A total of 2650 articles were considered for review; 102 articles were appropriate for further selection, of which 79 met the inclusion criteria. The majority of the studies were conducted in North America (78.5%) using pre-post interventional design (58.2%; at least 1619 participants); they focused on practicing physicians (36.7%; at least 3448 participants), resident physicians (6.3%; n = 516), and medical students (15.2%; n = 275). Twenty-eight articles did not report the number of participating practicing physicians, resident physicians, or medical students. More detail regarding the characteristics of the selected articles is shown in **Table 1**. Of the articles, 87% concluded that their interventions were effective in delivering appropriate care and reducing costs, volume, or unnecessary procedures. Among the 14 randomized clinical trials, 12 addressed knowledge transmission, 7 reflective practice, and 1 supportive environment; 10 (71%) concluded that the intervention was effective. Summaries of articles are provided in **Table 2**, with more details provided in the eTable in the Supplement.

The data analysis of the included articles concluded that the success of educational interventions preparing future and practicing physicians for the delivery of high-value, cost-conscious care may depend on 3 factors: knowledge transmission, reflective practice, and a supportive environment. These 3 factors were the result of an analytic process in which we first collected potential program theories, contexts, mechanisms, and outcomes as presented in the included articles. Second, we identified recurrent patterns of contexts and outcomes that could be explained by mechanisms found in the included articles. These patterns were extensively discussed within the entire research team to identify overarching factors that influence the learning of practicing physicians, resident physicians, and medical students.

Knowledge Transmission

Increasing knowledge about high-value, cost-conscious care behavior among practicing physicians, resident physicians, and medical students has been associated with reduction in unnecessary or inappropriate health care delivery. Such knowledge interventions specifically focused on 3 subject areas

Table 2. Overview of Included Articles

Source	Design	Aim	Target Group	Focus of Intervention	Main Results	Quality of Rigor/Relevance[a]
Articles That Addressed All 3 Factors (Knowledge Transmission, Reflective Practice, and Supportive Environment)						
Roth et al,[27] 2001	Pre-post interventional (no control group)	Wise allocation of resources	Residents, practicing physicians, other (n = NR)	Cost information flyer, expert reflection, telephone reminders	20% increase in less costly anticoagulant ($P < .001$), annual cost savings of $66 000; 58% increase in less costly nonsteroidal anti-inflammatory drugs ($P < .002$); no cost savings due to overall increase in use	+/+
de Leon et al,[32] 2013	Pre-post interventional	Decrease rate of inappropriate use of drugs	Residents, practicing physicians, other (n = NR)	Guidelines and prescribing indications, educational sessions, evidence-based facilitator guide for discussion	Significant reduction of inappropriate stress ulcer prophylaxis (19% vs 6.6%; $P = .02$)	−/−
Barbarello-Andrews et al,[37] 2006	Pre-post interventional	Increase efficiency and cost-effectiveness	Practicing physicians, other (n = NR)	Educational communication forms and posters, patient-specific physician-pharmacist discussion	Decrease of monthly expenditure in 3 of 4 target medications	+/+
Dowling et al,[41] 1989	Pre-post interventional	Decrease nonindicated testing	Residents (n = 20)	Feedback, evidence-based medicine indications, cost-effectiveness theme for preclinical talks	Significant reduction in thyroid-stimulating hormone test ordering ($P < .001$) and complete blood cell counts ($P = .05$); percentage of appropriate thyroid-stimulating hormone tests indicated increased ($P < .001$).	+/+
Sucov et al,[55] 1999	Pre-post interventional, time series	Decrease tests not clinically indicated	Residents, other (n = NR)	Guideline, lecture on evidence-based medicine and cost containment, discuss ordering with attending physician, utilization feedback	Significant decline in total testing from 209 to 163 tests per 100 patients ($P < .001$); $50 000-$100 000 less charged	+/+
Lee et al,[61] 2014	Pre-post interventional, time series	Decrease unnecessary antibiotic use	Practicing physicians, residents, medical students (n = 42)	Teaching session regarding importance of antibiotic stewardship, guidelines and recommendations; implementation of checklist for time-out audit and feedback regarding appropriateness	15% of time-out audits led to antibiotics change; annual costs of antibiotics decreased ($149 743 to $80 319); volume of antibiotics unchanged; no significant changes in quality outcomes	+/+
Wein and Hoffman,[64] 1987	Pre-post interventional (no control group)	Improve cost-effective utilization	Medical staff, other (n = NR)	Utilization criteria, newsletter, expert reflection on prescribing	Average monthly prescribing costs decreased $6300 (−13.5%)	−/+
Gregory et al,[65] 1999	Pre-post interventional	Decrease rate of cesarean deliveries without lowering health care quality	Residents, physicians, other (n = NR)	Discussion indications, utilization feedback, focus groups on attitudes regarding vaginal birth after cesarean delivery	Cesarean delivery rate decreased (21.2%); postintervention cesarean delivery rate increased; no statistically or clinically significant increase in various complications	−/−
von Ferber et al,[69] 1999	Pre-post interventional, time series	Improve quality of practice, lower costs	Practicing physicians (n = 79)	Feedback and reflection with peers (Balint setting), evidence-based guideline	Significant decrease in prescription rate (eg, 7.2 to 4.8 per physician) and costs (eg, $853 to $527) of the majority of targeted drugs ($P < .05$).	+/+
Moriates et al,[71] 2013	Pre-post interventional	Increase cost-awareness, promote attitude toward cost-control cultivating cost-effective behavior	Medical students, residents (n = 55); practicing physicians (n = 19)	Cost awareness session, price information, review of evidence-based guideline, reflection on ordering, stimulate evidence-based and cost-effective care	Positive Likert scale scores (1-5) on several items "relevant to medical practice": mean, 4.6 (SD, 0.6); "likely to change practice": mean, 4.3 (SD, 0.7)	+/+

(continued)

Table 2. Overview of Included Articles (continued)

Source	Design	Aim	Target Group	Focus of Intervention	Main Results	Quality of Rigor/Relevance[a]
Bornard et al,[81] 2011	Pre-post interventional	Increase quality of prescribing by decreasing unnecessary prescribing	Residents (n = 4); practicing physicians (n = 4)	Feedback and experts' advice to improve, sessions on medical topics, multidisciplinary discussions	Prevalence of adequate antibiotics prescriptions before and after intervention (73% vs 80%; *P* = .31); more frequent reassessment of diagnosis between day 2 and day 4 (11% vs 32%; *P* = .02); improved adaptation of antibiotic therapies to positive microbiology result (25% before vs 50% after; *P* = .18)	+/−
Manheim et al,[82] 1990	Pre-post interventional	Increase cost-awareness, decrease costs	Residents (n = 105)	Chart audits of high costs, comparative feedback on generated costs, evidence-supported discussions about cost-effectiveness of care	Experimental group interns had significantly lower charges (*P* = .036) and length of stay (*P* = .008) per patient vs control group	+/+
Niquille et al,[83] 2010	Pre-post interventional	Contain prescribing costs	Practicing physicians, other (n = 18-60)	Discussion with expert on (over)use, risk/benefit	Annual drug cost per patient increased 74% in control group vs 32% in intervention group (period of 8 y). Cost savings of $225 000 per general physician	+/−
Mallows,[88] 2013	Pre-post interventional	Decrease ordering of tests	Medical students, residents, practicing physicians (n = NR)	Utility discussion, information on costs and quality of testing, fine for ordering	Significant absolute reduction in rate of C-reactive protein test ordering (17.6%; *P* < .001)	−/+
Ijo and Feyerharm,[46] 2011	Quasi experimental	Increase quality of care, lower costs by improving prescribing	Practicing physicians, other (n = NR)	Feedback, peer discussions, expert reflection, evidence-based newsletters	Shorter length of stay in intensive care unit (6 d vs 11-36 d), increase in drug cost expenses (+$192 over 4 mo with infectious disease–related interventions).	−/−
Miyakis et al,[70] 2006	Quasi experimental	Improve quality, lower costs of testing	Residents, practicing physicians, other (n = NR)	Feedback on knowledge and appropriateness, discussion on strategies to reduce testing	Preintervention: 24 482 tests were ordered (28.6% of avoidable tests occurred during first day; 69.3% after first day); postintervention: 10 297 tests were ordered (26.7% of avoidable tests occurred during first day; 63.2% after first day)	+/+
Articles That Addressed 2 Factors						
Verstappen et al,[43] 2003	RCT	Effective test ordering	Practicing physicians (n = 174)	Reflection on feedback, guidelines	Decrease in total number of tests ordered (−67 tests per physician; *P* = .01) and inappropriate tests ordered (−16 tests per physician; *P* = .01)	+/+
Bernal-Delgado et al,[47] 2002	RCT	Change prescribing behavior to improve medical practice	Practicing physicians, other (n = 110)	Outreach visit with/without evidence-based brochure	Experimental group reduced prescriptions by 22.5%; mean cost per prescription decreased by 1.91%; no statistically significant difference found between experimental and control groups	+/−
Hux et al,[49] 1999	RCT	Improve rational drug use by promoting evidence-based prescribing	Practicing physicians (n = 250)	Comparison feedback, guideline, educational bulletin with tips	Median prescription cost ($11) remained constant in intervention group but increased in control group (*P* < .002); first-line drug use increased in intervention group but decreased in control group (*P* < .01)	+/+

(continued)

Table 2. Overview of Included Articles (continued)

Source	Design	Aim	Target Group	Focus of Intervention	Main Results	Quality of Rigor/Relevance[a]
Légaré et al,[57] 2011	RCT	Decrease overuse of antibiotics	Practicing physicians (n = 33)	Evidence-based medicine workshop, feedback, reminders of expected behavior	Intervention group reduced immediate use of antibiotics (49% vs 33%; $P = .08$); decisional conflict agreement was stronger in the intervention group ($P = .06$)	+/+
Fortuna et al,[63] 2009	RCT	Decrease prescribing of drugs	Practicing physicians, other (n = 257)	Computerized alert with recommendation supported by evidence-based medicine, co-payment information, patient information on adverse effects, interactive group discussion on barriers to guideline adherence	Prescribing marketed medication in intervention group less than in control group (relative risk, 0.74; 95% CI, 0.58-0.97; $P = .03$); 23.3% of prescriptions that received alert were altered	+/+
Rotman et al,[80] 1996	RCT	Decrease cost of prescribing	Residents (n = 37)	Cost information, guideline, alerts with suggestions	Increased user satisfaction; no significant differences in health or economic outcomes	+/−
Smith,[92] 1983	RCT	Stimulate cost consciousness	Medical students (n = 37)	Feedback on efficiency, errors, costs, risk, and discomfort, discussion with expert	No significant different in 6 patient management problems; significant ($P < .05$) improvement overall for student comparing pretest vs posttest	−/−
Sussman et al,[14] 2004	Pre-post interventional	Stimulate use of cost-effective alternatives	Practicing physicians, primary care (n = 57)	Information for cost-effective prescribing, specified suggestions for change, cost feedback	Use of high-cost drugs decreased from 38% to 30% ($P < .001$)	+/+
Post et al,[16] 2013	Pre-post interventional	Improve cost awareness and knowledge of costs and value	Residents (n = 83)	Feedback on cost data, reflection on ordering	Decreased error in cost estimates (mean, 83.1% vs 13.4%; $P < .001$); attitude regarding costs significantly changed ($P < .05$)	+/+
Das and Rahman,[31] 2010	Pre-post interventional	Optimize vitamin prescribing, decrease wastage of money	Practicing physicians (n = 30)	Prescriber focus group, feedback data, and evidence-based medicine reflection	Prevalence and cost of vitamin prescribing significantly decreased ($P < .001$).	+/+
Cammisa et al,[34] 2011	Pre-post interventional	Improve quality by decreasing overuse	Practicing physicians (n = NR)	Expert reflection on utilization, advice, guidelines	Postintervention, narcotics, muscle relaxants, magnetic resonance imaging, and spinal injections decreased ($P < .001$)	+/+
Self et al,[35] 1984	Pre-post interventional (no control group)	Improve rational use, lower costs	Medical students, residents (n = 18)	Guideline and indications, cost information	Prevalence of vitamin prescribing and contributions of vitamins in cost of drugs prescribed in vitamin-containing prescriptions significantly decreased ($P < .001$)	+/−
McKay et al,[36] 2011	Pre-post interventional	Decrease unnecessary drug prescribing	Residents, practicing physicians, other (n = 63)	Training to provide patient education, course on antibiotics use, strategies to prescribe appropriately	Significant ($P = .013$) increase in general knowledge; significant decrease in antibiotic use for acute bronchitis ($P = .023$) all indications ($P = .019$), and macrolides ($P < .001$); 4.5% reduction in antibiotics cost across province	−/−
Blackstone et al,[39] 1995	Pre-post interventional	Educate about cost awareness and cost containment	Residents (n = 2); surgery (n = 2); interns (n = 2)	Guidelines and recommendation, multidisciplinary discussions	Total median daily charges in postintervention group reduced vs control group by $818/intensive care unit day ($P = .0002$)	−/+

(continued)

Table 2. Overview of Included Articles (continued)

Source	Design	Aim	Target Group	Focus of Intervention	Main Results	Quality of Rigor/Relevance[a]
Fakih et al,[42] 2010	Pre-post interventional	Reduce unnecessary urinary catheter placements	Residents (n = 30); practicing physicians (n = 39)	Evidence-based clinical guideline and indications, pocket card, reflection	Intervention caused overall reduction in urinary catheter utilization from 16.4% to 13% (P = .018); physicians ordered 40% fewer urinary catheters postintervention	+/+
Poppleton et al,[44] 2003	Pre-post interventional	Maintain excellence and efficiency, decrease costs	Practicing physicians (n = NR)	Clinical practice guideline and education regarding use of clinical practice guideline and role of staff as initiators of process of implementation	Length of stay decreased by >1 d; 25% reduction in charges; no statistical analysis	+/−
Sleath et al,[45] 1997	Pre-post interventional	Stimulate appropriate care, reduce adverse events	Practicing physicians, other (n = 90)	Drug use review, educational letter with evidence-based suggestions for physicians and pharmacists	Decrease in mean monthly costs for β_2-agonists ($74.96 vs $61.14; P < .05); mean monthly cost per patient of all asthma medications decreased and cost for asthma-related use of the health system increased (not significant)	−/−
Bhatia et al,[48] 2013	Pre-post interventional	Decrease proportion of inappropriate echocardiograms	Medical students, residents, practicing physicians (n = NR)	Lecture on appropriate use criteria, pocket card providing tips, utilization, and feedback on appropriateness	Pre-post intervention had 26% reduction in number of transthoracic echocardiograms ordered per day (P < .001); proportion of inappropriate TTE was significantly lower (5% vs 13%; P < .001) and proportion of appropriate TTE was significantly higher (93% vs 84%; P < .001)	+/+
Larmour et al,[50] 2011	Pre-post interventional	Maintain quality while containing health care costs	Residents, practicing physicians (n = NR)	Guidelines, academic detailing, promotion among staff	A total of $3.16 million was saved; the annual savings increased each year	+/+
Phillips and Landsberg,[51] 1986	Pre-post interventional (no control group)	Cost savings	Residents, practicing physicians, other (n = NR)	Newsletter with price information and suggestions for improvement	No significant increase or decrease in percentage of intravenous doses in main 3 categories	−/−
Ziskind et al,[52] 1994	Pre-post interventional, time series	Increase use of cost-effective contrast	Practicing physicians (n = NR)	Guidelines with suggestions, educational memo on overuse, cost feedback	59% Decrease in use of high-cost contrast; $143 decrease in contrast expenditure per patient; no adverse events	+/+
Shane and Nishimura,[53] 1994	Pre-post interventional (no control group)	Stimulate appropriate and cost-effective care	Practicing physicians (n = NR)	Expert reflection, guidelines	Cost of therapy decreased from $983 to $729 (−26%) and from $737 to $294 (−60%)	−/−
Okpara et al,[56] 1995	Pre-post interventional	Stimulate appropriate and cost-effective prescribing	Residents, practicing physicians, other (n = 78)	Evidence-based criteria, expert recommendation for improvement	66 Physicians (84.6%) accepted the recommendation; estimated cost savings, $12 935 (2 mo)	−/+
Yang et al,[62] 2014	Pre-post interventional	Promote adherence to rational drug use guideline in antibiotic prophylaxis	Practicing physicians (n = NR)	Integration of guideline in ordering system, educational round by pharmacy department	Significant increase in proportion of cefazolin (P < .05); significant decrease in average hospital stay (P < .05); no significant change in surgical site infections and adverse drug events or reactions	+/+

(continued)

Table 2. Overview of Included Articles (continued)

Source	Design	Aim	Target Group	Focus of Intervention	Main Results	Quality of Rigor/Relevance[a]
Thakkar et al,[74] 2015	Pre-post interventional	Reduce laboratory tests	Practicing physicians, residents, other (n = NR)	Educational session with discussion, distribution of educational flyers and informative emails regarding utility of test, impact on costs, and recommendations	Reduction in number of overall tests ordered (4.14 vs 3.79 per patient per day; P = .001); cost reduction of $6.33 per patient per day	+/+
Krinsley,[78] 2003	Pre-post interventional	Safely decrease utilization of imaging	Residents (n = NR)	Reflective questions on ordering form	Chest x-ray utilization rate decreased by 22.5% during study period, resulting in $109 968 cost savings, which were not associated with any adverse clinical outcomes	−/+
Zeleznik and Gonnella,[84] 1979	Pre-post interventional	Contain costs and reduce inappropriate care	Medical students (n = 54)	Case discussion on appropriateness and costs	Intervention resulted in increased knowledge (6%) and attitude toward usefulness and costs	−/+
Lyle et al,[86] 1979	Pre-post interventional	Promote awareness of costs, decrease overutilization	Medical students, residents (n = NR)	Utilization feedback	21% Reduction in average length of stay; cost per admission increased 4.3% per year vs 14.5% increase in other services	+/+
Spiegel et al,[15] 1982	Quasi-experimental	Improve ability to choose appropriately	Medical students (n = 151)	Reflection on orders, evaluation of net benefit of decisions, cost information, evidence-based information on medical topics	Intervention group more often agreed with experts that a test was not useful (93% vs 73%; P = .004); control group called for 30% more hospitalizations	+/+
Schroeder et al,[28] 1984	Quasi-experimental	Eliminate unwarranted orders, reduce charges	Medical students, residents (n = 43)	Cost information, indications, utilization and cost feedback	Significant difference in length of stay (preintervention, 5.8 d vs postintervention, 6.5 d; P < .01); cost reduction, −$117 mean charges per medical house staff in total services and −$62 mean total services charges per surgery patient (nonsignificant) in control vs intervention groups	+/+
Gitelis et al,[29] 2015	Quasi-experimental	Decrease costs and use of disposable materials	Practicing physicians (n = 15)	Presentation on costs of disposable equipment, cost per individual surgeon, cost-effective alternatives	10% Reduction in mean cost (P < .001); no difference in readmissions/reoperations	−/−
Vigneswaran et al,[30] 2015	Quasi-experimental	Decrease costs and use of disposable materials	Practicing physicians (n = 10)	Presentation on costs of disposable equipment, cost per individual surgeon, cost-effective alternatives	Average cost reduction of $228 (−21%) for laparoscopic hernia repair (P < .001)	−/+
Attali et al,[72] 2006	Quasi-experimental	Decrease inappropriate laboratory testing	Residents, practicing physicians (n = 11)	Lecture on excessive or inappropriate test ordering, supervised ordering	Decrease of 97 365 tests during 3-y period, saving $1 914 194; no difference in readmission rate or number of diagnoses of conditions between departments	+/+
Zimmerman et al,[75] 1994	Quasi-experimental	Stimulate appropriateness, increase efficacy	Practicing physicians (n = NR)	Drug use review letter containing evidence, utilization feedback	Decrease in monthly drug dose (P < .10); reduction in total costs of $17.76 per month per patient (P < .05)	−/−
Zunker and Carlson,[76] 2000	Quasi-experimental (control)	Increase cost-effective prescribing	Practicing physicians (n = NR)	Evidence-based medicine information, expert feedback, utilization feedback	Three of 4 intervention clinics achieved total health care goal, 2 of 5 nonintervention clinics achieved goal; no statistical analysis of results	−/−

(continued)

Table 2. Overview of Included Articles (continued)

Source	Design	Aim	Target Group	Focus of Intervention	Main Results	Quality of Rigor/Relevance[a]
Rudy et al,[79] 2001	Quasi-experimental	Reduce costs, improve quality of care	Residents (n = 23)	Workshop on cost-effectiveness, decision making with/without charges	Intervention group spent less on testing ($1297 vs $2205; *P* = .03); lower appropriateness score (12.3 vs 18.8; *P* = .01)	+/+
Landgren et al,[91] 1988	Quasi-experimental	Improve appropriateness of prescribing	Practicing physicians (n = NR)	Campaign, feedback with discussion, satirical video to trigger discussion, visit of academic representative to explain campaign and answer questions	Antibiotic courses assessed as satisfactory in duration increased after first intervention campaign; no significant changes in prescribing occurred in control hospitals	+/−
Sommers et al,[22] 2012	Mixed methods (RCT, open comments)	Improve awareness of how decisions influence costs	Medical students, residents (n = 47)	Cost feedback, discussion of strategy to reduce costs, cost information	Nonsignificant reduction of $69 per admission in intervention group (*P* = .92); significant reduction in laboratory test price (−$163; *P* = .046); increased awareness among residents	+/+
McPhee et al,[68] 1984	Mixed methods (quasi-experimental design; observation and discussion)	Control increase in costs, decrease unnecessary ordering	Medical students, residents (n = NR)	Review of medical records, cost feedback, price information	Moderate to high acceptance of intervention; effect on use of hospital service was modest (no statistical analysis)	−/+
Sicotte et al,[77] 1996	Mixed methods (pre-post interventional design and interviews)	Reduce inappropriate resource use	Practicing physicians (n = 20)	Utilization feedback, reflection on feedback, involvement of head of department	Mixed results on behavior modification (no change, increase, decrease in resource utilization)	+/+
Articles That Addressed 1 Factor						
Davidoff et al,[19] 1989	RCT	Improve decision making	Residents (n = 24)	Course teaching cost-containment topics or probability theory	Significantly fewer orders for laboratory tests vs placebo group (*P* = .032; 16%)	−/+
Marconi and Nager,[38] 2010	RCT	Improve cost awareness, increase quality and cost-containment	Residents (n = 80)	Evidence-based guidelines	Significant increase in mean number of correct answers on pre-post intervention questionnaires compared with control group (*P* < .001)	+/−
Légaré et al,[58] 2012	RCT	Reduce overuse of antibiotics	Residents, practicing physicians (n = 151)	Tutorial on patient communication, workshop to implement lessons in practice	Percentage of patients deciding to use antibiotics after consultation was higher in control group (52.2%) vs intervention group (27.2%); intervention was associated with patients taking more active role in decision making (*z* = 3.9; *P* < .001)	+/−
Braido et al,[59] 2012	RCT	Improve guideline knowledge and adherence	Practicing physicians (n = 60)	Economic analysis course regarding prescribing and resource utilization	Knowledge improved significantly after training (correct answers to key questions, +13%; *P* < .001); cost containment (trained general practitioners, +0.5% vs controls, +18.8%) and greater attention to diagnosis and monitoring (increase in spirometry, +63.4%; *P* < .01)	+/−
Bates et al,[73] 1999	RCT	Reduce redundant test ordering	Practicing physicians (n = NR)	Feedback alert for redundant tests	Reminders resulted in 69% test cancellation and significantly fewer (*P* < .001) redundant tests ordered in intervention group	−/+

(continued)

Table 2. Overview of Included Articles (continued)

Source	Design	Aim	Target Group	Focus of Intervention	Main Results	Quality of Rigor/Relevance[a]
Collins et al,[89] 1997	RCT	Stimulate accuracy and appropriateness of prescribing	Practicing physicians (n = 285); pharmacists/other (n = 304)	Patient-specific information on inappropriately prescribed drugs and guideline information	Physician control group spent $37.01 per patient more on dipyridamole ($P < .025$) than physician-pharmacist intervention group	−/+
Ferris et al,[90] 2005	RCT	Improve quality and decrease costs of care	Practicing physicians (n = 651)	Case-based recommendation for prescribing/tests	Change in medication prescribing and diagnostic test use; nonsignificant change in patient outcomes and costs of care	+/+
Chandawarkar et al,[17] 2007	Pre-post interventional	Stimulate cost awareness	Residents (n = 53)	Costs pocket card	Difference found between baseline cost estimates and actual cost of treatment ($P = .03$); improvement between cost estimates before and after intervention ($P = .002$)	+/+
Ellemdin et al,[18] 2011	Pre-post interventional	Reduce costs of excessive laboratory tests	Practicing physicians (n = 434)	Ordering costs, costs written on ordering form	Mean cost per admitted patient decreased (27%); mean cost per day in intervention group decreased (36%)	+/+
Englander et al,[20] 2006	Pre-post interventional	Stimulate care that is of optimal value	Residents (n = NR)	Knowledge of cost savings, meeting regarding cost savings and system changes for online ordering	Use of iSTAT (mobile blood analysis machine) increased from 40% to 98% postintervention; estimated savings of $549 780 per year	−/−
Stuebing and Miner,[21] 2011	Pre-post interventional	Reduce unnecessary orders	Residents (n = NR)	Feedback on cost data	Decreased cost per patient per day correlation coefficient, −0.76 ($P = .002$)	−/+
Hart et al,[23] 1997	Pre-post interventional	Reduce unnecessary prescribing	Practicing physicians (n = 60)	Cost information	Awareness of drug costs affected physicians significantly; family physicians preferred less expensive drugs even before the intervention	+/+
Willens et al,[25] 2013	Pre-post interventional	Increase appropriateness of utilization	Practicing physicians (n = 28)	Appropriate use criteria, evidence-based lecture followed by discussion, reminders	No significant change in appropriateness rating of stress echocardiography ($P = .339$)	−/−
Qureshi et al,[26] 2011	Pre-post interventional (no control group)	Improve quality of drug prescriptions	Practicing physicians (n = 12)	Guidelines, prescribing course with health economy topics, group discussions	Increase in prescribing knowledge (all items $P < .02$); decreased number of antibiotics prescriptions and prescriptions of multiple drugs	+/+
Whiteside et al,[33] 1987	Pre-post interventional	Stimulate appropriate prescribing	Practicing physicians, residents (n = 94)	Guideline, evidence-based letter, price information	Appropriateness increased to 58% ($P < .001$); change from second-generation antibiotics to first-generation antibiotics in 28% of cases	−/+
James and Cyriac,[60] 2014	Pre-post interventional	Promote switch from intravenous to oral drugs	Practicing physicians (n = 50)	Oral presentation regarding guideline and bioavailability of drugs, distribution of pamphlets on criteria for switch	Increased knowledge (23.5%-28.7%) of indication for switch; mean cost of intravenous therapy decreased (preintervention, €44.63; postintervention, €28.74; $P = .021$); overall drug costs decrease (preintervention, €7419; postintervention, €4733; $P = .032$)	−/−

(continued)

Table 2. Overview of Included Articles (continued)

Source	Design	Aim	Target Group	Focus of Intervention	Main Results	Quality of Rigor/Relevance[a]
Pasquale et al,[66] 2004	Pre-post interventional	Improve care, decrease overall costs	Practicing physicians, other (n = NR)	Expert reflection regarding inappropriate ordering with suggestions	77% of suggestions were accepted; estimated cost savings, $124 480 (8 mo)	+/+
Gist et al,[85] 1997	Pre-post interventional	Reduce unnecessary breast biopsies, promote early detection of breast cancer	Practicing physicians (n = 22)	Evidence-based clinical algorithm with follow-up mailing	Effective in reducing incidence of unnecessary surgical procedures	−/−
Elligsen et al,[40] 2012	Quasi-experimental	Decrease inappropriate use of antimicrobials	Practicing Physicians, other (n = 6)	Expert reflection on therapy, feedback to physician	Significant decrease in experimental group for monthly broad-spectrum antibiotic use ($P < .001$) and days of therapy ($P = .0054$)	+/−
Weingarten et al,[54] 1994	Quasi-experimental	Decrease costs, improve quality	Practicing physicians (n = 155)	Guideline with recommendations, reminders, risk information	Guideline adherence, 50% during control periods and 69% during intervention periods ($P < .001$); reduced length of stay (26%; $P = .02$)	+/+
Parrino,[67] 1989	Quasi-experimental	Lower drug utilization, decrease costs	Practicing physicians (n = 202)	Cost feedback	No significant decline in those with high antibiotic expenditures data; no significant difference between feedback and no-feedback group	+/+
Polinski et al,[24] 2011	Mixed methods (quasi-experimental; interview)	Decrease cost of prescribing	Practicing physicians (n = 282)	Price information, evidence to support recommendations	Increased proportion of tablet splitting among participants from 4.4% to 7.5%; effect varied from >10% increase to <6% decrease	+/+
Colbert et al,[87] 2010	Qualitative	Improve awareness and responsiveness to system of health care	Medical students (n = 31)	Delivering care to patients without health insurance	Content analysis identified 6 themes: access to specialists was limited; cost containment; lack of resources affected delivery of care; delays in care due to lack of insurance; understanding of larger health care system and free clinic role; and delays in tests due to language barriers	+/+

Abbreviations: NR, not reported; RCT, randomized clinical trial.

[a] Plus signs indicate higher-quality rigor/relevance; minus signs, lower-quality rigor/relevance.

(prices of services and general health economics, scientific evidence, and patient preferences) and were represented in 67 articles (87%).

Prices and General Health Economics

The majority of interventions focused on raising awareness of prices of medical services and on teaching the basics of health economics.[14-30] The first was done by presenting prices on modified order forms, on pocket cards, or in web-based tools or by visualizing price indicators.[14,16-18,21-24,27] A high-quality study by Ellemdin et al[18] used a pocket-sized brochure to inform internal medicine physicians (n = 434) about the costs of laboratory testing and asked them to write these costs on the order form. Over the 4-month follow-up period, there was a 27% to 36% decrease in laboratory expenditures. Teaching physicians the basics of general health economics[15,19,20,25,26,28] was done by lectures and interactive sessions informing physicians about the competitive market forces and general health care economic principles, such as the role of insurance companies in price setting.[19,26] Although the weekly lectures for medical interns were associated with a nonsignificant reduction in the number of tests ordered during patient admissions,[19] the interactive sessions significantly improved physicians' knowledge of economics and rational prescribing.[26]

Scientific Evidence

A frequent approach to teaching efficiency was to provide the background evidence underlying indications and guidelines related to medical decision making.[14,15,19,21,24-26,31-63] Before implementing or discussing new,[26,32,42,47,53,55,62] modified,[44,50,64] or established[32-34,39,41,43,49,54] guidelines or clinical indications,[28,48,56,65] trainees and physicians were informed of the scientific evidence that supported these recommendations. A high-quality study by Lee et al[61] implemented a teaching session focusing on guidelines on antibiotic prescriptions among 42 practicing physicians, resident physicians, and medical students. These teaching sessions were accompanied by a checklist addressing dose, route, duration, and appropriateness of prescriptions. Their intervention resulted in an annual saving of $69.42 (baseline, $149.74, vs postintervention, $80.32). Effects associated with such teaching depended on several factors, such as expert involvement, complementary lectures, and timing of information. For example, when guidelines were developed by expert panels, they were accepted and adhered to more readily, especially when constructed in multidisciplinary teams.[32,40,44] Additionally, several interventions had an expert deliver didactic sessions or conduct outreach visits on the clinical topic to which the guideline applied.[32,34,35,46,47,54,66] Other interventions introduced guidelines using lectures about the key recommendations[42,55] or by email notifications.[25]

Another technique that was often used with the aim of increasing the likelihood that physicians would implement the guidelines was to provide just-in-time scientific evidence. For example, inserting guidelines or recommendations into charts allowed physicians to successfully translate these guidelines immediately into practice.[24,33,45,47,54] Complementing guidelines by suggestions to physicians for treatment of selected patients formed the core of several interventions aimed to improve physicians' prescribing patterns.[33,37,45,49,51] Two of these interventions used forms that were inserted in charts of selected patients, which were associated with a significant reduction in the prescription of the targeted pharmaceuticals.[33,37] For example, the change from a second-generation cephalosporin to a less expensive but equally effective first-generation cephalosporin occurred in 28% of cases (medium-quality study).[33] Moreover, when physicians were able to immediately accept or decline a suggestion to switch to a different drug and to modify their prescription to the more appropriate evidence-informed suggestion, a prescribing reduction of up to 43% was achieved (medium-quality study).[37]

Patient Preferences

Four studies were identified that sought to stimulate high-value, cost-conscious care by improving understanding of patient preferences.[24,39,57,58] Physicians involved patients in the decision-making process and in devising a plan of action. During consultation, physicians discussed risks and benefits of medical services and explored patient concerns to be able to provide the best possible care.[24,57] Knowledge of patients' preferences was deemed sufficient when patients felt comfortable about the shared decision that was made. Educational interventions such as DECISION+ combined evidence and patient preferences in workshops to optimize the prescription of antibiotics for acute respiratory tract infections by residents and practicing physicians[57,58]; the number of patients opting for immediate antibiotic therapy in this high-quality study declined 16% (49% [n = 70] in the control group vs 33% [n = 81] in the experimental group), but this was not statistically significant (P = .08).[57]

Reflective Practice

A second derived factor was to stimulate reflective practice in future and practicing physicians to help them gain insight into their performance, with a goal of influencing future behavior.* This was achieved by providing feedback, stimulating reflection, or a combination of both, in 56 articles including more than 2039 participants.

Feedback

Feedback to physicians about their performance was most often based on utilization data such as the number of ordered tests or amount of prescribed antibiotics.† This feedback could focus on various elements, which, in turn, influenced how trainees learned from feedback. Feedback could focus on volume (such as numbers of requested tests),[43,48,55,75-77] costs (eg, total costs of antibiotic prescriptions),[14,21,22,28] or appropriateness (eg, extent of adherence to guidelines).[67] Feedback could center on physicians' individual utilization or their utilization in relation to that of others.[34,49,52,67,76] Another element of importance was the frequency of feedback.[21,40,67] One high-quality study sent emails to 15

*References 16, 21, 22, 25, 29, 31, 34, 35, 37, 39, 40, 49, 52, 61, 65, 67-74
†References 14, 21, 22, 28-30, 34, 37, 43, 49, 52, 55, 61, 65, 67-70, 75-77

physicians in the upper 50th percentile for expenditures to point out the differences in their spending behavior compared with their peers over a 3-month period.[67] This measure did not lead to a significant expenditure reduction compared with the control group (per-physician expenditure difference of $654.45; $P = .64$), which might have been because of the short amount of time between feedback provision and measurement of changes in spending behavior. In contrast, Stuebing and Miner[21] made use of more frequent feedback: in their medium-quality study, attending physicians and residents in a surgical department (number not reported) received weekly notifications about the costs, expressed in terms of dollars per intensive care unit patient per day. Despite small increases in total expenditure that occurred each time residents switched services, there was a significant decrease in total laboratory costs.[21] At baseline, laboratory expenditures were $147.73 per patient per day, and a decrease of up to 27% (−$39.62) from baseline in expenditures per day was reached.

Reflective Questions

Peer- or supervisor-facilitated reflection on medical decisions and their influence on the quality and cost-effectiveness of care was the focus of several studies.‡ Supervisors,[39,55,72] peers,[69,79] and experts[27,37,53,56,64,66,76] in several clinical settings were the initiators of reflective discussions.[22,25,34,39] For example, they asked reflective questions during morning rounds or grand rounds and in the presence of other health care professionals. Reflective practice was guided by questions such as "What was the indication for this test?"; "What alternatives were available?"; or "Why do you think this specific test is redundant?"[16,39] Reflection on one's own behavior was further stimulated by means of reminder alerts whenever a laboratory request or prescription was ordered that was identified as redundant.[73,80] Although determining what classified as redundancy from the perspective of the research team and the participants was difficult, in a medium-quality study[73] the alerts appeared to be effective and resulted in cancellation of 69% of redundant tests by physicians (n = 282) compared with 51% in the control group (n = 4769) ($P < .001$).

Combining Feedback and Reflection

Eight articles used feedback as a starting point for reflection.[31,34,43,49,68,69,77,81] The authors chose this combination to counter the potential risk of creating a judgmental setting, which is not conducive to high-value, cost-conscious behavior.[49] von Ferber et al[69] introduced peer-to-peer review discussion groups (high-quality study). During these sessions, the motives that influence prescribing behavior and attitudes of physicians (n = 79), together with underlying causes of practice variation, were discussed in an open and tolerant environment. This approach was associated with significant decreases in prescription costs, from $853 to $527 for high prescribers and from $469 to $352 for low prescribers ($P < .001$ for both), and with cost-effective prescription of selected drugs.[69]

‡References 15, 16, 22, 25, 27, 34, 35, 39, 40, 53, 55, 56, 64, 66, 69, 71-74, 76, 78

Supportive Learning Environment

The data from 27 articles including more than 521 participants highlighted the essential role of the environment in which educational interventions are implemented. Support at the macro level, such as supportive payment systems, management policies, and reimbursement systems, was emphasized, together with the presence of clinical role models and teachers and a culture of high-value, cost-conscious care.

Macro-Level Support

There was a repeated emphasis in a number of publications (n = 29; 37%) on the effect of macro-level support for their interventions on practicing physicians, resident physicians, and medical students.§ The organization was often perceived to frustrate the training of physicians in the provision of high-value, cost-conscious care.[36,44,57,83-86] This was the case, for example, when physicians felt inhibited by fear of malpractice suits[84,85] and pressured to adhere to guidelines.[57] Other elements of the health care system that might either positively or negatively influence the delivery of high-value, cost-conscious care were the availability of resources,[15,31,34,87] workload,[36,66,84] bureaucratic structure,[55,84] and access to and transparency of health care costs.[16,25] For example, in a high-quality survey study by Post et al[16] of 68 residents with an 83% response rate, only 4 claimed that they had adequate access to the costs of care they provided. Furthermore, 59 of these residents claimed that better knowledge of costs would influence their ordering behavior. The use of incentives (financial or otherwise) to modify practice[28,47,55,76,84,86] and payment systems || are also examples of how macro-level decisions could influence individual physicians. The influence of the reimbursement system on the success of cost-containment interventions was identified by Lyle et al.[86] In this high-quality study, it was noted that the structure for financing hospital care could run counter to hospital economics, since a decrease in utilization is related to a decline in third-party payments.[86]

Clinical Role Models and Teachers

An environment in which learners have role models who are very much committed to delivering and demonstrating high-value, cost-conscious care was often mentioned as an important factor in preparing physicians for sustainable practice.# The lack of such clinical role models was described as the most common barrier to lessons learned.[22,40,48,84] Some authors noted that residents seeking to learn how to provide high-value, cost-conscious care received little or no support from supervisors or attending physicians. For example, the study by Post et al[16] implemented an intervention among 83 internal medicine residents based on knowledge of costs and reflective discussions regarding the appropriateness of health care services for selected patients. Their evaluation included a survey (n = 68); only 26 residents agreed with the statement "My supervising consultants consistently encourage me to consider costs when making medical decisions." As a re-

§References 16, 17, 19, 22, 24, 25, 28, 31-33, 44, 47, 48, 50, 55, 66, 68, 77, 82, 83
|| References 17, 19, 22, 28, 66, 76, 77, 82, 86
#References 15, 19, 20, 22, 34, 35, 40, 47, 49, 66, 79, 84

sult, residents became disheartened by fear of getting into conflict with supervisors or being overruled by them.[16,22,40]

The importance of the involvement of local role models and respected teachers in educational programs was acknowledged by several studies.** To enhance acceptance of educational interventions, people with established clinical expertise or managerial responsibilities or physicians considered to be opinion leaders were given a prominent place in the program.†† Illustrating the influence of teachers on training effectiveness, 1 study asserted that if workshops were not conducted by a highly motivated principal teacher, the effect of the intervention could not be reproduced.[57]

Culture of Interprofessional Collaboration in Relation to High-Value, Cost-Conscious Care

Learning within interprofessional collaborations compared with individual training of physicians was the focus of 14 interventions.‡‡ Associations with learning in collaborations was demonstrated in a medium-quality study by Collins et al,[89] who sent participants identical feedback emails discussing the appropriateness of dipyrimidole prescriptions. A physicians-only control group (n = 342) compared with a physicians-pharmacists intervention group (n = 91) spent $37.01 per patient more on dipyridamole ($P < .025$), even though specific pharmacist action had not been solicited.

The importance of the values and beliefs of coworkers, whether peers or other health care professionals, was highlighted by several other studies.§§ By raising cost issues in newsletters,[27,32,46,50,51,88,90] in posters,[32,33,36,37,50,57,64,91] in grand rounds, or at bedside teaching,[25,40,50,91] these studies aimed to create a prosustainability environment.[22,36,37,55,88] In a high-quality study,[55] feedback of participating physicians after an intervention that aimed to reduce the costs of laboratory ordering described that group discussions among staff increased consensus regarding the general understanding of the need for cost reduction in the emergency department. Additionally, the involvement of the nursing staff was defined by the authors as one of the key success factors of the intervention due to active involvement of the nursing staff as moderators in the discussions regarding appropriateness between residents and attending physicians. Declaring cost-effectiveness as the theme of the week was another tactic used to stimulate cost consciousness.[41] Three articles discussed the negative effect of the absence of an interprofessional collaborating culture toward high-value, cost-conscious care.[39,84,92]

Discussion

To ensure sustainable health care practices, physicians need to be trained to provide high-value, cost-conscious care. This realist review was conducted to examine how and under what circumstances educational interventions may help trainees and practicing physicians deliver such care. Three important elements emerged that could inform development of interventions aimed to train physicians: knowledge transmission, reflective practice, and a supportive environment.

First, knowledge transmission appeared to be pertinent to the cost of care and to health economics, scientific evidence, and patient preferences. In addition to raising awareness of how physicians contribute to health care costs, the literature suggested teaching trainees and practicing physicians how to judge medical value and gain insight into patients' personal values. The challenge of teaching physicians to deliver high-value, cost-conscious care seems to be to elicit a general understanding of how their medical decisions relate to value. Second, stimulating reflective practice on these different values through feedback, reflective questions, and group discussions incentivized physicians to think critically about medical decisions. The literature suggested that these elements would be most effective when their training goals are also supported by the environment in which trainees work and learn. Third, such a supportive environment may be necessary for clinical teachers, role models, and other health care professionals' trainees to appreciate the importance of high-value, cost-conscious care. These 3 factors combined provide a framework for the development and further research of educational programs that teach physicians to deliver high-value, cost-conscious care.

The amount of support within an environment may be critical for the success of efforts to train high-value, cost-conscious care. To be successful, transmission of knowledge and reflective practice may work best in environments that feature role models, attention to health care teams, and an organization that supports sustainable practice. An unsupportive environment might inadvertently negate the intended training effect,[93] underlining the importance that trainees witness the delivery of high-value, cost-conscious care in clinical practice. There is a risk of adverse effects of learning from poor role models, and good role models may be scarce, as many physicians who provide clinical education were trained with the assumption that costs have no place in medical decision making. Adding to confusion is that the current generation of physicians is practicing in a health care system that features continuously changing payment systems and accreditation requirements, with a legacy of health care costs lacking in transparency and unstable rules and regulations.

This review should be considered in the light of its limitations. First, because of the variability of definitions given to high-value, cost-conscious care, selection bias cannot be excluded. To minimize this risk, no cutoff date was used in the search and all related publications were screened, the oldest articles dating from 1979. Although the field of medicine has evolved tremendously since then, the elements of training inherent in our identified framework and the inherent barriers have remained stable, which reinforces the strength of the findings. A second limitation is the risk of publication bias, which is suggested by apparent effectiveness in 87% of the studies overall and in 71% of the 14 randomized clinical trials. We tried to reduce this bias as much

**References 19, 20, 26, 28, 34, 35, 47, 49, 50, 57, 66, 69, 76, 77, 85
††References 19, 47, 49, 50, 57, 66, 69, 76, 81, 85
‡‡References 37, 44-46, 48, 51, 55, 61, 65, 66, 68, 70, 74, 79, 83, 88, 89
§§References 22, 25, 27, 32, 33, 36, 37, 39-41, 46, 47, 50, 51, 55, 57, 64, 77, 84, 88, 90-92

as possible by searching multiple databases and placing no restrictions on the quality of journals. Nevertheless, the possibility of publication bias should be considered. Third, the assessment of quality of the included articles, ie, rigor and relevance, was derived from the professional judgments of the researchers. Although prone to subjectivity, we tried to counteract this through extensive discussions within the research team. Fourth, the factor of supportive environment was partly derived from qualitative data from quantitative studies, not as strong as the evidence used to derive knowledge transmission and reflective practice. Quantitative findings using randomized trials demonstrating an influence of the supportive environment on learning outcomes would have provided stronger evidence.

Although the reported effectiveness of educational interventions seems to provide scope for medical education to bring about improvement, training physicians to deliver high-value, cost-conscious care remains a complex task. Further research should focus on what makes a good role model of high-value, cost-conscious care and how such attributes can be cultivated by means of medical education. Additionally, there is a need to investigate how formal education can help mold the culture of the learning environment. Although measuring the value of care is extremely complex, outcome measures that focus solely on volume or costs might promote the incorrect assumption that cheaper is better. Therefore, thoughtful consideration of which outcome measures can be used to evaluate the effectiveness of interventions remains important.

Conclusions

Research on educating physicians to deliver high-value, cost-conscious care suggests that learning by practicing physicians, resident physicians, and medical students is promoted by combining specific knowledge transmission, reflective practice, and a supportive environment. These factors should be considered when educational interventions are being developed.

ARTICLE INFORMATION

Author Affiliations: Department of Educational Development and Research, Faculty of Health, Medicine, and Life Sciences, Maastricht University, Maastricht, the Netherlands (Stammen, Stalmeijer, Oudkerk Pool, Driessen); Department of Medical Education, OLVG Hospital, Amsterdam, the Netherlands (Paternotte, Scheele); Department of Medical Education, VU University Medical Centre, Amsterdam, the Netherlands (Scheele); Athena Institute for Trans-Disciplinary Research, VU University, Amsterdam, the Netherlands (Scheele); Department of Surgery, Maastricht University Medical Centre, Maastricht, the Netherlands (Stassen).

Author Contributions: Dr Stammen had full access to all of the data in the study and takes responsibility for the integrity of the data and the accuracy of the data analysis.
Study concept and design: Stammen, Stalmeijer, Driessen, Scheele, Stassen.
Acquisition, analysis, or interpretation of data: Stammen, Stalmeijer, Paternotte, Oudkerk Pool, Driessen, Scheele, Stassen.
Drafting of the manuscript: Stammen, Stalmeijer, Paternotte, Driessen, Scheele.
Critical revision of the manuscript for important intellectual content: Stammen, Stalmeijer, Oudkerk Pool, Driessen, Scheele, Stassen.
Study supervision: Stalmeijer, Paternotte, Driessen, Scheele, Stassen.

Conflict of Interest Disclosures: All authors have completed and submitted the ICMJE Form for Disclosure of Potential Conflicts of Interest and none were reported.

Additional Contributions: Angelique van den Heuvel, MA, Maastricht University, provided assistance with English-language editing of the manuscript as a staff member of the department of educational development and research. Jimmie Leppink, PhD, Maastricht University, provided statistical advice during manuscript preparation as a staff member of the department of educational development and research. Inge Verheijen, a final-year medical student at the Faculty of Health, Medicine and Life Sciences at Maastricht University, was involved in the screening of abstracts as a student assistent of our educational department. None of these individuals received additional compensation for their role in this study.

REFERENCES

1. Reinhardt UE. Waste vs value in American health care. *Economix*. September 13, 2013. http://economix.blogs.nytimes.com/2013/09/13/waste-vs-value-in-american-health-care/?_r=0. Accessed January 2014, 2014.

2. Berwick DM, Hackbarth AD. Eliminating waste in US health care. *JAMA*. 2012;307(14):1513-1516.

3. Blumenthal D. Controlling health care expenditures. *N Engl J Med*. 2001;344(10):766-769.

4. Altarum Institute. *Health Sector Economic Indicators: Insights From Monthly National Health Spending Data Through July 2015*. September 11, 2015. http://altarum.org/sites/default/files/uploaded-related-files/CSHS-Spending-Brief_September_2015.pdf. Accessed September 13, 2015.

5. Duke P. The ABIM Foundation's Choosing Wisely communication module. 2013. http://modules.choosingwisely.org/modules/m_00/. Accessed February 2014.

6. American College of Physicians. High value care curriculum. https://hvc.acponline.org/curriculum.html. Accessed February 2014.

7. Owens DK, Qaseem A, Chou R, Shekelle P; Clinical Guidelines Committee of the American College of Physicians. High-value, cost-conscious health care: concepts for clinicians to evaluate the benefits, harms, and costs of medical interventions. *Ann Intern Med*. 2011;154(3):174-180.

8. Organisation for Economic Co-operation and Development. Health spending, total % of GDP, 1970-2013. In: *OECD Health Data: Health Expenditure and Financing: Health Expenditure Indicators*. 2013. https://data.oecd.org/chart/4f22. Accessed February 2015.

9. Cutler D. The value equation in health care. Presented at: National Health Care Reform: Policy Options and Imperatives. February 23, 2007; Houston, TX.

10. Wong G, Greenhalgh T, Westhorp G, Buckingham J, Pawson R. RAMESES publication standards: realist syntheses. *BMC Med*. 2013;11:21.

11. Best Evidence Medical Education Collaboration. BEME data coding sheet. http://webcache.googleusercontent.com/search?q=cache:A7TGtAU88scJ:download.lww.com/wolterskluwer_vitalstream_com/PermaLink/ACADMED/A/ACADMED_86_11_2011_08_19_REINDERS_202668_SDC2.pdf+&cd=5&hl=nl&ct=clnk&gl=nl. Accessed June 2014.

12. Cochrane Library. Data collection form for RCT and non-RCT. http://www.cochranelibrary.com/cochrane-database-of-systematic-reviews/supplements.html. Accessed June 2014.

13. Pawson R, Greenhalgh T, Harvey G, Walshe K. *Realist Synthesis: An Introduction*. Manchester, England: University of Manchester; 2004.

14. Sussman AJ, Chabra B, Coblyn J, et al. Helping primary care physicians lower pharmaceutical expenses: an academic medical center's experience. *J Clin Outcomes Manag*. 2004;11(5):290-295.

15. Spiegel CT, Kemp BA, Newman MA, Birnbaum PS, Alter CL. Modification of decision-making behavior of third-year medical students. *J Med Educ*. 1982;57(10 pt 1):769-777.

16. Post J, Reed D, Halvorsen AJ, Huddleston J, McDonald F. Teaching high-value, cost-conscious care: improving residents' knowledge and attitudes. *Am J Med*. 2013;126(9):838-842.

17. Chandawarkar RY, Taylor S, Abrams P, et al. Cost-aware care: critical core competency. *Arch Surg*. 2007;142(3):222-226.

18. Ellemdin S, Rheeder P, Soma P. Providing clinicians with information on laboratory test costs leads to reduction in hospital expenditure. *S Afr Med J*. 2011;101(10):746-748.

19. Davidoff F, Goodspeed R, Clive J. Changing test ordering behavior: a randomized controlled trial

comparing probabilistic reasoning with cost-containment education. *Med Care*. 1989;27(1):45-58.

20. Englander R, Agostinucci W, Zalneraiti E, Carraccio CL. Teaching residents systems-based practice through a hospital cost-reduction program: a "win-win" situation. *Teach Learn Med*. 2006;18(2):150-152.

21. Stuebing EA, Miner TJ. Surgical vampires and rising health care expenditure: reducing the cost of daily phlebotomy. *Arch Surg*. 2011;146(5):524-527.

22. Sommers BD, Desai N, Fiskio J, et al. An educational intervention to improve cost-effective care among medicine housestaff: a randomized controlled trial. *Acad Med*. 2012;87(6):719-728.

23. Hart J, Salman H, Bergman M, et al. Do drug costs affect physicians' prescription decisions? *J Intern Med*. 1997;241(5):415-420.

24. Polinski JM, Schneeweiss S, Maclure M, Marshall B, Ramsden S, Dormuth C. Time series evaluation of an intervention to increase statin tablet splitting by general practitioners. *Clin Ther*. 2011;33(2):235-243.

25. Willens HJ, Nelson K, Hendel RC. Appropriate use criteria for stress echocardiography: impact of updated criteria on appropriateness ratings, correlation with pre-authorization guidelines, and effect of temporal trends and an educational initiative on utilization. *JACC Cardiovasc Imaging*. 2013;6(3):297-309.

26. Qureshi NA, Neyaz Y, Khoja T, Magzoub MA, Haycox A, Walley T. Effectiveness of three interventions on primary care physicians' medication prescribing in Riyadh City, Saudi Arabia. *East Mediterr Health J*. 2011;17(2):172-179.

27. Roth EJ, Plastaras CT, Mullin MS, Fillmore J, Moses ML. A simple institutional educational intervention to decrease use of selected expensive medications. *Arch Phys Med Rehabil*. 2001;82(5):633-636.

28. Schroeder SA, Myers LP, McPhee SJ, et al. The failure of physician education as a cost containment strategy: report of a prospective controlled trial at a university hospital. *JAMA*. 1984;252(2):225-230.

29. Gitelis M, Vigneswaran Y, Ujiki MB, et al. Educating surgeons on intraoperative disposable supply costs during laparoscopic cholecystectomy: a regional health system's experience. *Am J Surg*. 2015;209(3):488-492.

30. Vigneswaran Y, Linn JG, Gitelis M, et al. Educating surgeons may allow for reduced intraoperative costs for inguinal herniorrhaphy. *J Am Coll Surg*. 2015;220(6):1107-1112.

31. Das AK, Rahman MS. Prescribing vitamins at primary health care level: exploration of facts, factors and solution. *Bangladesh J Pharmacol*. 2010;5(2):92-97.

32. de Leon N, Sharpton S, Burg C, et al. The development and implementation of a bundled quality improvement initiative to reduce inappropriate stress ulcer prophylaxis. *ICU Dir*. 2013;4(6):322-325.

33. Whiteside ME, Lefkowitz S, Justiniani FR, Ratzan K. Changing prescribing patterns: a program of physician education. *Hosp Formul*. 1987;22(6):561-563, 566, 568.

34. Cammisa C, Partridge G, Ardans C, Buehrer K, Chapman B, Beckman H. Engaging physicians in change: results of a safety net quality improvement program to reduce overuse. *Am J Med Qual*. 2011;26(1):26-33.

35. Self TH, Smith SL, Boswell RL, Miller WA. Medical education provided by a clinical pharmacist: impact on the use and cost of corticosteroid therapy in chronic obstructive pulmonary disease. *Drug Intell Clin Pharm*. 1984;18(3):241-244.

36. McKay RM, Vrbova L, Fuertes E, et al. Evaluation of the Do Bugs Need Drugs? program in British Columbia: can we curb antibiotic prescribing? *Can J Infect Dis Med Microbiol*. 2011;22(1):19-24.

37. Barbarello-Andrews L, Susla G, Ng V, St John D, Lau C. Cost-effective medication use in critical care: Capital Health System's experience in VHA's MUSIC program. *J Clin Outcomes Manag*. 2006;13(11):615-622.

38. Marconi GP, Nager AL. Teaching residents established guidelines and standards of care to strengthen their cost-containment practices. *Manag Care*. 2010;19(5):46-51.

39. Blackstone ME, Miller RS, Hodgson AJ, Cooper SS, Blackhurst DW, Stein MA. Lowering hospital charges in the trauma intensive care unit while maintaining quality of care by increasing resident and attending physician awareness. *J Trauma*. 1995;39(6):1041-1044.

40. Elligsen M, Walker SA, Pinto R, et al. Audit and feedback to reduce broad-spectrum antibiotic use among intensive care unit patients: a controlled interrupted time series analysis. *Infect Control Hosp Epidemiol*. 2012;33(4):354-361.

41. Dowling PT, Alfonsi G, Brown MI, Culpepper L. An education program to reduce unnecessary laboratory tests by residents. *Acad Med*. 1989;64(7):410-412.

42. Fakih MG, Pena ME, Shemes S, et al. Effect of establishing guidelines on appropriate urinary catheter placement. *Acad Emerg Med*. 2010;17(3):337-340.

43. Verstappen WH, van der Weijden T, Sijbrandij J, et al. Effect of a practice-based strategy on test ordering performance of primary care physicians: a randomized trial. *JAMA*. 2003;289(18):2407-2412.

44. Poppleton VK, Moynihan PJ, Hickey PA. Clinical practice guidelines: the Boston experience. *Prog Pediatr Cardiol*. 2003;18(1):75-83.

45. Sleath B, Collins T, Kelly HW, McCament-Mann L, Lien T. Effect of including both physicians and pharmacists in an asthma drug-use review intervention. *Am J Health Syst Pharm*. 1997;54(19):2197-2200.

46. Ijo I, Feyerharm J. Pharmacy intervention on antimicrobial management of critically ill patients. *Pharm Pract (Granada)*. 2011;9(2):106-109.

47. Bernal-Delgado E, Galeote-Mayor M, Pradas-Arnal F, Peiró-Moreno S. Evidence based educational outreach visits: effects on prescriptions of non-steroidal anti-inflammatory drugs. *J Epidemiol Community Health*. 2002;56(9):653-658.

48. Bhatia RS, Milford CE, Picard MH, Weiner RB. An educational intervention reduces the rate of inappropriate echocardiograms on an inpatient medical service. *JACC Cardiovasc Imaging*. 2013;6(5):545-555.

49. Hux JE, Melady MP, DeBoer D. Confidential prescriber feedback and education to improve antibiotic use in primary care: a controlled trial. *CMAJ*. 1999;161(4):388-392.

50. Larmour I, Pignataro S, Barned KL, Mantas S, Korman MG. A therapeutic equivalence program: evidence-based promotion of more efficient use of medicines. *Med J Aust*. 2011;194(12):631-634.

51. Phillips L, Landsberg KF. Evaluation of a newsletter in altering physicians' prescribing patterns. *Can J Hosp Pharm*. 1986;39(4):102-104, 108.

52. Ziskind AA, Portelli J, Rodriguez S, et al. Successful use of education and cost-based feedback strategies to reduce physician utilization of low-osmolality contrast agents in the cardiac catheterization laboratory. *Am J Cardiol*. 1994;73(16):1219-1221.

53. Shane R, Nishimura L. Strategic management of therapeutic advances: experience with colony-stimulating factors. *Hosp Pharm*. 1994;29(9):824-829, 826-829.

54. Weingarten SR, Riedinger MS, Conner L, et al. Practice guidelines and reminders to reduce duration of hospital stay for patients with chest pain: an interventional trial. *Ann Intern Med*. 1994;120(4):257-263.

55. Sucov A, Bazarian JJ, deLahunta EA, Spillane L. Test ordering guidelines can alter ordering patterns in an academic emergency department. *J Emerg Med*. 1999;17(3):391-397.

56. Okpara AU, Maswoswe JJ, Stewart K. Criteria-based antimicrobial IV to oral conversion program. *Formulary*. 1995;30(6):343-348.

57. Légaré F, Labrecque M, LeBlanc A, et al. Training family physicians in shared decision making for the use of antibiotics for acute respiratory infections: a pilot clustered randomized controlled trial. *Health Expect*. 2011;14(suppl 1):96-110.

58. Légaré F, Labrecque M, Cauchon M, Castel J, Turcotte S, Grimshaw J. Training family physicians in shared decision-making to reduce the overuse of antibiotics in acute respiratory infections: a cluster randomized trial. *CMAJ*. 2012;184(13):E726-E734.

59. Braido F, Comaschi M, Valle I, et al; ARGA Study Group; EAACI/CME Committee. Knowledge and health care resource allocation: CME/CPD course guidelines-based efficacy. *Eur Ann Allergy Clin Immunol*. 2012;44(5):193-199.

60. James E, Cyriac J. Impact of educational interventions on the physicians for early switchover of parenteral drugs to oral therapy. *European Journal Hospital Pharmacy*. 2014;22:176-178.

61. Lee TC, Frenette C, Jayaraman D, Green L, Pilote L. Antibiotic self-stewardship: trainee-led structured antibiotic time-outs to improve antimicrobial use. *Ann Intern Med*. 2014;161(10)(suppl):S53-S58.

62. Yang Z, Zhao P, Wang J, et al. DRUGS system enhancing adherence of Chinese surgeons to antibiotic use guidelines during perioperative period. *PLoS One*. 2014;9(8):e102226.

63. Fortuna RJ, Zhang F, Ross-Degnan D, et al. Reducing the prescribing of heavily marketed medications: a randomized controlled trial. *J Gen Intern Med*. 2009;24(8):897-903.

64. Wein PJ, Hoffman RP. Promoting the cost-effective utilization of cefoxitin with a drug use education program. *Hosp Formul*. 1987;22(3):299-306.

65. Gregory KD, Hackmeyer P, Gold L, Johnson AI, Platt LD. Using the continuous quality improvement process to safely lower the cesarean section rate. *Jt Comm J Qual Improv*. 1999;25(12):619-629.

66. Pasquale TR, Komorny KM, Letting-Mangira D, Peshek S. A pharmacist-physician antibiotic support team. *P&T*. 2004;29(1):33-40.

67. Parrino TA. The nonvalue of retrospective peer comparison feedback in containing hospital antibiotic costs. *Am J Med*. 1989;86(4):442-448.

68. McPhee SJ, Chapman SA, Myers LP, Schroeder SA, Leong JK. Lessons for teaching cost containment. *J Med Educ*. 1984;59(9):722-729.

69. von Ferber L, Bausch J, Köster I, Schubert I, Ihle P. Pharmacotherapeutic circles: results of an 18-month peer-review prescribing-improvement programme for general practitioners. *Pharmacoeconomics*. 1999;16(3):273-283.

70. Miyakis S, Karamanof G, Liontos M, Mountokalakis TD. Factors contributing to inappropriate ordering of tests in an academic medical department and the effect of an educational feedback strategy. *Postgrad Med J*. 2006;82(974):823-829.

71. Moriates C, Soni K, Lai A, Ranji S. The value in the evidence: teaching residents to "choose wisely". *JAMA Intern Med*. 2013;173(4):308-310.

72. Attali M, Barel Y, Somin M, et al. A cost-effective method for reducing the volume of laboratory tests in a university-associated teaching hospital. *Mt Sinai J Med*. 2006;73(5):787-794.

73. Bates DW, Kuperman GJ, Rittenberg E, et al. A randomized trial of a computer-based intervention to reduce utilization of redundant laboratory tests. *Am J Med*. 1999;106(2):144-150.

74. Thakkar RN, Kim D, Knight AM, Riedel S, Vaidya D, Wright SM. Impact of an educational intervention on the frequency of daily blood test orders for hospitalized patients. *Am J Clin Pathol*. 2015;143(3):393-397.

75. Zimmerman DR, Collins TM, Lipowski EE, Sainfort F. Evaluation of a DUR intervention: a case study of histamine antagonists. *Inquiry*. 1994;31(1):89-101.

76. Zunker RJ, Carlson DL. Economics of using pharmacists as advisers to physicians in risk-sharing contracts. *Am J Health Syst Pharm*. 2000;57(8):753-755.

77. Sicotte C, Pineault R, Tilquin C, Contandriopoulos AP. The diluting effect of medical work groups on feedback efficacy in changing physician's practice. *J Behav Med*. 1996;19(4):367-383.

78. Krinsley JS. Test-ordering strategy in the intensive care unit. *J Intensive Care Med*. 2003;18(6):330-339.

79. Rudy DW, Ramsbottom-Lucier M, Griffith CH III, Georgesen JC, Wilson JF. A pilot study assessing the influences of charge data and group process on diagnostic test ordering by residents. *Acad Med*. 2001;76(6):635-637.

80. Rotman BL, Sullivan AN, McDonald TW, et al. A randomized controlled trial of a computer-based physician workstation in an outpatient setting: implementation barriers to outcome evaluation. *J Am Med Inform Assoc*. 1996;3(5):340-348.

81. Bornard L, Dellamonica J, Hyvernat H, et al. Impact of an assisted reassessment of antibiotic therapies on the quality of prescriptions in an intensive care unit. *Med Mal Infect*. 2011;41(9):480-485.

82. Manheim LM, Feinglass J, Hughes R, Martin GJ, Conrad K, Hughes EF. Training house officers to be cost conscious: effects of an educational intervention on charges and length of stay. *Med Care*. 1990;28(1):29-42.

83. Niquille A, Ruggli M, Buchmann M, Jordan D, Bugnon O. The nine-year sustained cost-containment impact of Swiss pilot physicians-pharmacists quality circles. *Ann Pharmacother*. 2010;44(4):650-657.

84. Zeleznik C, Gonnella JS. Jefferson Medical College student model utilization review committee. *J Med Educ*. 1979;54(11):848-851.

85. Gist D, Llorente J, Mayer J. A clinical algorithm for the management of abnormal mammograms: a community hospital's experience. *West J Med*. 1997;166(1):21-28.

86. Lyle CB Jr, Bianchi RF, Harris JH, Wood ZL. Teaching cost containment to house officers at Charlotte Memorial Hospital. *J Med Educ*. 1979;54(11):856-862.

87. Colbert CY, Ogden PE, Lowe D, Moffitt MJ. Students learn systems-based care and facilitate system change as stakeholders in a free clinic experience. *Adv Health Sci Educ Theory Pract*. 2010;15(4):533-545.

88. Mallows JL. The effect of a gold coin fine on C-reactive protein test ordering in a tertiary referral emergency department. *Med J Aust*. 2013;199(11):813-814.

89. Collins TM, Mott DA, Bigelow WE, Zimmerman DR. A controlled letter intervention to change prescribing behavior: results of a dual-targeted approach. *Health Serv Res*. 1997;32(4):471-489.

90. Ferris TG, Shea T, Jacobson BC, et al. A population-based intervention to improve management of patients on chronic acid suppression: a group-randomized trial. *J Clin Outcomes Manag*. 2005;12(1):35-43.

91. Landgren FT, Harvey KJ, Mashford ML, Moulds RF, Guthrie B, Hemming M. Changing antibiotic prescribing by educational marketing. *Med J Aust*. 1988;149(11-12):595-599.

92. Smith SR. An evaluation of a computerized exercise in teaching cost consciousness. *J Med Educ*. 1983;58(2):146-148.

93. Glicken AD, Merenstein GB. Addressing the hidden curriculum: understanding educator professionalism. *Med Teach*. 2007;29(1):54-57.