**Supplemental Table 7**

**Feasibility, Barriers, and Costs Associated with Implementation of Test Utilization Management Interventions**

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| **Study** | **Practice** | **Information** |
| Howell et al. 2014 | CDSS | Implementing study in other settings "may be difficult to accomplish due to many logistic and economic challenges, including difficulty implementing alerts within different EMR systems at different institutions." |
| Nightingale et al. 1994 | CDSS | "…where protocols have been devised they have not always been adhered to, owing, among other reasons, to the continual need to train new staff in their use and, perhaps more importantly, to the difficulty in applying routinely several, sometimes quite complex, rules simultaneously." |
| Poley et al. 2007 | CDSS | "…before CDSS can achieve its full potential some practical difficulties encountered by the laboratories need to be addressed, a process that may involve a range of solutions varying from relatively low-cost methods…to costlier ones. Costs for these procedures may drop in the long run, however, and make the process of test ordering less sensitive to error."; "Use of the CDSS may also be affected by financial aspects and incentives."; "Reduction in test ordering may be associated with substitution of care, for example a shift to other, perhaps more expensive healthcare procedures to reduce diagnostic uncertainty or to reassure patients." |
| VanWijk et al. 2001 | CDSS | "Increasingly, the literature shows that provision of decision support can change health care delivery." |
| Bindels et al. 2003 | CDSS | "…individual GPs need different approaches to change their diagnostic test ordering behavior." |
| Roukema et al. 2008 | CDSS | "…the effectiveness of CDSS will be limited by any deficiencies in the quality or relevance of the research evidence." |
| Georgiou et al. 2011 | CPOE | "The introduction of electronic prompts, structured screens, and decision support in clinical settings can be challenging. There is no guarantee that the provision of such electronic support will be used effectively, if at all. Successful decision support systems rely on several factors, including its usability, its perceived relevance, and even its design and presentation." "...implementation and sustainability of a decision-support system is part of a hospital-wide process..." |
| Horn et al. 2013 | CPOE | "Cost displays were well received by primary care physicians, and therefore may be extended to other health care services." |
| Hwang et al. 2002 | CPOE | Shifts in practice models and payer models "have influenced the design and implementation" of clinical information systems. |
| Bates et al. 1997 | CPOE | "The electronic record will be adopted much more rapidly if it can be demonstrated that it reduces costs and improves quality. Although data are accumulating to suggest that the electronic record can have these effects, more studies are needed."; "Interventions to reduce costs may be most successful if they do no affect quality adversely, can be maintained indefinitely, generalized to all providers, focused at the level of individual decisions, and yet be nonintrusive -- a difficult combination to achieve. Information technologies offer an opportunity to do all these things at once, and can readily be applied to the use of diagnostic testing." |
| Olson et al. 2015 | CPOE | "With every benefit, there is a cost; therefore both clinicians and laboratory medical directors must be involved in the development and effective implementation of these order sets." |
| Lippi et al. 2015 | CPOE | "…software is also configurable and customizable, so that the appropriateness rules can be modified according to local practices and also applied in outpatient settings." |
| May et al. 2006 | CPOE | Existence of "the apparent lack agreement about what constitutes appropriate laboratory testing."; Benefits of educational efforts demonstrate "transient and time-limited", while "Changes in requisition design have a more durable effect but are labor-intensive to design and require substantial subspecialty expertise."; In teaching hospitals "the least experienced physicians -- interns and residents (i.e., house staff) -- are responsible for ordering laboratory tests." |
| Bridges et al. 2014 | CPOE | "When the number of nuisance alerts is higher than valuable alerts, 'alert fatigue' can occur. Fortunately, imbedded in the CPOE system is an opportunity to minimize unnecessary alerts and introduce targeted alerts…" |
| Tierney et al. 1993 | CPOE | "Such systems can only affect costs and quality of care if physicians use them, which will only happen if "costs" are minimized and offset by perceived benefits." |
| Shalev et al. 2009 | CPOE | Difficulty is associated with "measuring the appropriateness of laboratory testing." |
| Kahan et al. 2009 | CPOE | "Efficiency of ordering procedures should be evaluated before implementing resource-intensive interventions to reduce laboratory test utilization." |
| Bates et al. 1999 | CPOE | "Despite available information about unnecessary utilization, test ordering has been resistant to change."; Strategies to reduce test ordering have "...produced transient reductions…", "with variable success, and implementation is labor-intensive and costly. Moreover, their effect decays with time." |
| Procop et al. 2015 | CPOE | "Improving the utilization of low-cost, high-volume testing is often challenging, since it may not be deemed worth the effort to try to improve the utilization of any one of these tests alone."; "We have evidence from previous investigations (data not shown) that 'popup fatigue' does occur and that the CDSTs are often not read and simply 'clicked through.'" |
| Westbrook et al. 2006 | CPOE | "The use of POE systems requires clinicians to change the way they work. Orders take longer to enter, yet this may decrease over time, and efficiencies have been observed in other clinical tasks."; "…the implementation of POE may change the very nature of the way in which clinicians works."; "Future POE evaluations should assess the ways in which systems integrate, or fail to integrate, with clinical work practices..."; "...we found that system implementation was not associated with an increase in test volume, negating concerns that these systems make it easier to order tests and thereby cause an increase in inappropriate testing." |
| Aesif et al. 2015 | Test Review | "There was no resistance to test review on the part of the ordering clinicians, given that this has been standard practice in the microbiology department for the greater part of two decades." |
| Thakkar et al. 2015 | Education | "…possible that fatigue or diminished attention to reminders will make providers less responsive over time." |
| Eisenberg 1977 | Education | "…educational programs can decrease laboratory use for a short period of time."; "It is likely that long-term modification of physician behavior will occur only with repeated educational programs or with incentives offered to the physician to induce behavioral modifications, especially in institutions where turnover of physicians is commonplace." |
| DellaVolpe et al. 2014 | Education | "…performing this study in a training institution involved challenges, to include the varying degrees of expertise amongst ordering physicians and multiple groups of residents rotating at a given week. We minimized this effect by training all residents at our institution, noting that less experienced providers were more likely to modify their practice when presented with evidence."; "Many clinicians can be hesitant to change ordering practices on a test which can have an immediate impact of complex critical decisions..." |
| Gama et al. 1992 | Feedback | "Many other 'successful' strategies have either initiated change but have been unable to maintain it, or have been too brief to evaluate long term effects." |
| Versappen et al. 2004 | Feedback | Possibility of "resistance to change."; "Many test-ordering problems that physicians encounter in everyday practice, such as demands for tests by patients and changing guidelines, can be discussed and may be solved in an open and respectful discussion among colleagues."; "More effort is needed, and feedback reports must be fit in with a more ambitious continuous quality improvement program."; "Evaluating these interventions calls for rigorous methodology and is both complex and challenging." |
| Miyakis et al. 2006 | Feedback | "The rotation of junior doctors in hospital departments…makes it unlikely that the effect of any intervention of this kind is sustained over time, unless audits are repeated at regular intervals, combined with continuous education of the medical roster on the reasons and consequences of inappropriate ordering of tests." |
| Baker et al. 2003 | Feedback | "Since local guidelines are likely to be the least costly intervention, evidence is needed about their impact when used to predispose general practitioners to change their use of diagnostic tests in response to feedback."; "Feedback on test use is a simple method that might be useful in influencing test ordering by general practitioners." |
| Chu et al. 2013 | Test Review | "Commonly employed interventions such as education, protocols and feedback, require ongoing monitoring and are resource intensive and problematic in departments where staff turnover is high. Successful implementation using a low maintenance strategy is necessary to sustain a long-term reduction in excessive test ordering." |
| Barazzoni et al. 2002 | Test Review | "Current research on practice guidelines indicates the relevance of the identification of barriers to the adoption of the recommended behaviors. In principle, end-users…are in the best position to identify contextual factors that may hinder or favour their adherence to guidelines in current clinical practice."; "The main task of the [multidisciplinary] working groups was to examine the clinical content of the recommendations and anticipate their organizational implications, taking into account the settings in which they had to be applied."; "The recommendations were not intended to be mandatory, rather they were presented to health professionals as 'advised clinical behaviors', and were not linked to any kind of financial incentives.""...discussion focused on the identification of possible barriers to the adoption of the guidelines by clinicians, as well as on identification of possible barriers to the adoption of the guidelines by clinicians, as well as on the development of feasible strategies to overcome them.";...promotion of behavioural changes can be relatively more difficult in centres with a higher degree of organizational complexity." |
| Dickerson et al. 2014 | Test Review | "…obscure test names are difficult for clinicians and laboratory personnel to decipher and can lead to errors in test ordering."; "Dedicated resources are required, but can be managed with just a few faculty and staff, which could include a mixture of pathologists, clinical chemists, clinical microbiologists, genetic counselors, and residents or fellows." |
| Bongauri et al. 2011 | Reflex | Problem of inappropriate use of laboratory resources challenging "due to several factors, including also inadequate collaboration or audit between physicians and laboratory professionals, availability of different techniques and methodologies for assessing biomarkers and the lack of homogenous terminology and diagnostic algorithms..." |
| Tampoia et al. 2007 | Reflex | "Before applying the protocol it was judged necessary to hold meetings with the directors and operators in the wards involved in the study to illustrate all possible advantages and overcome the inevitable resistance because of the need to include a greater quantity of data." |
| Wu et al. 1999 | Reflex | "It must be noted that labs must be careful in how they implement any reflex algorithm. Tests that are automatically added without a physician's order would be in violation of the Office of the Inspector General (IOG) and subjected to fines and penalties."; "...recommendations were not intended to be mandatory, rather they were presented to health professionals as 'advised clinical behaviours', and were not linked to any kind of financial incentive."; "Main takes of the [multidisciplinary] working groups was to examine the clinical content of the recommendations and anticipate their organizational implications, taking into account the settings in which they had to be applied...discussion focused on the identification of possible barriers to the adoption of the guidelines by clinicians, as well as development of feasible strategies to overcome them." |
| Larochelle et al. 2014 | Combined Practice | "Changing physician ordering behavior can be extremely challenging…"; Annual turnover of house staff…may make sustained behavioral change more challenging…" |
| MacPherson et al. 2005 | Combined Practice | "More recently, doctors are becoming increasingly aware of the need to improve pathology test ordering strategies in other settings, such as the emergency department."; "Any scheme that proposes to rationalize pathology test ordering much address issues...that will otherwise act as barriers."; "The greatest challenge in a project such as this is sustaining results for the long term."; The literature is replete with reports from studies that show pathology test ordering is excessive and wasteful. The real challenge is to design systems that allow this problem to be countered. Our study had determined that key points to success are: a workable set of guidelines, involving consultant staff at an early stage, continuing education of junior medical staff and constant audit of...test ordering practices."; "...improving professional practice does not necessarily need to be complex and expensive, and the substantial changes can be achieved with simple tools." |
| Riley et al. 2015 | Combined Practice | "There is an obligation to improve practice within the context of a paradigm shift in genetic and genomic test utilization and a value-based payment scheme." |
| Rosenbloom et al. 2005 | Combined Practice | "Unintended consequences of PCISs and CDS tools can lead to workflow inefficiency, excessive resource use, and reduced confidence in such systems, and actual clinical errors. Studies investigating the factors leading to unintended consequences of decision support remain uncommon." |
| Spiegel et al. 1989 | Combined Practice | "Computer databases in many hospitals could generate flow sheets for feedback with little difficulty." Suggest value in having a "charismatic authority figure", e.g. a "respected senior clinician", involved. |
| Vegtig et al. 2012 | Combined Practice | Describes intervention as involving "...a few simple measures…" |
| Wang et al. 2002 | Combined Practice | Suggest value of strategies "that target attitudes or knowledge...those that facilitate behaviors or reduce barriers to them…and those that reward or penalize certain behaviors…"; investigators "encountered...(and difficult to modify) perceptions" in relation to ABG test utilization among clinicians.; "Because house staff teams changed monthly, the practice of ordering frequent ABG measurements outside of the CCU may have hindered efforts to change practice within the CCU." |
| Warren et al. 2013 | Combined Practice | Indicates need to "engender user acceptability through the application of order sets and minimization of hurdles that could increase workload for providers."; indicates value of committees to vet current or proposed new laboratory tests, involving content experts and individuals with "extensive topic-specific clinical experience and are institutionally recognized authorities." |
| Newman et al. 2015 | Combined Practice | "Simple educational interventions…can be effective."; "These interventions [education and feedback] are inexpensive and provide an educational opportunity for improved patient care." |
| Jannsens et al. 2015 | Combined Practice | "The aim was to achieve consensus among all requestors on the reorganization of the test panels."; Following the initial investment of time, test ordering still needs to be supervised to keep the system orderly and efficient…we consider continued and obligatory consultation about new proposals the most important activity here. We also recommend regular inspecting the ordering screens and consulting with the operators who install and sustain the screens. Ideally a knowledgeable laboratory specialist who has insight into the doctor's needs, is practical and thinks economically should supervise the ordering process." |
| Minerowics et al. 2015 | Combined Practice | Suggests approach should not interfere with physician autonomy. "…altering the test menu to make test ordering more difficult for the clinicians…can be cumbersome and frustrating."; "A major strength to our approach was that is fostered a collegial, nonantagonistic relationship between the laboratory director and the internal medicine residents."; "Achieving meaningful and sustainable reductions in laboratory testing involves both the laboratory professionals performing the testing and the clinicians who order the tests." |
| Baricchi et al. 2014 | Combined Practice | "[Due to the simplicity of the pathology-specific laboratory profiles], they can be incorporated in computerized programs and produced in the form of flowcharts."; "Compliance with guidelines does not automatically translate into appropriate patient care...the significant discordance between guidelines recommendations and what doctors actually do may indicate that guidelines are incomplete or that new evidence has made them obsolete." |
| Calderon-Margalit et al. 2005 | Combined Practice | "Taking into account the modest resources needed for our intervention including communication between hospital management, the clinical biochemistry laboratory, and the directors of the hospital's divisions and wards, we conclude that this simple and low-cost intervention has achieved its goals..." |
| White et al. 2013 | Combined Practice | "Even the most well-informed providers might find it difficult to adapt to a new guideline that recommends doing less. However, the harms of overscreening…must not be overlooked in a population that is extremely unlikely to benefit from screening." |
| **Cost of implementation** | |  |
| **Study** | **Practice** | **Information** |
| Horn et al. 2013 | CPOE | "Minimal resource outlay" |
| Waldron et al. 2014 | CPOE | Intervention described as "cheap and sustainable". |
| Tierney et al. 1993 | CPOE | "The workstation network hardware costs approximately $20,000 per ward, with additional costs for installation and maintenance"; "…broad implementation of systems such as ours should be preceded by studies of their costs, benefits, and acceptability to physicians." |
| Winkens et al. 1992 | Feedback | Indicates extra costs associated with "data processing and analyses for the feedback reports." |
| Tierney et al. 1988 | CDSS | "Once in place, an intervention such as ours requires minimal labor to maintain and thus can be sustained indefinitely." |
| Poley et al. 2007 | CDSS | Total intervention costs were 79,000 euros (670 euros per practice) |
| DellaVolpe et al. 2014 | Education | Cost of implementation described as "minimal". |
| Thakkar et al. 2015 | Education | Cost of implementation described as "low-cost". |
| Dickerson et al. 2014 | Test Review | Cost to implement was $64,533. |
| Calderlon-Margalit et al. 2005 | Combined Practice | Intervention described as "low-cost". |