

Modeling the Cost-Effectiveness of Colorectal Cancer Screening: Policy Guidance Based on Patient Preferences and Compliance

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Abstract

Background: Obtaining regular screening exams can significantly reduce colorectal cancer (CRC) mortality. Most CRC models to date have assumed “ideal conditions” such as 100% compliance, and the effects of CRC screening tests have been assessed only under these conditions. In this study, we assess cost-effectiveness incorporating real-world patient preferences and compliance.

Methodology: We built an agent-based simulation model to assess the effect of compliance and patient preferences. Baseline values were derived from the 2003 and 2005 National Health Interview Survey, and effectiveness and cost parameters were obtained through literature review. Initial screening compliance was 45%, and compliance with follow-up diagnostic tests was 75%.

Results: The current level of screening reduces CRC mortality by 44.1% when compared with no screening. Increasing diagnostic follow-up compliance to 95% can

lead to an additional 9.3% reduction in CRC mortality, whereas increasing initial screening compliance to 95% can result in an additional 50.4% reduction. These increases can be achieved at a cost of about \$7,500 (\$1,309–\$32,864) per life year saved and \$14,000 (\$3,620–\$35,855) per life year saved for diagnostic follow-up and initial screening tests, respectively.

Conclusions: Increasing compliance with both initial screening test recommendation and diagnostic testing are cost-effective approaches. The most cost-effective approach under limited funding is to increase compliance with diagnostic testing for those already being screened. Targeted interventions, which are necessary to increase compliance, are generally cost-effective under the base case scenarios presented in this model, but additional studies are required to identify the most cost-effective approach. (Cancer Epidemiol Biomarkers Prev 2009;18(7):1971–8)

Introduction

Colorectal cancer (CRC) accounts for 10% of all new cancer cases and is the second leading cause of cancer-related mortality in the United States. Survival from CRC is inversely related to the stage at which the cancer is diagnosed, and it is estimated that the majority of CRC deaths are preventable with early detection (1, 2). Therefore, regular screening exams can significantly reduce CRC morbidity and mortality, and there is a growing recognition of the importance of CRC screening (3).

The U.S. Preventive Services Task Force, the American Cancer Society, the American College of Gastroenterology, and the American Gastroenterological Association have all published guidelines for CRC screening (3–5). The recent guidelines from the American Cancer Society, the U.S. Multi-Society Task Force on Colorectal Cancer, and the American College of Radiology (6) for the first time recommended that if resources are available, those tests that can both prevent (i.e., identify adenomas) and

detect cancer, such as colonoscopy, sigmoidoscopy, and computed tomographic colonography, should be the preferred choice over fecal tests, which are suited only to detect cancers. There are some differences between the published CRC screening guidelines, but they are consistent in the recommendation that screening should begin at age 50 years for all individuals at average risk (7). The recommendations to provide CRC screening have been incorporated in the health benefits offered by payers including Medicare and private insurers, but there is ongoing debate on the cost-effectiveness and long-term budget effects of the recommended tests. In addition, state health departments and federal agencies are in the planning stages or in early implementation of large-scale screening programs. Therefore, there is a need to provide practical guidance incorporating real-world constraints to inform the clinical and economic outcomes of CRC screening.

A large number of modeling studies have been done to assess the clinical and economic effects of CRC screening (8–12). Models have generally assessed the cost-effectiveness of screening the average-risk population who are 50 years or older and have compared costs and outcomes of not screening versus screening with a specific recommended test. The majority of the models to date have assumed “ideal conditions,” and effects of CRC screening tests have been assessed only under these conditions. Recently, there has been some interest in understanding the effects under more realistic conditions. For instance,

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models have assessed the endoscopic capacity available in the United States and the potential supply side barriers, especially those related to screening and diagnostic colonoscopies (13-16). In addition, models have attempted to evaluate the cost-effectiveness of recommended tests under both ideal compliance (100%) and more realistic scenarios of much lower levels of compliance. Although attempts have been made to incorporate real-world constraints into models (17, 18), more rigorous approaches and methods are required to systematically perform such assessments.

In this article, we develop a model that systematically incorporates real-world constraints related to patient compliance and preferences for screening tests to assess the most cost-effective approach to improve outcomes from CRC screening at the population level. Unlike prior assessments, our objective is not to compare which among the recommended CRC screening tests is the most cost-effective. Instead, we incorporate patient preferences for screening tests, and the proportion of each test used by the cohort screened in our model is based on those selected by individuals undergoing screening in the real world. We estimate the effect of CRC screening on incidence and mortality given the current level of compliance and identify the most cost-effective approach to increase the benefits from screening at the population level.

Materials and Methods

Framework. Our approach to modeling patient preferences and compliance is drawn from an overall framework that was developed to incorporate real-world constraints. As shown in Fig. 1, there are three components to this framework: modeling under ideal conditions, modeling incorporating real-world constraints, and guidance for implementation (i.e., analysis to guide policy making and implement findings). The theoretical approach for modeling under ideal conditions serves as the backbone of this framework, and constraints of reality are superimposed on this base model. Several assumptions are made when modeling under ideal conditions, including the following: all tests are substitutes in terms of patient/physician preference; there is 100% compliance with all testing and procedures;

there are no capacity constraints in obtaining screening tests, diagnostic procedures, treatments, and surveillance; and sensitivity and specificity of screening tests from specific studies can be generalized to the everyday practice.

To attempt to reflect the real-world situation, the behaviors observed in the everyday practice setting should be reflected in the model. For instance, there is a growing body of literature suggesting that patients generally have clear preferences for specific CRC tests (19-23). The features of a particular test, including the ease of the stool sample collection, comfort, accuracy, invasiveness, embarrassment and anxiety over preparation and the test itself, and out-of-pocket cost of the test, are all important factors that determine an individual's choice of CRC test. Therefore, the tests cannot be considered as direct substitutes for each other.

In addition, patient adherence to recommendations is a critical component, and compliance can affect the effectiveness of testing at several points along the cancer care continuum, as shown in Fig. 1 (17, 24). The currently available capacity is anticipated to support 22.4 million colonoscopies, and several studies have shown that this may be insufficient if there are increasing numbers of screening colonoscopies (25, 26). It is therefore important to assess testing recommendations in relation to the capacity available to perform both screening and diagnostic colonoscopies. In addition, sensitivity and specificity estimates, complication rates, and technical success (for instance, the ability to achieve complete colonoscopy examination) reported in clinical trials may differ from those experienced in the routine practice (27-30). The challenge in incorporating the real-world effectiveness of screening tests is the lack of studies providing these estimates, generally because of the difficulties in designing studies to collect these data accurately. Sensitivity analysis can be done to assess the effect of varying test performance on model results.

Using the real-world constrained model, several types of analysis can be done to guide policy and implement findings as stated in the "guidance for implementation" component of the framework. For example, in this study, we assess the effect of screening and diagnostic compliance and patient preference on CRC screening and discuss the policy implications of the findings. Modeling under ideal conditions remains an important component

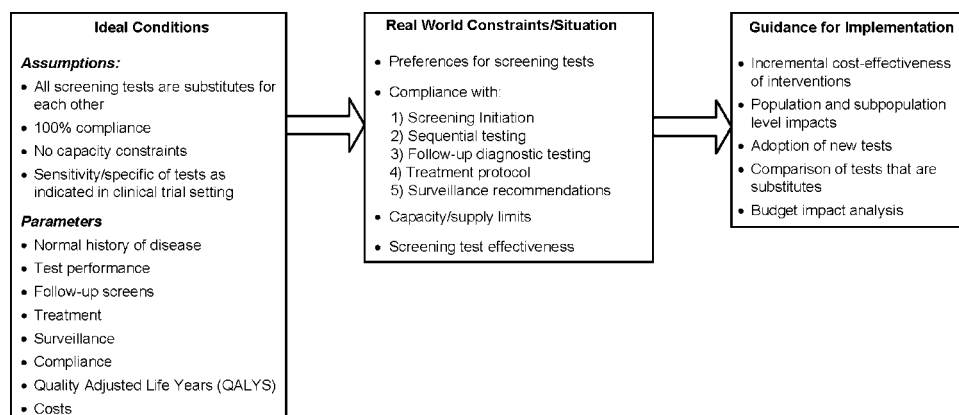


Figure 1. Framework for cost-effectiveness modeling of CRC screening incorporating real-world constraints.

of the framework because this provides the benchmark against which modeling under constraints can be compared. In addition, this allows policy makers to assess what is achievable if constraints are eliminated.

Model Incorporating Patient Preference and Compliance. We developed an agent-based simulation model using AnyLogic software (31) to study the cost and effectiveness of CRC screening. The agent-based model was selected because it allows for a relatively straightforward transition from a cohort study to population estimates. Additionally, this software allows for flexibility in future model development, as complex interactions can be achieved with straightforward modifications.

The model was built to simulate the incidence and mortality rates of CRC in the average-risk population. The model consists of biological, clinical, epidemiologic, and economic components. The disease progression from adenomas to CRC and screening, diagnostic, and treatment pathways were based on a previously published model (32). Disease progression was modeled with three major stages: the adenomatous stage, which progressed to the preclinical cancer stage, and finally the clinical cancer stage. The clinical stage was assigned when the cancer was clinically detected. The preclinical and clinical cancer stages were subdivided into American Joint Committee on Cancer/International Union Against Cancer stages I through IV.

All cancerous lesions were modeled to originate from adenomas, which were categorized into three size categories: ≤ 5 , 6 to 9, and ≥ 10 mm. Our model allowed for multiple adenomas in one individual. In addition, the model assumed that some adenomas do not progress to cancer by assigning a long average waiting time (80 y) before the adenomas progresses to cancer. Overall, some waiting times are shorter and some are longer, and only the adenomas with very short waiting times progress to cancer in the lifetime of the person modeled. Each person is modeled to have one level of risk to develop nonprogressive and progressive adenomas. The risk index is based on a gamma distribution, and individuals with higher risk indices are more likely to develop lesions. To reflect the adenoma frequency distribution found in autopsies, the variance of the distribution is twice that of the mean (32). Our model, however, does not take into account the location of the adenoma. We assumed that the prevalence of adenomas was 15% in the 50 to 59 y age group, 27% in the 60 to 69 y age group, and 33% in those 70 y and older on the basis of prior estimates derived from autopsy and colonoscopy studies (32). Because there are no data sources to provide the rates of progression through cancer stages and the probability of presenting with CRC symptoms, we derived these estimates based on clinically plausible ranges that mimic the CRC incidence and stage distribution reported in the Surveillance, Epidemiology, and End Results in 1988 before the initiation of widespread CRC screening (32). Based on this calibration, we estimated that the mean duration to move from preclinical stage I to II was 2 y, from stage II to III was 1 y, and stage III to IV was half a year. Mortality by CRC stage was derived in the model based on estimates from the Surveillance, Epidemiology, and End Results data (33). In addition to CRC-related mortality, individuals could die of other causes as well. Mortality rates for the general population were derived from the life tables

published by National Center for Health Statistics publications.

The screening module that allowed for the detection of polyps and cancers was superimposed on this framework of the natural history of CRC. A range of features were included to incorporate patient preferences and compliance in the screening episodes. First, the model allowed for multiple screening tests to be selected and the proportion of the individuals screened by specific tests to be varied. Second, the levels of initial compliance and diagnostic compliance could be varied as required to mimic real-world scenarios. Initial compliance refers to the proportion of the population who initiate cancer screening as recommended by guidelines, whereas diagnostic compliance refers to the proportion who obtain follow-up diagnostic testing as recommended. Third, we also incorporated the ability to either randomly select the population that was compliant at each screening interval or select a subset of the population who were consistently compliant over the long term. This feature was programmed to mimic the real world where a proportion of the population may remain unscreened and never interact with the screening module. In this model, we assumed 100% compliance with treatment and surveillance recommendations.

Average-risk individuals were eligible to receive screening starting at the age of 50 y. The appropriate age at which CRC screening should be discontinued is not known because the choice of screening elderly patients is based on functional status and comorbidities and, therefore, often is an individualized decision (34). Because screening studies have generally been restricted to patients younger than 80 y, we chose 80 y as the end age for our screening cohort (35). The choice of screening tests included fecal occult blood test (FOBT), sigmoidoscopy, and colonoscopy. Although there are other screening tests recommended for CRC, we chose to focus on these specific screening tests because they are the most widely used tests based on the most current national data available (19, 36, 37). The recommended screening frequency is yearly, every 5 y, and every 10 y for FOBT, sigmoidoscopy, and colonoscopy, respectively (4, 5). Under optimal care, all positive FOBTs and sigmoidoscopies are followed up by a diagnostic colonoscopy. After successful completion of treatment, surveillance colonoscopy was done at 5-y intervals.

Parameter estimates for patient preferences for screening tests and compliance are presented in Table 1. These estimates are derived from the National Health Interview Survey (NHIS), which is the leading source of health information on the civilian, noninstitutionalized population in the United States (38) and provides the most comprehensive estimates of CRC screening at the national level. Data from the 2000, 2003, and 2005 NHIS have been analyzed to provide detailed information on the use of FOBT and endoscopic tests for CRC screening (19, 36, 37, 39). We used the test selection patterns reported in the NHIS to derive estimates of patient preference for screening tests. Both the 2003 and 2005 NHIS report significantly higher use of colonoscopy for CRC screening compared with the 2000 NHIS in which the FOBT was the dominant screening test. The distribution of tests used in the model reflects the current choice of colonoscopy as the preferred screening test: 58% select colonoscopies, 30% FOBTs, and 12% sigmoidoscopies (37).

Table 1. Patient preference and compliance measures

	Value (%)	References
Patient preference		(37)
FOBT	30	
Sigmoidoscopy	12	
Colonoscopy	58	
Compliance rate		
Initial screening	45	(36, 37)
Follow-up abnormal test (diagnostic testing)	75	(40-42)
Never-screened population	35	(20, 43)

Data from the 2005 NHIS indicate that 48.8% to 51.2% (36) received CRC screening tests within the recommended time intervals, but this estimate includes tests received for screening as well as those done to investigate specific symptoms. After excluding the proportion receiving tests for specific symptoms, we estimate that about 45% of the population is compliant with screening recommendations each year. The rates of compliance with follow-up testing for abnormal findings when using FOBT or sigmoidoscopy as the primary screening test were derived from the literature (40-42). The proportion of the population estimated to have never received any CRC screening test was derived from studies that analyzed CRC screening compliance using NHIS data (19, 43).

Table 2 presents the base case estimates and ranges used in sensitivity analysis for test characteristics and cost. Information on test sensitivity, specificity, and cost was drawn from the best possible estimates available in

the literature (4, 5, 7, 9, 16, 17, 25, 32, 35, 44-54). Costs were approached from the perspective of a third party payer; therefore, only direct medical costs were included, and cost estimates were based on payment rates whenever possible.

We performed a series of assessments to compare the current level of screening compliance to the situation when no screening occurs to understand the benefits and cost of the present level of compliance with screening recommendations. We report the incremental cost, gain in life years, cost per life year saved, reduction in CRC incidence, and reduction in CRC mortality. The estimates are based on the current patient preference for screening tests (from Table 1). To derive population estimates of mortality from our cohort model, we resample individuals of different ages (the age groups were defined in 1-y increments) to form a nationally representative sample. In scenario 1, we report estimates based on screening compliance rate of 45%. We placed no restriction on the population that could be selected to receive screening tests in subsequent rounds of screening for this scenario. In essence, the cohort that is compliant and receives screening is randomly selected for each round of screening. Under scenario 2, we test the effect of having 35% of the population never receive any screening test. The intent of this was to replicate the real-world setting where some individuals are never screened and assess the effect of this restriction on the cost and benefits of screening. In scenario 3, we present the benefits and cost under the ideal condition of 100% compliance across the cancer care continuum, assuming the preference for screening tests remains the same.

Table 2. Model parameters related to test performance and cost

	Base case	Sensitivity analysis	References
<i>Test performance (%)</i>			
FOBT			(32, 35, 44-48)
Sensitivity for small polyps (≤ 5 mm)	2	0-5	
Sensitivity for medium polyps (6-9 mm)	2	0-5	
Sensitivity for large polyps (≥ 10 mm)	10	5-20	
Sensitivity for cancer	40	35-64	
Specificity	97	90-100	
Sigmoidoscopy			(4, 49)
Lesions within reach of the sigmoidoscope	50		
Sensitivity for small polyps (≤ 5 mm)	75	70-80	
Sensitivity for medium polyps (6-9 mm)	85	80-90	
Sensitivity for large polyps (≥ 10 mm)	95	85-98	
Sensitivity for cancer	95	85-98	
Specificity	100		
Colonoscopy			(8, 32, 35, 50, 51)
Sensitivity for small polyps (≤ 5 mm)	80	75-85	
Sensitivity for medium polyps (6-9 mm)	85	80-90	
Sensitivity for large polyps (≥ 10 mm)	95	85-98	
Sensitivity for cancer	95	85-98	
Specificity	100		
<i>Cost (\$)</i>			
FOBT	18	5-38	(25, 35, 52)
Colonoscopy	818	400-1,656	(18, 52, 53)
Sigmoidoscopy	349	200-500	(52, 53)
Polypectomy	380	250-500	(18, 53)
Complications of endoscopy (perforation)	24,000	10,000-30,000	(7, 35)
Lifetime CRC treatment			(54)
Stage I	32,700	20,000-60,000	
Stage II	34,400	25,000-65,000	
Stage III	41,600	30,000-80,000	
Stage IV	29,400	20,000-60,000	

Table 3. Benefits and cost of screening versus no screening incorporating patient preferences and compliance

	Average cost (\$)	Compared with no screening			
		Average gain in life expectancy (d)	Cost per life year gained (\$)	Reduction in CRC incidence (%)	Reduction in CRC mortality (%)
No screening	1,067 (740-1,965)	—	—	—	—
Scenario 1: 45% compliance*	1,536 (858-3,070)	15.6 (12.5-18.4)	10,994 (2,335-32,206)	39.2 (34.3-45.3)	44.1 (36.1-51.3)
Scenario 2: 45% compliance* with 35% of population never receiving a screening test	1,538 (872-3,050)	14.4 (11.9-16.6)	11,976 (2,907-33,110)	34.8 (30.9-39.3)	39.3 (33.1-44.8)
Scenario 3: 100% compliance	2,146 (1,065-4,446)	30.8 (26.5-33.9)	12,787 (3,492-34,207)	68.0 (57.2-75.9)	79.0 (69.2-85.4)

*Assuming 75% compliance with recommendation of follow-up diagnostic testing with colonoscopy.

We also present the incremental benefits and cost of increasing compliance with initial screening and diagnostic follow-up. These findings can help us understand the optimal distribution of limited funds to further reduce the burden of CRC. We increased the rate of compliance with diagnostic testing to 85% and 95%, while keeping the initial compliance constant at 45%, and report the decrease in mortality that can be achieved and the cost per life year saved. Similarly, we varied the initial compliance from 45% to 95% in increments of 10%, holding the rate of compliance for diagnostic testing at 75%, to assess incremental benefits and cost.

Prior assessments have shown that results from CRC models can be sensitive to changes in the model parameters (11, 35). Therefore, we report the “best-case” and “worst-case” scenarios for each estimate obtained to reveal the potential variation that could occur using the ranges of estimates presented in Table 2. For instance, to model the best-case scenario, we used the upper range values for test performance and lower range values for the cost. Both the costs and effectiveness were discounted at 3% as recommended by guidelines developed for economic models (55).

Results

Table 3 presents the results comparing no screening with screening incorporating patient preferences and compliance. The average cost of providing no screening is \$1,067 (range, \$740-\$1,965). This reflects the cost of providing treatment and follow-up for a person diagnosed with colon cancer. With 45% compliance (scenario 1), the average gain in life expectancy is 15.6 days (12.5-18.4 days) at a cost of \$10,994 (\$2,335-\$32,206) per life year saved. This translated to a 39.2% (34.3%-45.3%) decrease in CRC incidence and a 44.1% (36.1%-51.3%) decrease in CRC mortality. If 35% of the population is never screened (scenario 2), then the decrease in CRC mortality is only 39.3% (33.1%-44.8%) and the cost per life year gained is \$11,967 (\$2,907-\$33,110). With similar test preference and 100% compliance along the entire continuum of cancer care (scenario 3), a 79.0% (69.2-85.4%) reduction in CRC mortality is possible at a cost of \$12,787 (\$3,492-\$34,207) per life year saved.

As shown in Fig. 2, an increase in diagnostic compliance from 75% to 85% results in a 4.7% (2.8-5.9%) decrease in CRC mortality. When diagnostic compliance increases from 75% to 95%, CRC mortality decreases by 9.3% (7.4-11.1%). The base case cost per life

year saved (Fig. 3) is \$7,560 (\$1,309-\$32,864) and \$5,970 (\$1,407-\$22,457) for the increase in diagnostic compliance to 85% and 95%, respectively. On the other hand, as presented in Figs. 4 and 5, a 10% increase in screening compliance from 45% to 55% results in a 12.5% (9.4%-16.4%) decrease in CRC mortality (from the mortality at baseline compliance of 45%) and costs \$13,757 (\$3,620-\$35,855) per life year saved. CRC mortality can be decreased by 50.4% (41.4-59.0%) with an increase in screening compliance to 95%.

Discussion

In this article, we report on the outcomes and cost of CRC screening incorporating current levels of compliance and preferences for screening tests to provide guidance for policy makers based on real-world constraints. With current preferences for screening tests, compliance of 45% for screening tests, and compliance of 75% for diagnostic tests, CRC mortality is reduced by about 44.1% compared with no screening. The model results indicate that the findings are sensitive to how compliance is specified. With the constraint that 35% of the population never receives any screening, the mortality decrease is only about 39.3%. If 100% compliance across the cancer care continuum can be achieved, then a decrease of 79.0% is possible.

Cost-effectiveness under best- and worst-case scenarios was assessed. Under all scenarios, increasing compliance

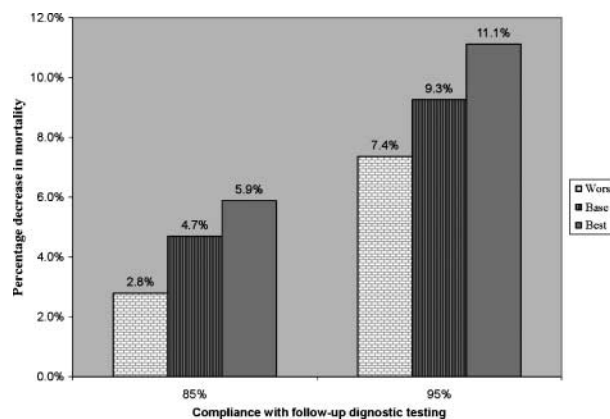


Figure 2. Reduction in mortality from increasing compliance with follow-up diagnostic testing from baseline compliance of 75%.

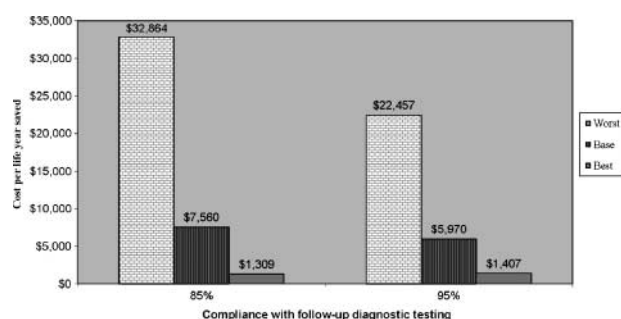


Figure 3. Cost of increasing compliance with follow-up diagnostic testing from baseline compliance of 75%.

at the population level is cost-effective. Although there is no firmly established threshold for cost-effectiveness, the estimates derived are comparable to those of generally accepted medical interventions (56, 57). Using the generally accepted cost-effectiveness threshold of \$50,000 per life year saved, both increasing compliance with initial screening and diagnostic testing are cost-effective, even for the worst-case scenarios presented. Under budget constraints and limited funding, however, the most efficient approach would be to focus efforts on increasing compliance with diagnostic testing for those already being screened; a 5% decrease in mortality can be achieved for about \$7,500 per life year saved. Increasing compliance with initial screening, which is ensuring a higher proportion of the population receives CRC screening, offers more benefit but at a higher cost. A 10% increase in compliance with screening recommendations can result in a reduction in CRC mortality of 12% with an average cost per life year saved of about \$14,000, which is almost double the cost incurred for increasing diagnostic compliance.

Achieving higher levels of compliance with screening or diagnosis recommendations will not be possible without specific interventions such as targeted education and use of navigators to assist patients to increase adherence. These interventions vary in their effectiveness and can cost as little as \$38 per person to more than \$200 per person (58-62). Under the base case scenarios

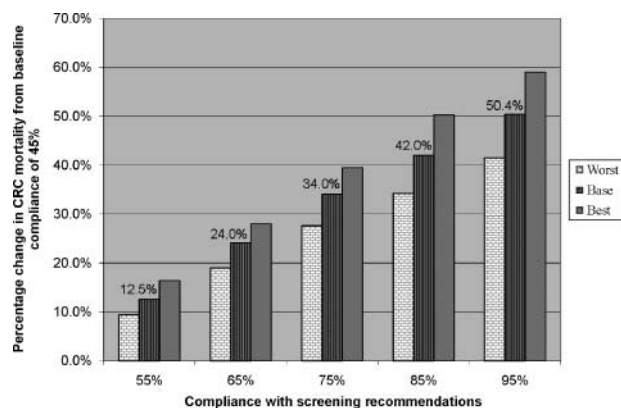


Figure 4. Reduction in mortality from increasing compliance with screening recommendations from baseline compliance of 45%.

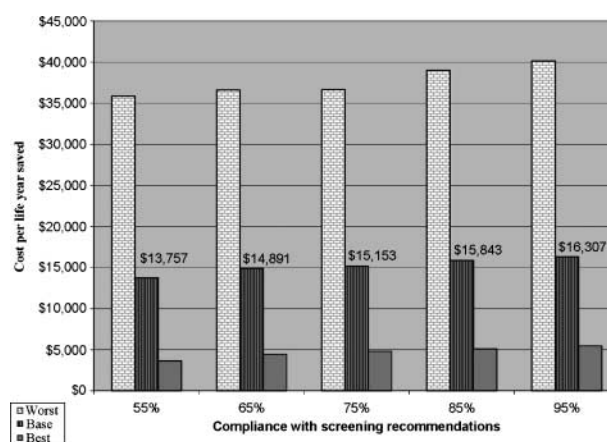


Figure 5. Cost of increasing compliance with screening recommendations from baseline compliance of 45%.

modeled in this study, costs incurred in this range to increase compliance by 10% will generally be cost-effective. However, the model results revealed large variation in cost per life year saved based on the best- and worst-case scenarios, ranging from about \$1,300 to \$34,000 per life year saved. Under the worst-case scenarios, high cost interventions may not be cost-effective assuming a \$50,000 threshold to assess cost-effectiveness. Additional studies should be done to evaluate the cost-effectiveness of increasing compliance. These studies should incorporate both the cost of the intervention and the increased cost of screening and diagnostic testing with higher rates of compliance. Priority should be given to studies that specifically assess approaches to increase compliance with follow-up diagnostic testing recommendations. Furthermore, the capacity available to perform both screening and diagnostic testing should be evaluated before initiating any interventions to increase compliance.

Although the increases in compliance were cost-effective under all scenarios, there was wide variation in cost per life year saved. Some of this variation was a result of the uncertainty surrounding the test performance of FOBT. This variation was incorporated in the model because there are several tests and they vary substantially in their accuracy for detecting cancers. When the specific type of FOBT is known, whether Hemocult SENSa (high sensitivity) or Hemocult II (low sensitivity) for instance, more precise test performance parameters can be incorporated in the model, which will result in a narrower range for the cost per life year saved. Therefore, whenever possible, information on the specific type of FOBT that will be used for screening should be incorporated in the model to generate more precise results. Another source of variation was the cost of FOBT and colonoscopy. If these costs are known, for example, when program administrators prenegotiate payment rates before the implementation of screening programs, cost-effectiveness estimates that are more accurate can be derived. The base case scenario in this study used cost estimates based on Medicare reimbursement, which is the payment rate used by most federal and state-funded CRC screening programs to reimburse for screening services. Therefore, for these

screening programs, the base case estimates provided in this assessment will be reflective of the costs they are likely to encounter, and therefore, these estimates can be used to guide decision making.

The framework described in this article incorporates some of the key features necessary for comprehensive modeling of cancer screening scenarios in the real-world settings. However, modeling reality is complex, and the model presented has limitations. First, the model does not incorporate an all-inclusive list of factors that are present in the real-world setting. For instance, we have not incorporated patient compliance with treatment and surveillance testing. Additionally, we have not addressed the issue of physician compliance with recommendations for screening, diagnosis, treatment, and surveillance. Second, we used patterns of CRC screening test use from the NHIS to identify patient preferences, but the selection of specific tests could have been influenced by provider preferences, ease of availability, insurance coverage practices, and other factors. Third, we have not explicitly included all societal costs required to perform economic assessments. The appropriate approaches to incorporate both health care and productivity costs should be considered in future modeling efforts. Fourth, although we attempted to use the best available parameter estimates to populate the model, they may not always be accurate estimates of what occurs in the real-world setting. We have presented estimates for the worst-case and best-case scenarios to allow policy makers to better understand the implication of variations in the parameter estimates.

Economic modeling studies can provide important information for health care decision makers. Models that incorporate real-world scenarios can be especially valuable in offering practical guidance for policy makers. Modeling under ideal conditions is useful in assessing what is theoretically possible but does not offer practical recommendations for implementation. In this article, we have taken the first step by incorporating patient preferences and compliance with screening and diagnostic testing in assessing the cost-effectiveness of CRC screening. Future models should expand on this effort by incorporating additional features present in the real world, including compliance with treatment and surveillance testing.

Disclosure of Potential Conflicts of Interest

No potential conflicts of interest were disclosed.

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References

1. Rex DK, Johnson DA, Lieberman DA, Burt RW, Sonnenberg A. Colorectal cancer prevention: screening recommendations of the American College of Gastroenterology. *American College of Gastroenterology. Am J Gastroenterol* 2000;95:868–77.
2. Smith RA, von Eschenbach AC, Wender R, et al. American Cancer Society guidelines for the early detection of cancer: update of early detection guidelines for prostate, colorectal, and endometrial cancers.

Also: update 2001-testing for early lung cancer detection. *CA Cancer J Clin* 2001;51:38–75.

3. Pignone M, Rich M, Teutsch SM, Berg AO, Lohr KN. Screening for colorectal cancer in adults at average risk: a summary of the evidence for the U.S. Preventive Services Task Force. *Ann Intern Med* 2002;137:132–41.
4. Winawer SJ, Fletcher RH, Miller L, et al. Colorectal cancer screening: clinical guidelines and rationale. *Gastroenterology* 1997;112:594–642.
5. Smith RA, Cokkinides V, Brawley OW. Cancer screening in the United States, 2008: a review of current American Cancer Society guidelines and cancer screening issues. *CA Cancer J Clin* 2008;58:161–79.
6. Levin B, Lieberman AD, McFarland B, et al. Screening and surveillance for the early detection of colorectal cancer and adenomatous polyps, 2008: a joint guideline from the American Cancer Society, the U.S. Multi-Society Task Force on Colorectal Cancer, and the American College of Radiology. *CA Cancer J Clin* 2008;58:130–60.
7. Pignone M, Saha S, Hoerger T, Mandelblatt J. Cost-effectiveness analyses of colorectal cancer screening: a systematic review for the U.S. Preventive Services Task Force. *Ann Intern Med* 2002;137:96–104.
8. Ness RM, Klein R, Holmes AM, Dittus R. At what age is one-time colonoscopic screening for colorectal cancer most cost-effective? *Am J Gastroenterol* 2000;95:1800–11.
9. Vijan S, Hwang I, Inadomi J, et al. The cost-effectiveness of CT colonography in screening for colorectal neoplasia. *Am J Gastroenterol* 2007;102:380–90.
10. Pickhardt PJ, Hassan C, Laghi A, et al. Cost-effectiveness of colorectal cancer screening with computed tomography colonography: the impact of not reporting diminutive lesions. *Cancer* 2007;109:2213–21.
11. Pignone M, Saha S, Hoerger T, Lohr KN, Teutsch S, Mandelblatt J. Challenges in systematic reviews of economic analyses. *Ann Intern Med* 2005;142:1073–9.
12. Loeve F, Brown ML, Boer R, van Ballegooijen M, van Oortmarssen GJ, Habbema JD. Endoscopic colorectal cancer screening: a cost-saving analysis. *J Natl Cancer Inst* 2000;92:557–63.
13. Seeff LC, Richards TB, Shapiro JA, et al. How many endoscopies are performed for colorectal cancer screening? Results from CDC's survey of endoscopic capacity. *Gastroenterology* 2004;127:1670–7.
14. Seeff LC, Tangka FK. Can we predict the outcomes of national colorectal cancer screening and can predictions help us plan? *Gastroenterology* 2005;129:1339–42.
15. Tangka FK, Molinari NA, Chattopadhyay SK, Seeff LC. Market for colorectal cancer screening by endoscopy in the United States. *Am J Prev Med* 2005;29:54–60.
16. Ladabaum U, Song K. Projected national impact of colorectal cancer screening on clinical and economic outcomes and health services demand. *Gastroenterology* 2005;129:1151–62.
17. Frazier AL, Colditz GA, Fuchs CS, Kuntz KM. Cost-effectiveness of screening for colorectal cancer in the general population. *JAMA* 2000;284:1954–61.
18. Vijan S, Hwang EW, Hofer TP, Hayward RA. Which colon cancer screening test? A comparison of costs, effectiveness, and compliance. *Am J Med* 2001;111:593–601.
19. Subramanian S, Amonkar MM, Hunt TL. Use of colonoscopy for colorectal cancer screening: evidence from the 2000 National Health Interview Survey. *Cancer Epidemiol Biomarkers Prev* 2005;14:409–16.
20. Leard LE, Savides TJ, Ganiats TG. Patient preferences for colorectal cancer screening. *J Fam Pract* 1997;45:205–8.
21. Ling BS, Moskowitz MA, Wachs D, Pearson B, Schroy PC. Attitudes toward colorectal cancer screening tests. *J Gen Intern Med* 2001;16:822–30.
22. Pignone M, Bucholtz D, Harris R. Patient preferences for colon cancer screening. *J Gen Intern Med* 1999;14:432–7.
23. Schroy PC, Heeren TA. Patient perceptions of stool-based DNA testing for colorectal cancer screening. *Am J Prev Med* 2005;28:208–14.
24. Subramanian S, Klosterman M, Amonkar MM, Hunt TL. Adherence with colorectal cancer screening guidelines: a review. *Prev Med* 2004;38:536–50.
25. Vijan S, Inadomi J, Hayward RA, Hofer TP, Fendrick AM. Projections of demand and capacity for colonoscopy related to increasing rates of colorectal cancer screening in the United States. *Aliment Pharmacol Ther* 2004;20:507–15.
26. Seeff LC, Manninen DL, Dong FB, et al. Is there endoscopic capacity to provide colorectal cancer screening to the unscreened population in the United States? *Gastroenterology* 2004;127:1661–9.
27. Podolsky D. Going the distance—the case for true colorectal-cancer screening. *N Engl J Med* 2000;343:207–8.
28. Woolf SH. The best screening test for colorectal cancer—a personal choice. *N Engl J Med* 2000;343:1641–3.
29. Ransohoff DF. Have we oversold colonoscopy? *Gastroenterology* 2005;126:1815.

30. Bowles CJ, Leicester R, Romaya C, Swarbrick E, Williams CB, Epstein O. A prospective study of colonoscopy practice in the UK today: are we adequately prepared for national colorectal cancer screening tomorrow? *Gut* 2004;53:277–83.
31. AnyLogic-Multi-Method Simulation Software. Lebanon (NJ): XJ Technologies Company 2008.
32. Loeve F, Boer R, van Oortmarssen GJ, van Ballegooijen M, Habbema JD. The MISCAN-COLON simulation model for the evaluation of colorectal cancer screening. *Comput Biomed Res* 1999;32:13–33.
33. National Cancer Institute. Surveillance, epidemiology, and end results (SEER) program public use [CD-ROM] (1973–2004). Bethesda (MD): National Cancer Institute, Division of Cancer Prevention and Control, Surveillance Program, Cancer Statistics Branch; released April 2007, based on November 2006 submission.
34. Losey R, Messinger-Rapport BJ. At what age should we discontinue colon cancer screening in the elderly? *Cleve Clin J Med* 2007;74:269–72.
35. Pignone M, Russell L, Wagner J, editors. Economic models of colorectal cancer screening in average-risk adults: workshop summary 2005. Washington (DC): Institute of Medicine and National Research Council; 2005.
36. Shapiro JA, Seeff LC, Thompson TD, Nadel MR, Klabunde CN, Vernon SW. Colorectal cancer test use from the 2005 National Health Interview Survey. *Cancer Epidemiol Biomarkers Prev* 2008;17:1623–30.
37. Meissner HI, Breen N, Klabunde CN, Vernon SW. Patterns of colorectal cancer screening uptake among men and women in the United States. *Cancer Epidemiol Biomarkers Prev* 2006;15:389–94.
38. National Center for Health Statistics. National Health Interview Survey (NHIS) description. Hyattsville (MD): National Center for Health Statistics; 2008.
39. National Center for Health Statistics. Data file documentation, National Health Interview Survey, 2000, 2003, 2005. Hyattsville (MD): National Center for Health Statistics; 2006.
40. Yabroff KR, Washington KS, Leader A, Neilson E, Mandelblat J. Is the promise of cancer-screening programs being compromised? Quality of follow-up care after abnormal screening results. *Med Care Res Rev* 2003;60:294–331.
41. Myers RE, Turner B, Weinberg D, et al. Impact of a physician-oriented intervention on follow-up in colorectal cancer screening. *Prev Med* 2004;38:375–81.
42. Turner B, Myers RE, Hyslop T, et al. Physician and patient factors associated with ordering a colon evaluation after a positive fecal occult blood test. *J Gen Intern Med* 2003;18:357–63.
43. Phillips KA, Liang SY, Ladabaum U, et al. Trends in colonoscopy for colorectal cancer screening. *Med Care* 2007;45:160–7.
44. Allison JE, Tekawa IS, Ransom LJ, Adrain AL. A comparison of fecal occult-blood tests for colorectal-cancer screening. *N Engl J Med* 1996;334:155–9.
45. Allison JE, Sakoda LC, Levin TR, et al. Screening for colorectal neoplasms with new fecal occult blood tests: update on performance characteristics. *J Natl Cancer Inst* 2007;99:1462–70.
46. Lieberman DA, Weiss DG. One-time screening for colorectal cancer with combined fecal occult-blood testing and examination of the distal colon. *N Engl J Med* 2001;345:555–60.
47. Ahlquist DA, Wieand HS, Moertell CG, et al. Accuracy of fecal occult blood screening for colorectal neoplasia. *JAMA* 1993;269:1262–7.
48. Allison JE, Feldman R, Tekawa IS. Hemocult screening in detecting colorectal neoplasm: sensitivity, specificity, and predictive value. *Ann Intern Med* 1990;112:328–33.
49. Wagner JL, Tunis S, Brown M, et al. Cost-effectiveness of colorectal cancer screening in average risk adults. In: Young GP, Rozen P, Levin B, editors. Prevention and early detection of colorectal cancer. Philadelphia; WB Saunders; 1996. p. 321–41.
50. Rex DK, Cutler CS, Lemmel GT, et al. Colonoscopic miss rates of adenomas determined by back-to-back colonoscopies. *Gastroenterology* 1997;112:24–8.
51. Rex DK. Colonoscopy. A review of its yield for cancers and adenomas by indication. *Am J Gastroenterol* 1995;90:353–65.
52. Fisher JA, Fikry C, Troxel AB. Cutting cost and increasing access to colorectal cancer screening: another approach to following the guidelines. *Cancer Epidemiol Biomarkers Prev* 2006;15:108–13.
53. Department of Health and Human Services, Centers for Medicare & Medicaid Services. Medicare program; revisions to payment policies, five-year review of work relative value units, changes to the practice expense methodology under the physician fee schedule, and other changes to payment under Part B. *Fed Regist* 2006;71:69623–70251.
54. Etzioni R, Ramsey SD, Berry K, Brown M. The impact of including future medical care costs when estimating the costs attributable to a disease: a colorectal cancer case study. *Health Econ* 2001;10:245–56.
55. Weinstein MC, Siegel JE, Gold MR, Kamlet MS, Russell LB. Recommendations of the panel on cost-effectiveness in health and medicine. *JAMA* 1996;276:1253–8.
56. Laupacis A, Feeny D, Detsky AS, et al. How attractive does a new technology have to be to warrant adoption and utilization? Tentative guidelines for using clinical and economic evaluations. *CMAJ* 1992;146:473–81.
57. Braithwaite RS, Meltzer DO, King JT, Jr., Leslie D, Roberts MS. What does the value of modern medicine say about the \$50,000 per quality-adjusted life-year decision rule? *Med Care* 2008;46:349–56.
58. Andersen MR, Urban N, Ramsey S, Briss PA. Examining the cost-effectiveness of cancer screening promotion. *Cancer* 2004;101:1229–38. Review.
59. Wolf MS, Fitzner KA, Powell EF, et al. Costs and cost effectiveness of a health care provider-directed intervention to promote colorectal cancer screening among Veterans. *J Clin Oncol* 2005;23:8877–83.
60. Lairson DR, DiCarlo M, Myers RE, et al. Cost-effectiveness of targeted and tailored interventions on colorectal cancer screening use. *Cancer* 2008;112:779–88.
61. Khankari K, Eder M, Osborn CY, et al. Improving colorectal cancer screening among the medically underserved: a pilot study within a federally qualified health center. *J Gen Intern Med* 2007;22:1410–4.
62. Shankaran V, McKoy JM, Dandade N, et al. Costs and cost-effectiveness of a low-intensity patient-directed intervention to promote colorectal cancer screening. *J Clin Oncol* 2007;25:5248–53.

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