Deaths Preventable in the U.S. by Improvements in Use of Clinical Preventive Services

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Background: Healthcare reform plans refer to improved quality, but there is little quantification of potential health benefits of quality care.

Purpose: This paper aims to estimate the health benefits by greater use of clinical preventive services.

Methods: Two mathematical models were developed to estimate the number of deaths potentially prevented per year by increasing use of nine clinical preventive services. One model estimated preventable deaths from all causes, and the other estimated preventable deaths from specific categories of causes. Models were based on estimates of the prevalence of risk factors for which interventions are recommended, the effect of those risk factors on mortality, the effect of the interventions on mortality in those at risk, and current and achievable rates of utilization of the interventions.

Results: Both models predicted substantial numbers of deaths prevented by greater use of the preventive services, with the greatest increases from services that prevent cardiovascular disease. For example, the all-cause model predicted that every 10% increase in hypertension treatment would lead to an additional 14,000 deaths prevented and every 10% increase in treatment of elevated low-density lipoprotein cholesterol or aspirin prophylaxis would lead to 8000 deaths prevented in those aged <80 years, per year. Overall, the models suggest that optimal use of all of these interventions could prevent 50,000–100,000 deaths per year in those aged <80 years and 25,000–40,000 deaths per year in those aged <65 years.

Conclusions: Substantial improvements in population health are achievable through greater use of a small number of preventive services. Healthcare systems should maximize use of these services.
(Am J Prev Med 2010;38(6):600–609)

Introduction

How can the healthcare system save the most lives? This simple question, which is important to inform the implementation of healthcare reform, has not, to our knowledge, been systematically addressed in the medical literature.

In recent years, systematic reviews of scientific evidence have identified clinical interventions that prevent illness and reduce mortality. However, time-pressured clinicians are forced to make choices about which of these clinical preventive services to offer during brief clinical encounters.[1,2] In the U.S., only slightly more than half of recommended healthcare interventions are provided during the course of normal care.[3] Perhaps the most important improvement in the quality of medical care could be increasing the proportion of people who receive clinical interventions that are demonstrated to reduce mortality.

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0749-3797/00/$17.00
doi: 10.1016/j.amepre.2010.02.016

To inform the current discussion on healthcare reform, it would also be useful to estimate the benefit of routinely providing the most effective preventive services. There have been few attempts to assess the relative or cumulative value of clinical preventive services in entire populations, and those that have been published have not estimated the marginal improvement in deaths prevented by increasing the use of these interventions from current levels of use.[4,5]

The potential population benefit of a clinical preventive intervention cannot be determined solely by the benefit it offers an individual. The population benefit also depends on the prevalence of risk factors in the population, the degree to which the population is already receiving the intervention, and the potential increase in the proportion of the population that could receive the intervention. For this study, mathematical models were developed to estimate the number of deaths that could be prevented by increasing the utilization for nine clinical preventive services in the U.S. population.

See related Commentary by Teutsch in this issue.

Methods

Selected Interventions

Initial consideration was given to clinical preventive services that received the highest level of recommendation (Grade A) from the U.S. Preventive Services Task Force (USPSTF) and are known to prevent the top two categories of causes of death in the U.S.: cardiovascular disease and cancer. Consideration was also given to one clinical preventive service with a USPSTF Grade-B rating (mammography) and two widely used immunizations recommended by the Advisory Committee on Immunization Practices (ACIP) that are commonly measured as healthcare quality indicators.

For USPSTF recommendations regarding screening for modifiable risk factors for disease, the effect of successful risk factor modification was modeled by the population at risk. For example, rather than considering screening for hypertension and elevated low-density lipoprotein (LDL) cholesterol, treatment of those risk factors was modeled. For smoking, the effect of providing smoking-cessation counseling and treatment (including use of medications) and that of *successful* treatment (i.e., cessation itself) were modeled separately. The result ranges for the two models were similar, with somewhat reduced benefits in the model of counseling and treatment, depending on assumptions regarding the percentage of smokers who ideally would accept pharmacologic treatment and the efficacy of that treatment; the model shown presents the results for smoking cessation itself.

The interventions ultimately modeled were as follows:

- Identification and treatment of hypertension
- Identification and treatment of elevated LDL cholesterol
- Aspirin chemoprophylaxis for people at elevated risk of cardiovascular disease
- Smoking cessation
- Colonoscopy screening for colorectal cancer in people aged >50 years
- Mammography screening for breast cancer in women aged >40 years
- Pap smear screening for cervical cancer
- Influenza vaccination for people aged >50 years
- Pneumococcal vaccination for people aged >65 years

Target Population

The 2007 U.S. population of adults aged 25–79 years was modeled, grouped in 5-year age categories.[6] Mortality rates were obtained by age group during 1999–2005 from the National Center for Health Statistics.[7] For each preventive service, the subset of the adult population that was eligible to receive it based on recommendations by the USPSTF or the ACIP was identified.

Modeling Approach

Clinical preventive services reduce deaths from specific categories of causes, for example, treatment of elevated LDL cholesterol reducing mortality from cardiovascular diseases. The population benefit of applying these interventions can be modeled in two ways. One method is to estimate the reduction of cause-specific deaths (e.g., cardiovascular deaths) and assume no risk or benefit of the intervention on deaths from other causes. A second method is to estimate the reduction in deaths from all causes, which would theoretically take into account any increase or decrease in mortality from causes other than those targeted. However, the effect of these interventions on the all-cause mortality of individuals is known usually with much less precision than the effect on cause-specific mortality of individuals. As either method has its drawbacks, models were developed using both methods.

For each intervention, the modeling approach required two steps: First, estimates were obtained of the number of people recommended to receive the intervention based on having risk factors, the number of those currently receiving the intervention, and the number currently dying of the category of deaths prevented by the intervention. From these numbers and the estimate of the mortality benefit of the interventions, the mortality rates in those receiving and those not receiving the intervention were calculated algebraically (see Appendix). Second, estimates were developed of the number of people who would receive each intervention if its utilization were to increase from its current value to various higher targets, including those achieved by high-performing health plans. (For the smoking-cessation intervention, *utilization* refers to cessation itself, not just provision of cessation services.)

The models assume no differences in the benefit of the service to those already utilizing the service compared to the additional people covered with increased utilization. The number of deaths that would occur under this hypothetic scenario was calculated as the sum of the deaths in those receiving and not receiving the intervention, which were themselves the products of the number of people and the mortality rates in each group. Then the number of deaths potentially prevented by that increase in use of the intervention was calculated as the difference between the number of deaths currently and the number of deaths in the hypothetic scenario.

To make benefit estimates comparable across interventions, benefits accruing to each 5-year age group were estimated during a 1-year period. This model does not aim to estimate resources required to increase utilization; therefore, one-time clinical services (e.g., screening) and services requiring sustained effort (e.g., adherence to medication) were modeled similarly. It was assumed that benefits begin immediately at the time of service utilization. All of these calculations were conducted for each 5-year age group and the results summed across age groups and rounded to the nearest 100 or 1000 deaths. Deaths prevented in those aged <80 years and in those aged <65 years were calculated separately.

The same approach was used for the cause-specific mortality model and the all-cause mortality model, except that in the cause-specific mortality model it was assumed that the mortality rates in people not dying from the causes targeted were the same as the mortality rates from all other causes for the population as a whole.

To estimate the years of life lost in those aged <80 years (YLL-80) that were preventable by these interventions, the midpoint age of each age group was subtracted from 80 for all deaths in that age group. This number was summed across all deaths with and without the increased utilization of the intervention and the results were compared.

No studies were found estimating the effect of Pap smear screening and colonoscopy on all-cause mortality, and there is substantial concern that currently available estimates of the effect of influenza vaccination on all-cause mortality are biased,[8–10] so these three services were modeled using the cause-specific mortality model only. Because smoking increases mortality risks for many different categories of causes, smoking cessation was modeled using the all-cause mortality model only. Finally, whereas the USPSTF recommends that screening for elevated LDL cholesterol begin at different ages for men and women, it was assumed that benefits from the screening, identification, and treatment of elevated LDL cholesterol begins at age 40 years for both men and women in order to simplify the calculation of aggregate estimate of population benefit from this service.

Parameters

For each 5-year age group, estimates for the percentage of people within the population who met criteria to receive an intervention (e.g., the prevalence elevated LDL cholesterol) and the percentage of eligible people currently receiving the intervention (e.g., the prevalence of statin therapy for elevated LDL cholesterol) were obtained from national surveys. For each intervention, the amount by which the associated risk factor increased cause-specific and all-cause mortality (e.g., the relative risk of mortality in people with untreated hypercholesterolemia compared to people without hypercholesterolemia) and the degree to which the preventive services reduced cause-specific and all-cause mortality (e.g., the reduction in mortality risk in people whose elevated LDL cholesterol is adequately treated) were based on estimates from published studies. These estimates were obtained from recent meta-analyses whenever available and from large population studies when meta-analyses were not available; some parameters were not reported in the form that the model required, so additional estimation was needed. Where available, all estimates were specific to 5-year age groups. Parameters, the variation of parameters by age group, and their sources are summarized in Table 1.[8,11–40]

Sensitivity Analysis

The parameters to which the models were most sensitive and for which there was often a substantial amount of uncertainty were the relative risks of mortality resulting from the interventions. Ranges were established for these parameters using confidence limits from meta-analyses when available and individual studies otherwise, except for Pap smear screening, for which the range represented best estimates from the effect on mortality after screening was implemented routinely. The ranges are summarized in Table 2. To evaluate the effect of varying the mortality relative risks of the interventions, the target utilization rates were fixed at levels reported by the most successful health plans in the U.S. (Table 2).[41,42]

Results

Effect of Varying Target Utilization Levels

The potential benefit of increasing utilization of services on deaths prevented in those aged <80 years is shown in Figure 1 (all-cause model) and Figure 2 (cause-specific model). Both models predicted that among all services considered, treatment of hypertension had the potential to prevent the most deaths and that treatment of hyperlipidemia and aspirin prophylaxis also had high potential. For example, the all-cause model predicted that every 10% increase in hypertension treatment would lead to an additional 14,000 deaths prevented per year in those aged <80 years. Every 10% increase in either treatment of hyperlipidemia or aspirin prophylaxis would prevent an additional 8000 deaths per year in those aged <80 years, but treatment of hyperlipidemia had greater potential because current utilization is lower. The model predicted that smoking cessation would lead to an additional 7000 deaths prevented per year for each 5% increase, but its potential in preventing larger numbers of deaths is limited, primarily because high cessation rates have proven difficult to attain.

The cause-specific model predicted a similar ranking of the effectiveness of services, but the absolute numbers were lower. Cancer screening interventions were predicted to have lower potential, but among these colonoscopy could prevent the most deaths (1900 deaths prevented per year for every 10% increase).

Comparison of Models and Sensitivity Analysis

Table 3 compares the results of the two models in preventable deaths and preventable YLL-80 at target utilization levels achieved by the most successful health plans. Although the cause-specific model predicted fewer deaths prevented by nearly every service analyzed, in the sensitivity analysis the ranges of results between the two models overlap substantially for most interventions that were modeled using both methods, and the rankings of

Table 1. Parameter values used in models and sources

Intervention/parameter	Value	Age-related variation	Source or rationale
Hypertension treatment			
Hypertension prevalence (%)	5–75	Rising with increasing age	NHANES 2001–2004[11]
People with hypertension currently controlled (%)	26–37	20-year age groups	NHANES 2003–2004[12]
RR of CVD mortality in those with hypertension	1.9–2.2	Decreasing from 2.2 in those aged <40 years to 1.7 in those aged >70 years	Estimated from data presented in Prospective Studies Collaboration[13]
RR all-cause mortality in those with hypertension	1.44–1.55	Decreasing from 1.55 in those aged <40 years to 1.44 in those aged >70 years	Estimated from data presented in Prospective Studies Collaboration[13]
RR CVD mortality from treatment of hypertension	0.70–0.89	Assuming age-related variation in benefit of treatment is proportional to age-related changes in CVD risk of hypertension	Blood Pressure Treatment Lowering Trialists Collaboration[14]
RR all-cause mortality from treatment of hypertension	0.84	No age-related variation	Blood Pressure Treatment Lowering Trialists Collaboration[14]
Hyperlipidemia treatment			
Prevalence of elevated LDL cholesterol (%)	12–54	Increasing from 12% in those aged 25–39 years to 54% in those aged >65 years	NHANES 1999–2004[15]
People with elevated LDL cholesterol currently treated with statins (%)	4–44	Increasing from 4% in those aged <40 years to 44% in those aged 60–74 years	NHANES 2003–2004[16]
RR CVD mortality in people with high-LDL cholesterol	1.5–2.0	Decreasing from 2.0 in those aged <40 years to 1.5 in those aged >65 years; see Prospective Studies Collaboration[13]	Prospective Studies Collaboration and research synthesis suggests 60-μg/mL increase associated with ~1.7 increase in risk[13,17]
RR all-cause mortality in people with elevated LDL cholesterol	1.06–1.30	Decreasing from 1.3 in those aged <40 years to 1.06 in those aged >70 years; see Prospective Studies Collaboration	Estimated from Prospective Studies Collaboration[13]
RR CVD mortality from treatment of elevated LDL cholesterol	0.83	No age-related variation	Cholesterol Treatment Trialists' Collaboration[18]
RR all-cause mortality from treatment of elevated LDL cholesterol	0.88	No age-related variation	Cholesterol Treatment Trialists' Collaboration[18]
Aspirin prophylaxis			
Prevalence of high risk (%; Framingham risk score for CVD >6% for 10 years)	2–95	Increasing steeply with age; 12% for ages 35–39 years, 51% for ages 50–54 years, 80% for ages 65–69 years	NHANES 2003–2004 (unpublished analysis)
People with high risk currently taking aspirin (%)	10–60	Increasing from 10% in those aged <40 years to 60% in those aged >65 years	National Survey 2004[19] and Behavioral Risk Factor Surveillance System 2003[20]
RR CVD mortality in people at high risk	2.9	No age-related variation	Estimated from data provided for several cohort studies[21]
RR all-cause mortality in people at high risk	1.7	No age-related variation	Estimated from data provided for several cohort studies[21]
RR CVD mortality from aspirin treatment	0.90	No age-related variation	Meta-analysis shows an OR of 0.87 for coronary mortality and 1.02 for stroke mortality[22]

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Table 1. Parameter values used in models and sources *(continued)*

Intervention/parameter	Value	Age-related variation	Source or rationale
RR all-cause mortality from aspirin treatment	0.93	No age-related variation	Meta-analysis[22]
Smoking cessation			
Prevalence of smoking (%)	9–24	Decreasing from 24% in those aged <35 years to 9% in those aged >65 years	Behavioral Risk Factor Surveillance System 2007[23]
Prevalence of smoking in past (%)	16–42	Increasing from 16% in those aged <35 years to 42% in those aged >65 years	Behavioral Risk Factor Surveillance System 2007[23]
Smokers currently quitting per year (%)	3	No age-related variation	Range in clinical and population-based studies is <2% to 5%[24–26]
RR all-cause mortality in smokers	2.2	No age-related variation	Range in studies is 1.7–2.7[27–31]
RR all-cause mortality from quitting	0.55	No age-related variation	Mortality RR for former smokers is approximately 1.2 (narrow range in several studies)[27–31]
Mammography			
Women aged >40 years currently receiving annual mammography (%)	64–73	Peaking at 73% for those aged 65–74 years	National Health Interview Survey 2005[11]
RR breast cancer mortality from mammography	0.60–1.0	Greatest benefit (RR=0.6) in those aged 50–64 years, increasing to 1.0 in those aged <40 years and 0.8 in those aged >70 years	Meta-analysis[32]
RR all-cause mortality from mammography	1.0	No age-related variation	Range in higher-quality studies is 0.98–1.06[32]
Pap			
Women aged >25 years who received Pap in previous 3 years (%)	43–87	Decreasing from 87% in those aged 25–44 years to 43% for those aged >75 years	National Health Interview Survey 2005[11]
RR cervical cancer mortality from Pap	0.6	No age-related variation	Estimated from historic population-level effects[33]
Colonoscopy			
People aged >50 years currently receiving colonoscopy (%)	36–55	Increasing from 36% in those aged 50–59 years to 55% in those aged >70 years	National Health Interview Survey 2005[34]
RR colon cancer mortality from colonoscopy	0.43	No age-related variation	Case–control study[35]
Influenza vaccination			
People currently receiving annual influenza vaccination (%)	15–69	Increasing from 15% in those aged 25–39 years to 69% in those aged >75 years	National Health Interview Survey 2006[11]
RR pneumonia and influenza mortality from influenza vaccination	0.87	No age-related variation	Meta-analyses of studies of community-dwelling elderly[8,36,37]
RR all-cause mortality from influenza vaccination	0.95	For people aged >50 years only	Estimate with substantial uncertainty (see Methods section)
Pneumococcal vaccination			
People currently receiving pneumococcal vaccination (%)	6–63	Increasing from 6% in those aged <50 years to 63% in those aged >75 years	National Health Interview Survey 2006[11]
RR pneumonia and influenza mortality from pneumococcal vaccination	0.71–0.80	0.71 for those aged <65 years, 0.80 for those aged >65 years	Meta-analyses and prospective study[38–40]

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Table 1. *(continued)*

Intervention/parameter	Value	Age-related variation	Source or rationale
RR all-cause mortality from pneumococcal vaccination	0.99	No age-related variation	Meta-analysis[40]

CVD, cardiovascular disease; LDL, low-density lipoprotein; NHANES, National Health and Nutrition Examination Survey; RR, relative risk

the preventive services in number of deaths prevented were similar between the two models.

Treatment of hypertension in 70% of people with this condition would result in 17,000 to 71,000 deaths prevented per year (point estimate 46,000) in those aged <80 years in the all-cause model and 6000 to 29,000 deaths prevented per year (point estimate 19,000) in those aged <80 years in the cause-specific model. Treatment of hyperlipidemia in 72% of those with high-LDL cholesterol would prevent 18,000 to 33,000 deaths per year (point estimate 25,000) in those aged <80 years in the all-cause model and 9000 to 14,000 deaths per year (point estimate 11,000) in those aged <80 years in the cause-specific model. Treatment of cardiovascular risk with aspirin in 75% of those eligible would prevent −4000 to 30,000 deaths per year in those aged <80 years in the all-cause model (point estimate 13,000) and −5000 to 18,000 in the cause-specific model (point estimate 6000).

Estimates of the effect of mammography screening on all-cause mortality are approximately 1.0,[32] so the point estimate in the all-cause mortality model shows no deaths prevented in those aged <80 years from mammography, with a range of −5000 to 1900. The uncertainty of the estimate of the effect of pneumococcal vaccine on all-cause mortality is large and extends above 1.0, so the modeled range of deaths prevented extends well below zero (from −26,000 to 29,000). The model predicted that slightly less than half of the deaths prevented would occur in those aged <65 years (Table 3).

Discussion

The models predicted that the clinical preventive services that would prevent the greatest number of deaths are those that reduce cardiovascular disease, particularly treatment of hypertension, treatment of hyperlipidemia, and aspirin prophylaxis. These services have the potential to prevent large numbers of deaths because the risk factors they address are common, they are relatively effective in reducing both cause-specific and all-cause mortality in those with these risk factors, and their current utilization is far below achievable levels. Given the uncertainty inherent in the models, the number of deaths prevented by these interventions is far from precise, but overall the results suggest that a wider use of a small number of interventions could prevent tens of thousands of premature deaths a year.

The mathematical models used in this study have limitations. The most important is the uncertainty of

Table 2. Characteristics of modeled preventive services

Service	Eligible population	RR for all-cause mortality (range)	RR for cause-specific mortality (range)	Target utilization (%)
Hypertension treatment	Adults with hypertension	0.84 (0.76, 0.94)	0.73 (0.64, 0.85)[c]	70
Elevated LDL treatment	Adults with elevated LDL	0.88 (0.84, 0.91)	0.83 (0.79, 0.87)	72
Aspirin prophylaxis	Adults with 10-year CVD risk ≥6%	0.93 (0.84, 1.02)	0.90 (0.72, 1.10)	75
Smoking cessation	Adult smokers	0.55 (0.41, 0.82)	—[b]	9
Colonoscopy	Aged 50–75 years	—[a]	0.43 (0.30, 0.63)	69
Mammography	Women aged ≥40 years	1.00 (0.98, 1.06)	0.80 (0.60, 0.90)[c]	84
Influenza vaccination	Aged ≥50 years	0.85 (0.53, 1.00)	0.87 (0.70, 1.09)	72
Pneumococcal vaccination	Aged ≥65 years	0.99 (0.80, 1.22)	0.80 (0.40, 1.00)	75
Pap	Women	—[a]	0.60 (0.40, 0.80)	88

[a]Analyzed in cause-specific model only
[b]Analyzed in all-cause model only
[c]Age-stratified estimates used in model calculations not shown
CVD, cardiovascular disease; RR, relative risk of mortality in those receiving intervention compared to those not receiving the intervention

the estimate of the benefit of these interventions for individuals. Aspirin prophylaxis, for example, may not be as effective in all populations as it was in patients participating in clinical trials. This was addressed in part by varying the intervention effect size around literature-based 95% CIs and estimating a potential range of additional lives saved; however, it is possible that the effects will fall outside even of these ranges. The model assumes that the benefits of the interventions would be experienced within the age group receiving them, whereas benefits of an intervention actually appear over a variable number of years.

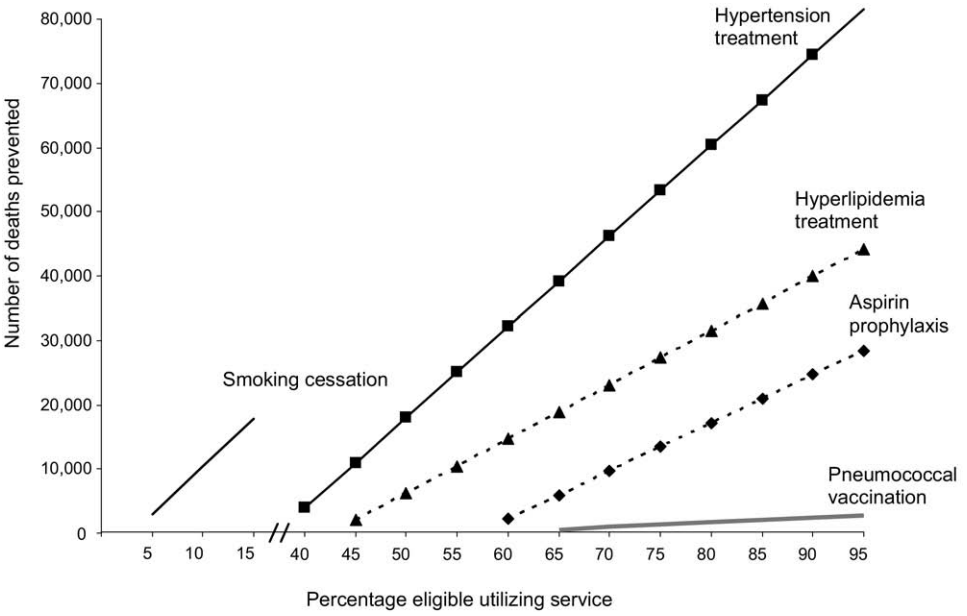

Figure 1. All-cause model results: estimated number of additional deaths prevented in those aged <80 years, per year, by increasing utilization of selected clinical preventive services to varying levels. Lines start at current utilization levels and extend beyond levels currently attained by highest-performing health systems.

The risk factors of hypertension and hyperlipidemia were simplified into categories of present or absent, but these risk factors in fact vary in severity; this model would tend to underestimate the value of treatment that does not reduce risk levels to below an arbitrary threshold but would tend to overestimate the value of treatment that reduces levels from slightly above to slightly below that threshold. With the exception of mammography and Pap, no distinction was made in the models in gender- or race-specific subgroups, because reliable estimates of the effect sizes of the interventions on these subgroups were generally not available. In addition, the effect of potential interactions among the preventive services was not considered. Nonetheless, these limitations seem unlikely to substantially change the ranking of the value of the interventions in deaths prevented, and the models provide first estimates of the life-saving potential of increasing utilization of these preventive health services.

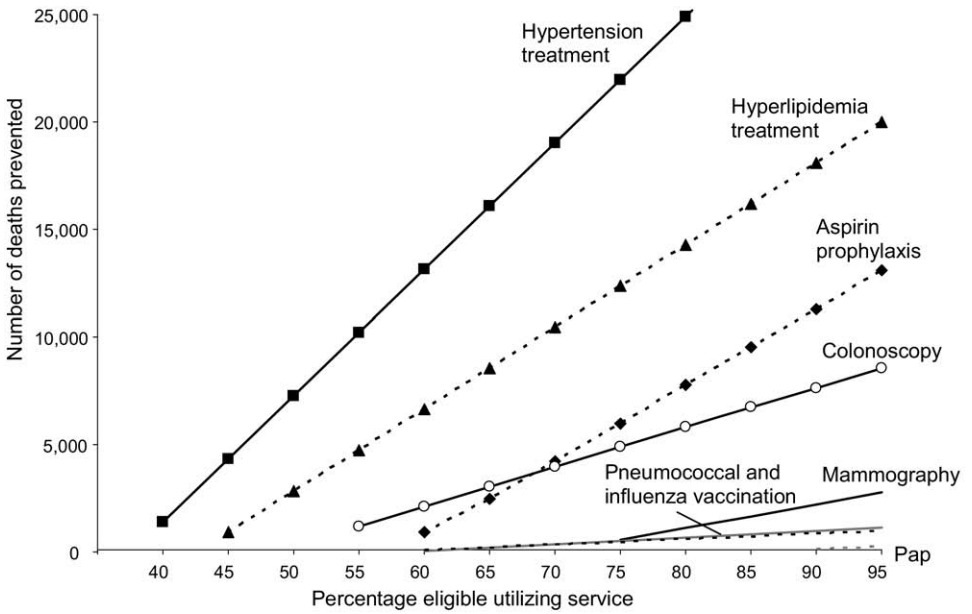

Figure 2. Cause-specific model results: estimated number of additional deaths prevented in those aged <80 years, per year, by increasing utilization of selected clinical preventive services to varying levels. Lines start at current utilization levels and extend beyond levels currently attained by health systems with the highest performance levels.

Table 3. Midpoint estimates of additional deaths preventable in those aged <80 and <65 years, per year, and preventable YLL-80 per year by increasing utilization of preventive services to levels achieved by high-performing health systems

	All-cause model			Cause-specific model		
Service	Preventable deaths in those aged <80 years	Preventable deaths in those aged <65 years	Preventable YLL-80	Preventable deaths in those aged <80 years	Preventable deaths in those aged <65 years	Preventable YLL-80
Hypertension treatment	46,000	15,000	570,000	19,000	9000	300,000
Hyperlipidemia treatment	25,000	9,000	310,000	11,000	4000	130,000
Aspirin prophylaxis	13,000	7,000	220,000	6,000	3000	92,000
Smoking cessation	9,000	6,000	180,000	—[b]	—[b]	—[b]
Colonoscopy	—[a]	—[a]	—[a]	4,000	2000	68,000
Mammography	0	0	0	1,600	1000	27,000
Influenza vaccination	—[a]	—[a]	—[a]	400	300	7,000
Pneumococcal vaccination	1,300	0	10,000	500	0	4,000
Pap	—[a]	—[a]	—[a]	100	100	3,000

[a]Analyzed in cause-specific model only
[b]Analyzed in all-cause model only
YLL-80, years of life lost in those aged <80 years

Other researchers have developed mathematical models to compare the value of different clinical preventive services. Maciosek et al.[4,43] evaluated 25 clinical preventive services recommended by the USPSTF and the ACIP on their "clinically preventable burden" and cost effectiveness. Although their objectives were similar to the objectives of the present study, their modeling approach differed in several ways, and therefore their findings are not directly comparable. Among these differences, they took a zero-based approach to estimating the benefit of services rather than assessing the marginal benefit of increasing utilization from current levels. Nonetheless, their results were similar to the present study's in that they found the greatest population benefits for adults from hypertension screening, cholesterol screening, aspirin prophylaxis, and smoking-cessation counseling.

In a supplementary analysis, they estimated the quality-adjusted life-years gained by increasing the utilization of these services from their current levels to 90% utilization and found the greatest potential gains to be from smoking-cessation counseling, influenza immunization, and screening for colorectal and breast cancer.[4] In their analysis, gains were far smaller for cholesterol and hypertension screening because screening levels for both are already very close to 90%. In this study, the decision was made to model the potential benefits of increasing the number of people treated for hypertension and elevated LDL cholesterol rather than screening, because high rates of successful treatment of these conditions are achievable in well-functioning health systems. The present model suggests that the greatest population benefit through these specific clinical preventive services now lies not in improving screening but in improving treatment and adherence.

Kahn and colleagues[5] evaluated various interventions to reduce cardiovascular disease with a model that simulated every individual in the U.S. and applied to them the results found in clinical trials. As with this model, their results predicted that the greatest benefits would be achieved by treatment of hypertension and elevated LDL cholesterol; in fact, their model indicated that achievement of these two goals alone (in diabetics and nondiabetics) would result in approximately two thirds of the improvements in life-years gained from effective provision of all of the services combined, a proportion that is consistent with the results of this study in preventable deaths.

In establishing priorities among clinical services, cost and cost effectiveness of those services should also be considered. The model by Kahn and colleagues[5] suggests that full utilization of services to prevent cardiovascular disease in all eligible people could *increase* medical costs by $283 billion per year even after taking into account savings from complications prevented. Maciosek et al.[4] found differences in the cost effectiveness of different services, with far greater cost effectiveness of aspirin treatment than screening for hypertension or hyperlipid-

emia. Additional research should evaluate the marginal cost effectiveness of increasing utilization of various preventive services and there should be concerted efforts to reduce the costs of services that are very effective but costly.

The cumulative benefit of applying all of the services modeled here cannot be estimated simply by adding the preventable deaths from each individual service, because multiple services address the same mortality risks. However, Kahn and colleagues[5] found that the overlap in potentially preventable deaths in their model was less than might be expected, with the life-years saved by doing all interventions being only 10% less than the sum of life-years saved by individual interventions. Taking into account this potential double-counting, the current model suggests that optimal use of all of these interventions could save perhaps 50,000–100,000 deaths per year in those aged <80 years and 25,000–40,000 deaths per year in those aged <65 years. For comparison, by a recent estimate,[44] approximately 20,000 Americans die each year because of lack of health insurance coverage.

The models used in this study suggest that while the benefit of expanded insurance cover is substantial, the benefit of more consistent use of a small number of proven preventive services is even greater. Increased utilization of clinical preventive services depends on access to health care, so healthcare reform is essential, but to maximize the benefit of that health care, reform efforts should not stop at a goal of universal insurance coverage but instead should also strongly encourage more consistent use of proven preventive clinical services, particularly to improve treatment of hypertension and hyperlipidemia and increase use of aspirin to prevent cardiovascular disease.

The individual-level benefits of clinical preventive services, particularly those to reduce cardiovascular disease, are widely known to clinicians and healthcare system managers, even though levels of treatment are far from optimal. Primary care needs to be more accessible, and these services should be given higher priority by clinicians, quality officers, and healthcare systems. In particular, electronic record systems that identify patients at risk and generate automated reminders for clinicians and patients, in combination with changes in practice workflow and reimbursement structures, have the potential to increase utilization of these preventive services and should be used more widely.[45,46]

The authors thank Dr. Kevin Konty for statistical assistance.

No financial disclosures were reported by the authors of this paper.

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Appendix. Calculation of Mortality Rates in Subpopulations

To construct the model, estimates were needed for the following parameters:

M_u = mortality rate in people with risk factor(s) who do not receive the intervention (e.g., people with elevated LDL cholesterol not taking statin drugs)
M_i = mortality rate in people with risk factor(s) who receive the intervention
M_n = mortality rate in people without risk factors.

Parameters that could be estimated from national statistics or published studies were:

M_t = mortality in the entire population
P_t = number of people in the entire population
P_u, P_i, P_n = the number of people in subpopulations with untreated risk factors, with treated risk factors, and without risk factors, respectively
R_u = relative risk of mortality in people with risk factor(s)
E = effect size of the intervention (i.e., the relative risk of mortality in people with risk factors who receive the intervention compared to people with risk factors who do not receive the intervention).

The number of deaths in the entire population is the sum of the deaths in each subpopulation, or

$$M_t \times P_t = (M_u \times P_u) + (M_i \times P_i) + (M_n \times P_n).$$

But the intervention effect size $E = M_i/M_u$ and the relative risk of mortality associated with risk factor(s) $R_u = M_u/M_n$. Solving these equations for M_i and M_n, respectively, and substituting the expressions into the equation above yields

$$M_t \times P_t = (M_u \times P_u) + (E \times M_u \times P_i) + (M_u \times P_n/R_u).$$

Solving this equation for M_u leads to

$$M_u = (M_t \times P_t)/(P_u + E \times P_i + P_n/R_u),$$

and then $M_i = E \times M_u$ and $M_n = M_u/R_u$.

For interventions recommended for the entire population (e.g., mammography), the terms M_n and P_n drop out and the final equation simplifies to:

$$M_u = (M_t \times P_t)/(P_u + E \times P_i).$$

The same approach applies whether the mortality rates calculated are for all causes of death or for specific causes.