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ARTICLE

Model-Based Analyses to Compare Health and Economic Outcomes of Cancer Control: Inclusion of Disparities

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Background Disease simulation models of the health and economic consequences of different prevention and treatment strategies can guide policy decisions about cancer control. However, models that also consider health disparities can identify strategies that improve both population health and its equitable distribution.

Methods We devised a typology of cancer disparities that considers types of inequalities among black, white, and Hispanic populations across different cancers and characteristics important for near-term policy discussions. We illustrated the typology in the specific example of cervical cancer using an existing disease simulation model calibrated to clinical, epidemiological, and cost data for the United States. We calculated average reduction in cancer incidence overall and for black, white, and Hispanic women under five different prevention strategies (Strategies A1, A2, A3, B, and C) and estimated average costs and life expectancy per woman, and the cost-effectiveness ratio for each strategy.

Results Strategies that may provide greater aggregate health benefit than existing options may also exacerbate disparities. Combining human papillomavirus vaccination (Strategy A2) with current cervical cancer screening patterns (Strategy A1) resulted in an average reduction of 69% in cancer incidence overall but a 71.6% reduction for white women, 68.3% for black women, and 63.9% for Hispanic women. Other strategies targeting risk-based screening to racial and ethnic minorities reduced disparities among racial subgroups and resulted in more equitable distribution of benefits among subgroups (reduction in cervical cancer incidence, white vs Hispanic women, 69.7% vs 70.1%). Strategies that employ targeted risk-based screening and new screening algorithms, with or without vaccination (Strategies B and C), provide excellent value. The most effective strategy (Strategy C) had a cost-effectiveness ratio of $28 200 per year of life saved when compared with the same strategy without vaccination.

Conclusions We identify screening strategies for cervical cancer that provide greater aggregate health benefit than existing options, offer excellent cost-effectiveness, and have the biggest positive impact in worst-off groups. The typology proposed here may also be useful in research and policy decisions when trade-offs between fairness and cost-effectiveness are unavoidable.

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Disease simulation models can guide policy decisions about cancer control by comparatively assessing the health and economic consequences of different prevention and treatment strategies. Health policy and cancer control policy specifically have two fundamental goals, improving population health and distributing that health fairly. These goals are often in tension, because measures to improve one may not be optimal for and may conflict with the other. Increased emphasis on the second goal is reflected by the focus on disparities of various US health agencies, including the National Cancer Institute (1–6). Our objective is to facilitate policy efforts to pursue both improvement and fair distribution. To do so, we evaluate cancer interventions to reveal the impact on both population health and on relevant health disparities and to identify strategies compatible with both.

Role of Disease Modeling in Cancer Prevention and Treatment Policy

The evaluation of different cancer interventions is particularly applicable to disease modeling. Predicting the population-level impact of a prevention program for cervical cancer is complex, because the time course from infection to cancer spans multiple decades, primary and secondary prevention efforts focus on different components of the disease spectrum, and randomized controlled

CONTEXT AND CAVEATS

Prior knowledge

Disease simulation models can be used to select both medically and economically effective cancer prevention strategies. However, all segments of the population may not benefit equally because of disparities in access to preventive care.

Study design

A typology of cancer disparities among black, white, and Hispanic populations was applied to the example of cervical cancer using a disease simulation model calibrated to clinical, epidemiological, and cost data for the United States.

Contribution

Explicitly modeling disparities between subgroups identified prevention strategies that could reduce the risk of cervical cancer overall as well as make access to prevention more equitable. In addition, when combined with vaccination, the proposed changes to screening were more effective and less costly than current screening patterns.

Implication

Although trade-offs between fairness and cost-effectiveness are unavoidable, explicit modeling of inequalities can improve access to health care for all segments of the population.

Limitations

The model was applied to a simplified example of cervical cancer prevention that included only a select number of strategies. Systemic disparities and differences attributable to choice can be difficult to model because they may be hard to distinguish in some instances. The incremental costs of implementing targeted programs to reduce disparities were not included.

From the Editors

trials are not feasible or ethical (7,8). Computer-based disease simulation modeling can provide a formal framework to synthesize data in an internally consistent and epidemiologically plausible way, extrapolate intermediate outcomes beyond the time horizon of individual studies, and compare multiple strategies targeting different points in the disease course.

Dramatic advances in the cancer field provide an opportunity to enhance the disease models of the 1990s. Increased knowledge about the natural history of disease has been accompanied by advances in modeling methodology, programming efficiency, and the ability to harness enormous computer power for data analysis and simulation. Contemporary models not only reflect the average course of disease in the population but also can capture important heterogeneities (eg, biological differences, disease determinants, risk factors).

Disease-specific cancer models are often used to generate the comparative health outcomes (ie, comparative effectiveness) associated with different prevention strategies. When this type of decision analysis also includes a comparison of economic consequences, it is considered to be a cost-effectiveness analysis, in which the underlying principle guiding the valuation of resources is opportunity cost, reflecting competing societal demands for limited resources (9). Traditionally, cost-effectiveness analyses maximized the health of a population subject to a resource constraint and did not explicitly address the distribution of benefits (10); this "neutral stance" has been the focus of ethical criticism because it fails to consider equity or fairness issues.

Modeling Inequalities to Reflect Cancer Disparities

Because many cancer simulation models now incorporate subgroup heterogeneities, producing estimates of both aggregated and subgroup-specific outcomes is feasible. The ability to reflect differences between racial and ethnic subgroups prompts consideration of how we might more formally include distributional equity (ie, fairness in the distribution and magnitude of health benefits provided by interventions) in cost-effectiveness analyses; however, to do so, careful thought is required about which factors that contribute to inequalities are of potential ethical relevance. If we are to encourage decision analysts to consider the distribution of important health outcomes among subgroups—and the policies to potentially alter them—then we need to be clear about the definition of "disparity." This is not straightforward because different definitions are used by various health and research agencies (1–4,6).

Differentiating Disparities from Inequalities

Several US agencies have developed definitions of health disparities (Table 1), but they vary in how they differentiate inequalities from disparities (1–4,6). For example, the definition by the Agency for Healthcare Research and Quality (AHRQ) treats any inequality greater than 10% of the reference group as a health disparity between population groups, even if the inequality is attributable to a genetic vulnerability or an informed personal choice (1). In our view (11,12) and that of others (6,13), only inequalities that arise from certain problematic differences in the distribution of the socially controllable factors influencing health should count as health disparities; those resulting from genetic or other biological variation or from informed voluntary choices are inequalities.

The AHRQ definition has the advantage that it is purely arithmetic and therefore transparent. It also has the disadvantage of ignoring the fact that many people reasonably want to distinguish and pay special attention to those inequalities that are unfair or unjust. Although we recognize that there may be some disagreements about what counts as unjust, even an egalitarian view of distributive justice (14) would consider differences arising from informed religious choices as fair and not as a disparity. A second feature of some US agency definitions is that they focus on health inequalities among certain social groups, without specifying why those inequalities should count as ethically problematic disparities. In some cases, the groups are the ones that clearly suffer from past or present discrimination, so the definition may rest on the assumption that those groups typically suffer from ethically problematic distributions of the socially controllable factors that affect health. Nevertheless, these approaches do not specify exactly what explains why the health inequalities between these social groups are unjust. If we want to have clear models of the impact of strategies on health for different groups, we must clearly define the mechanisms that underlie their health differences.

Table 1. Selected definitions of disparities in the United States*

Definition of disparities	Pros	Cons	US agency/source
"Any differences among populations that are statistically significant and differ from the reference group by at least 10 percent."	Defined numerically. Implies differences are unacceptable.	Could apply to any differences or comparisons between any groups (not necessarily specific to those who are socially disadvantaged). Population subgroups are not specified. Does not specify whether differences are avoidable. 10% difference is arbitrary.	AHRQ (1)
"Racial or ethnic differences in the quality of health care that are not due to access-related factors or clinical needs, preferences, and appropriateness of intervention."	Focuses on unacceptable factors (unrelated to acceptable differences in access, need, preferences or appropriateness of health care).	Focuses only on differences in quality of health care and among racial/ethnic groups.	IOM (2)
"Differences that occur by gender, race or ethnicity, education or income, disability, geographic location, or sexual orientation."	Specifies segments of population associated with social disadvantage. Distinguishes between inherent biological differences and social factors.	Could apply to any differences or comparisons between any groups.	CDC (3)
"Adverse differences in cancer incidence, cancer prevalence, cancer death, cancer survivorship, and burden of cancer or related health conditions that exist among specific population groups in the United States. These population groups may be characterized by age, disability, education, ethnicity, gender, geographic location, income, or race."	Focuses on defined social groups.	Could apply to any differences or comparisons between any groups.	NCI (4)
"Differences in health which are not only unnecessary and avoidable but, in addition, are considered unfair and unjust."	Specifies differences that are avoidable, unfair, and unjust.	Population subgroups are not specified.	Whitehead (6)

* AHRQ = Agency for Healthcare Research and Quality; CDC = Centers for Disease Control and Prevention; IOM = Institute of Medicine; NCI = National Cancer Institute.

One way to defend current agency definitions would be to claim that the term disparity does not carry with it the implication that the inequality is ethically problematic (unjust or unfair), but then we need another notion (perhaps "inequity") that carries this implication for a subgroup of disparities that we have extra reason for reducing. We, however, treat the terms inequity and disparity as equivalent and reserve for inequality the more general notion of difference, without any morally problematic implication. We note, of course, that we have social obligations to meet health needs, whether or not they are the result of an ethically problematic distribution of the socially controllable factors affecting health. In Daniels' (12) account of justice and health, such general obligations are rooted in our obligation to protect the range of opportunities open to people by keeping them as close as we can to functioning normally. People might reasonably think, however, that we have additional reason to redress health disparities because they result from some form of social injustice in socially controllable factors (12).

Definitions matter to model-based analyses intended to inform policy. If we can focus on the causes of differences that are ethically problematic and so make sure we are quantifying disparities, then analyses that seek to provide information on both average outcomes and the distribution of outcomes will be informative. If we simply identify differences between groups, we will not be able to distinguish strategies that reduce disparities from strategies that simply alter selected inequalities. Our premise, based on the ethical arguments above, is that we have additional reason to reduce those differences that are disparities when faced with policy alternatives.

We propose a typology of cancer disparities that accommodates the variation in types of inequalities across different cancers and allows for an explicit discourse about their ethical importance. The typology differentiates between inequalities in health status caused by differences in genetic or other biological factors (or by differences in informed behaviors or preferences) and those that result from ethically unacceptable differences in access to services or in the distribution of socially controllable factors (eg, poverty, socioeconomic status, insurance). We first discuss this typology in the context of breast, colorectal, and cervical cancer. We then demonstrate its application using an existing model that captures inequalities in cervical cancer incidence, stage distribution, and mortality among racial subgroups. We conduct an analysis that compares the

health and economic outcomes of different prevention strategies and present the results using aggregated population-based measures in a conventional format, followed by an augmented format that presents outcomes across racial and ethnic groups. In this context, we evaluate the total population-level benefits, the distribution of benefits, and the projected widening or narrowing of disparities associated with several strategies.

Methods

General Typology for Cancer Disparities

In the typology of cancer disparities proposed here, an individual's initial cancer risk evolves from early in life (through biological and/or genetic factors), throughout the life span (during which he/she may acquire risk factors), and then through a period in which access to cancer screening or other intervention may modify the risk (Figure 1). Following a diagnosis of cancer, the mortality rate and risk of recurrence (ie, long-term survival) are modified by the access, acceptability, quality, and ongoing availability of health care (Figure 1). Although certain factors (eg, genetic risk) are not modifiable, others are, at least in theory. Social determinants may affect cancer incidence through direct or indirect influence on environmental exposures and risk factors; socially controllable factors may also affect the likelihood of cancer incidence, mortality, and long-term survival through their influence on access to health care (prevention and treatment) and the quality of that care (Figure 1).

Our typology assumes that an inequality in a health-related outcome counts as a disparity only if it is the result of an ethically problematic distribution of socially controllable factors affecting cancer-related negative health consequences (eg, incidence, stage distribution, mortality) (11). Inequalities in negative health outcomes from genetic or other biological variation, and as a result of informed voluntary choices, may indeed be the focus of health services efforts but are not disparities.

Although we note the general potential relationships between social determinants and cancer risks and outcomes (Figure 1), we recognize that for each specific cancer, selected factors will be more or less salient. Specific cancers are associated with inequalities in different outcomes (eg, incidence, stage distribution, mortality); the reasons for the inequalities, when known, can help us to appropriately identify those that are disparities.

In addition, mapping specific cancers within our typology framework (Figure 1) can help identify interventions that would be

Variables influencing risk factors/cancer outcomes	Inequalities: Risk factors		Inequalities: Cancer outcomes			Modeling priorities for near-term policy: Characteristics		
	Exposure (biological, genetic, environmental)	Modifiable/ lifestyle	Incidence	Mortality	Recurrence	Included in cancer models	Modifiable /tractable	Priority for policy change in terms of feasibility
Social Determinants								
Socioeconomic								
Income, education, occupation	unknown	maybe	maybe	via health care access/quality	via treatment access/quality	sometimes	less so	3
Physical environment								
Geography, neighborhood	unknown	maybe	maybe	via health care access/quality	via treatment access/quality	sometimes	less so	3
Health Care and Services								
Access to health services								
Cultural barriers (eg, lack of trust)	no	no	via access to care	via health care access/quality	via treatment access/quality	rarely	less so	2
Health insurance	no	no	via access to care	via health care access/quality	via treatment access/quality	sometimes	should be	2
Primary and secondary prevention								
Reduce risk factor	no	maybe	yes	yes	n/a	usually	often	1-2
Screening	no	no	yes	yes	n/a	usually	yes	1
Treatment and ongoing health care								
Availability	no	no	no	yes	yes	usually	yes	1
Quality	no	no	no	yes	yes	sometimes	yes	1
Continuing care/follow-up	no	no	no	yes	yes	usually	yes	1

Figure 1. Framework for typology of inequalities and disparities. **Top row**: An individual's initial cancer risk represents biological and genetic factors and environmental exposures throughout life, from the time he or she may acquire risk factors (some more modifiable than others) and through a period during which access to cancer screening may modify risk. Following a cancer diagnosis, an individual's mortality rate and risk of recurrence (ie, long-term survival) are modified by the access, quality, and ongoing availability of health care. For each cancer (Figures 2–4), those inequalities we would consider disparities are highlighted in **yellow**. **Left column**: Selected social determinants (**upper section**) and factors representing health-care access (**lower section**). Although social determinants themselves influence and are associated with the likelihood of health-care accessibility and quality, they may also affect cancer incidence, mortality, and long-term survival through exposure to environmental risks and other risk factors. **Third column**: Some lifestyle factors that may be influenced by socioeconomic determinants would be considered disparities rather than differences attributable to fully informed choices. **Right three columns**: For disparities of ethical importance, these columns indicate whether the social determinants and health access indicators are generally included in disease-specific cancer models. A priority (1–3, **far right column**) for near-term policy is assigned depending on whether the influential factors contributing to the inequality are modifiable or tractable. In general, we assume that access and care factors are more tractable than social determinants and assign a policy priority of 1. Modifiable social determinants such as poverty and poor neighborhoods are the least tractable and assigned a 3. Those factors and interventions assessed as between these two in tractability are assigned a 2. For each cancer (Figures 2–4), characteristics for which we have identified an opportunity to narrow a true disparity with an effective intervention and tractable policy option are highlighted in **pink**.

required to narrow those inequalities considered disparities. For each category of social determinants and indicators of health-care accessibility, we indicate identifiable characteristics important for near-term policy discussions (Figure 1, right three columns). These include 1) whether the social determinant or health access indicator is generally included in disease-specific cancer models, 2) whether the influential factors contributing to the inequality are modifiable or tractable, and 3) based on the first two criteria, what the level of priority should be for inclusion in near-term policy options. In general, we assume that access and care factors are more tractable than social determinants for near-term policy choices, which should be considered in model-based analyses. This difference in tractability is analytically and ethically relevant because our obligation to improve a situation depends on our ability to actually do so.

Application of the Typology to Three Cancers

We applied our typology in three different cancers, cervical (Figure 2), breast (Figure 3), and colorectal (Figure 4), to illustrate how the association (magnitude and direction of influence) between social determinants and outcomes differs and to help identify disparities that would be early priorities for policy intervention.

Cervical Cancer. Cervical cancer is caused by infection with oncogenic types of human papillomavirus (HPV). Although the age-related prevalence of type-specific HPV varies, in the United States, differences in observed incidence rates between racial subgroups (eg, black vs Hispanic women) are predominantly a function of access to population-based screening and follow-up (eg, treatment of screen-detected precancerous abnormalities) (1,4,15–20). Screening for cervical cancer detects cervical abnormalities before they become cancerous, so it reduces both the incidence and mortality of cancer. Differences in cervical cancer outcomes are therefore largely attributable to differences in cervical cancer screening participation. Although self-reports of recent cervical cancer screening by black women are similar to those in

Variables influencing risk factors/cancer outcomes	Inequalities: Risk factors: Exposure (biological, genetic, environmental)	Inequalities: Risk factors: Modifiable/ lifestyle (eg, sexual behavior – HPV)	Inequalities: Cancer outcomes: Incidence	Inequalities: Cancer outcomes: Mortality	Inequalities: Cancer outcomes: Recurrence	Modeling priorities for near-term policy: Characteristics: Included in cancer models	Modifiable /tractable	Priority for policy change in terms of feasibility
Social Determinants								
Socioeconomic								
Income, education, occupation	unknown	maybe	via screening	via health care access/quality	via treatment access/quality	sometimes	less so	3
Physical environment								
Geography, neighborhood	unknown	maybe	via screening	via health care access/quality	via treatment access/quality	sometimes	less so	3
Health Care and Services								
Access to health services								
Cultural barriers (eg, lack of trust)	no	no	via screening	via health care access/quality	via treatment access/quality	rarely	less so	2
Health insurance	no	no	via screening	via health care access/quality	via treatment access/quality	sometimes	yes	2
Primary and secondary prevention								
Reduce risk factor (eg, HPV infection)	no	yes	yes	yes	n/a	usually	often	1
Screening (eg, Pap smear, HPV testing)	no	no	yes	yes	n/a	usually	yes	1
Treatment and ongoing health care								
Availability	no	no	no	yes	yes	usually	yes	1
Quality	no	no	no	yes	yes	sometimes	yes	1
Continuing care/ follow-up	no	no	no	yes	yes	usually	yes	1

Figure 2. Framework for typology of inequalities and disparities for cervical cancer. **Top row**: A woman's initial risk of cervical cancer represents biological and genetic factors and environmental exposures throughout her life, from the time she may acquire risk factors (some more modifiable than others) and through a period during which access to cancer screening may modify risk. Following a cervical cancer diagnosis, a woman's mortality rate and risk of recurrence (ie, long-term survival) are modified by the access, quality, and ongoing availability of health care. Those inequalities we would consider disparities in cervical cancer are highlighted in **yellow**. **Left column**: Selected social determinants (**upper section**) and factors representing health-care access (**lower section**). Although social determinants themselves influence and are associated with the likelihood of health-care accessibility and quality, they may also affect cancer incidence, mortality, and long-term survival through exposure to environmental risks and other risk factors. **Third column**: Some lifestyle factors that may be influenced by socioeconomic determinants would be considered disparities rather than differences attributable to fully informed choices. **Right three columns**: For disparities of ethical importance, these columns indicate whether the social determinants and health access indicators are generally included in disease-specific cancer models. A priority (1–3, **far right column**) for near-term policy is assigned depending on whether the influential factors contributing to the inequality are modifiable or tractable. In general, we assume that access and care factors are more tractable than social determinants and assign a policy priority of 1. Modifiable social determinants such as poverty and poor neighborhoods are the least tractable and assigned a 3. Those factors and interventions assessed as between these two in tractability are assigned a 2. For cervical cancer, characteristics for which we have identified an opportunity to narrow a true disparity with an effective intervention and tractable policy option are highlighted in **pink**. HPV = human papillomavirus.

Variables influencing risk factors/cancer outcomes	Inequalities: Risk factors: Exposure (biological, genetic, environmental) (eg, aggressive tumors, family history)	Inequalities: Risk factors: Modifiable/ lifestyle (eg, age at 1st birth, HRT)	Inequalities: Cancer outcomes: Incidence	Inequalities: Cancer outcomes: Mortality	Inequalities: Cancer outcomes: Recurrence	Modeling priorities for near-term policy: Characteristics: Included in cancer models	Modifiable /tractable	Priority for policy change in terms of feasibility
Social Determinants								
Socioeconomic								
Income, education, occupation	unknown	maybe	no	via health care access/quality	via treatment access/quality	sometimes	less so	3
Physical environment								
Geography, neighborhood	unknown	unknown	unknown	via health care access/quality	via treatment access/quality	sometimes	less so	3
Health Care and Services								
Access to health services								
Cultural barriers (eg, preferences)	no	unknown	no	via health care access/quality	via treatment access/quality	rarely	less so	2
Health insurance	no	no	no	via health care access/quality	via treatment access/quality	sometimes	yes	2
Primary and secondary prevention								
Reduce risk factor	no	maybe	maybe	no	maybe	usually	variable	2
Screening (eg, mammogram)	no	no	no	yes	surveillance post-tx	usually	yes	1
Treatment and ongoing health care								
Availability	no	no	no	yes	yes	usually	yes	1
Quality	no	no	no	yes	yes	sometimes	yes	1
Continuing care/follow-up	no	no	no	yes	yes	usually	yes	1

Figure 3. Framework for typology of inequalities and disparities for breast cancer. **Top row**: A woman's initial risk of breast cancer represents biological and genetic factors and environmental exposures throughout her life, from the time she may acquire risk factors (some more modifiable than others) and through a period during which access to cancer screening may modify risk. Following a breast cancer diagnosis, a woman's mortality rate and risk of recurrence (ie, long-term survival) are modified by the access, quality, and ongoing availability of health care. Those inequalities we would consider disparities in breast cancer are highlighted in **yellow**. **Left column**: Selected social determinants (**upper section**) and factors representing health-care access (**lower section**). Although social determinants themselves influence and are associated with the likelihood of health-care accessibility and quality, they may also affect cancer incidence, mortality, and long-term survival through exposure to environmental risks and other risk factors. **Third column** Some lifestyle factors that may be influenced by socioeconomic determinants would be considered disparities rather than differences attributable to fully informed choices. **Right three columns**: For disparities of ethical importance, these columns indicate whether the social determinants and health access indicators are generally included in disease-specific cancer models. A priority (1–3, **far right column**) for near-term policy is assigned depending on whether the influential factors contributing to the inequality are modifiable or tractable. In general, we assume that access and care factors are more tractable than social determinants and assign a policy priority of 1. Modifiable social determinants such as poverty and poor neighborhoods are the least tractable and assigned a 3. Those factors and interventions assessed as between these two in tractability are assigned a 2. For breast cancer, characteristics for which we have identified an opportunity to narrow a true disparity with an effective intervention and tractable policy option are highlighted in **pink**. HRT = hormone replacement therapy.

white women, Hispanic women are much less likely to have been screened in the last 3 years. In addition, compared with white women, a greater proportion of black and Hispanic women report having never received a Pap test (1,4,15–20). Differences in ever screening between race and ethnic subgroups are particularly important in light of findings that approximately half of cervical cancers are among women who have not been screened in the past 3 years or ever. In black women, mortality is two to three times higher, and 5-year survival is lower compared with white women. This is attributable to multiple factors including diagnosis at later stages, higher rates of loss to follow-up, and a lower probability of receiving appropriate treatment. Because 80% of cervical cancer deaths occur in women of low socioeconomic status, other social determinants that can be overrepresented in some racial subgroups (eg, income level or insurance status, knowledge of and access to cervical cancer screening, distribution of health services within a region) also influence access and quality of care (1,4,15–20).

Cervical cancer incidence, mortality, and recurrence would all be considered disparities because they are secondary (at least in part) to socially controllable factors (Figure 2). Given that cervical cancer screening and treatment differences are generally included in cervical cancer disease models and are tractable, we would consider them to be near-term policy targets for priority attention. This implies that in a cost-effectiveness analysis, a policy analyst might include strategies that target racial and ethnic minorities, as well as women of low socioeconomic status who lack insurance for enhanced access to screening, improved treatment access, and quality of care.

Breast Cancer. In contrast to cervical cancer screening, breast cancer screening reduces mortality rather than incidence, because detection of cancer in earlier stages allows for more successful treatment than cancer detected in later stages. The incidence of breast cancer in the United States is higher among white women than black women and is also higher among women of higher socioeconomic status. This increased incidence is above the increased detection of cancer attributable to higher rates of screening (1,4,15–17,21–23). In contrast to the inequality in incidence of

Variables influencing risk factors/cancer outcomes	Inequalities: Risk factors: Exposure (biological, genetic, environmental) (eg, family history, polyps)	Inequalities: Risk factors: Modifiable/ lifestyle (eg, smoking, alcohol, physical activity, diet)	Inequalities: Cancer outcomes: Incidence	Inequalities: Cancer outcomes: Mortality	Inequalities: Cancer outcomes: Recurrence	Modeling priorities for near-term policy: Characteristics: Included in cancer models	Modifiable /tractable	Priority for policy change in terms of feasibility
Social Determinants								
Socioeconomic								
Income, education, occupation	maybe	yes	maybe via risk factors	via health care access/quality	via treatment access/quality	sometimes	less so	3
Physical environment								
Geography, housing, neighborhood (proximity to liquor, fresh fruit/vegetables)	maybe	yes	maybe via risk factors	via health care access/quality	via treatment access/quality	sometimes	less so	3
Health Care and Services								
Access to health services								
Cultural barriers (eg, preferences)	no	yes	maybe via risk factors	via health care access/quality	via treatment access/quality	rarely	less so	2
Health insurance	no	yes	maybe via risk factors	via health care access/quality	via treatment access/quality	increasing	yes	2
Primary and secondary prevention								
Reduce risk (eg, smoking cessation, nutritional)	no	yes	yes	no	maybe	usually	variable	2-3
Screening (eg, FOBT, colonoscopy)	no	no	no	yes	surveillance post-tx	usually	yes	1
Treatment and ongoing health care								
Availability	no	no	no	yes	yes	usually	yes	1
Quality	no	no	no	yes	yes	sometimes	yes	1
Continuing care/follow-up	no	no	no	yes	yes	usually	yes	1

Figure 4. Framework for typology of inequalities and disparities for colorectal cancer. **Top row**: An individual's initial cancer risk represents biological and genetic factors and environmental exposures throughout life, from the time he or she may acquire risk factors (some more modifiable than others) and through a period during which access to cancer screening may modify risk. Following a cancer diagnosis, an individual's mortality rate and risk of recurrence (ie, long-term survival) are modified by the access, quality, and ongoing availability of health care. Those inequalities we would consider disparities in colorectal cancer are highlighted in **yellow**. **Left column**: Selected social determinants (**upper section**) and factors representing health-care access (**lower section**). Although social determinants themselves influence and are associated with the likelihood of health-care accessibility and quality, they may also affect cancer incidence, mortality, and long-term survival through exposure to environmental risks and other risk factors. **Third column**: Some lifestyle factors that may be influenced by socioeconomic determinants would be considered disparities rather than differences attributable to fully informed choices. **Right three columns**: For disparities of ethical importance, these columns indicate whether the social determinants and health access indicators are generally included in disease-specific cancer models. A priority (1–3, **far right column**) for near-term policy is assigned depending on whether the influential factors contributing to the inequality are modifiable or tractable. In general, we assume that access and care factors are more tractable than social determinants and assign a policy priority of 1. Modifiable social determinants such as poverty and poor neighborhoods are the least tractable and assigned a 3. Those factors and interventions assessed as between these two in tractability are assigned a 2. For colorectal cancer, characteristics for which we have identified an opportunity to narrow a true disparity with an effective intervention and tractable policy option are highlighted in **pink**. FOBT = fecal occult blood test.

cervical cancer, differences in breast cancer incidence across races tend to be attributable to factors that are less socially controllable and thus would not necessarily be considered a disparity (Figure 3).

Despite the higher incidence of breast cancer in white women, black women are most likely to die of the disease (1,4,15–17,21–23). Differences in screening rates among racial groups are attenuated when controlling for insurance; regardless of race, women with no insurance are less likely to get a mammogram than women with insurance, and women of lower socioeconomic status have worse 5-year survival rates than those of higher socioeconomic status (16,21–23). Black women are less likely than women of all other races to get appropriate treatment, which contributes to the higher mortality rate (16,21–23). We consider mortality and survival differences in black vs white women a disparity because they are secondary (at least in part) to socially controllable factors (Figure 3).

Given that breast cancer screening and treatment differences are generally included in breast cancer disease models and are tractable, we consider these disparities deserving of priority attention. Alternatively, modifying social determinants that contribute to lower socioeconomic status and poverty would likely reduce disparities in the long term but are less tractable in the short term. For example, the disproportionate number of minorities in low socioeconomic status categories is itself the result of discriminatory practices outside the health system (jobs, education, residence), but the latter is less tractable in the short term. The implication would be that a policy analyst might include in cost-effectiveness analyses strategies that target screening of women lacking insurance and strategies that target improved treatment access or quality of care for black and Hispanic women, as well as women of low socioeconomic status.

Colorectal Cancer. Colorectal cancer screening can detect precancerous polyps, which can be removed before they progress to cancer, and can detect colorectal cancer at earlier stages when

treatment is associated with higher survival rates. Colorectal cancer incidence and mortality are higher in black men than white men, and these inequalities have widened during 1990–2010 (1,4,15–17,24–26). Although biological differences are unknown, environmental and behavioral factors do differ (eg, consumption of fruits and vegetables, physical exercise, multivitamins, smoking) (15,26). There are differences in race-specific screening rates; for blacks these differences can be largely explained by low socioeconomic status, whereas Hispanics have lower screening rates at all income levels (1,15,26). Differences in mortality are also attributable to differences in access to treatment. Individuals with lower socioeconomic status are less likely than those of higher status to be treated according to standard recommendations, and for every stage, blacks have a worse 5-year survival rate than any other group (1,17,24). The distribution of risk factors, incidence, mortality, and recurrence would be considered a disparity (Figure 4).

The inequalities observed in colorectal cancer outcomes vary in their tractability. For example, modifying the consumption of fruits and vegetables requires changes in well-entrenched dietary patterns that are supported (or caused) by reduced access to low-cost fruits and vegetables in urban communities. In contrast, some treatment differences—also influenced by socially controllable factors—may be more tractable. For example, strategies that target improved treatment access or quality of care for black men, and improved access to screening for individuals of lower socioeconomic status, would be reasonable to consider in a policy or cost-effectiveness analysis.

Simulation of Cervical Cancer Natural History and Prevention: Calculation of Clinical and Economic Outcomes in Different Strategies

We synthesized epidemiological, clinical, and economic data from the United States (27–31) using a previously described empirically calibrated individual-based Monte Carlo simulation model of HPV infection and cervical cancer (32–36). The natural history of disease in an individual was characterized as a sequence of monthly transitions between mutually exclusive health states that distinguished HPV infection with type 16, type 18, other high-risk types, and other low-risk types; cervical intraepithelial neoplasia (CIN) grade 1 (CIN1) and CIN grades 2 and 3 (CIN2 and CIN3); and local, regional, and distant cervical cancer. Individual girls enter the model at age 9 years, before sexual debut and free of HPV infection, and transition between health states throughout their lifetimes according to transition probabilities (ie, model input parameters) that depended on HPV type, age, history of previous HPV infection, type-specific natural immunity, previously treated CIN, and screening pattern. Our model accommodates complex cervical cancer prevention strategies and tracks each woman's history (such as vaccination, screening, treatment, and past abnormalities) and resource use; a running tally was maintained for all events, length of time spent in each health state, and the cost and quality of life associated with each health state. Racial subgroup heterogeneities such as competing mortality risk and screening coverage were included (37,38). Summary statistics for each individual were compiled to compute population measures such as average lifetime costs and quality-adjusted life expectancy.

Results

With the introduction of HPV DNA testing for screening and prophylactic vaccines against the two most common cancer-causing HPV types, 16 and 18, there are opportunities to improve both outcomes and efficiencies of current cervical cancer programs in the United States (8,39–42). In earlier work, we used a simulation model that incorporated the natural history of cervical carcinogenesis, multiple HPV types, risk factors, and comorbidities to compare population-level health and economic outcomes for different strategies and reported aggregated average results for the entire modeled population (32–36). For this work, however, we disaggregated outcomes by racial and ethnic subgroups, which differ in their socioeconomic, demographic, and cervical cancer risk profile, as well as in their access to preventive and quality treatment health services.

General Population-Based Screening

We compared the health and economic consequences of three population-based screening strategies (strategies A1, A2, and A3). With the exception of women older than 30 years in strategy A3, all strategies assumed screening with cytology (Pap smears) and HPV triage (cytology followed by HPV DNA testing for equivocal results), a fairly standard screening protocol (Table 2). All three strategies assumed continued racial and ethnic screening patterns. Strategy A2 combined adolescent HPV16 and HPV18 vaccination (33% coverage) with screening, and strategy A3 combined adolescent HPV16 and HPV18 vaccination (33% coverage) with screening using HPV DNA testing as a primary test in women older than 30 years, reserving cytology for women older than 30 years who have high-risk HPV-positive results.

Conventional cost-effectiveness calculations (Table 2) using aggregated population-based measures (eg, mean reduction in cancer risk, average lifetime costs, average life expectancy) showed that depending on the strategy, the average cancer reduction ranged from 60% to 74.5%. Combined vaccination and screening (strategy A2) had a cost-effectiveness ratio (cost per year of life saved [YLS]) of less than $50 000. The cost for strategy A3, combined vaccination with the new screening algorithm in women older than 30 years, was more than $100 000 per YLS. Although there is no consensus on a strict benchmark ratio below which a strategy would be considered cost-effective, a common heuristic is $50 000–$75 000 per YLS (43–45); following this practice would imply that strategy A2 provides "good value for money." However, the conventional analysis provides no information on the distribution of benefits.

The augmented analysis (Table 2) included model-based outcomes for three subgroups, including the race-specific reduction in lifetime risk of cancer, and the absolute difference in the mean reduction in cancer compared with the best-off subgroup (white women). Despite overall reduction in cancer risk, benefits were unequally distributed, and disparities were wider. For example, the overall reduction in cancer incidence for strategy A1 (current screening patterns) was 60%, but reductions ranged from 54.8% for Hispanic women to 62.5% for white women (Table 2, Figure 5, A). The gains in overall average US cervical cancer reduction by adding vaccination to screening represent an increased reduction

Table 2. Conventional and augmented analyses of outcomes and costs under different screening strategies*

Outcomes	Strategy		
	A1: No vaccine, current screening patterns†	A2: Vaccine (33% coverage), current screening patterns†	A3: Vaccine (33% coverage), new screening algorithm†
Conventional analysis			
Average reduction in cancer incidence, %	60.0	69.3	74.5
Average discounted life expectancy per woman, y‡	34.92	34.92	34.93
Average lifetime costs per woman, US dollars§	1415	1545	1900
ICER (cost per YLS), US dollars§		26 500	131 640
Augmented analysis			
Reduction in cancer incidence, %			
Average	60.0	69.3	74.5
White‖	62.5	71.6	76.9
Black‖	60.1	68.3	73.4
Hispanic‖	54.8	63.9	68.7
Average discounted life expectancy, y‡	34.92	34.92	34.93
Average lifetime costs per woman, US dollars§	1415	1545	1900
ICER (cost per YLS), US dollars§		26 500	131 600
Disparity measure (difference from white), %¶			
Black	2.4	3.4	5.2
Hispanic	7.6	8.2	7.9

* HPV = human papillomavirus; ICER = incremental cost-effectiveness ratio; YLS = year of life saved.

† Screening assumes use of cytology (Pap smears) with HPV triage (cytology followed by HPV DNA testing for atypical squamous cells of unknown significance). Strategies A1, A2, and A3 all assume continued racial and ethnic screening patterns, even with the introduction of the HPV vaccine (strategy A2) and the new screening algorithm with more sensitive HPV DNA testing as a primary test, along with cytology triage for high-risk HPV-positive results in women older than 30 years (strategy A3).

‡ Average population-based life expectancy shown. Racial and ethnic subgroups face different competing mortality risks, which were included in the model. Because the cost-effectiveness calculations rely on an incremental analysis (incremental costs relative to incremental benefits calculated within each racial subgroup), the incremental change in life expectancy with a specific strategy vs the next best strategy is comparable across subgroups with very little impact of differential competing mortality rates on the overall policy results and insights.

§ Costs are expressed in discounted 2008 US dollars. Costs represent the total expected (discounted) lifetime cost of a given strategy, reflecting general programmatic costs but not additional outreach costs of targeting previously unscreened or underscreened groups. The ICER was calculated as the difference in costs divided by the difference in life expectancies between a given strategy and the next most expensive strategy. Although there is no consensus on a threshold cost-effectiveness ratio above which strategies would be considered cost ineffective, a commonly used heuristic in the United States is less than $50 000–$75 000 per YLS (43–45).

‖ Shown is the race-specific reduction in lifetime risk of cancer.

¶ Disparity measure is the absolute difference in the mean reduction in cancer compared with white women.

in lifetime risk of cancer of approximately 9% (from 60% to 69%) (Figure 5, A). With respect to the distribution of outcomes across subgroups, disparities were widest for Hispanic women (increase from 54.8% to 63.9% in cancer incidence reduction), followed by black women (increase from 60.1% to 68.3%), compared to white women (increase from 62.5% to 71.6% in cancer incidence reduction) (Figure 5, A). Without altering race-specific screening patterns, and only adding HPV vaccination, disparities persisted despite the overall gain in clinical benefits for the average population and for each individual subgroup.

Targeted Risk-Based Screening

The results for both average and distributional outcomes, coupled with the typology that identifies cervical cancer incidence and mortality as true disparities, motivated us to examine if additional strategies would result in disparity reductions among groups. We assessed two new strategies we refer to as targeted screening protocols (strategies B and C) (Table 3, Figure 5, B). These strategies assumed initial targeting of racial and ethnic minorities to bring screening participation up to the mean population level, with subsequent frequency dependent on the clinical risk profiles of individual women (eg, history of prior abnormal cervical screening tests).

The use of the more sensitive HPV DNA test at a lower frequency provided the same protection as traditional cytology used more frequently, as evidenced by the average reduction in cancer incidence increasing from 60% with current screening patterns (strategy A) to nearly 70% with the new screening algorithm (strategy B) (Table 3). Note that although all subgroups experience benefits, the magnitude of cancer risk reduction is greatest in the worst-off populations (eg, from 54.8% for Hispanic women at current screening patterns to 70% reduction with targeted screening compared with a smaller increase for white women, from 62.5% to 69.7%), and disparities are dramatically reduced (Figure 5, B).

The expanded cost-effectiveness analysis, which made outcomes across racial and ethnic groups explicit, found that both new strategies (B and C) provided health gains for all subgroups, reduced disparities, and were more effective and less costly than original strategies that widened disparities (Table 3). Without vaccination, targeted screening to racial and ethnic minorities, with subsequent risk-based screening, resulted in a reduction in

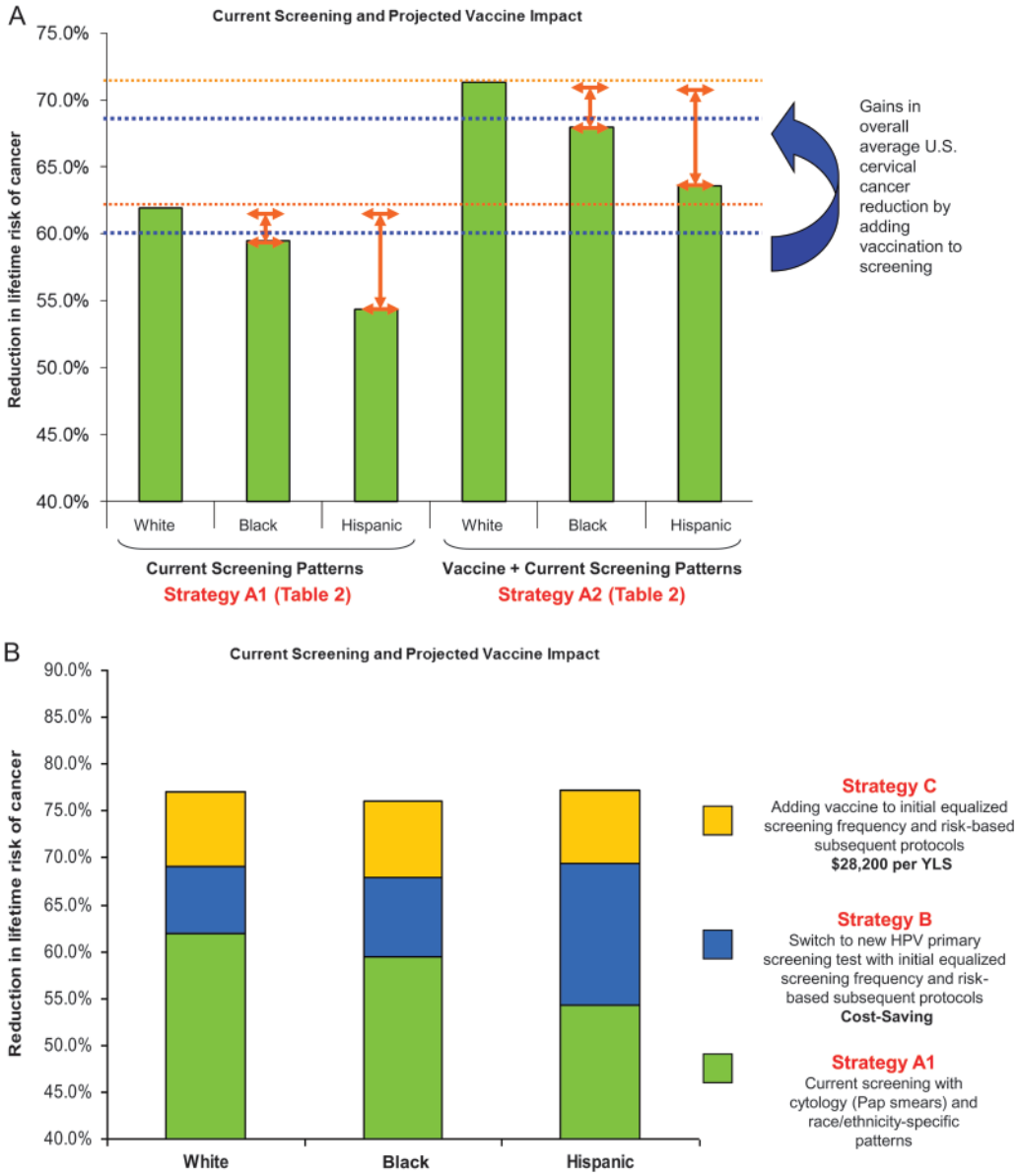

Figure 5. Reduction in lifetime risk of cervical cancer according to different strategies. **A**) Overall average US cervical cancer reduction and distribution of outcomes by racial and ethnic subgroups. The average cervical cancer reduction with the addition of adolescent vaccination to cervical cancer screening is depicted by the distance between the lower and upper **dashed blue lines**. Disparities are widest for Hispanic, followed by black women. Without altering race-specific screening patterns, and only adding human papillomavirus (HPV) vaccination, disparities persist despite the overall gain in clinical benefits for the average population, and for each individual subgroup. **B**) Reduction in the lifetime risk of cervical cancer with alternative strategies. Results are shown for current screening patterns (**green-shaded area**) and two new strategies, Strategy B and Strategy C. Strategy B (**blue-shaded area**) used the new HPV screening algorithm in women older than 30 years, but the frequency of screening was every 2–3 years for all racial subgroups, in contrast to the variation in screening frequency among subgroups, which ranged from every year to more than every 5 years; subsequent screening protocols were based on risk and a woman's screening history. Strategy C (**yellow-shaded area**) assumed that women would also have access to HPV vaccination as adolescents. Although all subgroups experience substantial clinical benefits, the magnitude of cancer risk reduction is greatest in the worst-off populations, and disparities are dramatically reduced. Cost saving refers to the difference in lifetime costs between this strategy and the next best nondominated strategy (average per woman lifetime savings of approximately $300). Strategies that are more costly and less effective than an alternative strategy are considered strongly dominated. Those that are less costly and less cost-effective are considered weakly dominated.

cancer incidence of nearly 70% compared with 60% with current screening patterns. Targeted screening also had lower lifetime costs (an average of $1115 compared with $1415 for current screening patterns), resulting in cost savings of approximately $300 per woman over her lifetime. The most effective strategy, of vaccination at coverage rates of 33% and targeted screening with new screening algorithms, had a cost-effectiveness ratio of $28 200 per YLS when compared with the same strategy without vaccination. Further, disparities were essentially eradicated for Hispanic women (achieving 77% reduction in cancer incidence, the same as the average reduction) and were reduced by more than 50% for black women (difference in cancer incidence reduction compared with

white women falling from 2.4% with current screening patterns to 0.9% with vaccination and targeted screening); these racial differences demonstrate that targeted screening was effective at nearly eliminating disparities for Hispanic women, but black women would also require improved access and quality care once diagnosed with cancer.

Discussion

Explicitly modeling disparities between subgroups according to our proposed typology of cancer disparities allowed us to identify points of overlap among effectiveness, equity, and efficiency in the context of different options for cervical cancer prevention. Using a previously published cervical cancer model (32–36), we showed that several new strategies would reduce the lifetime risk of cervical cancer averaged across all subgroups; however, although some strategies widened disparities between groups, others dramatically reduced them. Furthermore, we identified strategies associated with both favorable average and distributional outcomes. Adding vaccination to current screening patterns or implementing a new screening algorithm and targeting risk-based screening resulted in reduced cancer incidence across all groups; the targeted risk-based screening strategies, with or without vaccination, resulted in the greatest reduction in disparities for black and Hispanic women, as compared with white women. The proposed changes to screening (new screening algorithm and targeted risk-based screening) were more effective and less costly than current screening patterns; strategies that combined these screening changes with vaccination were more effective and more cost-effective than the status quo. These points of convergence are "win-win" in the sense that they have the biggest positive impact in worst-off groups as well as on population health overall. Our claim is that such win-win strategies are most desirable from the perspective of both goals of health policy, population health improvement, and health equity.

We also demonstrate a format for reporting results that allows a clear and explicit portrayal of the distributional effects of different strategies. Although our typology points us in the right direction in terms of identifying potential targets, it cannot help us describe or quantify the trade-offs between strategies that improve overall population health but widen disparities and those that may be marginally less effective or less cost-effective but reduce disparities. Presenting the results of both clinical and cost-effectiveness analyses in the format suggested here can make these trade-offs transparent. We believe that this will promote a more specific dialogue in those cases for which trade-offs between fairness and cost-effectiveness are unavoidable.

To illustrate this point, consider Mechanic's (46) claim that policies that improve aggregate health, even when increasing health disparities, are morally acceptable provided that they also improve the absolute level of health for the less-than-equal groups. This claim ignores the fact that there may be a range of strategies that could produce different absolute levels of improvement for less-than-equal groups with or without accompanying changes in the aggregate health improvement. Yet, policy makers must choose among these alternatives even though they have different implications for health equity. One reason for the vagueness of Mechanic's (46) claim is that we do not have good (ie, quantified) examples of how different intervention strategies may affect the health levels of worse-off groups relative to aggregate population health. Our discussion of cervical cancer suggests that quantified illustrations of these trade-offs and similar examples can be used to make clearer arguments about the ethics of following one intervention strategy rather than another. By providing quantified illustrations, modeling gets us beyond purely hypothetical cases, even if some hypotheticals are embedded in the modeling alternatives. Thus, modeling allows for more rigorous discussion of policies and their actual consequences.

We emphasize that our suggested typology and stylized example represent a preliminary exploration of how we might begin to better align the methods we use in model-based cost-effectiveness analysis with our policy goals of improved population health and fair distribution of that health. Accordingly, there are several limitations that should be noted. First, we present a simplified example of cervical cancer prevention in which we purposefully restrict our analysis to a select group of strategies. We chose to do so in part because the model is already well described (32–36) but also to ensure that the most important point of this article does not get lost in the context of a complex analysis. Thus, the results of this particular example are not intended to inform current policy but rather to illustrate the potential advantage of including the distribution of outcomes in model-based analyses of cancer control. It is important to realize that policies may unintentionally widen disparities as well as be targeted to reduce disparities. The assessment of both of these possibilities is critical to good health policy.

A second limitation is that although our typology assumes that disparities are those inequalities that result from an ethically problematic distribution of socially controllable factors, cancer outcomes that differ as a result of informed voluntary choices can be challenging to disentangle. For example, we view most smoking as a socially controllable factor amenable to policy decisions rather than an informed voluntary behavior because it is primarily the result of behaviors in adolescents who then become addicted to nicotine.

Third, our judgments about relative tractability are admittedly uncertain. For example, some treatment or screening interventions that have poor uptake by certain groups may seem to be tractable; whereas we ought to be able to improve access to them in theory, the obstacles to doing so may be difficult in practice. Even so, favorable results that assume tractability may indeed motivate more intensive efforts to remove barriers to implementation.

Fourth, we did not include all possible strategies that might indeed be tractable; for example, we did not model the costs and benefits of improved access to high-quality cervical cancer treatment. However, in one of our examples of targeted screening in which disparities were essentially eradicated for Hispanic women but only reduced by 50% for black women, the favorable economic profile of this strategy coupled with the explicit and persistent racial disparity could motivate targeted investments to improve high-quality stage-specific cancer treatment for black women. Similarly, as better data become available, strategies that address factors such as race-specific health-seeking behavior, differential access to care based on location (eg, rural vs urban), and the relative influence of socioeconomic factors such as insurance status would allow for refinement of this framework.

Table 3. Expanded analysis to include new strategies that reduce disparities*

Outcomes	Strategy				
	A1: No vaccine, current screening patterns†	A2: Vaccine (33% coverage), current screening patterns†	B: New screening algorithm, targeted risk-based protocols‡	A3: Vaccine (33% coverage), new screening algorithm†	C: Vaccine (33% coverage), new screening algorithm, targeted risk-based protocols‡
Conventional analysis					
Average reduction in cancer incidence, %	60.0	69.3	69.5	74.5	77.1
Average discounted life expectancy per woman, y§	34.92	34.92	34.92	34.93	34.93
Average lifetime costs per woman, US dollars‖	1415	1545	1115	1900	1215
ICER (cost per YLS), US dollars‖		¶	Cost saving#	¶	28200
Augmented analysis					
Reduction in cancer incidence, %					
Average	60.0	69.3	69.5	74.5	77.1
White**	62.5	71.6	69.7	76.9	77.3
Black**	60.1	68.3	68.5	73.4	76.3
Hispanic**	54.8	63.9	70.1	68.7	77.6
Average discounted life expectancy, y§	34.92	34.92	34.92	34.93	34.93
Average lifetime costs per woman, US dollars‖	1415	1545	1115	1900	1215
ICER (cost per YLS), US dollars‖		¶	Cost saving#	¶	28200
Disparity measure (difference from white), %††					
Black	2.4	3.4	1.3	5.2	0.9
Hispanic	7.6	8.2	−0.4	7.9	−0.3

* HPV = human papillomavirus; ICER = incremental cost-effectiveness ratio; YLS = year of life saved.

† Screening assumes use of cytology (Pap smears) with HPV triage (cytology followed by HPV DNA testing for atypical squamous cells of unknown significance). Strategies A1, A2, and A3 all assume continued racial and ethnic screening patterns, even with the introduction of the HPV vaccine (strategy A2) and the new screening algorithm with more sensitive HPV DNA testing as a primary test, along with cytology triage for high-risk HPV-positive results in women older than 30 years (strategy A3).

‡ Targeted risk-based protocols (strategies B and C) assume equalized initial screening frequency by targeting racial and ethnic minorities with subsequent risk-based screening frequency. For example, a woman with consecutive negative screening test results would be screened every 3 years and women with positive results more frequently. Strategy B used the new HPV screening algorithm in women older than 30 years, but the frequency of screening was every 2–3 years for all racial subgroups, in contrast to the variation in screening frequency among subgroups, which ranged from every year to more than every 5 years; subsequent screening protocols are based on risk and a woman's screening history. Strategy C assumes that women would also have access to HPV vaccination as adolescents.

§ Average population-based life expectancy shown. Racial and ethnic subgroups face different competing mortality risks, which were included in the model. Because the cost-effectiveness calculations rely on an incremental analysis (incremental costs relative to incremental benefits calculated within each racial subgroup), the incremental change in life expectancy with a specific strategy vs the next best strategy is comparable across subgroups with very little impact of differential competing mortality rates on the overall policy results and insights.

‖ Costs are expressed in discounted 2008 US dollars. Costs represent the total expected (discounted) lifetime costs of a given strategy, reflecting general programmatic costs but not additional outreach costs of targeting previously unscreened or underscreened groups. The ICER was calculated as the difference in costs divided by the difference in life expectancies between a given strategy and the next most expensive strategy. Although there is no consensus on a threshold cost-effectiveness ratio above which strategies would be considered cost ineffective, a commonly used heuristic in the United States is less than $50000–$75000 per YLS (43–45).

¶ Strategies that were more costly and less effective (ie, strongly dominated) or less costly and less cost-effective (ie, weakly dominated) than an alternative strategy were eliminated from the incremental cost-effectiveness calculations.

Cost saving refers to the difference in lifetime costs between this strategy and the next best nondominated strategy (average per woman lifetime savings of approximately $300).

** Shown is the race-specific reduction in lifetime risk of cancer.

†† Disparity measure is the absolute difference in the mean reduction in cancer compared with white women.

Fifth, we did not include specific incremental programmatic costs that might be required for implementation of targeted programs to reduce disparities, which are high-priority empirical data that will be needed in future analyses. Sixth, for this initial work, we have focused on health-care interventions, avoiding the somewhat less tractable social determinants of health. However, if we

develop a better understanding of how to quantify trade-offs involving interventions for which we have a clearer idea of the mechanisms involved and which are tractable features of health policy, we will be in a better position to address how to include interventions that modify social determinants of cancer. The extension of this work clearly requires a robust research agenda.

In line with a point made by Neumann and Weinstein (47) about the use of cost-effectiveness analysis in policy decisions, we cannot avoid difficult trade-offs by simply disregarding the costs and benefits of our choices. Furthermore, the socioeconomic and demographic changes we expect in coming years and the potential for widening disparities in the United States (48), coupled with anticipated changes in how health care is delivered and financed, support the critical importance of reliable information about the distributional effects (as well as average costs and benefits) of interventions to prevent and treat cancer.

In conclusion, this preliminary work represents a potential framework from which we can consider how to prioritize interventions that reduce inequalities that are most unjust while also considering their tractability. Use of decision analytic methods to explicitly quantify and examine both the population benefits and impact on disparities associated with different strategies allows us to identify those policy choices that might contribute to both equity and efficiency. More importantly, in the majority of cases in which trade-offs between equity and efficiency are inevitable, illuminating the nature and magnitude of these trade-offs will reveal influential data gaps, promote critical dialogue and debate, broaden the conversation about what we value as a society, and move us one step closer to having those values reflected in our policies.

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