

The Prostate Cancer Conundrum Revisited

Treatment Changes and Prostate Cancer Mortality Declines

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BACKGROUND: Prostate cancer mortality rates in the United States declined by >40% between 1991 and 2005. The impact of changes in primary treatment and adjuvant and neoadjuvant hormone therapy on this decline is unknown. **METHODS:** The authors applied 3 independently developed models of prostate cancer natural history and disease detection under common assumptions about treatment patterns, treatment efficacy, and survival in the population. Primary treatment patterns were derived from the Surveillance, Epidemiology, and End Results registry; data on the frequency of hormone therapy were obtained from the CaPSURE (Cancer of the Prostate Strategic Urologic Research Endeavor) database; and treatment efficacy was based on estimates from randomized trials and comparative effectiveness studies of treatment alternatives. The models projected prostate cancer mortality without prostate-specific antigen screening and in the presence and absence of treatment benefit. The impact of primary treatment was expressed as a fraction of the difference between observed mortality and projected mortality in the absence of treatment benefit. **RESULTS:** The 3 models projected that changes in treatment explained 22% to 33% of the mortality decline by 2005. These contributions were accounted for mostly by surgery and radiation therapy, which increased in frequency until the 1990s, whereas hormone therapies contributed little to the mortality decline by 2005. Assuming that treatment benefit was less for older men, changes in treatment explained only 16% to 23% of the mortality decline by 2005. **CONCLUSIONS:** Changes in primary treatment explained a minority of the observed decline in prostate cancer mortality. The remainder of the decline probably was because of other interventions, such as prostate-specific antigen screening and advances in the treatment of recurrent and progressive disease. *Cancer* 2012;118:5955-63. © 2012 American Cancer Society.

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INTRODUCTION

Since the early 1990s, we have witnessed a spectacular decline in prostate cancer mortality in the United States. Between 1991 and 2005 alone, prostate cancer mortality declined by 42% from 103 to 60 deaths per 100,000 men ages 50 to 84 years. This remarkable success story coincided with dramatic changes in the control of the disease: the widespread adoption of prostate-specific antigen (PSA) screening beginning around 1987, advances in treatment of early stage tumors, and changes in the detection and treatment of recurrent and progressive disease.

Because of the simultaneous dissemination of PSA screening and changes in treatment, a clear explanation for the drop in prostate cancer deaths has been elusive. In a 2003 editorial titled *The Prostate Cancer Conundrum*, Albertsen questioned the relative roles of primary surgery and adjuvant hormone therapy for localized disease in explaining the mortality trends.¹ Rates of surgery surged in the 1980s after the development of nerve-sparing techniques for radical prostatectomy (RP). Randomized trial results indicate that RP improves disease-specific survival relative to watchful waiting, with a 38% reduction in the risk of prostate cancer death.² Hormone therapy, which previously was reserved for men with advanced cancers, is particularly efficacious when used in combination with external-beam radiation therapy (RT), and its use dramatically increased in the middle to late 1990s.³

The role of PSA screening in explaining the drop in disease-specific deaths also has been questioned⁴ but has not been conclusively determined. Long-awaited results from 2 large prostate cancer screening trials failed to convincingly establish screening benefit: The European trial demonstrated a 20% lower disease-specific mortality rate in the screening

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arm over a median of 9 years,⁵ and the US trial demonstrated no difference between the control and screening arms after 7 years of complete follow-up.⁶ However, it is generally recognized that, because men on the control arm of the US trial received “usual care”, which included routine screening,⁷ the results should be interpreted as a comparison between moderate and high screening intensities.⁸

The Cancer Intervention and Surveillance Modeling Network (CISNET) prostate group was formed to quantify the relative contributions of screening and treatment changes to the mortality declines. Previously, CISNET prostate models were used to demonstrate that early detection because of screening could account for approximately 45% to 70% of the decline in prostate cancer mortality under a “stage-shift” mechanism for screening benefit. The stage-shift mechanism specifies that disease shifted to an earlier stage by screening enjoys a corresponding improvement in disease-specific survival. This mechanism is a central motivator underlying all cancer screening studies; however, the extent to which it holds is not known conclusively in the case of prostate cancer.

In this article, we take a different approach and quantify the fraction of the mortality decline plausibly caused by treatment changes among men with nonmetastatic disease. To do this, we model the dissemination and benefits of first-line treatment (RP and RT alone or in combination with hormone therapy) and project their impact on mortality in the absence of screening. The results are informative about the likely role of treatment changes in explaining prostate cancer mortality declines. In addition, they are suggestive of a potential role for screening and/or other practice changes, such as treatment for recurrent or progressive cancer.

MATERIALS AND METHODS

The Cancer Intervention and Surveillance Modeling Network Paradigm

The CISNET approach, at its core, is a model of disease natural history, representing the individual experience of disease onset and progression, diagnosis, and death in the absence of any interventions of interest. Interventions, such as screening and/or treatment, are then superimposed based on analyses of patterns of care in the population and on known efficacy from randomized trials or assumed mechanisms of benefit.

In the current setting, the models first produce projections of prostate cancer mortality in the absence of screening and treatment among men diagnosed from 1975, because limited, population-representative data are

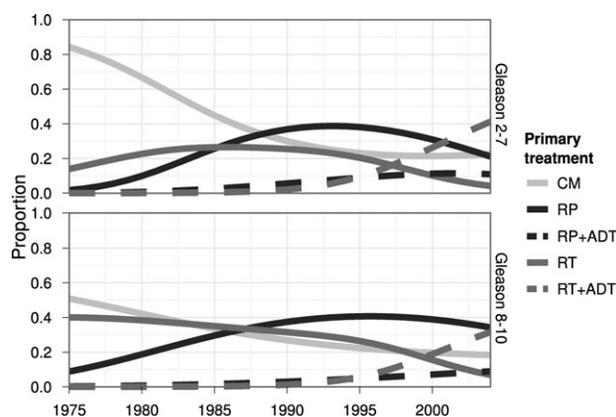


Figure 1. Primary treatment dissemination patterns in the United States are illustrated. Radical prostatectomy (RP) is defined by Surveillance, Epidemiology, and End Results (SEER) codes 50, 58, 60, and 68 before 1997 and by SEER codes 50 and 70 beginning in 1998. Radiation therapy (RT) is defined according to SEER categories as beam radiation, radioactive implants, radioisotopes, a combination of beam with implants or isotopes, or radiation with method or source unspecified. Androgen-deprivation therapy (ADT) data are from CaPSURE (Cancer of the Prostate Strategic Urologic Research Endeavor). CM indicates conservative management.

available before 1975 to inform the natural history models. By “absence of treatment” we mean in the absence of treatment benefit, as all projections under this setting assume that primary treatment interventions are not beneficial (ie, the hazard ratio for disease-specific survival equals 1.0 relative to conservative management [CM]). The models also project mortality in the presence of treatment but in the absence of screening, ie, assuming that stage and grade distributions at diagnosis would have remained as observed in the pre-PSA era. We project mortality in the absence of screening because projections in the presence of screening would rely on an assumed survival benefit of screening, a benefit with greater uncertainty than the benefits of primary treatments.

The impact of treatment occurs through changes in treatment distributions (Fig. 1) as well as through treatment benefit (treatment-specific hazard ratios for disease-specific survival that are less than 1.0 relative to CM). We use the terms “in the presence of treatment” and “in the presence of changes in treatment” interchangeably. By comparing the mortality projections in the presence and absence of treatment with observed disease-specific mortality trends, we can quantify the fraction of the mortality decline associated with treatment. For example, if a projection in the presence of treatment lies half way between our projection in the absence of treatment and observed mortality, we would conclude that treatment alone (because of treatment benefit and changes in treatment

patterns) accounts for approximately 50% of the observed mortality decline.

The CISNET prostate working group consists of 3 groups developing independent models of prostate cancer natural history informed by common information on patterns of screening, disease incidence, and other-cause mortality. Each natural history model is different, but each model is calibrated using age-specific, year-specific, stage-specific, and grade-specific prostate cancer incidence from the Surveillance, Epidemiology, and End Results (SEER) Program before and after the introduction of PSA screening. The calibrated natural history models are then combined with common information on treatment patterns and disease-specific survival to project prostate cancer mortality under plausible assumptions about treatment efficacy.

In the section below, we briefly describe each natural history model and the calibration methods used. Then, we detail survival modeling procedures, our data sources, and assumptions regarding treatment efficacy.

Model Structures

Detailed descriptions of individual models and a joint report comparing the models are available at <http://cisnet.cancer.gov/prostate/profiles.html> (Accessed May 3, 2012).

The Fred Hutchinson Cancer Research Center Model

In the Fred Hutchinson Cancer Research Center (FHCRC) model, the risk of disease onset and associated Gleason grade category, which is fixed at onset, depend on age. Disease progresses from localized to metastatic stages and from latent to symptomatic states based on risks that depend on grade-specific PSA levels. Distributions of PSA growth rates were estimated using longitudinal PSA measurements from men in the control arm of the Prostate Cancer Prevention Trial.⁹ Given individual PSA trajectories and natural histories; PSA screening patterns¹⁰; biopsy compliance frequencies observed in the US-based Prostate, Lung, Colorectal, and Ovarian cancer screening trial^{11,12}; and trends in biopsy sensitivity in the population,¹³ risks of transitioning from 1 state to the next were estimated using maximum likelihood to obtain parameter estimates that best reproduce SEER incidence.¹⁴

The Erasmus University Medical Center Microsimulation Screening Analysis Model

In the Erasmus University Medical Center Microsimulation Screening Analysis (MISCAN) prostate model, cancer development is modeled as a semi-Markov process governing transitions from 1 state to the next. In addition to the healthy state, there are 18 states in the natural

history of prostate cancer that are derived from combinations of clinical tumor (T1, T2, and T3) and metastasis (M0 and M1) stages in the TNM staging system and Gleason grade (well, moderately, and poorly differentiated). Cancers in each state may be clinically diagnosed or detected by a PSA test and subsequent biopsy, the probability of which is combined in a single sensitivity parameter that is state-specific. Model parameters (progression rates between states and test sensitivities) were estimated using data from the Rotterdam section of the ERSPEC.^{15,16} For calibration to the US situation, we re-estimated the test sensitivity parameters and estimated an additional stage-specific risk of clinical diagnosis to capture different pre-PSA disease diagnosis patterns in the United States compared with Europe. US-specific estimates for the parameters were obtained by calibrating the model to the observed age-specific incidence and age-specific metastatic stage distribution using maximum likelihood.¹⁷

The University of Michigan Model

The University of Michigan (UMICH) natural history model consists of disease-free, preclinical, and clinical states. An analytic formulation first estimates age-specific and year-specific disease incidence based on PSA screening patterns,¹⁰ assuming parametric distributions for age at onset and for time from onset to diagnosis, and increasing test sensitivity with time since onset. Like the MISCAN model, test sensitivity reflects both the diagnostic properties of the test itself and the frequency and sensitivity of any subsequent biopsy. Parameters are estimated by averaging over these distributions and calibrating the resulting marginal incidence against observed incidence.¹⁸ Next, disease stage (SEER locoregional or distant) and grade category (Gleason score 2-7 or 8-10) at diagnosis are estimated based on time from onset to diagnosis and mode of detection (screen or clinical) using a multinomial logistic model.¹⁹ Maximum-likelihood estimation of the joint model of age-specific incidence trends and stage/grade distributions informs the distributions of these clinical characteristics.

Modeling Survival

In the absence of treatment, all 3 models generate disease-specific survival based on SEER data among men diagnosed just before the PSA era, during the calendar interval from 1983 to 1986. A Poisson regression model is fit to the disease-specific survival frequencies, censoring deaths from other causes and adjusting for age, stage, and grade at diagnosis and initial treatment (RP, RT, both, or neither). Then, the fitted survival curve for men receiving neither treatment is used to predict disease-specific survival times

under no screening and no initial therapy. Relative to locoregional survival, trends in survival for distant-stage disease have remained fairly constant over time.²⁰

Treatment Dissemination and Efficacy

Dissemination of treatment is modeled based on 2 data sources. Trends in primary treatments—RP and RT—are based on data from SEER, which records the first cancer-directed therapy received. Trends in receipt of adjuvant or neoadjuvant androgen-deprivation therapy (ADT), also called hormone therapy, are based on the Cancer of the Prostate Strategic Urologic Research Endeavor (CaPSURE) database.^{3,21} CaPSURE was initiated in 1995 to document community trends in prostate cancer practice patterns, epidemiology, and outcomes. It is a longitudinal, observational database accruing data from 40 urologic practice sites over its history. Currently, there are over 14,000 men enrolled in CaPSURE. CaPSURE collects approximately 1000 clinical and patient-reported variables. Clinical information is collected by the treating urologist at baseline and with each follow-up visit. Figure 1 documents trends in primary treatment by Gleason category.

We model 5 initial treatment courses for locoregional disease: CM, RP, RP+ADT, RT, and RT+ADT. These treatments are modeled because they represent the predominant treatment interventions used to treat prostate cancer, because their use has changed over time, and because there is quantitative evidence regarding efficacy available from randomized trials. We grouped 3-dimensional, conformal-beam, external-beam RT; intensity modulated RT; and low-dose and high-dose interstitial brachytherapy into a single RT. This was based on a recent comparative effectiveness review from the Agency for Healthcare Research and Quality's Evidence-Based Practice Center at Tufts University, which identified no studies that reported a significant difference in overall survival or biochemical failure among the various forms of radiation.²² Unfortunately, there are no randomized comparisons of all treatments; consequently, we integrate evidence from several sources.

To briefly summarize the comparative effectiveness results for these treatments, there is evidence that RP is more efficacious than CM with a relative risk of 0.62.² To our knowledge, there are no clinical trials directly comparing RP with RT; however, comparative effectiveness studies adjusting for case mix and progression risk consistently demonstrate a benefit for RP over RT, with 2 recent studies producing adjusted relative risks of 0.45 and 0.47 for the endpoint of disease-specific mortality.^{23,24} There is evidence from clinical trials that RT+ADT is more effica-

cious than RT alone²⁵⁻²⁷ and evidence from a recent comparative effectiveness study that RT+ADT is similar to RP (relative risk, 1.14 for RT+ADT relative to RP; $P = .61$ ²⁴). For a recent review, see Wilt et al.²⁸

On the basis of those studies, we assume a hazard ratio of 0.62 for RP relative to CM and for RP+ADT relative to CM, and we apply this to prostate cancer-specific survival for untreated cases. However, to make the relative benefit of RT alone consistent with published studies either would require RT alone to be almost without benefit or would require RT+ADT to be far superior to RP. Therefore, our assumed benefit range for RT compromises, reflecting lower benefit than either RP or RT+ADT, but not so low that it makes RT completely ineffective. We also assume a time-varying relative risk associated with RT relative to CM to reflect the improvement in the efficacy of RT as more intense dose-delivery regimens evolved. Specifically, we assume the hazard ratio for RT relative to CM improved linearly from 0.9 in 1990 to 0.7 or 0.8 in 1995 and remained constant thereafter. This assumption implies a relative risk for RP versus RT that is either $0.62/0.8 = 0.77$ or $0.62/0.7 = 0.89$ after 1995. To reflect an even greater relative benefit of RP relative to RT alone, consistent with recent comparative effectiveness studies,^{23,24} we also conduct a high-efficacy sensitivity experiment in which we use the more efficacious assumption for RT (hazard ratio, 0.7 relative to CM after 1995) and lower the hazard ratio for RP relative to CM to 0.4, suggesting a relative risk for RP versus RT of $0.4/0.7 = 0.57$ after 1995.

We also consider age-specific hazard ratios for all curative treatments based on the finding from the Scandinavian trial that RP was more beneficial in younger men than in older men. Specifically, we consider hazard ratios for RP, RP+ADT, and RT+ADT relative to CM of 0.49 for men ages 50 to 64 years at diagnosis and 0.83 for men ages 65 to 84 years at diagnosis.² Corresponding hazard ratios for RT among men ages 50 to 64 years at diagnosis improve from 0.9 in 1990 to $0.49 \times 0.70/0.62 \approx 0.55$ and to $0.49 \times 0.80/0.62 \approx 0.63$ in 1995, remaining constant thereafter; whereas the hazard ratio for RT is constant at 0.9 for men ages 65 to 84 years at diagnosis for all years. In other words, we preserve the benefits of RT relative to RP within each age group. These 4 basic assumption sets (not including the high-efficacy sensitivity experiment) are summarized in Table 1.

Finally, we consider 2 additional sensitivity experiments, both using the more efficacious assumptions for RP (hazard ratio, 0.62 relative to CM for all ages) and RT (hazard ratio, 0.7 relative to CM after 1995). The first uses the

Table 1. Assumed Hazard Ratios for Prostate Cancer Survival for Primary and Hormone Treatments Relative to Conservative Management

Efficacy Assumption	Hazard Ratio ^a			
	RP, RP+ADT, and RT+ADT		RT by 1995	
	50-64 Years	Ages 65-84 Years	Ages 50-64 Years	Ages 65-84 Years
Assumption set 1	0.62	0.62	0.70	0.70
Assumption set 2	0.62	0.62	0.80	0.80
Assumption set 3	0.49	0.83	0.55	0.90
Assumption set 4	0.49	0.83	0.63	0.90

Abbreviations: ADT, androgen-deprivation therapy; RP, radical prostatectomy; RT, radiation therapy.

^aAll-age and age-specific hazard ratios for RP, RP+ADT, and RT+ADT are from Bill-Axelsson et al² with similarity between RP and RT+ADT based on Cooperberg et al.²³ We assume RP+RT is similar to RP. The all-age hazard ratio for RT is 0.90 until 1990, improves linearly to 0.70 (assumption set 1) or 0.80 (assumption set 2) in 1995, and remains constant thereafter. The age-specific hazard ratio for RT among men ages 50 to 64 years at diagnosis is 0.90 until 1990, improves linearly to 0.55 (assumption set 3) or 0.63 (assumption set 4) in 1995, and remains constant thereafter; the hazard ratio for RT among men ages 65 to 84 y at diagnosis is a constant 0.90 across calendar years.

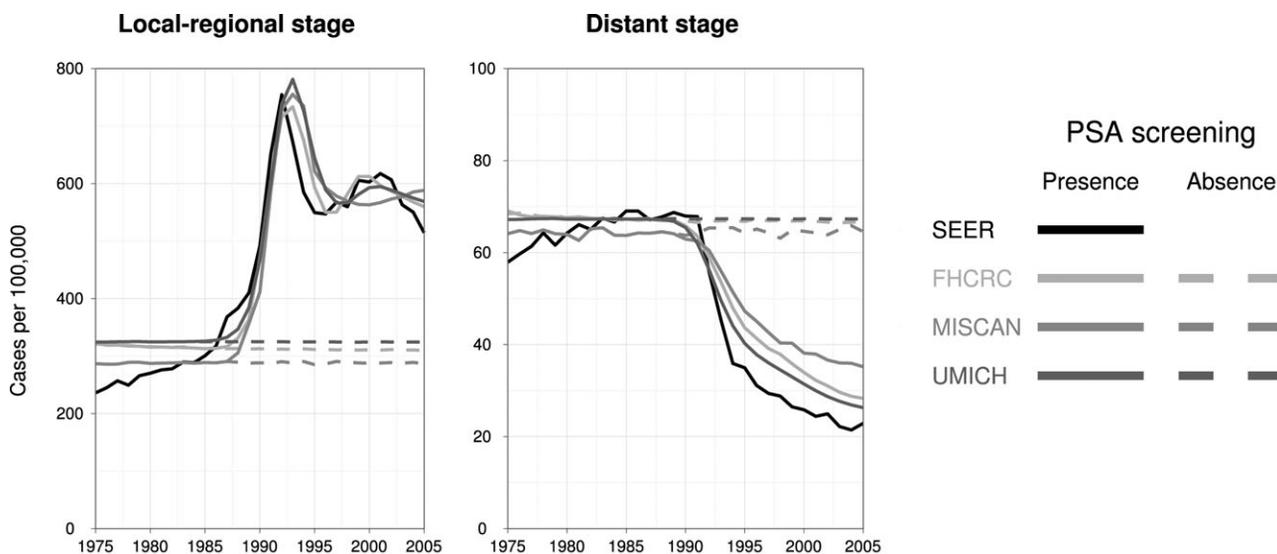


Figure 2. Age-adjusted Surveillance, Epidemiology, and End Results (SEER) (black lines) and Cancer Intervention and Surveillance Modeling Network (CISNET) model-projected prostate cancer incidence is illustrated in the presence (solid gray lines) and absence (dashed gray lines) of prostate-specific antigen (PSA) screening. FHCRC indicates Fred Hutchinson Cancer Research Center model; MISCAN, Erasmus University Medical Center Microsimulation Screening Analysis prostate model; UMICH, University of Michigan model.

UMICH model and allows prostate cancer incidence to continue its pre-PSA increase in the absence of screening, lowering the both distant-stage incidence and prostate cancer mortality. The second uses the FHCRC model and assumes that all patients who reportedly received CM in SEER actually received RT as an extreme correction for possible under-reporting of RT in SEER registries.²⁹

RESULTS

Age-adjusted prostate cancer incidence trends observed in the SEER registries are illustrated by stage in Figure 2. Also illustrated are corresponding incidence trends pro-

jected by the 3 models. The model projections replicate key features of the trends in locoregional incidence, including the rapid escalation in the late 1980s, the peak and initial decline in the early 1990s, and the stabilization at a higher level in the late 1990s. There is greater variability across models in the distant-stage trends, although all models reproduce the scale of pre-PSA incidence and the rapid decline in the middle to late 1990s.

We present incidence projections in the presence of PSA screening to demonstrate how well the calibrated natural history models perform relative to observed incidence. On the basis of these calibrated natural history

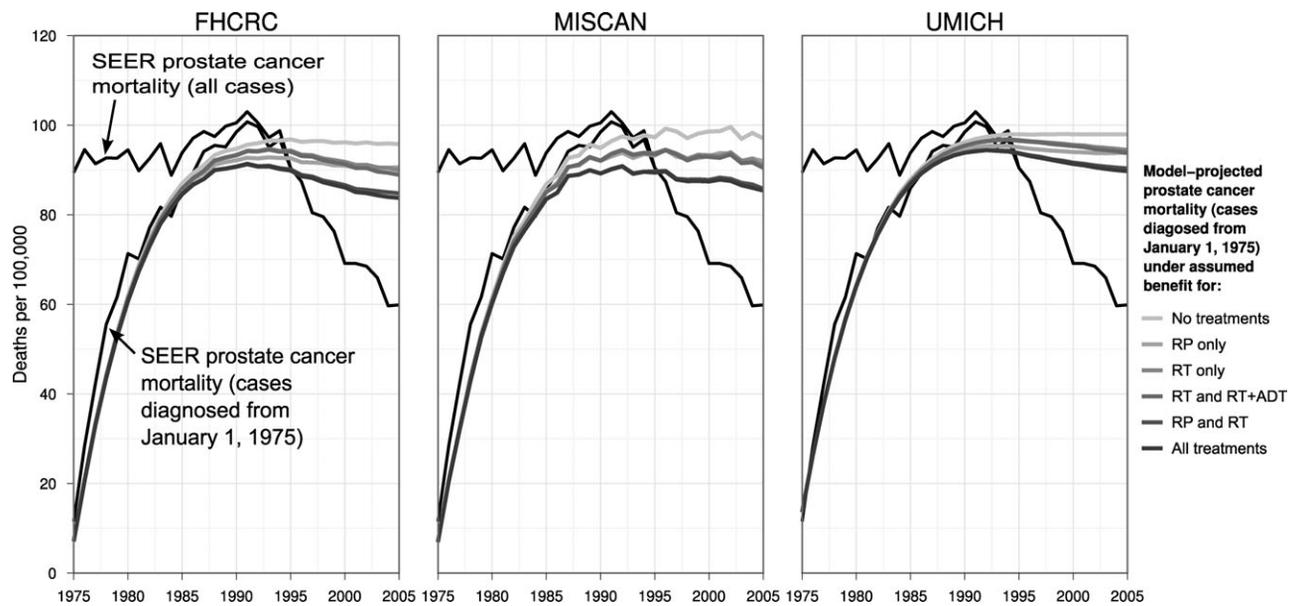


Figure 3. Age-adjusted Surveillance, Epidemiology, and End Results (SEER) (black lines) and Cancer Intervention and Surveillance Modeling Network (CISNET) (gray lines) model-projected prostate cancer mortality is illustrated for cases diagnosed after January 1, 1975, under assumptions of no primary treatment benefit or a combination of primary treatments. Model projections are based on assumption set 1 (see Table 1). For comparison, this figure also illustrates SEER prostate cancer mortality among all cases. FHCRC indicates Fred Hutchinson Cancer Research Center model; MISCAN, Erasmus University Medical Center Microsimulation SChreeing ANALysis prostate model; UMICH, University of Michigan model; RP, radical prostatectomy; RT, radiation therapy; ADT, androgen-deprivation therapy.

models, under common assumptions about treatment and survival, we project prostate cancer mortality in the absence of PSA screening.

Age-adjusted mortality projections that allow benefit for each treatment based on assumption set 1 are presented in Figure 3. All models reproduce the accumulation of prostate cancer deaths by 1985 and slightly underestimate the peak in 1991. All models project a more-or-less constant continuation of mortality in the absence of treatment benefit and a modest decrease in the presence of treatment benefit. By 2005, mortality projections that allow benefit for all treatments represent up to 66% of the difference between mortality projected in the absence of treatment benefit and observed mortality.

Table 2 provides a quantitative summary of the estimated contribution of each treatment to the observed mortality decline. The 3 models generally agree that changes in RP and RT each played a role in the mortality decline. Under assumption set 1, RP explains 11% to 14%, RT explains 9% to 16%, and ADT explains 1% to 3% of the mortality decline relative to projected mortality in the absence of treatment benefit. Impacts are smaller when treatment is less beneficial for older men; under assumption set 4, corresponding impacts are 10% to 12%, 5% to 7%, and 1% to 3% (changes in treatment

explain 22%-33% to 16%-23% across the 4 sets of assumed efficacy levels).

Despite conceptual differences across models about how prostate cancer develops and progresses, the models provide consistent results concerning the contributions of treatment to the difference between observed mortality in the year 2005 and the mortality that would have been expected in the absence of advances in treatment. Specifically, the models project that prostate cancer mortality would have stabilized at just under 100 deaths per 100,000 men ages 50 to 84 years in the absence of treatment benefit. Our computation of the percentage of the mortality decline explained by treatment trends in the year 2005 indicates a significant role for primary treatment, with treatment alone explaining up to 33% of the difference between the observed mortality rate in the year 2005 and the rate projected in the absence of treatment benefit.

Under our high-efficacy sensitivity experiment, changes in treatment still explained only about half (range across the 3 models, 42%-53%) of the decline in mortality by 2005. Allowing prostate cancer incidence to continue its pre-PSA increase in the absence of screening, the UMICH model projects that changes in treatment explained 30% rather than 22% of the decline in

Table 2. Projected Prostate Cancer Mortality Rates per 100,000 Men Ages 50 to 84 Years in 2005 by Model, Assumption About Primary and Hormone Treatment Benefit, and Treatment Allowing Benefit^a

Model	None	RP	RT	RT+ADT	RP+RT	RP+RT+ADT
FHCRC						
Set 1	95.8	90.6 (14.4)	90 (16.2)	88.9 (19)	84.8 (30.5)	83.8 (33.4)
Set 2	95.8	90.6 (14.4)	91.9 (10.7)	89.5 (17.4)	86.8 (25.1)	84.4 (31.8)
Set 3	95.8	91.3 (12.4)	92.8 (8.2)	91.8 (10.9)	88.4 (20.7)	87.4 (23.4)
Set 4	95.8	91.3 (12.4)	93.1 (7.4)	92 (10.5)	88.7 (19.8)	87.5 (23)
MISCAN						
Set 1	97.1	92 (13.7)	90.9 (16.6)	90.5 (17.7)	85.8 (30.3)	85.4 (31.3)
Set 2	97.1	92 (13.7)	93.0 (10.9)	91.5 (15)	88 (24.6)	86.4 (28.7)
Set 3	97.1	94.4 (7.3)	94.2 (7.8)	93.8 (8.8)	91.5 (15.1)	91.1 (16.2)
Set 4	97.1	94.4 (7.3)	94.4 (7.3)	93.9 (8.7)	91.6 (14.7)	91.1 (16)
UMICH						
Set 1	98	93.8 (10.8)	94.5 (9.1)	93.8 (10.9)	90.4 (20)	89.7 (21.6)
Set 2	98	93.8 (10.8)	95.6 (6.3)	94.3 (9.6)	91.5 (17)	90.1 (20.6)
Set 3	98	94.1 (10.1)	95.9 (5.3)	95.4 (6.8)	92 (15.6)	91.5 (16.9)
Set 4	98	94.1 (10.1)	96.1 (4.9)	95.4 (6.7)	92.2 (15.1)	91.6 (16.7)

Abbreviations: ADT, androgen-deprivation therapy; FHCRC, Fred Hutchinson Cancer Research Center model; MISCAN, Erasmus University Medical Center Microsimulation Screening Analysis prostate model; RP, radical prostatectomy; RT, radiation therapy; UMICH, University of Michigan model.

^aThe corresponding mortality rate from Surveillance, Epidemiology, and End Results (SEER) was 59.9 in 2005. Percentage declines relative to the difference between mortality projected for no treatment benefit and SEER observed mortality are indicated in parentheses.

mortality by 2005. And, assuming that all patients reported as receiving CM in SEER actually received RT, the FHCRC model projects that changes in treatment explained 46% rather than 33% of the decline in mortality by 2005.

Thus, we conclude that advances in primary treatment likely played an important role in the dramatic drop in prostate cancer mortality observed since the early 1990s. However, changes in primary treatment alone do not explain the majority of the mortality decline.

DISCUSSION

The decline in prostate cancer mortality that began in the early 1990s has been striking and sustained. Between 1994 and 2005, prostate cancer deaths dropped by an average rate of 4.1% per year, and they are still declining. In the current study, we used comparative modeling to investigate 1 of the most plausible explanations for the mortality decline, ie, changes in primary treatment, with the objective of also shedding light on the potential roles of screening and other interventions. Our results indicate that treatment explains a nontrivial fraction of the drop in disease-specific deaths, but the majority of the decline is likely explained by other factors, such as screening or improvements in disease management after primary therapy. For example, with almost all patients being monitored with PSA after diagnosis, metastatic or potentially metastatic tumors are being retreated considerably earlier.³⁰ Salvage treatments received at the time of bio-

chemical failure have been associated with significant improvements in disease-specific survival.³¹ These changes in secondary disease management may have been primarily responsible for the early decline in mortality; based on recent screening trial results, we would not expect to observe a substantial decline in mortality as early as was observed because of screening alone.

Our results rest on several key assumptions. First, each natural history model makes different assumptions about disease onset, progression, and diagnosis in the absence of screening. Consequently, the 3 models project 3 estimates for the fraction of the mortality decline explained by treatment. We observe that our conclusions are robust even given this intermodel uncertainty. Second, all models assume that disease incidence would have remained constant at pre-PSA levels after 1987. A sensitivity experiment indicated that our conclusions are robust even if disease incidence would have continued its increasing trend. Third, all models assume that baseline (in the absence of screening or treatment) prostate cancer survival remained constant in the PSA era. Even if this survival improved over time, perhaps because of advances in treating recurrent disease, this would have little impact on our results, because it would suggest similar relative differences between projected mortality rates in the presence and absence of changes in treatment.

Our study uses data from a variety of sources that are subject to limitations. Although SEER is the most authoritative resource for information on disease

incidence and survival in the United States, we note again that estimates of prostate cancer survival in the absence of screening are not available in the PSA era. We also use SEER data on the first course of cancer-directed therapy to estimate the frequencies of RP and RT. A sensitivity experiment indicated that our conclusions are robust even if all patients recorded as receiving CM in SEER actually received RT. Finally, our treatment efficacy estimates, which are based on the most rigorous and up-to-date results from randomized trials and comparative effectiveness studies, still are subject to moderate uncertainty. Our sensitivity experiments demonstrated that our conclusions are robust even assuming that RP primarily benefits younger men and/or assuming that improvements in radiation technology achieved efficacy similar to RP.

The models use estimates of the efficacy of RP relative to CM from the benchmark Scandinavian randomized controlled trial.² A recent observational study³² compared Medicare patients in the United States who did and did not undergo RP. After adjusting for selection, those authors observed an advantage for surgery, even among older men, who did not benefit significantly in the Scandinavian trial. If surgery is more efficacious in the United States, then our results may be somewhat conservative, because changes in the frequency of RP are associated with an important portion of the decline in mortality associated with primary treatment.

In conclusion, the results of this modeling study clearly identify a role for primary treatment changes in US prostate cancer mortality declines, but a large fraction of the decline is left unexplained. This clearly suggests a role for PSA screening, but it also indicates that we should not assume that screening is as effective as suggested by the overall drop in prostate cancer mortality observed in the PSA era. Indeed, there is a clear role for primary treatment change and possibly advances in treatment for recurrent or progressive disease, and there may be a synergy with earlier detection because of screening. Further modeling studies will investigate the extent to which screening and treatments jointly explain the mortality decline and will also highlight the role of other interventions, such as advances in disease management for recurrent and metastatic disease.

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CONFLICT OF INTEREST DISCLOSURES

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