Temporal Patterns in Colorectal Cancer Incidence, Survival, and Mortality From 1950 Through 1990

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Background: **Colorectal cancer mortality rates among U.S. white males remained relatively constant from 1950 through 1984 but declined sharply from 1985 through 1990. Those for U.S. white females decreased consistently from 1950 through 1984, with an acceleration of the decline from 1985 through 1990.** ***Purpose:*** **A study was planned to investigate patterns in incidence, survival, and mortality rates over time in order to examine possible reasons for the gender difference in mortality trends and for the decrease in the slope of the mortality trends for both males and females in the late 1980s.** ***Methods:*** **Incidence and survival data from the Connecticut Cancer Registry were examined to investigate the gender differences in mortality rates from 1950 through 1984. Incidence and survival data from the Surveillance, Epidemiology, and End Results (SEER) Program were investigated to examine reasons for the abrupt downturn in mortality rates for both white males and white females beginning around 1985.** ***Results:*** **During the period 1950 through 1984, the colorectal cancer incidence rates in Connecticut increased for males and declined slightly for females. Survival rates were similar for both sexes, increasing on average over 1% per year for both females and males from 1950 through 1984. Examination of SEER data from 1975 through 1990 revealed that for both males and females there were 1) declines in overall incidence and mortality rates beginning in the mid-1980s, 2) steady declines in distant disease incidence rates since 1975, 3) increases in regional disease incidence rates until the early 1980s followed by declines in the late 1980s, and 4) increases in local disease incidence rates until the mid-1980s followed by declines in the late 1980s. Age–period–cohort analyses of mortality rates indicated a statistically significant moderation of colorectal cancer risk with both advancing birth cohorts and recent calendar periods.** ***Conclusions:*** **The gender differences in colorectal cancer mortality rate trends observed from 1950 through 1984 are due to differences in incidence rate trends between males and females. Declining colorectal mortality rates in the late 1980s for males and females appear to reflect improved early detection. The peaking and subsequent decline of stage-specific incidence rates at later years for successively lower stage indicate sequential stage shifts as cancers are detected increasingly earlier over time. The increased use of sigmoidoscopy and fecal occult blood tests (triggering colonoscopy) appears to have played an important role in reducing colorectal cancer mortality. Improvements in birth cohort trends in risk for colorectal cancer for each sex suggest that lifestyle changes may have also contributed to the steady reductions in colorectal cancer mortality. [J Natl Cancer Inst 86:997-1006, 1994]**

About one out of every eight cancers in the United States is of colorectal origin. Colorectal cancer is the second leading cause of cancer death in the United States overall, being third to lung and prostate cancers in males and third to lung and breast cancers in females. Colorectal cancer is responsible for about one out of every 10 cancer deaths. It is predicted that in 1994 there will be 75 000 new cases with 27 800 deaths in men and 74 000 new cases with 28 200 deaths in women in the United States (*1*).

U.S. colorectal cancer mortality rates in white males and white females combined decreased by 29% from 1950 through 1990 (*2,3*), as displayed in Fig. 1. Examination of the rates by gender shows important differences in mortality trends (Fig. 1). The purpose of this study was to seek explanations for the trends in males and females by examining colorectal cancer incidence, survival, and mortality data from 1950 through 1990.

Subjects and Methods

Colorectal cancer mortality data were obtained from the National Center for Health Statistics (Centers for Disease Control and Prevention, Public Health Service, Department of Health and Human Services) and were furnished by the Surveillance, Epidemiology, and End Results (SEER) Program (National Cancer Institute, National Institutes of Health, EPN, Rm. 330, Bethesda, MD 20892).[1] The ninth revision of the International Classification of Diseases was used to identify the colorectal cancer cases. Codes 153.0-153.9 were used for colon cancer, and codes 154.0-154.1 were used for rectal cancer.

Two sources of data were explored for the incidence and survival rate studies. Annual colorectal cancer incidence and survival rates from 1950 through 1990 were obtained from the Connecticut Cancer Registry, a population-based tumor registry (*4*). They were examined to investigate causes of the gender differences in mortality from 1950 through 1984.

In order to explore reasons for an abrupt downturn in mortality rates identified for both males and females beginning around 1985, we obtained SEER-area incidence and survival data from 1975 through 1990. One-year relative

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See "Notes" section following "References."

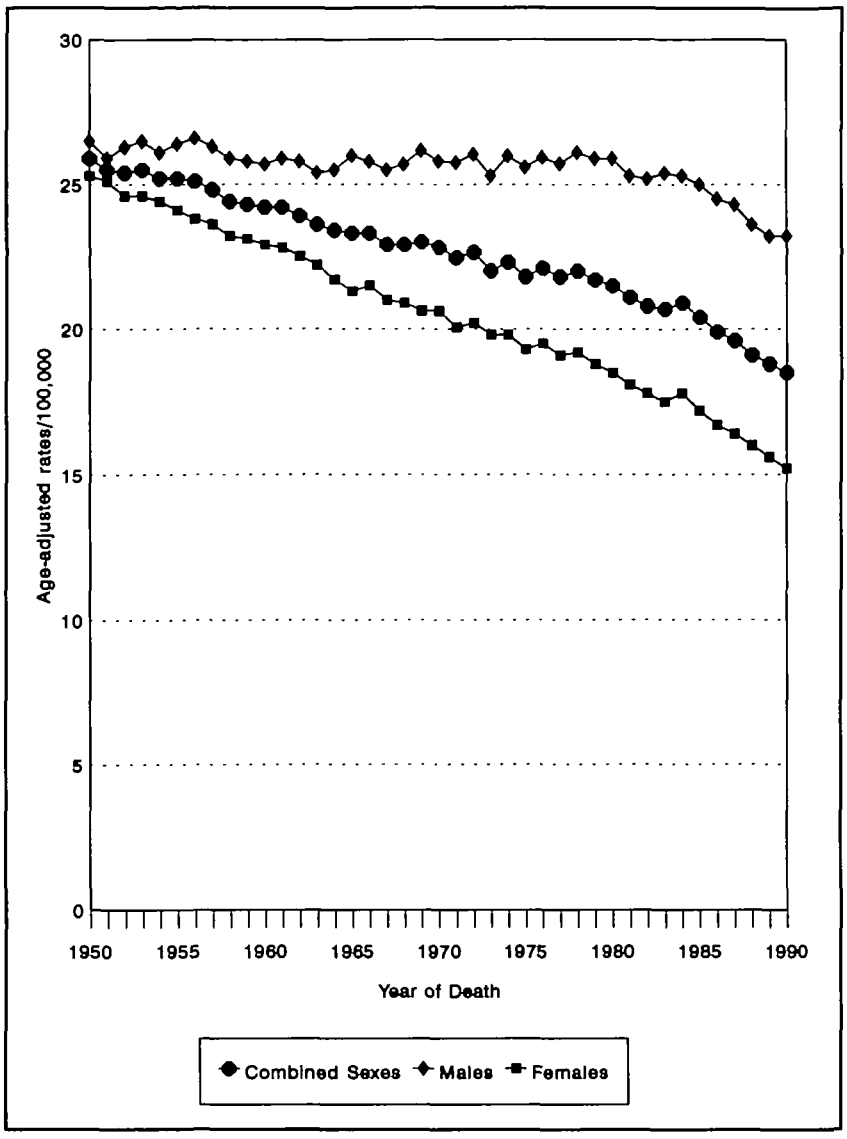

Fig. 1. U.S. colorectal cancer mortality rates for white males and females from 1950 through 1990.

survival rates were examined to allow analyses of survival rates through 1990. The areas covered by SEER contain about 10% of the U.S. population. Although SEER incidence and survival data are available since 1973, we chose to use incidence data since 1975, the earliest date at which all registries were contributing data to SEER.

The colorectal anatomic sites include the cecum, appendix, ascending colon, hepatic flexure, transverse colon, splenic flexure, descending colon, sigmoid colon, intestinal tract (not otherwise specified), rectosigmoid junction, and rectum.

This investigation considers mortality, incidence, and survival rates for whites only, because the population of Connecticut (the source of the incidence and survival data since 1950) is predominantly white.

Unless otherwise stated, the incidence rates are for one primary only or first primary malignant colorectal cancers, i.e., excluding second or later colorectal cancer primaries and in situ lesions.

To determine if there is an abrupt change in the trend of colorectal cancer rates and to identify the point in time of such a change, piecewise regression analyses were performed (*5*). This procedure allows the identification of a point in time when there is a significant change in the slope of a trend (*see* "Appendix I" section).

Age–period–cohort analyses (i.e., consideration of age, calendar period, and birth cohort factors simultaneously) on the U.S. colorectal cancer mortality data were performed using the standard Poisson regression methods (*see* "Appendix II" section), but using 2-year age groups (ages 24-83 years) and 2-year calendar periods (years 1970-1989).[2] The long-term trends in risk by calendar period and by birth cohort were examined for evidence of changes in slope, changes that are identifiable in the standard log-linear model (*6-8*).[2]

Results

The piecewise regression analyses of U.S. colorectal cancer mortality rates from 1950 through 1990 indicate a statistically significant change in slope for both males and females beginning in 1985. For males, colorectal cancer mortality rates changed little throughout the period from 1950 through 1984 (–0.09% ± 0.02% [±SE] annually [P<.0001]). Beginning in 1985, however, a sharp and statistically significant decline in colorectal cancer mortality occurred (–1.72% ± 0.14% annually [P<.0001]). The colorectal cancer mortality rate declined much more rapidly for females than for males from 1950 through 1984 (–1.07% ± 0.01% annually [P<.0001]). From 1985 through 1990, the female rate declined at a significantly steeper rate (–2.50% ± 0.10% annually [P<.0001]). Thus, both males and females had statistically significant decreases in the slopes of their mortality rate trends beginning in 1985.

Subsequent results are divided into two sections. The first section deals with the period 1950 through 1984 to explore possible reasons for the gender differences in long-term mortality trends using Connecticut Cancer Registry data. The second section deals with the period 1975 through 1990 to explore possible reasons for the downturn in trends in males and females in the mid-1980s using SEER data.

Analysis of Colorectal Cancer Trends From 1950 Through 1984

The colorectal cancer incidence rates by sex for Connecticut from 1950 through 1990 are given in Fig. 2 and show different trends for males and females. From 1950 through 1984, the incidence rates rose in males (a statistically significant annual increase of 0.62% ± 0.05% [±SE] [P<.0001]), while rates declined in females (an annual decrease of –0.31% ± 0.08% [P = .0004]). In contrast, males and females in Connecticut had similar trends in survival from 1950 through 1984, the 5-year relative survival rates demonstrating statistically significant annual increases of 1.5% ± 0.09% (P<.0001) and 1.3% ± 0.08% (P<.0001) for males and females, respectively.

Analysis of Colorectal Cancer Declines in the Mid-1980s

Piecewise regression analyses for U.S. colorectal cancer mortality rates by age groups are reported in Table 1, with the point of change set to 1985. These analyses allow a comparison of the effects of age on the trend in the late 1980s. For males and females, all age groups have had annual percentage decreases of 2%-3% since 1985.

The age-adjusted total invasive colorectal cancer incidence rates as well as incidence rates specific to stage at diagnosis (including carcinomas in situ) were determined from SEER data and are plotted in Fig. 3 for males and in Fig. 4 for females. Similar patterns of trends were observed for both males and females. Rates for distant disease have been declining steadily since 1975. Rates for regional disease increased from 1975 to the early 1980s, leveled off in the mid-1980s, and then declined in the late 1980s. Rates for localized disease increased from 1975 to the mid-1980s and then declined in the late 1980s. Finally, rates for in situ disease increased until the late 1980s and have shown signs of recent declines.

The general trends for the 1-year relative survival rates from 1975 through 1990 for all colorectal cancer as well as for local-

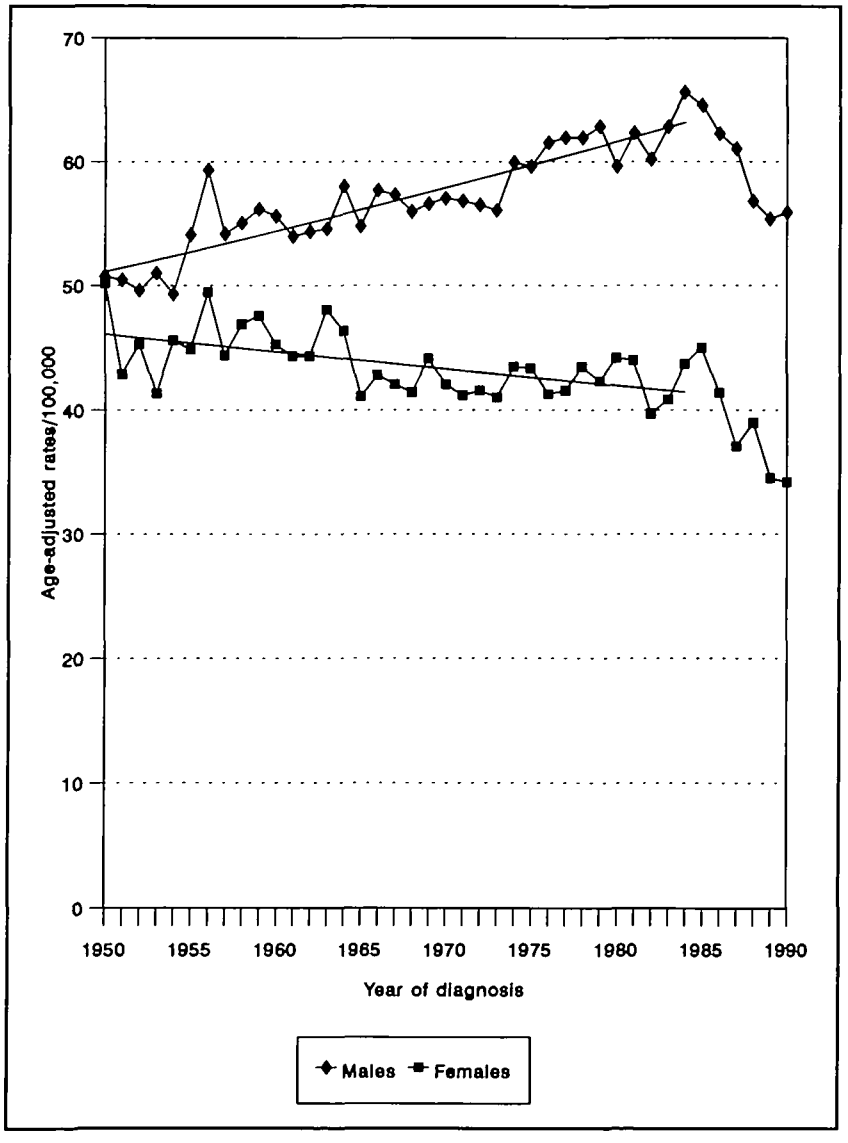

Fig. 2. Colorectal cancer incidence rates for white males and females in Connecticut from 1950 through 1990 with regression lines drawn for years 1950 through 1984.

Table 1. Annual percent change of U.S. colorectal cancer mortality by age from 1970 through 1990 using piecewise regression analyses with point of change set to 1985

	Linear trends for annual percent change in mortality, %*			
	Males		Females	
Age, y	1970-1984	1985-1990	1970-1984	1985-1990
40-49	−0.93 ± 0.25	−2.28 ± 0.90	−2.73 ± 0.17	−2.78 ± 0.61
50-59	−0.49 ± 0.09	−2.15 ± 0.31	−1.79 ± 0.11	−3.67 ± 0.40
60-69	−0.39 ± 0.08	−1.78 ± 0.28	−1.26 ± 0.10	−3.38 ± 0.36
70-79	−0.16 ± 0.06	−2.24 ± 0.22	−1.06 ± 0.07	−3.02 ± 0.24
≥80	0.41 ± 0.10	−1.54 ± 0.35	−0.24 ± 0.09	−2.08 ± 0.31
All ages	−0.18 ± 0.06	−1.96 ± 0.20	−1.12 ± 0.05	−2.75 ± 0.18

*Values = slope ± SE.

ized, regional, and distant disease (Fig. 5) indicated no gender differences. Survival increased for both males and females without an abrupt change in the slope of the trend. There was no indication of any major change in survival in the middle to late 1980s that could account for the declines in mortality rates.

Analyses of colorectal cancer mortality rates for age–period–cohort effects using Poisson regression with 2-year age and calendar period groups from 1970 to 1989 indicate a statistically significant moderation of the calendar period trend in 1980-1989 compared with 1970-1979 for both males and females (i.e., the slope of the linear trend in period effects was significantly less [$P<.0001$] in the latter 10 years for each gender). The moderation of the period trend was greatest over the last two calendar periods, consistent with the piecewise regression analyses of U.S. mortality rates, which indicated a statistically significant improvement in both sexes beginning in 1985. These nonlinear changes in trends can be seen in plots of the period coefficients from the age–period–cohort analyses of colorectal cancer mortality for males and females (Fig. 6). These calendar period trend shifts suggest improvements that benefit all ages, regardless of birth cohort. Improvements in early detection procedures and/or treatment techniques could lead to such period trend shifts.

The age–period–cohort analyses also provided evidence of a statistically significant moderation of birth cohort risk in both males and females. Comparison of the slopes of the birth cohort trends in the 1899-1913 cohorts, the 1921-1935 cohorts, and the

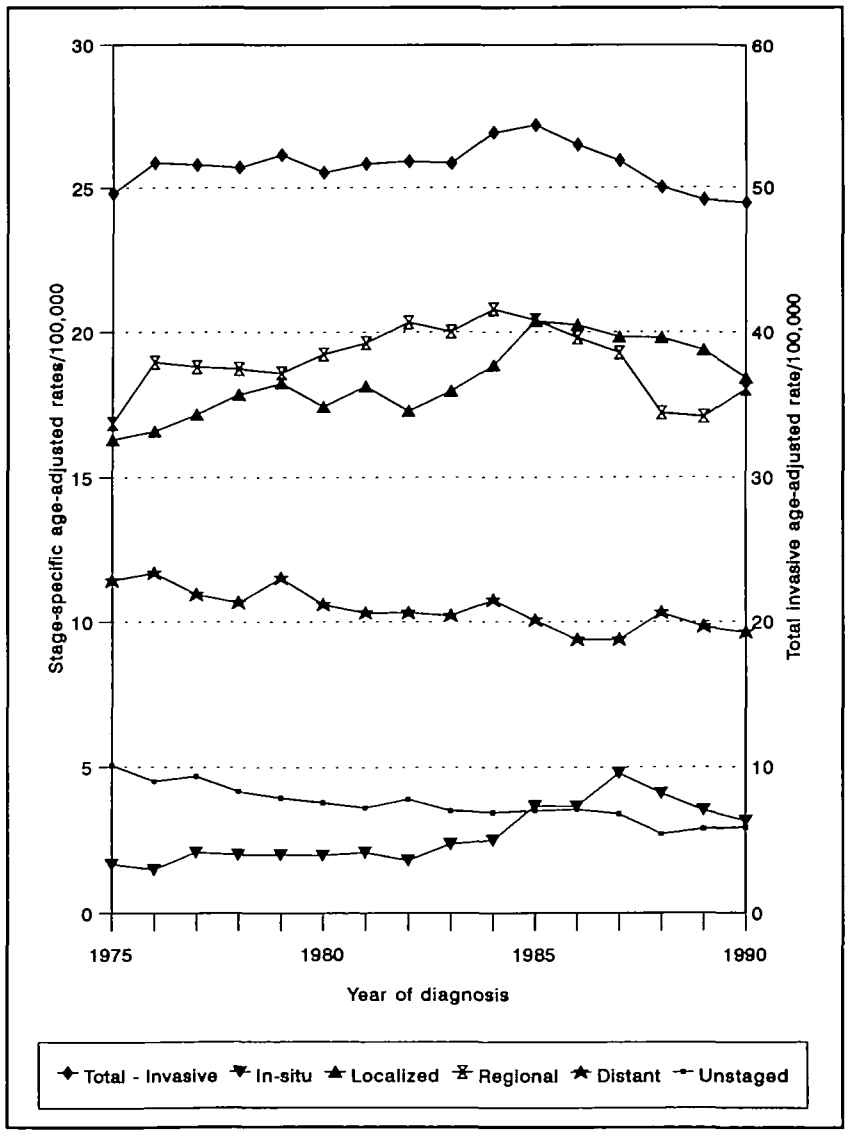

Fig. 3. SEER-area colorectal cancer incidence rates for white males by disease stage at diagnosis. Left ordinate = stage-specific age-adjusted rates/100 000. Right ordinate = total invasive age-adjusted rate/100 000 (top curve only).

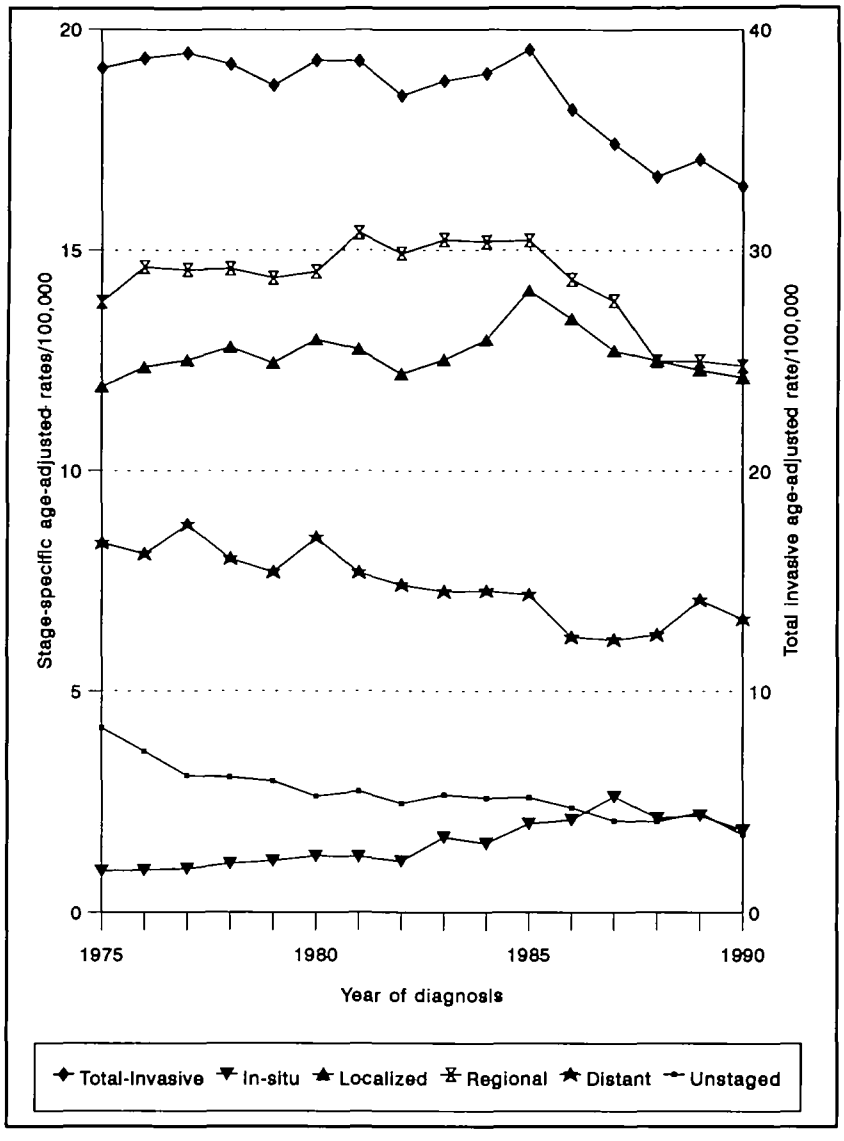

Fig. 4. SEER-area colorectal cancer incidence rates for white females by disease stage at diagnosis. Left ordinate = stage-specific age-adjusted rates/100 000. Right ordinate = total invasive age-adjusted rate/100 000 (top curve only).

1943-1957 cohorts showed that the 1921-1935 slopes were significantly less than the 1899-1913 slopes ($P<.001$, each sex) and that the 1943-1957 slopes were significantly less than the 1921-1935 slopes ($P<.001$ for males; $P<.02$ for females). Thus, cohort trend analyses indicate a steady moderation of colorectal cancer risk with advancing birth cohorts. In both males and females, the largest decrease in slopes was for the 1943-1957 birth cohorts. These nonlinear changes in trend can be seen in plots of the cohort coefficients from the age–period–cohort analyses of the colorectal cancer mortality (Fig. 7). Since the decrease in mortality rates in the late 1980s is not greater in young age groups than in old age groups (Table 1), the birth cohort moderation of risk cannot explain the abrupt mortality decrease in the late 1980s.

Discussion

The discussion is divided into two sections: 1) reasons for the gender differences from 1950 through 1984 and 2) reasons for the declines in the mid-1980s for both sexes.

Reasons for Gender Differences From 1950 Through 1984

The gender difference in mortality trends from 1950 through 1984 appears to be due to the gender difference in the incidence trends. The incidence rates of colorectal cancer in males have been increasing, while those in females have been declining slightly, although to a lesser extent than female mortality rates. Survival rates are comparable in males and females and have been increasing at similar rates during this period. As a consequence, the sharp decline in mortality in females seems to be due to slightly decreasing incidence rates and increasing survival rates. For males, the increasing survival rates appear to have offset increasing incidence rates to yield level mortality rates. The increasing survival rates from 1950 through 1984 likely reflect better control of infections after surgery and other advances in surgical technique (*9*), although improvements in early detection may have contributed to better survival from the late 1970s onward.

Further research is required to determine reasons for the gender difference in colorectal cancer incidence trends. This disparity, which suggests differences between males and females in

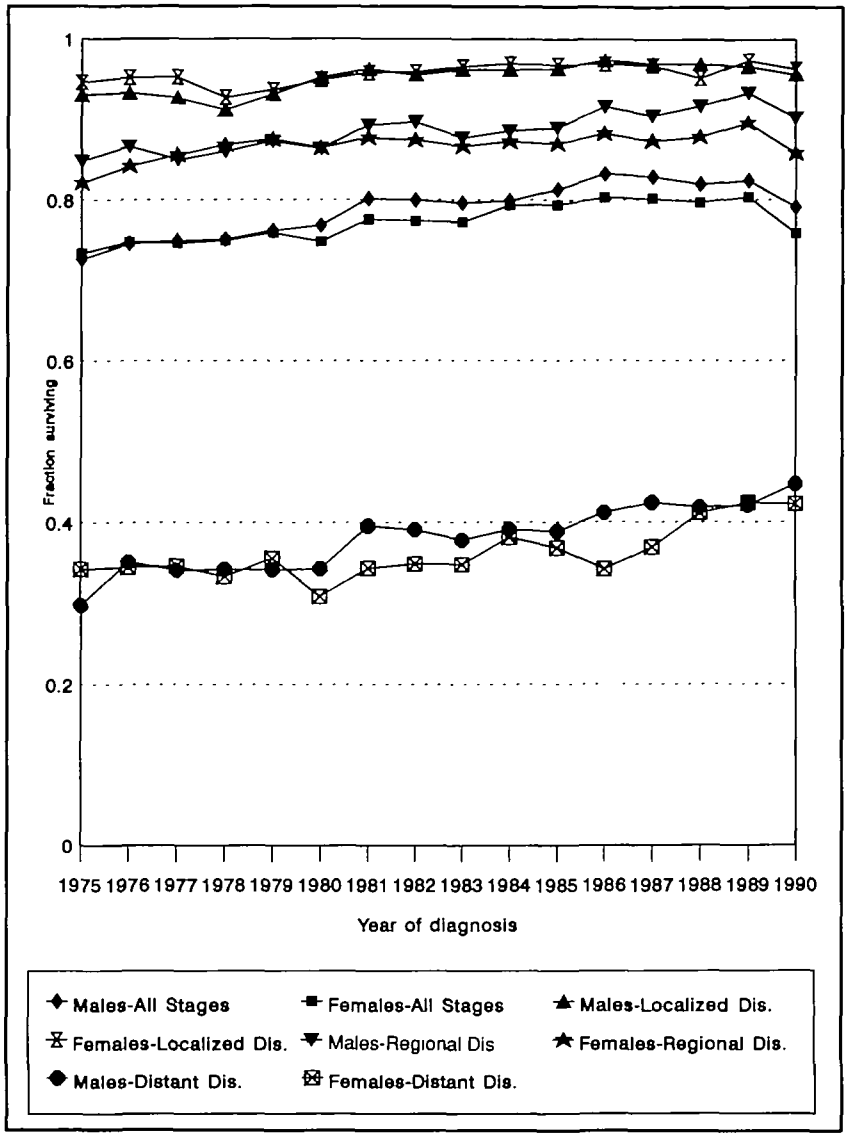

Fig. 5. SEER-area 1-year relative survival rates from colorectal cancer by disease stage at diagnosis for white males and females.

the etiology of colorectal cancer, has been noted previously (*10-15*). It has been proposed that gender differences in risk could be a consequence of hormonal effects on bile composition resulting in formation of cancer-promoting secondary bile acids, differential bowel transit time leading to differences in contact times with fecal carcinogens, use of exogenous hormones, or gender-related differences in lifestyle factors such as diet (*11-13,16*). On the one hand, males could be exposed increasingly to a carcinogenic risk or risks to which females either are not exposed or are exposed to a lesser extent. On the other hand, females may have a protective factor, perhaps hormonal, that is absent in males. In the 1940s, males did not have higher colorectal cancer rates than females, suggesting that an inherent hormonal protective factor in females is unlikely. Because male incidence rates increased substantially from 1950 to 1984 while female rates remained stable from 1965 to 1984, it might be conjectured that exposures increasing the risk of colorectal cancer in males are responsible for the sex difference. Because information is insufficient on gender differences in long-term temporal trends of potential risk factors for colorectal cancer, analytic studies will be required to further investigate gender differences in trends.

Cigarette smoking, a risk factor consistently associated with increased risk of colorectal adenomas in previous studies (*17,18*), has recently been found to be associated with increased risk of colorectal cancer in men and women who started smoking 35-40 years ago (*19,20*). If smoking is proven to be a risk factor with a long induction period for colorectal cancer, differences in smoking trends may explain, at least in part, the divergence of colorectal cancer trends in males and females. Women began smoking substantially in the 1940s and 1950s (*21*). Thus, while the time frame considered in the current study would have allowed for a contribution of increased smoking in men over the first half of the century to the male colorectal cancer trend, it might not have allowed a sufficient induction period to observe the impact of more recent increases in smoking in women on their colorectal cancer rates.

Reasons for Declines in the Mid-1980s for Both Sexes

The reasons for the decline of U.S. mortality rates during the late 1980s are more complex. Any explanation of the changes in

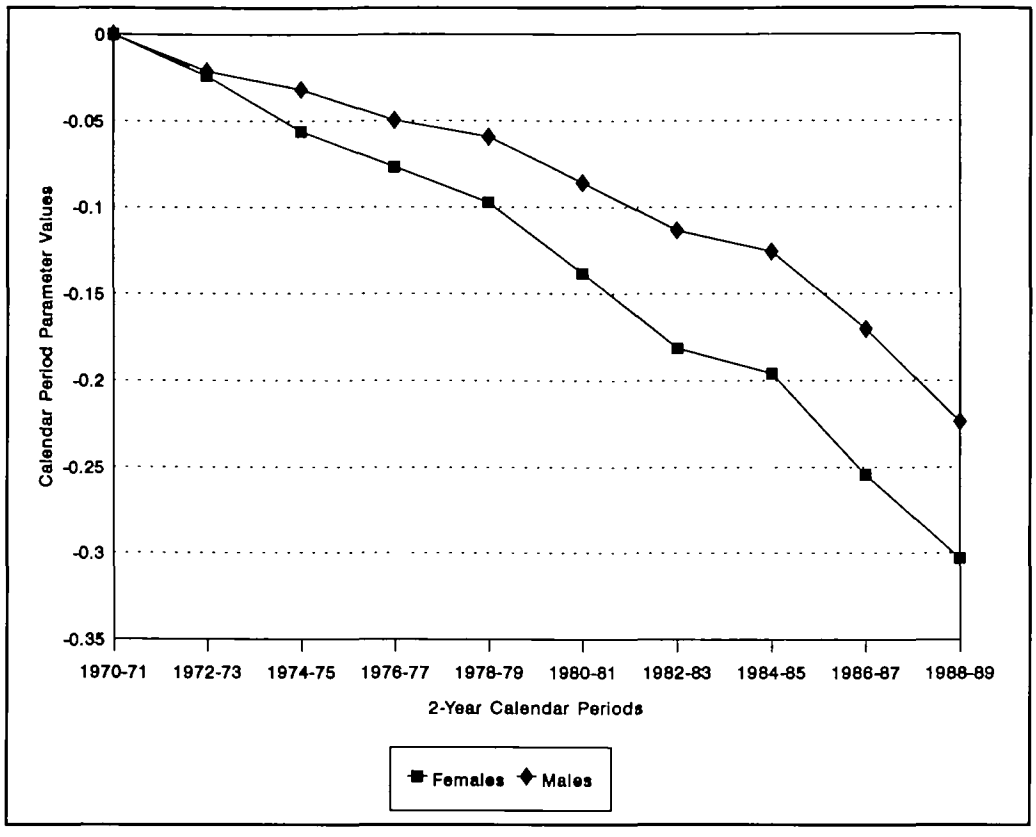

Fig. 6. Calendar period coefficients from age–period–cohort analyses of U.S. colorectal cancer mortality among white males and females.

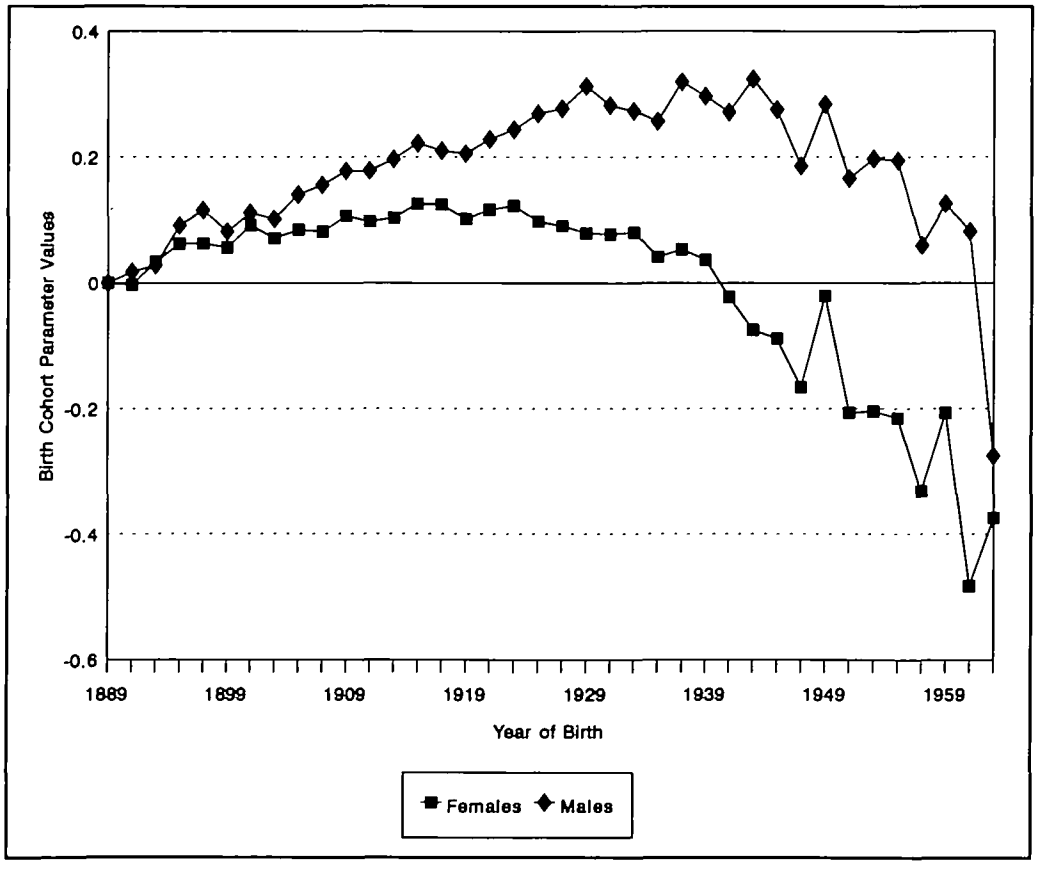

Fig. 7. Cohort coefficients from age–period–cohort analyses of U.S. colorectal cancer mortality among white males and females.

trends must account for the following effects seen in males and females: 1) declines in rates of distant disease since 1975, 2) increases in rates of regional disease until the early 1980s and then declines in the late 1980s, 3) increases in rates of local disease until the mid-1980s followed by declines in the late 1980s, and 4) increases in rates of in situ disease until the late 1980s with very recent declines. This inverse relationship between disease stage and the year at which stage-specific incidence rates peak and begin to decline is consistent with increasingly earlier detection of colorectal cancer as time goes by.

It is difficult to model the exact impact of early detection on the pattern of stage-specific colorectal cancer rates, because early detection does not result from widespread population screening, but rather results from the application of improved diagnostic procedures in work-ups of symptomatic patients and in routine physical examinations. Certainly, however, a stage shift from distant disease to regional disease (i.e., early detection in the regional stage of cancers that would not be diagnosed clinically until the distant stage) should first cause a decrease in distant disease and an increase in rates of regional disease, consistent with the pattern observed in SEER stage-specific incidence data. Although improved diagnostic techniques initially would be used primarily in the work-up of symptomatic patients, if useful, they would eventually find increasing application in routine physical examinations. A stage shift to local disease (i.e., early detection in the local stage of cancers that would not be diagnosed clinically until the regional or distant stage) would result from this eventual increased use of early detection techniques in physical examinations, ultimately leading to a decrease in rates of regional disease. The rapid increase in rates of local disease in the early 1980s preceding the decrease in rates of regional disease in the late 1980s gives evidence of such a stage shift. Similarly, a stage shift from local and in situ disease to preneoplastic lesions, such as adenomas or polyps, should lead to a subsequent decline in rates of local and in situ colorectal cancers, consistent with the observed declines in these rates in the late 1980s in the SEER incidence rates.

An earlier examination of incidence trends by stage based on SEER incidence rates in 3-year calendar periods through 1987 proposed that decreasing rates of distant disease and increasing rates of local disease provided evidence of earlier detection due to improved diagnostic techniques (*22*). The current study demonstrates that the incidence rate trends for all disease stages are consistent with stage shifts due to improved early detection. In addition, the recent declines in the rates of localized and in situ cancers suggest that lesions are increasingly being discovered in a preneoplastic stage, before progressing to cancer. The proposed stage shifts are consistent with the multiple shifts seen in a randomized trial of fecal occult blood tests, where there was a deficit of late-stage disease cases in the screened group compared with the unscreened control group (*23*).

Diagnostic technologies are available for colorectal cancer that not only can detect cancers at an early stage, but also can detect and remove preneoplastic lesions (i.e., adenomas). Early detection methods such as sigmoidoscopy and colonoscopy have been available since the early 1970s (*24*). In addition, the fecal occult blood test, which analyzes for the presence of blood in stool specimens, has been available since the mid-1970s. Positive fecal occult blood tests are increasingly followed up with colonoscopic examinations, since bleeding can occur anywhere within the colon.

The capabilities of these early detection procedures to lead to reductions in mortality from colorectal cancer have been examined. In a recent randomized trial in which fecal occult blood screening with colonoscopy in one group was compared with no screening in a control group (*23*), there was a 33% reduction in mortality in the screened group. In addition, a case–control study (*25*) suggests that the fecal occult blood test can reduce colorectal cancer mortality. The efficacy of sigmoidoscopy has not been demonstrated in a randomized trial; however, two case–control studies (*26,27*) suggest that sigmoidoscopy can reduce mortality from distal colon and rectal cancers by as much as 60%-70%.

The patterns of use of these technologies are less well defined. In 1977, the American Cancer Society (ACS) (*28*) recommended that all adults aged 40 or older should have a sigmoidoscopic examination annually and that they should have a periodic health checkup that included digital examination and fecal occult blood test. In 1980, the ACS (*29*) changed its recommendations and recommended that those 40 or older have an annual digital rectal examination and that those 50 or older undergo sigmoidoscopy once every 3 years as well as have an annual fecal occult blood test. The number of Americans who had ever had one of the early detection procedures for colorectal cancers (i.e., digital rectal examination, stool blood test, and proctoscopic examination) increased by 4%, 17%, and 11%, respectively, between 1983 and 1987 (*30*). Former President Ronald Reagan's colon cancer in July 1985 led to a marked increase in the use of early detection methods (evidenced by sharp increases in Medicare reports of sigmoidoscopic and colonoscopic procedures after 1984), which continued at least through 1987 (*31*). This unplanned, early detection event, evidenced by a noticeable acceleration in 1985 in the rate of increase in rates of localized and in situ disease (Fig. 3 for males and Fig. 4 for females), may be contributing to the abrupt decline in colorectal cancer mortality rates in the late 1980s.

If the SEER data reflect changes due to early detection of cancer, this would mean that stage shifts in colorectal cancer have been achieved in the general population by early detection measures, without a formal screening program. Through early detection guidelines, such as those offered by the ACS in 1980, and through the widespread adoption of the use of fecal occult blood testing and sigmoidoscopies by primary-care physicians, our health promotion, early detection, and health care systems have been able to achieve national decreases in colorectal cancer incidence and mortality rates.

In addition to early detection, changes in the prevalence of risk or protective factors also may have an impact on the incidence rates. While some potential risk factors for colorectal cancer, such as obesity and high intake of total calories and protein (*32,33*), increased from the mid-1970s to the 1980s (*34,35*), other factors, such as sedentary lifestyle (*36*) and high intake of animal fat (*37*) and alcohol (*38,39*), declined (*40,41*).[3] Many factors that may be protective against colorectal cancer, such as high intake of fruits, vegetables, dietary fiber, calcium, and antioxidants (beta carotene and vitamin C) (*32,37,42-44*), also increased during the past decade (*34,45,46*). In addition,

use of nonsteroidal anti-inflammatory drugs (NSAIDs) has been associated with a reduction in colorectal cancer risk (*47,48*). Prescriptions for NSAIDs in the United States did not increase from 1982 to 1990 (*49*). Furthermore, the protective effect of aspirin, the most common NSAID available over-the-counter, on cardiovascular disease (*50,51*) and possibly colorectal cancer (*47*) was not known until the late 1980s. Thus, aspirin use is unlikely to account for the declines in colorectal cancer incidence and mortality beginning in the mid-1980s.

Lifestyle effects are often generational and may be expected to be reflected in birth cohort patterns of risk. Our age–period–cohort analyses indicate a steady moderation of colorectal cancer risk with advancing birth cohorts for both males and females, with the largest decrease in the slope of the cohort risk trend occurring in recent cohorts. Because the mortality rate decreases in the late 1980s were similar in all age groups, however, it is unlikely that generational lifestyle changes were responsible for the abrupt downturn in mortality since 1985.

Other possible explanations for the changes in colorectal cancer rates also need to be addressed. Coding changes could account for sudden changes in rates and would be manifested as a calendar period effect. There are, however, separate coding schemes for incidence [International Classification of Diseases for Oncology (*52*)] and mortality [International Classification of Diseases, 9th Revision (*53*)]. Thus, there would have to be simultaneous changes in incidence and mortality coding schemes for coding changes to account for the observed declines for colorectal cancer. In addition, changes in the ascertainment of cancers in SEER areas (i.e., case finding) could affect the incidence rates. There were no changes in coding schemes or in case-finding techniques in the mid-1980s that could explain the abrupt changes in colorectal cancer trends in rates (Ries LAG: personal communication, SEER Program).

Unlike the United States, Canada (*54,55*) and England (*56*) do not have early detection guidelines that recommend sigmoidoscopy and fecal occult blood tests (with colonoscopy follow-up). However, these countries should have medical treatments and dietary habits similar to those in the United States. Colorectal cancer incidence rates among Canadian males through 1988 do not show the abrupt decline seen in males in the United States (*57*). Similarly, colorectal cancer mortality rates among Canadian males also have not shown an abrupt decline from 1984 through 1990 (*58*). Although England's colorectal cancer incidence rates through 1988 were not available, the colorectal cancer mortality rates among males in England and Wales increased from 1985 to 1990 (*58*).

As with any observational epidemiologic study using correlations with grouped data, there is the possibility of the ecological fallacy, i.e., improper inferences based on using ecological data or grouped data rather than individual data (*59*). There can be no disputing the gender differences in the colorectal cancer incidence and mortality rate trends from 1950 through 1984 and the downturn in incidence and mortality rates for both males and females in the mid-1980s. Our explanations of these results are only hypotheses, however, and require verification in future analytic studies.

Appendix I

Let the calendar years be indexed by $i = 1, 2, \ldots I$ and the rate for the calendar year i be denoted R_i. The piecewise regression analyses were performed after taking a logarithmic transformation of rates. For each i_0 from 3 to I-2, the linear model, $\alpha + \beta_1 i + \beta_2 x_i(i - i_0)$, was fit to $\log(R_i)$ using standard multiple regression methods, where x_i is defined to be an indicator function taking the value 0 if $i \leq i_0$ and 1 if $i > i_0$. The value of i_0 giving the best fit was chosen to be the value giving the maximum R^2 value. If, for the best fitting model, the regression coefficient β_2 was significantly different from 0 based on the usual t test for multiple regression parameters, then the trend was considered to have a change in slope over the period from i_0 to I compared with the period 1 to i_0

Appendix II

Let R_{ij} denote the colorectal cancer mortality rate for individuals dying in the jth of P calendar periods at an age in the ith of A age intervals. In full age–period–cohort notation, the birth cohort of an individual dying in calendar period j at age i would be indicated by an additional subscript, $c = A + j - i$, but to simplify the notation, we will suppress the birth cohort subscript. With A age intervals and P calendar periods, the number of birth cohorts is $C = A + P - 1$. In the above notation, $c = 1$ corresponds to the earliest birth cohort, and $c = C$ corresponds to the most recent birth cohort. Inferences regarding the variation of rates by calendar period and birth cohort are obtained by modeling the mean, E_{ij}, of the logarithm of the disease rate, R_{ij}, as

$$E_{ij} = \alpha_i + \pi_j + \gamma_c,$$

where the α_i are the age effects, the π_j are the calendar period effects, and the γ_c are the birth cohort effects. Maximum likelihood estimates of the model parameters are obtained using standard Poisson regression methods (*6-8*). The calendar period effects, π_j, are plotted in Fig. 6, and the birth cohort effects, γ_c, are plotted in Fig. 7. For each $j > 1$, π_j is the logarithm of the relative risk of dying of colorectal cancer in calendar period j compared with the first calendar period, and for each $c > 1$, γ_c is the logarithm of the relative risk for birth cohort c compared with the first birth cohort.

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Notes

[1]Editor's note: SEER is a set of geographically defined, population-based central tumor registries in the United States, operated by local nonprofit organizations under contract to the National Cancer Institute (NCI). Each registry annually submits its cases to the NCI on a computer tape. These computer tapes are then edited by the NCI and made available for analysis.

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[3]Division of Biometry and Epidemiology, National Institute on Alcohol Abuse and Alcoholism: Alcohol Epidemiologic Data System.

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