Further Enhanced Monitoring of Cancer Patient Survival by Stage-Adjusted Period Analysis

Hermann Brenner and Volker Arndt

Department of Epidemiology, German Centre for Research on Ageing, Heidelberg, Germany

Abstract

Monitoring progress in cancer patient survival is an important task of population-based cancer registration. Period analysis has been shown to provide more up-to-date estimates of cancer patient survival than traditional methods of survival analysis. However, even period estimates may disclose recent improvements in long-term survival with some delay as they are still partly based on the survival experience of patients diagnosed years ago. If these patients had a less favorable stage distribution than the patients diagnosed in a more recent calendar period (e.g., due to progress in early detection), period estimates may underestimate long-term survival for patients diagnosed in that period. This particular source of potential underestimation can be overcome by adjustment of the stage distribution of all patients included in period analysis to the stage distribution of the patients diagnosed in the period of interest. The principle, application, and use of stage adjustment of period survival estimates are illustrated with 5- and 10-year relative survival estimates of patients diagnosed with breast cancer and followed with respect to survival in the United States between 1973 and 2001, using data of the Surveillance, Epidemiology, and End Results Program of the National Cancer Institute. We show that stage adjustment may often further enhance the benefits of period analysis for deriving up-to-date cancer survival estimates. (Cancer Epidemiol Biomarkers Prev 2005;14(8):1917–21)

Introduction

Monitoring long-term cancer patient survival is an important task of population-based cancer registries (1). Trends in cancer patient survival should be captured as timely as possible. Therefore, cancer registry data should be collected and worked up in a timely manner, and the data should be analyzed in a way that enables timely detection of such trends. The period analysis methodology, first introduced in 1996 by Brenner and Gefeller (2, 3), has been shown to be particularly useful in this context (4). As cancer survival rates are increasing over time for many forms of cancer, the latest period estimates of cancer patient survival are often substantially higher than the corresponding estimates obtained by traditional ''cohort'' or ''complete'' survival analysis (5-7). Nevertheless, even the period estimates may sometimes be too pessimistic in situations where cancer survival rates continue to increase rapidly.

Increases in survival over time may be due to a variety of reasons. Typically, the most important reasons are advancements in early detection or therapy. As even the period estimates of survival for some recent time period partly reflect the survival experience of patients diagnosed in earlier years, it is not surprising that they may still be lower than the survival rates later experienced by patients diagnosed in those recent time periods. As far as advancements in early detection are concerned, this problem may be overcome to some extent by adjusting the stage distribution of all patients involved in period analysis to the stage distribution of patients diagnosed in the recent period of interest. The aim of this paper was to evaluate empirically if and to what extent such ''stage adjustment'' may further enhance the use of period analysis for deriving up-to-date estimates of long-term cancer patient survival.

Received 2/7/05; revised 5/25/05; accepted 6/15/05.

The costs of publication of this article were defrayed in part by the payment of page charges. This article must therefore be hereby marked advertisement in accordance with 18 U.S.C. Section 1734 solely to indicate this fact.

This research was supported in part by a grant from the German Cancer Foundation (Deutsche Krebshilfe), Project No. 70-3166-ßö5

Requests for reprints: Hermann Brenner, Department of Epidemiology, German Centre for Research on Ageing, Bergheimer Strasse 20, D-69115 Heidelberg, Germany. Phone: 49-6221-548140; Fax: 49-6221-548142. E-mail: brenner@dzfa.uni-heidelberg.de

doi:10.1158/1055-9965.EPI-05-0103

Materials and Methods

Database. This analysis is based on data on cancer incidence and survival from the 1973 to 2001 public use database of the Surveillance, Epidemiology, and End Results (SEER) program of the National Cancer Institute (8). The SEER Program is the most authoritative source of information on cancer incidence and survival in the United States. Quality control has been an integral part of SEER since its inception. Every year, studies are conducted in the SEER areas to evaluate the quality and completeness of the data being reported (SEER standard for case ascertainment is 98%).

Data from nine population-based cancer registries (Connecticut, New Mexico, Utah, Iowa, Hawaii, Atlanta, Detroit, Seattle-Puget Sound, and San-Francisco/Oakland), which together cover a population of ~30 million people, are included in the 1973 to 2001 SEER database. Our analysis is restricted to women diagnosed with a first primary cancer of the breast between January 1, 1973, and December 31, 1996, who were followed with respect to vital status until the end of 2001. Breast cancer was selected for this empirical evaluation as it is the most common form of cancer among women, and both the proportion of patients diagnosed at earlier stages as well as population-based survival rates have increased over time. Patients with unknown length of follow-up (0.7%) were excluded, as were patients who were reported to the registries by death certificate only (0.7%) or by autopsy only (0.1%).

Statistical Analysis. We calculated 5-year survival rates actually experienced by consecutive cohorts of patients diagnosed in calendar years 1978 to 1996 and compared them with the estimates of 5-year survival that could have been derived with the data potentially available in those years by traditional cohort or complete analysis or by period analysis. The principle of the different types of analyses is outlined for the most recent year, 1996, in Fig. 1, and the data included in pertinent calculations for the other years are summarized in Table 1. For example, the most up-to-date 5-year survival estimate potentially available in 1996 from cohort analysis would reflect the survival experience in 1991 to 1996 of patients diagnosed in 1991. The most up-to-date

Table 1. Years of diagnosis and years of follow-up included in calculations of 5-year survival later observed for patients diagnosed in various calendar years and in estimates of 5-year survival potentially available at the end of those calendar years by cohort, complete, and period analysis

Observed		Cohort analysis		Complete analysis		Period analysis	
Years of diagnosis	Years of follow-up	Years of diagnosis	Years of follow-up	Years of diagnosis	Years of follow-up	Years of diagnosis	Years of follow-up
1978	1978-1983	1973	1973-1978	1973-1978	1973-1978	1973-1978	1978
1979	1979-1984	1974	1974-1979	1974-1979	1974-1979	1974-1979	1979
1980	1980-1985	1975	1975-1980	1975-1980	1975-1980	1975-1980	1980
...	...	...	...	...	...	...	...
1996	1996-2001	1991	1991-1996	1991-1996	1991-1996	1991-1996	1996

5-year survival estimate potentially available in 1996 from complete analysis would reflect the survival experience in 1991 to 1996 of patients diagnosed in 1991 to 1996.By contrast, the most up-to-date 5-year survival estimate potentially available in 1996 from period analysis would exclusively reflect the survival experience in 1996 of patients diagnosed in 1991 to 1996.

In addition to the usual ''crude period analysis,'' we also carried out a ''stage-adjusted period analysis'' in which the stage distribution of all patients involved in period analysis was adjusted to the stage distribution of patients diagnosed in the period of interest (here, the most recent calendar year). The rationale for this procedure can also be derived from the illustration of period analysis for 1996, the most recent calendar year included in this analysis (Fig. 1). Although only survival experience in 1996 is included, the analysis is based on the survival experience of patients diagnosed in 1991 to 1996. If patients diagnosed in 1991 to 1995 had a less favorable stage distribution than patients diagnosed in 1996, they may provide too pessimistic conditional survival estimates to the 1996 period analysis. To overcome this potential problem, their stage distribution was adapted to the stage distribution of the patients diagnosed in 1996 by a recently introduced adjustment procedure (9).

Although this adjustment procedure was primarily introduced for age adjustment, it may equally be applied to adjust for differences in stage distribution between cancer populations. This is achieved by assigning appropriate weights to patients in the various stage groups, and then doing a weighted analysis, as described in detail elsewhere (9). The following stage categories were used for adjustment: local, regional, and distant tumor spread. In addition, a separate category for patients with unknown tumor spread was used.

Because cancer-related deaths beyond 5 years following diagnosis are not uncommon among patients with breast cancer, we carried out analogous evaluations for 10-year survival for those calendar years for which pertinent comparisons between the different types of analyses were possible with the 1973 to 2001 SEER database (see Table 2).

Throughout this paper, relative rather than absolute survival estimates are presented. Relative survival rates reflect survival rates of cancer patients compared with those of the general population. As described in detail elsewhere (10, 11), they are calculated as the ratio of absolute survival rates of cancer patients divided by the expected survival rates of a group of individuals of the corresponding gender and the corresponding age in the general population. Estimates of expected survival were derived according to Hakulinen's method (12) from U.S. sex, age, race, and calendar period–specific life tables. For the years 1973 to 1975, 1976 to 1985, and 1986 to 1995, we used U.S. life tables for the years 1970, 1980, and 1990, respectively, which were provided with the SEER public use database (8). For the years 1996 to 2001, U.S. life tables for the year 2000 were used (13).

In addition to point estimates of relative survival, their SE values were also calculated according to Greenwood's formula (14). However, as they were generally very small (below 0.8% units for all relative survival estimates), they are not individually reported in this paper. All analyses were carried out by the SAS software system using the macro *adperiodh* for analyses of relative survival (9).

Results

Table 3 shows the numbers of patients with breast cancer and the distribution of tumor spread by calendar years. The annual numbers of diagnoses in the nine registry areas almost doubled from 8,613 in 1978 to 14,616 in 1996. Tumor spread at diagnosis was known for >95% of breast cancers in all years. The proportion of patients with localized tumors increased over time from ~47% at the end of the 1970s to >62% since the year 1992. Conversely, the proportion of patients with regional tumor spread decreased from >40% up to 1982 to <30% since 1991. Despite some overall minor decrease over time, the proportion of patients with distant tumor spread remained fairly constant at levels between 8.1% and 5.6% throughout the period of investigation.

Table 2. Years of diagnosis and years of follow-up included in calculations of 10-year survival later observed for patients diagnosed in various calendar periods and in estimates of 10-year survival available at the end of those calendar periods by cohort, complete and period analysis

Observed		Cohort analysis		Complete analysis		Period analysis	
Years of diagnosis	Years of follow-up	Years of diagnosis	Years of follow-up	Years of diagnosis	Years of follow-up	Years of diagnosis	Years of follow-up
1983	1983-1993	1973	1973-1983	1973-1983	1973-1983	1973-1983	1983
1984	1984-1994	1974	1974-1984	1974-1984	1974-1984	1974-1984	1984
1985	1985-1995	1975	1975-1985	1975-1985	1975-1985	1975-1985	1985
...	...	...	...	...	...	...	...
1991	1991-2001	1981	1981-1991	1981-1991	1981-1991	1981-1991	1991

Table 3. Proportions of patients with local, regional, or distant tumor spread by calendar years of diagnosis

Year of diagnosis	*n*	Tumor spread (%)			
		Local	Regional	Distant	Unknown
1978	8,613	47.2	41.0	8.1	3.7
1979	8,928	47.1	42.2	7.1	3.6
1980	9,082	47.4	42.0	7.3	3.3
1981	9,573	47.7	42.1	7.1	3.1
1982	9,682	48.1	41.5	6.8	3.6
1983	10,301	48.5	39.3	7.8	4.4
1984	10,749	50.6	38.3	6.9	4.2
1985	11,674	52.4	36.7	6.6	4.4
1986	12,061	54.1	35.8	6.4	3.7
1987	13,010	56.9	33.6	5.7	3.9
1988	12,824	58.5	32.4	5.8	3.3
1989	12,523	58.1	32.2	6.1	3.6
1990	13,180	60.3	30.5	6.0	3.2
1991	13,610	61.1	29.9	6.0	3.1
1992	13,621	62.3	28.9	5.7	3.1
1993	13,591	62.6	28.7	5.6	3.1
1994	13,946	62.3	29.0	5.6	3.2
1995	14,306	63.1	28.4	5.7	2.8
1996	14,616	63.3	28.0	6.0	2.7

As expected, there was a strong gradient in prognosis according to tumor spread. For example, in a summary analysis for all patients diagnosed in 1978 to 1996, 5-year relative survival was 95.2%, 74.2%, and 20.4% for patients with local, regional, and distant tumor spread, respectively.

Overall 5-year relative survival increased almost steadily from 74.7% for patients diagnosed in 1978 to 87.0% for patients diagnosed in 1996 (see Table 4). Cohort (complete) estimates of 5-year relative survival potentially available in the years of diagnosis of the breast cancer patients would have been between 0.2 and 7.9% units (0.5 and 6.8% units) lower. Application of the usual ''crude'' period analysis would have provided more up-to-date estimates of relative survival. Nevertheless, even the period estimates would have been generally lower than the 5-year relative survival later observed for patients diagnosed in the respective calendar years. The difference was <1.5% units in 13 of 19 calendar years, but it ranged up to 5.3% units in the late 1980s when the shift of the stage distribution was most pronounced (see Tables 3 and 4). Adjustment for tumor spread as outlined above would have further reduced the discrepancies. The maximum difference to the 5-year relative survival rates later observed in the respective calendar years would have been reduced to 3.7% units, and the difference was <1.5% units for 16 of 19 years.

Table 5 shows analogous analyses for 10-year relative survival rates. Overall, 10-year relative survival rates were substantially lower than the corresponding 5-year survival rates for patients with breast cancer due to the relatively high rates of late cancer deaths among these patients. Furthermore, the discrepancy between the cohort as well as the complete estimates available at each calendar year and the relative survival rates actually experienced by patients diagnosed in that year was much larger for 10-year relative survival rates than for 5-year relative survival rates. Again, these discrepancies could be strongly reduced, but not entirely overcome by application of period analysis; this effect could be further enhanced by application of stage-adjusted rather than crude period analysis. The maximum discrepancies were 14.9% units for cohort analysis, 12.3% units for complete analysis, 9.3% units for crude period analysis, and 6.9% units for adjusted period analysis. For eight of nine calendar years, crude period analysis did substantially better than cohort analysis. Likewise, stage-adjusted period analysis did substantially better than crude period analysis for eight of nine calendar years.

Discussion

It is now widely recognized that the period analysis methodology provides better estimates of long-term survival of the most recently diagnosed cancer patients than traditional cohort-based methods of survival analysis, at least if survival rates are increasing over time. In this paper, we illustrate that the use of period estimates can further be enhanced by ''stage adjustment'' in situations in which the improvement of survival rates over time is at least partly due to a shift of the stage distribution toward prognostically more favorable tumor stages.

The rationale for stage adjustment is that even the period estimates for some calendar period are partly determined by

Table 4. Five-year relative survival later observed for patients diagnosed in various calendar years compared with estimates of 5-year relative survival that might have been available in those years by traditional cohort and complete analysis, or by crude and adjusted period analysis

Year of diagnosis	Observed	Estimates available during year of diagnosis (difference*)			
		Cohort	Complete	Period (crude)	Period (adjusted for spread)
1978	74.7	72.6 (−2.1)	73.4 (−1.3)	74.7 (±0.0)	74.6 (−0.1)
1979	74.6	74.1 (−0.5)	74.1 (−0.5)	74.8 (+0.2)	74.8 (+0.2)
1980	75.7	75.5 (−0.2)	74.7 (−1.0)	75.8 (+0.1)	75.8 (+0.1)
1981	76.2	74.9 (−1.3)	74.7 (−1.5)	76.1 (−0.1)	76.2 (±0.0)
1982	77.5	75.4 (−2.1)	75.1 (−2.4)	75.4 (−2.1)	75.8 (−1.7)
1983	76.9	74.7 (−2.2)	74.7 (−2.2)	76.1 (−0.8)	76.0 (−0.9)
1984	78.7	74.6 (−4.1)	75.1 (−3.6)	76.5 (−2.2)	77.2 (−1.5)
1985	78.9	75.7 (−3.2)	75.9 (−3.0)	77.8 (−1.1)	78.7 (−0.2)
1986	80.6	76.2 (−4.4)	76.9 (−3.7)	78.4 (−2.2)	79.4 (−1.2)
1987	83.4	77.5 (−5.9)	77.7 (−5.7)	78.8 (−4.6)	80.3 (−3.1)
1988	84.8	76.9 (−7.9)	78.0 (−6.8)	80.2 (−4.6)	81.6 (−3.2)
1989	84.9	78.7 (−6.2)	79.3 (−5.6)	81.6 (−3.3)	82.1 (−2.8)
1990	84.9	78.9 (−6.0)	80.8 (−4.1)	82.8 (−2.1)	83.5 (−1.4)
1991	85.6	80.6 (−5.0)	82.4 (−3.2)	84.9 (−0.7)	85.5 (−0.1)
1992	86.2	83.4 (−2.8)	84.0 (−2.2)	85.0 (−1.2)	85.7 (−0.5)
1993	86.1	84.8 (−1.3)	84.6 (−1.5)	85.7 (−0.4)	86.2 (+0.1)
1994	86.8	84.9 (−1.9)	85.1 (−1.7)	86.3 (−0.5)	86.6 (−0.2)
1995	87.0	84.9 (−2.1)	85.2 (−1.8)	86.2 (−0.8)	86.4 (−0.6)
1996	87.1	85.6 (−1.5)	85.5 (−1.6)	86.1 (−1.0)	86.1 (−1.0)

*Difference from observed.

Table 5. Ten-year relative survival later observed for patients diagnosed in various calendar years compared with estimates of 10-year relative survival that might have been available in those years by traditional cohort and complete analysis, or by crude and adjusted period analysis

Year of diagnosis	Observed	Estimates available during year of diagnosis (difference*)			
		Cohort	Complete	Period (crude)	Period (adjusted for spread)
1983	65.1	60.6 (−4.5)	63.0 (−2.1)	64.7 (−0.4)	64.8 (−0.3)
1984	67.3	62.9 (−4.4)	63.3 (−4.0)	64.1 (−3.2)	65.1 (−2.2)
1985	68.7	64.1 (−4.6)	63.3 (−5.4)	65.0 (−3.7)	66.4 (−2.3)
1986	71.3	62.7 (−8.6)	63.2 (−8.1)	65.0 (−6.3)	66.6 (−4.7)
1987	74.0	63.5 (−10.5)	63.5 (−10.5)	66.2 (−7.8)	68.7 (−5.3)
1988	76.4	62.7 (−13.7)	64.1 (−12.3)	66.8 (−9.6)	69.3 (−7.1)
1989	76.9	62.0 (−14.9)	64.6 (−12.3)	69.0 (−7.9)	70.7 (−6.2)
1990	77.0	63.1 (−13.9)	66.1 (−10.9)	70.7 (−6.3)	72.7 (−4.3)
1991	77.6	63.7 (−13.9)	67.2 (−10.4)	72.9 (−4.7)	74.6 (−3.0)

*Difference from observed.

the survival experience of patients diagnosed before the period of interest (albeit much less so than the cohort and complete estimates available during the same calendar periods). If the stage distribution of cancers was less favorable among cancer patients diagnosed before the calendar period of interest, the period estimates for that calendar period may become somewhat too pessimistic, an effect that may be overcome by stage adjustment to the stage distribution of cancers diagnosed in the period of interest.

As expected from theory, the impact of application of period analysis, and in particular of stage-adjusted period analysis, was strongest in our analysis for those calendar years during which the strongest improvement in stage distribution compared with the preceding calendar years was observed. The method may, therefore, be most useful for survival analyses in situations where such improvements are ongoing. Fortunately, shifts toward a more favorable stage distribution have been achieved for breast cancer and some other cancers in different countries in recent years (15-17), and these trends might continue or even speed up in the future if current or new tools for early detection become more widely available. On the other hand, stage adjustment would be expected to have no impact at all in situations in which stage distribution remains constant over time.

Although stage adjustment enhanced the period estimates of survival in our analyses, even the stage-adjusted period estimates remained somewhat too pessimistic (i.e., lower than the survival rates later observed for patients diagnosed in the respective calendar periods in most cases). This pattern, which was particularly pronounced for the period estimates of 10-year relative survival in the late 1980s, suggests that improvements other than those in stage distribution, such as progress in therapy, are likely to be responsible for the increase in population-based survival rates. For breast cancer, one such improvement was the introduction of tamoxifen therapy for estrogen receptor–positive cancers (18). The proportions of breast cancer patients receiving tamoxifen therapy strongly increased during the 1980s (19), which may at least partly explain why the stage-adjusted period survival estimates for the late 1980s were still too pessimistic, as these estimates were still based to some extent on the survival experience of cohorts of patients in whom tamoxifen therapy was less commonly applied. Another reason may be that the relatively crude classification of tumor spread used in this analysis may not warrant full adjustment for the improvement in distribution of tumor spread over time.

A potential tradeoff of stage adjustment is the increased complexity of analyses and their slightly less straightforward interpretation. However, the former may be handled with tolerable extra efforts, e.g., by use of recently developed adjustment tools (including pertinent computer programs; ref. 9). Although the latter have primarily been developed for age adjustment of cancer survival rates, they may easily be adapted for the use for stage adjustment as described in this paper. The interpretation of crude period survival estimates as the survival rates expected for patients diagnosed in the period of interest assuming that the conditional survival rates observed in that period prevail over time requires only slight modification for the stage-adjusted period survival estimates: The latter can be interpreted as the survival rates expected for patients diagnosed in the period of interest assuming that the stage-specific conditional survival rates observed in that period prevail over time.

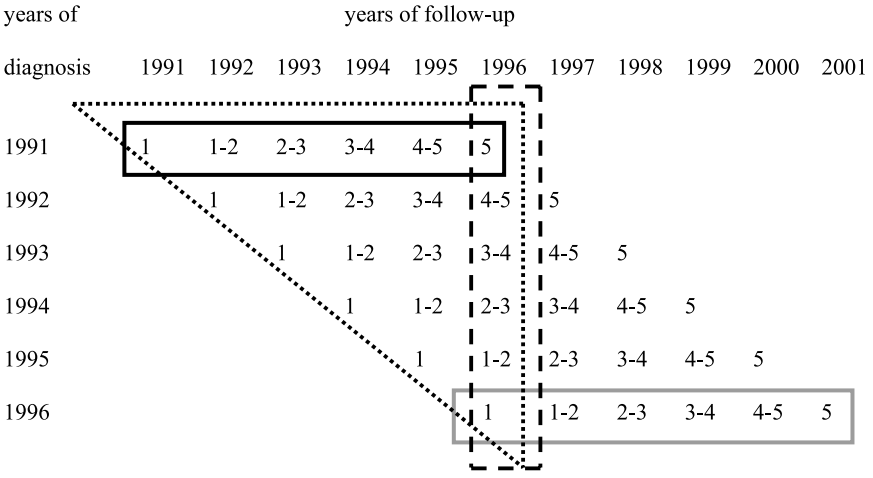

Figure 1. Years of diagnosis and years of follow-up included in calculations of observed 5-year survival for patients diagnosed in 1996 (*solid gray frame*), and in calculations of 5-year survival based on data potentially available at the end of 1996 using either traditional cohort analysis (*solid black frame*), traditional complete analysis (*dotted black frame*), or period analysis (*dashed black frame*). The numbers within the cells indicate the years following diagnosis.

Despite its potential general advantages, stage adjustment of period estimates of survival may also carry dangers in specific situations. For example, if refinement of diagnostic procedures would lead to increased detection of regional and distant metastases in a given calendar period, a phenomenon known as stage migration, this may result in an apparent shift toward a more unfavorable stage distribution compared with the preceding years. In such a situation, stage adjustment of cancers diagnosed in preceding years to the stage distribution of the cancers diagnosed in the period of interest would erroneously give more weight to the prognostically unfavorable cancers, and may hence lead to overly pessimistic period estimates. Therefore, stage adjustment should be applied only if stage classification can be assumed to be comparable during the calendar periods included in the analysis.

The focus of this paper is on adjustment of period survival estimates for tumor spread at diagnosis, a factor known to be strongly associated with prognosis. In principle, analogous adjustments may also be made for other factors of prognostic relevance, such as race, the proportion of patients detected by screening, etc., in certain situations. Although the proportion of patients receiving novel effective therapy may also be a strong determinant of population-based survival rates in some situations, adjustment for differences in the proportions of patients receiving such therapy would have to be made with particular caution due to the potential for confounding by indication.

In summary, our analyses indicate that careful application of stage adjustment of period estimates may further increase their use in some situations. The decision whether or not to implement stage adjustment should take the specific circumstances, such as changes in early detection procedures over time and their effects, into account. Stage adjustment would typically be most valuable in situations in which improvement in survival over time mostly results from detecting an increasing proportion of cancers in earlier, curable stages.

References

1. Jemal A, Clegg LX, Ward E, et al. Annual report to the nation on the status of cancer, 1975-2000, with a special feature regarding survival. Cancer 2004;101:3–27.
2. Brenner H, Gefeller O. An alternative approach to monitoring cancer patient survival. Cancer 1996;78:2004–10.
3. Brenner H, Gefeller O. Deriving more up-to-date estimates of long-term patient survival. J Clin Epidemiol 1997;50:211–6.
4. Brenner H, Hakulinen T. Advanced detection of time trends in long-term cancer patient survival: experience from 50 years of cancer registration in Finland. Am J Epidemiol 2002;156:566–77.
5. Brenner H, Hakulinen T. Up to date survival curves of patients with cancer by period analysis. J Clin Oncol 2002;20:826–32.
6. Brenner H, Söderman B, Hakulinen T. Use of period analysis for providing more up-to-date estimates of long-term survival rates: empirical evaluation among 370,000 cancer patients in Finland. Int J Epidemiol 2002;31:456–62.
7. Talbäck M, Stenbeck M, Rosén M. Up-to-date long-term survival of cancer patients: an evaluation of period analysis on Swedish Cancer Registry data. Eur J Cancer 2004;40:1361–72.
8. Surveillance, Epidemiology, and End Results (SEER) Program (http://www.seer.cancer.gov/). Public-use data (1973-2001). Bethesda (MD): National Cancer Institute DCCPS, Surveillance Research Program, Cancer Statistics Branch. Released April 2004, based on the November 2003 submission.
9. Brenner H, Arndt V, Gefeller O, Hakulinen T. An alternative approach to age adjustment of cancer survival rates. Eur J Cancer 2004;40:2317–22.
10. Ederer F, Axtell LM, Cutler SJ. The relative survival rate: a statistical methodology. J Natl Cancer Inst Monogr 1961;6:101–21.
11. Henson DE, Ries LA. The relative survival rate. Cancer 1995;76:1687–8.
12. Hakulinen T. Cancer survival corrected for heterogeneity in patient withdrawal. Biometrics 1982;39:933–42.
13. Arias E. United States life tables, 2000. Natl Vital Stat Rep 2002;51:1–39.
14. Greenwood M. A report on the natural duration of cancer. London: Ministry of Health, HSMO; 1926.
15. Pisani P, Forman D. Declining mortality from breast cancer in Yorkshire, 1983-1998: extent and causes. Br J Cancer 2004;90:652–6.
16. Brenner H, Arndt V. Long-term survival rates of patients with prostate cancer in the prostate-specific antigen screening era: population-based estimates for the year 2000 by period analysis. J Clin Oncol 2005;23:441–7.
17. Eloubeidi MA, Mason AC, Desmond RA, El-Sarag HB. Temporal trends (1973-1997) in survival of patients with esophageal adenocarcinoma in the United States: a glimmer of hope? Am J Gastroenterol 2003;98:1627–33.
18. Early Breast Cancer Trialists' Collaborative Group. Tamoxifen for early breast cancer. Cochrane Database Syst Rev 2001;(1):CD000486.
19. Mariotto A, Feuer EJ, Harlan LC, Wun LM, Johnson KA, Abrams J. Trends in use of adjuvant multi-agent chemotherapy and tamoxifen for breast cancer in the United States. J Natl Cancer Inst 2002;94:1626–34.

Further Enhanced Monitoring of Cancer Patient Survival by Stage-Adjusted Period Analysis

Hermann Brenner and Volker Arndt

Cancer Epidemiol Biomarkers Prev 2005;14:1917-1921.