Projection of lung cancer mortality in Japan

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According to the National Vital Statistics data, age-standardized mortality rates (ASRs) of lung cancer have shown slightly declining trends in Japan for both men and women. In order to evaluate whether this tendency will continue, a Bayesian age-period-cohort (APC) model was applied using the National Vital Statistics data from 1952 to 2001. In the projection, a Gaussian autoregressive prior model was applied to smooth age, period, and cohort effects from its 2 immediate predecessors by extrapolation. Posterior distributions from which we drew inferences on mortality rates were derived from 15,000 iterations using 5000 burn-in iterations. We defined the median of the iterated values as the overall summary mortality rate of the iterated results. Our results suggest that the number of deaths due to lung cancer will double for men and women during the next 3 decades due to the aging of the baby-boomer generation (individuals who were born between 1947 and 1951). Currently declining trends in some age groups will reverse and start to increase again in the next decades. However, for recent birth cohorts, the results of the projection varied according to whether the data set included early age group mortality or not. Lung cancer mortality in the future depends on the risk factors engaged in by today's young people, especially smoking. Strong promotion of anti-smoking measures and careful surveillance for lung cancer are needed. (Cancer Sci 2003; 94: 919–923)

In Japan, lung cancer is the most common cause of cancer death for men and the second most common for women, followed by gastric cancer. In 1999, lung cancer accounted for 21.6% of all deaths due to malignant neoplasm for men and 15.6% for women.[1)] The most effective method of lung cancer prevention is tobacco control. However, as of this date, drastic tobacco control programs have not been implemented in Japan. According to data from Japan Tobacco Industry, Inc., overall smoking prevalence in men was 50% in 2000. This is a decrease from over 80% in the 1960s. Although the overall smoking prevalence is only 13.7% for women, it has recently been increasing among young women. Thus, the epidemic of tobacco-related mortality is expected to continue in Japanese society for some time to come. But even with such a large proportion of the population smoking, the age-standardized mortality rates (ASRs) for lung cancer showed slightly declining trends in the updated vital statistics analysis.[2)] Such declining trends lead us to believe that lung cancer mortality may continue to decline. It is important for health policymakers to know whether the trend in lung cancer mortality will continue to decrease or if it will change direction and increase instead. So a precise method of predicting lung cancer mortality would be very useful.

Several attempts have been made to project lung cancer mortality in Japan. Kuroishi *et al.* applied an age-group-stratified simple linear regression model using a time period as an explanatory variable.[3)] Hamajima and Aoki projected the number of lung cancer deaths in men by parameterizing changing rates of mortality between neighboring birth cohorts, preventive strategy effects, and new therapeutic procedure effects.[4)] Yamaguchi *et al.*[5)] introduced the Markov Chain model of the natural history of lung cancer to project lung cancer deaths. It used 3 transition probabilities: preclinical to clinical, clinical to recovery, and clinical to death, and their changing rates according to time. Although their projections were relatively good, projection reports must be timely and periodically replaced by new ones based on accumulated statistical data.

An age-period-cohort (APC) model is a useful tool to project cancer incidence or mortality rates without any complicated assumptions. But in the past, the APC model was predominantly used to separate age, period, and birth cohort effects.[6–10)] A recognized problem with the APC model is the difficulty of distinguishing between the 3 effects (identifiability problem); however, the identifiability problem does not have a significant influence on the projection itself. A Bayesian APC model was recently developed to give the projection credible intervals. Furthermore, this model has given stable projections even with a small amount of real data.[11, 12)] In this paper, we projected lung cancer deaths in Japan until 2029 using the Bayesian APC model.

Materials and Methods

We obtained the number of deaths due to lung cancer according to sex and 5-year age groups for the years 1952 to 2001 from National Vital Statistics data. The International Classification of Diseases (ICD) code corresponding to lung cancer was 163 in the 6th revision (1952–1957), 162 and 163 in the 7th revision (1958–1967), 162 in the 8th (1968–1978) and 9th revisions (1979–1994), and C33 and 34 for the 10th revision (1995–2001). We divided the observation into 10 periods of 5 years each ($P=10$ periods) and summed up the number of deaths within each period. Death due to lung cancer is rare and its rate is unstable in young people, but the changing behavior of tobacco smoking among young people could affect the mortality projection. In order to confirm the influence of mortality rates in young people on the projection, we conducted two computations. *Projection a* used lung cancer mortality data of the whole age groups ($A=18$ quinquennial age groups); *Projection b* used mortality data for age groups greater than or equal to 40 ($A=10$ quinquennial age groups). In these 2 models, there were 27 and 19 birth cohorts, respectively (C=birth cohorts; $C=A+P-1$). Birth cohort categories in each age and period group were calculated using cohort=(number of age group)−(age group)+period. Corresponding Japanese population data according to sex, age group, and period of lung cancer death were obtained from the National Census, which is conducted every 5 years. Data for inter-census periods were obtained from data estimated by the Statistics Bureau and Statistics Center of the Ministry of Public Management, Home Affairs, Post, and Telecommunications.

Projections of mortality rates for the 6 periods (2002–2006,...,2027–2031) were calculated by applying Bayesian APC models presented by Bray[11)] with WinBUGS software

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(MRC Biostatistics Unit, Cambridge, UK) using Markov Chain Monte Carlo methods.[13] In general, an APC model includes log linear factors for each component and assumes that the number of deaths in age group (i) and period (p) has a Poisson distribution, such as log(rate)=age effect$_i$+period effect$_p$+cohort effect$_c$=$\alpha_i+\gamma_p+\beta_c$. In the projection using this Bayesian APC model, the basic idea is the same as the general APC model. However, the methodology and calculations for an extrapolation of period and cohort effects to the future are different. In this model, a Gaussian autoregressive prior model was applied to smooth age, period, and cohort effects and to extrapolate period and cohort effects from their 2 immediate predecessors. Posterior distributions, from which we drew inferences on mortality rates, were derived from 15,000 iterations using 5000 burn-in iterations that were not used to calculate summary statistics. We defined the median iterated values as an overall summary mortality rate and 90% credible intervals using values of 5th and 95th percentiles of the 10,000 iterated results. We also conducted the same procedures using mortality rates until 1991 to evaluate the accuracy of the projections for 1992–1996 and 1997–2001.

In order to demonstrate the temporal changes in lung cancer mortality rates between 1952 and 2031, ASRs for men and women greater than or equal to 40 years of age were compared using the standardized Japanese population of 1985.[14] For the calculation of ASR, estimated mortality rates from the Bayesian APC model were used for both the past and future periods.

Since the peak of the population pyramid in Japan is moving to older age groups, we also calculated the projected number of deaths due to lung cancer until 2031 in order to evaluate the burden of lung cancer on Japanese society. For this projection, we used data provided by the National Institute of Population and Social Security Research.[15]

Results

The results of the age-specific lung cancer death rates for men and women for the past 10 periods (1952–56, 1957–61,...,1997–2001) and empirical projections for the next 6 periods (2002–2006,...,2027–2031) are shown with 90% credible intervals in Figs. 1 and 2. Until the year 2001, the estimated rates fit well with narrow credible intervals in most age groups for men and women. Joint points from the observed rates around 2001 switched smoothly to the projected rates for both *Projections a* and *b*. However, the projected rates separated from each other for the birth cohort of 40–44 years of age in the period 1997–2001. For the birth cohorts prior to it, that is, the birth cohort of 70–74 years of age in the period 1997–2001, the projected mortality rates from the 2 mortality data sets were almost the same. We computed projection rates for 1992–1996 and 1997–2001 using mortality rates for young people until 1991. The results are shown in Fig. 3. The projection using mortality rates in whole age groups (*Projection a*) tended to underestimate the rate in the 40–44 year age group. On the other hand, the projection using mortality rates for age groups over 40 (*Projection b*) tended to be an overestimate.

ASRs are presented in Fig. 4. For men, the projected ASR differed between *Projection a* and *Projection b*. The ASR for *Projection b* reached a plateau around 2001 and increased afterward, but the ASR for *Projection a* continued to decline. For women, the ASR increased linearly until 2014, but the difference in the ASR became apparent between *Projection a* and *Projection b*.

Lung cancer mortality rates according to birth cohorts in log-scale for both men and women are presented in Fig. 5. A birth cohort includes individuals who were born within the period 4 years before and after the central year of the birth cohort. For example, the birth cohort year 1922 includes those who were born from 1918 to 1926. Only those who were born in the mid-

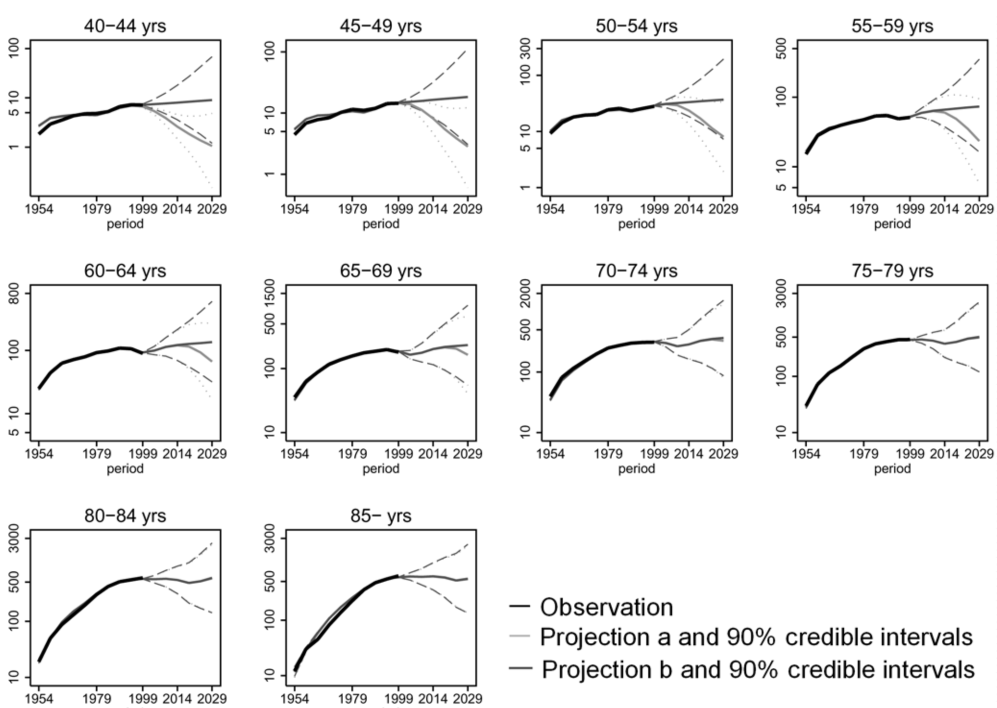

Fig. 1. Observed and projected age-stratified mortality rates of lung cancer in men. Black lines are observed mortality rates. Light gray solid lines with dotted lines are projected rates and their 90% credible intervals using mortality data of whole age groups (*Projection a*). Dark gray solid lines with truncated lines are projected rates and their 90% credible intervals using mortality data of groups greater than or equal to 40 years of age (*Projection b*).

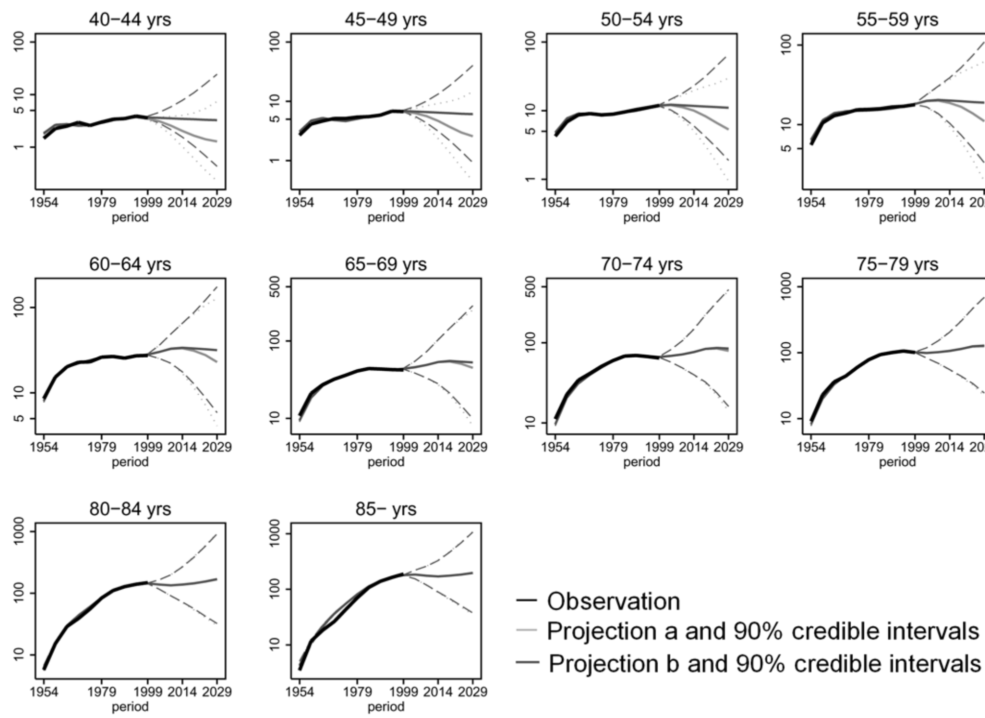

Fig. 2. Observed and projected age-stratified mortality rates of lung cancer in women. Black lines are observed mortality rates. Light gray solid lines with dotted lines are projected rates and their 90% credible intervals using mortality data of whole age groups (*Projection a*). Dark gray solid lines with truncated lines are projected rates and their 90% credible intervals using mortality data of groups greater than or equal to 40 years of age (*Projection b*).

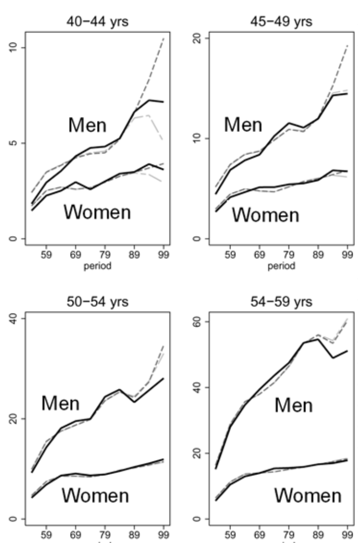

Fig. 3. Observed and projected age-stratified mortality rates of lung cancer for 1992–1996 and 1997–2001 using mortality data until 1991 in men and women. Black lines are observed mortality rates. Light gray truncated lines are projected rates using mortality data of whole age groups (*Projection a*). Truncated dark gray lines are projections using mortality data of groups greater than or equal to 40 years of age (*Projection b*).

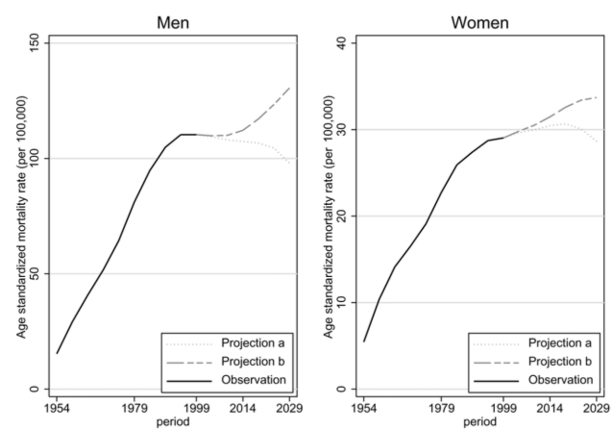

Fig. 4. Observed and projected age-standardized mortality rates (ASRs) for men and women. Black lines are observed ASRs. Light gray dotted lines are projected rates using mortality data of whole age groups (*Projection a*). Truncated gray lines are projections using mortality data of groups greater than or equal to 40 years of age (*Projection b*).

dle year (1922) contribute all 5 years to a certain 5-year age group in a given period. Individuals born in the adjacent years in this birth cohort contribute 4, 3, 2, or 1 year to the age group in this given period, and the remaining 1, 2, 3, or 4 years to the pre- or post-age groups. In this figure, the birth cohort of 1937 (men who were born between 1933 and 1941) had a reduced mortality from lung cancer compared to the rates of the adjacent birth cohorts. For women, the mortality trends showed a slight decrease for the birth cohort of 1927 (born between 1923 and 1931) compared to the rates of the adjacent birth cohorts.

In Table 1, past and projected numbers of lung cancer deaths are shown for the population aged greater than or equal to 40. The projected numbers of deaths for *Projection a* and *Projection b* were as follows: for men, 51,600 and 52,100 in 2009; 61,500 and 63,700 in 2019; and 62,500 and 74,000 in 2029, respectively. For women, they were 19,600 and 19,800 in 2009; 24,700 and 25,300 in 2019; and 28,200 and 30,000 in 2029, respectively.

Table 1. Observed and projected number of lung cancer deaths until 2028 in Japan

	Age group	1959	1969	1979	1989	1999	2009	2019	2029	2009	2019	2029
		Observation					*Projection a*[1)]			*Projection b*[2)]		
Males	40–44	67	151	201	335	282	169	79	36	337	359	310
	45–49	154	211	458	525	688	454	264	109	635	829	705
	50–54	287	417	826	934	1377	1110	721	336	1218	1464	1539
	55–59	495	797	1127	2030	2141	2671	1856	1078	2698	2611	3374
	60–64	620	1226	1779	3356	3356	5472	4051	2634	5491	4466	5356
	65–69	642	1604	2703	3876	5943	6777	8158	5650	6762	8291	8026
	70–74	543	1418	3171	4638	7934	8407	13,414	9921	8382	13,529	11,072
	75–79	267	799	2536	4843	6859	10,926	12,035	14,583	10,923	12,074	14,978
	80–84	81	296	1182	3274	5271	9490	9699	15,941	9500	9749	16,268
	85–	15	69	360	1611	3877	6148	10,249	12,180	6153	10,327	12,368
	Total	3171	6988	14,343	25,422	37,728	51,624	60,526	62,468	52,099	63,699	73,996
Females	40–44	61	106	125	175	140	112	69	43	153	143	110
	45–49	104	158	216	259	318	226	180	97	264	307	231
	50–54	144	235	316	425	588	431	358	223	460	495	461
	55–59	188	326	464	643	773	873	659	528	892	774	904
	60–64	222	433	644	871	1091	1664	1162	967	1676	1238	1333
	65–69	236	491	886	1215	1552	2086	2276	1712	2086	2318	2010
	70–74	191	467	977	1528	2025	2669	4018	2808	2662	4029	3002
	75–79	130	318	891	1769	2432	3389	4391	4801	3385	4371	4897
	80–84	46	150	534	1391	2434	3458	4440	6805	3463	4412	6858
	85–	14	53	236	1007	2798	4696	7170	10,173	4714	7170	10,214
	Total	1336	2737	5289	9283	14,151	19,604	24,723	28,157	19,755	25,257	30,020

1) Projection using mortality data of whole age groups.
2) Projection using mortality data of age groups greater than or equal to 40.

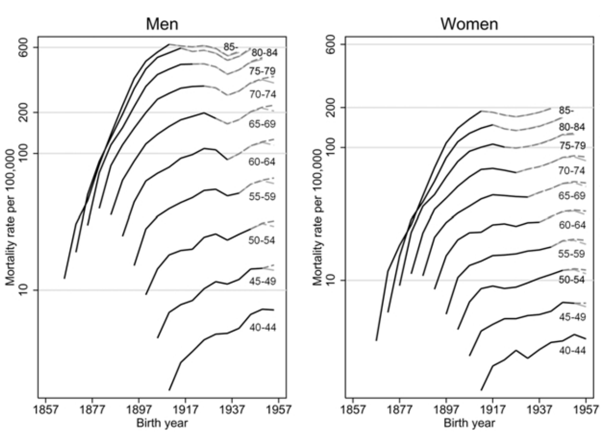

Fig. 5. Observed and projected age-stratified mortality rates focusing on birth cohort effects until the birth cohorts of 1957. Black lines are observed mortality rates. Light gray truncated lines are projected age-stratified mortality rates from 2002 to 2029 using mortality data of whole age groups (*Projection a*). Dark gray truncated lines are those using mortality data of groups greater than or equal to 40 years of age (*Projection b*).

Discussion

Our results suggest that the projected number of lung cancer deaths in 2029 will be double the current number as a result of aging of the baby-boomer generation (those born between 1947 and 1951). We found 2 issues with our model that can affect the projections. The first is the existence of birth cohorts with lower risks of lung cancer compared to adjacent birth cohorts. The second is the effect of lung cancer mortality rates in earlier age groups.

The existence of birth cohorts with a low lung cancer risk was one of the unexpected results from observed and projected mortality rates. The low risk cohorts are men born between 1933 and 1941 and women born between 1923 and 1931. Our projections demonstrate the existence of the low risk cohorts more clearly than studies using the APC model[16)] and another method[17, 18)] have in the past.

There was a scarcity of cigarettes in Japan during and after World War II.[19)] According to data provided by Japan Tobacco Industry, Inc., total cigarette sales and consumption per capita dropped to one-third of sales and consumption in adjacent years. It was not until 1950 that cigarette sales recovered and surpassed the level before the war.

While cigarettes were in short supply, the ages of individuals in the low-risk birth cohort ranged from 5 to 18 years for men and from 15 to 28 years for women. These are ages that usually correspond to the period of smoking onset. The scarcity of cigarettes could have delayed the initiation of smoking in these birth cohorts,[20–22)] thereby shortening the duration of exposure to tobacco.[23)] Moreover, the scarcity of cigarettes also could have lowered the rate of smoking initiation in these birth cohorts. This hypothesis is supported by data from 2 mass screening programs in Japan that showed about a 10% reduction in the rate of ever-smoking in the birth cohort around the 1930s, compared to the adjacent birth cohort.[24)] The combination of these 3 effects (i.e., late age at initiation, reduced length of exposure, and reduced rate of initiation), may have produced birth cohorts with decreased lung cancer risk compared to adjacent birth cohorts. The gender difference in the low-risk birth cohort mortality rates might be due to the difference in age of smoking initiation, which is about 8 years older for women according to a large-scale cohort study in Japan.[25)]

The low-risk birth cohort has reached an age that usually has a high probability of lung cancer, but we have shown that this cohort has a declining lung cancer mortality rate. This unexpected result may be due to the decreased availability of cigarettes when these people were young. The birth cohorts following this one have higher risks of lung cancer, so the current decreased rates in age groups over 60 will end and then start to rise again in the next decade.

Whereas the projection in earlier birth cohorts was stable, even with inclusion of mortality data for those under 40 years of age, the projections for the young birth cohorts are not stable. The projection using mortality data for those greater than or equal to 40 (*Projection b*) indicates that the current decrease in ASRs for lung cancer will end and will start to rise again in the next decade. On the other hand, the projection using the whole age group (*Projection a*) indicates that ASRs will continue to decline for men and will turn to decline in 2019 for women.

A Bayesian APC model gives stable projections even with small numbers.[11, 12] However, the projection is based on the assumption that past effects from age groups, time periods, and birth cohorts continue in the same manner into the future. In addition, small effects appearing in early age groups can affect the later projection for the same birth cohort. Therefore, the high sensitivity in this model could be a limitation for the projection using the whole age data.

On the other hand, the high sensitivity could be an advantage for the model using whole age group data, because future trends in lung cancer incidence are sensitive to current smoking behavior in young people. According to data from Japan Tobacco Industry, Inc., the rate of smoking for women under 40 has been increasing over the last 30 years. Furthermore, cigarette smoking rates in juveniles have also been increasing in recent years in Japan.[26] These trends, however, were not reflected in the projection for the young birth cohorts because the effect of cigarette smoking rates in juveniles on lung cancer mortality does not become apparent until years later. Thus, the projection is subject to the past effect movement of period and birth cohorts, especially to the prevalence of smoking in the previous 3 decades. Moreover, the etiology of lung cancer may be different in young versus older age groups.[27] Taking into consideration that small effects in the early age groups modify the later projection in the same birth cohort, projections for recent birth cohorts might not be useful in forming health policy.

In summary, we projected lung cancer mortality rates until the period of 2027–2031 using a Bayesian APC model. Our results revealed that the number of deaths due to lung cancer will double for men and women for the next 3 decades due to the aging of the baby-boomer generation. Currently declining trends in older age groups will reverse direction in the next decades. However, for the recent birth cohorts, the results of the projection varied according to whether the data set included early age group mortality or not. Taking into consideration that small effects in the early age groups modify the later projection in the same birth cohort, projections for recent birth cohorts might not be useful in forming health policy. The future mortality rates of lung cancer depend on the changing risks that young people take, especially smoking. Strong promotion of anti-smoking measures and careful surveillance for lung cancer are needed.

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