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Background: In recent decades, changes in breast cancer (BC) mortality trends have been observed across Europe. Our objective is to describe BC mortality trend in Spain during 1977–2001 and to estimate BC mortality projection in the period 2002–2016 using a Bayesian approach.

Material and methods: An age–period–cohort (APC) analysis has been carried out in order to investigate the effect of the age, period and birth cohort on BC mortality in Spain during 1977–2001 and to estimate future trends for the period 2002–2016. A Bayesian APC model with an autoregressive structure for the age parameters has been used for projections of BC mortality.

Results: BC mortality rates increased 2.18% per year during 1977–1991 followed by a significant fall after 1992 (estimated annual percent change = −2.67%; 95% confidence interval = −2.97, −2.31). Cohorts born before 1952 showed higher risk of death from BC than those born after this year. Projections showed an increase of mortality among women older than 50 years in the period 2002–2016 (range of increase = 10%–40%).

Conclusions: The decrease of BC mortality since 1992 could be attributable to BC down-staging due to early detection and effectiveness of cancer treatment. The effect of ageing on the female population, immigration and the increase of BC incidence observed in Spain could explain the increase in BC mortality predicted for the years to come among women older than 50 years. BC screening to the whole Spanish population and new treatments introduced in the last few years could modify the predictions of BC mortality. Future forecasting studies should be carried out considering these new factors in the natural history of BC in Spain.

Key words: age–period–cohort models, Bayesian approach, breast cancer, mortality, projections

introduction

Breast cancer (BC) is the most common cancer in European women in terms of incidence and mortality [1–3]. In the year 2004 in Europe, there were 370 100 incident cases estimated for BC (27.4% of all incident cancer cases in women) and 129 900 BC deaths (17.4% of all death causes in women) [4]. In the European Union, the highest age-adjusted BC mortality rates are found in western Europe (27.7 per 100 000 women-years), whereas two countries of southern Europe, Greece and Spain, present the lowest BC mortality rates (15.9 and 15.4 per 100 000 women-years, respectively) [5].

During the 1990s, a decrease in BC mortality rates was observed in most European countries [6–8]. In Spain, a decrease of 0.7% in age-adjusted BC mortality was described during the decade 1988–1997 [8]. In this study, it was observed that BC mortality decreased for all age groups, with the exception of the age group 65–74, for which BC mortality remained stable [8]. In addition, a decline in BC mortality was reported after 1992 and 1993 in two Spanish autonomous communities, Catalonia and Andalusia [9, 10]. These rates fell between 2% and 4% per year in both areas, although an increase in BC mortality was observed from 1975 until 1992–1993 (Andalusia = 2% and Catalonia = 6.8%) [9, 10].

The aims of our study are (i) to assess time trends of BC mortality in Spain in the period 1977–2001 taking into account the effect of birth cohort, age and period of death and (ii) to predict future trends of BC mortality in Spain, on the basis of the most updated data available.

material and methods

The National Institute of Statistics of the Spanish Government (Instituto Nacional de Estadística, http://www.ine.es/) has provided mortality data and
population age distribution for the period 1977–2001, as well as future population for the period 2002–2016. In Spain, throughout the period 1977–1998, the code for BC was C50 according to the ninth revision of the International Classification of Diseases (ICD-9) [11], and since 1998, the code was C50 according to the tenth revision of the ICD (ICD-10) [12]. BC mortality rates were age standardised using the world standard population [13].

Time trends of BC mortality have been evaluated through an age-period-cohort (APC) analysis. Data were arranged in five 5-year periods (1977–1981, 1982–1986, 1987–1991, 1992–1996 and 1997–2001) and twelve 5-year age groups (20–24 to 75–79 years). These age groups and calendar periods involved 16 overlapping 10-year cohorts due to the relation cohort = period − age [14, 15]. The cohort groups were defined by their midyears (starting with 1900 and finishing with the cohort 1975).

The assessment of the age (A), cohort (C) and period (P) effects was carried out by means of generalised linear models assuming that the number of deaths follow a Poisson distribution [14, 15]. A model with the three effects was initially fitted, and then each one of these effects was subsequently extracted in order to find the best-fitting model. To assess model adjustment, we first evaluated the increase (denoted with symbol Δ) in the deviance (DEV) and second the Akaike Information Criterion (AIC). The model with the lower AIC value was considered the best in terms of model adjustment [14, 15]. In the APC analysis, the relation cohort = period − age is associated with an identification problem in the parameter estimates [14–16]. We reported these parameter estimates of the full APC model following the same procedure described by Bray et al. [17] in the analysis of the incidence trends of adenocarcinoma of the cervix in Europe. In the first step of this procedure, we fitted an age-cohort (AC) model, using 1952 as the reference cohort. In the second step, we fitted a period effect to the residuals of the AC model by means of a Poisson model for the number of deaths with the log of the fitted values from the AC model as offset. By this procedure, the standard deviations of the estimated values of the effects can be obtained assuming that the secular trend is related with the cohort effect. In this approach, it has been denoted that the resulting effects are close to those obtained with the approach of Holford [16, 18–20]. We have done the graphical representation of the exponential of each one of these parameters and their 95% confidence intervals (CIs). The statistical software used for this part of the analysis was R [21].

A Bayesian APC model, similar to that described previously by Bashir and Estève [22], has been applied to predict BC mortality in Spain for the periods 2002–2006, 2007–2011 and 2012–2016. Constraints on first-order differences were set for the period and cohort effects [23–25], whereas a constraint on the second-order differences was set for the age parameters [22]. For this last constraint, it was assumed that one second-order difference is estimated as the mean value on the previous and subsequent second-order differences. This means that for any given age point (3 ≤ i ≤ Nα − 2; Nα; number of age parameters) the conditional expectation of the age effect is obtained through cubic interpolation from the two points on the other side [22].

To estimate BC projections in Spain, several models were tried on the basis of data from the 1977–2001 period, evaluating its performance and short-term predictions. A tool for the model choice in the Bayesian framework that recently has gained popularity is the Deviance Information Criterion (DIC) [26], which was proposed as a generalisation of the AIC. The model with lower values of DIC is considered the best-fitting model and with best out-of-sample predictive power [26]. In the initial Bayesian APC model, we could not obtain convergence for the model parameters, although some of the expected number of cases did. This was probably due to the complex autoregressive structure assumed for all parameters. We proceeded to select a model without constraints on the period and cohort terms, which showed the lowest DIC value and fastest convergence compared with all the other models tested. The software used for this analysis was WinBUGS 1.4 [27] which allowed us to carry out Bayesian inference using Gibbs sampling. WinBUGS code for this model is described in the Appendix.

In order to obtain the expected number of BC cases, three chains with 60 000 iterations have been run, discarding the first 10 000 burning samples. Samples from every 10th iteration have been stored (10 was the value for the thin parameter [27–32] in the run of the Markov chain Monte Carlo) in order to reduce autocorrelation in the sample and Monte Carlo errors [31, 32]. The plots of the sample trace and the Gelman and Rubin convergence diagnostics [31, 32] were used to check for convergence of the chains. R2WinBUGS library was used as an interface to run WinBUGS within R [33]. After convergence of all parameters was assessed, the posterior median value and posterior standard deviation for the expected number of BC cases in each age group were extracted.

**Results**

In Spain, 100 704 BC deaths were observed during the period 1977–2001. Figure 1 shows the pattern of age-specific BC mortality rates by birth cohort and period of death. This graphic shows the decrease of BC mortality in the last two 5-year periods for all age groups. An increase in BC mortality rates in women older than 60 years was detected, whereas BC mortality decreased for women younger than 44 years. Table 1 shows the age-adjusted BC mortality rates and their estimated annual percent changes (EAPCs) in the period 1977–2001. Different trends in BC mortality rates have been observed between periods 1977–1991 and 1992–2001. There is a significant increase in global BC mortality in all age groups until 1991 (EAPC 2.18%; 95% CI 1.99 to 2.39). The highest increase was observed among women older than 65 years (EAPC = 2.66%; 95% CI 2.26 to 3.09), whereas the lowest was detected in women younger than 44 years (EAPC = 1.38%; 95% CI 1.12 to 1.69). A significant decline in BC mortality rates was observed for all age groups after 1992 (EAPC = −2.67%; 95% CI −2.97 to −2.31), being smaller among women older than 65 (EAPC = −1.51; 95% CI −1.71 to −1.25).

Table 2 shows the model selection procedure for the APC analysis. A significant increase in deviance (ΔDEV) was achieved for the models which depart from the full APC model, which had the lowest AIC value (AIC = 631). This was an indicator that cohort and period effects should be taken into account. The ΔDEV was higher for the AC model (ΔDEV = 379.9) than for the age–period model (ΔDEV = 311.4), and this indicates that the period effect was found to be more important than the cohort effect. An APC analysis with data from 1977 to 1991 (Table 3), however, revealed that cohort effect was the most important factor to explain the variability of BC mortality rates during that period. In this last analysis, an AC model would be enough to explain variability of rates because a non-statistically significant ΔDEV between the APC (DEV = 13.9) and the AC (DEV = 16.1; P = 0.15) models was found. For that reason, the strength of the period effect during the study period 1977–2001 was due to the decrease in mortality trends from 1992 onwards.

Figure 2 depicts the age, period and cohort effects during the period 1977–2001. The age effect showed an exponential rising before the age of 50. After this age, there was a dramatic growth, climbing to a crude BC mortality rate near 90 cases per 100 000 women-years for the oldest age group analysed. The cohort
effect showed that women born between 1912 and 1952 (reference cohort) were at higher risk of death than those born after the 1960s, for whom the risk clearly declined. The period effect reached a peak in the third period, 1987–1991, and witnessed a sharp decrease after that period.

Table 1. Breast cancer mortality rates and annual percent change according to age groups 20–79 years during the period 1977–2001

<table>
<thead>
<tr>
<th>Global trend</th>
<th>Period</th>
<th>AAMR (Women)</th>
<th>EAPC (95% CI)</th>
<th>EAPR (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2000–2001</td>
<td>8651</td>
<td>22.52</td>
<td>–</td>
</tr>
<tr>
<td></td>
<td>1977–1991</td>
<td>55 545</td>
<td>2.18 (1.99 to 2.39)</td>
<td>–</td>
</tr>
<tr>
<td></td>
<td>1992–2001</td>
<td>45 159</td>
<td>2.67 (2.54 to 2.81)</td>
<td>–</td>
</tr>
<tr>
<td></td>
<td>1977–2001</td>
<td>100 704</td>
<td>0.58 (0.16 to 1.01)</td>
<td>–</td>
</tr>
</tbody>
</table>

Period, time interval where mortality trends rise or fall; AAMR, age-adjusted mortality rates; EAPC, estimated annual percent change extracted from an age + cohort model; 95% CI, 95% confidence interval; n, number of cases.

Table 2. APC model assessment for breast cancer mortality rates in Spain in the period 1977–2001

<table>
<thead>
<tr>
<th>Model</th>
<th>AIC</th>
<th>DEV</th>
<th>df</th>
<th>ΔDEV</th>
<th>Δdf</th>
<th>П</th>
</tr>
</thead>
<tbody>
<tr>
<td>APC</td>
<td>631</td>
<td>55.4</td>
<td>30</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>AC</td>
<td>1004.9</td>
<td>435.4</td>
<td>33</td>
<td>379.9</td>
<td>3</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>AP</td>
<td>914.4</td>
<td>366.8</td>
<td>44</td>
<td>311.4</td>
<td>14</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>A–drift</td>
<td>1460.3</td>
<td>918.7</td>
<td>47</td>
<td>863.3</td>
<td>17</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Age</td>
<td>1713.3</td>
<td>1173.2</td>
<td>48</td>
<td>1117.8</td>
<td>18</td>
<td>&lt;0.01</td>
</tr>
</tbody>
</table>

AIC, Akaike Information Criterion; DEV, deviance; ΔDEV, increase in deviance from the APC model; Δdf, increase in df from the APC model; П, P value of significance in increase of deviance and degrees of freedom; APC, full age–period–cohort model; AC, age–cohort model; AP, age–period model; A–drift, age–drift model; Age, age model; –, Reference model.

The effect showed that women born between 1912 and 1952 (reference cohort) were at higher risk of death than those born after the 1960s, for whom the risk clearly declined. The period effect reached a peak in the third period, 1987–1991, and witnessed a sharp decrease after that period.

Projections for the BC mortality in Spain have been carried out in four different scenarios related with different calendar periods. The first scenario used the period of 1977–2001 as calendar basis for future projections. There were subsequently incremented 5, 10 and 15 years from 1977 onwards, obtaining the following basis calendar periods: 1982–2001, 1987–2001 and 1992–2001. Table 4 shows the predicted number of BC cases for each future calendar period according to age. BC projections for the age groups 20–49 remained stable when 1977–2001 and 1982–2001 were the basis periods. The BC projection, on the basis of data from 1987–2001 and 1992–2001, increased substantially the posterior standard errors of the BC predicted cases. In women older than 50 years, however, BC projections showed an increase for each basis period (range from 10% to 40%), with a rise in the standard errors when calendar period increases.

Figure 3 shows projections of the BC mortality rates in Spain for the period 2002–2016 by 5-year age groups and birth cohorts, on the basis of the four previous scenarios. The observed BC mortality is represented by solid lines, whereas the projected BC mortality is represented by dashed lines. On the
basis of mortality data from 1977–2001, the projected BC mortality rates show a decrease for women younger than 60 years, whereas these remain stable for the other age groups. These BC projections were similar to those estimated from the 1982–2001 mortality data. The projected BC mortality rates (on the basis of BC mortality data from 1987–2001) showed a stabilisation for women <50 and a rise for those older, this last trend being more pronounced among women older than 65. These BC projections were similar in the last scenario, on the basis of the mortality data from 1992 to 2001.

**discussion**

This study has assessed recent time trends of BC mortality and projected trends for the next decade in Spain. An upward trend of 0.58% increase per year in age-adjusted BC mortality rates during 1977–2001 has been detected. A significant decrease of BC mortality since 1992 (EAPC = −2.67%), however, has been observed.

This study has shown that women born before the 1950s were at higher risk of death by BC than women born after that decade (cohort effect). Similar cohort effects were reported in a recently published study conducted among new member states of the European Union [3]. In that study, a decline in BC mortality among young and middle-aged women attributed to stage distribution was detected, whereas in elderly women a continued rise of mortality was observed [3]. Another Spanish study carried out in Andalusia during the period 1975–1999 showed results in agreement with ours. This study reported lower BC risk of death in women born after the 1960s [10].

The relevance of this cohort effect on BC mortality has been assessed during the period 1977–1991, before the implementation of BC-screening programmes in Spain. The role of the BC screening in BC mortality was evaluated during the period 1985–1997 in European countries such as England and Wales, Finland, Iceland, Netherlands, Scotland and Sweden [8], all of them with national screening programmes. A statistically significant decline in BC mortality in all age groups was found in all these countries. In the same study, countries without national BC screening, such as Czech Republic, Denmark, Estonia, France, Italy, Norway, Slovakia, Slovenia, Switzerland and Spain, did not show a decrease in BC mortality in women older than 65 years [8]. Several BC-screening programs in different regions of Spain were started between 1990 and 1996, covering the whole female Spanish population aged 50–69 since the beginning of 2000 [34]. The decline in BC mortality among young women detected in our study could not be attributed to the BC population-screening programmes. However, opportunistic screening as well as a progressive awareness of the need for early detection, both among physicians and among women, led to a more favourable stage distribution related with early detection [35, 36].

Some changes in lifestyles in the Spanish population could also explain the cohort effect observed in our study. Past consumption of meat and particularly beef meat seems to be associated with current BC mortality rates in Spain [37]. It has been also described that obesity increases the risk of BC in post-menopausal women [38]. A recent study estimated that

<table>
<thead>
<tr>
<th>Model</th>
<th>AIC</th>
<th>DEV</th>
<th>df</th>
<th>ΔDEV</th>
<th>Δdf</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>APC</td>
<td>374.1</td>
<td>13.9</td>
<td>10</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>AC</td>
<td>374.3</td>
<td>16.1</td>
<td>11</td>
<td>2.2</td>
<td>1</td>
<td>0.15</td>
</tr>
<tr>
<td>AP</td>
<td>417.4</td>
<td>81.1</td>
<td>22</td>
<td>67.2</td>
<td>12</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>A–drift</td>
<td>416.1</td>
<td>82.4</td>
<td>23</td>
<td>68.5</td>
<td>13</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Age</td>
<td>974.9</td>
<td>642.6</td>
<td>24</td>
<td>628.8</td>
<td>14</td>
<td>&lt;0.01</td>
</tr>
</tbody>
</table>

AIC, Akaike Information Criterion; DEV, deviance; ΔDEV, increase in deviance from the APC model; Δdf, increase in degrees of freedom from the APC model; P, P value of significance in increase of deviance and degrees of freedom; APC, full age–period–cohort model; AC, age–cohort model; AP, age–period model; A–drift, age–drift model; Age, age model; –, Reference model.

**Table 3.** APC model assessment for breast cancer mortality rates in Spain in the period 1977–1991

![Figure 2. Age, period and cohort effects for breast cancer mortality rates in Spain during the period 1977–2001.](image-url)

<table>
<thead>
<tr>
<th>Period/Age</th>
<th>20–49</th>
<th>50–64</th>
<th>265</th>
</tr>
</thead>
<tbody>
<tr>
<td>1977–1981 (n)</td>
<td>3754</td>
<td>6218</td>
<td>7408</td>
</tr>
<tr>
<td>1982–1986 (n)</td>
<td>3803</td>
<td>7592</td>
<td>9369</td>
</tr>
<tr>
<td>1987–1991 (n)</td>
<td>4449</td>
<td>8748</td>
<td>8690</td>
</tr>
<tr>
<td>1992–1996 (n)</td>
<td>4497</td>
<td>8824</td>
<td>9931</td>
</tr>
<tr>
<td>1997–2001 (n)</td>
<td>4000</td>
<td>7471</td>
<td>10 436</td>
</tr>
</tbody>
</table>

Projection basis 1977–2001

| 2002–2006 (n, SD) | 4012 (419) | 7635 (797) | 10 715 (1123) |
| 2007–2011 (n, SD) | 3961 (436) | 8193 (890) | 10 808 (1192) |
| 2012–2016 (n, SD) | 3746 (443) | 8390 (950) | 10 926 (1270) |

Projection basis 1982–2001

| 2002–2006 (n, SD) | 4482 (463) | 8261 (849) | 11 703 (1199) |
| 2007–2011 (n, SD) | 4538 (434) | 8876 (845) | 11 831 (1125) |
| 2012–2016 (n, SD) | 4382 (548) | 9183 (993) | 11 915 (1486) |

Projection basis 1987–2001

| 2002–2006 (n, SD) | 5376 (811) | 9554 (1447) | 14 029 (2127) |
| 2007–2011 (n, SD) | 5565 (1138) | 10259 (2013) | 14 375 (2799) |
| 2012–2016 (n, SD) | 5445 (1346) | 10887 (2747) | 14 664 (3641) |

Projection basis 1992–2001

| 2002–2006 (n, SD) | 5948 (1355) | 9769 (2210) | 14 669 (3319) |
| 2007–2011 (n, SD) | 6458 (1336) | 10635 (2184) | 14 754 (3055) |
| 2012–2016 (n, SD) | 6508 (1394) | 11519 (2485) | 14 958 (3152) |

BC, breast cancer; n, number of expected death cases by BC in Spain (posterior median); SD, posterior standard deviation of the number of expected death cases by BC in Spain.

approximately 80% of the Spanish population older than 60 years of age were overweight or obese [39]. In addition, the increase of BC mortality in older Spanish cohorts could be explained by other BC risk factors, such as alcohol consumption, oral contraceptives and hormonal replacement therapy [40–42]. On the contrary, the decline of some BC protector habits, such as breast-feeding, could explain the increase of BC incidence observed in women older than 40 in Catalonia during the period 1980–1999 [43].

The decline in BC mortality during the last two 5-year periods in all age groups detected in our study (period effect) suggests that early BC detection and the effect of various systemic adjuvant therapies have an effect on BC survival. A worldwide meta-analysis conducted among BC cases reported a 47% reduction of BC recurrences and 26% of BC mortality after tamoxifen implementation [44, 45]. Because tamoxifen was introduced in Spain in the early 1980s [46], this treatment could partially explain the fall of BC mortality since the mid-1990s.

Projected trends of BC mortality in Spain for the period 2002–2016 show that BC mortality in women younger than 50 will remain stable compared with mortality data from 1997 to 2001. The predicted increase in BC mortality projection among women older than 50 years, on the basis of the data from 1987 to 1992 and 1992 to 2001, could be mainly attributable to the ageing of female population as well as the expected increase, in absolute numbers, of female Spanish population in the years to come.

Projections of BC cases deceased among women older than 50 years showed high heterogeneity. A 10% increase on BC deaths between each 5-year periods (2002–2006, 2007–2011 and 2012–2016) is expected according to data from 1977 to 2001 and 1982 to 2001. The number of BC-deceased cases, however, dramatically increased (40%) when projections are estimated according to data from 1987 to 2001 and 1992 to 2001.

The interpretation of these results should take into account several limitations. The first one is the Spanish population growth related to immigration. In Europe, between 1990 and 2004, the most significant growth in the percentage of immigrants was observed in Luxembourg and in Spain [47]. The annual increase of immigrants in Spain could affect the precision of future population-estimated figures. In order to cope with this limitation, we have compared these trends with different population distributions and all of them showed the same pattern that we have described with the data used in this analysis. Second, the predicted number of BC deaths could be overestimated if improvements in treatment take place. As an example, it has recently been reported that trastuzumab improves BC survival in women with HER2-positive metastatic BC [48] and in the adjuvant treatment [49]. Improvements in BC treatment may entail changes in the natural history of this cancer, and its mortality could be modified. To avoid this limitation, the further step in prediction analyses should be to develop simulation models that incorporate the natural history of BC [50, 51]. Outcomes from these simulation models could then be used for forecasting (rather than projection) purposes of BC mortality. Forecasts use additional information in conjunction with the APC model, whereas projections extrapolate a model into the future [22]. This last aspect was the aim of our analysis, for which we assumed the limitation that current and past trends continue without change. A third limitation of our study is the possibility of underestimation of...
Our study predicts an increase in BC mortality in women older than 50 being mainly attributable to the ageing population which is sometimes neglected in interpreting predictions [52], and an increase, in absolute numbers, due to immigration. In addition, a proportion of the BC diagnosed will remain non-cured among older people, despite the improvements in BC-relative survival observed in the last decade [53, 54]. A study carried out in Finland suggested that BC diagnosed among women younger than 50 remains a chronic disease which affects prognosis for decades [55, 56]. This issue could increase the expected BC mortality in patients older than 50, and it should be reflected with an underestimation in the future BC-deceased cases. In Spain, studies of long-term BC survival should be carried out in order to assess BC curability. Outcomes of these studies would be also useful for future forecasting studies of BC mortality.

In Spain, BC incidence is increasing in women older than 40 years [43] making the projected BC mortality trends consistent with incidence data. This finding points out the need for further effort in BC prevention through screening in Spain, which has only been recently implemented in all territories and would have only a minor effect in the observed trends but a significant impact in the years to come. Changes in treatment could also have an impact in the projections of BC mortality in a positive direction. These projections could be useful in order to assess the consequences of cancer control policies in the most common form of cancer among women in both developing and developed countries [5]. Future forecasting studies should be carried out considering these new factors in the natural history of BC in Spain.

**appendix**

**autoregressive APC model for projections of mortality rates and expected number of deceased cases**

In order to smooth effects on each scale on time, Gaussian autoregressive prior models in the forward direction were proposed by Breslow and Clayton [57] and later by Berzuini and Clayton [58] and Bray [23–25]. In these models, it was assumed that second-order differences are independent normal covariates. Trends corresponding to age, period, and birth cohort were smoothed using second-degree autoregressive smoothing (non-parametric smoothing with autoregressive error component). For age, period, and cohort, these resulted in linear extrapolations.

Let $\alpha$, $\beta$, and $\gamma$ be the age, period, and cohort effects. In our final model, we have constrained the age effect, assuming that one second-order difference is estimated as the mean on the previous and subsequent second-order differences. The age effect in this APC parameterisation is defined as

$$\alpha_i | \alpha_j, \quad j \neq i \sim N(\mu_\alpha, \tau_\alpha),$$

$$\mu_\alpha = 2\alpha_1 - \alpha_3,$$

$$\mu_\beta = \frac{2\alpha_1 + 4\alpha_3 - \alpha_4}{5}.$$
\[
\mu_i = \frac{4\alpha_{i-1} + 4\alpha_{i+1} - \alpha_{i-2} - \alpha_{i+2}}{3},
\]
where \(\alpha_i\) being the effect of the \(i\)th age group \((i = 1, \ldots, A)\), \(\mu_i\) its prior mean value, \(\sigma_i\) its prior standard deviation and \(\tau_i\) its prior precision \((\text{inverse of the prior variance})\) [22]. Although precision of the parameters of the original APC Bayesian model was modelled through gamma prior distributions [22], uniform prior distributions for standard deviation of parameters of hierarchical models were recommended because it is expected that this would perform well unless the number of levels of the variable is approximately below five [59]. In addition, we have put two corner constraints to our model, \(\beta_1 = 0\) and \(\gamma_1 = 0\), assuming that the first period and first cohort are the reference ones.

WinBUGS code of the APC model with constraints on age parameters:

```r
# N: total of data; M: number of periods for projection;
# I: number of Age Groups
# J: Number of periods; K: number of cohorts
# N: total of data; M: number of periods for projection;
# 3 periods for projection with 12 age groups = 36 strata
ztotal.49.1 <- sum(pred.mu[1:6])
ztotal.49.2 <- sum(pred.mu[13:18])
ztotal.49.3 <- sum(pred.mu[25:30])
ztotal.64.1 <- sum(pred.mu[7:9])

ztotal.64.2 <- sum(pred.mu[19:21])
ztotal.64.3 <- sum(pred.mu[31:33])
ztotal.65.1 <- sum(pred.mu[10:12])
ztotal.65.2 <- sum(pred.mu[22:24])
ztotal.65.3 <- sum(pred.mu[34:36])

# Period effects: Corner constraint on the first period
for (k in 2:K){
  beta[k] ~ dnorm(0.0, taua);
}
beta[1] <- 0
taua <- pow(sigmamean, -2)
sigmamean ~ dunif(0.1, 100);

### Age constrained on the 2nd order differences
for (i in 3:(I-2)){
alphamean[i] <- (4*alpha[i-1] + 4*alpha[i+1] - alpha[i-2] - alpha[i+2])/6;
}
alphamean[I] <- 2*alpha[I-1] - alpha[I-2];
for (i in I-1){
  alphaprec[i] <- taua;
}
for (i in 1:I){
  alpha[i] ~ dnorm(alphamean[i], alphaprec[i]);
}
taua <- pow(sigmamean, -2);
sigmamean ~ dunif(0.1, 100);

### Cohort effects: Corner constraint on the first cohort
for (k in 2:K){
gamma[k] ~ dnorm(0.0, tauc);
}
gamma[1] <- 0
tauc <- pow(sigmamean, -2)
sigmamean ~ dunif(0.1, 100);
```

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References

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