Projecting mammographic screens

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Abstract

Objective—The purpose of mammographic screening is to reduce mortality from breast cancer. This study describes a method for projecting the number of screens to be performed by a mammographic screening programme, and applies this method in the context of New South Wales, Australia.

Method—The total number of mammographic screens was projected as the sum of initial screens and re-screens, and is based on projections of the population, rates of new recruitment, rates of attrition within the programme, and the mix of screening intervals. The baseline scenario involved: 70% participation of women aged 50–69 years, 90% return rate for the second and subsequent re-screens, 5% annual screens (95% biennial screens), and a specified population projection. The results were assessed with respect to variations in these assumptions.

Results—The projections were strongly influenced by: the rate of screening of the target age group; the proportion of women re-screened annually; and the rates of attrition within the programme. Although demographic change had a notable effect, there was little difference between different population projections. Standard assumptions about attrition within the programme suggest that the current target participation rates in NSW may not be achieved in the long term.

Conclusions—A practical model for projecting mammographic screens for populations is described which is capable of forecasting the number of screens under different scenarios.

Implications—Projections of mammographic screens provide important information for the planning and financing of equipment and personnel, and for testing the effects of variations in important operational parameters. Re-screening attrition is an important contributor to screening viability.

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Keywords: breast cancer; mammographic screening; public health screening; projections; rescreening

Breast cancer is the most common cause of death from cancer in women in most developed countries, including Australia. Mammography screening has become the standard approach to the secondary prevention of breast cancer in economically developed countries since the accumulation of sufficient overseas trial evidence of mortality reduction from regular screening. The implementation of mammography screening for populations is a complex and expensive task, and projections of mammographic screens into the future provide important information for the planning and financing of equipment and personnel.

The evolution of a mammographic screening programme may be described using three phases. Programmes start with initial screens (phase I—the initial phase). Then, after a period of years (depending on the length of the screening cycle), a significant number of re-screens are performed, with initial screens continuing to predominate until the programme reaches maximum penetration (phase II—the transitional phase). Penetration refers to the participation rate. Finally, the programme reaches maturity (phase III—the mature phase) where most mammographies are re-screens. The duration of the transitional phase (phase II) will depend on the rapidity of implementation of the programme, including whether various subpopulations are incorporated simultaneously or sequentially. However, the rate of recruitment in the transitional phase (phase II) is constrained by the requirement not to establish equipment and personnel that would be surplus to mature phase (phase III) requirements.

Systematic population mammographic screening in New South Wales (NSW) women started in 1991–92; implementation was staged such that all geographic subpopulations had access by 1995–96. Women aged 50–69 years are actively recruited, but women aged under 50 years or above 70 years are screened on request.

This paper describes a method for projecting the number of screenings to be performed by a mammographic screening programme, and the application of this method to the projection of the number of mammographic screenings to be undertaken by the state mammographic screening service in NSW, Australia. The method illustrated combines projections of the populations of NSW women by age group with assumptions for proportions of women screened by age group which depend on the likely penetrance of the programme. Numbers of re-screens are calculated from initial screens after discounting according to different attrition scenarios. The sensitivity of results to the choice of plausible assumptions made and impact on participation rates are discussed.

Methods

The projection method allows the number of mammographic screenings to be performed to be affected by demographic factors, particularly changes in the numbers of women in the target mammographic screening ages, by programme design factors, particularly programme recruitment targets and promotion strategies, and by rates of attrition within the
projecting mammographic screens

Demographic changes, particularly changes in the numbers of women in the target mammographic screening age groups, will affect the number of screens to be performed. The projections were made using Australian Bureau of Statistics (ABS) Series II population projections. Series II projections assume a gradual decline in mortality, a level of international migration that is slightly below that experienced in 1995–96 and a net loss caused by interstate migration from NSW at levels similar to those in the early 1990s. Both ABS Series I and II projections assume a gradual decline in mortality (to life expectancy at birth of 82 years for males and 86 years for females by 2051), and a fall in the total fertility rate to 1.75 per woman by 2005–06 (followed by stability). ABS Series II assumes net international migration to NSW of around 30 000 per annum, while Series I assumes a larger a level of international migration at 38 500. Although the assumed net interstate migration loss from NSW is slightly higher per annum in Series I than Series II (17 v 15 000), ABS Series I produces higher population estimates.

The projection method partitions the number of screenings into two components: initial screens (the first time a woman is screened by the mammographic screening programme) and re-screens. Women’s age specific propensities to have initial screens are affected by the programme’s recruitment targets and promotional material, which are aimed primarily at women in the 50–69 year age group. The NSW programme sends personalised invitations for mammographic screening to women aged 50–69 years, identified from the electoral register; women aged 40–49 and 70+ can be screened on request. The numbers of re-screens will be affected by past numbers of screens (both initial and re-screens), by the time intervals between screens, and by attrition within the programme—specifically if and when women present for a re-screen. The numbers of initial screens and numbers of re-screens by re-screen round are projected separately, and then added to give the projected total number of screenings.

PROJECTING NUMBERS OF INITIAL SCREENS

The number of initial programme screens is projected as the sum of the products of projected numbers of women of different ages, and projected propensities of women of different ages (40–49 years, 50–69 years, and ≥70 years) to have initial screens. The standard method for projecting the sizes of the target age groups—the cohort component method— involves adjusting the existing age distribution of women in NSW for future changes in women’s ages over time and for changes in numbers of women in different age groups due to mortality, international migration and interstate migration.

Numbers of women in an age group who have been “ever screened” can be readily estimated from past numbers of initial screens by age and year of screen. In the NSW projections, rates of initial screens have been based on estimates of the percentages of women in particular age groups who have ever had a mammographic screening provided by the national programme without cross-state-border matching. Assumptions for projections of initial screening rates have been formulated in two stages. In the first stage, women are recruited for initial screens until the percentage of women in this group who have been “ever screened” reaches the assumed maximum. In the second stage, the percentage of women in an age group who have been “ever screened” is maintained at the target level by screening new entrants to the age group. The projected numbers of screenings during the first stage depends on the number of years taken to achieve target levels.

The basic projection method may be extended to allow for the effects of mammographic screening outside the programme. In Australia, mammograms in the private sector are only rebatable under Medicare (the Commonwealth Government funded health scheme) if they are for diagnostic purposes, but anecdotal evidence suggests that a proportion of these mammograms is for screening purposes. For the screening projections shown in this paper, we have decided not to discount for private sector mammography (some of which is likely to be screening), but we have shown the possible effects of private sector screening in the calculation of biennial participation rates.

PROJECTING NUMBERS OF RE-SCREENS

The projected number of re-screens in a particular year is estimated from the numbers of initial screens and re-screens for years before that year, the mixture of different screening interval lengths (lengths of time between successive re-screens) and various assumed attrition rates from the programme between screening rounds. In the scenarios presented, the predominant screening interval is two years, but proportions of annual re-screens (because of family history) are incorporated into the model.

Attrition rates may differ by the number of previous screenings a woman has had. The NSW projections assume a higher attrition rate between the first and second screenings than between later screenings. Our initial analysis of attrition rates for a cohort of 125 069 women first screened in NSW between January and December 1994 shows that, from initial screen to first re-screen, 73.2% return within 30 months of the initial screen; reliable assessment of the rates of return after subsequent re-screens is not yet possible for this cohort. The projected number of re-screens is calculated by projecting separately the number of first re-screens and the number of second or subsequent re-screens, and then summing up the results. The projected number of first re-screens in a particular year is calculated by summing over the various screening interval lengths the products of propensities to submit for a first re-screen after a screening interval of a certain number of years and the number of...
Table 1 Assumptions used in the scenarios for mammographic screening projections for NSW 1997–2008

<table>
<thead>
<tr>
<th>Variable</th>
<th>Baseline scenario</th>
<th>Other scenarios</th>
</tr>
</thead>
<tbody>
<tr>
<td>Screening percentages</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Percentage of females aged 40–49 to be ever screened by 2000–01</td>
<td>40</td>
<td>70</td>
</tr>
<tr>
<td>Percentage of females aged 50–69 to be ever screened by 2000–01</td>
<td>70</td>
<td>60 or 80</td>
</tr>
<tr>
<td>Percentage of female immigrants aged 50–69 screened on entry</td>
<td>70</td>
<td>60 or 80</td>
</tr>
<tr>
<td>Percentage of female immigrants aged 70–79 screened on entry</td>
<td>15</td>
<td></td>
</tr>
<tr>
<td>Biennial re-screening rate</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Percentage of initial screens re-screened within next two years</td>
<td>75</td>
<td></td>
</tr>
<tr>
<td>Percentage of first re-screens to have second re-screen within next two years</td>
<td>90</td>
<td>75 or 80</td>
</tr>
<tr>
<td>Percentage of second or higher order re-screens to have further re-screen in following 2 years</td>
<td>90</td>
<td>75 or 80</td>
</tr>
<tr>
<td>Population projections*</td>
<td>ABS Series II</td>
<td>ABS Series I</td>
</tr>
<tr>
<td>Percentage of female immigrants aged 50–69 to be ever screened by 2000–01</td>
<td>15</td>
<td></td>
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<td>90</td>
<td>75 or 80</td>
</tr>
<tr>
<td>Time to completion of initial screens</td>
<td>4 years (2000–01)</td>
<td></td>
</tr>
</tbody>
</table>

*For definitions of ABS population projections, see Methods.

Initial screens for that number of years before the projection year. The projected number of second or subsequent re-screens is calculated in a similar way.

ASSUMPTIONS USED FOR THE PROJECTIONS
The main projection is termed the baseline projection. Each of the sets of assumptions used for the other projections differs from that used for the baseline projection for one input variable only. All projections of numbers of mammographic screens are for the period 1997–98 to 2007–08 with actual data used until 1996–97.

THE BASELINE PROJECTION
The baseline projection was developed using standards recommended in the National Accreditation Requirements (NAR) of BreastScreen Australia and data currently available in the NSW programme. The assumption adopted was formulated in terms of “ever screened” rates and was based on a target recommended by a steering committee for the programme, derived from the experience of international and local trials. The baseline scenario assumes 70% of women aged 50–69 years are to be screened at least once, with this figure to be reached by the end of the 2000–01 financial year. It further assumes that the numbers of initial screens to raise penetrance to this level over the four years 1997–98 to 2000–01 would be uneven, with more initial screenings in the earlier years. It also assumes the upper limit for the percentage of 49 year olds who have ever been screened will be 40%. The projection assumes 70% of migrant women in the 50–69 year group and 15% of migrant women in the 70–79 year group are screened in the year of entry. The annual re-screen rate is assumed to be 5%, with the balance having twice yearly screens. NSW data show that, for a cohort of 125 069 women first screened between January and December 1994, of those women who returned for a first re-screen within 30 months 6.2% did so within 18 months. There also is evidence of a fairly small number of women returning for a re-screen after an interval of more than 30 months. The model has been adjusted to incorporate the effects of “irregular” attendance. Future re-screen rates used in the baseline projection are based on the NAR standard that at least 75% of women who present for an initial screen will come back for their first re-screen within two years of the initial screen. Actual data from the 1996 BreastScreen Australia statistical report confirm that the initial screen to first re-screen retention rate (74%) is very close to that used in the baseline projection.

For the baseline projection, we notionally assumed that 90% of women who present for a re-screen in each round will return in the next two years for the subsequent screening round.

OTHER SCENARIOS
Variations include: notional screening proportion of women aged 50–69 years was varied from the 70% used in the baseline to 60% and to 80%; return for a subsequent re-screen was changed from the baseline 90% to 80% and to 75%; and the proportion of women who are re-screened annually was varied from the baseline 90% to 0% and 14%. The projected increase in the sizes of the key population age groups also was varied to illustrate the effects of different future levels of international and internal migration and for female mortality. Table 1 summarises the various projection assumptions used.

BIENNIAL SCREENING PARTICIPATION RATES
Biennial screening participation rates for women aged 50–69 years were calculated for 1997–2008 using the baseline scenario assumptions and different methods for estimating participation, depending on whether private sector mammography was ignored or incorporated into numerators or denominators.

results

Baseline Scenario
Using the assumptions of the baseline scenario the total screens by the programme increase rapidly to around 292 000 per year at 1999–2000, and then increase gradually to around 297 000 per year by 2007–08 (table 2). The initial screens peaked in 1994–95 and are projected to decline to 33 000 per year in 2001–02 with a slow recovery to 35 000 per year in 2007–08. Re-screens are projected to reach 260 000 per year in 2001–02, and then slowly increase to 263 000 per year in 2007–08. The age profile of women having screens grows.
The assumptions used in the baseline scenario (see fig 1); ABS Series II population projections were used (see Methods).

The projections show how the activity of the mammographic screening programme is at first dominated by initial screens, then, as the programme matures, the main activity centres on re-screening, with a stable low level of initial screens changing only gradually with the gradual change in numbers of unscreened women moving into the screening age groups. The rapid growth in projected numbers of mammograms before 2001 is due to a combination of the assumed rising penetrance rates and the projected rapid growth of the target age groups. The continuation of the growth in projected mammograms after 2001, when maximum penetration for initial screens per cohort is assumed to have been reached, is mostly due to the growing numbers of re-screens, a legacy of the past rises in initial screen rates and demographic growth in the key age groups—the age groups 50–69 years are projected to increase by 27% between 1997 and 2006.

VARIATIONS ON THE BASELINE SCENARIOS

The results of the projection are strongly influenced by the ultimate rate of screening of the target age group. Increasing or decreasing the maximum penetrance of the 50–69 years age group by 10% from the baseline 70% will increase or decrease the number of screens performed in 2007–08 by 35 000.

The proportion of women who are re-screened annually also has a significant effect on the number of mammograms performed (table 2). Varying the proportion of women screened between 0% and 14% produces a difference of 26 000 screens in 2007–08 (between 10 000 screens below the baseline projection and 16 000 above).

The projected numbers of mammograms are heavily affected by attrition rates within the programme. Moreover, the effects of attrition rates on the number of screens performed become compounded over time. For example, if the propensity for women who have been re-screened to return for a subsequent re-screen is reduced from the 90% level used in the baseline scenario to 80%, the projected number of mammograms performed is 48 000 lower in 2000–01 and 98 000 lower in 2007–08. Moreover, under the higher attrition scenario the projected number of mammograms declines after 1998–99 (fig 2). Projected numbers of mammograms are even lower for a scenario in which the attrition is 25% between each re-screen after the first.

Future demographic change also has a significant effect on the results of the projection (table 2). Were the population to remain constant at 1996 levels the projected number of screens would be 18 000 lower in 2000–01 and 32 000 lower in 2007–08 based on ABS Series II projections. The impact of demographic change increases over time, both because of the continued increase of the target groups and a compounding of the effects of past demographic changes. The choice of population projection series is of minor importance to the results of the projection—if ABS Series I predictions had been used, which assume a higher level of net international and interstate migration than for Series II, the maximum difference in population for the projection period would have been an increase of

### Table 2 Projections of total screens by the mammographic screening program in NSW women 1997–2008 under variations from the baseline scenario

<table>
<thead>
<tr>
<th>Financial year</th>
<th>Initial mammograms (’000s)</th>
<th>Re-screening (’000s)</th>
<th>Total mammograms (’000s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1997–98</td>
<td>214.4</td>
<td>262.3</td>
<td>476.7</td>
</tr>
<tr>
<td>1998–99</td>
<td>263.2</td>
<td>280.5</td>
<td>543.7</td>
</tr>
<tr>
<td>1999–2000</td>
<td>285.1</td>
<td>298.8</td>
<td>583.9</td>
</tr>
<tr>
<td>2000–01</td>
<td>293.4</td>
<td>309.3</td>
<td>602.7</td>
</tr>
<tr>
<td>2001–02</td>
<td>292.7</td>
<td>314.6</td>
<td>607.3</td>
</tr>
<tr>
<td>2002–03</td>
<td>295.1</td>
<td>316.2</td>
<td>611.3</td>
</tr>
<tr>
<td>2003–04</td>
<td>297.2</td>
<td>314.1</td>
<td>611.3</td>
</tr>
<tr>
<td>2004–05</td>
<td>297.7</td>
<td>313.0</td>
<td>610.7</td>
</tr>
<tr>
<td>2005–06</td>
<td>297.2</td>
<td>313.7</td>
<td>610.9</td>
</tr>
<tr>
<td>2006–07</td>
<td>297.7</td>
<td>313.7</td>
<td>611.4</td>
</tr>
<tr>
<td>2007–08</td>
<td>297.7</td>
<td>313.7</td>
<td>611.4</td>
</tr>
</tbody>
</table>

*Assumptions used in baseline scenario (see fig 1); ABS Series II population projections were used (see Methods).
under the baseline scenario, refer to legend for fig 1.

Baseline scenario with variation in the attrition after the first re-screen. For assumptions used—such as for attrition rates and ever, it may be appropriate to vary the assumptions made for attrition rates and related expenditures. Our approach also allows the projected number of mammographic screenings to be partitioned into initial screenings and re-screenings. Such information is important because—for example, assessment rates and cancer detection rates following initial screens and re-screens differ considerably—and so the separate projection of initial screens and re-screenings will facilitate the accurate projection of numbers of assessments, cancers detected and related expenditures.

Our paper describes a “flow-type” or cohort method for projecting mammographic screens. An alternative approach would be to use a “participation rates” projection method in which projected numbers of screenings are calculated as the sum of the products of projected numbers of women by age and assumed levels of future age specific mammographic programme participation rates—that is, proportions of women in an age group having a mammogram in any given year. The difference between the two approaches is that in our model, the programme participation rate is viewed as the product of a pattern of new recruitment to the programme and the retention of women within the programme. Our approach is more complex, but allows the sensitivity of results to a wider range of assumptions to be studied. For example, unlike the “participation rates” approach, the flow-type method that we applied is able to illustrate the critical importance of attrition rates on the future number of mammograms performed. Our approach also allows the projected number of mammographic screenings to be partitioned into initial screenings and re-screenings. Such information is important because—for example, assessment rates and cancer detection rates following initial screens and re-screens differ considerably—and so the separate projection of initial screens and re-screenings will facilitate the accurate projection of numbers of assessments, cancers detected and related expenditures.

Over the next five years, mammographic screening participation rates for women aged 50–69 are likely to fall without a significant increase in initial screen penetration or a

Discussion
The projection of mammographic screenings provides important intelligence that assists the preparation of strategic plans for mammographic screening programmes. Estimates of the future number of mammograms provide a basis for long term budget forecasts and for estimating the capital input needs of the screening program. For example, the number of mammogram machines that will be required may be estimated by dividing projected numbers of mammograms by estimates of the number of mammograms performed per machine. Estimates of future numbers of women recalled after a screen for medical assessment of a suspicious lesion are prepared using projected numbers of initial screens and re-screens and multiplied by assumed levels of future assessment rates for initial screens and re-screens—that is, the percentages of initial screens and re-screens leading to recalls. Projections of likely programme outputs, such as estimates of numbers of cancers detected and the programme’s effect on breast cancer mortality, may also be prepared based on projections of mammographic screenings.

The projection method described here is also used to generate projections of numbers of mammographic screening requirements for populations below state level. Once the projection models have been specified and the spreadsheet programmes written, it is a simple task to insert data for subpopulations. However, it may be appropriate to vary the assumptions used—such as for attrition rates and annual re-screen rates—between the various subpopulations.

The results of our projections illustrate the effects of demographic changes, programme screening targets, annual re-screen rates, and attrition rates on numbers of mammograms to be performed. Particularly striking is the sensitivity of the number of mammograms to rates of re-screening, and the compounding of the effect of this attrition rate on the number of mammograms over time, shown by our projections. Should the re-screen rate drop to 80%, the total number of screens declines considerably in the years beyond 2000–01. Therefore, considerable emphasis needs to be devoted to retaining women in the screening programme. It is critical that national level, state level, and service level research into re-attendance behaviour is implemented urgently. In view of the sensitivity of numbers of screens to changes in initial screen rates and re-screen rates, a continuous monitoring of trends in these model parameters and regular revision of projections in the light of changes is needed.

Our projections illustrate the considerable impact that demographic changes have on the demand for mammographic screening in NSW. The most important demographic factor is the considerable momentum for growth in the target age groups for mammographic screening already present in the current age structure of the NSW population.

2000 women (accounting for at most 0.6% more screens).

Biennial rates of mammographic screening vary by up to seven percentage points depending on the method used to estimate population participation. The highest and probably most realistic participation is obtained by the addition of private sector screening mammographies to women screened by the screening service, divided by the number of eligible women (aged 50–69 years).

The results of our projections illustrate the considerable momentum for growth in the target age groups for mammographic screening already present in the current age structure of the NSW population.

Our paper describes a “flow-type” or cohort method for projecting mammographic screens. An alternative approach would be to use a “participation rates” projection method in which projected numbers of screenings are calculated as the sum of the products of projected numbers of women by age and assumed levels of future age specific mammographic programme participation rates—that is, proportions of women in an age group having a mammogram in any given year. The difference between the two approaches is that in our model, the programme participation rate is viewed as the product of a pattern of new recruitment to the programme and the retention of women within the programme. Our approach is more complex, but allows the sensitivity of results to a wider range of assumptions to be studied. For example, unlike the “participation rates” approach, the flow-type method that we applied is able to illustrate the critical importance of attrition rates on the future number of mammograms performed. Our approach also allows the projected number of mammographic screenings to be partitioned into initial screenings and re-screenings. Such information is important because—for example, assessment rates and cancer detection rates following initial screens and re-screens differ considerably—and so the separate projection of initial screens and re-screenings will facilitate the accurate projection of numbers of assessments, cancers detected and related expenditures.

Over the next five years, mammographic screening participation rates for women aged 50–69 are likely to fall without a significant increase in initial screen penetration or a

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significant reduction in rates of attrition between re-screen rounds.

Methodological appendix

SPECIFICATION OF THE MODEL

If \( S_t \) denotes the projected total number of screens in some future year \( t \) and \( I_t \) and \( R_t \) denote the projected number of initial screens and re-screens that year, then

\[
S_t = I_t + R_t
\]

where

\[
I_t = \sum x (P_{x,t} \times i_{x,t})
\]

Where \( P_{x,t} \) denotes the projected number of women aged \( x \) at future time \( t \) and \( i_{x,t} \) denotes the assumed proportion of women aged \( x \) at time \( t \) who are recruited for an initial screen.

And

\[
R_t = \sum R_{j,t}
\]

where \( R_{j,t} \) denotes the number of women who have their \( j \)th re-screen in year \( t \) with

\[
R_{j=1,t} = \sum I_{t-k} \times r_{1,k,t}
\]

\[
R_{j=2,t} = \sum R_{j=1,k} \times r_{j,k,t}
\]

Where \( r_{j,k,t} \) denotes the proportion of women having their \( j \)th re-screen in year \( t-k \) who have their next re-screen in year \( t \). In the illustrative projections we assumed subsequent re-screens occurred either one or two years after the preceding screen. So the values of \( r_{j,k,t} \) are zero for all values of \( k \) greater than or equal to three. A woman’s probability of returning for a re-screen after a particular interval will be related to the length of her preceding screening intervals. The parameters of formula (5) should reflect this.

Substituting from equations (4) and (5) into equation (3) gives us

\[
R_t = \sum I_{t-k} \times r_{1,k,t} + \sum \sum R_{j=1,k} \times r_{j,k,t}
\]

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