The Cost-effectiveness of Mammographic Screening Strategies

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Objective.—To compare and analyze the cost-effectiveness of different mammographic screening strategies.

Design.—A computer simulation model was developed to compare mammographic screening with observation without screening. Cost-effectiveness was expressed as marginal cost per year of life saved (MCYLS) and was calculated for the following mammographic screening strategies: (1) annual for ages 40 to 79 years; (2) annual for ages 50 to 79 years; (3) biennial for ages 50 to 79 years; (4) annual for ages 40 to 49 years with biennial for ages 50 to 79 years; (5) annual for ages 40 to 64 years with biennial for ages 65 to 79 years; (6) biennial for ages 40 to 49 years with annual for ages 50 to 79 years; and (7) annual for high-risk and biennial for normal-risk women aged 40 to 49 years with annual for ages 50 to 79 years.

Data Sources.—The probability and cost of all outcomes were established from previously published data or community experience.

Results.—The most cost-effective screening strategy is biennial mammography for women aged 50 to 79 years, with an MCYLS of $16 000. Adding annual mammography for women aged 40 to 49 years increases the MCYLS to $20 200, but is more cost-effective than other tested protocols that included women in their 40s; annual mammography for ages 40 to 49 years with biennial for ages 50 to 79 years is also more cost-effective than annual mammography for ages 50 to 79 years.

Conclusion.—Screening programs that include women in their 40s can be as cost-effective as some that exclude such women. Choice of a screening strategy depends on financial resources and desired effectiveness.

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MAMMOGRAPHIC screening is effective in reducing deaths from breast cancer, yet the optimal screening strategy remains unknown. There is controversy regarding the ages at which women should undergo mammography and the necessary frequency of such testing. The American Cancer Society and 10 other national organizations support mammographic screening every 1 to 2 years between the ages of 40 and 49 years with annual screening beginning at age 50 years.[1] The National Cancer Institute has rescinded its support for these guidelines. The American Academy of Family Practice recommends annual screening for women aged 50 to 75 years. The US Preventive Services Task Force recommends annual or biennial screening for ages 50 to 75 years.[2] Medicare reimburses for screening mammograms on a biennial basis for older women.

Studies have shown that the lead time gained with mammographic screening in women aged 40 to 49 years is 12 to 24 months,[3,4] while in women older than 50 years it is 3.5 to 4 years.[3] These data have led some authorities to suggest that the most effective screening strategy is annual mammography for younger women with biennial screening for those aged 50 years and older.[3-5]

The variety of mammographic screening strategies advocated by different experts and organizations are mainly based on differing views of the efficacy of mammography in reducing mortality from breast cancer. In this time of increasing concern about the cost of health care, consideration must also be given to the cost-effectiveness of different mammographic screening strategies. In this study, a computer model was used to assess the cost-effectiveness of a variety of possible mammographic screening strategies. When combined with data on effectiveness, this information may be useful for establishing mammographic screening policies.

MATERIALS AND METHODS

Study Model

A Markov model was developed to compare two hypothetical populations of women—one undergoing mammographic screening for breast cancer and the other undergoing observation without screening. A commercially available software product (Smltree, Version 2.9, James Hollenberg, Roslyn, NY) was used to generate the model and to tabulate all costs and benefits accrued in each group. All outcomes (states of health) for both screened and unscreened women during each year from the beginning age of screening to age 79 years were included. The basic model has been described in detail and validated elsewhere.[6]

In this model, women undergoing mammographic screening could have positive or negative results of mammography. Outcomes for those with positive studies included biopsy or short-interval (6 months) follow-up mammography. In the group undergoing biopsy, it was assumed that 50% had surgical biopsies, 50% had needle-core biopsies, and the accuracy of these two procedures was equal.[7] Biopsies could be benign or malignant. If short-interval follow-up mammography showed the lesion to be unchanged, it was assumed that the woman would resume her annual screening schedule 6 months later. Women with diagnoses of malignancy were assumed to undergo definitive treatment. Outcomes (states of health) in these women included death from breast cancer, death from other causes, and presentation for annual screening mammography the next year. Women with negative mammograms could die of other causes, develop an interval palpable breast mass (which could be benign or malignant), or present for annual screening mammography the next year.

In the observed group, the outcomes included continued observation without mammographic screening, death from a cause other than breast cancer, and development of a palpable breast mass with subsequent testing and either a benign or malignant diagnosis. Those with breast cancer were then assumed to undergo annual screening mammography.

The probability and cost of each outcome were established from previously published data[8-16] or community experience (Tables 1 through 3). We used data from the National Cancer Institute[17] for the following age-specific incidences of breast cancer per 100 000 population: 40

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to 44 years, 129.4; 45 to 49 years, 159.4; 50 to 54 years, 220.0; 55 to 59 years, 261.6; 60 to 64 years, 330.7; 65 to 69 years, 390.7; 70 to 74 years, 421.8; and 75 to 79 years, 461.4. The prevalence of breast cancer at the first screen for 40-year-old women was 209 breast cancers per 100 000 women; when screening began at age 50 years, the prevalence was increased to 467 cancers per 100 000 women.[18] Deaths from causes other than breast cancer were determined by subtracting age-specific breast cancer death rates from overall age-specific death rates.

Cost-effectiveness Analysis

Cost-effectiveness is expressed as marginal cost per year of life saved (MCYLS). It is determined by dividing the marginal cost of screening (the difference between the total costs for screening and the total costs for observation over the period encompassed by the model) by the marginal effectiveness (the difference between years of life accumulated in the screened group and years of life accumulated in the observed group).

The MCYLS was calculated for each of the following screening strategies: (1) annual mammography for ages 40 to 79 years; (2) annual mammography for ages 50 to 79 years; (3) biennial mammography for ages 50 to 79 years; (4) annual mammography for ages 40 to 49 years with biennial mammography for ages 50 to 79 years; (5) annual mammography for ages 40 to 64 years with biennial mammography for ages 65 to 79 years; (6) biennial mammography for ages 40 to 49 years with annual mammography for ages 50 to 79 years; and (7) annual mammography for high-risk women and biennial mammography for normal-risk women age 40 to 49 years with annual mammography for ages 50 to 79 years.

Reductions in breast cancer mortality among screened women (Table 4) and interval cancer rates (Table 5) were varied by age and screening interval, according to published data.[4,9,19-25] Since there is controversy about the effect of mammographic screening on women aged 40 to 49 years, three sensitivity analyses were performed; the assumed reduction in breast cancer mortality for this age group was varied from the baseline of 4% up to 20% for biennial mammographic screening, while the breast cancer mortality reduction in women aged 50 to 79 years screened annually was held constant and MCYLS was calculated over this range of reductions in mortality. In a separate analysis, the reduction in mortality among women aged 40 to 49 years undergoing annual screening was varied from the baseline of 23% down to 4% while the breast cancer mortality reduction with biennial screening in ages 50 to 79 years was held constant; MCYLS was also calculated over this range to illustrate the sensitivity of cost-effectiveness to different assumed breast cancer mortality reductions among screened women aged 40 to 49 years. In the third analysis, annual mammography for women aged 40 to 79 years was examined; the reduction in breast cancer mortality among screened women in their 40s was varied from the baseline of 23% down to 4%, while the reduction in mortality for screened women aged 50 years and older was held constant.

For the strategy using annual screening for high-risk women in the younger age group, 7% of women aged 40 to 49 years were assumed to be at high risk because of a significant positive family history of breast cancer.[26] The risk of breast cancer was assumed to be increased by 2.4 times in this group[26,27]; the risk in the women without a positive family history was comparably adjusted downward so that total population incidence of the disease remained constant.

All results are expressed in US dollars and were rounded to the nearest \$100. Discounting was not used in the primary analysis; however, the effect of discounting both costs and years of life saved at 5% per year was evaluated.

Table 1.—Asymptomatic Women in Screening Mammography Program

Assumption (Reference)	P
Positive predictive value of biopsy based on mammography (Basset et al[8])	.31
False-negative mammogram result (Baker[9])	.09
Suggestion of short-interval follow-up at prevalence screen (community experience)	.09
Suggestion of short-interval follow-up at incident screen (community experience)	.03
Biopsy because of change within 1 year (Sickles[10])	.007
Cancer diagnosed within 1 year in patients undergoing short-interval follow-up (Sickles[10])	<.001

Table 2.—Women in Observation Program With Palpable Masses

Assumption (Reference)	P
Cyst that requires no biopsy (Ellis and Cox[11])	.22
Mass that requires biopsy (Ellis and Cox[11] and Donegan[12])	.78
Positive predictive value for biopsy (Bassett et al[8])	.34
Death from breast cancer in those with the disease (US Dept of Commerce[13])	.25

Table 3.—Cost of Procedures

Procedure (Reference)	Cost, \$
Mammography*	84
Fine-needle aspiration of palpable mass (community experience)	150
Needle core biopsy of occult lesion (community experience)	850
Excisional biopsy of occult lesion (Parker et al[14] and Schmidt et al[15])	2800
Excisional biopsy of palpable lesion (community experience)	2400
Definitive treatment (Eddy et al[16])	6100

*Includes prorated cost of breast ultrasound (\$150 per examination) for 7% of patients, as well as additional mammographic views (\$50 per examination) for 5% of patients. Base cost of screening mammogram was \$75.

Table 4.—Reduction in Breast Cancer Mortality Among Screened Women

	Assumed Mortality Reduction, % (Reference)	
Age, y	Annual Mammography (Shapiro et al[19])	Biennial Mammography
40-49	23	4 (Sickles and Kopans[20] and Fletcher et al[21])
50-59	32	30 (Roberts et al[22] and Tabar et al[23])
60-69	32	27 (Tabar et al[23] and Anderson et al[24])
70-79	32	23 (Tabar et al[23])

Table 5.—Breast Cancers Diagnosed in Interval Between Mammographic Screenings

	Assumed Portion of Interval Cancers (Reference)	
Age, y	Annual Mammography (Tabar et al[4] and Baker[9])	Biennial Mammography (Tabar et al[4] and Ikeda et al[25])
40-49	0.29	0.42
50-59	0.14	0.29
60-69	0.14	0.21
70-79	0.18	0.19

RESULTS

The MCYLS was calculated for each of the screening strategies as compared with observation (Table 6). The most cost-effective screening strategy is biennial mammography for women aged 50 to 79 years, with a MCYLS of \$16 000. Adding annual mammography in women aged 40 to 49 years increases the MCYLS to \$20 200. The least cost-effective screening strategy is that in which high-risk women aged 40 to 49 years receive annual mammography while normal-risk women in the same age group receive biennial examinations and all women aged 50 to 79 years are screened annually; the MCYLS for this strategy is \$31 900.

Differences in MCYLS result from differences in marginal costs attributable to screening and from differences in marginal effectiveness (years of life saved) (Table 6). Differences in marginal cost are mainly attributable to the number of mammograms performed. The strategy with the greatest marginal cost was annual mammography from ages 40 to 79 years. Marginal costs were decreased by 62% if women received biennial mammography only between the ages of 50 and 79 years, but marginal effectiveness was also lowered by 36%.

The marginal effectiveness for each screening strategy changed as a result of differences in mortality reduction with different screening intervals. Marginal effectiveness was highest for the group receiving annual mammography from ages 40 to 79 years. It was reduced by 13% for annual mammography between ages 40 and 49 years with biennial mammography between ages 50 and 79 years. Marginal effectiveness was lowest for biennial mammography from ages 50 to 79 years.

For the strategy with the highest MCYLS (annual screening in high-risk women and biennial screening in normal-risk women aged 40 to 49 years with annual screening from ages 50 to 79 years), marginal costs were 13% lower than if mammography were performed annually from ages 40 to 79 years, but years of life saved were decreased by an even greater percentage (26%).

The strategy proposed by some experts (annual screening for ages 40 to 49 years and biennial screening at 50 years and older) is more cost-effective than the strategy currently recommended by the American Cancer Society (annual screening in high-risk women aged 40 to 49 years, biennial screening in normal-risk women aged 40 to 49 years, and annual screening in ages 50 or older). This increase in cost-effectiveness is attributable to a 26% reduction in marginal cost coupled with a 17% increase in marginal effectiveness.

Since the magnitude of the reduction in breast cancer mortality in women aged 40 to 49 years is not known with certainty, the MCYLS was calculated for a range of mortality reductions for the following screening strategies: (1) annual mammography in women aged 40 to 79 years, (2) annual mammography in women aged 40 to 49 years with biennial mammography in women aged 50 to 79 years, and (3) biennial screening in women aged 40 to 49 years with annual examinations in women aged 50 to 79 years (Table 7).

Discounting increases the MCYLS of all screening strategies, but it has a greater effect on protocols that include women in their 40s. Discounted at 5% per year, the MCYLS of biennial mammography in ages 50 to 79 years rises to $17 900; for annual mammography in ages 50 to 79 years, the discounted MCYLS is $28 200. For annual screening in ages 40 to 49 years with subsequent biennial screening until aged 79 years, the discounted MCYLS is similar ($28 400); this strategy continues to be the most cost-effective of those that include women in their 40s. When discounting is used, annual screening in high-risk women in their 40s combined with biennial screening in normal-risk women aged 40 to 49 years and annual screening in women aged 50 to 79 years remains the least cost-effective protocol (MCYLS of $35 100).

Table 6.—The Cost-effectiveness of Different Mammographic Screening Schedules

Age, y	Frequency of Mammography	Marginal Cost of Screening, $*	Marginal Effectiveness of Screening, y†	MCYLS, $‡
50-59	Biennial	1120	.0701	16 000
40-49 50-79	Annual Biennial	1915	.0950	20 200
40-64 65-79	Annual Biennial	2510	.1006	25 000
50-79	Annual	2212	.0863	25 600
40-79	Annual	2972	.1096	27 100
40-49 50-79	Biennial Annual	2550	.0818	31 200
40-49 (high risk) 40-49 (normal risk) 50-79	Annual Biennial Annual	2583	0.809	31 900

*Difference between total costs for screening and total costs for observation over the period of the model.
†Difference between years of life accumulated in the screened group and years of life accumulated in the observed group over the period of the model.
‡MCYLS indicates marginal cost per year of life saved, which is the marginal cost of screening divided by the marginal effectiveness of screening. Amounts rounded to the nearest $100.

Table 7.—Sensitivity of the Cost-effectiveness of Various Mammographic Screening Schedules to Changes in the Assumed Mortality Reduction Among Screened Women Age 40 to 49 Years

Assumed Mortality Reduction in Age 40-49 y, %	MCYLS, $*		
	Annual for Ages 40-79 y	Annual for Ages 40-49 y; Biennial for Ages 50-79 y	Biennial for Ages 40-49 y; Annual for Ages 50-79 y
4	33 600	26 700	31 200†
8	31 900	25 000	29 300
12	30 400	23 500	27 700
16	29 100	22 200	26 300
20	27 900	21 000	25 000
23	27 100 (Baseline)	20 200 (Baseline)	. . .

*MCYLS indicates marginal cost per year of life saved, and amounts are rounded to the nearest $100.

COMMENT

The controversy surrounding the optimal screening strategy for breast cancer stems from questions about the efficacy of screening mammography in younger women as well as the economic implications of screening for all women. Other studies have shown that the average MCYLS for mammographic screening is within the range of other accepted medical procedures.[28,29] The MCYLS for each of the screening schedules examined in this analysis is also in this range. This study provides additional useful information about the relative cost-effectiveness of various screening protocols, which may allow an appropriate balance between cost and efficacy.

If financial resources are unlimited, policymakers should choose the mammographic screening strategy with the highest marginal effectiveness—annual examination for all women aged 40 to 79 years. When funds are restricted, cost-effectiveness must be considered in the selection of a protocol.

Among the strategies evaluated in this study, biennial mammographic screening for women age 50 to 79 years was the most cost-effective. Kattlove et al[30] recently supported this view in their analysis of mammographic screening as part of a basic health care benefit package. Adoption of such a strategy, however, suggests the belief that there is conclusive evidence that screening in younger women does not offer a survival benefit.

Determination of the optimal screening protocol requires a careful assessment of the published evidence regarding the efficacy of screening mammography in women in their 40s. Randomized controlled trials of screening have failed to show a statistically significant benefit for these women, but this is likely attributable to flaws in experimental design as well as technical deficiencies in implementation.[20,31] Other evidence suggests that screening women in this age group is beneficial.[32,33] Since breast cancer is a disease with significant impact on women in their 40s and mammographic screening is likely to be effective in these women, a screening strategy, if cost-effective, should include this age group.

When women in their 40s participate in a mammographic screening program, annual screening in women aged 40 to 49 years and biennial screening for ages 50 years and older is the most cost-effective strategy. This is more cost-effective than the American Cancer Society guidelines, which are probably the most commonly followed strategy in the United States today. The difference in cost-effectiveness between these two protocols is largely the result of the cost-savings when biennial rather than annual mammography is performed in women older than 50 years. Evidence suggests that the efficacy of screening mammography is not significantly decreased by biennial screening in these women.[19,22,23]

The magnitude of the assumed breast cancer mortality reduction among screened women in their 40s was varied to determine the sensitivity of MCYLS to such changes. Use of annual mammography in women aged 40 to 49 years with biennial mammography in women aged 50 years and older is consistently more cost-effective than both annual mammography from ages 40 to 79 years and biennial mammography in women in their 40s with annual mammography for older women. This is primarily attributable to lower costs since fewer mammograms are performed if screening is done biennially in women aged 50 to 79 years. The sensitivity analysis also demonstrates that if women aged 50 years and older had biennial mammography, the reduction in breast cancer mortality among women in their 40s undergoing annual screening could be assumed to be as low as 8% before the MCYLS by screening would increase to the level of any of the less cost-effective strategies, including annual mammography for women aged 50 years and older.

In this article, MCYLS is reported for the entire screened population from the age at which screening is begun until age 79 years. Other studies have considered the MCYLS for each decade separately.[30,34] Even if the efficacy of screening for younger women is equal to that of older women, there is a lower incidence of breast cancer in women aged 40 to 49 years, so the cost per detection of cancer will be higher for younger than for older women if each decade is considered separately.

Discounting decreases the future value of costs and benefits. Its use is controversial because the appropriate discount rate is difficult to determine, especially for health benefits. In this analysis, calculations and comparisons of the MCYLS for each screening schedule were performed without discounting. When the effect of discounting of 5% on cost-effectiveness was evaluated, the MCYLS for all screening schedules increased, and the effect was more pronounced on those schedules that included women in their 40s. Despite the reduction in cost-effectiveness of all screening strategies, comparisons between strategies remain similar to comparisons when nondiscounted MCYLS figures are used. With discounting, the MCYLS for annual screening in ages 40 to 49 years with biennial screening in ages 50 to 79 years is lower than for any other strategy that includes women in their 40s, and it is approximately the same as the discounted MCYLS for annual screening in women aged 50 to 79 years. Even when discounting is used, screening programs that include women in their 40s remain cost-effective.

Although studies using computer simulation models are often criticized as lacking original data, they make it possible to conduct analyses that would otherwise be extremely difficult. It would be virtually impossible to construct an observational trial using each of the screening strategies assessed here to compare their cost-effectiveness. Furthermore, hypothetical models allow sensitivity testing of the various factors used in the simulation so that the effect of changing these factors on cost-effectiveness can be assessed.

Most clinical research related to screening mammography has addressed the issue of the effectiveness of the examination in reducing mortality from breast cancer. Based on studies that have shown effectiveness, a variety of screening schedules have been proposed both by professional organizations and by authorities in mammography. It is now generally accepted that fiscal resources for medical care are limited and that choices must be made about the best use of funds that are available. As an aid to decision making, the cost-effectiveness of various proposed mammographic screening schedules has been analyzed. In selecting a particular strategy, health planners and policymakers must consider the cost and desired effectiveness of a mammographic screening program, as well as the alternative uses of the available resources.

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