Transition From Film to Digital Mammography

Impact for Breast Cancer Screening Through the National Breast and Cervical Cancer Early Detection Program

Nicolien T. van Ravesteyn, PhD, Lisanne van Lier, MSc, Clyde B. Schechter, MD, MA, Donatus U. Ekwueme, PhD, MS, Janet Royalty, MS, Jacqueline W. Miller, MD, Aimee M. Near, MPH, Kathleen A. Cronin, PhD, Eveline A.M. Heijnsdijk, PhD, Jeanne S. Mandelblatt, MD, MPH, Harry J. de Koning, MD, PhD

Introduction: The National Breast and Cervical Cancer Early Detection Program (NBCCEDP) provides mammograms and diagnostic services for low-income, uninsured women aged 40–64 years. Mammography facilities within the NBCCEDP gradually shifted from plain-film to digital mammography. The purpose of this study is to assess the impact of replacing film with digital mammography on health effects (deaths averted, life-years gained [LYG]); costs (for screening and diagnostics); and number of women reached.

Methods: NBCCEDP 2010 data and data representative of the program's target population were used in two established microsimulation models. Models simulated observed screening behavior including different screening intervals (annual, biennial, irregular) and starting ages (40, 50 years) for white, black, and Hispanic women. Model runs were performed in 2012.

Results: The models predicted 8.0–8.3 LYG per 1,000 film screens for black women, 5.9–7.5 for white women, and 4.0–4.5 for Hispanic women. For all race/ethnicity groups, digital mammography had more LYG than film mammography (2%–4%), but had higher costs (34%–35%). Assuming a fixed budget, 25%–26% fewer women could be served, resulting in 22%–24% fewer LYG if all mammograms were converted to digital. The loss in LYG could be reversed to an 8%–13% increase by only including biennial screening.

Conclusions: Digital could result in slightly more LYG than film mammography. However, with a fixed budget, fewer women may be served with fewer LYG. Changes in the program, such as only including biennial screening, will increase LYG/screen and could offset the potential decrease in LYG when shifting to digital mammography.

(Am J Prev Med 2015;48(5):535–542)

Introduction

In the U.S., breast cancer mortality rates decreased steadily from 1990 to 2009.[1] The decrease in mortality has been attributed in part to mammography screening.[2] However, not all women have benefited equally from screening mammography, with low-income, uninsured women having substantially lower screening rates than their more advantaged, insured counterparts.[3]

To help reduce disparities in screening rates, CDC established the National Breast and Cervical Cancer

From the Department of Public Health (van Ravesteyn, van Lier, Heijnsdijk, de Koning), Erasmus MC, University Medical Center, Rotterdam; Department of General Practice and Elderly Care Medicine (van Lier), VU University Medical Center, Amsterdam, the Netherlands; Departments of Family & Social Medicine and Epidemiology & Population Health (Schechter), Albert Einstein School of Medicine, Bronx, New York; CDC (Ekwueme, Royalty, Miller), Atlanta, Georgia; Department of Oncology (Near, Mandelblatt), Georgetown University, Lombardi Comprehensive Cancer Center, Washington, District of Columbia; and the Statistical Research and Application Branch (Cronin), Division of Cancer Control and Population Sciences, National Cancer Institute, NIH, Bethesda, Maryland

Address correspondence to: Nicolien van Ravesteyn, PhD, Department of Public Health, Erasmus MC, P.O. Box 2040, 3000 CA Rotterdam, the Netherlands. E-mail: n.vanravesteyn@erasmusmc.nl.

0749-3797/$36.00
http://dx.doi.org/10.1016/j.amepre.2014.11.010

Early Detection Program (NBCCEDP). Started in 1991, the program offers free or low-cost mammograms to low-income, uninsured, and underinsured women aged 40–64 years. Specific eligibility criteria vary by state but are generally limited to women with incomes ≤250% of the federal poverty level, approximately 10% of all U.S. women aged 40–64 years.[4] In 2011, NBCCEDP screened 332,788 women for breast cancer with mammography (11.7% of those eligible for screening within the NBCCEDP),[4] reaching a variety of race/ethnicity groups (47% white, 24% Hispanic, 18% black, 5% Asian/Pacific Islander, and 6% other, multiracial, unknown).[5] The NBCCEDP supports biennial screening. However, some women are screened annually when it is recommended by their healthcare provider.

Following publication of the Digital Mammographic Imaging Screening Trial (DMIST) in 2005,[6] mammography facilities gradually began shifting from plain-film to digital mammography, and by 2010, 47% of screening examinations within the NBCCEDP were performed using digital mammography. Digital mammography has been found to have higher test sensitivity than plain film for women aged <50 years and women with dense breasts.[6] Overall, the diagnostic accuracy of digital and film mammography is similar, but digital screening is more expensive than plain film.[6,7] This poses a potential dilemma for the NBCCEDP, which operates based on a fixed appropriation. If the program were to cover the higher costs of digital screening, it would not be able to reach as many women as it could by paying for the less-expensive plain-film modality. However, if digital were to perform better, then more lives might be saved. Thus, it is unclear what the consequences of the transition from film to digital mammography would mean for the number of averted breast cancer deaths and life-years gained (LYG) through the program.

Two well-established microsimulation models were used to estimate the impact of the transition from film to digital mammography among the target population of the NBCCEDP in terms of program budget, numbers of women served, numbers of averted breast cancer deaths, and LYG. In addition, possibilities to increase the efficiency of the program were evaluated (e.g., by only including the most cost-effective screening scenarios).

Methods

MIcrosimulation SCreening ANalysis—Fatal Diameter (MISCAN-Fadia) and Simulating Population Effects of Cancer Control inTerventions—Race and Understanding Mortality (SPECTRUM) were used to assess the implications of shifting from film to digital mammography for the NBCCEDP. The models have been developed independently within the Cancer Intervention and Surveillance Modeling Network (CISNET) and were exempt from IRB approval. The models have previously been described in detail[8,9]; information about the models can be found in the Appendix (Appendix Figure 1) and online (cisnet.cancer.gov/breast/profiles.html). Briefly, the models simulated life histories for individual women. After estimating breast cancer incidence and mortality in the absence of screening and adjuvant therapy, the models overlaid screening use and improvements in survival associated with treatment advances.[2,10–12]

MISCAN-Fadia models continuous tumor growth, where tumors can be detected once they are beyond a detection threshold and cured if the tumor is below a fatal diameter.[9] In SPECTRUM, tumors progress through stages, with screening effects due to age and stage shifts and adjuvant treatment reducing the hazard of death.[8] In both models, ductal carcinoma in situ is represented as a state that can regress, remain, and be diagnosed or progress to invasive cancer.

A combination of primary data from 2010 from the NBCCEDP and national data representative of the program's target population were used to develop common input parameters. In 2008, the majority of women (89%) served by the NBCCEDP consisted of low-income white, black, and Hispanic women.[13] These groups were modeled separately because the three groups have different disease risk and characteristics.[14] Model runs were performed in 2012.

A multicohort population matching the demographics of the three racial/ethnic groups of women born between 1945 and 1970 (aged 40–64 years in 2010) was simulated. Each woman was assigned a date of death due to causes other than breast cancer based on race-specific data from the National Center for Health Statistics.[15] For Hispanic women, the non–breast cancer mortality of white women was used because their life expectancy has been found to be very similar.[16] The simulated women die because of breast cancer or of other causes, whichever comes first.

The breast cancer incidence in the absence of screening was based on an age–period–cohort model for the U.S. population.[17] These data were applied for incidence rates for white women. Age-specific relative risks for black versus white and Hispanic versus white women from the Surveillance, Epidemiology, and End Results (SEER) database were used to create age–period–cohort data for each race/ethnic group.

SEER data for stage distribution and breast cancer–specific survival for white and black women from 1975 to 1979 were used to model the natural history of breast cancer in the absence of mammography screening and adjuvant therapy, as these cancer control interventions did not begin to disseminate into the population substantially until after 1980.[10] SEER data for Hispanic women specifically were only available from 1990 onwards. Therefore, the stage distribution of clinical and interval cancers from the Breast Cancer Surveillance Consortium (BCSC) were used to estimate the stage distribution in the absence of screening for Hispanic women (http://breastscreening.cancer.gov/). Breast cancer–specific survival of Hispanic women was assumed to be equal to that of whites, when corrected for multiple factors (including age, estrogen receptor [ER] status, and surgical treatment).[18]

Different screening behaviors as observed in the 2010 NBCCEDP were used in the models by defining annual screening (with an interval of <18 months); biennial screening (18–30 months); and screening irregularly or once (an interval of >30 months or no previous screen within the NBCCEDP). The percentages of screens performed annually, biennially, and irregularly varied somewhat by age and by race/ethnicity group (Table 1).

Table 1. Main Model Parameters

Distribution of mammograms in the NBCCEDP					
Screening interval	**Age group**	**White, %**	**Black, %**	**Hispanic, %**	**Total, %**
Annual (<18 months)	40–49	6.2	1.5	3.1	10.9
	50–64	18.7	6.3	5.6	30.6
Biennial (18–30 months)	40–49	2.0	0.6	1.3	3.9
	50–64	2.9	1.4	1.4	5.7
Irregular/once	40–64	26.9	9.3	12.7	49.0
Total		56.8	19.0	24.1	100.0
Screening test performance: sensitivity[a]					
Screening interval	**Age group**		**Film**	**Digital**	
Annual (<18 months)	40–49		0.74	0.76	
	50–64		0.78	0.81	
Biennial (18–30 months)	40–49		0.80	0.82	
	50–64		0.84	0.85	
Irregular/once	40–49		0.88	0.90	
	50–64		0.91	0.92	
Screening test performance: specificity					
Screening interval	**Age group**		**Film**	**Digital**	
Annual (<18 months)	40–49		0.91	0.89	
	50–64		0.92	0.91	
Biennial (18–30 months)	40–49		0.90	0.87	
	50–64		0.91	0.89	
Irregular/once	40–49		0.81	0.77	
	50–64		0.84	0.80	
Cost of screening mammography[b]			Film	Digital	
			$84	$115	
Cost of diagnostic workup[b]			Film	Digital	
True positive			$1,842	$1,896	
False positive			$394	$443	

[a]Sensitivity based on a 12-month follow-up period for defining interval cancers.
[b]Costs in 2010 U.S. dollars.
NBCCEDP, National Breast and Cervical Cancer Early Detection Program.

Data from BCSC from 1996 to 2007 was used for screening performance in terms of sensitivity and specificity of film and digital mammography by age (40–49 and 50–64 years) and screening interval (Table 1). Screening performance was assumed to be equal for the three race/ethnicity groups.[19] Treatment effectiveness was age- and ER/human epidermal growth factor receptor 2 (HER2)–specific and based on synthesis of recent clinical trials.[20–22] Treatment effects were modeled as a proportionate reduction in mortality risk or the proportion cured. Treatment use and treatment effects were modified for blacks versus whites based on prior research.[10] Treatment impact and use for Hispanic women were assumed to be equal to those for whites.[18] Specific treatment data were available until 2005; thereafter, the same rates were assumed.

The most recent cost estimates were used for breast cancer screening and follow-up diagnostics (Table 1). For the program cost of screening, the weighted average NBCCEDP reimbursement rates in 2009–2010 were used for film and digital mammography. For the cost of diagnostic workup, mean workup costs within 12 months of initial screening of women

with a true-positive and false-positive mammography interpretation for digital and plain-film evaluations were used.[7] All costs were updated to 2010 U.S. dollars, using the medical care component of the Consumer Price Index (www.bls.gov/cpi/data.htm).

Both models have previously been validated for black and white women.[10] For Hispanic women, model-projected age-adjusted incidence and mortality were compared with actual SEER rates available for 1992–2007 and 1990–2007, respectively. The costs and health effects (LYG and breast cancer deaths averted) of the screening scenarios performed within the NBCCEDP were estimated by using the percentages of screens currently performed annually, biennially, and irregularly or once in each age and race/ethnicity group for film mammography. In addition, the costs and health effects of shifting to digital mammography assuming the same screening distributions were assessed. Subsequently, the health effects of the program using digital mammography were estimated assuming a fixed budget for the cost of screening and diagnostics. Finally, the implications of only including the most cost-effective digital screening scenarios in the NBCCEDP were assessed. As biennial screening has been found to be more cost effective than annual screening,[23,24] the effect of only including biennial digital screening was evaluated.

Multiple sensitivity analyses were performed to assess the uncertainty around the costs and performance of digital mammography using the upper and lower limit for the screening test performance (sensitivity, specificity) and by assuming a 10% lower cost for digital screening. The cost of diagnostics was also varied, as previous work showed that the increase in follow-up costs associated with digital mammography diminished over time.[25]

Results

The age-adjusted incidence and mortality rates of both models have been previously published for black and white women.[10] For Hispanic women, the predicted age-adjusted incidence and mortality rates of both models were close to the observed SEER rates (Appendix Figures 2 and 3). The health effects of screening varied by race/ethnicity: the models predicted 8.0–8.3 (range across models) LYG per 1,000 film screens for black women, 5.9–7.5 for white women, and 4.0–4.5 for Hispanic women. The absolute change in LYG when the 1,000 screens were performed digitally was rather small and also varied by race/ethnicity and model (0.089–0.316) (Table 2). The number of false-positives and costs per 1,000 screens did not vary substantially by race/ethnicity, and both increased considerably with digital mammography. Per 1,000 screens, the number of false-positives increased by 24–28 and the costs increased by $47,000–$51,000 (Table 2).

Table 2. Predicted Health Outcomes and Costs for the Different Race/Ethnicity Groups per 1,000 Mammograms

Race/ethnicity	Modality	Breast cancer deaths averted	Change	LYG	Change	False-positives	Change	Costs (screen and diagnostics),[a] $	Change, $
MISCAN-Fadia									
White	Film	0.32		5.9		112		137,000	
White	Digital	0.34	0.014	6.2	0.276	136	25	185,000	47,000
Black	Film	0.46		8.0		112		136,000	
Black	Digital	0.48	0.018	8.3	0.316	136	24	183,000	47,000
Hispanics	Film	0.21		4.0		122		137,000	
Hispanics	Digital	0.22	0.009	4.2	0.178	148	26	186,000	49,000
SPECTRUM									
White	Film	0.45		7.5		128		149,000	
White	Digital	0.45	0.007	7.6	0.122	155	27	199,000	50,000
Black	Film	0.49		8.3		126		148,000	
Black	Digital	0.50	0.009	8.4	0.156	153	27	198,000	50,000
Hispanics	Film	0.26		4.5		133		146,000	
Hispanics	Digital	0.26	0.005	4.6	0.089	162	28	196,000	51,000

[a]Costs rounded to nearest 1,000.
LYG, life-years gained; MISCAN-Fadia, MIcrosimulation SCreening Analysis–Fatal Diameter; SPECTRUM, Simulating Population Effects of Cancer Control inTerventions–Race and Understanding Mortality.

The models estimated that within the NBCCEDP using film mammography, the 329,721 mammograms that were performed in 2010 would avert 107–136 breast cancer deaths with 1,948–2,305 LYG. If the same number of mammograms were performed digitally, there would be 111–138 breast cancer deaths averted and 2,034–2,345 LYG, a 2%–4% increase (Table 3). At the same time, the program costs would increase 34%–35%. Assuming level funding and a transition to entirely digital screening, 25%–26% fewer women could be served with digital than with film mammography. This would result in fewer breast cancer deaths averted (23%–24%) and LYG (22%–24%) (Table 3).

When only including biennial digital screening, still fewer women would be served, but the benefit per screen was higher for biennial than for annual screening. Restricting the screening interval to biennial therefore leads to a higher number of LYG per screen. When a fixed budget was assumed, the change in LYG inversed from a loss of 22%–24% to an increase of 8%–13% (Table 3). Moreover, if biennial screening were restricted to women aged ≥50 years, the number of LYG would increase by 16%–17%.

Varying the screening test performance of digital mammography did not change the results substantially; when including the upper limit of the screening test sensitivity, LYG and breast cancer deaths averted only slightly increased (<2%). When a 10% lower cost for digital screening was assumed, the total cost of screening and diagnostics increased by 26% (both models) instead of 34%–35%. Total costs increased by 29%–30% when assuming the same cost of diagnostics for digital as for film mammography.

Table 3. Implications of Switching from Film to Digital Mammography in the NBCCEDP

Modality	Distribution of mmg	Assumptions	Number of mmg (% change)[a]	LYG (% change)[a]	BC deaths averted (% change)[a]	Costs screen and diagnostics (million $) (% change)[a]
MISCAN-Fadia						
Film	As observed within the NBCCEDP[b]	Fixed no. of mmg	329,721	1,948	107	$45.2
Digital	As observed within the NBCCEDP[b]	Fixed no. of mmg	329,721	2,034 (4.4%)	111 (4.2%)	$60.9 (34.7%)
Digital	As observed within the NBCCEDP[b]	Fixed budget	244,723 (−25.8%)	1,510 (−22.5%)	83 (−22.6%)	$45.2
Digital	Biennial[c]	Fixed budget	277,257 (−15.9%)	2,196 (12.8%)	116 (8.9%)	$45.2
Digital	Biennial[c] age ≥50	Fixed budget	282,474 (−14.3%)	2,257 (15.9%)	135 (26.1%)	$45.2
SPECTRUM						
Film	As observed within the NBCCEDP[b]	Fixed no. of mmg	329,721	2,305	136	$48.8
Digital	As observed within the NBCCEDP[b]	Fixed no. of mmg	329,721	2,345 (1.7%)	138 (1.7%)	$65.4 (34.0%)
Digital	As observed within the NBCCEDP[b]	Fixed budget	246,020 (−25.4%)	1,749 (−24.1%)	103 (−24.1%)	$48.8
Digital	Biennial[c]	Fixed budget	275,113 (−16.6%)	2,481 (7.7%)	141 (3.6%)	$48.8
Digital	Biennial[c] age ≥50	Fixed budget	273,420 (−17.1%)	2,693 (16.8%)	169 (24.0%)	$48.8

[a]Compared to film mammography.
[b]See Table 1.
[c]Screening interval 18–30 months.
BC, breast cancer; LYG, life-years gained; MISCAN-Fadia, MIcrosimulation SCreening ANalysis–Fatal Diameter; mmg, mammograms; NBCCEDP, National Breast and Cervical Cancer Early Detection Program; SPECTRUM, Simulating Population Effects of Cancer Control inTerventions–Race and Understanding Mortality.

Discussion

Digital mammography could result in slightly more LYG than film mammography within the NBCCEDP. However, with a fixed budget, fewer women may be served with fewer LYG, because a lower number of screening tests can be funded. Digital mammography is more costly, mainly because of the higher cost of the screening test and higher cost due to more false-positives. When performing the same number of mammograms in the NBCCEDP using digital mammography, program costs would increase by 34%–35%. Changes in the program, such as only including biennial screening, will lead to more LYG per screen and could thereby offset the potential decrease in LYG when shifting to digital mammography. However, for a subset of women who switch from annual to biennial screening, their cancers will be detected at a later, more advanced stage.

Assuming continued level funding, there are several ways that the NBCCEDP might maintain its reach and achieve comparable health effects (LYG and breast cancer deaths averted) of film and digital mammography. The first way would be a price reduction of digital mammography (or a change in reimbursement fee). In California's Every Woman Counts program, digital mammography was reimbursed at the same rate as film mammography.[23] However, this has recently been changed and is not easily achievable for the NBCCEDP. The second way is to implement program changes and only provide screening with a biennial interval. In this case, the number of LYG can even be increased. Another option is to only include women aged $\geq$50 years. However, the effect of this change is quite small, as only 15% of the NBCCEDP mammograms are performed on women aged $<$50 years. In addition to the options that were investigated, there might be other program changes that would potentially be even more cost effective (e.g., screening with even longer intervals or focusing on high-risk groups). As the NBCCEDP is concerned with providing screening services based on the best evidence, the present study focused on scenarios that were in line with current U.S. Preventive Services Task Force breast cancer screening recommendations.[26]

The implementation of mandatory coverage for breast cancer screening under the Affordable Care Act may reduce the demand for the NBCCEDP. Currently, NBCCEDP is projected to reach around 11.7% of those eligible, and in the near future, the number eligible will likely still exceed the number served. However, previous work projected changes in the population characteristics of the eligible population, including a larger percentage of Asians and Hispanics.[27]

An important strength of this study is that an ethnically diverse population was included by specifically modeling white, black, and Hispanic women. As these racial/ethnic groups have been found to have different risks of getting and dying from breast cancer,[28] it is essential to specifically incorporate these differences to adequately reflect the women served by the NBCCEDP, as highlighted by the finding that the impact of the transition to digital mammography varied by race/ethnicity. In addition, two models were used to provide a range of plausible effects and illustrate the effects of differences in model structure. Furthermore, recent data on screening performance were used from the BCSC because previous work found that results from BCSC and NBCCEDP were broadly similar.[29] An advantage is that data from BCSC reflect screening performance in community practice, which might be different from the performance in screening trials.

Despite these strengths and the consistent results, this study has some limitations. First, it was assumed that women in the NBCCEDP received the same treatment as women in the overall U.S. population. Although low-income, uninsured women might not always receive optimal treatment,[30] women diagnosed through the NBCCEDP are enrolled in Medicaid for treatment, and it has been found that almost 94% of women initiated treatment within 60 days after diagnosis.[31] Second, it was not feasible to include other minority groups, including Asian/Pacific Islanders, other/unknown, and multiracial women, because of the limited available data for these groups. Together, these latter groups comprise 11% of NBCCEDP's population. Adding these other minority groups would probably not have substantially influenced the findings, although Asian women more often have dense breasts,[32] and for women with dense breasts, digital mammography might be more cost effective. Finally, it has been found that the performance of digital mammography may improve and costs may decrease over time.[25,33,34] A recent study[25] found that the increase in downstream breast-related cost (follow-up services related to diagnostic workup) associated with digital mammography diminished over time. In the sensitivity analysis, when assuming the same cost of diagnostics for digital as for film, maintaining current screening levels would increase the cost to the program by 29%–30% instead of 34%–35%.

In conclusion, although digital could result in slightly more LYG than film mammography, fewer women can be served by the NBCCEDP with shifting from film to digital mammography, thus leading to fewer LYG. As mammography facilities have switched to using digital mammography, it is important for program administrators and decision-makers at the state and federal level to understand the health benefit and cost impact related to using digital versus film mammography.

We thank the National Comprehensive Cancer Network investigators for use of data on treatment dissemination. We thank the Breast Cancer Surveillance Consortium (BCSC) investigators for the data they have provided for this study. BCSC data collection was supported by the National Cancer Institute (NCI)–funded Breast Cancer Surveillance Consortium (Grant No. HHSN261201100031C). A list of the BCSC investigators and procedures for requesting BCSC data for research purposes are provided at: breastscreening.cancer.gov/. Drs.Mandelblatt and de Koning contributed equally to this work as senior authors.

This study was supported by an Interagency Agreement from CDC to the NCI and funded under Grant No. U01CA115337-10S1. This study was also supported in part by the NCI (Grant Nos. U01CA152958, U01CA088283; grant No. KO5CA96940 [JM]) and the Department of Defense (Grant No. BC043120 [JM]). Model results are the sole responsibility of the authors. The findings and conclusions in this report are those of the authors and do not necessarily represent the official position of CDC.

Dr. Heijnsdijk and Dr. de Koning report receiving a research grant from SCOR. No other financial disclosures were reported by the authors of this paper.

References

1. Jemal A, Simard EP, Dorell C, et al. Annual report to the nation on the status of cancer, 1975-2009, featuring the burden and trends in human papillomavirus (HPV)-associated cancers and hpv vaccination coverage levels. *J Natl Cancer Inst*. 2013;105(3):175–201. http://dx.doi.org/10.1093/jnci/djs491.
2. Berry DA, Cronin KA, Plevritis SK, et al. Effect of screening and adjuvant therapy on mortality from breast cancer. *N Engl J Med*. 2005;353(17):1784–1792. http://dx.doi.org/10.1056/NEJMoa050518.
3. Sabatino SA, Coates RJ, Uhler RJ, Breen N, Tangka F, Shaw KM. Disparities in mammography use among U.S. women aged 40-64 years, by race, ethnicity, income, and health insurance status, 1993 and 2005. *Med Care*. 2008;46(7):692–700. http://dx.doi.org/10.1097/MLR.0b013e31817893b1.
4. CDC. National Breast and Cervical Cancer Early Detection Program (NBCCEDP). www.cdc.gov/cancer/nbccedp/about.htm.
5. CDC. National Breast and Cervical Cancer Early Detection Program (NBCCEDP). www.cdc.gov/cancer/nbccedp/data/summaries/national_aggregate.htm.
6. Pisano ED, Gatsonis C, Hendrick E, et al. Diagnostic performance of digital versus film mammography for breast-cancer screening. *N Engl J Med*. 2005;353(17):1773–1783. http://dx.doi.org/10.1056/NEJMoa052911.
7. Tosteson AN, Stout NK, Fryback DG, et al. Cost-effectiveness of digital mammography breast cancer screening. *Ann Intern Med*. 2008;148(1):1–10. http://dx.doi.org/10.7326/0003-4819-148-1-200801010-00002.
8. Mandelblatt J, Schechter CB, Lawrence W, Yi B, Cullen J. The SPECTRUM population model of the impact of screening and treatment on U.S. breast cancer trends from 1975 to 2000: principles and practice of the model methods. *J Natl Cancer Inst Monogr*. 2006(36):47–55. http://dx.doi.org/10.1093/jncimonographs/lgj008.
9. Tan SY, van Oortmarssen GJ, de Koning HJ, Boer R, Habbema JD. The MISCAN-Fadia continuous tumor growth model for breast cancer. *J Natl Cancer Inst Monogr*. 2006;36:56–65. http://dx.doi.org/10.1093/jncimonographs/lgj009.
10. van Ravesteyn NT, Schechter CB, Near AM, et al. Race-specific impact of natural history, mammography screening, and adjuvant treatment on breast cancer mortality rates in the United States. *Cancer Epidemiol Biomarkers Prev*. 2011;20(1):112–122. http://dx.doi.org/10.1158/1055-9965.EPI-10-0944.
11. Mandelblatt JS, Cronin KA, Bailey S, et al. Effects of mammography screening under different screening schedules: model estimates of potential benefits and harms. *Ann Intern Med*. 2009;151(10):738–747. http://dx.doi.org/10.7326/0003-4819-151-10-200911170-00010.
12. van Ravesteyn NT, Miglioretti DL, Stout NK, et al. Tipping the balance of benefits and harms to favor screening mammography starting at age 40 years: a comparative modeling study of risk. *Ann Intern Med*. 2012;156(9):609–617. http://dx.doi.org/10.7326/0003-4819-156-9-201205010-00002.
13. Eheman CR, Benard VB, Blackman D, et al. Breast cancer screening among low-income or uninsured women: results from the National Breast and Cervical Cancer Early Detection Program, July 1995 to March 2002 (United States). *Cancer Causes Control*. 2006;17(1):29–38. http://dx.doi.org/10.1007/s10552-005-4558-y.
14. Desantis C, Siegel R, Bandi P, Jemal A. Breast cancer statistics, 2011. *CA Cancer J Clin*. 2011;61(6):409–418. http://dx.doi.org/10.3322/caac.20134.
15. Carter S, Gartner S, Haines M, Olmstead A, Stuch R, Wright G. *Historical Statistics of the United States*. New York: Cambridge Universiy Press; 2006.
16. Smith DP, Bradshaw BS. Rethinking the Hispanic paradox: death rates and life expectancy for U.S. non-Hispanic White and Hispanic populations. *Am J Public Health*. 2006;96(9):1686–1692. http://dx.doi.org/10.2105/AJPH.2003.035378.
17. Holford TR, Cronin KA, Mariotto AB, Feuer EJ. Changing patterns in breast cancer incidence trends. *J Natl Cancer Inst Monogr*. 2006;36:19–25. http://dx.doi.org/10.1093/jncimonographs/lgj016.
18. Li CI, Malone KE, Daling JR. Differences in breast cancer stage, treatment, and survival by race and ethnicity. *Arch Intern Med*. 2003;163(1):49–56. http://dx.doi.org/10.1001/archinte.163.1.49.
19. Gill KS, Yankaskas BC. Screening mammography performance and cancer detection among black women and white women in community practice. *Cancer*. 2004;100(1):139–148. http://dx.doi.org/10.1002/cncr.11878.
20. Early Breast Cancer Trialists' Collaborative Group. Polychemotherapy for early breast cancer: an overview of the randomised trials. *Lancet*. 1998;352(9132):930–942. http://dx.doi.org/10.1016/S0140-6736(98)03301-7.
21. Early Breast Cancer Trialists' Collaborative Group. Tamoxifen for early breast cancer: an overview of the randomised trials. *Lancet*. 1998;351(9114):1451–1467. http://dx.doi.org/10.1016/S0140-6736(97)11423-4.
22. Early Breast Cancer Trialists' Collaborative Group. Effects of chemotherapy and hormonal therapy for early breast cancer on recurrence and 15-year survival: an overview of the randomised trials. *Lancet*. 2005;365(9472):1687–1717. http://dx.doi.org/10.1016/S0140-6736(05)66544-0.
23. Melnikow J, Tancredi DJ, Yang Z, et al. Program-specific cost-effectiveness analysis: breast cancer screening policies for a safety-net program. *Value Health*. 2013;16(6):932–941. http://dx.doi.org/10.1016/j.jval.2013.06.013.
24. Schousboe JT, Kerlikowske K, Loh A, Cummings SR. Personalizing mammography by breast density and other risk factors for breast cancer: analysis of health benefits and cost-effectiveness. *Ann Intern Med*. 2011;155(1):10–20. http://dx.doi.org/10.7326/0003-4819-155-1-201107050-00003.
25. Henderson LM, Hubbard RA, Onega TL, et al. Assessing health care use and cost consequences of a new screening modality: the case of digital mammography. *Med Care*. 2012;50(12):1045–1052. http://dx.doi.org/10.1097/MLR.0b013e318269e0d1.
26. U.S. Preventive Services Task Force. Screening for breast cancer: U.S. Preventive Services Task Force recommendation statement. *Ann Intern*

Med. 2009;151(10):716–726. http://dx.doi.org/10.7326/0003-4819-151-10-200911170-00008 (W-236).
27. Levy AR, Bruen BK, Ku L. Health care reform and women's insurance coverage for breast and cervical cancer screening. *Prev Chronic Dis*. 2012;9:E159. http://dx.doi.org/10.5888/pcd9.120069.
28. Howlader N, Noone AM, Krapcho M, et al. *SEER Cancer Statistics Review, 1975-2010*. Bethesda, MD: National Cancer Institute; seer.cancer.gov/csr/1975_2010/, based on November 2012 SEER data submission, posted to the SEER web site, April 2013.
29. Smith-Bindman R, Chu PW, Miglioretti DL, et al. Comparison of screening mammography in the United States and the United Kingdom. *JAMA*. 2003;290(16):2129–2137. http://dx.doi.org/10.1001/jama.290.16.2129.
30. Coburn N, Fulton J, Pearlman DN, Law C, DiPaolo B, Cady B. Treatment variation by insurance status for breast cancer patients. *Breast J*. 2008;14(2):128–134. http://dx.doi.org/10.1111/j.1524-4741.2007.00542.x.
31. Richardson LC, Royalty J, Howe W, Helsel W, Kammerer W, Benard VB. Timeliness of breast cancer diagnosis and initiation of treatment in the National Breast and Cervical Cancer Early Detection Program, 1996-2005. *Am J Public Health*. 2010;100(9):1769–1776. http://dx.doi.org/10.2105/AJPH.2009.160184.
32. El-Bastawissi AY, White E, Mandelson MT, Taplin S. Variation in mammographic breast density by race. *Ann Epidemiol*. 2001;11(4):257–263. http://dx.doi.org/10.1016/S1047-2797(00)00225-8.
33. Bluekens AM, Karssemeijer N, Beijerinck D, et al. Consequences of digital mammography in population-based breast cancer screening: initial changes and long-term impact on referral rates. *Eur Radiol*. 2010;20(9):2067–2073. http://dx.doi.org/10.1007/s00330-010-1786-7.
34. Hofvind S, Skaane P, Elmore JG, Sebuodegard S, Hoff SR, Lee CI. Mammographic performance in a population-based screening program: before, during, and after the transition from screen-film to full-field digital mammography. *Radiology*. 2014;272(1):52–62. http://dx.doi.org/10.1148/radiol.14131502.

Appendix

Supplementary data

Supplementary data associated with this article can be found at http://dx.doi.org/10.1016/j.amepre.2014.11.010.