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Aggregate Cost of Mammography Screening in the United States: Comparison of Current Practice and Advocated Guidelines

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Abstract

Background—Enormous controversy exists over how often and at what age to implement mammography screening. Given that scientific evidence supports less frequent screening, the cost differences among advocated screening policies should be better understood.

Objective—To estimate the aggregate cost of mammography screening in the United States in 2010 and compare the costs of screening strategies as currently practiced or recommended by professional organizations.

Design—A simulation model was developed to estimate the cost of mammography screening in 2010 as actually practiced. Three screening strategies were then modeled: annual (40–84 year-olds), biennial (50–69 year-olds), and USPSTF guidelines (biennial 50–74 year-olds, personalized <50 and ≥75 year-olds).

Setting—United States.

Patients—Women 40–85 years old.

Intervention—Mammography annually, biennially, or following USPSTF guidelines.

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All authors had full access to all the data in the study and take responsibility for the integrity of the data and the accuracy of the data analysis.

Measurements—Cost of screening per year, using lower bound of costs (Medicare reimbursement).

Results—The estimated cost of mammography screening in the US in 2010 under actual practice was $7.8 billion, with approximately 70% of women participating. The simulated cost of screening the target of 85% of women was $10.1 billion for annual screening, $2.6 billion for biennial screening, and $3.5 billion for USPSTF guidelines. The largest drivers of cost (in order) were: screening frequency, percent women screened, cost of a mammogram, percent digital mammography, and percent women recalled.

Limitations—Cost estimates and assumptions used in the model were intended to be conservative.

Conclusions—The cost of mammography varies by almost $8 billion per year based on screening strategy, even using the lower bound of costs. The USPSTF recommended biennial screening based on similar efficacy to annual frequency and would allow substantial resources to be saved. Personalized risk assessment could be used to identify higher-risk women who might benefit from more frequent, younger initiation, and longer duration of screening and prevention. Given that a population-based strategy following USPSTF recommendations costs much less than actual and annual screening practices, resources may be better allocated by screening women biennially and using personalized risk assessment for women younger than 50 years or older than 75 years.

INTRODUCTION

The frequency and appropriate age to start mammography screening for the detection of breast cancer have been debated in the United States for decades. Controversy intensified after the United States Preventive Services Task Force (USPSTF) recommended a change to biennial mammography on the basis that both annual and biennial screening reduce mortality but with biennial, the negative impacts are reduced.(1) However in the US, there has been resistance to reducing frequency or modifying the age range for mammography. The USPSTF guidelines conflict with professional organizations such as the American Cancer Society, which recommend annual screening from age 40 years and continued regardless of a woman's age as long she is without serious, chronic health problems. Given the broad population mammography serves, it is important to consider the economic impact of the conflicting guidelines.

The USPSTF, in 2009, recommended biennial screening for women between the ages of 50–74, with consideration of screening 40–49-year-old women on a risk benefit decision.(2) The USPSTF recommendations are based on a rigorous review of screening trials and work from the Cancer Intervention and Surveillance Modeling (CISNET) investigators that demonstrated there is little or nothing to gain by increasing the frequency of mammography.(3) The CISNET modeling is corroborated by evidence from the Breast Cancer Surveillance Consortium (BCSC) showing that false-positive recall and biopsy rates are significantly lower in the setting of biennial screening, but without a significant increase in the number of later stage cancers detected.(4–6) The USPSTF recommendations on frequency are now in alignment with most European countries, where many of the defining mammography trials were conducted, with the exceptions of the United Kingdom and Finland, which screen every three years.(7–12)

Screening in the US is delivered locally or regionally and covered by myriad payer and health plan organizations. Thus the total resources required or the cost-tradeoffs of different recommendations are currently unknown. This study was designed to inform the debate by estimating the lower bound of the aggregate cost of mammography screening practiced in the US as compared to recommended screening strategies. Our findings should be valuable to women, clinicians, and health policy makers alike who are aware of the many conflicting guidelines.

METHODS

Study Design

To estimate the cost of mammography in the US, we created a simulation model using mammography screening in 2010 as our base case. We then simulated three strategies (Annual, Biennial, and USPSTF), from the payer perspective. Analyses were performed using R statistical software.(13)

Table 1 shows the four screening strategies, one of which is an estimate of actual practice.(14,15) The other three standardize on the population screened (85%) but differ on the age at which to start and stop and the frequency at which to screen. The biennial strategy represents the European approach, the annual strategy reflects the American Cancer Society (among others) recommendations, and the USPSTF strategy represents a risk-based strategy for screening under 50 and over 75 based on their 2009 recommendations.

The final output of the model was the aggregate cost of mammography screening per year. The summation included the cost of screening mammograms, the cost of computer-aided detection (CAD), and the cost of recalls and biopsies. A description of the modeling methods is available in Supplemental Appendix A.

Inputs and Variables

Model inputs were attained from multiple sources including the BCSC(16) and are listed in Table 2. (17–22) All input variables except costs were age-specific. The number of mammograms was calculated by determining the population of women at risk by using census data. To focus on screening as opposed to diagnostic or surveillance mammography, we limited the population of women at risk to those between the ages of 40 and 85 and excluded the number of women diagnosed with breast cancer in the past five years, who should be receiving surveillance mammography.

We used data from the Behavioral Risk Factor Surveillance System (BRFSS) 2010 Survey, a telephone health survey conducted by the Center for Disease Control, to determine the frequency and percentage of women receiving mammography. We corrected for survey bias by using the correction suggested by Rothman et al.; and though the survey does not distinguish between screening and diagnostic, we excluded women below 40 and above 85 years and those with recent history of breast cancer to best estimate screening as opposed to diagnostic mammograms.(23) In our base case model of actual practice, we included women who reported receiving a mammogram in the past one to five years and estimated the number who would have screened in one given year; otherwise, the simulated strategies only simulated women receiving mammography every one or two years. The simulated strategies modeled an optimal participation of 85%, a screening participation achieved in the past for cervical cancer screening.(24) The USPSTF strategy modeled 20% of 40–50 year-old-women as high-riskting a full and simulated biennial screening for this cohort based on evidence that 40–49 year-old women with a 2-fold increased risk have similar harm-benefit ratios from biennial screening as 50–74 year-old women with average risk.(25) The USPSTF strategy also modeled screening women between the ages of 70 and 85 who are healthy, defined as having fewer than three self-reported chronic conditions as reported by Medicare. (26)

The percent of recalled mammograms was obtained from the BCSC using mammography screening performance data from 1,908,447 exams for 749,597 women screened from 2001–2007. Following the BI-RADS manual,(27) a recall was defined as an initial BI-RADS assessment of 0 (needs additional imaging evaluation), 4 (suspicious abnormality), 5 (highly suggestive of malignancy), or a BI-RADS assessment of 3 (probably benign finding) if it was accompanied by a recommendation for immediate work-up. Separate estimates were computed for recall rates at first and subsequent mammography (i.e. prevalent and incident screens) as well as stratified by frequency of screening, digital versus film mammography, and a woman's age.

The estimated costs of the modeled strategies include the cost of the screening mammogram and the subsequent recall costs. Costs for mammograms and CAD were determined using 2010 national Medicare reimbursements rates. Recall costs were calculated from the Digital Mammography Imaging Screening Trial's (DMIST) results of work-up costs including additional imaging and biopsies from false positive and true positive exams.(22) We adjusted DMIST recall costs proportional to the use of digital versus film mammography in 2010. We adjusted all cost data to 2010 US dollars based on inflation as estimated by the medical portion of the Consumer Price Index.(28)

Sensitivity Analysis

We used Monte Carlo simulations to estimate the uncertainty of our total cost estimates and to quantify the sensitivity of the output (total cost) to the model inputs (for details, see Supplemental Appendix A). (29) In the sensitivity analysis, all terms in the formulas were assumed to be independent and to follow beta distributions as detailed in Appendix A.

RESULTS

Our model simulated screening practices in 2010 and estimated the aggregate cost of mammography per year. Three mammography screening strategies advocated by various professional societies under optimal participation rates were also simulated and yielded costs that ranged from $10.1 to $2.6 billion for the most to the least intensive screening strategies (Figure 1).

The Aggregate Cost of Mammography Screening in the U.S

We estimated the aggregate cost of mammography screening in the US by simulating screening for 40–85-year-old women, which follow a mixture of screening strategies in actual practice. Given the disparate recommendations and the reality of screening in the US, an individual woman who has had a mammogram in a given year may follow annual screening guidelines, biennial guidelines, or be screened irregularly. We modeled participation rates from 61% of women between the ages of 40–45 to 75% of women between the ages of 65–70.(18) Simulating this mix of actual mammography screening practices for women 40 to 85 years-old, we estimated the aggregate cost of mammography screening in 2010 to be in the range of $7.8 billion. Given that Medicare reimbursements rates are at the lower bound of costs, we additionally estimated the impact on aggregate cost per 10% increase in mammography, CAD, and recall. For each 10% increment above medicare costs, the aggregate costs increase by $700 million.

Estimated Cost of Proposed Screening Strategies with Optimal Participation

The results of the estimated costs of the annual, biennial, and USPSTF mammography screening strategies are summarized below and in Table 2.

According to our model, annual screening of women between the ages of 40 and 84 is estimated to cost $10.1 billion per year. This strategy follows the guidelines of many policy making medical groups and would increase mammography screening costs by $2.3 billion per year from actual practice. A 10% increase in reimbursements rates increase the aggregate cost by $1 billion.

Biennial screening of 85% of women between the ages of 50–70 is estimated to cost $2.6 billion per year, the least expensive of the strategies. The biennial strategy is $7.7 billion less than annual screening of the 85% of the population aged 40–84 years and $5.4 billion less than what is estimated to be spent in actual practice. Increasing the reimbursements rates by 10% leads to an increase in aggregate cost by $270 million.

The USPSTF strategy simulates biennially screening 50–74 year-old women, and includes screening of high-risk women 40–49 years old and women 75 to 85 years with fewer than three comorbidities. Screening women according to the USPSTF guidelines is estimated to cost $3.5 billion per year. With the same optimal participation rates of 85%, a USPSTF strategy is estimated to cost $6.7 billion less than an annual mammography strategy. The USPSTF strategy covering 85% of the population costs $4.4 billion less than actual practice. For the USPSTF strategy a 10% increase in reimbursements leads to an increase in aggregate cost by $350 million.

Determinants of Cost

We used a sensitivity analysis to determine the inputs to which the model was most sensitive; or in other words, which inputs had the most effect on the cost outcomes of the model (Figure 2.) Frequency of screening was the largest driver of cost and the input to which the model was most sensitive. Varying the frequency of screening from biennial to annual had a cost difference of over $7 billion.

The next largest drivers of costs for the model in decreasing order of impact were: the variation of the percent women screened, percent film versus digital mammography, the cost of individual mammograms, the number of recalls and the recall cost (Figure 2). Each input was varied across a range of likely possibilities. Since digital mammography and CAD are becoming the standard, we estimated the cost of a complete shift to using these methods; though only about $70 more per mammogram this would cost an additional $1.2 billion compared to actual practice (where digital and CAD are used for about 82% and 27% of all mammograms, respectively). The impact of increased costs per mammogram is less for strategies with lower screening frequency.

A sensitivity analysis was done for each screening strategy (Figure 2). The major drivers of cost remained consistent for all four strategies; however, the cost of screening for each strategy, varying the range of inputs, differs greatly. The magnitude of change is billions of dollars for each strategy, but each varies around its estimated overall screening cost per year and there is little overlap in projected costs.

DISCUSSION

Our study shows that mammography screening in the US, as currently implemented, is estimated to cost in the range of $7.8 billion per year. If a USPSTF strategy was implemented to screen 85% of women, we estimate that it would cost $3.5 billion per year with a simulated 15% greater participation rate and cost $4.4 billion less than current practice. If an annual strategy were implemented to screen 85% of the population it would cost an estimated $10.1 billion per year, or $2.3 billion more than current practice. Finally, screening biennially and eliminating screening for women in their forties or over seventy would cost $2.6 billion, not much less than the broader USPSTF strategy.

In 2001, the aggregate cost of mammography was estimated to cost $3–5 billion for all US screening aged women.(30) A study focused on the cost of breast cancer screening for a subset of women, the in fee-for-service Medicare population, used the SEER-Medicare database to estimate screening cost per beneficiary billed during 2006–2007 and multiplied the total number of Medicare beneficiaries to estimate a cost greater than $1billion annually for this subset of older Medicare women.(31) This result is consistent with our analysis considering the use of 10–20% digital mammography during that earlier time period. They also noted that increases in the unit cost of mammography, from digital mammography and CAD, explained 65% of the difference in the regional variation of costs. The introduction of digital mammography confers many advantages including ease of finding prior films, eliminating film processing, and has the opportunity to improve recall rates by eliminating BI-RADS 0 and instituting better biopsy thresholds. The impact of mammography cost changes, such as the increased use of digital, is much less when mammography frequency is lower and is a good investment. Our analysis identifies alternative strategies that will maintain screening performance but can lower the associated burdens by reducing additional recalls and biopsies using fewer resources.

Mammography frequency and age appropriateness affect the cumulative number of abnormal exams that require supplemental imaging, clinical evaluation and possible biopsy.

Over the past decade, we have come to realize more of mammography's limitations.(32,33) Multiple studies have shown that annual mammography does not have improved outcomes for cancer detection as compared to biennial screening.(3,34,35) However, annual compared to biennial screening is associated with a greater likelihood of false-positive recalls (61.3% vs. 41.6%) and biopsies (7% vs. 4.8%) over ten years.(4) Such consequences impact women's well-being and quality of life.(36,37) The costs per quality adjusted life year (QALY) for annual compared with biennial mammography are more than $340,000 for all ages, well beyond the $75,000-$100,000 per QALY considered a cost-effective intervention.(14) The CISNET modeling group projected that women with a relative risk of 1.9 (range 1.5 to 4.4) for breast cancer were the women likely to benefit from biennial screening in their forties.(25) To determine the appropriate age to start screening, experts recommend risk-based approaches for personalized screening, which is more in line with USPSTF guidelines.(38)

The implementation of the Affordable Care Act is expected to increase screening by 500,000 mammograms per year as mammography access improves.(39,40) Disparities in mammography relate to access to high-quality facilities and use of breast imaging specialists to read mammograms.(41,42) Mammography quality is improved when read by dedicated mammographers at high quality facilities, which would also likely lower recalls, a large driver of screening costs.(43) Recall rates vary significantly nationally and internationally and the average recall rates in the US are double to triple of those reported in Europe.(44–47) Biennial screening policies that target age-appropriate women make high-quality mammography available to more women while reducing their travel and time burdens.

The Institute of Medicine report *Best Care at Lower Cost* describes opportunities to reduce costs and improve the value of health care including missed prevention opportunities ($55 billion) and inefficiently delivered services ($130 billion).(48) Tailored screening policies address improved care at lower cost. As our analysis suggests, similar or higher quality screening can be obtained at similar or lower costs, freeing resources for risk-assessment and prevention that are not currently part of screening. Learning to set better thresholds for recall and biopsy would also safely generate substantial savings and reduced burden on women. (49,50)

Limitations of this analysis include the mammography participation estimates in which we were conservative by using a correction to the BRFSS and used rates lower than the CDC's estimates of 72–79%.(51) We used Medicare costs, which are at the lower end of reimbursement rates and thus actual costs could be substantially higher. Recall costs were inflated to 2010 costs from 2005 data; however, current diagnostic workups may now be more expensive with greater use of imaging technology such as MRI. We did not evaluate direct nonmedical or indirect costs associated with screening such as transportation or loss of time off from work. The additional cost of digital mammography compared to film was only modeled for the actual costs of the mammogram and not associated costs. We did not model the overall costs of a missed diagnosis; though evidence suggests that biennial screening is not associated with a statistically significant increase in the diagnosis of late stage cancers nor that screening costs make a significant difference in the costs of initial cancer treatment.(4,6,31) We did not address the impact of possible overdiagnosis on costs.

(32,50) Mammography practices may have changed since 2010 to align actual practice with USPSTF guidelines; however, recent studies have shown that since the release of the guidelines, screening practices have not greatly changed.(52) Lastly, we excluded the cost of screening women under 40 and older than 85 to simplify guidelines and focus on screening; however, screening women outside of recommended policies is likely to have similar costs across strategies. The accumulation of assumptions is likely to make the projected costs an underestimate for each strategy. This analysis was not intended to provide a highly accurate point estimate; but rather, an approximate range and relative ranking of the costs for each strategy.

Although an individual mammogram is not expensive, the aggregate national cost of screening millions of women is enormous. Costs of false-positive recalls and biopsies are also magnified and contribute to making mammography so resource intensive. Better understanding of the limitations of mammography will enable using this screening tool more effectively. A screening policy following the USPSTF guidelines uses fewer resources, has fewer false-positive biopsies and recalls compared to annual screening and is being incorporated into quality guidelines.(53) Those who advocate annual screening should justify the increased costs of almost $7 billion per year compared to biennial policies.

The billions saved from avoiding less-effective mammography screening can be used in multiple ways to improve women's health including: increasing participation in screening; routine assessment of breast cancer risk and referral for breast cancer prevention services if at high risk, especially for women less than 50 years; genetic counseling for women with strong family history (52); alternative modalities for screening women with dense breast tissue; and supporting a more programmatic/ public health approach to screening (as in Europe) with double reading, screening by invitation, and outcomes tracking. Resources can be better allocated to improve screening, with the emphasis on higher quality mammograms read by specialized mammographers (54). More resources should go into improving the quality of the reads rather than simply a higher frequency. It is also clear that higher unit reimbursement costs have a lower impact on aggregate costs when the frequency is less, such as with the USPSTF recommendations. Numerous publications have demonstrated that the most experienced readers, or systems of double reading, improve sensitivity as well as specificity.(55) As our sensitivity analysis demonstrates, the cost per mammogram is not the largest driver of cost, but rather frequency. High quality interpretation should be covered, as it would improve screening performance and reduce recall costs. Lastly, current screening participation rates fall short of national goals(56) and though the Affordable Care Act aims to improve access, utilizing mammography effectively following guidelines such as the USPSTF will ensure that resources exist to expand screening participation.

In conclusion, mammography screening is resource intensive at an estimated cost of $7.8 billion per year as currently practiced. Following mammography screening guidelines, such as the USPSTF, that optimize frequency on the basis of best available evidence will put us in a position to improve screening and save billions of dollars that can be invested in personalized risk-based screening and prevention strategies. Such a change in screening practice is likely to improve the quality of screening and is in line with our national goals of advancing health care delivery while improving cost-efficiency.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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References

1. U.S. Preventive Services Task Force. Screening for Breast Cancer: U.S. Preventive Services Task Force Recommendation Statement. Ann Intern Med. 2009; 151:716–726. [PubMed: 19920272]
2. Nelson HD, Tyne K, Naik A, Bougatsos C, Chan BK, Humphrey L. Screening for breast cancer: an update for the U.S. Preventive Services Task Force. Annals of internal medicine [Internet]. 2009 Nov 17; 151(10):727–737. W237–W242. Available from: http://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=2972726&tool=pmcentrez&rendertype=abstract.
3. Mandelblatt JS, Cronin KA, Bailey S, Berry DA, De Koning HJ, Draisma G, et al. Effects of mammography screening under different screening schedules: model estimates of potential benefits and harms. Annals of internal medicine [Internet]. 2009 Nov 17; 151(10):738–747. Available from: http://www.annals.org/cgi/content/abstract/151/10/738.
4. Hubbard R, Kerlikowske K, Flowers C, Yankaskas BC, Weiwel Z, Miglioretti DL. Cumulative Probability of False-Positive Recall or Biopsy Recommendation After 10 Years of Screening Mammography. Annals of Internal Medicine. 2011; 155(8):481–492. [PubMed: 22007042]

5. Kerlikowske K. Outcomes of Screening of Screening Mammography. JAMA Internal Medicine [Internet]. 2013 Mar 18.1 Available from: http://archinte.jamanetwork.com/article.aspx?doi=10.1001/jamainternmed.2013.307.
6. Kerlikowske K, Zhu W, Hubbard RA, Geller B, Dittus K, Braithwaite D, et al. Outcomes of Screening Mammography by Frequency, Breast Density, and Postmenopausal Hormone Therapy. JAMA Internal Medicine [Internet]. 2013 Mar 18.:E1–E10. Available from: http://archinte.jamanetwork.com/article.aspx?doi=10.1001/jamainternmed.2013.307.
7. Andersson I, Aspegren K, Janzon L, Landberg T, Lindholm K, Linell F, et al. Mammographic screening and mortality from breast Malmo mammographic screening trial the. BMJ. 1988; 297:943–948. [PubMed: 3142562]
8. Nyström L, Andersson I, Bjurstam N, Frisell J, Nordenskjöld B, Rutqvist LE. Long-term effects of mammography screening: updated overview of the Swedish randomised trials. Lancet [Internet]. 2002 Mar 16; 359(9310):909–919. Available from: http://www.ncbi.nlm.nih.gov/pubmed/11918907.
9. Miller AB, To T, Baines CJ, Wall C. Canadian national breast screening study-2: 13-year results of a randomized trial in women aged 50–59 years. Journal of the National Cancer Institute [Internet]. 2001 Mar 7.92:1400–1409. Available from: http://www.ncbi.nlm.nih.gov/pubmed/11238702.
10. UK Trial of Early Detection of Breast Cancer group. 16-year mortality from breast cancer in the UK Trial of Early Detection of Breast Cancer. Lancet [Internet]. 1999 Jun 5; 353(9168):1909–1914. Available from: http://www.ncbi.nlm.nih.gov/pubmed/10371568.
11. Gøtzsche P, Nielsen M. Screening for breast cancer with mammography. Cochrane database of systematic reviews. 2011; (1):CD001877. [PubMed: 21249649]
12. Alexander FE, Anderson TJ, Brown HK, Forrest aP, Hepburn W, Kirkpatrick aE, et al. 14 years of follow-up from the Edinburgh randomised trial of breast-cancer screening. Lancet [Internet]. 1999 Jun 5; 353(9168):1903–1908. Available from: http://www.ncbi.nlm.nih.gov/pubmed/10371567.
13. R Core Team. R: A Language and Environment for Statistical Computing [Internet]. Austria: Vienna; 2013. Available from: http://www.r-project.org
14. 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. Annals of internal medicine [Internet]. 2011 Jul 5; 155(1):10–20. Available from: http://www.annals.org/cgi/content/abstract/155/1/10.
15. CMS. Characteristics and Perceptions of the Medicare Population [Internet]. Baltimore, MD: 2010. p. 572010 Available from: http://www.cms.gov/Research-Statistics-Data-and-Systems/Research/MCBS/Data-Tables-Items/2010-Char-and_Perc.html
16. Ballard-Barbash R. Breast Cancer Surveillance Consortium: a national mammography screening and outcomes database. American Journal of Radiology [Internet]. 1997 Oct.169:1001–1008. Available from: http://www.ncbi.nlm.nih.gov/pubmed/0009308451.
17. Howden, L.; Meyer, J. Age and Sex Composition: 2010 Census Brief [Internet]. Washington: 2011. p. 1-15.Available from: http://www.census.gov/2010census/data/
18. Centers for Disease Control and Prevention (CDC). Behavioral Risk Factor Surveillance System Survey Data [Internet]. Atlanta, Georgia: U.S.: Department of Health and Human Services, Center for Disease Control and Prevntion; 2010. Available from: http://www.cdc.gov/brfss/technical_infodata/surveydata/2010.htm
19. Centers for Medicare and Medicaid Services. Medicare Physician Fee Schedule look-up (CPT/HCPCS G0202, 77057, 77052) [Internet]. Available from: http://www.cms.gov/apps/physician-fee-schedule/.
20. U.S. Food and Drug Administration. [cited 2012 Jan 25] Mammography Quality Standards Act and Program. [Internet]. 2010. Available from: http://www.fda.gov/Radiation-EmittingProducts/MammographyQualityStandardsActandProgram/DocumentArchives/ucm199497.htm
21. Fenton JJ, Abraham L, Taplin SH, Geller BM, Carney Pa, D'Orsi C, et al. Effectiveness of computer-aided detection in community mammography practice. Journal of the National Cancer Institute [Internet]. 2011 Aug 3; 103(15):1152–1161. Available from: http://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=3149041&tool=pmcentrez&rendertype=abstract.

22. Tosteson ANA, Stout NK, Fryback DG, Acharyya S, Herman BA, Hannah LG, et al. Cost-effectiveness of digital mammography breast cancer screening. Annals of internal medicine [Internet]. 2008 Jan 1; 148(1):1–10. Available from: http://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=2662630&tool=pmcentrez&rendertype=abstract.
23. Rothman, KJ.; Greenland, S.; Lash, TL. Modern Epidemiology. 4th ed.. Philadelphia: Lippincott Williams and Wilkins; 2008.
24. Smith R, Cokkinides V, Eyre HJ. Cancer screening in the United States, 2007: a review of current guidelines, practices, and prospects. CA: a cancer journal for clinicians [Internet]. 2007; 57(2):90–104. Available from: http://www.ncbi.nlm.nih.gov/pubmed/17392386.
25. Van Ravesteyn NT, Miglioretti DL, Stout NK, Lee SJ, Schechter CB, Buist DSM, et al. Tipping the balance of benefits and harms to favor screening mammography starting at age 40 years: a comparative modeling study of risk. Annals of Internal Medicine [Internet]. 2012; 156(9):609–617. Available from: http://www.ncbi.nlm.nih.gov/pubmed/22547470.
26. Centers for Medicare and Medicaid Services. Medicare Current Beneficiary Survey, CY 2003 Cost and Use Public Use File. 2003. Table 2.4
27. D'Orsi, CJ.; Bassett, LW.; Berg, WA.; Al, E. Breast Imaging Reporting and Data System: ACR BI-RADS - Breast Imaging Atlas. 4th edition. Reston, VA: American College of Radiology; 2003. BI-RADS: Mammography.
28. Bureau of Labor Statistics. Consumer Price Index [Internet]. Washington (DC): 2011. Available from: http://www.bls.gov/cpi/data.htm
29. Saltelli A, Ratto M, Tarantola S, Campolongo F. Sensitivity analysis practices: Strategies for model-based inference. Reliability Engineering & System Safety. 2006; 91(10–11):1109–1125.
30. Burnside E, Belkora J, Esserman L. The Impact of Alternative Practices on the Cost and Quality of Mammographic Screening in the United States. Clinical Breast Cancer [Internet]. 2001 Jul 1; 2(2):145–152. Available from: http://cigjournals.metapress.com/openurl.asp?genre=article&id=doi:10.3816/CBC.2001.n.019.
31. Gross CP, Long JB, Ross JS, Abu-Khalaf MM, Wang R, Killelea BK, et al. The cost of breast cancer screening in the medicare population. JAMA internal medicine [Internet]. 2013 Feb 11; 173(3):220–226. Available from: http://www.ncbi.nlm.nih.gov/pubmed/23303200.
32. Bleyer A, Welch H. Effect of three decades of screening mammography on breast-cancer incidence. New England Journal of Medicine [Internet]. 2012; 367:1998–2005. Available from: http://www.nejm.org/doi/full/10.1056/NEJMoa1206809.
33. Independent UK Panel on Breast Cancer Screening. The benefits and harms of breast cancer screening: an independent review. Lancet [Internet]. 2012 Oct 29; 6736(12):1–9. Available from: http://www.ncbi.nlm.nih.gov/pubmed/23117178.
34. Van Ravesteyn NT, Miglioretti DL, Stout NK, Lee SJ, Schechter CB, Buist DSM, et al. Tipping the balance of benefits and harms to favor screening mammography starting at age 40 years: a comparative modeling study of risk. Annals of Internal Medicine [Internet]. 2012; 156(9):609–617. Available from: http://www.ncbi.nlm.nih.gov/pubmed/22547470.
35. Hubbard R, Kerlikowske K, Flowers C, Yankaskas BC, Weiwel Z, Miglioretti DL. Cumulative Probability of False-Positive Recall or Biopsy Recommendation After 10 Years of Screening Mammography. Annals of Internal Medicine. 2011; 155(8):481–492. [PubMed: 22007042]
36. Hafslund B, Espehaug B, Nortvedt MW. Effects of False-Positive Results in a Breast Screening Program on Anxiety, Depression and Health-Related Quality of Life. Cancer Nursing [Internet]. 2011 Available from: http://www.ncbi.nlm.nih.gov/pubmed/22067696.
37. Keyzer-Dekker CMG, De Vries J, Van Esch L, Ernst MF, Nieuwenhuijzen GA, Roukema JA, et al. Anxiety after an abnormal screening mammogram is a serious problem. The Breast Journal [Internet]. Elsevier Ltd;. 2012; 21(1):83–88. Available from: http://www.ncbi.nlm.nih.gov/pubmed/21924905.
38. Nelson HD, Zakher B, Cantor A, Fu R, Griffin J, O'Meara ES, et al. Risk Factors for Breast Cancer for Women Aged 40 to 49 Years. Annals of Internal Medicine [Internet]. American College of Physicians (190 N. Indenpence Mall West, Philadelphia PA 19106-1572, United States). 2012; 156(9):635–648. Available from: http://www.annals.org/content/156/9/635.full.pdf+html?sid=685fb8f3-78d4-4856-b5aa-b7467e9ec242.

39. Frieden TR. Use of Selected Clinical Preventive Services Among Adults--United States, 2007–2010. MMWR. Morbidity and mortality weekly report [Internet]. 2012 Jun 15.61(Suppl 1–2) Available from: http://www.ncbi.nlm.nih.gov/pubmed/22695456.
40. Levy AR, Bruen BK, Ku L. Health Care Reform and Women’s Insurance Coverage for Breast and Cervical Cancer Screening. Preventing Chronic Disease [Internet]. 2012 Oct.9:E159. Available from: http://www.ncbi.nlm.nih.gov/pubmed/23098646.
41. Rauscher GH, Allgood KL, Whitman S, Conant E. Disparities in screening mammography services by race/ethnicity and health insurance. Journal of women’s health (2002) [Internet]. 2012 Feb; 21(2):154–160. Available from: http://www.ncbi.nlm.nih.gov/pubmed/21942866.
42. GAO. MAMMOGRAPHY: Current Nationwide Capacity Is Adequate, but Access Problems May Exist in Certain Locations, GAO-06-724 [Internet]. Washington, DC: 2006 Oct. Available from: www.gao.gov/cgi-bin/getrpt?GAO-06-724
43. Joy, J.; Penhoet, E.; Petitti, D., editors. Saving Women’s Lives: Strategies for Improving Breast Cancer Detection and Diagnosis. Washington, DC: The National Academies Press; 2005. p. 63-116.
44. Onega T, Smith M, Miglioretti DL, Carney Pa, Geller Ba, Kerlikowske K, et al. Radiologist agreement for mammographic recall by case difficulty and finding type. Journal of the American College of Radiology : JACR [Internet]. Elsevier Inc. 2012 Nov; 9(11):788–794. Available from: http://www.ncbi.nlm.nih.gov/pubmed/23122345.
45. Elmore JG, Nakano CY, Koepsell TD, Desnick LM, Carl J, Orsi D, et al. International Variation in Screening Mammography Interpretations in Community-Based Programs. JNCI Journal of the National Cancer Institute. 2003; 95(18):1384–1393.
46. Smith-Bindman R, Chu PW, Miglioretti DL, Sickles EA, Blanks R, Ballard-Barbash R, et al. Comparison of screening mammography in the United States and the United kingdom. JAMA: the journal of the American Medical Association [Internet]. 2003 Oct 22; 290(16):2129–2137. Available from: http://jama.ama-assn.org/cgi/content/abstract/290/16/2129.
47. Hofvind S, Vacek PM, Skelly J, Weaver DL, Geller BM. Comparing screening mammography for early breast cancer detection in Vermont and Norway. Journal of the National Cancer Institute [Internet]. 2008 Aug 6; 100(15):1082–1091. Available from: http://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=2720695&tool=pmcentrez&rendertype=abstract.
48. Smith M, Saunders R, Stuckhardt L, Mcginnis JM. Best Care at Lower Cost The Path to Continuously Learning Health Care in America Committee on the Learning Health Care System in America. 2012
49. Flowers C, O’Donoghue C, Moore D, Goss A, Kim D, Kim J, et al. Reducing false-positive biopsies: a pilot study to reduce benign biopsy rates for BI-RADS 4A/B assessments through testing risk stratification and new thresholds for intervention. Breast Cancer Res Treat. 2013; 139(3):769–777. [PubMed: 23764994]
50. Esserman L, Thompson I, Reid B. Overdiagnosis and Overtreatment in Cancer: An Opportunity for Improvement. JAMA: the journal of the American Medical Association. 2013
51. Frieden TR. Use of Selected Clinical Preventive Services Among Adults--United States, 2007–2010. MMWR. Morbidity and mortality weekly report. 2012 Jun; 61(Suppl):1–2. [PubMed: 22695456]
52. Pace LE, He Y, Keating NL. Trends in mammography screening rates after publication of the 2009 US Preventive Services Task Force recommendations. Cancer [Internet]. 2013 Apr 19.:2009–2014. Available from: http://www.ncbi.nlm.nih.gov/pubmed/23605683.
53. National Committee for Quality Assurance. Proposes Changes to Existing Measure for HEDIS 2014: Breast Cancer Screening [Internet]. Washington, DC: 2013. p. 1-11.Available from: http://www.ncqa.org/SearchResults.aspx?Search=hedis+2014
54. Herdman, R.; Norton, L., editors. Saving Women’s Lives: Strategies for Improving Breast Cancer Detection and Diagnosis. Washington, DC: The National Academies Press; 2005. Committee on New Approaches to Early Detection and Diagnosis of Breast Cancer.
55. Esserman L, Cowley H, Eberle C, Kirkpatrick A, Chang S, Berbaum K, et al. Improving the accuracy of mammography: volume and outcome relationships. Journal Of The National Cancer

Institute [Internet]. 2002; 94(5):369–375. Available from: http://www.ncbi.nlm.nih.gov/pubmed/11880475.

56. U.S. Department of Health and Human Services. [cited 2013 Aug 11] Healthy People 2020 Topics & Objectives, Cancer [Internet]. 2013. p. C–17Available from: http://www.healthypeople.gov/2020/topicsobjectives2020/objectiveslist.aspx?topicId=5

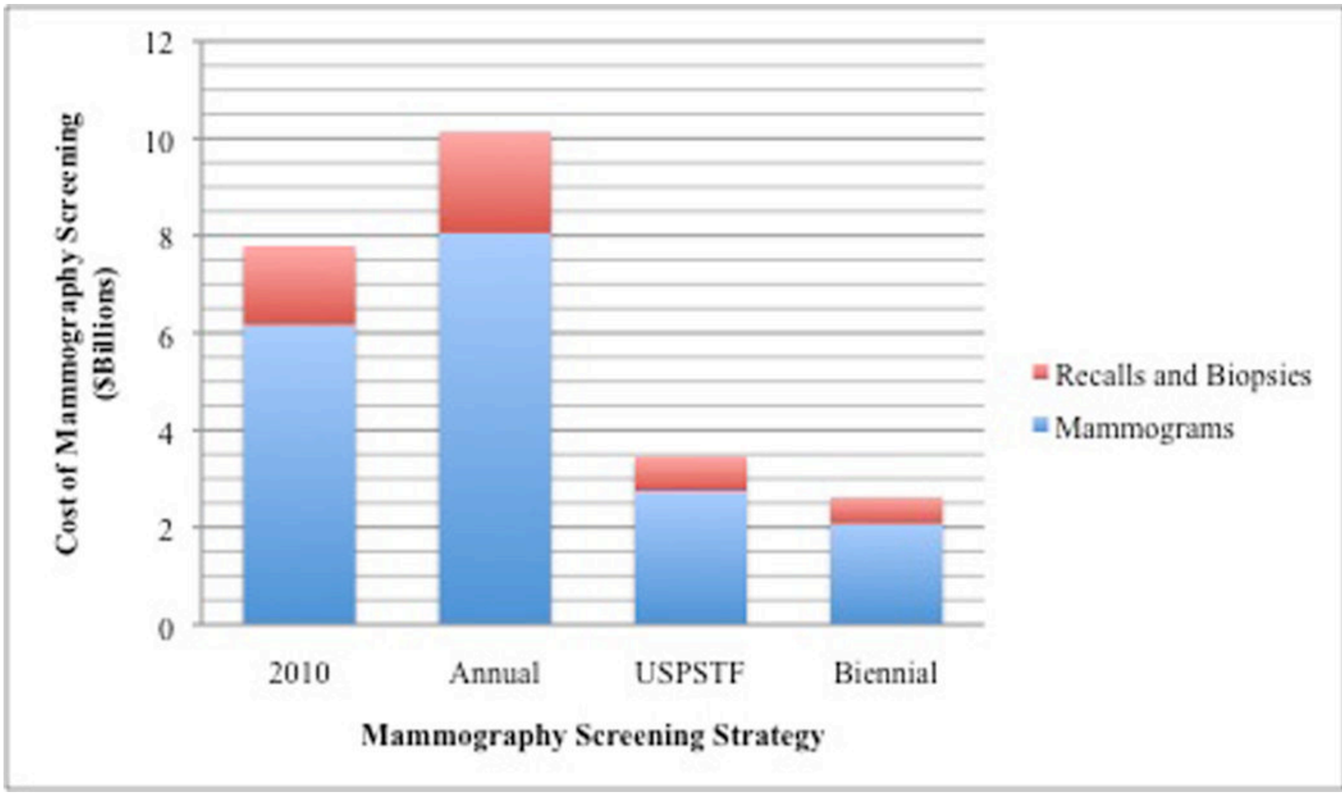

Figure 1.

Comparison of the Costs of Screening Strategies per Year. Each bar represents the total cost of mammography screening per year, demarcating the costs from screening mammograms and the subsequent recalls and biopsies.

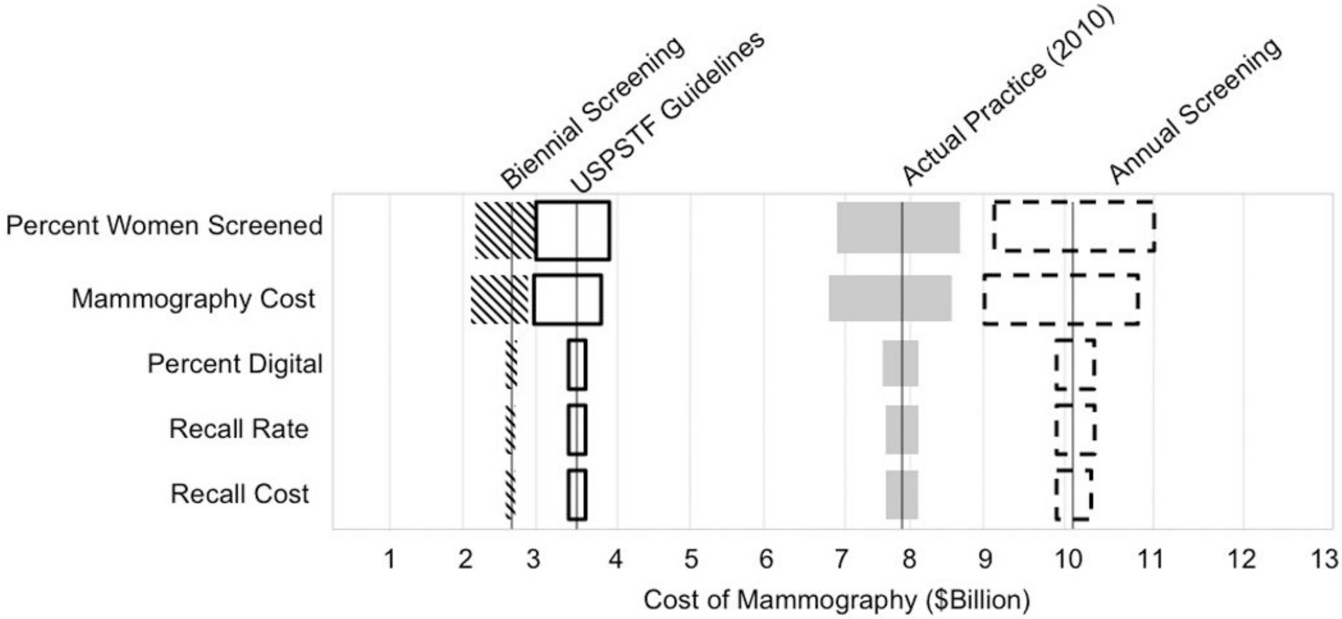

Figure 2.

Sensitivity Analyses of Mammography Screening Practice and Advocated Screening Strategies. Tornado diagrams depicting sensitivity analyses done for the largest determinants of cost for each strategy. The x-axis depicts the cost of mammography screening per year. The bold line within each tornado diagram is the point estimate of cost for each strategy and the horizontal bars represent the impact on cost the input ranges have in the sensitivity analyses. Frequency is the largest driver of cost as demonstrated by the wide range of cost between least frequent strategy, biennial screening, versus the most frequent strategy, annual screening. The next largest drivers of cost, by decreasing level of impact, were: the variation of the percent women screened, the cost of individual mammograms, percent film versus digital mammography, the number of recalls and the recall cost.

Table 1

Model Inputs and Formulas including Mammography Screening Strategies Simulated

Screening Strategy				
	Frequency	**Modeled Participation**		
		40–49 years	**50– 69 years**	**70– 85 years**
Annual Strategy	Every year	85.0%	85.0%	85.0%
Biennial Strategy	Every 2 years	0.0%	85.0%	0.0%
USPSTF	Every 2 years	20.0% (high-risk)	85.0%	25.0%-37.2%
Actual Practice*	Variable	61%-71%	74%-75%	72%-74%
Other Inputs		40– 49 years	50–69 years	70– 85 years
Women at Risk (52)**		21994479	36820954	12610766
Percent Recalled† First mammogram Subsequent		16.8%-20.1% 8.7%-10.3%	17.4%-20.6% 6.4%-9.8%	16.2%-16.8% 5.7%-8.2%
Cost per Mammogram (18) Film Digital CAD		$86.09 $137.24 $17.93		
Cost per Recall (53)		$421.97 $467.93		
Percent Digital Mammography (19)		81.7%		
Percent CAD (20)		27.8%		
Cost computations				
Number of women at risk	Number of women - Number of women receiving surveillance mammograms			
Number of Digital Mammograms	Number of women at risk × Proportion of women screened§ × Proportion of digital mammograms			
Number of Film Mammograms	Number of women at risk × Proportion of women screened§ × Proportion of film mammograms			
Number of CADs	Number of women at risk × Proportion of CAD examinations			
Number of Recalls	Proportion recalled after a mammogram × (Number of digital mammograms + Number of film mammograms)			
Total cost	Number of digital mammograms × Cost of digital mammogram + Number of film mammograms × Cost of film mammogram + Number of CADs × cost of CAD + Number of recalls × Cost of recall			
Sensitivity analysis				
A probabilistic sensitivity analysis was performed to assess the impact of each variable on the aggregate cost. The variables were assumed to follow beta-distributions as detailrd in Appendix A.				

*With calculated correction for self-reported data in the BRFSS. (16)

**Women at risk is the population of women from the census (53) excluding women with breast cancer in the past 5 years.

†Data provided by the Breast Cancer Surveillance Consortium.

§Proportion of women screened varied depending on screening strategy modeled. The basecase modeling actual screening practice averaged the proportion of women screened in one year that had been screened over every 1, 2, 3, 4 and, 5 years. Annual strategies screened 85% of all women at risk in a given year. Biennial and USPSTF strategies screened 42.5% of women per year (85% of women at risk every two years).

All costs are reported in 2010 US dollars. Abbreviations: USPSTF, United States Preventative Services Task Force; CAD, computer assisted detection.

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Table 2

Total Cost of Mammography Screening by Strategy in Billions of Dollars

		40– 49 years	50– 69 years	70– 74 years	>75 years	Total Cost (All ages)
Actual Practice	Mammography cost	1.77 (1.55–1.98)	3.32 (2.91– 3.71)	0.46 (0.4– 0.51)	0.63 (0.56–0.71)	6.17 (5.42– 6.91)
	Recall cost	0.55 (0.48– 0.61)	0.85 (0.74– 0.95)	0.1 (0.09– 0.11)	0.13 (0.11– 0.14)	1.62 (1.43– 1.82)
	Total cost	2.32 (2.03–2.59)	4.16 (3.66– 4.66)	0.56 (0.49– 0.62)	0.76 (0.67–0.85)	**7.80** (6.73–8.92)
Annual Strategy	Mammography cost	2.48 (2.18–2.79)	4.15 (3.65– 4.67)	0.57 (0.5–0.64)	0.86 (0.75–0.96)	8.06 (7.08–9.05)
	Recall cost	0.76 (0.66–0.85)	1.04 (0.91–1.17)	0.12 (0.1–0.13)	0.17 (0.15–0.19)	2.08 (1.83–2.34)
	Total cost	3.24 (2.84–3.64)	5.2 (4.56–5.83)	0.69 (0.6–0.77)	1.02 (0.9– 1.15)	**10.14** (8.61–11.89)
Biennial Strategy	Mammography cost	NA	2.08 (1.82–2.33)	NA	NA	2.08 (1.82–2.33)
	Recall cost	NA	0.54 (0.47–0.6)	NA	NA	0.54 (0.47–0.6)
	Total cost	NA	**2.61** (2.29–2.93)	NA	NA	**2.61** (2.19–3.07)
USPSTF	Mammography cost	0.29 (0.26–0.33)	2.08 (1.82–2.32)	0.17 (0.15–0.19)	0.21 (0.18–0.23)	2.75 (2.41–3.07)
	Recall cost	0.09 (0.08–0.1)	0.54 (0.47–0.6)	0.04 (0.03–0.04)	0.04 (0.04–0.05)	0.71 (0.62–0.79)
	Total cost	0.38 (0.34–0.43)	2.62 (2.29–2.92)	0.21 (0.18–0.23)	0.25 (0.22–0.28)	**3.46** (2.94–4.01)