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Identifying Equitable Screening Mammography Strategies for Black Women in the United States Using Simulation Modeling

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Background: Screening mammography guidelines do not explicitly consider racial differences in breast cancer epidemiology, treatment, and survival.

Objective: To compare tradeoffs of screening strategies in Black women versus White women under current guidelines.

Design: An established model from the Cancer Intervention and Surveillance Modeling Network simulated screening outcomes using race-specific inputs for subtype distribution; breast density; mammography performance; age-, stage-, and subtype-specific treatment effects; and non–breast cancer mortality.

Setting: United States.

Participants: A 1980 U.S. birth cohort of Black and White women.

Intervention: Screening strategies until age 74 years with varying initiation ages and intervals.

Measurements: Outcomes included benefits (life-years gained [LYG], breast cancer deaths averted, and mortality reduction), harms (mammographies, false positives, and overdiagnoses), and benefit–harm ratios (tradeoffs) by race. Efficiency (benefits per unit resource), mortality disparity reduction, and equity in tradeoffs were evaluated. Equitable strategies for Black women were defined as those with tradeoffs closest to benchmark values for screening White women biennially from ages 50 to 74 years.

Results: Biennial screening from ages 45 to 74 years was most efficient for Black women, whereas biennial screening from ages 40 to 74 years was most equitable. Initiating screening 10 years earlier in Black versus White women reduced Black–White mortality disparities by 57% with similar LYG per mammogram for both populations. Selection of the most equitable strategy was sensitive to assumptions about disparities in real-world treatment effectiveness: The less effective treatment was for Black women, the more intensively Black women could be screened before tradeoffs fell short of those experienced by White women.

Limitation: Single model.

Conclusion: Initiating biennial screening in Black women at age 40 years reduces breast cancer mortality disparities and yields benefit–harm ratios that are similar to tradeoffs of White women screened biennially from ages 50 to 74 years.

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Screening mammography guidelines provide recommendations for the overall U.S. population (1, 2) but do not explicitly consider racial disparities in breast cancer epidemiology, screening, and treatment. Compared with White women, Black women in the United States have a younger age at breast cancer diagnosis (58 vs. 62 years) (3); are diagnosed more often with adverse features, including triple-negative (4) and advanced-stage disease (3); and have higher age-standardized rates of breast cancer mortality (28.2 vs. 20.3 per 100 000 persons) (3, 5).

These disparities are partially mediated through and further complicated by racism, particularly the institutionalized (6), structural (7), and interpersonal (6) forms. Structural racism drives breast cancer disparities by influencing upstream health care factors (for example, insurance access [8]) and broader societal constructs (for example, poverty [9]), which influence stage and treatment receipt. Structural and interpersonal racism may also explain point-of-care disparities that drive screening and treatment differences (10–13). Finally, all 3 forms of racism (institutionalized, interpersonal, and individualized [6]) influence competing mortality (14, 15), which modifies screening outcomes. These complexities suggest that Black women may need different screening schedules to achieve similar screening outcomes to White women.

Unfortunately, no randomized trial data exist to optimize screening by race because few Black women were included in early trials (16, 17). New trials would ideally test screening schedules by race, but such trials are not feasible because of the large sample sizes required. In these situations, simulation modeling can synthesize race-specific data and test a range of screening strategies. The Cancer Intervention and Surveillance Modeling Network (CISNET) models were previously used to inform breast cancer screening guidelines, but guideline-focused studies lack race-specific modeling (18, 19). Separate race-specific modeling studies lack current knowledge about molecular subtypes and modern therapy (20, 21).

See also:

Editorial comment
Summary for Patients

In this study, we used an updated, race-specific CISNET model to identify equitable screening strategies, defined as strategies for Black women that yielded benefit–harm tradeoffs similar to those of White women screened according to U.S. Preventive Services Task Force (USPSTF) guidelines (1). The results are intended to inform discussions about health equity, given that race-neutral screening guidelines can do harm if they yield unequal outcomes and are applied instead of more equitable alternatives that retain acceptable tradeoffs.

METHODS

We used CISNET Model GE (Georgetown University Medical Center and Albert Einstein College of Medicine) for this study (22–24). The study was considered human subjects–exempt by the Georgetown University Institutional Review Board because public deidentified data were used.

Screening Strategies and Population

We evaluated 9 strategies that varied by starting age (40, 45, and 50 years) and interval (annual, biennial, and the following hybrids: annual from age 40 to 49 years and biennial thereafter, biennial from age 40 to 49 years and annual thereafter, and the American Cancer Society recommendation of annual from age 45 to 54 years and biennial thereafter [2]), with cessation at 74 years. The 9 strategies were compared with biennial screening of White women aged 50 to 74 years because this is the implicit benchmark for outcomes and benefit–harm ratios based on USPSTF guidelines (1). In secondary analyses, we evaluated 2 additional strategies: annual screening starting at 30 or 35 years through 39 years followed by biennial screening from 40 to 74 years (**Appendix Figure 1**, available at Annals.org).

We modeled the cohort of U.S. women born in 1980, who turned age 40 years in 2020, followed for their lifetimes starting from age 25 years (because breast cancer is rare before then). As in prior modeling studies (18), to focus on screening efficacy, we assumed that 100% of Black and White women used screening. This assumption was considered reasonable because contemporary studies show minimal to no difference in screening mammography use between Black and White women (25).

Model Overview

The model has been described in detail elsewhere (**Appendix Figure 2**, available at Annals.org) (22–24) and is available for use via collaboration. Additional information is available on request. In brief, model GE is a parallel-universe population simulation model that begins with estimates of breast cancer incidence and survival trends, specific to molecular subtype (based on estrogen receptor and human epidermal growth factor receptor 2 status), in the absence of screening or adjuvant treatment (23, 24, 26, 27). Breast cancer is modeled to have a molecular subtype–specific distribution of preclinical screen-detectable periods (sojourn time) and clinical detection times. The model assumes that one third of ductal carcinoma in situ cases do not progress to invasive cancer. Treatment tailored to molecular subtype and stage reduces the hazard of breast cancer death. Women can die of breast cancer or other causes.

Model Input Parameters

The model parameters (23, 27) were updated with race-specific inputs (**Table 1**) . Race was typically defined by self-report. Breast cancer incidence was modeled on the basis of an age–period–cohort model (26). Race-specific rates were obtained by applying an age-specific relative risk for breast cancer for Black versus White women using SEER (Surveillance, Epidemiology, and End Results) data (29).

Race-specific breast density was modeled using Breast Imaging Reporting and Data System categories (36) and assigned from ages 25 to 40 years. Density could decrease by 1 category or remain the same at age 50 to 64 years and again at age 65 years on the basis of prevalence observed in the Breast Cancer Surveillance Consortium database (37) (O'Meara ES. Personal communication). We assumed that density affected mammography performance characteristics and incidence.

Screening sensitivity and specificity by age, race, and density group were calibrated to Breast Cancer Surveillance Consortium data for invasive cancer and ductal carcinoma in situ combined on initial versus subsequent mammography (O'Meara ES. Personal communication).

Stage was based on criteria from the American Joint Committee on Cancer, version 6, and was dependent on age group (<50 years vs. ≥50 years), density, molecular subtype, and screen versus clinical detection (O'Meara ES. Personal communication). Stage- and molecular subtype–specific chemotherapy included anthracycline-based regimens with taxanes, estrogen receptor–positive tumors included 5 years of endocrine therapy, and tumors positive for human epidermal growth factor receptor 2 (*ERBB2*; formerly *HER2*) included trastuzumab.

We modeled treatment effects by considering treatment efficacy and dissemination. Treatment efficacy was based on clinical trials (31) and was modeled as a reduction in the hazard of breast cancer death. We used data from pooled analyses of National Surgical Adjuvant Breast and Bowel Project trials to estimate race-specific treatment efficacy (32). That analysis showed similar or slightly lower efficacy of systemic therapy for Black relative to White women treated in the same trials when age, stage, comorbidities, and estrogen receptor status were considered (32). Therefore, we conservatively assumed equal efficacy by race.

However, outside clinical trials, treatment effectiveness depends on differences in treatment dissemination, including access, delays, dose reductions, and discontinuation. Suboptimal treatment dissemination occurs more often in Black than White women (21, 34, 38, 39). In previous policy-oriented work (18), we assumed full dissemination (that is, all women receive the most effective therapy) to identify a pure effect of screening under optimal treatment conditions. However, given the differences in treatment dissemination by race, we used published data (34) to estimate the effect of disparities in dissemination. The best available evidence we identified showed that after mediators contained in our model (for example, stage

Table 1. Model Input Parameters

Parameter	Description and Race Specificity	Race Definition	References
Births	Birth cohorts from 1890 to 2000 by race	Self-report	28
Incidence	Age–period–cohort model with age-specific relative risk for Black vs. White incidence	Self-report prioritized if available, otherwise peer SEER standards, used data from medical records	18, 26, 29*
Mammography use	Assumed equal by race and 100% to isolate the effect of mammography under ideal screening conditions	–	–
Mammography sensitivity	Age-specific rates for first and subsequent screening examinations by race	Self-report	O'Meara ES. Personal communication†
Breast density	Prevalence by age and race	Self-report	O'Meara ES. Personal communication†
ER/HER2	Probability of ER/HER2 conditional on age, stage, and race	Self-report	O'Meara ES. Personal communication†
Sojourn time	Calibrated parameters; γ distributions by age, ER status, and HER2 status	–	23‡
Unscreened stage distribution	Clinically detected cases, 2005 to 2017, by age and race	Self-report	O'Meara ES. Personal communication†
Screened stage distribution	Digital screen and interval-detected cases, 2005 to 2017, by age and race	Self-report	O'Meara ES. Personal communication†
Survival without treatment	Survival by race from SEER, 1975 to 1979, assumed equal by race	Self-report prioritized if available, otherwise peer SEER standards, used data from medical records	30*
Treatment efficacy	Reduction in hazard of breast cancer death, meta-analyses of randomized trial results by ER/HER2; assumed equal by race (32)	–	31–33§
Treatment dissemination	Assumed 100% for White women per previous modeling studies for USPSTF; reduced for Black women to account for effect of disparities in treatment receipt; assumed 80% for Black women for base case with sensitivity analysis performed using a range of 50% to 100%	Self-report	34‖
Non–breast cancer (other-cause) mortality	Age-, race-, and cohort-specific other-cause mortality rates by year	Self-report	35¶

BCSC = Breast Cancer Screening Consortium; CDC = Centers for Disease Control and Prevention; CISNET = Cancer Intervention and Surveillance Modeling Network; ER = estrogen receptor; GE = Georgetown University Medical Center and Albert Einstein College of Medicine; HER2 = human epidermal growth factor receptor 2; SEER = Surveillance, Epidemiology and End Results; USPSTF = U.S. Preventive Services Task Force.
* SEER.
† Unpublished BCSC data, agreement DR285e.
‡ Model GE calibration.
§ Clinical trial meta-analyses.
‖ National Comprehensive Cancer Network data.
¶ Modeling performed by University of Wisconsin Breast CISNET group/CDC Wonder.

and subtype) are accounted for, a residual Black–White disparity in breast cancer death remains (hazard ratio, 1.24; Table 3, model 3, in Warner and colleagues [34]). We converted this hazard ratio to a percentage (80.6%) and incorporated it into the dissemination parameter to account for decreased treatment effects in Black women.

We used existing non–breast cancer mortality rates from the United States that were specific to age and race (26, 35). These mortality rates implicitly capture the net effect of racism, downstream disparities (for example, comorbidities, social determinants of health, and access to care), and other factors that differentially influence survival by race.

Statistical Analysis

We simulated 100 million life histories from birth to death, or age 120 years, to account for the entire potential life history in the absence of screening and treatment. Simulation strategies were repeated with screening and treatment effects for each strategy among Black women. We also simulated biennial screening of White women from age 50 to 74 years followed by optimal systemic therapy. The results for White women served as the benchmark for acceptable benefit–harm ratios. Benefits included percentage reduction in breast cancer mortality, breast cancer deaths averted, and life-years gained (LYG). Harms included false positives, benign biopsies, and overdiagnoses, with the latter often leading to surgical treatment, such as lumpectomy or mastectomy. False positives were calculated using specificity estimates and were defined as screens resulting in additional imaging that did not result in the diagnosis of breast cancer within 12 months (40). Overdiagnoses were defined as cases that would not have been clinically detected in the absence of screening because of lack of progressive potential or preceding death from competing causes other

Table 2. Benefits, Harms, and Benefit–Harm Ratios of Breast Cancer Screening Strategies for Black Women Compared With the Benchmark (B50–74) Strategy for White Women*

Strategy	Per 1000 Women Screened (Versus No Screening)						Benefit–Harm Ratio		Breast Cancer Death Disparity Reduction (vs. B50–74 for Both Races), %
	Mammograms	Benefits			Harms				
		LYG	Breast Cancer Deaths Averted†	Percentage Mortality Reduction	False Positives	Overdiagnoses	LYG/M (× 10−3)	LYG per Overdiagnosis	
White women									
B50–74	11 137	161	8.3	37	864	8.0	14.5	20.1	–
Black women									
B50–74	10 761	176	9.5	35	829	7.0	16.3	25.1	0
B45–74	12 826	210	10.5	39	1031	7.3	16.4	28.8	31.4
B40–74	15 576	233	11.3	42	1264	8.1	15.0	28.8	57.0
A45-B55–74	17 511	219	10.8	40	1399	7.4	12.5	29.6	42.2
A40-B50–74	20 370	244	11.7	43	1693	8.2	12.0	29.8	69.3
A50–74	20 660	192	10.4	38	1522	7.6	9.3	25.3	29.2
A45–74	25 411	234	11.9	44	1950	8.3	9.2	28.2	74.2
B40-A50–74	25 464	249	12.3	45	1957	8.7	9.8	28.6	86.0
A40–74	30 257	260	12.7	47	2385	8.8	8.6	29.5	97.7

A = annual; B = biennial; LYG, life-years gained; LYG/M, life-years gained per mammogram.
* Numbers after "A" or "B" denote cessation and transition ages. Data shown represent the base case of 80% treatment effects/dissemination.
† Breast cancer deaths per 1000 women without screening: Black, 27.07691; White, 22.65354.

than breast cancer. We calculated benefits, harms, and benefit–harm ratios for each combination of metrics. We chose LYG as our primary outcome metric given the differences in age-specific breast cancer incidence and non–breast cancer mortality by race. The number of mammograms and the ratio of LYG to mammograms were our primary harm and benefit–harm metrics for comparability with past guideline analyses (18, 19). Ratios of other metrics were secondary measures.

We used benchmarks for White women to identify the most equitable strategies for Black women, defined as strategies resulting in the most similar benefit–harm ratios (that is, tradeoffs). We also quantified the change in the breast cancer mortality disparity compared with equivalent screening, defined as the difference between the Black-White mortality disparities under equivalent screening (that is, biennial screening beginning at age 50 years and stopping at age 74 years [B50–74] for both racial groups) and tailored screening (for example, B50–74 in White women and biennial screening beginning at age 45 years and stopping at age 74 years [B45–74] in Black women), divided by the disparity under equivalent screening.

We displayed data for the screening scenarios among Black women on an efficiency frontier (41) by connecting the sequence of points representing the largest change in incremental benefits per harm. Strategies on the frontier were considered to be efficient. Strategies that caused more harms or required more mammograms but provided fewer benefits than any other strategy were considered to be strongly dominated. We also applied the concept of weak or extended dominance. Weakly dominated strategies are strategies with an incremental harm–benefit ratio greater than that of a more beneficial strategy (42).

Sensitivity analyses tested the effect on results of a range of systemic therapy effects for Black versus White women. We varied our base-case estimate of 80% from 50% to 100% in sensitivity analysis, where 100% indicated that treatment effects were the same for Black and White women.

Role of the Funding Source

The funders had no role in the design or conduct of the study; collection, management, analysis, or interpretation of the data; preparation, review, or approval of the manuscript; or decision to submit the manuscript for publication.

RESULTS

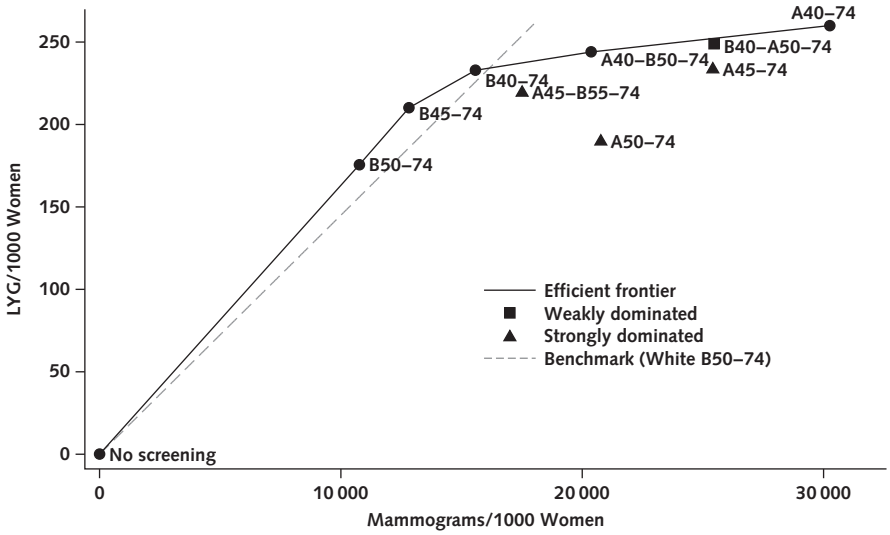
Benefits

Among the strategies tested in Black women, benefits generally increased as the number of mammograms increased due to initiating screening earlier than age 50 years or screening more frequently (Table 2). Efficient strategies for Black women always included the biennial strategies and the most intensive strategy, annual screening beginning at age 40 years and stopping at age 74 years (A40–74). Biennial screening from age 45 to 74 years was most efficient for LYG per mammogram (LYG/M) (Figures 1 and 2). Annual strategies starting at age 45 or 50 years and the American Cancer Society hybrid strategy were dominated (Figure 1; Appendix Figure 3, available on Annals.org). Efficient strategies were similar considering other metrics (Appendix Figure 3). Marginal benefits for initiating biennial screening at age 40, 45, or 50 years versus no screening and B50–74 are shown in Appendix Figure 4 (available at Annals.org).

Equity in Benefit–Harm Ratios

The strategy that yielded the LYG/M ratio closest to the benchmark (B50–74 for White women) was biennial

Figure 1. Efficiency frontier for the base case (80% treatment effects for Black women) for LGY/M.



Treatment effects are described as "dissemination" here to clarify the assumptions made: Efficacy was assumed to be equal for Black and White women, but dissemination differed because of disparities in treatment receipt that affected breast cancer survival. Efficient (*circles and solid line*), weakly dominated (*squares*), and strongly dominated (*triangle*) strategies are shown. The dashed line shows the LYG/M benchmark (B50–74 in White women). Strategies for Black women that fall above the line yield greater LYG/M than benchmark, and those that fall below the line yield fewer LYG/M than the benchmark. Throughout, A = annual and B = biennial; the numbers after "A" or "B" denote cessation and transition ages. LYG/M = life-years gained per mammogram.

from age 40 to 74 years (15.0 vs. benchmark: 14.5 LYG/M) (Table 2). Among the 3 strategies that yielded benefit–harm ratios that met or exceeded the benchmark, B40–74 resulted in the largest mortality reduction for Black women (Figure 1 and Table 2). Strategy B40–74 resulted in 32% more LYG and 19% more breast cancer deaths averted than screening Black women biennially from ages 50 to 74 years but required 45% more mammograms and resulted in 52% more false positives (calculated from Table 2). For secondary metrics, B40–74 remained the most equitable strategy (Appendix Figure 5, available at Annals.org), with the exception that B45–74 was slightly more equitable when considering breast cancer deaths averted per false positive.

Effect on Mortality Disparities

If Black and White women were screened biennially from age 50 to 74 years, there would be an excess of 3.29 deaths among Black women (17.62 vs. 14.33 deaths per 1000 persons for Black vs. White women, respectively; calculated from Table 2). In contrast, if biennial screening was initiated in Black women beginning at age 40 years, deaths would decrease by 1.88 per 1000 women (from 17.62 to 15.74), removing 57% of the racial disparity (Table 2) in mortality expected under current guideline screening (1.88 of 3.29 excess deaths).

Sensitivity Analysis

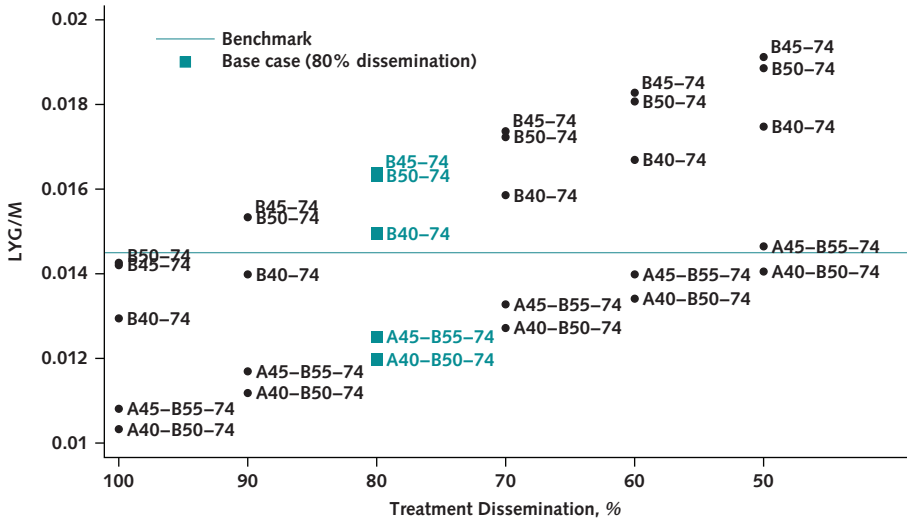
The results were sensitive to assumptions about treatment disparities. As treatment dissemination decreased, the relative benefits of screening increased, permitting use of progressively more intensive strategies before tradeoffs fell below benchmarks (Figure 2). If treatment were equally disseminated for Black and White women (but current levels of competing mortality disparities persisted), screening Black women biennially from age 50 to 74 years would yield similar benefit–harm ratios to the benchmark values for White women (Figure 2; Appendix Tables 1 and 2, available at Annals.org). If disparities in treatment resulted in Black women having 90% or less of the treatment effectiveness experienced by White women, then biennial screening would need to start at age 40 or 45 years in Black women to achieve benefit–harm ratios similar to benchmark values.

Discussion

To our knowledge, this is the first study to use simulation modeling to consider whether race-neutral guidelines for breast cancer screening lead to unequal outcomes. Our results suggest that, in self-identified Black women, initiation of earlier screening than is presently recommended for the overall U.S. population by the USPSTF (1) or the American Cancer Society (2) can reduce mortality disparities and maintain acceptable benefit–harm tradeoffs. This highlights an important concept in health equity: Equivalent interventions may yield inequitable outcomes (43).

Our results were highly sensitive to assumptions about disparities in treatment dissemination. Consistent with previous modeling studies (44), relative benefits of screening increased as treatment effectiveness decreased (that is, Black–White disparities widened). This explains why more intensive screening strategies can be used as disparities widen without compromising tradeoffs (relative to benchmark

Figure 2. LYG/M sensitivity analysis.



The Black–White ratio of treatment effects is varied from 50% to 100%, with 80% representing the base case (*squares*). Treatment effects are described as "dissemination" here to clarify the assumptions made: Efficacy was assumed to be equal for Black and White women, but dissemination differed because of disparities in treatment receipt that affected breast cancer survival. Strategies above and below the benchmark line yield greater and lesser LYG/M, respectively, than the benchmark (B50–74 in White women). Throughout, A = annual and B = biennial; the numbers after "A" or "B" denote cessation and transition ages. LYG/M = life-years gained per mammogram.

values). Although our previous policy-oriented studies (18) estimated screening benefits under ideal treatment conditions, this assumption ignores the effect of racism and other causes of disparities. Racism increases disparities in treatment and competing mortality, but these 2 inputs have opposing effects (that is, competing mortality decreases relative screening benefits). Therefore, ignoring decades-old treatment disparities would have underestimated relative screening benefits for Black women.

Similar to conclusions from our past modeling analyses (18, 19), most annual screening strategies for Black women were inefficient; they had fewer benefits and more harms than biennial strategies. One explanation is that although higher age-specific incidence of breast cancer in their 40s in Black versus White women provides sufficient benefit to outweigh harms of starting screening at age 40 years, there may not be sufficient differences in the parameters we used to model tumor biology to warrant annual versus biennial screening. We will reassess as knowledge about breast cancer biology evolves.

Comorbidities also vary in a complex, race-specific manner. For example, obesity decreases treatment effectiveness (due to suboptimal completion and other factors) but has mixed effects on breast cancer incidence. Obesity also decreases breast cancer incidence premenopausally but increases incidence postmenopausally. Unfortunately, the barriers that preclude equitable breast cancer treatment often prevent equitable treatment of comorbidities (45). Our group previously modeled the effect of obesity on racial disparities in breast cancer and found that obesity had no net effect on disparities due to opposing pre- and postmenopausal effects (20). In the current study, the net effect of comorbidities on breast cancer incidence and treatment is already implicitly considered, given that our inputs are derived from real-world data sets that contain women with comorbidities. However, specific comorbidities may sufficiently alter screening outcomes for subsets of women. In future analyses, we will model screening recommendations for groups of women by race with specific comorbidities.

The role of screening in reducing disparities represents a dynamic interplay among tumor growth, early detection, and molecular-targeted therapy. This is illustrated by our finding that when disparities in treatment dissemination were eliminated, similar screening could yield similar outcomes for Black and White women; however, if treatment disparities persist or widen, then Black women might benefit from more intensive screening than White women. Although earlier screening may partially mitigate the effect of treatment disparities, it should not supersede efforts to achieve treatment equity. Indeed, CISNET (21) and others (34) have shown that disparities in treatment represent one of the largest modifiable mediators of disparities in breast cancer survival. Therefore, addressing treatment disparities remains a high priority. However, aspects of treatment disparities are attributable to systemic racism, which is difficult to change and will not be resolved in the near term. We reduce harm by compensating for this with enhanced screening. Implementation of equitable screening represents a practical, sustainable, high-impact solution for reducing disparities that could be implemented in the short term.

However, elimination of breast cancer racial disparities goes beyond screening and treatment. Racial disparities in insurance and stage at diagnosis reflect the larger and longstanding issue of structural racism (employment, educational opportunity, and so forth) (7,

8). Well-placed efforts within health care may, therefore, fall short of eliminating cancer inequity.

This study used a well-established CISNET model and followed best modeling practices (18, 27). However, several caveats should be considered. First, we used a single model. All models make structural assumptions about nonobservable aspects of breast cancer, including the proportion of ductal carcinoma in situ cases that progress to invasive cancer. We plan to expand these analyses with several CISNET models to test the effect of structural uncertainty on conclusions about race-specific screening schedules. Parameter uncertainty also exists in any simulation model, but we have used the model previously and calibrated it to U.S. trends using multiple real-world data sources (27).

Second, our purpose was to establish whether there was a scientific rationale for recommending different screening strategies by race assuming full screening efficacy (that is, 100% use). However, patterns of use may vary by age and race, affecting screening outcomes. For example, if younger Black women are less likely to complete biannual screening examinations than older Black women, the benefits of starting screening at 40 versus 50 years would decrease. If return to screening after a false positive differs by race (46) (or age [47]), then relative benefit–harm ratios for Black and White women might shift. We will address the age and race patterns in future analyses. We will account for the fact that tomosynthesis may decrease false positives (48) and that culturally competent coping strategies (49) and physician counseling (50) can reduce mammography avoidance after false positives. Our findings are likely to be relevant into the future until there are major changes in early detection technology or treatment paradigms. The models consider survival after local and systemic therapy but do not model types of surgery. We did not model cost but plan to in subsequent analyses. Earlier screening initiation may increase patient, payer, and societal costs, but earlier detection may reduce treatment costs and save more lives. Screening harms (for example, false positives, benign biopsy results, and overdiagnoses) can affect quality of life, but no current data suggest that the quality-of-life effects differ by race. In addition, our study is designed to inform population-level guidelines and cannot fully capture nuances that may alter the risks and benefits for individual women whose characteristics differ substantially from those in our study.

Finally, race and racism (whether structural, interpersonal, or internalized [6]) are complex constructs. Many, including members of our own team, have published studies on race, and we recognize that associations between race and health or societal outcomes are often rooted in racism as opposed to biology (20, 21, 51–57).

Our modeling used nationally representative data for U.S. women who self-report as Black. Our choice of approach was guided by modeling best practices (22, 58), guidelines on presenting research on racial inequities (59), and consideration of the practicalities of making recommendations for screening in clinical practice. We use self-reported race because it is strongly associated with breast cancer mortality (3), breast cancer molecular subtype distribution (3), observed treatment effectiveness (34), and competing mortality (14). These associations persist even after socioeconomic status is considered (14, 34), suggesting that substituting socioeconomic status for race would not be methodologically appropriate in our study. These data also informed our modeling of treatment effects in Black women: Black women with different molecular subtypes of breast cancer derive equal benefits from equal treatment in clinical trials (32), but treatment remains unequal in practice (4, 57).

We acknowledge that racism, and not race, is likely the primary driver of many of the disparities in inputs in our study. However, few data sets contain validated measures of racism, so self-reported race remains the best available variable at present. Racial disparities in breast cancer mortality are complex and can persist after partial efforts to control for socioeconomic status. We are exploring data sources that could better capture the effects of lifetime socioeconomic status and racism in future studies. Until then, most of our model inputs are derived from U.S. population-based data. The results capture the heterogeneity in Black women and are generalizable to those who self-identify as such. Our results suggest that, compared with screening guidelines for the overall U.S. population, alternative screening guidelines provide an opportunity to reduce racial disparities in breast cancer mortality without increasing harms. Failing to consider race in this context may represent a missed opportunity to reduce breast cancer disparities while allowing Black women to derive the same screening tradeoffs as White women.

Overall, despite some improvements (29, 60), Black–White breast cancer disparities persist. Our results suggest that Black women consider initiating biennial screening at age 40 years instead of age 50 years. Given that this screening strategy falls within the "individual decision making" category for the USPSTF, this represents a practical, evidence-based opportunity to advance equity.

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Note: Learn more about the Breast Cancer Surveillance Consortium at www.bcsc-research.org.

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Appendix Table 1. Sensitivity Analyses Demonstrating Life-Years Gained for Benchmark (White B50–74) and Black Women With Varying Treatment Effects*

Life-Years Gained	Race and Treatment Effects						
	White, 100% (Benchmark)	Black					
		100%	90%	80%	70%	60%	50%
Per 1000 mammograms							
B50–74	14.5†	14.3†	15.3	16.3	17.2	18.1	18.9
B45–74	–	14.2	15.3	16.4	17.4	18.3	19.1
B40–74	–	12.9	14.0†	15.0†	15.9	16.7	17.5
A55-B55–74	–	10.8	11.7	12.5	13.3†	14.0†	14.6†
A40-B50–74	–	10.3	11.2	12.0	12.7	13.4	14.1
A50–74	–	8.1	8.7	9.3	9.8	10.3	10.8
A45–74	–	8.0	8.6	9.2	9.8	10.3	10.8
B40-A50–74	–	8.4	9.1	9.8	10.4	10.9	11.5
A40–74	–	7.4	8.0	8.6	9.1	9.6	10.1
Per 1000 false positives							
B50–74	187†	186†	199	212	224	235	245
B45–74	–	177	191†	204	217	228	239
B40–74	–	160	173	185†	196†	206	216
A55-B55–74	–	136	147	157	166	175†	184†
A40-B50–74	–	125	135	144	153	162	169
A50–74	–	110	119	126	134	141	147
A45–74	–	104	113	120	128	135	141
B40-A50–74	–	110	119	128	136	143	150
A40–74	–	94	102	109	116	123	129

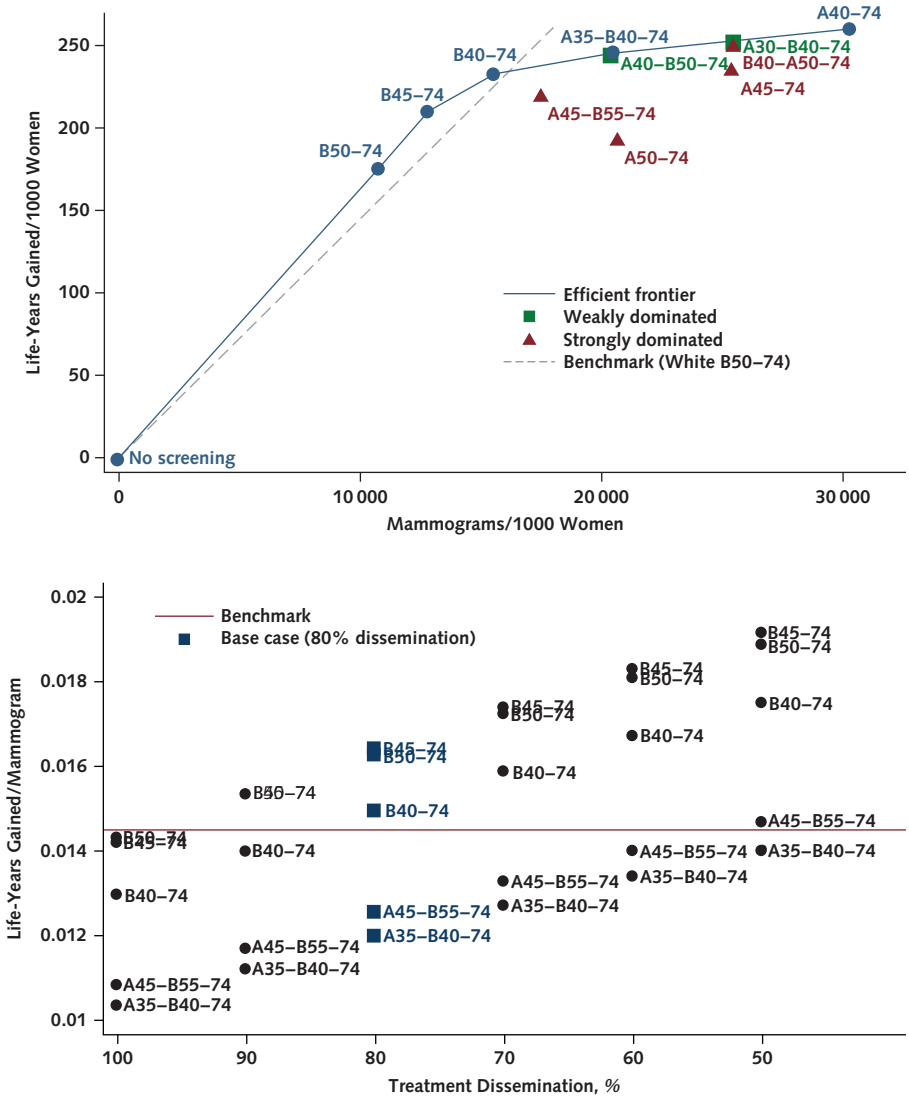
A = annual; B = biennial.
* Numbers after "A" or "B" denote cessation and transition ages.
† The scenario yielding the benefit–harm ratio in Black women most similar to the benchmark.

Appendix Table 2. Sensitivity Analysis Demonstrating Breast Cancer Deaths Averted for Benchmark (White B50–74) and Black Women With Varying Treatment Effects*

Breast Cancer Deaths Averted	Race and Treatment Effects						
	White, 100% (Benchmark)	Black					
		100%	90%	80%	70%	60%	50%
Per 1000 mammograms							
B50–74	0.75†	0.76†	0.82	0.88	0.93	0.97	1.02
B45–74	–	0.71	0.76†	0.82	0.87	0.91	0.95
B40–74	–	0.63	0.68	0.73†	0.77†	0.81†	0.85
A55-B55–74	–	0.53	0.58	0.62	0.66	0.69†	0.72†
A40-B50–74	–	0.50	0.54	0.58	0.61	0.64	0.67
A50–74	–	0.44	0.47	0.50	0.53	0.56	0.59
A45–74	–	0.40	0.44	0.47	0.50	0.52	0.55
B40-A50–74	–	0.42	0.45	0.48	0.51	0.54	0.56
A40–74	–	0.36	0.39	0.42	0.44	0.47	0.49
Per 1000 false positives							
B50–74	9.6†	9.9†	10.7	11.4	12.1	12.7	13.2
B45–74	–	8.8	9.5†	10.2†	10.8	11.4	11.9
B40–74	–	7.8	8.4	9.0†	9.5†	10.0†	10.5
A55-B55–74	–	6.7	7.3	7.8	8.2	8.7	9.1†
A40-B50–74	–	6.0	6.5	6.9	7.4	7.8	8.1
A50–74	–	6.0	6.4	6.9	7.3	7.6	8.0
A45–74	–	5.3	5.7	6.1	6.5	6.8	7.2
B40-A50–74	–	5.4	5.9	6.3	6.7	7.0	7.4
A40–74	–	4.6	5.0	5.3	5.7	6.0	6.2

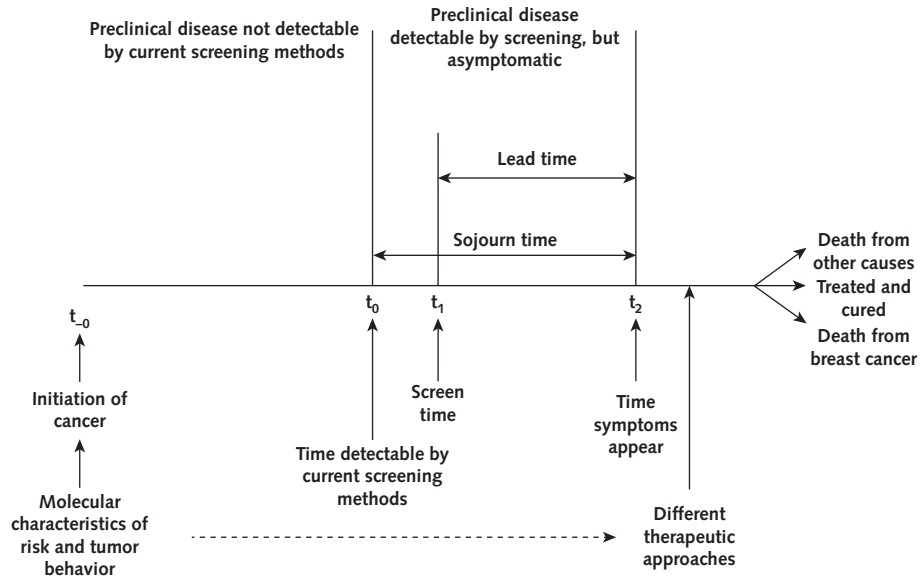
A = annual; B = biennial.
* Numbers after "A" or "B" denote cessation and transition ages.
† The scenario yielding the benefit–harm ratio in Black women most similar to the benchmark.

Appendix Figure 1. Supplemental analyses involving screening strategies with initiation before age 40 years.



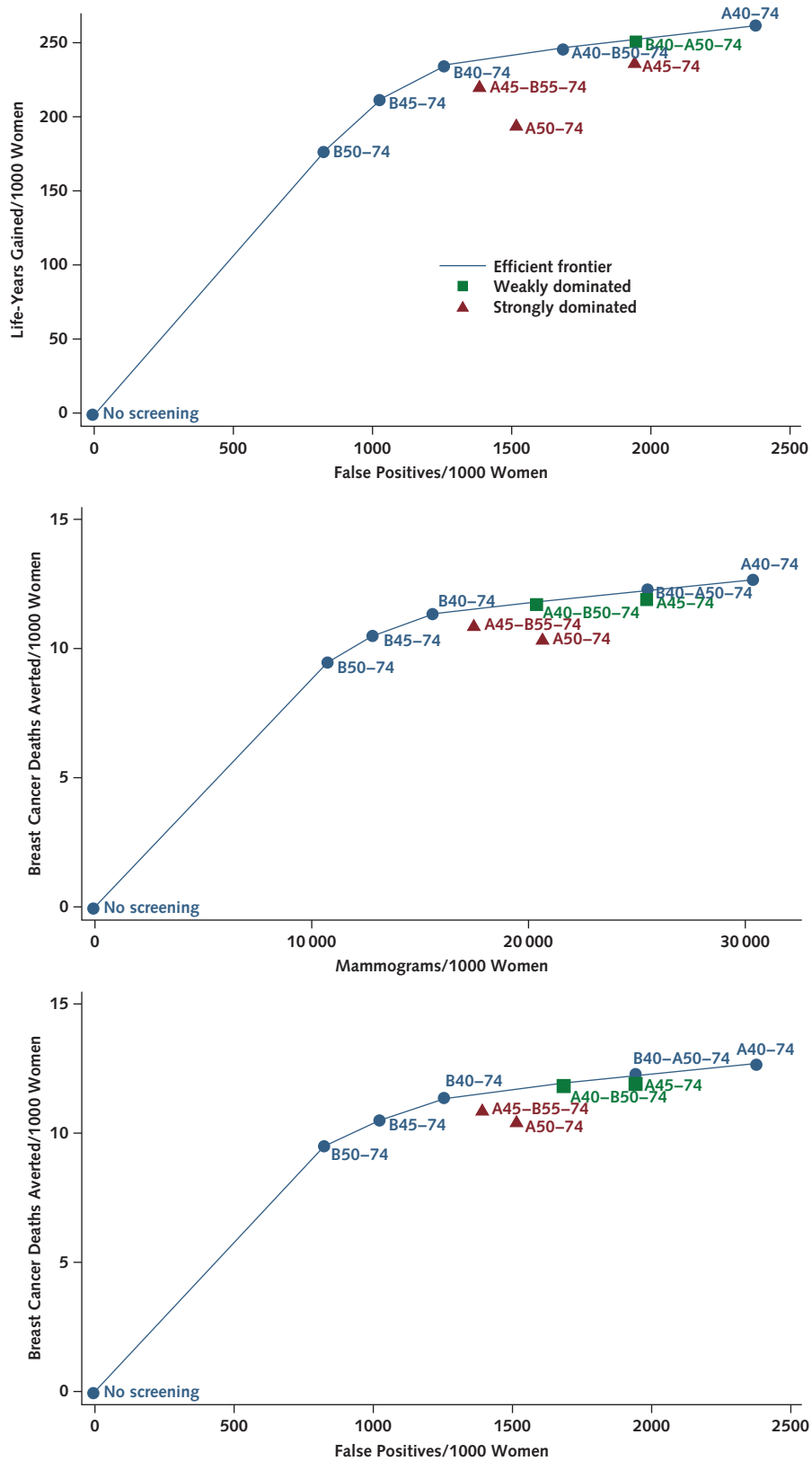
Top. Efficiency frontiers for base case (80% treatment dissemination) for Black women for life-years gained per mammogram, including results for the 2 additional strategies that begin at age 30 y and at age 35 y, run as supplemental analyses. Blue circles on the blue line are efficient strategies, whereas green squares are weakly dominated and red triangles are strongly dominated. **Bottom.** Sensitivity analysis demonstrating life-years gained per mammogram for benchmark (White B50–74) and Black women with varying treatment dissemination. The top 4 strategies with respect to life-years gained per mammogram are shown, as well as A35–B40–74 (A40–B50–74 is omitted because it overlaps with A35–B40–74 as shown here [*bottom*] and in Figure 2). The red horizontal line demonstrates the benchmark, blue squares demonstrate the base case, and black circles demonstrate other values for treatment dissemination.

Appendix Figure 2. Schematic overview of the Georgetown–Einstein CISNET model.



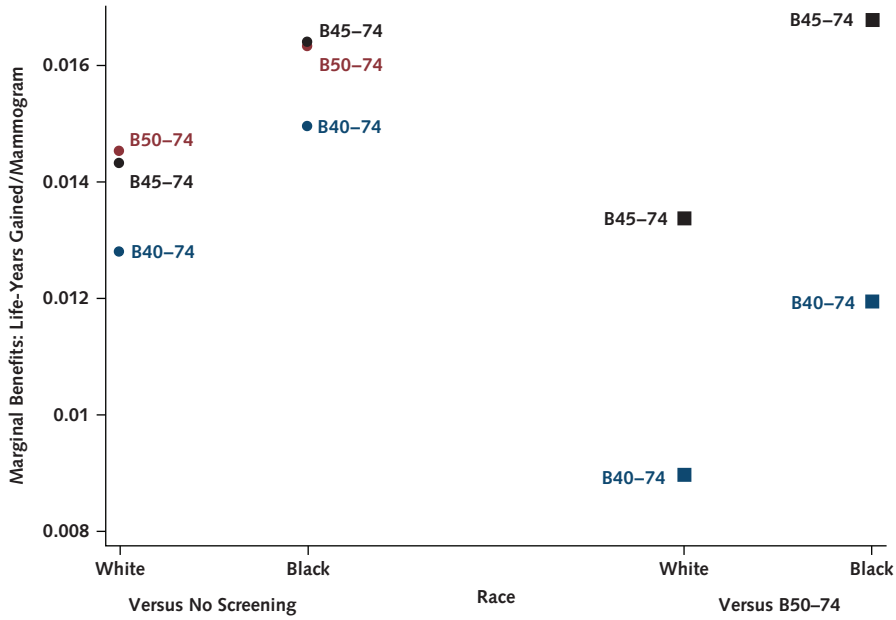
CISNET = Cancer Intervention and Surveillance Modeling Network.

Appendix Figure 3. Efficiency frontiers for base case (80% treatment dissemination) for Black women.



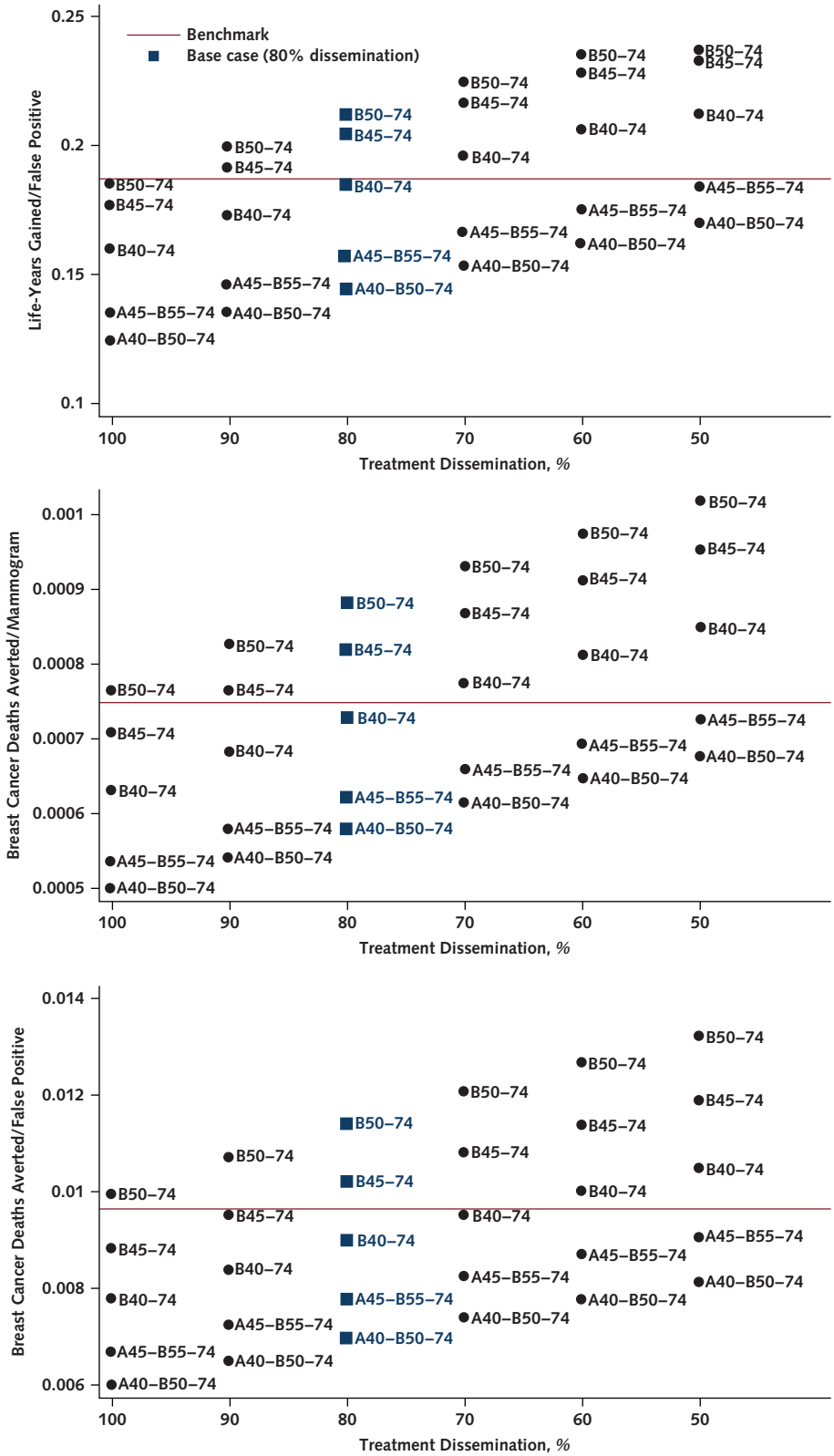
For all panels, blue circles on the blue line are efficient strategies, whereas green squares are weakly dominated and red triangles are strongly dominated. **Top.** Life-years gained per false positive. **Middle.** Breast cancer deaths averted per mammogram. **Bottom.** Breast cancer deaths averted per false positive.

Appendix Figure 4. Marginal benefits are shown in life-years gained per mammogram for White women and Black women (80% treatment dissemination base case scenario) for the 3 biennial screening strategies that start at ages 40, 45, or 50 y.



Comparison with no screening (*left*) and B50–74 (*right*). For all of these scenarios, marginal benefits are greater than 0. When compared with White women, Black women always have larger marginal benefits for the same strategy, indicating that Black women derive larger marginal benefits with earlier screening. Although marginal benefits remain greater than 0, they generally decrease as the screening age decreases, except for the case of B45–74 compared with no screening for Black women, which has slightly greater marginal benefits than B50–74 compared with no screening. As noted in the text, B45–74 is therefore identified as the most efficient strategy, whereas B40–74 is determined to be the most equitable given that the marginal benefits compared with no screening for Black women are roughly equivalent to the marginal benefits for B50–74 for White women compared with no screening.

Appendix Figure 5. Sensitivity analyses for benchmark (White B50–74) and Black women with varying treatment dissemination.



For all panels, the red horizontal line demonstrates the benchmark, blue squares demonstrate the base case, and black circles demonstrate other values for treatment dissemination. **Top.** Life-years gained per false positive. **Middle.** Breast cancer deaths averted per mammogram. **Bottom.** Breast cancer deaths averted per false positive.