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Mammography adherence in relation to function-related indicators in older women

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Abstract

Prior studies of screening mammography patterns by functional status in older women show inconsistent results. We used Breast Cancer Surveillance Consortium-Medicare linked data (1999–2014) to investigate the association of functional limitations with adherence to screening mammography in 145,478 women aged 66-74 years. Functional limitation was represented by a claims-based function-related indicator (FRI) score which incorporated 16 items reflecting functional status. Baseline adherence was defined as mammography utilization 9-30 months after the index screening mammography. Longitudinal adherence was examined among women adherent at baseline and defined as time from the index mammography to end of the first 30-month gap in mammography. Multivariable logistic regression and Cox proportional hazards models were used to investigate baseline and longitudinal adherence, respectively. Subgroup analyses were conducted by age (66-70 vs. 71-74 years). Overall, 69.6% of participants had no substantial functional limitation (FRI score 0), 23.5% had some substantial limitations (FRI score 1), and 6.8% had serious limitations (FRI score≥2). Mean age at baseline was 68.5 years (SD=2.6), 85.3% of participants were white, and 77.1% were adherent to screening mammography at baseline. Women with a higher FRI score were more likely to be non-adherent at baseline (FRI≥2 vs. 0: aOR=1.13, 95% CI=1.06, 1.20, *p-trend<0.01*). Similarly, a higher FRI score was associated with longitudinal non-adherence (FRI≥2 vs. 0: aHR=1.16, 95% CI=1.11, 1.22, *p-trend<0.01*). Effect measures of FRI did not differ substantially by age categories. Older women with a higher burden of functional limitations are less likely to be adherent to screening mammography recommendations.

Keywords

mammography; functional limitation; breast cancer screening; epidemiology; gerontology

1. Introduction

To date, epidemiological evidence has identified many factors that may impact breast cancer risk (Kelsey et al., 1993; Zhang et al., 2020b) and older age is an important etiological factor for increased risk (Moser et al., 2007; White et al., 2014). The Surveillance, Epidemiology, and End Results (SEER) Program reports that about 276,480 women have been diagnosed with invasive breast cancer in the US during 2020, with 44.5% aged 65 years or older at diagnosis (Hiatt et al., 2008), suggesting a need of preventive measures for these older vulnerable people.

Screening mammography is a fundamental secondary preventive technique to reduce breast cancer morbidity and mortality by identifying early malignant lesions (Johns et al., 2017). Currently, the United States Preventive Services Task Force (USPSTF) recommends that average-risk women between 50 and 74 years undergo screening mammography every 2 years (Merten et al., 2015). However, in older women undergoing mammography, age-related functional decline or impairment may offset survival improvement among early-stage breast cancer patients and induce more burdens than benefits (Keeler et al., 2010; Nattinger, 2000; Oeffinger et al., 2015). For example, a cohort study of 216 US women (mean age 81 years) suggested that older women with unfavorable functional status were less likely to experience survival benefit after screening mammography (Walter et al., 2001).

Currently, over one-fourth of people aged ≥65 years in the US live with moderate or severe functional limitations (Jindai et al., 2016), which can affect utilization patterns of many preventive medical services, including screening mammography (Ahmed et al., 2009). Although previous research suggests a negative impact of functional limitations on screening benefits, the extent to which functional limitations may impact adherence to screening mammography among older women is less well studied. Because functional limitation can indicate shorter life expectancy and impact effectiveness of mammography (Keeler et al., 2010; Nattinger, 2000), understanding its relationship with mammography utilization may provide knowledge needed to improve personalized screening in older women and prevent adverse events following screening mammography (e.g., invasive medical procedures).

In this study, we leveraged the Breast Cancer Surveillance Consortium (BCSC)-Medicare linked dataset to evaluate how screening mammography adherence varied by pre-existing functional limitations among older women in the US.

2. Methods

2.1. BCSC-Medicare and study population

The BCSC is a collaborative research network (Ahern et al., 2009) of breast imaging registries in the United States which aims to assess and improve the delivery and quality of breast cancer screening and related outcomes (Ballard-Barbash et al., 1997). The BCSC registries collect demographic information, breast cancer-related risk factors, screening history, pathological characteristics of breast lesions, and mammography indication and results. The BCSC data are pooled at a central Statistical Coordinating Center (SCC). In our study, claims data from Kaiser Permanente Washington and Medicare claims data from Carolina Mammography Registry, New Hampshire Mammography Network, San Francisco Mammography Registry, and Vermont Breast Cancer Surveillance System were linked to BCSC data (Ross et al., 2014). All registries and the SCC received institutional review board approval for active or passive consenting processes or a waiver of consent to enroll participants, link data, and perform data analysis. All procedures were Health Insurance Portability and Accountability Act (HIPAA) compliant, and all registries and the SCC have a Federal Certificate of Confidentiality and other protection for the identities of women, physicians, and facilities that are subjects of this research.

Participants with the following characteristics in the BCSC-Medicare linked data were included in our analysis: (1) aged 66-74 years at index screening mammography; (2) underwent index screening in 1999-2014; (3) were continuously enrolled in Medicare Parts A and B and not enrolled in a Medicare managed care plan from 1 year before to 30 months after the index screening mammography (or, for Kaiser Permanente Washington members, were continuously enrolled from 1 year before to 30 months after index screening); (4) had no history of breast cancer; and (5) were not diagnosed with invasive breast cancer or ductal carcinoma in situ (DCIS) and did not die within 30 months after the index screening mammography. Screening mammography was defined as routine bilateral screening views performed in women without imaging in the previous nine months and without a history of breast cancer, breast implants, or mastectomy. In our study, the first screening mammography that fit these criteria was treated as the index screening mammography.

2.2. Exposure and outcome of interest

The exposure of interest in our study was functional limitation, as represented by 16 function-related indicators (FRI) in Medicare Part A and B (or KPWA claims) data during the year before index BCSC screening mammography (Supplementary Table 1). Medicare Part A data included inpatient, skilled nursing facility, and hospital outpatient claims for the full study period; home health and hospice data were available for 1998-2006. Medicare Part B data included carrier claims for the full study period. We identified these function-related items according to an accepted claims-based algorithm and assigned 1 point to each (Chrischilles et al., 2014; Chrischilles et al., 2016; Zhang et al., 2021). We categorized FRI as an ordinal variable (0, 1, and ≥2) for analysis. FRI score 0 indicates no substantial functional impairment, 1 indicates some substantial impairment, and ≥2 indicates serious impairment.

Outcomes of interest included baseline and longitudinal screening mammography adherence whose definitions were based on a prior BCSC study (Hubbard et al., 2016). Baseline adherence was defined as mammography utilization 9-30 months after index screening. Because different guidelines for screening mammography recommend different screening intervals (Merten et al., 2015; Oeffinger et al., 2015), we referred to prior literature (Hubbard et al., 2016) and conservatively allowed a 30-month time window in which participants might receive subsequent mammography following index screening. We used 30 months as the upper time limit to correspond to the maximum recommended interval (2 years) plus time to make the appointment and allow for potential logistical difficulties or delays (6 months). Based on prior literature (Hubbard et al., 2016), we excluded the first 9 months following the index screening mammogram to avoid including diagnostic mammography after a positive index screening exam; during follow-up, both screening and diagnostic mammograms were included to allow for the possibility that a woman might forego a screening mammogram if she had recently received a diagnostic mammogram. Longitudinal adherence—reflecting the length of time a woman remained adherent to screening recommendations—was examined among women who were adherent at baseline and defined as time from the index screening to the end of the first 30-month gap in mammography.

2.3. Other covariates

Selection of study covariates was based on variables used in previously published literature using the BCSC data (Hubbard et al., 2016) and prior knowledge. Age, race/ethnicity, education level, and family history of breast cancer in a first degree relative were obtained from self-report at the index mammography or from electronic medical records; specifically, we considered family history of breast cancer in our study because women with this history may be more likely to adhere to screening schedules due to elevated risk (Braithwaite et al., 2018). Area-level median annual household income was obtained by linking 2007-2011 American Community Survey Data to the participant's residential zip code at the index mammography and was categorized using approximate quartiles (≤54,000, 54,001-68,000, 68,001-88,000, and >88,000). Rurality was measured using Rural-Urban Commuting Area (RUCA) codes linked to residential zip codes and classified as urban focused, large rural, small rural, or isolated rural (Braithwaite et al., 2012). Breast density at index screening and prior biopsy results were considered for analysis because they could impact women's awareness and perceived harm of breast cancer, affecting screening behavior (Rhodes et al., 2015). In BCSC, breast density at index screening was interpreted by radiologists based on Breast Imaging Reporting and Data System (BI-RADS) and categorized as almost entirely fat, scattered fibroglandular densities, heterogeneously dense, or extremely dense. Information regarding the most severe prior biopsy result was obtained from pathology and self-report and categorized as no prior biopsy, unknown pathological outcome, non-proliferative disease, proliferative without atypia, and high risk lesions. Comorbidities were represented by the National Cancer Institute (NCI) comorbidity index, a weighted score based on 16 health conditions identified from hospital and physician claims data computed using algorithms provided by NCI and categorized as 0, 1, and ≥2 (Newman et al., 2006).

2.4. Statistical analysis

First, we descriptively summarized distributions of covariates in the overall sample and by FRI (0, 1, and ≥2). Then, we summarized distributions of these variables and FRI by baseline adherence.

Logistic regression models treating baseline non-adherence as the dependent variable and adjusting for BCSC registry and exam year were used to calculate adjusted odds ratios (aOR) and 95% confidence intervals (CI) for the association between FRI and non-adherence. Two additional multivariable logistic regression models were used to estimate aOR of FRI by adjusting for different covariates. The first model adjusted for BCSC registry, index exam year, age, race/ethnicity, education, income, rurality, family history of breast cancer, breast density, and prior biopsy result. We included year of the index screening exam in models to adjust for differential screening patterns by era because screening guidelines varied by organization and over time during the study period. The second one additionally adjusted for NCI comorbidity index, which may be a confounder because functional limitations might be downstream events of comorbidities (Zhang et al., 2020a) and comorbidities might impact screening mammography utilization (Demb et al., 2018). We compared aORs from these 2 multivariable models and considered a substantial change in point estimate (>10%) to reflect additional confounding by comorbidities. Subgroup analyses were performed to examine the impact of functional limitations by age (66-70 vs. 71-74 years).

Longitudinal analysis was conducted among women who were adherent to screening recommendations at baseline. Kaplan-Meier curves were created to depict the probability of adherence by month. We used Cox proportional hazards models to estimate the hazard ratio (HR) of longitudinal non-adherence associated with baseline FRI. In this analysis, women who were adherent at baseline had a mammography 9-30 months after the index screening mammography, plus an additional 30 months before they could be considered non-adherent. Therefore, all women in the longitudinal analysis were adherent for at least 39 months after their index screening. Accordingly, longitudinal follow-up began 39 months after the index screening mammography (Supplementary Figure 1). Time to non-adherence was measured from 39 months after index screening to the end of the first 30-month gap after a subsequent mammogram; death; diagnosis of breast cancer; disenrollment from Medicare Parts A or B; enrollment in a Medicare managed care plan; disenrollment from Kaiser Permanente Washington (for that study site); end of complete radiology, cancer, or vital status data capture; or December 31, 2015; whichever occurred first. We included one index mammogram per woman and followed participants until non-adherence or censoring. In multivariable Cox proportional hazards models, we adjusted for the same covariates as in the baseline analysis, and subgroup analyses were performed by age at the index screening mammography (66-70 vs. 71-74 years). The proportionality assumption was examined by checking scaled Schoenfeld residuals (Xue et al., 2013) and there was no violation.

Logistic regression and Cox proportional hazards models were performed for women without missing values of FRI and other covariates, and we tested for a linear trend across the FRI parameter estimates. Two-sided values of $p<0.05$ were considered to be statistically significant. All analyses were performed by SAS version 9.4 (SAS Institute Inc., Cary, NC).

3. Results

A total of 145,478 women were included in our study. Table 1 presents distributions of study covariates by FRI. Overall, 69.6% of women had no functional limitation, 23.5% had FRI score 1, and 6.8% had FRI score≥2. The mean age was 68.5 (SD=2.6) and 74.9% of participants were age 66-70 years. Most participants (85.3%) were white, 5.9% were black, and the rest belonged to Hispanic (2.2%), Asian/Pacific Islander (5.0%), or other race/ethnicity groups (1.5%). Over half (56.5%) of participants had received some college education, about a quarter (24.7%) were living in communities with a median household income≤$54,000/year, and 58.6% were living in urban areas. Three-fourths of women had no major comorbidities (75.2%), 19.3% had NCI comorbidity index 1, and 5.5% had index≥2. About one-third of the women had dense breasts (heterogeneously dense: 32.2%, extremely dense: 3.5%). Women with higher FRI scores tended to be older and have more comorbidities (Table 1). Table 2 presents study characteristics by baseline adherence. The

77.1% of women who were adherent at baseline had a slightly lower FRI score, younger age, and fewer comorbidities than the non-adherent.

A total of 93,871 women with non-missing covariate data were included in logistic regression analysis examining baseline adherence (Table 3). Time between index screening and the first mammography during the 9-30 months afterwards had a bimodal distribution with modes approximately at 1 and 2 years. Models suggested positive associations between FRI scores and baseline non-adherence regardless of covariate adjustment. Specifically, FRI≥2 was associated with 21% relative increase in odds of non-adherence compared with FRI=0 (aOR=1.21, 95% CI=1.14, 1.29, *p-trend<0.01*) when adjusting for age, race/ethnicity, education, income, rurality, family history of breast cancer, breast density, prior biopsy result, mammography registry, and year of index screening. The association between FRI and non-adherence was attenuated but remained statistically significant after further adjustment for NCI comorbidity index (FRI≥2 vs. 0: aOR=1.13, 95% CI=1.06, 1.20, *p*-trend<0.01). Among women aged 66-70 years, aORs were significantly positive and largely unchanged compared to effect measures of the overall sample. Among women aged 71-74 years, FRI≥2 was positively associated with baseline non-adherence in models adjusted for risk factors (compared to FRI=0: aOR=1.18, 95% CI=1.05, 1.32, *p*-trend=0.01); however, effect measures of FRI became non-significant after further adjustment for NCI comorbidity index (FRI≥2 vs. 0: aOR=1.10, 95% CI=0.98, 1.24, *p*-trend=0.11).

A total of 62,993 women with non-missing covariate data and adherent at baseline were included in the analysis of longitudinal adherence. The Kaplan-Meier curves illustrated the probability of longitudinal adherence over time (Figures 1A and 1B). In both age groups, the curves declined more sharply among women with FRI≥2, whereas we found the curves were similar between women with FRI score 0 and 1. Results from Cox proportional hazard models (Table 4) were consistent with the Kaplan-Meier curves. In the model adjusting for age, race/ethnicity, education, income, rurality, family history of breast cancer, breast density, prior biopsy result, mammography registry, and year of index screening mammography, FRI≥2 was associated with a significant increase in risk of non-adherence (compared to FRI=0: aHR=1.21, 95% CI=1.16, 1.27, *p*-trend<0.01), whereas the effect measure of FRI=1 was only slightly elevated; this pattern did not change after adjustment for the NCI comorbidity index (FRI≥2 vs. 0: aHR=1.16, 95% CI=1.11, 1.22, *p*-trend<0.01). Similar to the baseline adherence analysis, the point estimates of aHRs did not vary substantially by age; aHRs of FRI≥2 remained significantly positive in both age subgroups.

Adjusted effect measures of other covariates for baseline and longitudinal adherence are presented in Supplementary Table 2 and Table 3, respectively. Particularly, older age, lower education, residing in urban areas, and a higher burden of comorbidities were associated with a higher probability of baseline and longitudinal non-adherence in multivariate models. Women with higher clinical risk were less likely to be non-adherent.

4. Discussion

In this study of screening mammography in older women, we found that most women were adherent to recommended guidelines and that a higher burden of functional impairment was often associated with non-adherence. Overall, over three-fourths of women in our cohort were adherent at baseline and we observed an inverse association between adherence and FRI score. Although we found no difference in longitudinal adherence between women with FRI score 1 (indicating some substantial impairment) compared to score 0 (indicating no substantial impairment), women with FRI score≥2 (indicating significant impairment) versus 0 had substantially shorter time to non-adherence. Associations between functional status and non-adherence to screening recommendations persisted after adjusting for comorbidity, with point estimates somewhat reduced but still significant in the model, and effect measures of FRI varied little between subgroups by age; these suggest that personalized screening mammography decisions should consider functional status as well as age and comorbidity.

Our results are consistent with a previous meta-analysis investigating screening mammography utilization by functional status. Demb et al. synthesized data from 8 studies (14 effect measures) and reported an inverse association between functional limitation and screening mammography use (OR_{pool}=0.72, 95% CI=0.62, 0.83; I^2=71.8%) (Demb et al., 2018); however, 6 effect measures synthesized in that study were non-significant and the I^2 value in the random-effects model reflected large statistical heterogeneity. The 8 studies have smaller sample sizes (range: 526-4,610), suggesting potentially large imprecision in statistical analysis. Moreover, the studies in the meta-analysis used activities of daily living and instrumental activities of daily living as proxy measures of functional status that mainly indicate mobility decline and difficulty in limb movement. In contrast, our study had a large sample size and used an FRI score incorporating 16 health conditions and health services utilized, which better reflects functional status among the elderly and improved validity of the measure of association for functional limitation (Chrischilles et al., 2014; Chrischilles et al., 2016).

Several factors may partially explain why older women in the BCSC-Medicare linked dataset with a higher burden of functional limitations are less likely to be adherent to mammography recommendations. First, a higher FRI score can predict shorter life expectancy in older people (Keeler et al., 2010) and physicians may consider the potential for harms to outweigh benefits of screening because older women with a higher burden of functional limitations who undergo screening mammography may not survive long enough to benefit from early cancer detection (Braithwaite et al., 2016; Kerlikowske et al., 1999), making physicians less likely to recommend mammography to older women with pre-existing functional decline. Clinicians may also be inclined to treat the functional limitations or underlying illnesses of older patients before offering screening services (Merten et al., 2015; Wei et al., 2006), which would make mammography unlikely to be recommended as a high priority for older women with a higher burden of functional limitations. In addition, the practice of screening mammography involves a series of upper extremity movements which can be strenuous for older adults with functional impairments and mobility decline (Keeler et al., 2010), suggesting that the mammography utilization rate may be lower among these patients due to practical challenges and technical difficulties in the clinic. However, we could not determine whether study participants with higher FRI scores discontinued screening earlier due to decisions made with the physician or because they experienced more barriers to screening.

Our study has strengths in design and analysis. Most importantly, we used a validated index to reflect functional status (Chrischilles et al., 2016); this method may better differentiate older women with functional limitations from their healthier counterparts than seen in earlier studies (Chrischilles et al., 2014). We included a large sample of older women enrolled from 5 geographically diverse breast imaging registries across 16 years, which ensured good power and statistical precision of effect estimates. In addition, the consistent pattern we observed between functional status and both baseline and longitudinal adherence in older women is robust. However, limitations should be considered when interpreting the results. The USPSTF recommends screening mammography for women aged 50-74 years (Piccirillo et al., 2004), whereas our study only included women aged 66-74 years who were continuously enrolled in Medicare Parts A and B (or, for KPWA, enrolled in a managed care plan). This suggests that our results may not be generalizable to screening-eligible women under 66 years or with intermittent Medicare enrollment—women who may differ from our study population in many aspects; specifically, women at younger ages may be healthier and have different screening utilization patterns (Hubbard et al., 2016; Shimada et al., 2009). In our analysis, we defined adherence as utilization of any mammogram, either screening or diagnostic, 9 to 30 months after the initial mammogram. Although this approach can estimate the percentage of women who do not need screening because of a recent mammogram, it may overestimate the proportion of women participating in screening. This strategy was adopted in our analysis in order to account for participants foregoing screening because of a recent diagnostic mammogram (Hubbard et al., 2016). The BCSC data reflects mammography screening in U.S. community practice and does not require a standardized protocol. We do not know whether adherence defined in this study reflects the physician's recommendation. For example, a woman who was recommended annual screening but screened within the 30-month period may be non-adherent to her physician's recommendation but adherent in our study. Because about 85% of the study cohort was white, our results may be less generalizable to women of other racial/ethnic groups, suggesting that screening disparity should be further explored in future studies with a higher proportion of non-white population. Finally, since different types of functional impairment may have differential effects on mammography screening, women in the same FRI category may be heterogeneous with respect to functional impairment.

5. Conclusion

In conclusion, women aged 66-74 years with a higher burden of functional limitations have a lower likelihood of screening mammography adherence compared to their counterparts without functional limitations. Our recent study (Zhang et al., 2021) using BCSC data suggested that older women with a higher burden of functional limitations had higher mortality after screening mammography. Together with findings from the current study, we conclude that personalized screening mammography based on functional status—a strong predictor of life expectancy—is important for older women. Clinicians should carefully consider the harms and benefits when recommending screening mammography for older women with differential functional status.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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Abbreviations:

BCSC	Breast Cancer Surveillance Consortium
CI	confidence interval
FRI	function-related indicator
HR	hazard ratio
NCI	National Cancer Institute
OR	odds ratio
USPSTF	United States Preventive Services Task Force

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Highlights

- Functional limitations are common in older women eligible for screening mammography
- Women with functional limitations are less likely to undergo screening mammography
- The association of functional limitations exists after adjusting for comorbidities

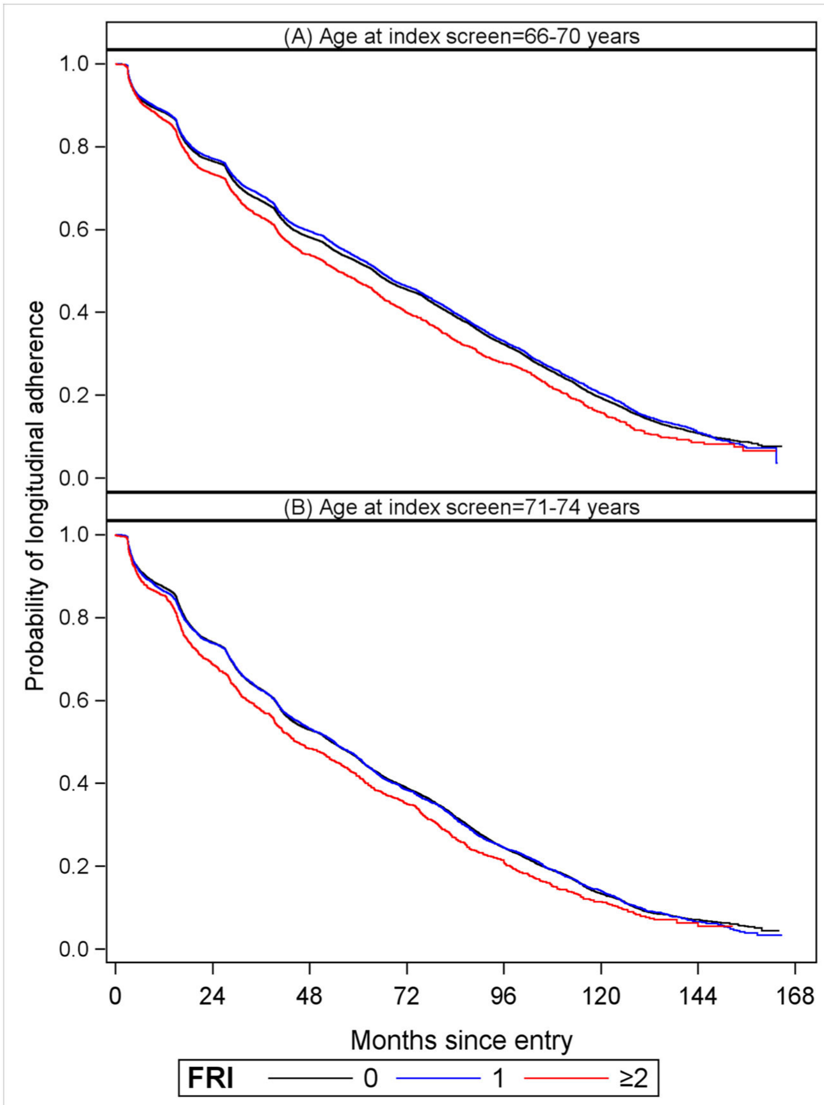

Figure 1.
Kaplan-Meier curves showing probability of longitudinal adherence to mammography guidelines by FRI among women (A) aged 66-70 years and (B) aged 71-74 years. Abbreviation: FRI: function-related indicator.

Table 1.

Baseline characteristics of women by function-related indicator (FRI) level in the Breast Cancer Surveillance Consortium

Characteristic	Overall (N=145,478) N (%)[a]	FRI=0 (N=101,297) N (%)[a]	FRI=1 (N=34,242) N (%)[a]	FRI≥2 (N=9,939) N (%)[a]
Age (y)				
66-70	108,905 (74.9)	76,488 (75.5)	25,412 (74.2)	7,005 (70.5)
71-74	36,573 (25.1)	24,809 (24.5)	8,830 (25.8)	2,934 (29.5)
Race/ethnicity				
White	117,193 (85.3)	80,853 (84.5)	28,223 (87.4)	8,117 (87.2)
Black	8,120 (5.9)	6,116 (6.4)	1,540 (4.8)	464 (5.0)
Hispanic	3,012 (2.2)	2,039 (2.1)	748 (2.3)	225 (2.4)
Asian/Pacific Islander	6,908 (5.0)	5,385 (5.6)	1,239 (3.8)	284 (3.1)
Other	2,098 (1.5)	1,331 (1.4)	550 (1.7)	217 (2.3)
Missing	*8,147*	*5,573*	*1,942*	*632*
Education				
<High School Graduate	16,104 (12.5)	10,972 (12.3)	3,882 (12.7)	1,250 (14.2)
High School Graduate or GED	39,849 (31.0)	28,246 (31.7)	9,029 (29.6)	2,574 (29.3)
Some College or Technical School	34,040 (26.5)	23,367 (26.2)	8,306 (27.2)	2,367 (26.9)
College Graduate	38,495 (30.0)	26,567 (29.8)	9,327 (30.5)	2,601 (29.6)
Missing	*16,990*	*12,145*	*3,698*	*1,147*
Median household income [b]				
≤54,000	34,018 (24.7)	24,519 (25.5)	7,353 (22.8)	2,146 (22.9)
54,001-68,000	34,859 (25.3)	24,480 (25.5)	8,085 (25.1)	2,294 (24.5)
68,001-88,000	33,397 (24.3)	22,705 (23.7)	8,309 (25.8)	2,383 (25.5)
>88,000	35,305 (25.7)	24,277 (25.3)	8,492 (26.3)	2,536 (27.1)
Missing	*7,899*	*5,316*	*2,003*	*580*
Rural/urban				
Urban Focused	81,815 (58.6)	56,776 (58.3)	19,277 (58.8)	5,762 (60.7)
Large Rural	26,773 (19.2)	18,940 (19.4)	6,145 (18.8)	1,688 (17.8)
Small Rural	14,478 (10.4)	10,157 (10.4)	3,376 (10.3)	945 (10.0)
Isolated Rural	16,598 (11.9)	11,537 (11.8)	3,970(12.1)	1,091 (11.5)
Missing	*5,814*	*3,887*	*1,474*	*453*
NCI comorbidity index				
0	109,420 (75.2)	79,959 (78.9)	24,280 (70.9)	5,181 (52.1)
1	28,112 (19.3)	17,880 (17.7)	7,450 (21.8)	2,782 (28.0)
≥2	7,946 (5.5)	3,458 (3.4)	2,512 (7.3)	1,976 (19.9)
Family history of breast cancer				
No	104,774 (82.6)	72,408 (82.7)	25,035 (82.4)	7,331 (81.6)
Yes	22,134 (17.4)	15,117 (17.3)	5,359 (17.6)	1,658 (18.4)
Missing	*18,570*	*13,772*	*3,848*	*950*

Characteristic	Overall (N=145,478) N (%)[a]	FRI=0 (N=101,297) N (%)[a]	FRI=1 (N=34,242) N (%)[a]	FRI≥2 (N=9,939) N (%)[a]
Breast density				
Almost entirely fat	16,152 (12.2)	10,942 (11.8)	3,937 (12.6)	1,273 (14.1)
Scattered fibroglandular densities	69,136 (52.1)	48,199 (52.0)	16,201 (52.0)	4,736 (52.4)
Heterogeneously dense	42,835 (32.2)	30,176 (32.6)	9,926 (31.9)	2,733 (30.2)
Extremely dense	4,703 (3.5)	3,323 (3.6)	1,079 (3.5)	301 (3.3)
Missing	*12,652*	*8,657*	*3,099*	*896*
Prior biopsy result [c]				
No prior biopsy	109,981 (75.6)	77,003 (76.0)	25,533 (74.6)	7,445 (74.9)
Biopsy, pathology unknown	30,084 (20.7)	20,685 (20.4)	7,325 (21.4)	2,074 (20.9)
Non-proliferative disease	3,506 (2.4)	2,326 (2.3)	897 (2.6)	283 (2.8)
Proliferative without atypia	1,498 (1.0)	1,017 (1.0)	380 (1.1)	101 (1.0)
High risk lesions	409 (0.3)	266 (0.3)	107 (0.3)	36 (0.4)

Abbreviations: FRI: function-related index, GED: General Educational Development, NCI: National Cancer Institute

[a]Column percentages for each characteristic value excluded missing values

[b]The area-level income was obtained based on 2007-2011 American Community Survey Data

[c]No prior biopsy includes unknown; high risk lesions include proliferative with atypia and lobular carcinoma in situ

Table 2.

Characteristics of women by baseline adherence to mammography screening recommendations

Characteristic	Not adherent (N=33,348) N (%)[a]	Adherent (N=112,130) N (%)[a]
FRI		
0	22644 (67.9)	78653 (70.1)
1	8033 (24.1)	26209 (23.4)
≥2	2671 (8.0)	7268 (6.5)
Age		
66-70	23,356 (70.0)	85,549 (76.3)
71-74	9,992 (30.0)	26,581 (23.7)
Race/ethnicity		
White	24,315 (82.3)	92,878 (86.2)
Black	2,289 (7.7)	5,831 (5.4)
Hispanic	728 (2.5)	2,284 (2.1)
Asian/Pacific Islander	1,711 (5.8)	5,197 (4.8)
Other	497 (1.7)	1,601 (1.5)
Missing	*3,808*	*4,339*
Education		
<High School Graduate	4,231 (15.9)	11,873 (11.7)
High School Graduate or GED	8,579 (32.2)	31,270 (30.7)
Some College or Technical School	6,900 (25.9)	27,140 (26.6)
College Graduate	6,904 (25.9)	31,591 (31.0)
Missing	*6,734*	*10,256*
Median household income [b]		
≤54000	8,641 (27.3)	25,377 (24.0)
54001-68000	7,661 (24.2)	27,198 (25.7)
68001-88000	7,262 (22.9)	26,135 (24.7)
>88000	8,143 (25.7)	27,162 (25.7)
Missing	*1,641*	*6,258*
Rural/urban		
Urban Focused	19,917 (61.9)	61,898 (57.6)
Large Rural	5,358 (16.6)	21,415 (19.9)
Small Rural	3,011 (9.4)	11,467 (10.7)
Isolated Rural	3,913 (12.2)	12,685 (11.8)
Missing	*1,149*	*4,665*
NCI comorbidity index		
0	23,570 (70.7)	85,850 (76.6)
1	7,294 (21.9)	20,818 (18.6)
≥2	2,484 (7.4)	5,462 (4.9)
Family history of breast cancer		

Characteristic	Not adherent (N=33,348) N (%)[a]	Adherent (N=112,130) N (%)[a]
No	24,950 (85.8)	79,824 (81.6)
Yes	4,141 (14.2)	17,993 (18.4)
Missing	*4,257*	*14,313*
Breast density		
Almost entirely fat	4,025 (13.3)	12,127 (11.8)
Scattered fibroglandular densities	16,672 (55.1)	52,464 (51.1)
Heterogeneously dense	8,682 (28.7)	34,153 (33.3)
Extremely dense	875 (2.9)	3,828 (3.7)
Missing	*3,094*	*9,558*
Prior biopsy result [c]		
No prior biopsy	26,667 (80.0)	83,314 (74.3)
Biopsy, pathology unknown	5,859 (17.6)	24,225 (21.6)
Non-proliferative disease	546 (1.6)	2,960 (2.6)
Proliferative without atypia	222 (0.7)	1,276 (1.1)
High risk lesions	54 (0.2)	355 (0.3)

Abbreviations: FRI: function-related indicator, GED: General Educational Development, NCI: National Cancer Institute

[a]Column percentages for each characteristic value excluded missing values

[b]The area-level income was obtained based on 2007-2011 American Community Survey Data

[c]No prior biopsy includes unknown; high risk lesions include proliferative with atypia and lobular carcinoma in situ

Table 3.

Association between FRI and baseline non-adherence to mammography screening recommendations

FRI	aOR (95% CI)[a]	aOR (95% CI)[b]	aOR (95% CI)[c]
Overall (N=93,871)			
0	REF	REF	REF
1	1.09 (1.04, 1.13)	1.08 (1.04, 1.12)	1.06 (1.02, 1.10)
≥2	1.27 (1.20, 1.35)	1.21 (1.14, 1.29)	1.13 (1.06, 1.20)
	p-trend<0.01	*p-trend<0.01*	*p-trend<0.01*
66-70 years (N=73,490)			
0	REF	REF	REF
1	1.11 (1.06, 1.16)	1.11 (1.06, 1.16)	1.09 (1.04, 1.13)
≥2	1.26 (1.17, 1.35)	1.22 (1.14, 1.32)	1.14 (1.06, 1.23)
	p-trend<0.01	*p-trend<0.01*	*p-trend<0.01*
71-74 years (N=20,381)			
0	REF	REF	REF
1	1.01 (0.93, 1.09)	1.01 (0.93, 1.09)	0.99 (0.91, 1.07)
≥2	1.19 (1.06, 1.34)	1.18 (1.05, 1.32)	1.10 (0.98, 1.24)
	p-trend<0.01	*p-trend=0.01*	*p-trend=0.11*

Abbreviations: aOR: adjusted odds ratio, CI: confidence interval, FRI: function-related indicator

[a] Model adjusted for mammography registry and year of index screening mammography.

[b] Model adjusted for age, race/ethnicity, education, income, rurality, family history of breast cancer, breast density, prior biopsy result, mammography registry, and year of index screening mammography.

[c] Model additionally adjusted for NCI comorbidity index.

Non-adherence was treated as the dependent variable in logistic regression models.

Table 4.

Association between FRI and longitudinal non-adherence to screening mammography recommendations

FRI	aHR (95% CI)[a]	aHR (95% CI)[b]	aHR (95% CI)[c]
Overall (N=62,993)			
0	REF	REF	REF
1	1.03 (1.01, 1.06)	1.03 (1.00, 1.06)	1.02 (0.99, 1.05)
≥2	1.24 (1.18, 1.29)	1.21 (1.16, 1.27)	1.16 (1.11, 1.22)
	p-trend<0.01	*p-trend<0.01*	*p-trend<0.01*
66-70 years (N=49,344)			
0	REF	REF	REF
1	1.02 (0.99, 1.05)	1.03 (1.00, 1.06)	1.02 (0.99, 1.05)
≥2	1.22 (1.16, 1.29)	1.22 (1.16, 1.29)	1.18 (1.12, 1.24)
	p-trend<0.01	*p-trend<0.01*	*p-trend<0.01*
71-74 years (N=13,649)			
0	REF	REF	REF
1	1.04 (0.99, 1.09)	1.04 (0.99, 1.09)	1.03 (0.98, 1.08)
≥2	1.22 (1.12, 1.32)	1.20 (1.11, 1.31)	1.14 (1.04, 1.24)
	p-trend<0.01	*p-trend<0.01*	*p-trend<0.01*

Abbreviations: aHR: adjusted hazard ratio, CI: confidence interval, FRI: function-related indicator

[a] Model adjusted for mammography registry and year of index screening mammography.

[b] Model adjusted for age, race/ethnicity, education, income, rurality, family history of breast cancer, breast density, prior biopsy result, mammography registry, and year of index screening mammography.

[c] Model additionally adjusted for NCI comorbidity index.

Time to non-adherence was treated as the dependent variable in Cox proportional hazards models.