

# Patterns of Breast Imaging Use Among Women with a Personal History of Breast Cancer



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**BACKGROUND:** National patterns of breast imaging in women with a personal history of breast cancer (PHBC) are unknown making evaluation of annual surveillance recommendations a challenge.

**OBJECTIVE:** To describe variation in use of mammography and breast magnetic resonance imaging (MRI) examinations beginning 6 months after diagnosis among women with PHBC in US community practice. We report on the breast imaging indication, imaging intervals, and time since breast cancer diagnosis by examination type.

**DESIGN:** Longitudinal study using cross-sectional data.

**SETTING:** Breast Cancer Surveillance Consortium breast imaging facilities.

**PARTICIPANTS:** 19,955 women diagnosed between 2005 and 2012 with AJCC stage 0-III incident breast cancer who had 69,386 mammograms and 3,553 breast MRI examinations from January 2005 to September 2013; median follow-up of 37.6 months (interquartile range, 22.1–60.7).

**MAIN MEASURES:** Breast imaging indication, imaging intervals, and time since breast cancer diagnosis by examination type.

**KEY RESULTS:** Among women with a PHBC who received breast imaging, 89.4% underwent mammography alone, 0.8% MRI alone, and 10.3% had both mammography and MRI. About half of mammograms and MRIs were indicated for surveillance vs. diagnostic, with an increase in the proportion of surveillance exams as time from diagnosis increased (mammograms, 45.7% at 1 year to 72.2% after 5 years; MRIs, 54.8% at 1 year to 78.6% after 5 years). In the first post-diagnosis period, 32.8% of women had  $\geq 2$  breast imaging examinations and of these, 65.8% were less than 6 months apart. During the first 5-year post-diagnosis, the frequency of examinations per year

decreased and the interval between examinations shifted towards annual examinations.

**CONCLUSION:** In women with a PHBC who received post-diagnosis imaging, a third underwent multiple breast imaging examinations per year during the first 2-year post-diagnosis despite recommendations for annual exams. As time since diagnosis increases, imaging indication shifts from diagnostic to surveillance.

**KEY WORDS:** breast cancer; cancer surveillance; mammography; breast magnetic resonance imaging; cancer survivorship.

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## INTRODUCTION

In 2016 in the US, there were an estimated 3.5 million women living with a personal history of breast cancer (PHBC); by 2026, this number is expected to increase to 4.5 million women.<sup>1</sup> Guidelines from the American Cancer Society (ACS), the American Society of Clinical Oncology, and the National Comprehensive Cancer Network (NCCN) recommend annual surveillance mammography for women with a PHBC who have not received a bilateral mastectomy.<sup>2–5</sup> However, surveillance mammography is imperfect; 35% of second breast cancers diagnosed in women with a PHBC occur within 1 year after a negative mammogram.<sup>6,7</sup> Thus, women and providers may seek additional breast imaging options, either decreasing the interval between surveillance mammograms<sup>8</sup> or looking to other modalities such as magnetic resonance imaging (MRI), despite few existing guidelines on supplemental modalities or evidence on the benefits and harms of frequent use. While the ACS and the NCCN support adjunct breast MRI screening for women with >20% lifetime risk based on family history, a known cancer predisposition syndrome, or receipt of chest radiation therapy between ages 10 and 30 years, these organizations do not recommend annual

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MRI for surveillance of asymptomatic women with a PHBC irrespective of lifetime risk.

Surveillance mammography use in women with a PHBC ranges from 70 to 90% and has been reported to decrease by time since breast cancer diagnosis.<sup>9–15</sup> Some women may undergo mammography for indications other than surveillance, based on facility specific protocols or reimbursement practices. Although breast MRI use has increased over the past 15 years,<sup>16,17</sup> there is little information on MRI use among women with a PHBC. A few prior studies evaluated breast imaging examination types and/or frequency or intervals between examinations among women with a PHBC once they return to care after curative intent treatment, but these are limited to women with ductal carcinoma in situ (DCIS) or fail to capture the examination indication.<sup>9–15</sup> From Breast Cancer Surveillance Consortium (BCSC) focus groups among women with PHBC, women reported multiple exams within the first few years post-treatment for breast cancer that decreased over time.<sup>18</sup> Clinicians in key informant interviews also suggested that “their practice” includes diagnostic imaging and more frequent imaging, sometimes with breast MRI, for women with PHBC in the first 2–3 years post-diagnosis.<sup>19</sup>

Studies are needed to evaluate the comparative effectiveness of surveillance strategies in women with a PHBC; however, these studies will need to ensure the same type of examinations are being directly compared. For women with a PHBC, this may necessitate including all indications, not just surveillance mammograms, in order to appropriately estimate surveillance mammography use since exams performed for screening indications may currently be coded as diagnostic exams. We used BCSC data from 2005 to 2013 to describe the patterns of mammography and MRI use in women with a PHBC beginning 6 months after diagnosis. Specifically, we examined indication, frequency, and breast imaging intervals by time since breast cancer diagnosis to understand breast imaging patterns and guide future work focused on comparative studies of different imaging strategies and interventions aimed at promoting surveillance that is consistent with clinical guidelines.

## METHODS

### Study Setting

The BCSC is a collaboration of population-based breast imaging registries predominantly from community settings across the US.<sup>20,21</sup> BCSC registries obtain prospective risk factor data, which are linked to breast imaging data collected as part of routine clinical care. These data are linked with state cancer or Surveillance Epidemiology and End Results Program registries and pathology databases for incident and recurrent cancer outcome ascertainment. Each BCSC registry site and the Statistical Coordinating Center (SCC) received institutional review board approval for either active or passive consent or a waiver of consent to enroll participants, link data,

and perform analyses. All procedures are Health Insurance Portability and Accountability Act compliant and all registries and the SCC received a Federal Certificate of Confidentiality and other protection for the identities of women, physicians, and facilities who are subjects of this research.

### Participants

For this longitudinal study using cross-sectional data, we included data from five BCSC registries: the Carolina Mammography Registry, New Hampshire Mammography Network, San Francisco Mammography Registry, Kaiser Permanente Washington, and Vermont Breast Cancer Surveillance System. Women ages 18 and older diagnosed with American Joint Committee on Cancer (AJCC)<sup>22</sup> stage 0-III primary breast cancer from 2005 to 2012 were included provided they did not receive a bilateral mastectomy as part of initial treatment. Women were also required to have at least one breast imaging examination during the follow-up period to be included.

### Measures

Women self-report their race, ethnicity, menopausal status, and education at each examination. Community-level income was ascertained using the woman’s zip code linked with 2010 US Census data. We calculated 5-year and lifetime breast cancer risk at the time of diagnosis. The National Cancer Institute Breast Cancer Risk Assessment Tool (BRCAT) was used to calculate lifetime breast cancer risk<sup>23–28</sup> and the BCSC risk model version 1 was used to estimate 5-year breast cancer risk.<sup>29,30</sup> Information at the time of the incident breast cancer included diagnosis date, type of primary therapy (breast conserving surgery without radiation therapy (RT), breast conserving surgery with RT, and mastectomy), AJCC stage, tumor size, ER status, and progesterone receptor (PR) status.

Mammography and breast MRI examinations were included if they occurred at least 6 months after primary breast cancer diagnosis and were performed at BCSC facilities between July 2005 and September 2013. Examination indication and date were obtained primarily using electronic radiology systems but also included chart abstraction, scanned forms, and billing systems. Indication was reported by the facility and included (1) surveillance for a second primary or recurrent breast cancer; (2) additional evaluation; (3) short-interval follow-up; (4) evaluation of a breast problem; (5) evaluation of extent of disease or axillary adenopathy, unknown primary (MRI only); and (6) diagnostic not otherwise specified (NOS). We excluded mammograms with “other indications” and MRI exams with an indication for response to chemotherapy or implant evaluation. We included all imaging examinations, regardless of self-reported symptoms.

We categorized the time since diagnosis as 1 year (6 to less than 18 months), 2 years (18 to less than 30 months), 3 years (30 to less than 42 months), 4 years (42 to less than 54 months), 5 years (54 to less than 66 months), and > 5 years (66+

months) and evaluated examination frequency in each category. We also evaluated the interval between examinations based on months since a prior breast imaging examination using the most recent of self-reported and prior examination date in the BCSC database.

## Statistical Analysis

During the follow-up period, women could have multiple breast imaging examinations. We calculated follow-up time as the time from breast cancer diagnosis until last recorded imaging examination. We calculated frequencies of imaging examination indication by modality type (mammography or MRI) and time since breast cancer diagnosis. We compared patterns of indication by stage of breast cancer diagnosis and by primary therapy (breast conserving surgery without radiation therapy (RT), breast conserving surgery with RT, and unilateral mastectomy) to evaluate if patterns differed by either of these factors. We also examined the number of examinations per woman and months since prior examination by year since diagnosis overall and separately for mammograms and MRI.

## RESULTS

### Cohort Characteristics

We included 19,955 women with a PHBC who received at least one breast imaging exam post-diagnosis (Table 1).

### Breast Imaging

During follow-up, 19,955 women with a PHBC underwent 69,386 mammograms and 3,553 breast MRIs; median follow-up was 37.6 months (interquartile range, 22.1 to 60.7). Most women had mammography alone (89.4%) (Table 2). Among women who underwent breast MRI, most had a combination of MRI and mammography, with <1% having breast MRI alone.

### Patterns of Imaging by Indication and Time Since Diagnosis

Examination indication varied by imaging modality and time since diagnosis (Table 3). In the first post-diagnosis period, 45.7% of mammograms were surveillance, which increased to 72.2% at >5-year post-diagnosis (66+ months). Additionally, short-interval follow-up mammograms declined from 23.7% at 1-year post to 3.3% at >5 years post, as did additional evaluation mammograms (7.4% at 1 year versus 3.6% at >5 years). Evaluation of a breast problem remained fairly constant over the follow-up time, ranging from 16.9 to 19.2%.

For MRI examinations, indication also varied by time since diagnosis. Similar to patterns observed for mammography, the proportion of MRIs coded as surveillance increased as time since diagnosis increased; 54.8% at 1 year to 78.6% at >

5 years. As surveillance MRIs increased by time since diagnosis, short-interval follow-up (18.5% at 1 year versus 4.8% at >5 years), additional evaluation (9.9% at 1 year versus 4.1% at >5 years), and extent of disease/axillary adenopathy decreased over time (10.6% at 1 year versus 3.0% at >5 years).

Indication by time since diagnosis stratified by AJCC stage did not show differences in imaging patterns (Online Appendix 1 in the Electronic Supplementary Material (ESM)). Women with breast conserving surgery with or without RT had similar patterns to the overall results (Online Appendix 2 in the ESM). Women with mastectomy who underwent unilateral mammography had a higher proportion of examinations coded as surveillance in the first few years and a lower proportion of mammograms coded as short-interval follow-up.

Comparing patterns for mammography and MRI in women with a PHBC who received at least one breast imaging exam post-diagnosis, the proportion of examinations with an indication of surveillance was consistently lower for mammograms than for MRIs (Table 3). Patterns for other indications were similar for mammography and MRI.

In the first-year post-diagnosis, 81.8% of women had at least one breast imaging examination and one-third had more than one examination; this decreased over time such that only 13% of women had more than one examination at 5 years post-diagnosis (Table 4). The pattern for mammography is similar to the overall pattern as the majority of examinations are mammograms. However, only 6% of women with an MRI had multiple MRI examinations in the first-year post-diagnosis. In the first-year post-diagnosis, women who underwent mammography had multiple examinations at fairly short intervals (18.5% within 3 months of a prior examination, 45.0% within 3 to <6 months, 35.1% within 6 to <9 months, and 1.4% within 9 to <12 months) (Fig. 1a). As years post-diagnosis increased, the pattern shifted so that by years 3–5, most women shifted to 12 to <24 months between examinations.

The pattern for women undergoing MRI differed from that of mammography (Fig. 1b). In women who had MRI in the first-year post-diagnosis, 55.2% had a prior imaging examination within 3 months, 31.3% in 3 to <6 months, 13.1% in 6 to <9 months, and 0.5% in 9 to <12 months. While the proportion of women having examinations within <3 months decreased over time, the majority of women with MRIs had mammography at intervals shorter than every 12 months.

## DISCUSSION

Our findings provide descriptive information about breast imaging examinations that women with a PHBC and at least one breast imaging exam post-diagnosis receive during the post-treatment phase of care. We found that in the 6 to 18 months post-diagnosis, about 82% of women have at least one breast imaging examination and of those with an

**Table 1 Sociodemographic and Tumor Characteristics of 19,955 Women with a Personal History of Breast Cancer (PHBC), Breast Cancer Surveillance Consortium (BCSC) 2005–2013**

Characteristic	Women with PHBC N (%) N = 19,955
Age group, years	
18–39	781 (4)
40–49	3670 (18)
50–59	5449 (27)
60–69	5385 (27)
70–79	3220 (16)
≥ 80	1450 (7)
Race	
White	14376 (72)
African-American	1702 (9)
Asian or Pacific Islander	2534 (13)
Other	498 (3)
Hispanic	790 (4)
Missing	55
Menopausal status	
Post-menopausal	11107 (76)
Pre/Peri menopausal	3421 (24)
Missing	5427
BI-RADS breast density at time of diagnosis	
Almost entirely fat	773 (7)
Scattered fibroglandular tissue	4929 (42)
Heterogeneously dense	4969 (43)
Extremely dense	963 (8)
Missing	8321
Education	
<High school graduate	904 (7)
High school graduate/GED	2657 (21)
Some college	3340 (27)
College graduate	5687 (45)
Missing	7367
Income (approx. quartiles)	
< \$47,000	4185 (21)
\$47,000–< \$63,000	4628 (23)
\$63,000–< \$86,000	5312 (27)
≥ \$86,000	5719 (29)
Missing	111
BRCAT lifetime risk*	
< 15%	13798 (93)
15 to < 20%	717 (5)
≥ 20%	328 (2)
Missing	5112
BCSC 5-year risk*	
< 1.67%	5252 (59)
1.67 to < 3%	2776 (31)
≥ 3%	847 (10)
Missing	11080
AJCC stage	
0	4502 (23)
I	8620 (43)
IIA	3505 (18)
IIB	1822 (9)
III	1506 (8)
Tumor size	
< 10 mm	5014 (26)
10 to < 20 mm	6685 (35)
20 to < 50 mm	5711 (30)
≥ 50 mm	1608 (8)
Missing	937
Estrogen receptor status	
Negative	3250 (18)
Positive	15276 (82)
Missing	1429
Progesterone receptor status	
Negative	5045 (27)
Positive	13470 (73)
Missing	1440
Surgery at time of incident breast cancer	
None	427 (2)
Breast conserving surgery without RT	3339 (17)

(continued on next page)

**Table 1. (continued)**

Characteristic	Women with PHBC N (%) N = 19,955
Breast conserving surgery with RT	10834 (56)
Mastectomy (unilateral or laterality unspecified)	4844 (25)
Missing	511
Year of diagnosis	
2005	2795 (14)
2006	3001 (15)
2007	2955 (15)
2008	2931 (15)
2009	2602 (13)
2010	2165 (11)
2011	2087 (10)
2012	1419 (7)

BCRAT Breast Cancer Risk Assessment Tool, BI-RADS Breast Imaging Reporting and Data System, AJCC American Joint Committee on Cancer, RT radiation therapy

\*BRCAT and BCSC risk scores are calculated at the mammogram prior to breast cancer diagnosis

examination, about one-third had more than one examination in the first year. Multiple breast imaging examinations per year (mostly mammograms) were common and continued for the first few years post-diagnosis, suggesting there is a subset of women with a PHBC who are undergoing breast imaging more frequently than recommended guidelines. As time since diagnosis increased, the proportion of examinations (both mammography and MRI) with an indication of surveillance increased. We did not observe widespread use of MRI, either alone or in conjunction with mammography for women with a PHBC. When MRI was used, it tended to occur within 3 or 6 months of mammography.

Our study provides observational data to supplement prior reports of breast imaging in women with a PHBC based on survey and claims data. Ruddy et al. used claims data from 27,212 women with PHBC and found that in the first-year after definitive breast cancer surgery 78% of women had mammography alone, 1% had MRI alone, 8% had both mammography and MRI, and 13% had neither.<sup>13</sup> This is similar to our study in which 82% of women had breast imaging in the first year, with most having mammography alone (76%), followed by mammography and MRI (4%) and < 1% having MRI alone. Given that Ruddy et al. used claims data, they were unable to determine the indication for the examinations. Another study of women with a personal history of DCIS found that during the first year of follow-up, 79% of women had at least one surveillance mammogram and 11.5% had more than one.<sup>14</sup> In the second year, 75% had at least one surveillance mammogram but only 4.6% had more than one surveillance mammogram. In the first-year of follow-up, 5.3% of women had at least one diagnostic mammogram, with a slight increase in year 2 to 11.3%.<sup>15</sup> Examination indications in our study and these two DCIS studies differ, as a much lower proportion of mammograms had a surveillance

**Table 2 Breast Imaging Combinations Among 19,955 Women with a Personal History of Breast Cancer, Breast Cancer Surveillance Consortium 2005–2013**

Imaging modality	N women (%)* N=19,955
Mammogram only	17,836 (89.4)
MRI only	162 (0.8)
Any MRI and mammogram	1,957 (9.8)
1 MRI and 1 mammogram	216 (1.1)
1 MRI and > 1 mammogram	953 (4.8)
> 1 MRI and > 1 mammogram	788 (4.0)

\*Women in this table have differing follow-up (median = 37.6 months, IQR = 22.1 to 60.7)

indication in our study. The pattern of multiple surveillance mammograms in the 1-year post-diagnosis is similar to our findings; however, we did not observe such a sharp decline in the proportion of women with multiple mammograms in year 2. These differences could be due to differing stage distributions in studies, indication for exam, or availability and use of other imaging modalities such as MRI. Differences in the proportion of women with more than one exam between studies could stem from the indications included.

Breast MRI in the general population is increasing<sup>20,21</sup> with limited information on its use and effectiveness in women with a PHBC. Using BCSC data from 2005 to 2009, Wernli and colleagues reported an increase in breast MRI use from 4.2 to 11.5 examinations per 1000 women from 2005 to 2009 with 45% of MRIs performed in women with a PHBC.<sup>16</sup> Stout et al. reported an increase in MRI use (6.5 to 130.7 examinations per 10,000 women) in a northeastern US population from 2000 to 2009 using claims data,<sup>17</sup> with 23% of MRIs performed in women with a PHBC. Stout et al.

used an algorithm to define examination indication and among 3167 women with a PHBC with at least one MRI, a similar proportion had MRI for staging/treatment and surveillance (66.7% versus 65.9%, respectively) while a lower proportion (34.0%) had MRI for diagnostic evaluation. 65.9% of women in the Stout study who had surveillance MRI is similar to the proportion of women in our study with surveillance indication (54.8% in year 1 to 78.6% at > 5 years).

This study provides important information for understanding the type of imaging women with a PHBC are undergoing. Through the course of 6 focus groups from 41 women with a PHBC in three BCSC geographic regions of the US in 2014, almost all women reported receiving mammography every 3 to 6 months for 1 to 3 years after completion of treatment, and then annual mammography or staggered mammography and MRI every 6 months.<sup>18</sup> The women reported that they did not question having multiple examinations in a given year; in fact, women stated that they were assured that their provider was looking for another cancer. These focus group findings of multiple examinations in the first few years are similar to our findings from almost 20,000 women.

In 2018, findings from a national 8-question online survey of radiologists regarding their use of diagnostic versus screening mammography for women with a PHBC found significant variability in imaging protocols for women with a PHBC based on women's treatment (lumpectomy versus mastectomy) and facility characteristics.<sup>31</sup> Radiologists reported that protocols for women with lumpectomy were more likely to have a combination of diagnostic and screening examinations compared

**Table 3 Indication of Breast Imaging Examination by Modality and Time Since Breast Cancer Diagnosis, Breast Cancer Surveillance Consortium 2005–2013**

Modality and indication	N (%) examinations in the time since diagnosis (months)					
	1-year post-diagnosis (6 to < 18 mo)	2-year post-diagnosis (18 to < 30 mo)	3-year post-diagnosis (30 to < 42 mo)	4-year post-diagnosis (42 to < 54 mo)	5-year post-diagnosis (54 to < 66 mo)	> 5-year post-diagnosis (66+ mo)
	N (%)	N (%)	N (%)	N (%)	N (%)	N (%)
Mammography indication (N = 69,386)	N = 21,331	N = 15,693	N = 11,585	N = 8,477	N = 5,894	N = 6,406
Surveillance	9,742 (45.7)	8,548 (54.5)	6,846 (59.1)	5,195 (61.3)	3,711 (63.0)	4,625 (72.2)
Additional evaluation	1,570 (7.4)	1,302 (8.3)	908 (7.8)	562 (6.6)	372 (6.3)	230 (3.6)
Short-interval follow-up	5,049 (23.7)	2,533 (16.1)	1,487 (12.8)	1,032 (12.2)	557 (9.5)	214 (3.3)
Evaluation of breast problem	3,786 (17.8)	2,682 (17.1)	1,961 (16.9)	1,454 (17.2)	1,113 (18.9)	1,227 (19.2)
Diagnostic, not otherwise specified	1,184 (5.6)	628 (4.0)	383 (3.3)	234 (2.8)	141 (2.4)	110 (1.7)
MRI indication (N = 3,553)	N = 1,141	N = 807	N = 599	N = 434	N = 301	N = 271
Surveillance	625 (54.8)	539 (66.8)	440 (73.5)	314 (72.4)	230 (76.4)	213 (78.6)
Additional evaluation	113 (9.9)	87 (10.8)	44 (7.4)	33 (7.6)	20 (6.6)	11 (4.1)
Short-interval follow-up	211 (18.5)	78 (9.7)	58 (9.7)	44 (10.2)	19 (6.3)	13 (4.8)
Evaluation of breast problem	71 (6.2)	65 (8.1)	41 (6.8)	30 (6.9)	25 (8.3)	26 (9.6)
Extent of disease/axillary adenopathy	121 (10.6)	38 (4.7)	16 (2.7)	13 (3.0)	7 (2.3)	8 (3.0)

MRI magnetic resonance imaging, mo month

**Table 4** Number of Examinations by Time Since Breast Cancer Diagnosis, Overall and by Exam Modality for All Indications, Breast Cancer Surveillance Consortium 2005–2013

	Number of years post-diagnosis (months)					
	1-year post-diagnosis (6 to <18 mo)	2-year post-diagnosis (18 to <30 mo)	3-year post-diagnosis (30 to <42 mo)	4-year post-diagnosis (42 to <54 mo)	5-year post-diagnosis (54 to <66 mo)	>5-year post-diagnosis (66+ mo)
	<i>N</i> (%)	<i>N</i> (%)	<i>N</i> (%)	<i>N</i> (%)	<i>N</i> (%)	<i>N</i> (%)
All exams						
<i>N</i> women	16,318	13,139	10,265	7,667	5,438	3,979
<i>N</i> exams	22,472	16,500	12,184	8,911	6,195	6,677
<i>N</i> exams per woman						
1	10,965 (67.2)	10,109 (76.9)	8,512 (82.9)	6,521 (85.1)	4,735 (87.1)	2,123 (53.4)
2	4,625 (28.3)	2,720 (20.7)	1,601 (15.6)	1,056 (13.8)	653 (12.0)	1,206 (30.3)
3 or more	728 (4.5)	310 (2.4)	152 (1.5)	90 (1.2)	50 (0.9)	650 (16.3)
Mammogram						
<i>N</i> women	16,065	12,962	10,134	7,579	5,356	3,948
<i>N</i> exams	21,331	15,693	11,585	8,477	5,894	6,406
<i>N</i> exams per woman						
1	11,305 (70.4)	10,423 (80.4)	8,774 (86.6)	6,733 (88.8)	4,841 (90.4)	2,171 (55.0)
2	4,282 (26.7)	2,356 (18.2)	1,275 (12.6)	795 (10.5)	494 (9.2)	1,200 (30.4)
3 or more	478 (3.0)	183 (1.4)	85 (0.8)	51 (0.7)	21 (0.4)	577 (14.6)
MRI						
<i>N</i> women	1,075	780	579	422	293	211
<i>N</i> exams	1,141	807	599	434	301	271
<i>N</i> exams per woman						
1	1,010 (94.0)	753 (96.5)	559 (96.5)	411 (97.4)	285 (97.3)	159 (75.4)
2	64 (6.0)	27 (3.5)	20 (3.5)	10 (2.4)	8 (2.7)	45 (21.3)
3 or more	1 (0.1)	0 (0)	0 (0)	1 (0.2)	0 (0)	7 (3.3)

MRI magnetic resonance imaging, mo month

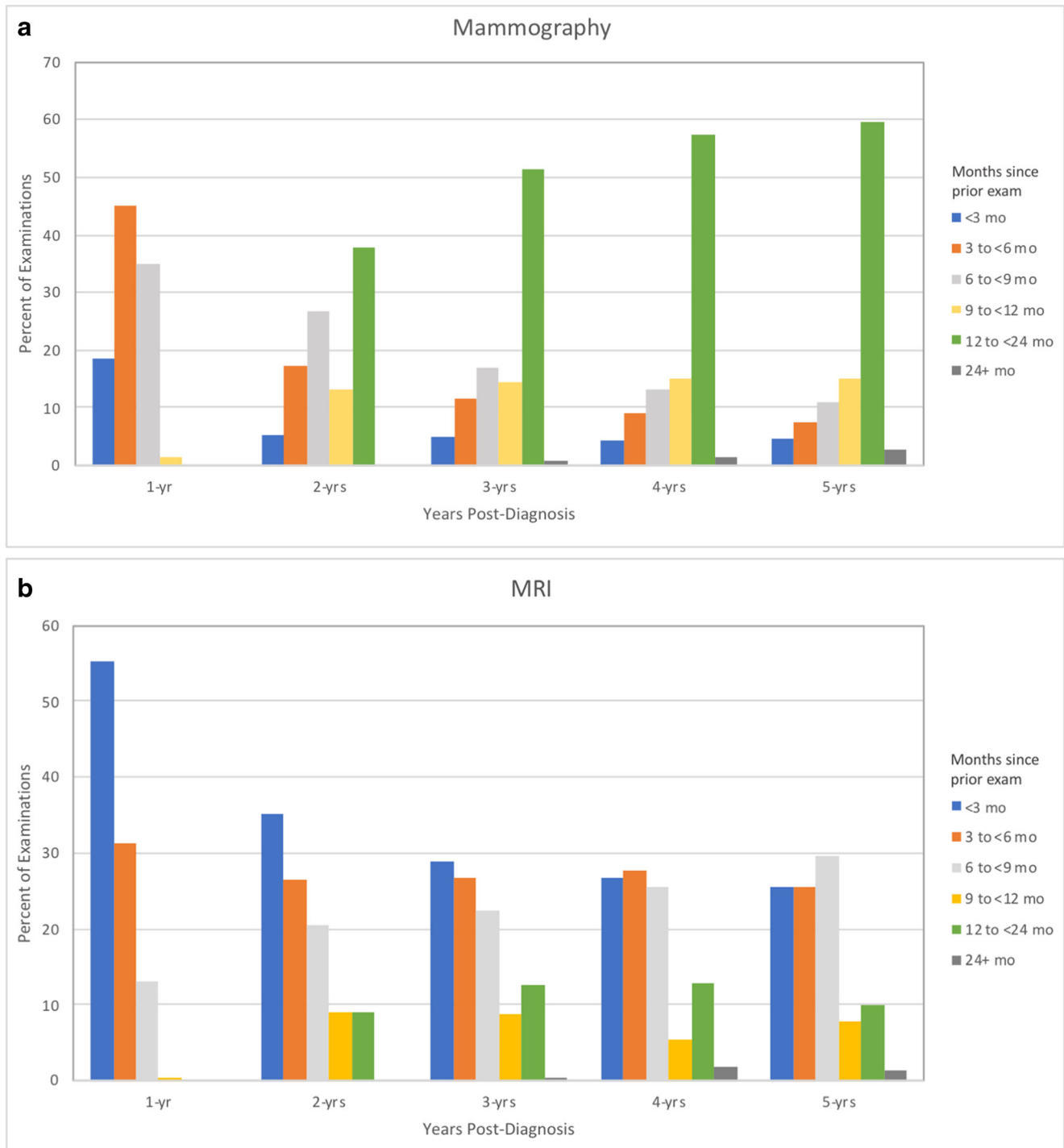
to women with mastectomy, who were more likely to have diagnostic only or screening only examinations. The most frequently reported imaging interval was every 6 months for 1–2 years (49%), with the next most common interval every 12 months for 2–5 years then screening (33%), and the least common interval was for 6 months–1 year then screening (18%). Radiologists working in academic settings were less likely to recommend diagnostic mammography after lumpectomy or mastectomy than community radiologists and were less likely to use diagnostic surveillance for periods beyond 2 years. In our results stratified by treatment type (Online Appendix 2 in the ESM), we found that women with a PHBC treated with mastectomy had a consistently higher proportion of examinations coded as surveillance by time since diagnosis.

Breast imaging examination indication in BCSC data is assigned at the breast imaging facility with variability in how this information is documented. Indication may come from the interpreting radiologist, the technologist performing the examination, the scheduler, or the physician who referred the woman for the examination. Medicare will pay for an annual screening or diagnostic mammogram for women with a PHBC<sup>32</sup> and the ACR Practice Parameter of Screening and Diagnostic Mammography states that asymptomatic women with a PHBC may undergo screening or diagnostic mammography at the discretion of the facility,<sup>33</sup> which may drive some of the observed variability in patterns for indication. Due to differences in underlying disease prevalence by indication,

analyses of performance and outcomes are typically stratified by indication. Our observational data from community practice suggest a significant proportion of examinations are coded as diagnostic when they may be performed for surveillance. Using 2007–2013 BCSC data from 2,084,052 digital screening and diagnostic mammograms in women ages 18 and older, 5.3% of exams had an indication of evaluation of a breast problem,<sup>34,35</sup> which is much lower than the 16.9–19.2% we found in women with a PHBC.

A major strength of our study is the BCSC data which is the only national data source that collects breast imaging data with the level of detail needed to evaluate patterns and frequency of imaging indication. While women could receive imaging outside of BCSC registry catchment areas, in a subset of 31,628 examinations with a prior mammogram date from both self-report and the BCSC database, 97% have the two dates within 1 year of each other. We are unable to make this comparison for MRI as date of prior MRI is not available in the BCSC data. Additionally, we do not have complete 5-year follow-up for all women.

Our study showed that while women with a PHBC are recommended to undergo annual surveillance mammography, a third of women with a PHBC and at least one breast imaging exam receive multiple breast imaging examinations per year during the first 2 years post-diagnosis. Heterogeneity in breast imaging indication by time since breast cancer diagnosis may well be a reflection of reimbursement and facility variation. The patterns of more surveillance examinations as the time since diagnosis



**Fig. 1** Observed frequency of mammography (panel a) and MRI (panel b) examinations by the number of years post-diagnosis and months since prior examination in women with a personal history of breast cancer. Blue bars represent exams with another exam in the prior 3 months, orange bars represent exams with another exam in the prior 3 to less than 6 months, light gray bars represent exams with another exam in the prior 6 to less than 9 months, yellow bars represent exams with another exam in the prior 9 to less than 12 months, green bars represent exams with another exam in the prior 12 to less than 24 months, and dark gray bars represent exams with another exam in more than 24 months. a

Proportion of mammograms by months since prior examination and time since breast cancer diagnosis, Breast Cancer Surveillance Consortium 2005–2013. b Proportion of MRI examinations by months since prior examination and time since breast cancer diagnosis, Breast Cancer Surveillance Consortium 2005–2013.

increases and the use of multiple examinations in the first few years appears to be in line with women's self-reports as well as those of radiologists. Comparative effectiveness

studies are needed to evaluate different surveillance strategies in women with a PHBC and to assess potential overutilization of imaging. To conduct these studies,

additional work is needed to understand what is driving facility variability in coding indication such as time since diagnosis, calendar year, and patient characteristics.

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#### Compliance with Ethical Standards:

**Conflict of Interest:** Author Diana L. Miglioretti was a member of the Scientific Advisory Board for Hologic in 2017. Author Janie M. Lee is a consultant for General Electric Healthcare and receives a Research Grant from General Electric Healthcare. All remaining authors declare that they do not have a conflict of interest.

**Disclaimer:** The design and conduct of the study; collection, management, analysis, and interpretation of the data; preparation, review, or approval of the manuscript; and decision to submit the manuscript for publication are solely the responsibility of the authors and does not necessarily represent the official views of the Patient-Centered Outcomes Research Institute, the National Cancer Institute or the National Institutes of Health.

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