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Predictors of Preoperative Magnetic Resonance Imaging for Breast Cancer: Differences by Data Source

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Abstract

Aim—Investigate how the results of predictive models of preoperative magnetic resonance imaging (MRI) for breast cancer change based on available data

Materials and Methods—1919 insured women aged 18 with stage 0-III breast cancer diagnosed 2002-2009. Four models were compared using nested multivariable logistic, backwards stepwise regression; model fit was assessed via area under the curve (AUC), R^2 .

Results—MRI recipients ($n=245$) were more recently diagnosed, younger, less comorbid, with higher stage disease. Significant variables included: Model 1/Claims (AUC=.76, $R^2=0.10$): year, age, location, income; Model 2/Cancer Registry (AUC=.78, $R^2=0.12$): stage, breast density, imaging indication; Model 3/Medical Record (AUC=.80, $R^2=0.13$): radiologic recommendations; Model 4/Risk Factor Survey (AUC=.81, $R^2=0.14$): procedure count.

Conclusions—Clinical variables accounted for little of the observed variability compared to claims data.

Keywords

breast cancer; magnetic resonance imaging; claims/utilization data; chart abstraction; risk factor data; survey data; predictive variables

Introduction

Pre-operative magnetic resonance imaging (MRI) in staging and operative planning for breast cancer has grown rapidly [1-3]. While preoperative breast MRIs do appear to detect a greater number of occult cancers in the ipsilateral and contralateral breast, preoperative

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breast MRIs have not been reliably associated with reduced rates of re-excision and are associated with more extensive surgery (i.e. mastectomy) of both the primary and contralateral breast [4-10]. Whether more extensive surgery results in any improvement in local disease control or survival is uncertain[6]. As a result, questions regarding the benefit of preoperative breast MRI have led stakeholders, including insurers and policymakers, to call for more research and (potentially) limits on the use of breast MRI [11, 12]. Comparative effectiveness research (CER) has been identified as one approach to better understand the appropriateness of predictors of preoperative breast MRI for breast cancer [12, 13].

However, the role imaging plays in cancer diagnosis and treatment can be complex. For example, imaging studies such as those assessing preoperative breast MRI may simultaneously inform both the (retrospectively) observed stage of cancer and treatment choice. And comparative effectiveness studies, particularly those using only administrative data (i.e. claims or utilization data), may be hampered both by inherent limitations of the available data as well as the absence of (potentially) more important clinical and patient-reported variables. Furthermore, clinical and patient-reported variables may help clarify whether women who receive MRI are fundamentally different than women who do not (often referred to as clinical selection). When present, clinical selection can lead to “selection bias. This in turn can lead to incorrect conclusions about the usefulness of MRI, particularly when those conclusions are based on results from studies with imperfect or incomplete data.

To better understand both the magnitude and effect of these potential methodological problems for CER studies of preoperative breast MRI, we identified a population of women diagnosed with incident in situ or invasive breast cancer. For this sample of insured women (receiving care in a mixed-model insurer and managed care organization) complete information was available across a wide spectrum of known and hypothesized explanatory variables, including mammographic findings, cancer stage and behavior, and personal and family history. The overall goal was to contrast results from claims-based models with those from more complex models that include clinical and patient-reported data to determine whether differences in data (variable) availability may significantly influence the interpretation of what is driving MRI use and/or the perceived risk of clinical selection, and therefore selection bias. Understanding these two issues, particularly in the age of comparative effectiveness, is critically important for those researching the role of MRI on downstream outcomes like surgery (i.e. mastectomy versus lumpectomy) or mortality.

Materials and Methods

Sample selection

This research was approved by the Human Subjects Committee at Group Health Cooperative. The research included enrolled members of Group Health, a nonprofit mixed-model health care system based in Seattle, Washington, which acts both as an insurance company and as a staff-model managed care system. We identified all women aged 18 years or older diagnosed with incident stage 0-III breast cancer or ductal carcinoma in situ (DCIS) from 2002-2009 from the underlying Surveillance Epidemiology and End Results (SEER)

registry (Figure 1). Women must have been enrolled members of Group Health for at least the 4 months prior to and the 4 months after diagnosis with enrollment gaps of no more than 60 days, unless the subject died within 120 days of diagnosis. Women were excluded if they had a prior history of cancer (n=689); bilateral cancer diagnosed prior to surgical resection of the first cancer diagnosis (n=24) or another breast cancer diagnosed before the surgery date of the first (n=30); or stage IV disease, unknown cancer size or stage (n=215).

Cancer had to be both biopsy-proven and surgically removed with definitive surgery (mastectomy or lumpectomy) within 120 days of SEER diagnosis [14-16], with a preoperative MRI occurring at least one day after the final observed breast biopsy and one day before breast surgery (N=317 women excluded). Determination of occurrence and date of MRI, biopsy and surgery were completed using claims for external services and utilization data for services received in GHC facilities (i.e. International Classification of Diseases, Ninth edition, ICD-9, and Current Procedural Terminology, CPT, based). No grace period was observed around dates.

Data sources

Data were taken from four sources: 1. the Puget Sound SEER registry, 2. an existing database which includes Group Health's Breast Cancer Surveillance registry risk factor data (from patient surveys) [17], 3. Group Health enrollment, internal and external claims and utilization data (including linkage to 2000 Census data), and 4. medical records for final radiologic interpretation of the screening and diagnostic mammograms (with or without ultrasound) taken immediately prior to the cancer diagnosis. Since 1996, breast cancer risk factors have been collected through self-administered risk surveys at the time of each mammogram at Group Health and the sensitivity and specificity of this survey data has been validated [18]. Eligible women had to have completed a survey in the two years prior to breast cancer diagnosis. If multiple surveys had been completed, the survey completed most immediately prior to their diagnosis was used.

Variables

Receipt of a post-diagnosis, preoperative breast MRI (the dependent variable) was determined via Group Health claims and utilization data as described above. Identification of the provider ordering the MRI (and his/her discipline) was obtained from multiple sources including physician electronic order entry, prior authorization information captured electronically in Group Health data systems and claims data. Selection of independent variables was based on prior published studies of predictors of pre-operative breast MRI [3, 7] and available variables in our setting that were hypothesized *a priori* as potentially important predictors (see Table 1). Independent variables were categorized as either: 1. claims/utilization-based (C), 2. SEER cancer-registry based (CR), 3. medical record or health plan based (MR), or 4. patient-survey based risk-factor data (RF). For C variables related to patient or family history, utilization or claims data was searched for ICD-9 "V" codes from 12-24 months prior to the patient's cancer diagnosis. Insurance category was based on Group Health enrollment information. Median household and family income was based on the residential zip code of the woman at the time of her diagnosis, linked to 2000

Census data, using block level data. The Klabunde modification of the Charlson comorbidity index (excluding cancer) was assessed at 12 months prior to diagnosis [19].

All CR model variables were taken directly from SEER variables, except for stage and a variable constructed from SEER variables, entitled “early stage at diagnosis.” Stage was based on American Joint Commission on Cancer Staging, version six for all cases [20]. The early stage variable had two definitions, the first was invasive or DCIS disease with tumor size ≤ 10 millimeters and no positive lymph nodes and the second definition was invasive or DCIS disease with tumor size ≤ 15 millimeters and no positive lymph nodes [21, 22].

For MR variables, the presence of drug coverage (yes or no) came from Group Health enrollment data and was included as a gross indicator of how generous the patient's insurance coverage might be. Other measures such as cost-sharing or deductible are not easily available and were outside the scope of this paper. Mammographic breast density and mammographic or ultrasonography Breast Imaging-Reporting and Data System (BI-RADS) findings including evidence of abnormality, classification, and final recommendation were recorded by the interpreting clinical radiologist [23]. For this study, entirely fat and scattered fibroglandular densities were combined to create a category labeled “fatty” while heterogeneously dense and extremely dense were combined to create the category “dense”. In brief, for mammographic evidence of abnormality the chart abstracted categories were collapsed to create a “normal” and an “abnormal” category. For mammographic recommendation, the categories were collapsed to create a “follow-up/normal” and (immediate) “biopsy” category. Collapsing the data was necessary due to small cell sizes. The mammogram with valid data most immediately prior to the cancer diagnosis date was selected. This mammogram had to occur within the four months prior to the cancer diagnosis. If the mammogram closest to the cancer diagnosis date with valid risk factor data was a screening mammogram (rather than a diagnostic mammogram), these data were used to populate a variable labeled screening mammogram (yes or no).

Risk factors were based on patient-responses recorded on the risk factor surveys [17]. For this survey a breast biopsy was defined as any removal of tissue from the breast, not including removing fluid from a cyst; whereas a breast procedure included cyst aspiration, breast reconstruction, breast reduction or breast implants. Hormones use included self-reported use of estrogen, progesterone, tamoxifen, raloxifen or another hormones, excluding birth control pills, Norplant, Depo-Provera or fertility-enhancing hormones. The modified Gail lifetime risk score [24-28] was calculated from the answers to the following questions: age, age at first menstrual period, age of first live birth, number of first-degree relatives with breast cancer (history), personal history of breast biopsy, personal history of breast cancer, and race/ethnicity.

Methods

Unadjusted logistic regression was used to determine the relationship between independent variables in each model set and receipt of MRI to explore clinical and patient selection factors. Then four incremental multivariable logistic models were fit using backwards stepwise regression modeling with the significance level set to 0.1. All variables found to be significant in an earlier model were retained in the later models. Specifically, the significant

C variables were forced into the (nested) RD model. Then both the C and CR variables were forced into the nested CR model. Finally, the C, CR and MR variables were forced into the nested RF model. The purpose of this approach was to mimic increasing levels of model complexity and data availability, beginning first with the most simplistic claims-based model. While variable selection was literature review and hypothesis-based, we purposefully did not select specific variables to include in each nested model *a priori*, instead selecting stepwise regression. The goal of this paper was to demonstrate in a general way the relationship of the models to each other, without assuming which data sources and discrete variables researchers might have access to (or include) in future studies.

Model fit was assessed using Area Under the Curve (AUC) and R^2 . To limit the loss of subjects due to missing data and, more importantly, to clarify whether missing data was predictive of receipt of pre-operative MRI, “missing” indicator variables were included in all analyses for all variables with greater than 10% missing data. Again, this was selected (rather than imputing data) because the goal was not to correct the problem of missing data but rather to better understand any possible relationships between receipt of MRI and missingness which might be important for future research. Data for variables with more than 10% missing data are also included as a separate category in descriptive tables. For discrete variables with less than 10% missing data, missing data were included in the base category and are not separately identified. For median family income, the median value was assigned to the <10% of individuals with missing data. All analyses were conducted using SAS software version 9.2, SAS Institute Inc., Cary, NC, USA.

Results

Just over one in 10 women (N=245, 12.8%) received post-diagnosis, preoperative breast MRI. Of the MRIs obtained, 178 (72.7%) were ordered by surgeons or medical oncologists. In univariate analyses, women receiving MRIs were more recently diagnosed, younger and had higher stage tumors (see Table 2). Women who received pre-operative MRI also tended to live in non-urban areas, have higher median family income, have a history of two or more diagnostic breast procedures and radiographic interpretations indicating normal breasts or the need for further follow-up, compared to women with recommendations for immediate biopsy. Women with fatty (versus dense) breasts were less likely to receive MRI. Median health plan enrollment prior to diagnosis was 170 months (standard deviation [SD] 79) and there was no significant difference in length of enrollment by receipt of MRI.

Very few women were identified as having a family history of breast or other cancers using ICD-9-based V-codes (N=16). Similarly, few women were identified via CPT codes/ utilization as having had a prior breast biopsy, procedure or MRI (N=31). Given this, these variables were excluded from further analysis. In multivariable analysis, four variable categories were included in the claims-based C model (Model 1): diagnostic year, age, non-urban location and log of median family income (Table 3). Model fit demonstrated AUC of 0.76 (receiver operator curve for the model). R-squared (R^2) was 0.10 with maximum rescaled R-squared (MR R^2) of 0.18.

In comparing Model 1 to Model 2 (CR or cancer registry data), all nested variables remained significant except non-urban location, with the addition of cancer stage, the only variable that entered the model at this step. No other Model 1 variables aside from non-urban location showed significant change in magnitude, direction or confidence intervals (Table 4). AUC for Model 2 was 0.78, $R^2=0.12$ and $MR R^2=0.22$.

Significant Model 3 (MR or medical record/health plan data) variables included breast density, whether the mammogram was a screening mammogram, and if the radiographic report from the mammogram recommended follow-up or was normal (versus recommending immediate biopsy). In comparing Model 2 to Model 3, point estimates regarding the diagnostic year uniformly increased more than 10%, remaining significant with a greater magnitude (see Table 4). AUC for Model 3 was 0.80, $R^2=0.13$ and $MR R^2=0.24$.

Finally, in comparing Model 3 to Model 4 (RF, patient-reported breast cancer risk factors), only the number of patient-reported prior breast procedures entered the model. The point estimates for diagnostic year increased more than 10% but remaining significant. AUC for Model 4 was 0.81, $R^2=0.14$ and $MR R^2=0.26$.

Discussion

This is one of the first studies of clinical selection factors in receipt of pre-operative breast MRI in a community-based population of women of all ages (not simply Medicare-aged females) at variable-risk for breast cancer. Our study suggests women who receive preoperative breast MRI have different risk factors than women who do not. In this study patient factors such as age, breast density, higher cancer stage and a greater number of prior breast procedures before initial diagnosis were associated with receipt of preoperative breast MRI. This is evidence of clinical selection, and is largely consistent with prior literature and guidelines regarding the effective use of MRI [29, 30]. However the inclusion of these variables (i.e. use of mammographic findings such as breast density and radiographic recommendation and prior number of breast biopsies) in the prediction of receipt of preoperative MRI is novel.

Year of diagnosis was a strong predictor of receipt of MRI. This is similar to other studies, which also have shown a strong temporal trend in the use of breast MRI [1-3]. During the study period, prior authorization was needed for breast MRI and all breast MRI was completed by external, contracted facilities, consistent with the patient's insurance plan coverage. Additionally, there were no decision aids available for pre-operative breast MRI. Variability in MRI referrals and receipt would have been largely driven by provider and patient preference. This may explain the presence of median family income, as well as the marginal significance of non-urban location in the Claims model, suggesting that socioeconomic and geographic factors may have played a role in overcoming the additional difficulty in receipt of MRI, even in this insured population. In this study we were not able to investigate differences in the range of insurance plans in the sample to better understand the effect of insurance benefits on receipt of MRI.

In this study, little explanatory power would be lost using only the claims-based model variables in predicting receipt of MRI. Despite the wealth and putative importance of the other explanatory variables we considered, the overall variability in preoperative MRI receipt was explained largely by temporal trends (i.e. year of diagnosis). Omission or inclusion of the SEER, chart-review and patient-reported variables did not significantly alter the estimates for the claims-based variables (particularly given that changes in point estimate for diagnostic year could be related to reductions in power with the inclusion of additional variables). Further research is needed to identify other predictors of pre-operative breast MRI, particularly as trends in its use change over time.

In light of our results, the importance of the cancer registry, chart-abstracted and patient-reported variables must be evaluated in relation to the goals of the planned study. For example, if the purpose of a study is to identify factors associated with increased use of MRI that might be targeted for intervention, then these variables may remain important to consider. In contrast claims-based variables that are not easily mutable (year, age, non-urban location and median family income), may be less useful. While this paper demonstrates that clinical selection in receipt of preoperative MRI receipt is both present and significant, and that temporal trends are important, this study does not address selection bias directly. Addressing selection bias would require investigating the effect of these variables on an important outcome (such as mortality or receipt of mastectomy). Therefore, these results should not be used in defense of omitting cancer registry, chart-review or patient-reported variables from all outcome models, which may be subject to selection bias, particularly in populations with different distributions of the dependent variable.

This study has limitations. First, we did not explore or address clinical selection in receipt of treatment (i.e. women who do not have a biopsy or who do not go on to receive surgery) or the possibility that the MRI was obtained to assess treatment effect of preoperative chemotherapy. However the vast majority of women with early stage breast cancer do undergo surgery for curative intent. Second, we examined only the most straightforward breast cancer cases (i.e. those with first, incident cancer and unilateral disease). This represents a subset of all breast cancer, but was selected to facilitate and limit how the information obtained from the preoperative MRI might be being used in the clinical setting. We were able to examine who ordered the preoperative breast MRI, confirming that the decision is largely in the hands of surgeons and medical oncologists in our population. What was not included was more detailed information on why the MRI was ordered. It is likely that there are complex interactions between providers and patients during the diagnostic work-up process that influence whether an MRI is ordered, including system, provider and patient level factors. This is an area deserving of additional research. Other intermediate variables, such as breast size or preoperative physical exam (e.g. addressing concerns regarding chest wall invasion) might shed light on the role and value of MRI results for both clinicians and patients in surgical decision-making (i.e. mastectomy versus lumpectomy). These data, while potentially present in the medical record and recoverable via chart abstraction, were also outside the scope of this study. Finally, this study was conducted in a single geographic region using data from a single health insurer.

Conclusions

This study provides critical information for researchers considering future studies of preoperative breast MRI in community-based women, of all ages, at average risk of breast cancer. The addition of mammographic results including breast density and radiographic recommendations as well as prior number of breast biopsies to the list of known predictors of breast MRI is an important contribution to the literature. Our study also emphasizes the impressive predictive ability of temporal trends in determining receipt of MRI. Finally this study emphasizes the importance of considering these factors in both predicting MRI and potentially influencing (directly and indirectly) important outcomes, such as receipt of mastectomy.

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Executive Summary

- Pre-operative magnetic resonance imaging (MRI) in staging and operative planning for breast cancer has grown rapidly despite questions regarding its impact on disease control or survival
- Studies of breast MRI (particularly comparative effectiveness studies using only administrative data) may be hampered by inherent limitations of the available data as well as absence of important clinical and patient-reported variables.
- This is one of the first studies of clinical selection factors in receipt of pre-operative breast MRI in a community-based population of women of all ages at variable risk for breast cancer
- Our study suggests women who receive breast MRI have different risk factors than women who do not (indicating clinical selection)
- Specifically, the study of breast density, radiographic recommendation, and prior number of breast biopsies in the prediction of preoperative MRI is novel.
- However, temporal trends were the most significant predictor of breast MRI and little explanatory power would be lost using only claims-based variables in predicting receipt of MRI.
- Future studies should address whether selection bias affects receipt of breast MRI and outcomes such as mastectomy or survival.

Future Perspective

Data availability and variable selection will continue to be critically important in model specification, particularly for comparative effectiveness research where clinical selection and selection bias may be important.

Figure 1. Sample Selection

Table 1
Variables considered in regression analysis by model

Model 1: Claims model Variables extracted from claims/utilization data			
Year of diagnosis	ICD-9-based Modified Charlson comorbidity index ¹⁹	ICD-9 code for breast cancer	Family history of ovarian cancer (V16.41)
Age at diagnosis			
Insurance type	Rural/urban classification by census (based on zip code of residence at diagnosis)	CPT code for:	Family history of breast cancer (V16.3)
Medicare	Census block median family or household income (of zip code of residence at time of diagnosis)	Breast biopsy	Personal history of breast cancer (V10.3)
Private Pay		Breast procedures	Personal history of ANY cancer (V10-V10.9)
Commercial		MRI	
Model 2: Registry model Variables extracted from SEER cancer registry data			
Race/ethnicity	Histology (invasive or DCIS)	Estrogen receptor status (negative, positive, or missing)	
Cancer stage (0, 1, 2, 3)	Grade (I/II, III/IV, unknown)	Early stage at diagnosis, definition 1 and 2 (see definitions below)	
Cancer size (in millimeters)	Lymph node status (positive or negative)		
Model 3: Electronic medical record (EMR) data Variables extracted from medical record or health plan data			
Patient drug coverage (yes or no)	Screening mammogram (yes or no)	Mammographic evidence of abnormality (BIRADS abnormal, BIRADS normal, missing)	
	Mammographic breast density (dense, fatty, missing)	Mammogram or ultrasound recommendation (biopsy, follow-up, normal, missing)	
Model 4: Risk factor model Variables extracted from patient risk factor surveys before diagnosis			
Current/prior use of hormonal medications, other than birth control or fertility medications (i.e. estrogen, progesterone, tamoxifen, raloxifene, other)	Modified Gail lifetime or 5 year risk score ²⁷	Patient survey report of:	
		History of breast biopsies	
		Number of breast biopsies	
		Number of breast procedures	
		Personal history of breast cancer	
		Family history of breast cancer in first or second degree relative	
		Family history of ovarian cancer in first or second degree relative	

ICD-9: International Classification of Diseases, Ninth edition

CPT: Current Procedural Terminology

DCIS: Ductal carcinoma in situ

Early stage at diagnosis^{21, 22}(i.e. minimal cancer):

Definition 1: DCIS or invasive disease, tumor size less than or equal to 10 millimeters with no positive lymph nodes

Definition 2: DCIS or invasive disease, tumor size less than or equal to 15 millimeters and no positive lymph nodes

BIRADS: Breast Imaging-Reporting and Data System

Table 2
Characteristics of 1919 women with first, incident breast cancer diagnosed between 2002-2009 who did and did not receive pre-operative breast magnetic resonance imaging (MRI) for variables that significantly entered one of four nested models

	Receipt of preoperative breast MRI					
	Yes N=245		No N=1674		p-value	
	N	Column %	N	Column %		
Claims-Based Variables						
Year of diagnosis					<.0001	
2002	4	1.6	255	15.2		
2003	15	6.1	238	14.2		
2004	24	9.8	200	11.9		
2005	34	13.9	206	12.3		
2006	28	11.4	227	13.6		
2007	40	16.3	198	11.8		
2008	51	20.8	172	10.3		
2009	49	20.0	178	10.6		
Age at diagnosis (years)					<.0001	
<40	19	7.8	38	2.3		
40-49	54	22.0	206	12.3		
50-59	98	40.0	475	28.4		
60-64	28	11.4	250	14.9		
65-74	33	13.5	390	23.3		
75	13	5.3	315	18.8		
Residence location					0.08	
Non-urban	44	18.0	231	13.8		
Urban	201	82.0	1443	86.2		
*Median Family Income (median, [standard deviation])	63571.0	[19081.0]	60800.0	[20205.3]	0.03	
Registry-Based Variables						
AJCC version 6 cancer stage at diagnosis					<.0001	

Receipt of preoperative breast MRI					
Yes N=245			No N=1674		
N	Column %		N	Column %	p-value
0	27	11.0	272	16.2	
I	85	34.7	819	48.9	
II	94	38.4	477	28.5	
III	39	15.9	106	6.3	
Electronic Medical Record-Based Variables					
Mammographic breast density					
Fatty	32	13.1	455	27.2	<.0001
Dense	170	69.4	938	56.0	
Unknown	43	17.6	281	16.8	
Screening mammogram					
No/Unknown	237	96.7	1560	93.2	0.03
Yes	8	3.3	114	6.8	
^Mammogram recommendation					
Biopsy	211	86.1	1471	87.6	0.69
Follow-up	12	4.9	78	4.7	
Normal/Unknown	22	9.0	125	7.5	
Patient-Reported Risk Factor-Based Variables					
Number of prior breast procedures before breast cancer diagnosis					
0	168	68.6	1300	77.7	<.0001
1	37	15.1	238	14.2	
2+	9	3.7	14	0.8	
Unknown	31	12.7	122	7.3	

* Median family income was based on Census block level information from 2000 for the zip code in which the woman lived at the time of her breast cancer diagnosis.
AJCC: American Joint Commission on Cancer

^This recommendation is taken from the mammogram report for the exam immediately prior to the cancer diagnosis.

Table 3
Likelihood of receiving preoperative breast magnetic resonance imaging (MRI) following diagnosis of ductal carcinoma in situ or invasive breast cancer in relation to Claims, Registry, Electronic medical record (EMR) and Risk-factor data for the final model

	Odds Ratio	95% Confidence Interval	
Model 1: Claims			
Year of Diagnosis	Reference category 2002		
2003	5.76	1.81	18.35
2004	14.93	4.83	46.13
2005	18.37	6.04	55.88
2006	14.65	4.76	45.05
2007	25.03	8.29	75.61
2008	44.34	14.69	133.76
2009	41.15	13.59	124.60
Age	Reference category 50-59 years		
39	3.00	1.52	5.92
40-49	1.21	0.80	1.84
60-64	0.47	0.29	0.77
65-74	0.38	0.24	0.59
75	0.17	0.09	0.32
Location	Reference category urban		
Non-urban	1.45	0.98	2.17
Log of median family income	2.30	1.41	3.77
Model 2: Registry			
Stage	Reference category stage I		
0	0.59	0.36	0.97
II	1.69	1.20	2.39
III	3.59	2.23	5.78
Model 3: Electronic medical record			
Breast density	Reference category dense		
Fatty breasts	0.52	0.34	0.79
Unknown	0.95	0.54	1.66
Recommendation from mammogram or ultrasound	Reference category biopsy		
Follow-up	3.55	1.59	7.89
Normal/unknown	2.05	0.98	4.28
Screening mammogram	Reference category no		
Yes	2.57	1.09	6.07
Model 4: Risk factor			
Number of prior breast procedures	Reference category 0		
1	1.31	0.86	1.99

	Odds Ratio	95% Confidence Interval	
2+	13.50	4.85	37.57
Unknown	1.13	0.67	1.93

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Table 4
Maximum likelihood estimates and standard errors by variable for all models

Parameter	Model 1 Results: Claims (C)		Model 2 Results: C plus Cancer Registry (CR)		Model 3 Results: C, CR plus Medical record/Health plan (MR)		Model 4 Results: C, CR, MR plus Patient-reported Risk Factor (RF)	
	Estimate	Standard Error	Estimate	Standard Error	Estimate	Standard Error	Estimate	Standard Error
Model 1: Claims								
Year of Diagnosis								
2003	1.52 ^b	0.57	1.51 ^b	0.58	1.65 ^b	0.59	1.75 ^b	0.59
2004	2.30 ^d	0.55	2.36 ^d	0.56	2.64 ^d	0.57	2.70 ^d	0.58
2005	2.39 ^d	0.54	2.47 ^d	0.55	2.80 ^d	0.56	2.91 ^d	0.57
2006	2.17 ^d	0.55	2.22 ^d	0.55	2.53 ^d	0.57	2.68 ^d	0.57
2007	2.76 ^d	0.54	2.85 ^d	0.54	3.11 ^d	0.56	3.22 ^d	0.56
2008	3.10 ^d	0.53	3.28 ^d	0.54	3.61 ^d	0.56	3.79 ^d	0.56
2009	3.12 ^d	0.54	3.24 ^d	0.54	3.57 ^d	0.56	3.72 ^d	0.57
Age								
39	1.13 ^c	0.33	1.11 ^c	0.33	1.05 ^c	0.34	1.10 ^c	0.35
40-49	0.31 ^a	0.20	0.26 ^a	0.20	0.19 ^a	0.21	0.19 ^a	0.21
60-64	-0.72 ^c	0.24	-0.74 ^c	0.24	-0.72 ^c	0.24	-0.75 ^c	0.25
65-74	-1.02 ^d	0.22	-.99 ^d	0.22	-0.94 ^d	0.23	-0.98 ^d	0.23
75	-1.65 ^d	0.31	-1.70 ^d	0.31	-1.70 ^d	0.32	-1.78 ^d	0.32
Location (versus urban)								
Rural	0.38 ^b	0.19	0.33 ^a	0.20	0.34 ^a	0.20	0.37 ^a	0.20
Log median family income	0.74 ^c	0.24	0.84 ^c	0.24	0.79 ^c	0.25	0.83 ^c	0.25
Model 2: Registry								
Cancer stage (versus stage I)								
0			-0.40 ^a	0.24	-0.51 ^b	0.25	-0.52 ^b	0.25
II			0.53 ^b	0.17	0.49 ^b	0.17	0.53 ^b	0.18
III			1.29 ^c	0.24	1.25 ^d	0.24	1.28 ^d	0.24

Parameter	Model 1 Results: Claims (C)		Model 2 Results: C plus Cancer Registry (CR)		Model 3 Results: C, CR plus Medical record/Health plan (MR)		Model 4 Results: C, CR, MR plus Patient-reported Risk Factor (RF)	
Model 1: Claims	Estimate	Standard Error	Estimate	Standard Error	Estimate	Standard Error	Estimate	Standard Error
Model 3: Electronic Medical Record								
Breast density (versus dense)								
Fatty					-0.67 <i>b</i>	0.21	-0.66 <i>b</i>	0.22
Unknown					-0.08 <i>a</i>	0.28	-0.05 <i>a</i>	0.29
Screening mammogram (versus no)								
Yes					0.99 <i>b</i>	0.44	0.94 <i>b</i>	0.44
Mammogram recommendation (versus biopsy)								
Follow-up					1.21 <i>b</i>	0.40	1.27 <i>b</i>	0.41
Normal/unknown					0.72 <i>a</i>	0.36	0.72 <i>a</i>	0.38
Model 4: Risk-factor								
Number of prior breast procedures (versus 0)								
1							0.27 <i>a</i>	0.22
2+							2.6 <i>d</i>	0.52
Unknown							0.12 <i>a</i>	0.27

a >0.05

b 0.05-0.0011

c 0.0010-0.0002

d <0.0001