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Inequities in access to mammographic screening in Brazil

Inequidades no acesso ao rastreamento por mamografia no Brasil

Inequidades en el acceso a las pruebas de cribado mamográfico en Brasil

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Abstract

Our objectives with this study were to describe the spatial distribution of mammographic screening coverage across small geographical areas (micro-regions) in Brazil, and to analyze whether the observed differences were associated with spatial inequities in socioeconomic conditions, provision of health care, and healthcare services utilization. We performed an area-based ecological study on mammographic screening coverage in the period of 2010-2011 regarding socioeconomic and healthcare variables. The units of analysis were the 438 health micro-regions in Brazil. Spatial regression models were used to study these relationships. There was marked variability in mammographic coverage across micro-regions (median = 21.6%; interquartile range: 8.1%-37.9%). Multivariable analyses identified high household income inequality, low number of radiologists/100,000 inhabitants, low number of mammography machines/10,000 inhabitants, and low number of mammograms performed by each machine as independent correlates of poor mammographic coverage at the micro-region level. There was evidence of strong spatial dependence of these associations, with changes in one micro-region affecting neighboring micro-regions, and also of geographical heterogeneities. There were substantial inequities in access to mammographic screening across micro-regions in Brazil, in 2010-2011, with coverage being higher in those with smaller wealth inequities and better access to health care.

Health Inequalities; Breast Neoplasm; Health Services Accessibility

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Introduction

Breast cancer is the most common female cancer worldwide, ranking second as a cause of death due to cancer [1]. Mammographic screening programs have been established in many high-income countries since the late 1980s, when results from randomized trials on their effectiveness were first published [2,3,4,5,6]. Although such programs provide the potential to reduce mortality from breast cancer, participation is crucial, with coverage above 70-75% being regarded as a requirement to achieve such [7,8].

Several individual-level factors have been shown to affect mammographic screening uptake, including a woman's demographic and socioeconomic characteristics and level of access to health care. Research has also shown that women who reside in socioeconomically deprived areas are less likely to comply with screening [9,10,11,12,13,14,15], even after controlling for individual-level factors [9,11,13]. The characteristics of a woman's area of residence may directly affect her access to screening (e.g., local availability of mammographic screening services), and indirectly through availability of social and material resources (e.g., local breast cancer awareness initiatives, transport networks etc.).

Breast cancer has been the most common female cancer in Brazil since the 1980s [12]. It is estimated that a total of 59,700 new cases will be diagnosed yearly in 2018-2019, corresponding to 56.33 cases per 100,000 women-years [16]. In all, 16,069 women died from breast cancer in Brazil in 2016, the latest year for which national mortality statistics are available (Departamento de Informática do SUS. http://www.datasus.gov.br). The first guidelines for breast cancer control, which include the recommendation of biannual mammographic screening for women aged 50-69 years, were published by the Brazilian Ministry of Health in 2004 [17]. National surveys, which include both women with and without private health insurance, showed that mammographic screening coverage has been increasing, with the percentage of women self-reporting a mammographic examination in the previous two years increasing from 54.2% in 2008 [18] to 60% in 2013 (Departamento de Informática do SUS. Pesquisa Nacional de Saúde – 2013 – módulo de cobertura de mamografia entre mulheres de 50 anos ou mais. http://tabnet.datasus.gov.br/cgi/deftohtm.exe?pns/pnskb.def, accessed on 02/Sep/2016).

However, these surveys demonstrated marked geographical differences in coverage, pointing to inequities in access to, and uptake of, screening mammography.

The objectives of our study are to describe the spatial distribution of mammographic screening coverage across small geographical areas (i.e., health micro-regions) in Brazil, and to analyze the hypothesis that geographical differences are associated with spatial inequities in socioeconomic conditions, provision of health care, and healthcare services utilization. Health micro-regions are key geographical units in healthcare implementation and provision in Brazil, since each is responsible for coordinating the planning and implementation of healthcare activities and services across several municipalities. Our findings will inform the development and implementation of locally-tailored policies aimed at tackling inequities between the health micro-regions in access to mammographic screening in Brazil.

Methods

Study design and units of analysis

An area-based ecological study was conducted in which the units of analysis were the 438 Brazilian health micro-regions (population sizes: ~21,000 to > 11 million). Their boundaries were established by the Brazilian Administrative Directive, in accordance with a 2011 federal law which defines a health micro-region as a group of neighboring municipalities with similar socioeconomic features and centralized planning and provision of healthcare services [19].

Outcome

The outcome of interest was mammographic screening coverage. Since the Brazilian Unified National Health System (SUS) does not collect information on either the number of women screened or the number of women eligible for screening in each year, we estimated, according to previous studies [20], the yearly average number of mammographies performed in 2010-2011 (N = 3,432,090) in SUS among women aged 50-69 years divided by half of the number of women living in the same health micro-region and of similar age, who depended uniquely on SUS (i.e., who did not have private health insurance) during the same period (Supplementary Table 1: http://cadernos.ensp.fiocruz.br/site/public_site/arquivo/suppl-e00099817_4234.pdf).

Exposures

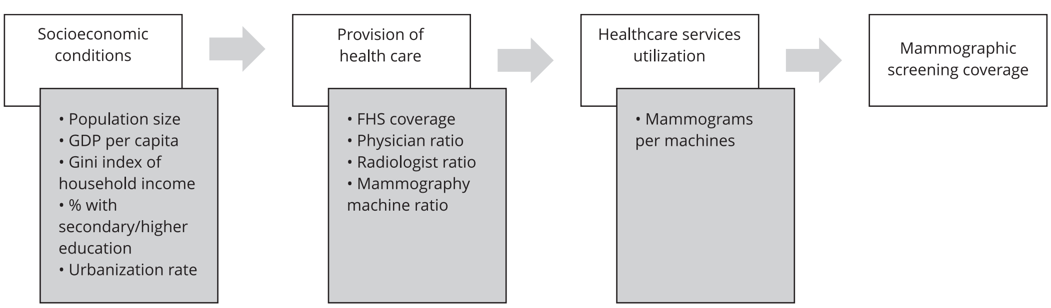
Explanatory variables of interest were grouped according to whether they were distal or proximal in the chain leading from socioeconomic conditions to mammography coverage, according to our substantive model depicted in Figure 1. To represent socioeconomic conditions (deemed as distal variables) specific to each unit of analysis, the following variables were analyzed: population size (log transformed), average Gross Domestic Product (GDP)/per capita (x 1,000 BRL), Gini index of per capita household income (in %, ranging from 0, if perfect equality, to 100, if maximal inequality), high education rate (i.e., percentage of the population with secondary or higher education), and urbanization rate (%). For the provision of health care – the intermediate variables – we considered: percentage of the population registered in the Family Health Strategy (FHS), number of physicians/1,000 inhabitants, number of radiologists/100,000 inhabitants, and number of available mammography machines/10,000 inhabitants. To describe healthcare services utilization, the most proximal dimension, we used number of yearly mammograms per mammography machine. All variables refer to the year 2010 and are available from the Brazilian Health Informatics Department system (DATASUS. http://www.datasus.gov.br) (Supplementary Table 1: http://cadernos.ensp.fiocruz.br/site/public_site/arquivo/suppl-e00099817_4234.pdf).

Confounders/effect modifiers

Geographical region, as defined by the Brazilian Institute of Geography and Statistics (IBGE) [21] – i.e., Southeast (deemed here as the reference category), South, Northeast, Central, and North –, was included in all analyses to control for factors that were associated with both the exposures and the average yearly number of mammographies, not considered by the selected exposures.

Figure 1

Conceptual model of area-based associations between socioeconomic conditions, provision of health care, and healthcare services utilization and mammographic screening coverage.



FHS: Family Health Strategy; GDP: Gross Domestic Product.

Statistical methods

After initial descriptive and exploratory spatial analyses, four types of regression models were fitted to explain variations in mammographic coverage: simple linear regression; multiple linear regression; multiple linear regression adjusted for spatial autocorrelation; and spatial regimes models, which were also adjusted for spatial autocorrelation [22]. Spatial regression models were necessary to control for spatial dependence, which emerges from the interaction of agents across micro-regions, and spatial heterogeneity, which occurs when neighboring micro-regions vary according to the effect of the exposure of interest (e.g., socioeconomic status) on the outcome (i.e., screening coverage) because of interactions with other (observable or not) ecological factors (e.g., political or geographical aspects). If these are disregarded, inferences are likely to be biased.

For each model, we followed the hierarchical step approach proposed by Victora et al. [23] when including additional explanatory variables, each step with inclusion of a group of exposures, from distal to proximal.

For each fitted regression model, predicted residuals were investigated to detect evidence of heteroscedasticity and/or spatial autocorrelation. Linear regression models were fitted using ordinary least squares (OLS) estimation, whereas spatial regression models were estimated using maximum likelihood (ML) estimation, which results in asymptotically normally distributed parameter estimates with large samples and regular spatial weight matrix [24]. The spatial auto-regressive (SAR) model, which includes a spatial lag of the dependent variable as an explanatory variable, in addition to all other explanatory variables, was found to fit the data better than the alternative regression models, according to the Lagrange multiplier test [25]. Nested models were compared using the Akaike information criterion (AIC), with smaller values indicating better fit.

Both components of the impact coefficient were estimated: direct, describing the effect on the micro-region itself, and indirect, concerning the effect on its neighboring micro-regions. The total impact corresponds to their sum [26].

Formal comparisons of the regimes and non-regimes spatial models were carried out using the spatial Chow test [27]; such test assesses the significance of regional dependences in the model coefficients.

Analyses were carried out using the geographical information system TerraView 4.2.2 (http://www.dpi.inpe.br/terraview/index.php), TabWin 3.2 (http://www2.datasus.gov.br/DATASUS/index.php?area=060805&item=3), R 3.2.2 (https://www.r-project.org/), and R Studio 0.99 (https://www.rstudio.com/).

Results

In Table 1 and Figure 2 we show the distributions of the exposure and outcome variables per health micro-region and geographical region in Brazil. There was marked variability in mammographic screening coverage across the 438 Brazilian micro-regions, in 2010-2011 (median = 21.6%; interquartile range (IQR): 8.1%-37.9%) (Table 1). This variability was present both within and between geographical regions, with micro-regions in the South region having, on average, a 6-fold higher mammographic coverage than those in the North region.

There was also wide variability in the exposure variables across micro-regions. Micro-regions in the North and Northeast had, on average, the lowest average population size, GDP per capita, rate of urbanization, and percentage of the population with secondary or higher educational level, but the largest inequities in household income as observed by the Gini index (Table 1). Micro-regions in the North and Northeast also had, on average, the highest FHS coverage, but the lowest numbers of physicians, radiologists, and mammographic machines per population. Notably, micro-regions in the South and Southeast had not only the highest numbers of mammography machines per population, but also the highest utilization levels (as perceived by the number of mammograms performed per machine). The average number of machines available in micro-regions in the Central region was similar to those in the South and Southeast, but the level of utilization was much lower (Table 1).

Predicted residuals from fitted multiple linear regression models that included geographical region showed significant spatial dependence. Hence, alternative spatial regression models were

Table 1

Distribution of mammographic screening coverage among women aged 50-69 years and of potential explanatory variables, per health micro-region in Brazil as a whole, and in each of its five geographical regions, 2010-2011.

Variable */Brazilian regions **	Number of health micro-regions	Variable distribution per health micro-regions						
		Mean	SD	Minimum value	Q1	Median	Q3	Maximum value
Outcome variable								
Mammography ratio (per 100 women, %), 2010-2011								
Brazil	438	24.15	17.96	0.05	8.06	21.58	37.87	84.15
Southeast	153	37.04	14.81	2.19	27.72	37.26	44.66	84.15
South	68	37.19	12.81	13.95	27.92	36.52	43.02	73.58
Northeast	133	13.40	10.70	0.05	5.94	12.15	17.48	51.55
Central	39	8.55	8.57	0.19	2.82	5.03	12.32	32.56
North	45	5.95	6.72	0.20	0.80	4.20	9.68	30.31
Socioeconomic conditions (distal variables)								
Population size (x 1,000), 2010								
Brazil	438	435.52	846.80	21.47	152.19	250.12	396.32	11253.50
Southeast	153	525.26	1272.24	44.27	128.29	236.19	393.43	11253.50
South	68	402.75	466.20	94.96	182.14	271.87	397.34	3223.84
Northeast	133	399.11	501.23	44.66	187.46	277.16	400.62	3908.76
Central	39	360.46	507.38	21.47	102.66	161.29	354.36	2570.16
North	45	352.54	421.38	41.34	137.53	214.88	377.47	2119.74
GDP per capita (x 1,000 BRL), 2010								
Brazil	438	14.62	9.48	3.15	6.73	13.04	19.17	59.22
Southeast	153	19.01	10.35	4.48	12.15	17.76	23.43	59.22
South	68	20.08	6.55	10.04	15.53	18.84	22.89	43.10
Northeast	133	7.14	4.19	3.15	4.77	5.80	8.08	39.49
Central	39	18.01	8.81	7.08	12.99	15.59	21.86	58.33
North	45	10.61	5.40	3.18	6.07	10.39	12.45	30.83
Gini index of per capita household income (%), 2010								
Brazil	438	50.92	5.11	38.00	48.00	51.00	54.00	71.00
Southeast	153	47.85	3.47	40.00	45.00	48.00	50.00	65.00
South	68	47.00	4.00	38.00	44.00	47.50	50.00	54.00
Northeast	133	53.68	2.92	48.00	51.00	54.00	56.00	63.00
Central	39	51.69	3.77	46.00	49.00	51.00	54.00	64.00
North	45	58.40	4.28	50.00	55.00	58.00	61.00	71.00
Population with secondary or higher education (%), 2010								
Brazil	438	46.11	10.22	20.54	36.91	46.69	53.74	70.75
Southeast	153	51.11	8.94	26.63	46.57	52.90	57.87	66.90
South	68	51.38	6.10	39.79	47.66	50.08	54.66	67.74
Northeast	133	37.91	8.28	26.35	32.43	35.70	40.54	70.15
Central	39	48.76	6.96	38.30	43.80	46.88	52.13	70.75
North	45	43.08	10.41	20.54	36.11	40.35	48.84	65.79

(continues)

Table 1 (continued)

Variable */Brazilian regions **	Number of health micro-regions	Variable distribution per health micro-regions						
		Mean	SD	Minimum value	Q1	Median	Q3	Maximum value
Socioeconomic conditions (distal variables)								
Urbanization rate (%), 2010								
Brazil	438	75.16	15.43	40.00	63.00	77.00	89.00	100.00
Southeast	153	84.86	12.30	42.00	80.00	89.00	94.00	100.00
South	68	78.68	10.94	55.00	70.50	80.00	85.25	99.00
Northeast	133	63.47	13.18	40.00	54.00	62.00	70.00	100.00
Central	39	79.87	10.91	58.00	69.00	81.00	89.50	98.00
North	45	67.31	13.95	43.00	57.00	65.00	77.00	98.00
Provision of health care (intermediate variables)								
FHS coverage (%)								
Brazil	438	78.42	22.65	13.01	64.92	86.50	98.11	100.00
Southeast	153	66.89	25.23	13.01	47.02	68.06	90.33	100.00
South	68	69.14	22.52	20.70	57.06	71.06	84.93	100.00
Northeast	133	94.53	9.62	40.63	92.76	98.13	100.00	100.00
Central	39	80.66	17.12	27.69	71.97	85.84	93.33	100.00
North	45	82.10	14.02	43.20	75.13	83.80	91.80	100.00
Physician ratio (per 1,000), 2010								
Brazil	438	1.00	0.62	0.12	0.54	0.85	1.31	3.64
Southeast	153	1.35	0.63	0.30	0.93	1.24	1.64	3.64
South	68	1.27	0.54	0.63	0.87	1.14	1.44	2.99
Northeast	133	0.64	0.40	0.26	0.42	0.53	0.68	2.69
Central	39	0.92	0.54	0.42	0.58	0.85	0.96	2.73
North	45	0.59	0.38	0.12	0.33	0.47	0.72	1.47
Radiologist ratio (per 100,000), 2010								
Brazil	438	2.93	2.59	0.00	1.00	2.00	4.00	20.00
Southeast	153	3.94	2.92	0.00	2.00	3.00	5.00	20.00
South	68	3.91	2.28	1.00	2.00	3.50	5.00	10.00
Northeast	133	1.79	1.85	0.00	1.00	1.00	2.00	11.00
Central	39	2.87	2.48	0.00	1.00	2.00	4.00	11.00
North	45	1.38	1.51	0.00	0.00	1.00	2.00	5.00
Mammography machines ratio (per 10,000), 2010								
Brazil	438	1.19	0.86	0.00	0.63	1.14	1.66	7.70
Southeast	153	1.44	0.78	0.00	0.89	1.43	1.86	3.87
South	68	1.38	0.59	0.39	0.89	1.32	1.76	3.29
Northeast	133	0.84	0.70	0.00	0.43	0.71	1.18	3.31
Central	39	1.31	0.96	0.00	0.66	1.38	1.95	3.67
North	45	0.95	1.31	0.00	0.00	0.73	1.36	7.70
Healthcare services utilization (proximal variable)								
Mammographic examinations per machine (x 100), 2010								
Brazil	438	7.14	6.86	0.00	1.43	6.03	10.30	52.06
Southeast	153	9.66	6.58	0.00	5.38	8.21	12.48	30.39
South	68	11.94	6.42	3.80	7.89	9.75	13.79	34.33
Northeast	133	5.02	6.28	0.00	0.14	3.87	7.78	52.06
Central	39	2.24	2.66	0.00	0.11	1.59	3.67	10.52
North	45	1.82	3.06	0.00	0.00	0.22	2.41	12.42

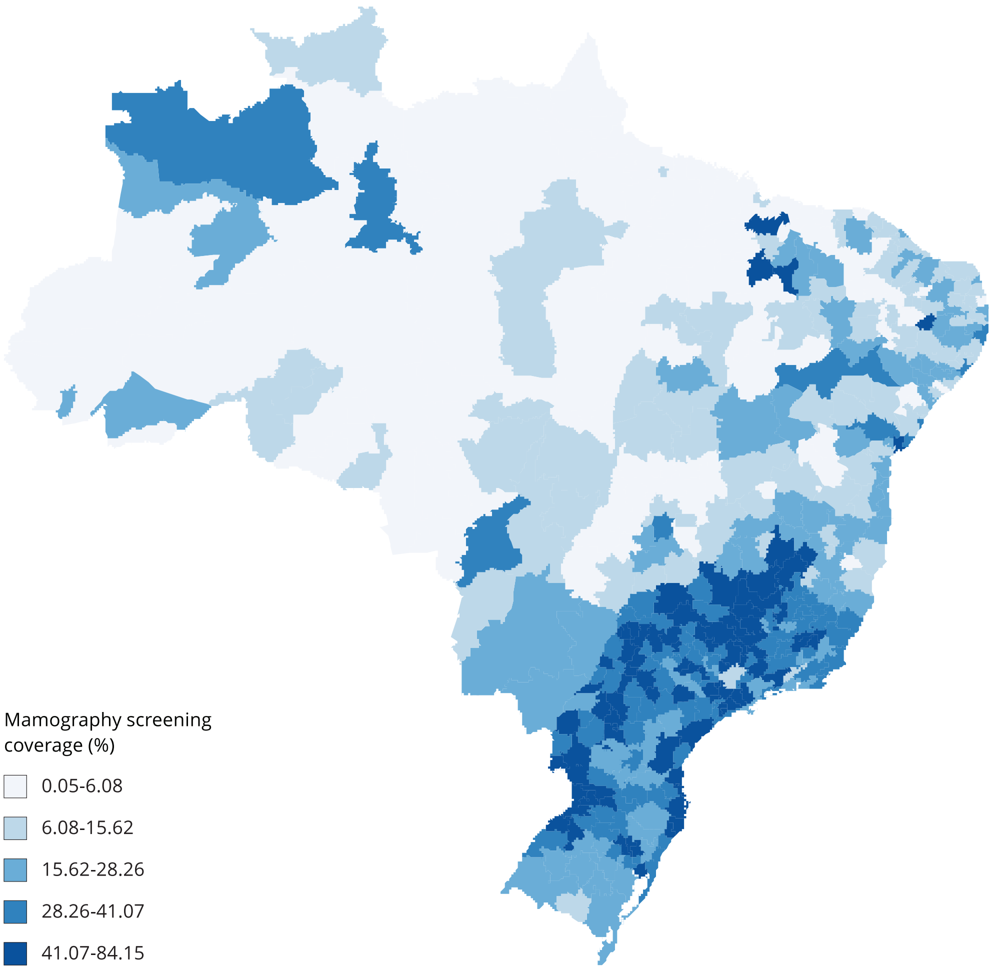
FHS: Family Health Strategy; GDP: Gross Domestic Product; Q1: 25% percentiles of the distribution; Q3: 25% and 75% percentiles of the distribution; SD: standard deviation.

* See Supplementary Table 1 (http://cadernos.ensp.fiocruz.br/site/public_site/arquivo/suppl-e00099817_4234.pdf) for definition of each variable and its data sources;

** Geographical regions listed in descending order of their average population size.

Figure 2

Distribution of mammographic screening coverage among women aged 50-69 years in 2010-2011 by health micro-region (n = 438), Brazil.



considered. The results from fitting the best spatial model, SAR, are presented in Table 2. The first step involved jointly modelling all distal explanatory variables (i.e., socioeconomic indicators) as well as geographical regions. Because of collinearities with other variables, high education rate was not kept in the model. Both population size (direct impact = 1.985; indirect impact = 1.251) and degree of urbanization (direct impact = 0.158; indirect impact = 0.099) were positively associated with mammography coverage, whereas the Gini index (direct impact = -0.648; indirect impact = -0.408) was inversely associated with mammographic coverage, with the magnitude of direct impacts being higher than the magnitude of the indirect ones (via neighboring micro-regions). These impacts mean that, for example, a 1% increase in the Gini index was associated with a 0.6% decrease in mammographic coverage in a given micro-region, and a 0.4% decrease in its neighboring micro-regions, maintaining the other socioeconomic indicators constant. On the other hand, a 1% increase in the urbanization rate was associated with a 0.2% increase in coverage in a given micro-region, as well as a 0.1% increase in its neighboring micro-regions, again maintaining the other variables constant. There were also significant estimated differences in mammographic coverage between geographical

Table 2

Correlates of mammographic screening coverage (%) at the health micro-region level. Brazil, 2010-2011.

Variables *	**Step 1 Impacts (p-value)**			**Step 2 Impacts (p-value)**			**Step 3 Impacts (p-value)**		
	Direct	**Indirect**	**Total**	**Direct**	**Indirect**	**Total**	**Direct**	**Indirect**	**Total**
Regions **									
Southeast	Ref.	Ref.	Ref.	Ref.	Ref.	Ref.	Ref.	Ref.	Ref.
South	0.263	0.166	0.429	-0.103	-0.065	-0.167	-2.006	-0.859	-2.865
	(0.859)	(0.863)	(0.860)	(0.850)	(0.859)	(0.853)	(0.100)	(0.142)	(0.108)
Northeast	**-6.732**	**-4.241**	**-10.972**	**-6.793**	**-4.274**	**-11.067**	-2.676	-1.145	-3.820
	(0.001)	**(0.001)**	**(< 0.001)**	**(< 0.001)**	**(< 0.001)**	**(< 0.001)**	(0.078)	(0.089)	(0.075)
Central	**-14.693**	**-9.257**	**-23.951**	**-14.811**	**-9.319**	**-24.130**	**-9.846**	**-4.214**	**-14.060**
	(< 0.001)	**(< 0.001)**	**(< 0.001)**	**(< 0.001)**	**(< 0.001)**	**(< 0.001)**	**(< 0.001)**	**(< 0.001)**	**(< 0.001)**
North	**-8.500**	**-5.355**	**-13.856**	**-7.831**	**-4.927**	**-12.758**	-2.641	-1.131	-3.772
	(0.001)	**(0.002)**	**(0.001)**	**(0.001)**	**(0.001)**	**(0.000)**	(0.237)	(0.261)	(0.237)
Population (x 1,000, log)	**1.985**	**1.251**	**3.236**	**1.668**	**1.050**	**2.718**	-0.278	-0.119	-0.396
	(0.005)	**(0.016)**	**(0.006)**	**(0.039)**	**(0.058)**	**(0.042)**	(0.734)	(0.738)	(0.734)
GDP per capita (x 1,000 BRL)	0.102	0.064	0.166	0.101	0.064	0.165	0.112	0.048	0.160
	(0.106)	(0.115)	(0.106)	(0.144)	(0.150)	(0.142)	(0.152)	(0.188)	(0.156)
Gini index (%)	**-0.648**	**-0.408**	**-1.056**	**-0.600**	**-0.378**	**-0.978**	**-0.562**	**-0.241**	**-0.803**
	(< 0.001)	**(0.002)**	**(0.000)**	**(0.000)**	**(0.000)**	**(0.000)**	**(< 0.001)**	**(< 0.001)**	**(< 0.001)**
Urbanization rate (%)	**0.158**	**0.099**	**0.257**	0.074	0.046	0.120	0.037	0.016	0.052
	(0.002)	**(0.009)**	**(0.002)**	(0.363)	(0.382)	(0.368)	(0.421)	(0.457)	(0.429)
FHS coverage (%)				0.049	0.031	0.080	-0.004	-0.002	-0.006
				(0.120)	(0.126)	(0.117)	(0.805)	(0.815)	(0.807)
Radiologists ratio per 100,000 inhabitants				**0.870**	**0.548**	**1.418**	**0.919**	**0.393**	**1.312**
				(0.001)	**(0.011)**	**(0.002)**	**(< 0.001)**	**(0.001)**	**(< 0.001)**
Mammography machines ratio per 10,000 inhabitants				**2.451**	**1.542**	**3.993**	**3.715**	**1.590**	**5.305**
				(< 0.001)	**(0.001)**	**(< 0.001)**	**(< 0.001)**	**(< 0.001)**	**(< 0.001)**
Mammograms per mammography machine (x 100)							**0.948**	**0.406**	**1.353**
							(< 0.001)	**(< 0.001)**	**(< 0.001)**
Model diagnostics									
AIC	3302.700			3278.900			3140.200		
Breusch-Pagan test heterocedasticity	0.106			0.167			0.290		
Test for residual autocorrelation	0.396			0.460			0.072		

AIC: Akaike information criterion; FHS: Family Health Strategy; GDP: Gross Domestic Product; Ref.: reference.

* See Supplementary Table 1 (http://cadernos.ensp.fiocruz.br/site/public_site/arquivo/suppl-e00099817_4234.pdf) for definition of each variable and its data sources;

** Regions listed in descending order of their average population size.

regions, despite having controlled for the other distal explanatory variables. Relative to micro-regions in the Southeast, mammographic coverage was, on average, 24% lower in those in the Central, 13.9% lower in those in the North, and 11% lower in those in the Northeast.

The second step involved jointly modelling distal and intermediate (i.e., provision of health care) variables. Because of collinearity, physician ratio was not included in these analyses. Population size remained with its positive association, and the Gini index, its negative association, with mammographic coverage, whereas urbanization rate was no longer associated with the outcome. Among the variables of provision of healthcare services, only number of radiologists and number of machines per population were positively associated with the outcome, with their direct impacts being higher than their indirect ones. Micro-regions in the Central, North, and Northeast had, as in step 1, lower average mammography coverage than those in the Southeast, with little changes in the magnitude of the estimates (Table 2).

Finally, a positive association was found between mammographic coverage and healthcare services utilization – as observed by the number of mammograms per machine – when this variable was jointly modelled with the distal and provision of healthcare services variables (step 3) (Table 2). Both the number of radiologists and the number of mammographic machines per population remained positively associated with the outcome in such model. However, the Gini index was the only distal variable that remained associated (inversely) with mammographic coverage, although with a slightly smaller estimated impact than in step 2. In this more comprehensive model, only micro-regions in the Central region had significantly lower mammographic coverage than those in the Southeast (reference).

Results of the spatial regime analysis, in which the SAR model was expanded to allow for region-specific coefficients, i.e., interactions with the region, are shown in Table 3. As before, the three-step hierarchical approach was implemented. There was evidence of heterogeneity of results across regions, which was corroborated by the spatial Chow test, between the models fitted at each step, and its equivalent model of spatial regimes. In the wealthiest regions, namely South and Southeast, accounting for intermediate and proximal variables, mammographic coverage was associated with only a few specific socioeconomic indicators (i.e., inversely with the Gini index in both regions and positively with population size only in the South), but (positively) associated with all provision of health care and healthcare services utilization indicators (with the exception of FHS coverage) (Table 3). In the Central and North regions, coverage was (positively) associated only with provision of health care indicators (i.e., number of radiologists/population in Central; number of mammography machines/population in the North) and the healthcare services utilization variable (Table 3). Finally, in the Northeast, the healthcare services utilization variable (mammograms/machine) was the only variable found to be associated (positively) with the outcome (Table 3).

Table 3

Correlates of mammographic screening coverage at the health micro-region level, stratified by geographical region *.

Regions/Variables	**Step 1**			**Step 2**			**Step 3**		
	Impacts (p-value)			**Impacts (p-value)**			**Impacts (p-value)**		
	Direct	**Indirect**	**Total**	**Direct**	**Indirect**	**Total**	**Direct**	**Indirect**	**Total**
Souheast									
Population (x 1,000, log)	0.848	0.450	1.298	0.878	0.444	1.323	-1.566	-0.489	-2.055
	(0.395)	(0.408)	(0.394)	(0.562)	(0.569)	(0.561)	(0.114)	(0.154)	(0.115)
GDP per capita (x 1,000 BRL)	0.146	0.077	0.224	0.153	0.077	0.231	0.144	0.045	0.189
	(0.229)	(0.296)	(0.247)	(0.137)	(0.191)	(0.147)	(0.129)	(0.162)	(0.127)
Gini index (%)	**-1.416**	**-0.751**	**-2.168**	**-1.373**	**-0.695**	**-2.067**	**-0.914**	**-0.285**	**-1.199**
	(< 0.001)	**(< 0.001)**	**(< 0.001)**	**(< 0.001)**	**(0.001)**	**(< 0.001)**	**(< 0.001)**	**(0.003)**	**(< 0.001)**
Urbanization rate (%)	-0.052	0.071	0.205	0.030	0.015	0.045	0.030	0.009	0.039
	(0.230)	(0.250)	(0.230)	(0.614)	(0.675)	(0.632)	(0.919)	(0.924)	(0.919)
FHS coverage (%)				0.008	0.004	0.013	**-0.061**	-0.019	-0.080
				(0.906)	(0.900)	(0.903)	**(0.048)**	(0.083)	(0.050)
Radiologists ratio per 100,000 inhabitants				0.598	0.303	0.901	**0.692**	**0.216**	**0.908**
				(0.063)	(0.089)	(0.064)	**(0.014)**	**(0.049)**	**(0.015)**
Mammography machines ratio per 10,000 inhabitants				**2.300**	**1.432**	**4.262**	**5.510**	**1.719**	**7.229**
				(0.008)	**(0.031)**	**(0.011)**	**(< 0.001)**	**(0.001)**	**(< 0.001)**
Mammograms per mammography machine (x 100)							**0.965**	**0.301**	**1.266**
							(< 0.001)	**(0.001)**	**(< 0.001)**

(continues)

Table 3 (continued)

Regions/Variables	Step 1 Impacts (p-value)			Step 2 Impacts (p-value)			Step 3 Impacts (p-value)		
	Direct	Indirect	Total	Direct	Indirect	Total	Direct	Indirect	Total
South									
Population (x 1,000, log)	**9.210**	**4.885**	**14.095**	**7.710**	**3.902**	**11.613**	**5.946**	**1.856**	**7.802**
	(0.000)	**(0.011)**	**(0.000)**	**(0.004)**	**(0.027)**	**(0.006)**	**(< 0.001)**	**(0.012)**	**(< 0.001)**
GDP per capita (x 1,000 BRL)	-0.018	-0.010	-0.027	0.025	0.013	0.038	0.101	0.031	0.132
	(0.975)	(0.966)	(0.972)	(0.991)	(1.000)	(0.994)	(0.698)	(0.726)	(0.703)
Gini index (%)	**-1.275**	**-0.676**	**-1.951**	**-0.872**	**-0.441**	**-1.313**	**-0.899**	**-0.280**	**-1.179**
	(0.000)	**(0.006)**	**(0.000)**	**(0.011)**	**(0.028)**	**(0.012)**	**(0.002)**	**(0.008)**	**(0.001)**
Urbanization rate (%)	-0.223	-0.118	-0.341	-0.058	-0.029	-0.088	-0.114	-0.035	-0.149
	(0.158)	(0.216)	(0.169)	(0.737)	(0.734)	(0.734)	(0.417)	(0.442)	(0.418)
FHS coverage (%)				**0.203**	**0.103**	**0.306**	0.072	0.022	0.094
				(0.002)	**(0.012)**	**(0.002)**	(0.167)	(0.220)	(0.173)
Radiologists ratio per 100,000 inhabitants				1.259	0.637	1.896	**1.127**	0.352	**1.478**
				(0.072)	(0.117)	(0.080)	**(0.037)**	(0.101)	**(0.043)**
Mammography machines ratio per 10,000 inhabitants				3.871	1.959	5.830	**13.215**	**4.124**	**17.339**
				(0.071)	(0.115)	(0.078)	**(< 0.001)**	**(0.001)**	**(< 0.001)**
Mammograms per mammography machine (x 100)							**1.311**	**0.409**	**1.720**
							(< 0.001)	**(0.002)**	**(< 0.001)**
Northeast									
Population (x 1,000, log)	**3.572**	**1.895**	**5.467**	**2.744**	1.389	**4.133**	0.332	0.104	0.436
	(0.012)	**(0.027)**	**(0.013)**	**(0.049)**	(0.059)	**(0.047)**	(0.741)	(0.740)	(0.739)
GDP per capita (x 1,000 BRL)	0.345	0.183	0.528	0.265	0.134	0.097	0.032	0.010	0.042
	(0.156)	(0.207)	(0.167)	(0.272)	(0.301)	(0.276)	(0.956)	(0.958)	(0.956)
Gini index (%)	0.154	0.082	0.236	0.106	0.054	0.160	0.079	0.025	0.103
	(0.557)	(0.599)	(0.569)	(0.586)	(0.604)	(0.588)	(0.885)	(0.891)	(0.886)
Urbanization rate (%)	0.096	0.051	0.148	0.020	0.010	0.030	0.094	0.029	0.123
	(0.299)	(0.307)	(0.295)	(0.762)	(0.776)	(0.765)	(0.347)	(0.379)	(0.350)
FHS coverage (%)				-0.078	-0.040	-0.118	-0.069	-0.022	-0.091
				(0.570)	(0.555)	(0.562)	(0.476)	(0.489)	(0.476)
Radiologists ratio per 100,000 inhabitants				0.514	0.260	0.774	0.757	0.236	0.994
				(0.490)	(0.519)	(0.496)	(0.191)	(0.228)	(0.193)
Mammography machines ratio per 10,000 inhabitants				1.547	0.783	2.330	0.951	0.297	1.248
				(0.192)	(0.202)	(0.188)	(0.336)	(0.382)	(0.340)
Mammograms per mammography machine (x 100)							**1.036**	**0.323**	**1.360**
							(0.000)	**(0.001)**	**(0.000)**
Central									
Population (x 1,000, log)	**4.946**	2.623	7.569	1.574	0.797	2.371	0.575	0.180	0.755
	(0.049)	(0.103)	(0.059)	(0.644)	(0.676)	(0.652)	(0.712)	(0.726)	(0.714)
GDP per capita (x 1,000 BRL)	-0.008	-0.004	-0.012	-0.218	-0.110	-0.328	-0.277	-0.087	-0.364
	(0.852)	(0.877)	(0.859)	(0.284)	(0.314)	(0.288)	(0.231)	(0.265)	(0.233)
Gini index (%)	-0.036	-0.019	-0.056	-0.110	-0.056	-0.166	-0.123	-0.038	-0.161
	(0.895)	(0.884)	(0.891)	(0.852)	(0.855)	(0.852)	(0.647)	(0.661)	(0.648)
Urbanization rate (%)	-0.052	-0.028	-0.079	0.024	0.012	0.035	-0.122	-0.038	-0.160
	(0.883)	(0.876)	(0.880)	(0.869)	(0.865)	(0.867)	(0.536)	(0.541)	(0.534)
FHS coverage (%)				0.107	0.054	0.161	0.050	0.015	0.062
				(0.425)	(0.441)	(0.427)	(0.690)	(0.672)	(0.683)
Radiologists ratio per 100,000 inhabitants				**2.767**	**1.400**	**4.167**	**2.293**	0.716	**3.008**
				(0.003)	**(0.020)**	**(0.004)**	**(0.018)**	(0.074)	(0.024)
Mammography machines ratio per 10,000 inhabitants				0.624	0.316	0.940	0.968	0.302	1.270
				(0.810)	(0.797)	(0.805)	(0.434)	(0.434)	(0.430)
Mammograms per mammography machine (x 100)							**1.848**	**0.577**	**2.425**
							(0.009)	**(0.033)**	**(0.009)**

(continues)

Table 3 (continued)

Regions/Variables	Step 1 Impacts (p-value)			Step 2 Impacts (p-value)			Step 3 Impacts (p-value)		
	Direct	Indirect	Total	Direct	Indirect	Total	Direct	Indirect	Total
North									
Population (x 1,000, log)	1.912	1.014	2.926	1.122	0.568	1.690	-0.320	-0.100	-0.420
	(0.394)	(0.413)	(0.396)	(0.584)	(0.635)	(0.599)	(0.803)	(0.808)	(0.803)
GDP per capita (x 1,000 BRL)	0.153	0.081	0.234	0.065	0.033	0.097	0.052	0.016	0.068
	(0.629)	(0.654)	(0.635)	(0.791)	(0.785)	(0.788)	(0.883)	(0.900)	(0.886)
Gini index (%)	-0.063	-0.034	-0.097	0.012	0.006	0.018	-0.124	-0.039	-0.162
	(0.942)	(0.982)	(0.956)	(0.997)	(0.966)	(0.987)	(0.810)	(0.835)	(0.815)
Urbanization rate (%)	0.246	0.130	0.376	0.152	0.077	0.230	0.036	0.011	0.047
	(0.075)	(0.108)	(0.080)	(0.383)	(0.411)	(0.390)	(0.742)	(0.756)	(0.743)
FHS coverage (%)				-0.021	-0.011	-0.032	-0.069	-0.021	-0.090
				(0.938)	(0.903)	(0.925)	(0.474)	(0.526)	(0.482)
Radiologists ratio per 100,000 inhabitants				0.777	0.393	1.170	0.672	0.210	0.881
				(0.641)	(0.648)	(0.641)	(0.671)	(0.665)	(0.667)
Mammography machines ratio per 10,000 inhabitants				1.663	0.842	2.505	**2.089**	0.652	**2.741**
				(0.135)	(0.171)	(0.140)	**(0.037)**	(0.091)	**(0.040)**
Mammograms per mammography machine (x 100)							**1.148**	**0.358**	**1.507**
							(0.014)	**(0.041)**	**(0.014)**

FHS: Family Health Strategy; GDP: Gross Domestic Product.

* The spatial Chow test was significant (p < 0.001) for each of the models fitted according to the three steps, indicating evidence for regional dependence in the model's coefficients.

Discussion

In 2010-2011, mammographic coverage among women aged 50-69 years for the majority of the 438 health micro-regions of Brazil was much lower (median = 21.6%; IQR: 8.1%-37.9%) than the 70%-75% coverage recommended by the World Health Organization (WHO) [7] and the European guidelines [8]. There were, however, marked inequities concerning coverage ranging from < 1% to 84% among health micro-regions of the country, highlighting large geographical inequities in the access to, and uptake of, this public health intervention. Higher coverage was observed in the more socioeconomic developed micro-regions, which were also the ones with smaller wealth inequalities. Area-based associations between socioeconomic variables and mammographic coverage were, as expected, greatly mediated by the more proximal provision of health care and healthcare services utilization variables; but, notably, the association with the Gini index persisted even after adjustment for the latter variables, strongly emphasizing the role of wealth inequalities. The findings also provided strong evidence of spatial correlations, with exposures directly affecting mammographic coverage in a micro-region as well as indirectly through their influence on neighboring micro-regions.

Extensions of the spatial regime model to include region-specific effects showed that correlates of mammographic coverage varied according to the region to which a micro-region belonged. In the South and Southeast, the two most developed regions, household income inequality (as observed by the Gini index), as well as all the provision of health care and healthcare utilization variables, were found to be independent correlates of mammography coverage. In the North and Northeast, the two less developed regions, the only variables found to be independently associated with coverage were the number of radiologists/population and the number of mammograms/machine, indicating that low human resources and poor availability of equipment may be more critical than wealth inequalities.

Our findings are consistent with those from previous studies. In an ecological study using data from a telephone-based survey conducted among adults living in the capitals of the 26 Brazilian states, a positive correlation was observed between the human development index, an area-based marker of socioeconomic development, and self-reported mammographic examination among women aged

50-69 years (correlation coefficient [r] = 0.66 for having had a mammographic examination in the two years prior to the survey) [28]. In individual-based studies, mammographic coverage was found in one city in the Northeast to be higher among better educated women and those with private health insurance [29] and, in another study in the South region, among those living in urban areas [30].

Data from the 2003 and 2008 Brazilian national household surveys showed that self-reported mammographic screening among women aged 50-69 years increased between surveys (from 54.6% to 71.5%), and was positively associated with family income, education, being married, having consulted a doctor, and having private health insurance [31]. Similarly, data from the 2013 national household survey demonstrated that self-reported mammographic screening in the previous two years was higher among women living in the South and Southeast and those of white ethnicity, better educated, and with private health insurance [32]. The low coverage of mammographic screening in Brazil reflects, at least in part, its opportunistic implementation.

Socioeconomic indicators – the most distal variables in the evaluated models – were, with the exception of GDP per capita, associated with mammographic coverage. Coverage was massive in the largest urban centers, which were also the least socially unequal. A study based on data for the 161 IBGE intermediate regions of urban articulation in Brazil, for the years 2008-2015, also showed smaller mammographic screening coverage to be associated with being located in the North and Northeast regions, lower Human Development Index (HDI) and higher Gini coefficient [33]. Countries with higher HDI have a higher percentage of breast cancer cases diagnosed in stage I, which is an indicator that they were probably detected by mammographic screening [34]. Authors of a systematic review on the association between area-based socioeconomic indicators and coverage of cancer screening found a great heterogeneity of methods and used indicators and outcomes [35]. For breast cancer, this review found predominantly positive area-based associations between socioeconomic indicators and screening coverage, but with these being attenuated according to adjustment for individual-level covariates, suggesting that the area-based associations may operate, at least in part, through individual-level factors; further studies, with appropriate conceptual models, are needed to clarify this information.

Estimates of mammographic coverage from previous studies tended to be higher than those reported here. There may be several reasons for this difference. First, we aimed to provide coverage estimates for micro-regions, not a national estimate. The latter would require calculation of a weighted mean of the micro-region estimates considering as weights the number of SUS-dependent women aged 50-69 years in each micro-region. Second, we excluded users of private healthcare services, whereas previous research included them. Third, in contrast to our study, which was based on SUS records, previous ones relied on self-reports of past screening experiences, which are likely to be prone to recall errors and even bias. Finally, some studies refer to a more recent period and it is conceivable that coverage might have increased since 2010-2011.

The regression models used in our study considered spatial dependence. The magnitude of indirect impacts of the exposure variables was lower, as expected, than the magnitude of their direct impacts. Nevertheless, modest indirect impacts were observed for most exposures, consistent with interactions between neighboring micro-regions, possibly reflecting transfers of knowledge, behaviors, and people across borders, but also the fact that the socioeconomic level, and the healthcare system, of a micro-region was likely to have influenced its neighboring micro-regions.

Our study has several strengths. The SUS mammographic data we collected were population-based and thus representative of all women resident in each health micro-region who relied exclusively on SUS, the public health system. SUS data are likely to be complete, since payment to providers depends on them submitting the necessary information. The quality of the exposure data is high, as demonstrated in previous ecological studies [36,37]. Our study has also some limitations. Its ecological design allowed identification of area-level correlations, but not causality. The quality of the SUS mammographic data might have been compromised by several factors. In particular, the SUS database contains information on the number of examinations performed rather than the number of women screened, and hence our estimates of coverage might have been inflated if some women were screened more than once over the 2-year period. A study conducted in the micro-region of Juiz de Fora, in the Southeast region, showed that the time interval between a normal mammogram undertook in 2010 and a subsequent one was < 18 months for 20% SUS women [38]. Finally, information on whether mammography was performed as a screening or diagnostic test was unreliable, and hence all examinations recorded in the SUS database were included in the analyses; however, diagnostic mammograms are likely to have constituted a small fraction of the total mammograms performed in any micro-region except, perhaps, in the few with cancer reference hospitals where a high volume of diagnostic mammograms was performed. We could not directly estimate mammographic coverage and, thus, a proxy variable was used as detailed in the Methods section.

Nevertheless, the study contributes to the emerging literature, showing that women who live in more socioeconomic disadvantaged areas are less likely to access breast cancer screening. Inequities in access to mammographic screening have also been found in high-income countries [10,11,12,13,14,15,39], including in those with free universal health care [10,12,14,15,37]. A decline in breast cancer mortality, which began in the 1990s (i.e., prior to the introduction of the screening program) has been observed in the capitals of the South and Southeast regions of Brazil, the most developed in the country [36], perhaps reflecting better access of symptomatic cases to early detection and treatment (i.e., downward stage migration) in these capitals, and also greater access of asymptomatic women to screening in the private health sector and, more recently, in the public sector as well.

The marked inequities in the access to, and uptake of, mammography throughout Brazil indicate an unequal distribution of barriers limiting access to screening. Tackling these inequalities will be crucial to ensure that mammographic screening will lead to reductions in breast cancer mortality. Further investigations are required to identify and develop locally-appropriate and culturally-sensitive interventions to improve access to, and uptake of, mammographic screening by, for instance, improving screening services and by encouraging women's participation through information and invitation strategies. An important first step towards the development of such appropriate interventions would be the conduct of in-depth studies on barriers to mammographic screening uptake across multiple health micro-regions. Such studies will provide the necessary evidence on woman-level and health system-level barriers to screening uptake, and the extent to which they vary across micro-regions, and will shed light on why some micro-regions have been able to achieve better screening coverage than others.

Contributors

M. C. Nogueira contributed to the study design, analysis and interpretation of data, writing the article and final approval of the version to be published. V. A. Fayer, C. S. L. Corrêa, M. R. Guerra, B. De Stavola, I. dos-Santos-Silva, M. T. Bustamante-Teixeira and G. Azevedo e Silva contributed to the study design, analysis and interpretation of data, relevant critical review of intellectual content and final approval of the version to be published. All authors declare being responsible for all aspects of the study in ensuring the accuracy and integrity of any part of the article.

Additional informations

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Resumo

O estudo teve como objetivos descrever a distribuição espacial do rastreamento por mamografia entre áreas geográficas pequenas (microrregiões) no Brasil, além de investigar se as diferenças observadas estavam associadas a inequidades espaciais nas condições socioeconômicas, na prestação de assistência à saúde e no uso de serviços de saúde. Este foi um estudo ecológico de base territorial, comparando a cobertura do rastreamento por mamografia em 2010-2011 com fatores socioeconômicos e de cuidados de saúde. O estudo usou 438 microrregiões sanitárias brasileiras como as unidades analíticas. Foram utilizados modelos de regressão espacial para estudar as associações. Houve uma importante variabilidade na cobertura por mamografia entre microrregiões (mediana = 21,6%; variação interquartil: 8,1%-37,9%). A análise multivariada identificou: forte desigualdade na renda familiar, número baixo de radiologistas/100 mil habitantes, número baixo de aparelhos de mamografia/10 mil habitantes e número baixo de mamografias realizadas com cada aparelho enquanto correlatos independentes da baixa cobertura mamográfica no nível microrregional. Houve evidência de forte dependência espacial nessas associações, em que as mudanças em uma microrregião afetavam as microrregiões vizinhas, além de heterogeneidade geográfica. O estudo revelou importantes inequidades no acesso ao exame de mamografia entre microrregiões brasileiras em 2010-2011, com cobertura mais alta nas microrregiões com menor desigualdade de renda e melhor acesso geral aos cuidados de saúde.

Iniquidade em Saúde; Neoplasias da Mama; Acesso aos Serviços de Saúde

Resumen

Los objetivos de este estudio fueron describir la distribución espacial de la cobertura del cribado mamográfico, a través de pequeñas áreas geográficas (microrregiones) en Brasil, y examinar si las diferencias observadas estuvieron asociadas con inequidades espaciales, en términos de condiciones socioeconómicas, sistema de atención de salud, y utilización de servicios de salud. Se trata de un estudio ecológico, basado en áreas incluidas en la cobertura de cribado mamográfico durante 2010-2011 y relacionadas con variables socioeconómicas y de salud. Las unidades de análisis fueron 438 microrregiones de salud en Brasil. Se utilizaron modelos de regresión espacial para estudiar estas relaciones existentes. Hubo una variabilidad marcada en relación con la cobertura mamográfica a través de las microrregiones (media = 21.6%; rango intercuartílico: 8,1%-37,9%). Los análisis multivariables identificaron una alta inequidad en los ingresos por hogar, bajo número de radiólogos/100,000 habitantes, bajo número de máquinas de mamografía/10.000 habitantes, y un bajo número de mamografías realizadas por cada máquina, lo que está independiente correlacionado con la baja cobertura de mamografías en el nivel de microrregión. Hubo evidencias de una dependencia espacial fuerte de estas asociaciones, con cambios en una microrregión afectando a microrregiones vecinas, y también de heterogeneidades geográficas. Hubo inequidades sustanciales en el acceso al cribado mamográfico a través de las microrregiones en Brasil, en 2010-2011, con una cobertura superior en aquellas con pequeñas inequidades respecto a la riqueza y mejor acceso a los servicios de salud.

Inequidad en Salud; Neoplasias de la Mama; Accesibilidad a los Servicios de Salud

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