REVIEW

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Radiology Surveillance for Breast Cancer Survivors: A Systematic Review and Meta-Analysis

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Abstract

Background: Breast cancer is a prevalent malignancy worldwide, with a growing number of survivors requiring post-treatment surveillance to improve outcomes. Radiologic surveillance, particularly mammography, is essential for early detection, however, there are disparities in the accuracy and effectiveness of various imaging modalities. **Objectives:** The aim of this systematic review and meta-analysis is to evaluate the effectiveness of radiology surveillance techniques for breast cancer survivors, focusing on diagnostic accuracy and mortality reduction. **Methods:** Studies assessing radiologic surveillance (e.g. mammography, ultrasonography, magnetic resonance imaging [MRI], and digital breast tomosynthesis) were included in this review. A comprehensive literature search was conducted in Medline, Cochrane Central Register of Controlled Trials, and Scopus databases. To obtain pooled estimates for sensitivity, specificity, accuracy, and mortality, we extracted and synthesized data using a random-effects model. The Newcastle-Ottawa Scale and QUADAS-2 instruments were used to assess the risk of bias. **Results:** A total of eighteen studies met the eligibility criteria for the review, of which eight were included in the meta-analysis (three for diagnostic accuracy and five for mortality. The pooled sensitivity, specificity, and accuracy of mammographic surveillance were 81% (95% CI 0.63-0.91), 71% (95% CI 0.31-0.93), and 76% (95% CI 0.59-0.88). A 50% reduction in mortality risk was linked to mammographic surveillance (OR 0.50; 95% CI 0.27-0.92). Heterogeneity was substantial for mortality analysis (I2=93%), while there was a low heterogeneity for the sensitivity analysis (I^2=16%). MRI showed better sensitivity (91%) and specificity (82%) than ultrasonography and mammography. **Conclusion:** Although mammographic surveillance has a lower diagnostic accuracy than that observed in the screening population, it considerably lowers mortality among breast cancer survivors. The use of adjunct imaging modalities, such as MRI, may enhance early detection. Standardized surveillance protocols and further research on imaging strategies in diverse populations are required to improve post-treatment monitoring and patient outcomes.

Keywords: Breast cancer- mortality- surveillance- cancer survivors- radiology

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Introduction

Despite notable progress in treatment and survival rates in recent decades, breast cancer remains one of the most prevalent malignancies worldwide. By 2020, breast cancer is accounted for 25% of all female cancer cases [1]. It is the most common cancer diagnosed in women, and its prevalence is rising globally, especially in transitioning countries [2]. According to GLOBOCAN 2020, with an estimated 2.3 million new cases, female breast cancer has replaced lung cancer as the most frequently diagnosed cancer worldwide [3]. Given the expanding population of breast cancer survivors, the necessity for effective surveillance after treatment has grown more and more crucial. Comprehensive follow-up care for breast cancer survivors is essential for timely identification of recurrence, control of treatment-induced adverse effects, and surveillance of general well-being [4].

Radiology surveillance is a critical component of post-treatment care for breast cancer survivors. Typically, this method includes imaging examinations such as mammography, ultrasonography, magnetic resonance imaging (MRI), and recent advances like contrast-enhanced mammography and molecular imaging [5]. The main objective of radiologic surveillance is to identify any possible recurrence in its earliest stages when it is more probable to be successful in treatment, improving overall survival rates and quality of life [6]. Several variables,

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including the patient's initial tumor features, treatment history, and individual risk of recurrence, influence the selection of imaging technology [7].

While radiological monitoring is essential, there is a continuous discussion on the most effective imaging strategies for follow-up. Numerous guidelines and suggestions are available, although there is variation in implementing (i.e. modality and frequency) these guidelines among various healthcare systems and populations [8]. The absence of consensus emphasizes the challenge of establishing a balance between efficient monitoring and the potential for overdiagnosis, unneeded biopsies, and radiation exposure [9].

This systematic review aims to evaluate the current evidence of the efficacy and accuracy of radiological techniques employed in the post-treatment care of individuals who have survived breast cancer through data synthesis from current studies. This review offers valuable insights into the most suitable imaging techniques that maximise results while inducing minimal damage. This will ultimately inform clinical practice and future research.

Materials and Methods

The design of this study was outlined in the published protocol on the International Prospective Register of Systematic Reviews (PROSPERO) under registration number CRD42024545396, prior to initiation of the review [10]. The reporting adhered to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines [11].

Search Strategies

Comprehensive systematic search was conducted by two reviewers (A.V.I and A.M.G) in the Cochrane Central Register of Controlled Trials, Medline, and Scopus to identify all studies eligible for inclusion in this review. The search strategies were adapted for each database. This systematic review included randomized controlled trials and observational studies evaluating accuracy of radiology surveillance and mortality in breast cancer survivors. We followed Cochrane methodology standards [12] and performed all steps regarding searching methods to identify all studies fulfilling the eligibility criteria, using keywords related to: 1) breast cancer survivor, 2) radiology surveillance. The search was also expanded by identifying studies from the reference lists of identified relevant studies.

Study Selection

Articles found from our search were merged in a reference manager to check and remove duplicates. Two reviewers (A.V.I and A.M.G) then screened the title and abstract of each article. We used Rayyan online tool [13] to upload and organize the title and abstracts of search results for a systematic review. Undecided results were still included for the next step. Then, the full texts of remaining articles were assessed for eligibility by two reviewers. If disputes about exclusion/inclusion occurred, a third reviewer was consulted to reach consensus. Unique titles and abstracts were reviewed for eligibility using prespecified Population, Intervention, Comparator, Outcome, and Study design (PICOS) criteria which are: 1) breast cancer survivors, 2) any modality of radiology surveillance, 3) any other modality for surveillance or no surveillance, 4) accuracy or mortality, and 5) interventional or observational studies. We excluded studies with no available full text. We imposed no language restrictions on the included studies. We did not reach out to authors for unpublished studies or those available only in abstract form. We documented the study selection process in a flow chart, as recommended in the PRISMA statement [11].

Data extraction

Two review authors independently extracted all data using standardized data extraction forms and assessed eligible studies for methodological quality and risk of bias. We extracted the following characteristics from included studies: country or region, objective, study population, intervention, comparison, outcome, study design, sample size, and quality assessment. This review gathered outcomes related to accuracy (including sensitivity, specificity, positive predictive value, and negative predictive value) as well as the mortality rate associated with radiological surveillance.

Study Quality Assessment

We evaluated the quality of the study by conducting a risk of bias assessment for studies included in the meta-analysis. Two independent reviewers systematically assessed the risk of bias associated with each study. For studies focused on diagnostic accuracy, the QUADAS-2 (Quality Assessment of Diagnostic Accuracy Studies 2) checklist was employed to evaluate the study quality [14]. In studies with mortality outcomes, such as case-control and cohort designs, the Newcastle-Ottawa Scale (NOS) Quality Assessment Form was utilized to assess the risk of bias [15].

Data syntheses and analyses

Data synthesis was conducted qualitatively, and for eligible studies, we also performed a quantitative analysis using meta-analysis. We performed statistical analysis using the statistical software R with the R-Studio user interface to facilitate meta-analysis for forest plot generation. The sensitivity, specificity, and accuracy for the forest plot were calculated using standard formulas for diagnostic test performance. For the mortality outcome, we used odds ratio as the effect estimate. The odds ratio compares the odds of mortality occurring in those receiving surveillance to the odds of the same event occurring in the control group. For studies reporting hazard ratio, we converted this data into odds ratio. To obtain the pooled estimates for sensitivity, specificity, accuracy, and mortality, these values from individual studies were meta-analysed using a random-effects model, which accounts for between-study variability. The pooled estimates are typically represented with their corresponding 95% confidence intervals (CIs), as shown in the forest plot. The statistical heterogeneity among studies was assessed by a Chi-square test on N-1 degrees

of freedom with an alpha of 0.05 for statistical significance and the I^2 analysis to detect the magnitude of variation attributable to heterogeneity rather than to chance. I^2 values of <50%, 50-75%, and >75% correspond to low, medium, and high levels of heterogeneity [16].

Results

The stepwise selection of articles according to our predefined criteria is summarized in Figure 1. The total number of articles initially determined based on the search strategy was 1959 studies: 1109 studies from Medline, 223 studies from Scopus, 627 studies from CENTRAL, and 8 studies were identified from the reference lists of the identified relevant studies. After removing 315 duplicates, we deleted another 1557 articles by reading the titles and abstracts of the article. Of the remaining papers, 76 articles could not be included in this research due to different populations, article types, study designs, and interventions. Ultimately, a total of 18 articles were included.

Study characteristics

Table 1 and Table 2 presents the characteristics of the studies included based on Population, Intervention, Comparator, Outcome, and Study design (PICOS) items [7, 9, 17-34]. The study designs varied from case control, prospective and retrospective study, to RCT. The most recent studies were published in 2023, while the earliest identified study dates back to 2004. The majority of these studies were carried out in high-income countries (HICs) (n = 17), with only one study originating from a low-middle income country (LMIC). Geographically, four studies were conducted in Asia, all from South Korea, while one study was conducted in Africa (Egypt). The remaining 13 studies were based in Europe (Germany, Italy, France, and Canada) and the United States. The studies were conducted in various countries, reflecting a diverse range of healthcare settings and patient populations.

The radiological surveillance modalities assessed range from ultrasonography, mammography, to more advanced imaging modalities, such as MRI and digital breast tomosynthesis (DBT). Most of the studies (70%) utilized mammography for surveillance. Five studies employed ultrasonography as the surveillance modality, whereas MRI and DBT were each reported in five studies as well. Additionally, the frequency of surveillance varied across studies, with intervals ranging from semiannual to annual screening. The stages of breast cancer also varied. Some studies focused on women with early stage (Stage I-IIA) breast cancer), while others included women with more advanced stages (up to Stage III).

Accuracy

Fourteen studies presented outcomes of accuracy (Table 3). Four studies on mammographic surveillance were included in the meta-analysis (Figures 3-5), revealing a pooled sensitivity of 0.81 (95% CI 0.63-0.91), specificity of 0.71 (95% CI 0.31-0.93), and accuracy of 0.76 (95% CI 0.59-0.88). While one study indicated that ultrasonography achieved a sensitivity of 0.87 and a

Table 1. Study Characteristics of Accuracy Studies

Studies	Country	Populations	Intervention	Comparison	Outcome	Study Design
Osman et al., 2018 [17]	Egypt	BC survivors	Mammography and DBT	Biopsy	Accuracy	Prospective study
Ternier et al., 2006 [18]	France	BC survivors, conservatively treated breast, with suspicious findings on routine surveillance	Mammography and ultrasonography	Histological findings from surgery	Accuracy	Prospective study
Aarts et al., 2019 [19]	Italy	BC survivors, developed second cancer in the contralateral breast, separated by at least 6 months	Mammography	Histological findings from surgery	Accuracy	Prospective study
Weinstock et al., 2015 [20]	US	BC survivors, <65 yo	Mammography	N/A	Accuracy	Retrospective study
Shin et al., 2005 [21]	South Korea	BC survivors, asymptomatic, after breast cancer surgery	Ultrasonography	N/A	Accuracy	Retrospective study
Viewheg et al., 2004 [22]	Germany	BC survivors	Mammography	N/A	Accuracy	Retrospective study
Tadros et al., 2017 [23]	US	BC survivors	MRI	N/A	Accuracy	Retrospective study
Gweon et al., 2014 [24]	South Korea	BC survivors, had negative mammography and sonography findings	MRI	N/A	Accuracy	Retrospective study
Brennan et al., 2012 [25]	US	BC survivors, no family history	MRI	N/A	Accuracy	Retrospective study
Kim et al., 2012 [26]	South Korea	BC survivors	Ultrasonography	N/A	Accuracy	Retrospective study
Bahl et al., 2021 [27]	US	BC survivors	Mammography	DBT	Accuracy	Retrospective study
Schlaiss et al., 2023 [28]	Germany	BC survivors	Mammography	MRI and Ultrasonography	Accuracy	Retrospective study

Note: BC, breast cancer; DBT, digital breast tomosynthesis; MRI, magnetic resonance imaging; MRM, magnetic resonance mammography; US, United States; RCT, randomized control trial; N/A, not applicable

Table 2. Study Characteristics of Mortality Studies

Studies	Country	Populations	Intervention	Comparison	Outcome	Study Design
Lash et al., 2006 [7]	US	BC survivors, >65 yo, stage I–IIA BC	Annual mammography(s)	No annual mammography	Mortality	Nested Case Control
Lash et al., 2007 [31]*	US	BC survivors, >65 yo, stage I–IIA BC	Annual mammography(s)	No annual mammography	Mortality	Nested Case Control
Schootman et al., 2007 [32]	US	BC survivors, >66 yo, stages 0–III BC	Mammography 1 years prior to death/ censoring	No mammography prior to death	Mortality	Case Control
Paszat et al., 2009 [9]	Canada	BC survivors all age, stage I and II BC	Mammography ≥ 1	No mammography	Mortality	Retrospective study
Jung et al., 2021 [33]	South Korea	BC survivors all age, all stage BC	Annual mammography or more frequent mammography within 3 years (≥ 3 times)	Mammography <3 times within 3 years	Mortality	Retrospective study
Buist et al., 2013 [34]	US	BC survivors >65 yo, stage I and II BC	Annual mammography(s) after 5 years of disease-free	No mammography	Mortality	Prospective study

Note: BC, breast cancer; US, United States. *Lash et al., 2006 and Lash et al., 2007 have different population

specificity of 0.73. However, a different study revealed the reverse trend, with a sensitivity of 0.70 and a specificity of 0.98 for ultrasonography, 18.21 Additionally, five studies on MRI reported consistently higher sensitivity, from 0.88 to 0.95, compared to mammography and ultrasonography [23-25, 27, 30] One study reported that the specificity of MRI is 0.82 (95% CI 0.78-0.85) [24].

Mortality

There were six studies reporting mortality outcomes of mammography surveillance, with detailed information provided in Table 4. Due to the heterogeneity across studies, only five were included in the meta-analysis, which involved a total sample size of 8,948 participants. The pooled odds ratio revealed that mammographic surveillance significantly reduced the odds of mortality by 50% (OR 0.50; 95% CI 0.27, 0.92) compared to individuals without surveillance (Figure 2). The high heterogeneity (I^2 = 93%) likely attributable to variations in the delivery of interventions (e.g., frequency, intensity) and differences in outcome measures (e.g., breast cancer mortality vs. all-cause mortality).

Study Quality

Quality assessment was conducted for studies included in meta-analysis, comprising four studies evaluating diagnostic accuracy outcomes and five studies reporting mortality outcomes. For the diagnostic accuracy studies, the QUADAS-2 (Quality Assessment of Diagnostic Accuracy Studies 2) tool was employed to evaluate the risk of bias and concerns regarding applicability across four domains: patient selection, index test, reference standard, and flow and timing. All three studies demonstrated a low risk of bias in each domain, as well as low concerns regarding applicability. For studies assessing mortality outcomes, which included both case-control and cohort designs, the Newcastle-Ottawa Scale (NOS) Quality Assessment Form was used. The majority of studies were reported as having low risk of bias, with only one study rated as having moderate risk, although two studies

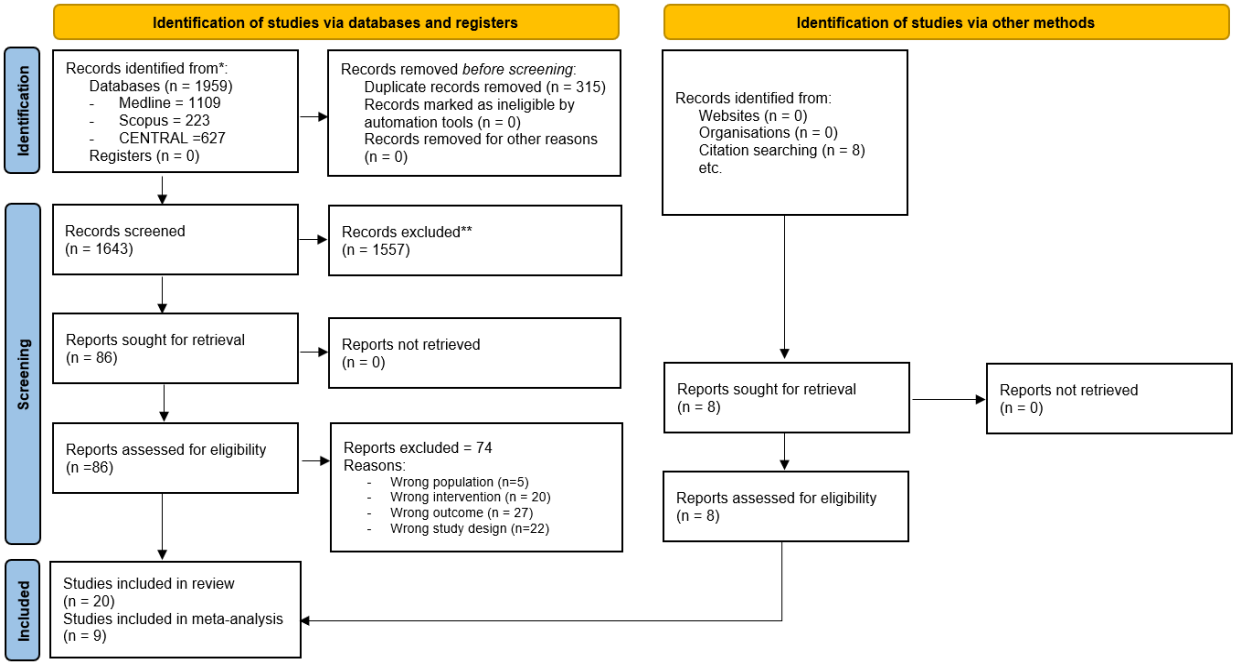

Figure 1. PRISMA 2020 Flowchart

Table 3. Outcome Accuracy

Studies	Sample size	Intervention	TP	FP	FN	TN	Sensitivity	Specificity	PPV	NPV
Osman et al., 2018 [17]	196	Mammography	85	29	18	64	84.2	53.1	48.9	86.7
		Mammography + DBT	74	NR	NR	NR	100	92.1	89.7	100
Ternier et al., 2006 [18]	103	Mammography	43	22	9	29	83	57	66	76
		US	45	14	7	37	87	73	76	84
Aarts et al., 2019 [19]	589	Mammography	226	NR	363	NR	91	NR	NR	NR
Weinstock et al., 2015 [20]	571	Mammography	NR	NR	NR	NR	23.1	96.4	NR	NR
Shin et al., 2005 [21]	57	US	24	33	NR	NR	70.6	98.3	42.1	NR
Viewheg et al., 2004 [22]	145	Mammography	10	13	1	121	91	90	43	99
Tadros et al., 2017 [23]	186	MRI	8	NR	1	NR	88.9	NR	24	NR
Gweon et al. 2014 [24]	607	MRI	11	106	1	489	91.7	82.2	9.4	0.2
Brennan et al., 2012 [25]	144	MRI	17	27	1	NR	NR	NR	39	NR
Kim et al., 2012 [26]	1256	US	16	NR	2	NR	NR	NR	41	NR
Bahl et al., 2021 [27]	8170	Mammography	N/A	N/A	N/A	N/A	75	94.7	64.9	NR
		DBT	N/A	N/A	N/A	N/A	77.8	95	56.4	NR
Schlaiss et al., 2023 [28]	176	Mammography	106	NR	54	NR	66.3	NR	NR	NR
		MRI	118	NR	56	NR	93.9	NR	NR	NR
		Ultrasonography	94	NR	2	NR	67.8	NR	NR	NR

Note: TP, true positive; FP, false positive; FN, false negative; TN, true negative; PPV, positive predictive value; NPV, negative predictive value; DBT, digital breast tomosynthesis; US, ultrasonography; MRI, magnetic resonance imaging; NR, not reported; N/A, not applicable

exhibited specific concerns in several domains. One study (Paszat et al.) had a high risk in the domain of case definition (A1), but demonstrated low risk in all other domains, resulting in an overall assessment of low risk of bias. Meanwhile Schootman et al. was rated as high risk in two domains, representativeness of the exposed cohort (A1) and assessment of outcome (A6) and low risk in the remaining domains, leading to an overall classification of moderate risk of bias.

Discussion

This systematic review and meta-analysis aimed to evaluate the efficacy of radiology surveillance in breast cancer survivors, particularly mammographic surveillance, focusing on accuracy and mortality outcomes. Effective post-treatment surveillance remains critical to improve long-term outcomes. Our analysis highlights the importance of mammographic surveillance

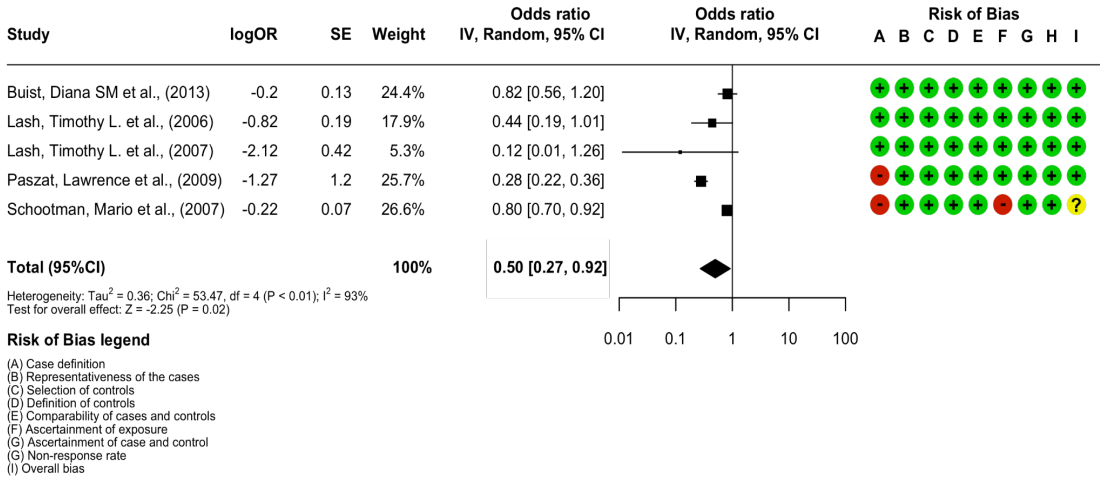

Figure 2. Forest Plot Presenting the Mortality Rate of Implementing Mammographic Surveillance vs no Mammographic Surveillance

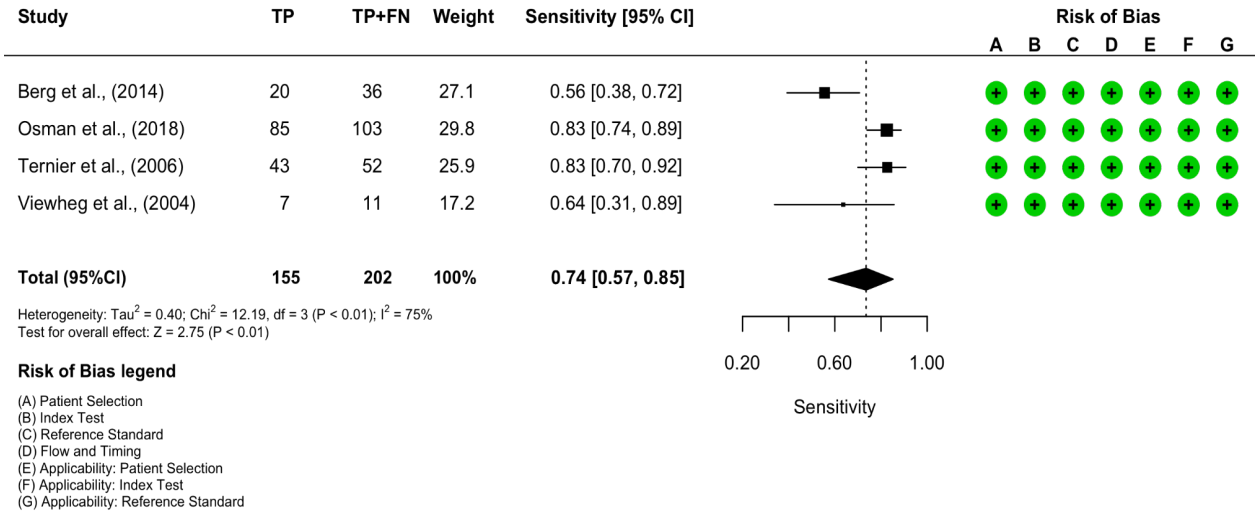

Figure 3. Forest Plot Presenting the Sensitivity of Mammographic Surveillance

in post-treatment care by showing 50% reduction in mortality risk (OR 0.50; 95% CI 0.27-0.92), compared to no surveillance [7, 33]. However, we noted the significant heterogeneity between studies (I^2 = 93%) in this meta-analysis, and should be taken into account when interpreting the results.

Several factors likely contributed to the heterogeneity observed in our analysis, including variations in surveillance protocols, imaging frequency, and outcome definitions. Three studies applied annual mammography, while two studies did not specify as long as the subject had once mammography examination during the study period. Moreover, discrepancies were also noted in mortality endpoints, as some studies assessed breast cancer–specific mortality, whereas others considered all-cause mortality. Whenever possible, we used the breast cancer mortality in our meta-analysis. Only one study [7] that used all-cause mortality that we include in our meta-analysis.

While our analysis reveals a substantial mortality benefit from mammographic surveillance, the diagnostic performance metrics suggest important limitations that must be acknowledged. The pooled sensitivity (81%, 95% CI 0.63-0.91), specificity (71%, 95% CI 0.31-0.93), and accuracy (76%, 95% CI 0.59-0.88) from our meta-analysis were notably lower than the 92% accuracy often reported in initial screening or diagnostic settings [29, 30]. This reduction may reflect the unique challenges of imaging the post-treatment breast, where interval cancers, scarring, and architectural distortion are more prevalent. In particular, breast-conserving therapy (BCT) frequently produces post-surgical and radiation-induced changes that obscure subtle lesions, increasing the risk of both false-positive and false-negative interpretations.

Given these diagnostic constraints, complementary imaging modalities may provide additional value in certain clinical contexts. Ultrasonography has demonstrated higher sensitivity in some studies, although often at the cost of reduced specificity, whereas magnetic resonance

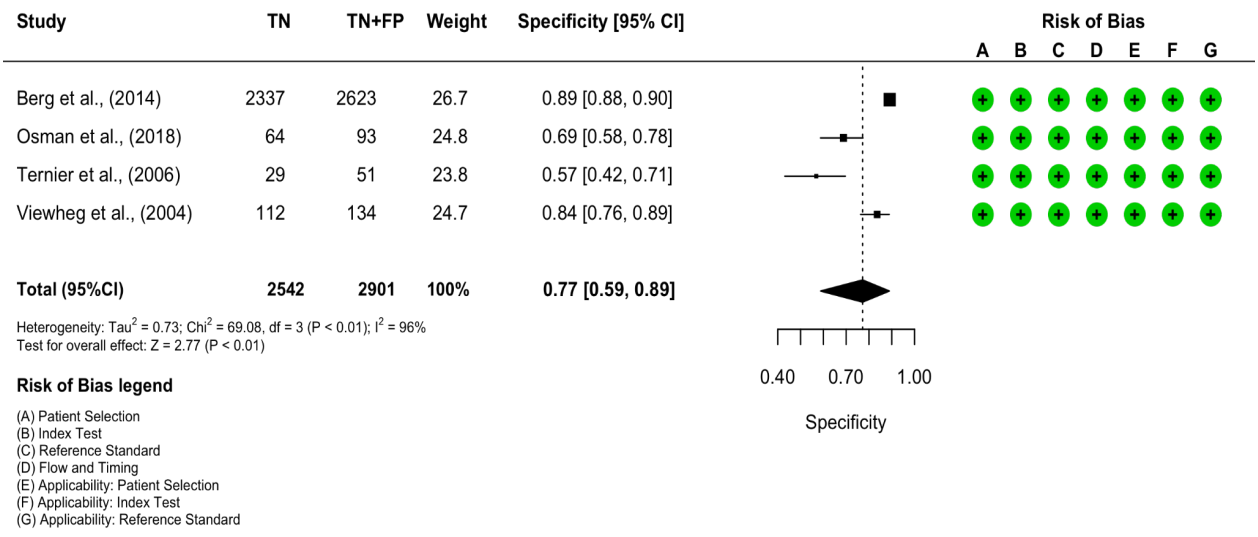

Figure 4. Forest Plot Presenting the Specificity of Mammographic Surveillance

Table 4. Outcome Mortality

Studies	Intervention	Outcome	Effect Measure	Death (Mammo)	No Death (Mammo)	Death (No Mammo)	No Death (No Mammo)	OR/RR (95% CI)
Lash et al., 2006 [7]	Annual mammography(s)	All cause mortality	Unadjusted OR					
	I1 (one time)		I1	10	75	12	74	0.82 (0.33–2.0)
	I2 (two time)		I2	7	69	12	74	0.63 (0.23–1.7)
	I3 (three time)		I3	2	24	12	74	0.51 (0.11–2.5)
	I4 (four or more)		I4	1	14	12	74	0.44 (0.7–3.7)
Lash et al., 2007 [29]	Annual mammography(s)	Breast cancer mortality	Unadjusted OR					
	I1 (one time)		I1	55	205	82	255	0.83
	I2 (two time)		I2	28	108	82	255	0.8
	I3 (three time)		I3	12	53	82	255	0.7
	I4 (four or more)		I4	1	13	82	255	0.23
			Adjusted OR					
			I1	N/A	N/A	N/A	N/A	0.67 (0.39–1.1)
			I2	N/A	N/A	N/A	N/A	0.52 (0.25–1.1)
			I3	N/A	N/A	N/A	N/A	0.36 (0.13–0.99)
			I4	N/A	N/A	N/A	N/A	0.12 (0.01–1.1)
Schootman et al., 2007 [30]	Mammography 1 years prior to death/ censoring	Breast cancer mortality	Unadjusted OR	N/A	N/A	N/A	N/A	0.59 (0.52–0.67)
			Adjusted OR[a]	N/A	N/A	N/A	N/A	0.83 (0.72–0.95)
		All cause mortality	Unadjusted OR	N/A	N/A	N/A	N/A	0.52 (0.49–0.56)
			Adjusted OR[b]	N/A	N/A	N/A	N/A	0.83 (0.76–0.90)
	Mammography 2 years prior to death/ censoring	Breast cancer mortality	Unadjusted OR	N/A	N/A	N/A	N/A	0.48 (0.42–0.54)
			Adjusted OR[c]	N/A	N/A	N/A	N/A	0.80 (0.70–0.92)
		All cause mortality	Unadjusted OR	N/A	N/A	N/A	N/A	0.34 (0.32–0.37)
			Adjusted OR[d]	N/A	N/A	N/A	N/A	0.72 (0.66–0.78)
Paszat et al., 2009 [9]	Mammography ≥ 1	Breast cancer mortality	Unadjusted HR	275	446	99	81	CRIBC: 0.36 (0.13-1.01)
								CPBC: 0.86 (0.2-3.77)
			Adjusted HRg					0.28 (0.22-0.37)
		Other cause mortality		84	637	54	126	N/A
Jung et al., 2021 [31]	Annual mammography or more frequent mammography within 3 years (≥ 3 times)	Breast cancer mortality	Unadjusted HR	2551	31518	1806	38026	0.56 (0.54-0.61)
			Adjusted HRe					0.59 (0.55-0.62)
			Adjusted HRf					0.59 (0.55-0.62)
		All cause mortality	Unadjusted HR	3179	31518	2062	38026	0.53 (0.50-0.56)
			Adjusted HR[e]					0.55 (0.52-0.58)
			Adjusted HR[f]					0.53 (0.49-0.58)
Buist et al., 2013 [32]	Annual mammography(s) after 5 years of disease-free	Breast cancer mortality	Adjusted IRR[h]	54	120	Unknown	Unknown	0.82 (0.56-1.19)
		Other cause mortality	Adjusted IRR[h]	185	393	Unknown	Unknown	0.95 (0.78-1.17)

Note: CRIBC, cancer recurrence within the ipsilateral conserved breast; CPBC, contralateral primary breast cancer; CI, confidence interval; HR, hazard ratio; I, intervention; IRR, incidence rate ratio; OR, odds ratio; RR, risk ratio; N/A, not applicable. [a], Adjusted for stage, year of diagnosis, age group, tumor grade, radiotherapy, type of surgery, race, comorbidity, tumor histology, marital status, primary care visit, oncologist visit, ambulatory care sensitive visit, registry site. [b], Adjusted for stage, year of diagnosis, age group, tumor grade, radiotherapy, type of surgery, chemotherapy, comorbidity, tumor histology, metastases, poverty rate, percent without high school degree, percent African American, marital status, primary care visit, oncologist visit, ambulatory care sensitive visit, registry site. [c], Adjusted for stage, year of diagnosis, age group, race, tumor grade, radiotherapy, type of surgery, chemotherapy, comorbidity, tumor histology, percent without high school degree, percent African Americans, primary care visit, oncologist visit, ambulatory care sensitive visit. [d], Adjusted for stage, year of diagnosis, age group, race, tumor grade, radiotherapy, type of surgery, chemotherapy, comorbidity, estrogen receptor status, primary care visit, oncologist visit, ambulatory care sensitive visit. [e], Adjusted for age, treatment, and Charlson Comorbidity Index. [f], Adjusted for stage, age, treatment, and Charlson Comorbidity Index. [g], Adjusted for age group, and characteristics and treatment for unilateral primary breast cancer. [h], Adjusted for site, age at year 6 after diagnosis, tumor stage, primary surgery type, and Charlson Comorbidity Index

imaging (MRI) has shown consistently higher sensitivity (91%) and specificity (82%) than mammography and ultrasonography in breast cancer survivors [27, 28]. These modalities may be particularly advantageous in patients with dense breasts, equivocal mammographic findings, or a history of BCT, where mammographic

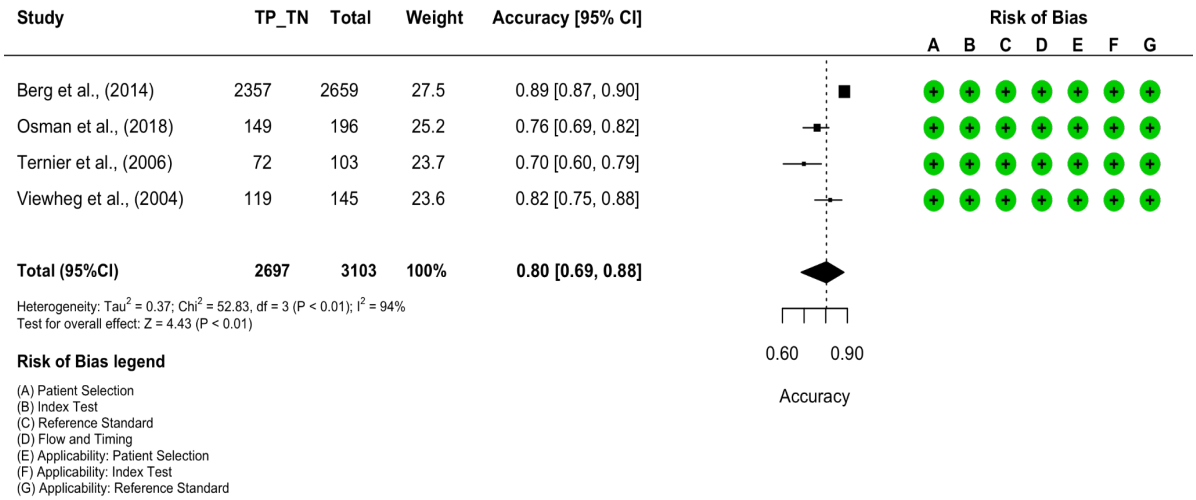

Figure 5. Forest Plot Presenting the Accuracy of Mammographic Surveillance

interpretation is most challenging. Incorporating tailored multimodality surveillance strategies, potentially guided by individual recurrence risk, could improve early detection rates and mitigate the limitations inherent to mammographic surveillance alone. Importantly, these considerations must be interpreted in the context of substantial heterogeneity across studies, which may reflect differences in surveillance protocols, imaging technology, and patient populations.

Subgroup analyses based on factors such as age, surgical approach (breast-conserving therapy versus mastectomy), or breast density could provide additional insights into heterogeneity of outcomes. However, because the required data were not available from the included study, we were unable to carry out these analyses in the current review. We acknowledge this as an important area for further investigation and recommend that future studies specifically explore these subgroups to strengthen the evidence base

It is important to note that the majority of the included studies were conducted in high-income countries, with limited evidence available from low- and middle-income settings. This geographic imbalance may limit the generalizability of our findings, as resource-limited environments often face different health system constraints, infrastructure challenges, and population health needs. Further research from low- and middle-income countries is needed to better understand the applicability and effectiveness of these interventions across diverse contexts.

Given these limitations, future research ought to focus on developing standardized guidelines for imaging surveillance among breast cancer survivors following therapy. More definitive recommendations might be offered by comparative studies evaluating various imaging modalities in diverse patient populations. Addressing the existing gaps in evidence from low- and middle- income countries is also important. Furthermore, the integration of artificial intelligence (AI)-driven image processing in mammographic surveillance may improve sensitivity and specificity, addressing some of the inherent limitations of traditional mammography [9].

Recent trials suggest that AI contributes to the early detection of clinically relevant breast cancer and reduces screen-reading workload without increasing false positives [31]. This highlights AI's potential to transform breast cancer surveillance by improving diagnostic accuracy, minimizing inter-observer variability, and optimizing resource use. In LMICs, where radiologist shortages and limited access to advanced imaging remain major challenges, AI could serve as a cost-effective adjunct to extend diagnostic capacity, enable earlier detection, and reduce treatment delays. By lowering false positives and unnecessary recalls, AI may also alleviate economic strain.

In conclusion, while mammographic surveillance is essential in reducing mortality among breast cancer survivors, its diagnostic accuracy remains suboptimal. In certain high-risk and BCT patients, the combination of MRI or ultrasonography may improve overall survival outcomes and early recurrence detection. Further research should focus on refining surveillance strategies, reducing unnecessary imaging, and addressing the existing gaps in evidence from low- and middle-income countries, as the majority of studies in this review were conducted in high-income countries.

Author Contribution Statement

All authors contributed equally in this study.

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References

1. Arnold M, Morgan E, Rumgay H, Mafra A, Singh D, Laversanne M, et al. Current and future burden of breast cancer: Global statistics for 2020 and 2040. The Breast. 2022 Dec 1;66:15-23.
2. Bray F, Ferlay J, Soerjomataram I, Siegel RL, Torre LA, Jemal A. Global cancer statistics 2018: Globocan estimates

of incidence and mortality worldwide for 36 cancers in 185 countries. CA Cancer J Clin. 2018;68(6):394-424. https://doi.org/10.3322/caac.21492.
3. Sung H, Ferlay J, Siegel RL, Laversanne M, Soerjomataram I, Jemal A, et al. Global cancer statistics 2020: Globocan estimates of incidence and mortality worldwide for 36 cancers in 185 countries. CA Cancer J Clin. 2021;71(3):209-49. https://doi.org/10.3322/caac.21660.
4. Yoon JH, Kim MJ, Kim EK, Moon HJ. Imaging surveillance of patients with breast cancer after primary treatment: Current recommendations. Korean J Radiol. 2015;16(2):219-28. https://doi.org/10.3348/kjr.2015.16.2.219.
5. American College of Radiology. ACR Appropriateness Criteria Imaging of Invasive Breast Cancer. 2023. Available from: https://acsearch.acr.org/docs/3186697/Narrative/
6. Cardoso F, Harbeck N, Fallowfield L, Kyriakides S, Senkus E. Improvements in breast cancer outcomes: A decade in review. J Clin Oncol. 2020;38(10):100–14.
7. Lash TL, Fox MP, Silliman RA. Reduced mortality rate associated with annual mammograms after breast cancer therapy. Breast J. 2006;12(1):2-6. https://doi.org/10.1111/j.1075-122X.2006.00177.x.
8. American Society of Clinical Oncology. American Cancer Society of Clinical Oncology Breast Cancer Survivorship Care Guideline. 2015. Available from: www.asco.org/guidelines/breastsurvivorship.
9. Paszat L, Sutradhar R, Grunfeld E, Gainford C, Benk V, Bondy S, et al. Outcomes of surveillance mammography after treatment of primary breast cancer: A population-based case series. Breast Cancer Res Treat. 2009;114(1):169-78. https://doi.org/10.1007/s10549-008-9986-4.
10. Booth A, Clarke M, Dooley G, Ghersi D, Moher D, Petticrew M, et al. The nuts and bolts of prospero: An international prospective register of systematic reviews. Syst Rev. 2012;1:2. https://doi.org/10.1186/2046-4053-1-2.
11. Moher D, Liberati A, Tetzlaff J, Altman DG. Preferred reporting items for systematic reviews and meta-analyses: The prisma statement. PLoS Med. 2009;6(7):e1000097. https://doi.org/10.1371/journal.pmed.1000097.
12. Higgins JPT, Thomas J, Chandler J, et al. Cochrane Handbook for Systematic Reviews of Interventions. Version 6.3. Cochrane; 2022. Available from: https://training.cochrane.org/handbook/current.
13. Ouzzani M, Hammady H, Fedorowicz Z, Elmagarmid A. Rayyan-a web and mobile app for systematic reviews. Syst Rev. 2016;5(1):210. https://doi.org/10.1186/s13643-016-0384-4.
14. Whiting PF, Rutjes AW, Westwood ME, Mallett S, Deeks JJ, Reitsma JB, et al. Quadas-2: A revised tool for the quality assessment of diagnostic accuracy studies. Ann Intern Med. 2011;155(8):529-36. https://doi.org/10.7326/0003-4819-155-8-201110180-00009.
15. Wells GA, Shea B, O'Connell D, Peterson J, Welch V, Losos M, Tugwell P. The Newcastle-Ottawa Scale (NOS) for assessing the quality of nonrandomised studies in meta-analyses; 2011.
16. Higgins JP, Thompson SG. Quantifying heterogeneity in a meta-analysis. Stat Med. 2002;21(11):1539-58. https://doi.org/10.1002/sim.1186.
17. Osman NM, Ghany EA, Chalabi N. The added benefit of digital breast tomosynthesis in second breast cancer detection among treated breast cancer patients. The Egyptian Journal of Radiology and Nuclear Medicine. 2018;49(4):1182-6. https://doi.org/10.1016/j.ejrnm.2018.07.007.
18. Ternier F, Houvenaeghel G, Lecrivain F, Brigand BL, Margain D, Brunelle S, et al. Computed tomography in suspected local breast cancer recurrence. Breast Cancer Res Treat. 2006;100(3):247-54. https://doi.org/10.1007/s10549-006-9218-8.
19. Aarts A, Duffy SW, Geurts SME, Vulkan DP, Houssami N, Zappa M, et al. Towards evidence-based follow-up intervals for breast cancer survivors: Estimates of the preclinical detectable phase of contralateral second breast cancer. Breast. 2019;45:70-4. https://doi.org/10.1016/j.breast.2019.03.003.
20. Weinstock C, Campassi C, Goloubeva O, Wooten K, Kesmodel S, Bellevance E, et al. Breast magnetic resonance imaging (mri) surveillance in breast cancer survivors. Springerplus. 2015;4:459. https://doi.org/10.1186/s40064-015-1158-5.
21. Shin JH, Han BK, Choe YH, Nam SJ, Park W, Im YH. Ultrasonographic detection of occult cancer in patients after surgical therapy for breast cancer. J Ultrasound Med. 2005;24(5):643-9. https://doi.org/10.7863/jum.2005.24.5.643.
22. Viehweg P, Rotter K, Laniado M, Lampe D, Buchmann J, Kölbl H, et al. Mr imaging of the contralateral breast in patients after breast-conserving therapy. Eur Radiol. 2004;14(3):402-8. https://doi.org/10.1007/s00330-003-2086-2.
23. Tadros A, Arditi B, Weltz C, Port E, Margolies LR, Schmidt H. Utility of surveillance mri in women with a personal history of breast cancer. Clin Imaging. 2017;46:33-6. https://doi.org/10.1016/j.clinimag.2017.06.007.
24. Gweon HM, Cho N, Han W, Yi A, Moon HG, Noh DY, et al. Breast mr imaging screening in women with a history of breast conservation therapy. Radiology. 2014;272(2):366-73. https://doi.org/10.1148/radiol.14131893.
25. Brennan S, Liberman L, Dershaw DD, Morris E. Breast mri screening of women with a personal history of breast cancer. AJR Am J Roentgenol. 2010;195(2):510-6. https://doi.org/10.2214/ajr.09.3573.
26. Kim MJ, Kim EK, Kwak JY, Park BW, Kim SI, Sohn J, et al. Sonographic surveillance for the detection of contralateral metachronous breast cancer in an asian population. AJR Am J Roentgenol. 2009;192(1):221-8. https://doi.org/10.2214/ajr.07.4048.
27. Bahl M, Panigrahi B, Nabh A, et al. Diagnostic accuracy of digital breast tomosynthesis in breast cancer surveillance. Radiology. 2021;299(2):327–36.
28. Schlaiss CR, Müller T, Becker AS, et al. Comparative effectiveness of MRI and mammography in post-treatment surveillance of breast cancer survivors. Eur Radiol. 2023;33(5):3251–63.
29. Lash TL, Fox MP, Buist DS, Wei F, Field TS, Frost FJ, et al. Mammography surveillance and mortality in older breast cancer survivors. J Clin Oncol. 2007;25(21):3001-6. https://doi.org/10.1200/jco.2006.09.9572.
30. Schootman M, Jeffe DB, Lian M, Aft R, Gillanders WE. Surveillance mammography and the risk of death among elderly breast cancer patients. Breast Cancer Res Treat. 2008;111(3):489-96. https://doi.org/10.1007/s10549-007-9795-1.
31. Jung SY, Kim YA, Lee DE, Joo J, Back JH, Kong SY, et al. Clinical impact of follow-up imaging on mortality in korean breast cancer patients: A national cohort study. Cancer Med. 2021;10(18):6480-91. https://doi.org/10.1002/cam4.3873.
32. Buist DS, Bosco JL, Silliman RA, Gold HT, Field T, Yood MU, et al. Long-term surveillance mammography and mortality in older women with a history of early stage invasive breast cancer. Breast Cancer Res Treat. 2013;142(1):153-63. https://doi.org/10.1007/s10549-013-2720-x.
33. Hernström V, Josefsson V, Sartor H, Schmidt D, Larsson AM,

Hofvind S, et al. Screening performance and characteristics of breast cancer detected in the mammography screening with artificial intelligence trial (masai): A randomised, controlled, parallel-group, non-inferiority, single-blinded, screening accuracy study. Lancet Digit Health. 2025;7(3):e175-e83. https://doi.org/10.1016/s2589-7500(24)00267-x.