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THE IMPACT OF LIFESTYLE AND ENVIRONMENTAL FACTORS ON THE DETECTABILITY OF BREAST CANCER BY MAMMOGRAPHY: IMPLICATIONS FOR THE PERSONALIZATION OF SCREENING TESTS - LITERATURE REVIEW

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ABSTRACT

Introduction and objective: Breast cancer remains the most commonly diagnosed cancer in women worldwide and one of the leading causes of cancer deaths in the female population (Sung et al., 2021). Despite advances in diagnosis and treatment, early detection of the disease remains a key factor in improving prognosis. Mammography is the primary screening method, but its diagnostic effectiveness varies and depends on many biological, hormonal, environmental, and lifestyle factors. Particular importance is attached to mammographic breast density, which simultaneously increases the risk of disease and reduces the sensitivity of the test by masking cancerous changes. A growing body of evidence suggests that lifestyle and environmental exposure can modify the structure of fibro-glandular tissue, affect its quantitative composition and radiological properties, and thus influence the detectability of cancerous changes.
The aim of this review was to comprehensively analyze the impact of lifestyle factors and environmental exposures on the detectability of breast cancer in mammography, with a particular focus on potential biological mechanisms and clinical implications.
Methods: A literature review was conducted in the PubMed database covering English-language publications from 2000 to 2025. Cohort studies, case-control studies, meta-analyses, and systematic reviews on the relationship between lifestyle, environmental factors, breast density, and mammography effectiveness were analyzed. Publications discussing radiological assessment standards, including the BI-RADS classification, were also included.
Conclusions: Available data indicate that lifestyle and environmental factors may influence the structure and composition of breast glandular tissue, modulating mammographic density and thus the sensitivity of screening. Incorporating these factors into personalized screening strategies may improve breast cancer detection, particularly in high-risk populations and women with high breast density.

KEYWORDS

Breast Cancer; Mammography; Breast Density; BI-RADS; Lifestyle Factors; Environmental Exposure; Screening Sensitivity; Early Detection

CITATION

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1. Introduction

Breast cancer is the most commonly diagnosed malignant tumor in women worldwide, with more than 2 million new cases diagnosed annually (Sung et al., 2021). In many developed countries, the introduction of population-based mammography screening programs has contributed to a significant reduction in mortality by detecting preclinical lesions and enabling the implementation of breast-conserving treatment (Tabár et al., 2011).

Despite its documented effectiveness, the sensitivity of mammography is not constant and can range from approximately 60% to over 90%, depending on the individual characteristics of the patient and the properties of the breast tissue (Boyd et al., 2007). One of the most important factors limiting the detection of cancerous changes is high mammographic density, which can mask the presence of a tumor, especially in the case of small changes that do not cause tissue architecture disorders (McCormack & dos Santos Silva, 2006).

A growing number of studies indicate that breast density is not a constant feature and can be modified by hormonal, metabolic, environmental, and lifestyle factors (Maskarinec et al., 2006; Vachon et al., 2007). Therefore, understanding these relationships is important for optimizing screening programs and potentially implementing individualized screening strategies.

Modern medicine is moving towards the personalization of diagnostic procedures, which is why identifying factors that influence the effectiveness of mammography may be of both epidemiological and clinical importance.

2. Methodology

A literature review was conducted in the PubMed database using the following combinations of keywords: breast cancer; mammography; breast density; BI-RADS; lifestyle factors; environmental exposure; screening sensitivity; early detection.

Only articles published in English between 2000 and 2025 were included. The analysis included observational studies, both cohort and case-control, meta-analyses, and systematic reviews. Priority was given to publications covering large populations and studies evaluating mammographic density as a quantitative or semi-quantitative variable.

Non-English publications, reports without full text, and studies not directly related to breast cancer detection in mammography were excluded. The analysis was review-based and focused on a comprehensive assessment of the available studies.

3. Definition and objectives of breast cancer screening

The aim of screening is to identify breast cancer at an asymptomatic stage, which allows for earlier treatment and improves prognosis (Independent UK Panel on Breast Cancer Screening, 2012). Early detection of the disease increases the chances of breast-conserving surgery and reduces the need for aggressive systemic therapy.

The sensitivity of mammography is defined as the percentage of correctly detected cases of cancer among all actually present tumors. Both technical and biological factors influence the effectiveness of the test. High breast density increases the risk of cancer by up to four to six times and makes it difficult to visualize on X-rays (Boyd et al., 2007).

In clinical practice, mammographic images are evaluated using the BI-RADS (Breast Imaging Reporting and Data System) developed by the American College of Radiology. This scale ranges from 0 to 6 and is used to standardize descriptions and further diagnostic procedures.

In addition, the BI-RADS system includes an assessment of breast density in four categories from A to D, where category D indicates extremely dense breasts. Women classified as categories C and D have a significantly higher risk of cancer and lower mammography sensitivity compared to women in categories A and B. For this reason, mammographic density is now recognized as both a risk biomarker and a factor limiting the effectiveness of screening. In some countries, patients with high breast density are informed of the need to consider additional imaging methods, such as ultrasound or magnetic resonance imaging.

4. Lifestyle factors and breast cancer detectability

4.1. Obesity

The relationship between obesity and mammographic density is complex and varies depending on menopausal status. In postmenopausal women, a higher BMI is usually associated with lower relative density, which may increase the sensitivity of mammography (Maskarinec et al., 2006). At the same time, obesity promotes breast cancer development through increased aromatization of androgens to estrogens in adipose tissue and through chronic inflammation (Iyengar et al., 2015).

Adipocytes also produce pro-inflammatory cytokines such as TNF-α and IL-6, which can affect the microenvironment of glandular tissue. In clinical practice, this creates a paradox: in some women with a higher BMI, the mammographic image may be relatively clearer, while at the same time the biological risk of developing cancer remains increased and its course tends to be more aggressive.

In addition, cohort studies indicate that obesity may affect not only relative but also volumetric breast density, which is increasingly assessed by digital methods as a more accurate risk indicator (Vachon et al., 2007). High body weight may mask the actual proportion of fibro-glandular tissue, as an increase in adipose tissue reduces the percentage of dense tissue without necessarily reducing its absolute volume. In this context, interpreting breast density solely in percentage terms may lead to an underestimation of risk in obese women.

In addition, obesity is associated with an increased risk of interval cancers, i.e., those diagnosed between screening rounds, suggesting that the biological aggressiveness of the tumor may partially compensate for the potentially greater transparency of the mammographic image (Boyd et al., 2007). These mechanisms include the activation of insulin- and IGF-1-dependent proliferation pathways, increased oxidative stress, and adipokine disorders such as leptin and adiponectin (Iyengar et al., 2015).

From the perspective of personalizing screening, it seems reasonable to include metabolic parameters, rather than just BMI, in risk stratification models. Integrating data on body weight, fat distribution, and mammographic density may increase the accuracy of predicting the effectiveness of mammography in this population.

4.2. Physical activity

Regular physical activity has a beneficial effect on hormone balance and insulin sensitivity, which may reduce the risk of breast cancer (Friedenreich et al., 2010). Some studies suggest that women who are more physically active have lower breast density, which may contribute to greater mammographic transparency (Vachon et al., 2007).

Physical activity may also reduce circulating estrogen levels and chronic inflammation, which translates into changes in the structure of fibro-glandular tissue. From a population perspective, promoting physical activity may therefore not only reduce the risk of disease, but also improve the effectiveness of screening.

Epidemiological studies have shown that physical activity can modulate mammographic density, especially in premenopausal women, whose glandular tissue structure is more susceptible to hormonal changes (Maskarinec et al., 2006). This relationship is not always linear, but there is a tendency toward lower density in groups with higher activity levels, which may limit the masking effect described by McCormack & dos Santos Silva (2006).

Physical activity also affects the expression of genes related to estrogen metabolism and inflammatory processes, which may be important for maintaining a favorable breast tissue profile in the long term (Friedenreich et al., 2010). A reduction in the concentration of circulating inflammatory markers may limit stromal remodeling and excessive proliferation of the fibrous component, potentially improving the sensitivity of mammography.

From the perspective of screening programs, physical activity is one of the few modifiable factors that can simultaneously reduce the risk of biological and influence imaging parameters. Including information about activity levels in predictive models could support a more individualized approach to qualifying women for additional imaging methods, especially in groups with borderline breast density according to BI-RADS (Boyd et al., 2007).

4.3. Alcohol consumption

Meta-analyses indicate a linear relationship between alcohol consumption and breast cancer risk (Bagnardi et al., 2015). Alcohol increases estrogen levels and may enhance the proliferation of mammary gland epithelial cells. As a result, it may increase mammographic density, potentially reducing the sensitivity of the test.

Even moderate alcohol consumption may be clinically significant, especially in women with other risk factors. In the context of breast cancer detection, it is important to consider alcohol consumption as part of the individual risk assessment.

Long-term alcohol consumption can also lead to disturbances in estrogen metabolism in the liver and increased serum estradiol concentrations, which correlates with higher mammographic density in some populations (Vachon et al., 2007). Since high breast density increases the risk of cancer four- to six-fold and reduces the detectability of lesions (Boyd et al., 2007), the effect of alcohol may be twofold—both carcinogenic and diagnostic.

Alcohol also induces oxidative stress and the formation of reactive metabolites, such as acetaldehyde, which can damage DNA and promote cancerous transformation. These processes co-occur with the activation of inflammatory mediators, which may affect the remodeling of the extracellular matrix and the microenvironment of breast tissue (Iyengar et al., 2015).

In the context of mammography effectiveness, it is important to note that increased density and structural heterogeneity of tissue may exacerbate the masking effect of cancerous changes (McCormack & dos Santos Silva, 2006). For this reason, alcohol consumption should be analyzed not only as a risk factor for disease, but also as a potential factor affecting the sensitivity of screening tests.

Taking into account the amount and pattern of alcohol consumption in risk stratification models may contribute to better adjustment of screening intervals and eligibility for follow-up examinations in populations with increased breast density.

4.4. Hormone replacement therapy (HRT)

The use of estrogen-progestogen therapy is associated with increased breast density and a higher frequency of false-negative results (Chlebowski et al., 2003). Increased proliferation of glandular tissue makes it difficult to identify small cancerous lesions, which may lead to delayed diagnosis.

The effect of HRT is particularly noticeable in the first years of therapy, and changes in breast density may be reversible after discontinuation. For this reason, the decision to implement hormone therapy should take into account not only the symptomatic benefits, but also the potential impact on the effectiveness of diagnostic imaging.

5. Environmental factors and breast cancer detectability

5.1. Estrogen-like substances

Environmental exposure to estrogen-like substances is of growing interest to researchers because these compounds can affect both the development of breast cancer and the nature of breast glandular tissue, which in turn has a potential impact on the detectability of changes on mammography. These substances are collectively referred to as endocrine disrupting chemicals (EDCs) - they are synthetic or natural chemical compounds that can mimic or modulate the action of estrogens, leading to changes in hormonal signaling and proliferation of breast glandular cells (Sánchez Ocaña et al., 2025).

5.1.1. Xenoestrogens – examples and exposure

The most important compounds include bisphenol A (BPA), phthalates, parabens, pesticides, and dioxins, as well as polychlorinated biphenyls (PCBs). Bisphenol A is one of the most widespread estrogen-like compounds and is used in the production of polycarbonates and epoxy resins, which are found in food packaging, reusable bottles, can linings, and many everyday products, including kitchen equipment. Epidemiological studies have shown that higher serum BPA concentrations correlate with higher mammographic density in postmenopausal women, which is an indirect marker of increased breast cancer risk (Sprague et al., 2013).

Phthalates are commonly used plasticizers in plastics, found in food packaging, cosmetics, personal care products, and consumer materials. After metabolism to monoesthers, phthalates can bind to estrogen receptors ( ) and modulate hormonal pathways. Studies on phthalate metabolites have shown an association with increased breast density, although results vary depending on the specific metabolite (Sprague et al., 2013; EPA-HERO).

Parabens are preservatives used in cosmetics, personal care products, and some food products. Not all parabens show a clear association with breast density, but some paraben metabolites actively bind to estrogen receptors and modulate glandular tissue proliferation (EPA-HERO).

Pesticides and dioxins, including DDT (dichlorodiphenyltrichloroethane) metabolites such as p,p'-DDE (p,p'-dichlorodiphenyldichloroethylene) and TCDD (2,3,7,8-tetrachlorodibenzo-p-dioxin) - considered the most toxic and biologically active dioxin, classified as a persistent organic pollutant (POP) - exhibit estrogen-like properties and the ability to modulate the endocrine system. Systematic reviews indicate that exposure to these compounds may be associated with an increased risk of breast cancer, especially when exposure occurs during breast development (Lang et al., 2021; Sánchez Ocaña et al., 2025; Endocrine disruptors review).

Polychlorinated biphenyls (PCBs), widely used in industry as insulating agents, and dioxins, produced as by-products of combustion, are associated with steroid receptor modulation and endocrine disruption. The presence of these compounds in the environment has been linked to the risk of hormone-dependent cancers (Sánchez Ocaña et al., 2025).

5.1.2. Mechanisms of action

Endocrine disruptors act by mimicking natural estrogens and binding to estrogen receptors, leading to the proliferation of breast glandular cells. They can also interfere with hormone metabolism and receptor signaling, increasing proliferation and disrupting normal tissue differentiation processes. In addition, EDCs can induce epigenetic changes and modify the microenvironment of breast tissue, affecting both the risk of malignant transformation and the radiological properties of the tissue.

5.1.3. Occurrence of compounds in the environment

BPA and phthalates are present in polycarbonate and PVC plastics, as well as in food wraps. Parabens and phthalate metabolites are found in cosmetics, shampoos, lotions, and deodorants. Pesticides, PCBs, and dioxins remain in soil, water, and animal products, including fish, leading to chronic exposure. PM2.5 particulate matter can carry chemicals and contribute to systemic exposure to EDCs.

5.1.4. Relationship with mammographic breast density

The Wisconsin Breast Density Study found that postmenopausal women with higher serum concentrations of BPA (bisphenol A) or mono-ethyl phthalate had a statistically higher percentage of mammographic density than women with levels below detection (17.6% vs. ~12–14%) (Sprague et al., 2013). Higher breast density makes it difficult to identify small cancerous lesions and potentially reduces the sensitivity of mammography, which can lead to false negative results.

5.2. Air pollution

Air pollution, particularly exposure to fine particulate matter PM2.5, is increasingly being identified as a risk factor for breast cancer. Epidemiological studies indicate that long-term exposure to PM2.5 may be associated with both an increase in breast cancer incidence and changes in glandular tissue structure (White et al., 2023; Huang et al., 2025). One possible mechanism by which air pollution affects breast cancer detectability is through its impact on mammographic density. An analysis conducted by the Breast Cancer Surveillance Consortium showed a positive correlation between PM2.5 levels and higher breast density categories according to the BI-RADS classification classification (Yaghjyan et al., 2017).

High mammographic density is a recognized risk factor for breast cancer and at the same time reduces the sensitivity of mammography by masking cancerous changes. Biologically, this effect can be explained by the induction of chronic inflammation and oxidative stress. PM2.5 leads to the generation of reactive oxygen species (ROS), DNA damage, and the activation of proliferative pathways in breast epithelial cells (Turner et al., 2023). Epigenetic changes, including DNA methylation modifications, are also observed, which affect the expression of genes responsible for the differentiation and proliferation of glandular cells.

From a clinical perspective, populations living in areas with high levels of air pollution may require a more individualized approach to screening, especially when other factors that increase breast density are present. Including environmental exposure in risk stratification models has the potential to improve the effectiveness of screening programs.

5.3. Exposure to ionizing radiation

Ionizing radiation is a well-documented risk factor for breast cancer, particularly when exposure occurs at a young age, when glandular tissue is undergoing intense proliferation. Cohort analyses of atomic bomb survivors have shown a linear relationship between radiation dose and breast cancer risk (Preston et al., 2007).

The mechanism of radiation-induced carcinogenesis involves direct DNA damage, including double-strand breaks, chromosomal aberrations, and point mutations. Radiation can also activate oxidative stress mechanisms and disrupt DNA repair processes, increasing the likelihood of malignant transformation.

In the context of breast cancer detection, the potential impact of radiation on the structure of glandular tissue is important. Studies suggest a link between occupational or medical exposure to ionizing radiation and changes in volumetric mammographic density (Pepłońska et al., 2022). An increased fibro-glandular component may reduce the sensitivity of mammography, especially in the detection of small cancerous lesions. Although the radiation doses used in mammography are low, statistical models indicate that cumulative population exposure may slightly increase cancer risk (Pauwels et al., 2015; Miglioretti et al., 2016). Nevertheless, the benefits of screening significantly outweigh the potential risk of cancer induction.

From the perspective of personalized screening, women with a history of exposure to higher doses of radiation, e.g., as part of radiotherapy at a young age, may require extended imaging diagnostics, including magnetic resonance imaging, especially if they also have high breast density.

6. Biological mechanisms

The impact of lifestyle and environmental factors on breast cancer detectability is largely mediated by changes in the composition of glandular tissue. Key factors include estrogen level modulation, activation of inflammatory pathways, oxidative stress, and changes in the tumor microenvironment (Iyengar et al., 2015).

High breast density reflects a higher content of fibro-glandular tissue in relation to fatty tissue, which increases both the risk of malignant transformation and the effect of masking changes in mammography (McCormack & dos Santos Silva, 2006). Inflammatory processes and hormonal imbalances may contribute to the persistence of high breast density over a longer period of time.

The importance of epigenetic changes and interactions between environmental factors and genetic predisposition is also increasingly emphasized. The influence of lifestyle may therefore go beyond direct hormonal effects and include the regulation of gene expression related to cell proliferation.

From the point of view of diagnostic imaging, it is crucial to emphasize that the biological mechanisms described above have a direct impact not only on the process of carcinogenesis, but also on the radiological properties of breast tissue. Increased proliferation of the fibro-glandular component, enhanced angiogenesis, and persistent inflammation lead to an increase in breast radiological density, which may mask the presence of neoplastic changes in mammographic images. This means that lifestyle factors and environmental exposures not only affect the biological risk of cancer development, but also modulate the effectiveness of its detection. Thus, they are a factor influencing both the epidemiology of the disease and the effectiveness of screening programs.

7. Variables affecting the sensitivity of mammography

The effectiveness of mammography is influenced by the patient's age, menopausal status, breast density, BMI, and use of hormone therapy. In younger women with dense glandular tissue, the percentage of interval cancers is higher (Boyd et al., 2007).

Technical factors such as the quality of the equipment, the experience of the radiologist, and the imaging protocols used are also important. The introduction of breast tomosynthesis has increased the detectability of lesions in dense breasts and reduced the number of false-positive results (Ciatto et al., 2013).

In some populations, combining mammography with other imaging methods is being considered, particularly in women with a BI-RADS category of C or D, which may improve the overall effectiveness of the screening program.

8. Limitations

Limitations of this review include the heterogeneity of breast density assessment methods and differences in the definitions of environmental exposures. Most of the available studies are observational in nature, which limits the possibility of causal inference. In addition, the impact of lifestyle on mammography sensitivity is often assessed indirectly through breast density analysis rather than direct detection rates.

Differences between populations, varying healthcare systems, and varying access to additional tests may also influence the interpretation of results.

9. Discussion

A review of the literature indicates that lifestyle and environmental factors have a measurable impact on breast cancer detection. Obesity, physical activity, alcohol consumption, and HRT modify breast density and thus mammography sensitivity. Exposure to environmental pollutants and endocrine-active substances may affect tissue microstructure and increase the risk of false-negative results.

Implications for clinical practice include: Considering additional imaging methods in women with high breast density. Taking modifiable factors into account in individual risk assessment. Promoting a healthy lifestyle not only for prevention but also to optimize diagnostic effectiveness.

From a public health perspective, integrating lifestyle and environmental exposure information with BI-RADS classification and breast density assessment may provide the foundation for more effective and personalized screening strategies.

The data collected suggest that the effectiveness of mammography should not be viewed solely in technological terms, but as the result of a dynamic interaction between biological, environmental, and behavioral factors. Incorporating these variables into risk stratification models may be a step toward more accurate and equitable population-based diagnostics.

10. Conclusions

Lifestyle and environmental factors may influence breast cancer detectability by modulating mammographic density and the microenvironment of glandular tissue. Incorporating data on BMI, physical activity levels, alcohol consumption, hormone therapy, and environmental exposures into risk stratification models may be an important step toward truly personalized screening programs.

It should be emphasized that these factors affect not only the risk of developing the disease, but also the diagnostic effectiveness of mammography, influencing the masking effect of cancerous changes. As a consequence, they may determine the number of interval cancers and diagnostic delays.

In the context of medical technology development, future screening strategies should consider integrating clinical, environmental, and behavioral data with digital imaging systems and artificial intelligence algorithms. This approach may increase the effectiveness of population-based screening programs, improve risk stratification, and reduce inequalities in access to early diagnosis.

Further prospective studies are needed to determine whether lifestyle modifications can not only reduce the risk of developing cancer, but also improve the detection of breast cancer in mammography and reduce the incidence of interval cancers.

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