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Mammography In Breast Cancer Screening – Current Knowledge, Challenges, The Impact of Artificial Intelligence, And Effectiveness With A Focus On Poland

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Abstract

Mammography is a critical tool in breast cancer screening and secondary prevention, enabling early detection and significantly reducing breast cancer mortality. This literature review assesses the effectiveness of mammography in identifying early-stage tumors, discussing its advantages, limitations, and specific challenges. Additionally, advancements in imaging techniques, such as 3D tomosynthesis, are examined, especially for their enhanced sensitivity in women with dense breast tissue, which reduces structural overlap and improves diagnostic precision. The integration of artificial intelligence (AI) in mammographic image analysis opens new opportunities, supporting radiologists by automating the detection and classification of potential lesions, thereby increasing screening efficiency and reducing false-positive rates. However, effective implementation of AI requires seamless integration with clinical systems and ongoing research to refine algorithms for diverse clinical needs. Furthermore, legal frameworks are essential to delineate responsibility in AI-supported diagnostics.

This review emphasizes the status of breast cancer screening in Poland, where participation rates remain low despite the availability of free screenings. This highlights the need for improved public awareness and accessibility, especially in underserved areas. Overall, the findings underscore the fundamental role of mammography in breast cancer detection, with AI and other technological advancements significantly enhancing diagnostic accuracy while identifying areas for further improvement.

Keywords: breast cancer; mammography; AI; screening; Poland

Introduction

Breast cancer is the most common malignant tumor among women both in Poland and worldwide [1,2]. There has been a global increase in the incidence of this cancer, with the phenomenon being particularly intense in industrialized countries [1]. In Poland, breast cancer accounts for approximately 23% of all malignant cancer cases among women. The risk of developing this cancer increases in women post-menopause and those over 50 years of age [2]. The most significant risk factors for breast cancer include:

- Age, with an increase in incidence observed from the age of 35, peaking in the 50-70 age group;
- Genetic mutations, particularly in the BRCA1 and BRCA2 genes (less frequently in TP53, PTEN, STK11, LKB1, CDH1, ATM, CHEK2, PALB2). Notably, in cases of BRCA1 and BRCA2 mutations, regular MRI screenings are recommended as a screening method due to its higher sensitivity than traditional mammography in detecting early stages of breast cancer [3];
- Hormonal factors, including: early menarche before the age of 12 or late menopause after the age of 55, use of oral contraceptives containing estrogen, prolonged hormone replacement therapy, having a child after the age of 35 and obesity, especially in postmenopausal women, and low physical activity;
- Proliferative breast diseases;
- History of cancer in one breast;
- High intake of animal fats in the diet;
- Alcohol abuse;
- Nulliparity;
- Treatment for other breast diseases [2,4].

The following subjective and objective symptoms may occur with breast cancer:

- A palpable lump in the breast;
- Changes in the size, shape, or firmness of the breast;
- Thickening and/or retraction of the skin and nipple retraction, which may be an indirect sign of malignancy;
- Skin changes on or around the nipple;
- Nipple discharge (especially bloody);
- Redness and thickening of the skin (orange peel sign);
- Enlargement of skin veins in the breast;
- Ulceration of the breast skin;
- Enlargement of lymph nodes in the axilla [4,5].

Detecting breast cancer at the earliest possible stage significantly influences treatment outcomes and extends survival, achievable through mammography screening [2,5]. The effectiveness of X-ray mammography has been confirmed in randomized clinical trials, distinguishing it as the only screening method proven for breast cancer detection. This emphasizes the importance of mammography in the secondary prevention of this cancer [5].

Aim of the work

The aim of this study is to review the current applications of mammography as a diagnostic and screening tool in the context of breast cancer, with a particular focus on the impact of advanced technologies and artificial intelligence in improving diagnostic outcomes. The study also analyzes the limitations of mammography and presents the status of the breast cancer screening program in Poland, emphasizing the challenges related to increasing participation in preventive screenings.

Methods

This study is a literature review based on the analysis of scientific publications concerning the role of mammography in the diagnosis and prevention of breast cancer. The analysis included articles published in both Polish and English, sourced from databases such as Web of Science, PubMed, and Google Scholar, as well as websites and textbooks. A total of 51 sources were gathered, of which 28 met methodological criteria and were included in the further analysis.

The review included only publications that met the following criteria:

- Presented the application of mammography and its role in the prevention and diagnosis of breast cancer;
- Assessed the effectiveness of mammography in detecting breast cancer and its impact on mortality rates;
- Studies comparing the effectiveness of mammography with other imaging methods and examining the influence of new technologies, including artificial intelligence (AI), on improving the sensitivity and specificity of tests.

The review covered both research and review articles related to mammographic diagnostics and the role of artificial intelligence, with an emphasis on high methodological and clinical standards.

Literature review results

Mammography Examination

Mammography is an imaging examination of the breast, utilizing low doses of X-ray radiation to enable early detection of pathological changes. The term “mammography” generally refers to breast imaging and can include various techniques, such as ultrasound, MRI, or tomosynthesis, depending on the clinical situation [6]. The currently used examination method is full-field digital mammography, which, through advanced computer technology, processes radiological images, assisting doctors in identifying even subtle changes [5]. In this study, the term “mammography” will refer to classical X-ray mammography.

The mammography procedure involves positioning the patient in a standing position, applying gentle pressure to the breast, and taking an X-ray image.

This process provides a detailed tissue image while minimizing radiation exposure; however, the compression can sometimes cause skin damage, as highlighted in studies by Stephens et al. [7].

The most important component of the mammographic examination report is the assessment of the lesion using the BI-RADS scale:

- BI-RADS 0 – requires additional imaging tests and/or comparison with previous examinations;
- BI-RADS 1 – normal mammography;
- BI-RADS 2 – benign lesion, no further diagnostics required;
- BI-RADS 3 – probably benign lesion; initial observation and follow-up examination are suggested within a short period (usually six months);
- BI-RADS 4 – suspicious lesion, biopsy should be considered;
- BI-RADS 5 – lesion with high probability of cancer;
- BI-RADS 6 – diagnosed breast cancer [5].

Modern studies have also confirmed that BI-RADS assessments are consistent with MRI results, making this system a reliable tool in breast cancer diagnostics [8].

It is worth mentioning advanced breast imaging methods as a supplement to classical X-ray mammography. One of these is breast tomosynthesis, also known as 3D mammography, which uses a series of low-dose X-ray images taken at different angles. This technique provides a detailed image of the breast in the form of thin slices, minimizing structural overlap and increasing lesion detectability, especially in women with dense breast tissue. Tomosynthesis improves diagnostic accuracy, allowing for more precise tissue differentiation compared to traditional 2D mammography, reducing the risk of false-positive results and the need for repeat examinations [9].

Mammographic Appearance of Breast Cancer

Breast tumors are classified by the WHO based on the stage and histological origin. There are two main types: *in situ*cancers, which remain localized at the site of origin, and invasive cancers, characterized by the ability to infiltrate surrounding tissues and metastasize.

The *in situ* cancers include:

- Ductal carcinoma in situ (DCIS) – the most common type, confined to the milk ducts;
- Lobular carcinoma in situ (LCIS) – originates from the breast lobules.

The main invasive cancers include:

- Invasive ductal carcinoma (IDC) – the most common invasive type, developing within the milk ducts;
- Invasive lobular carcinoma (ILC) – less common, more difficult to detect in mammography;
- Other rare types, such as acinar adenocarcinoma (AAB), which exhibit more specific mammographic features that facilitate identification [5,10].

An important finding in mammography that strongly indicates a malignant breast tumor is the so-called *spiculated mass*. This is a round or oval mass of high density, with an irregular central part surrounded by a ring of extensions. This finding most often indicates IDC [5].

Tabár et al. also draw attention to the characteristic star-shaped or spherical appearance of masses typical of AAB. These features allow for precise localization of the tumor, especially in its earliest stages [11].

Another important finding that allows for the detection of even small, non-palpable breast cancers is microcalcification. It is worth noting that mammography is the only reliable method for their assessment. According to the literature, DCIS often manifests with microcalcifications, which are key to detecting this lesion in mammography [5,12,13].

A study by Lilleborge et al. found that certain morphological features of microcalcifications, such as thin, branching lines, increase the risk of breast cancer progression up to 20-fold compared to more typical linear or pleomorphic patterns. This characteristic is particularly noticeable in DCIS cases. Lilleborge et al. also noted that branching microcalcifications often occur in cases with higher histological grade and larger lesion diameter, suggesting an increased risk of local recurrence [13].

These findings are also confirmed by Weaver and Yang, who further emphasize that while DCIS is mainly detected through mammographic microcalcifications (up to 90% of cases), ILC rarely shows calcifications, making its detection more challenging and often less precise based solely on mammography [12].

Most commonly, however, mammography reveals a well-defined lump, which in 95% of cases turns out to be benign [5].

Mammography in Breast Cancer Screening

Mammography is the primary examination used in breast cancer screening programs worldwide. Studies report that in groups of women participating in screening programs involving mammography, mortality from breast cancer is reduced by 20-45%. The false-negative rate ranges from 3% to 30% [5]. According to 2020 data, mammography screening prevents an average of 21,680 breast cancer deaths in Europe annually. With maximum coverage, assuming 100% participation, an additional 12,434 deaths could be prevented, especially in Eastern Europe, where the potential reduction could be as high as 23% [14].

In most European countries, both organized and opportunistic screening programs coexist. Organized screening is a structured, nationwide preventive program involving regular invitations for specific age groups at a predetermined interval. Opportunistic screening, on the other hand, relies on individual initiatives from patients and their doctors, resulting in less consistent coverage and challenges in monitoring quality and effectiveness. Although both types of screening reduce mortality, studies have shown that organized screening is more effective in reducing breast cancer deaths [14,15].

The *Chiraiya* project has also highlighted the importance of mobile mammography units in reaching as many women as possible in the screening-eligible group. This project, implemented in India, involved deploying mobile mammography units to reach women in hard-to-reach areas such as Jammu Province. The project also underscored the importance of educational sessions in raising awareness about early breast cancer detection and dispelling myths about mammography. Such efforts proved essential in increasing interest in screening in rural communities [16].

The Situation in Poland

In Poland, new guidelines for the breast cancer prevention program have been in place since January 2024. Current recommendations for screening mammography include women aged 45-74, as well as women who have completed a five-year period after surgical treatment for breast cancer and remain on adjuvant hormone therapy (HT) and women who have completed breast cancer treatment and a five-year monitoring process following treatment completion [2].

Despite the availability of free mammograms, participation in Poland is low. Between 2012-2015, only 20-40% of women eligible for free mammography took advantage of the program, with 34% participation in 2022 [17,18]. Between 2016–2021, there was an increase in interest in screenings; however, the COVID-19 pandemic contributed to a decrease in the number of screenings performed in 2020, further reducing the effectiveness of breast cancer screening [19]. Polish women often avoid screenings due to social, psychological, and organizational reasons, such as a perception of good health, fear of results, or difficulty accessing medical facilities [17].

These participation rates are significantly lower than in countries such as Denmark, Finland, and Sweden, where participation exceeds 80%, indicating the need for more effective educational strategies, automated reminder systems, and support programs for patients to increase screening attendance [18]. To meet target goals, it is necessary to raise participation to at least 70% [17].

Advantages and Disadvantages of Mammography

The main benefit of mammography screening is the reduced risk of death from breast cancer. Observational studies have shown that relative mortality reduction ranges from 13% to 17%, highlighting the significant role of mammography in detecting breast cancer at an early, treatable stage [20]. Research indicates that annual mammography screening from ages 40-84 can reduce breast cancer mortality by up to 40% compared to no screening [21]. Other population studies have shown that screening mammography can reduce breast cancer mortality by approximately 20% among women aged 50-69 and lower the risk of severe cancer symptoms, allowing for earlier and less invasive treatment [22].

Mammography allows for the detection of localized cancers, which in turn reduces the risk of invasive procedures. Women who do not undergo screening are 3.4 times more likely to undergo mastectomy and 2.5 times more likely to receive chemotherapy, underscoring the importance of early cancer detection through mammography. The risk of cancers induced by mammographic radiation is considered minimal, estimated at one case per 76,000–97,000 women undergoing annual screening between ages 40-49, a statistically very low risk [21].

A significant drawback of mammography can be the technical limitations of this examination, which may lead to low contrast between various breast tissues, making it difficult to identify cancer foci against the background of normal tissues. Some types of breast tumors may even be completely undetectable in mammography [5]. Breast density is one of the main challenges in screening mammography, as dense areas can mask cancer presence, leading to false-negative results and reduced screening effectiveness [22].

One major issue associated with mammography screening is the phenomenon of overdiagnosis. This involves the detection of cancers that may never develop into symptomatic or life-threatening conditions. It is estimated that among women aged 50–69 who undergo biennial screenings, overdiagnosis affects 15 per 1,000 women [20]. This phenomenon raises concerns, especially since overdiagnosis can lead to unnecessary surgeries, radiation therapy, or chemotherapy [22].

Mammography screening carries the risk of false-positive results, which can lead to additional biopsies and tests. Studies have shown that the risk of a false-positive result for women regularly undergoing screening is approximately 20%, which can negatively affect patients' quality of life and perception of their health [20,21]. About 75% of women who undergo additional tests after screening mammography are found to be healthy, indicating a high rate of false alarms [22].

Interval cancers, detected between regular screening exams, are a diagnostic challenge because they may be missed during mammography or develop rapidly between screenings. It is estimated that 28-33% of breast cancers detected in women participating in screening are interval cancers [20].

The Impact of AI on Mammography

Artificial intelligence (AI) based on deep learning is capable of automatically detecting and classifying cancerous changes in mammography, increasing diagnostic accuracy and effectiveness in mammographic screening. The use of AI for mammogram interpretation allows for a significant reduction in the time needed to interpret images, reducing radiologists' workload and enabling them to focus on more complex cases [23]. An example includes a study on the impact of AI on the time required for radiologists to assess mammograms, which showed an improvement in assessment speed from 64 seconds to 30.4 seconds with AI support, as well as findings from the implementation of AI in the Danish breast cancer screening program, which reported a 33.5% reduction in radiologists' workload due to AI [24,25].

A study of Swedish radiologists revealed that 80.8% expressed positive opinions about integrating AI in mammographic screening, seeing potential for reducing workload and improving cancer detection accuracy [26]. AI, as an addition to the double-reading system, is viewed as a way to reduce false-positive results and increase test sensitivity, as proven in studies [24,26].

The introduction of AI in the Danish mammography screening program reduced the false-positive rate by 20.5%, significantly decreasing unnecessary recall for further tests. Following the AI implementation, the breast cancer detection rate increased from 0.70% to 0.82%, indicating higher effectiveness in identifying cases requiring further diagnosis. AI helped increase the detection rate of small tumors (≤1 cm) by 8.3%, which is crucial for early diagnosis and improving patient prognosis [25].

AI has also been shown to help radiologists more accurately classify mammograms into the appropriate BI-RADS category, increasing agreement between them, especially with more challenging cases, such as subtle asymmetries. Studies have shown that AI use improved the Area Under the Curve (AUC) from 0.739 to 0.773, indicating a significant increase in breast cancer detection precision in mammography, particularly in complex cases [27].

These conclusions are further supported by Ma et al., who report that the implementation of AI in mammographic examinations helps achieve an AUC score of 0.95, comparable to the results achieved by experienced radiologists. The increased effectiveness in classifying suspicious breast lesions allows for a reduction in the number of unnecessary biopsies [28].

Swedish radiologists expressed concerns about the legal responsibility for decisions made with AI assistance, particularly in cases where AI operates as an independent assessment system without human supervision, raising questions regarding the division of liability [26]. Lamb et al. also highlight the need to establish clear responsibility guidelines between algorithm developers and clinical users [24].

In the opinion of Swedish radiologists, AI may positively impact patient relations by increasing screening efficiency. However, some are concerned that the increase in AI results requiring additional assessment may lead to further radiologist overload, potentially reducing their work precision [26].

While AI shows promising potential, further research is needed to confirm its effectiveness across different clinical scenarios and adapt algorithms to varied work environments [23]. Full implementation also requires precise integration with existing organizational structures, including internal validation, user education, and ongoing performance monitoring, allowing for full utilization of modern algorithms' advantages [24].

Conclusions

Mammography, as one of the most important screening tests in breast cancer diagnosis, plays a crucial role in secondary prevention by enabling the detection of cancer at an early stage, which contributes to reduced breast cancer mortality. Detecting cancer at an early stage allows for more effective treatment and improves patient prognosis. The introduction of 3D tomosynthesis further enhances the sensitivity of cancer detection, especially in women with dense breast tissue, which minimizes the problem of structural overlap and improves diagnostic precision.

The integration of artificial intelligence (AI) in mammographic image analysis opens up new possibilities in screening. AI assists radiologists in automatically detecting and classifying cancerous lesions, reducing the time needed for image analysis and decreasing the number of false-positive results. However, the full implementation of AI requires precise integration with existing organizational structures and further research on adapting algorithms to specific clinical requirements. Legal regulations also remain necessary to clearly define the scope of responsibility for decisions made with AI assistance, especially when it operates as an independent assessment system.

Despite the numerous advantages of X-ray mammography, this technology has certain limitations, such as breast density, which can mask the presence of tumors, leading to false-negative results. Additionally, overdiagnosis and the risk of false-positive results can negatively impact patients' quality of life, leading to unnecessary biopsies and treatments.

The breast cancer screening program in Poland continues to struggle with low female participation rates, which limits its effectiveness. Challenges remain in increasing social awareness about the importance of preventive screenings and facilitating access to screenings, especially in regions with lower participation rates.

Raising participation to a satisfactory level requires the implementation of integrated educational campaigns, automated reminder systems, and support programs for patients.

In summary, mammography remains a fundamental tool in breast cancer detection, and its advancement, supported by modern technologies such as AI, significantly contributes to improving treatment outcomes. At the same time, it is necessary to continue developing methods that minimize the risk of overdiagnosis and provide patients with a safer and more precise diagnostic process.

Authors' Contributions Statement

All authors have read and agreed with the published version of the manuscript.
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