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Applications of Artificial intelligence in the assessment of breast imaging

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ABSTRACT

Artificial intelligence helps doctors and researchers of diagnostic imaging through higher sensitivity and specificity in diagnosis, most importantly, by avoiding wrong positive and negative findings. The purpose of the article is to explain how to enhance 'diagnostic confidence' in imaging diagnosis of nipple lesions to tell the difference between benign and malignant lesions. The article presents the projects and the technology of the AI hybridization with the current mammography, MRI, and ultrasound devices. The development prospects and challenges, encompassing ethical and evolutionary considerations, along with validation and scaling issues, for solutions widely adopted in imaging diagnostics of highlighted breast lesions.

Keywords: AI in radiology, AI in breast cancer, AI in mammography, AI in MRI of breast, AI in an ultrasound examination of the breast

1. INTRODUCTION

Integrating of AI into the existing screening process can lead to faster and more accurate results, making it more convenient for patients. However, there are still challenges that must be addressed, such as ensuring the generalizability of AI systems and addressing ethical concerns (Morgan and Mates 2020). Breast imaging is seeing a rise in the incorporation of artificial intelligence, resulting in substantial improvements in interpretative and operational capabilities. AI-based screening triage systems can efficiently identify regular examinations, while AI-driven computer-aided detection (AI-CAD) enhances cancer detection rates and reduces false positives (Morgan and Mates 2020). In addition, AI simplifies risk assessment, quality assurance, and numerous workflow processes (Morgan and Mates 2020). The implementation of AI in healthcare settings relies on substantial research findings that show enhanced quality, greater efficiency, and lower costs. Artificial intelligence (AI) is a broad and rapidly evolving field that encompasses a variety of technologies and applications. They all share a common goal: to use computer algorithms and data to solve problems or complete tasks that would traditionally require human intellectual capacity.

In the last 10-15 years, we have witnessed considerable advances in the availability and computing power of hardware, which enables the storage and processing of the ever-increasing data sets necessary for the development of AI. Moreover, a key element of this revolution has been the exponential growth in the amount and availability of data that can be used to train AI algorithms (Taylor et al., 2023). Machine learning (ML) is a technology that involves training models to learn to detect features and parameters that best describe the data. Deep learning is a sophisticated form of machine learning, employing deep neural networks that are modeled after the workings of the human brain. These networks' hierarchical architecture enables the step-by-step conversion of data, from basic to more intricate concepts (Le et al., 2019). In contrast to conventional CAD methods, modern AI algorithms, encompassing deep learning (DL), employ a distinct approach to image analysis. Machine learning algorithms can improve diagnostic accuracy by analyzing large datasets without relying on pre-existing image features, leading to more precise diagnoses (Retson and Eghtedari 2023).

A study published in 2020 showed that artificial intelligence algorithms were more effective than radiologists in identifying breast cancer through mammogram screenings. AI is being evaluated as an additional reader, aiming to decrease the workload of radiologists by automatically categorizing normal and suspicious cases. In particular, we focus on machine learning (ML), which enables computers to acquire skills and carry out specific tasks autonomously, bypassing the need for explicit human programming in each step. In most instances, ML algorithms rely on human-defined characteristics as an initial foundation for training; still, more sophisticated methods, like representation learning, allow systems to discover critical features within the data automatically.

Further advanced in its development is deep learning, which combines hierarchically organized, simple features into more complex structures to facilitate highly efficient data processing, particularly for images (Taylor et al., 2023). Over the past decade, convolutional neural networks, especially in deep learning, have had a substantial impact on non-medical image analysis. Image classification and object detection are now integral technologies in everyday processes across many industries, with applications including tasks such as these. These achievements in non-medical image analysis have paved the way for applications in radiology.

In this sector, artificial intelligence can carry out crucial clinical functions like categorization (for instance, verifying the existence or absence of a disease), demarcation (precise analysis of organs or lesions, which can aid in surgical planning), or recognition (for example, pinpointing tumors or other abnormalities). Radiology is becoming one of the most promising uses for AI, with the field's potential continuing to grow annually (Taylor et al., 2023).

2. METHODOLOGY

Materials and Methods

The article was developed based on the literature review of the available sources, which were in the form of full articles and were retrieved from Google Scholar and the PubMed database for the period Jan 2022- Feb 2025, on the use of artificial intelligence in the detection of changes in the nipples that cannot be seen. The following keywords were selected: AI in breast cancer, AI in breast cancer, Application of AI in mammography diagnosis, MRI, and Ultrasound. The article is a review, and the source articles were chosen subjectively according to the criteria of large research samples and competitive projects that are opinion leaders in the area discussed.

Inclusion and Exclusion Criteria

The current review was conducted on the usage of AI in the diagnostic imaging of focal lesions in the breast. Included studies were those published between Jan 2022- Feb 2025, were written in English, were fully available, and assessed the effectiveness of the AI methods in breast cancer diagnosis using mammography, MRI, and US. Studies had to involve comparisons with traditional diagnostic methods or the use of AI algorithms in clinical practice.

Exclusion criteria

Exclusion criteria were studies of low methodological quality, for example, no control group, insufficient number of participants; experimental studies that did not have clinical significance; and review articles that did not contain data from primary research. Information Sources and Search Strategy The search was performed on Google Scholar and PubMed from Jan 2022- Feb 2025. The search terms used were: 'AI in breast cancer', Artificial intelligence in mammography, 'Application of AI in diagnostic imaging', MRI breast cancer' and 'Ultrasound AI'. In addition to the initial search, other articles and systematic reviews were also examined to broaden the scope of the search.

Selection Process

Two independent reviewers first assessed titles and abstracts to determine eligibility. If there was any controversy, the third reviewer resolved it. Some tools were developed to help in the identification of duplicates and in the acquisition of the full texts (Figure 1).

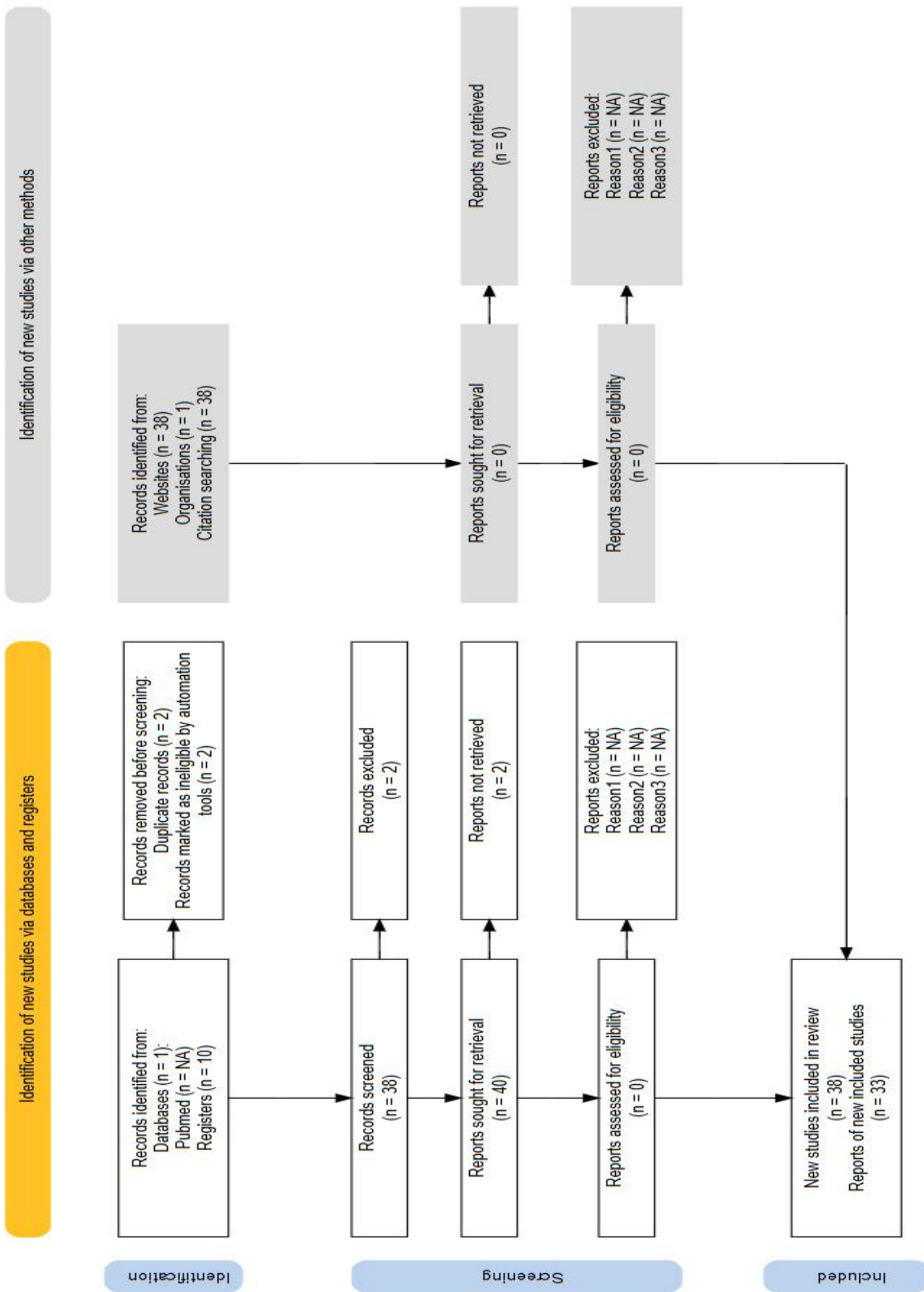

Figure 1: PRISMA-compliant methodology flow diagram

Data Collection and Extraction

The data were collected using a standardized extraction form, which includes study characteristics, methodology, outcomes, and risk of bias assessment. Two independent reviewers performed data extraction to guarantee consistency and accuracy in the data collection process, thereby preventing errors. Risk of Bias Assessment Risk of bias was evaluated using tools like RoB 2 for randomized trials and ROBINS-I for non-randomized studies, including selection bias, assessment of outcomes bias, and missing data bias. Risk of bias was classified into low, moderate, and high.

Synthesis Methods

We report our results using meta-analysis with random-effects models and quantify heterogeneity with the I^2 statistic. In cases where heterogeneity is significant, a sensitivity analysis and subgroup analysis will be conducted to pinpoint the origin of heterogeneity. The credibility of the evidence was assessed using the GRADE approach, which considers factors such as limitations in methodology, inconsistencies in results, indirectness of evidence, the precision of the measurements, and the risk of publication bias.

3. RESULTS AND DISCUSSION

Opportunities for AI applications in breast imaging

Breast imaging possesses distinct characteristics that offer distinct opportunities for the creation and integration of artificial intelligence (AI). A crucial component of supporting AI development in this area is the BI-RADS (Breast Imaging-Reporting and Data System) classification system, which was developed by the American College of Radiology. The BI-RADS system serves as a standardized lexicon and reporting framework for mammography, breast ultrasound, and breast MRI, encompassing terminology, classification, communication, and medical audit procedures. This system not only enables radiologists to interpret imaging studies but also provides a consistent framework for use by AI applications (Taylor et al., 2023).

Combining clinical findings with imaging assessments enables the development of datasets that are crucial for training and testing artificial intelligence models. Standardized mammography screening, which entails capturing images of each breast from both the oblique-medial and cranio-caudal angles, aids in the standardization of data in machine learning algorithms. Moreover, the availability of large datasets such as those containing more than one million mammographic examinations with corresponding patient information and clinical outcomes provides a solid basis for developing complex AI models. Available data is substantially more accessible for mammography than it is for other imaging techniques like ultrasound or MRI (Taylor et al., 2023).

The application of AI in radiological diagnostics of breast cancer

Breast cancer remains the most diagnosed cancer in women and the second most common cause of cancer death in the United States. In 2021, there were more than 281,000 new cases and 43,000 deaths due to it. Due to this high incidence, the development of methods to predict risk, detect and diagnose breast cancer early, and assess response to therapy has great potential to impact public health. In recent decades, medical imaging techniques have become a crucial factor in cancer identification, classification, treatment preparation, and tracking (Le et al., 2019). The main application of AI in breast cancer prevention is the integration of machine learning and deep learning algorithms to facilitate pre-screening and early detection of the disease. These algorithms can examine genetic data or histopathological images to identify early warning signs of breast cancer, thereby enabling prompt intervention and better patient outcomes. Thorough screening significantly enhances early diagnosis and treatment, integrating AI into existing screening methods can streamline and hasten the results process.

In the United States, breast cancer accounts for the highest frequency of cancer among women, except for skin cancers. Approximately one in three new cases of female cancer occurs annually. The continued development and integration of AI-based tools for breast cancer detection and prevention are crucial (Hu and Giger, 2021). The growing incidence of breast cancer has prompted the medical community to explore using the latest developments in artificial intelligence and machine learning to improve screening and early diagnosis techniques (Le et al., 2019). Early detection of the disease greatly improves a patient's prospects, substantially raising the chances of successful treatment, particularly when the condition is recognized before it progresses to a more invasive stage (Al-Karawi et al., 2024). The incorporation of artificial intelligence, featuring deep learning (DL) and machine learning (ML) methods, enables the automatic detection, segmentation, and categorization of breast tissue irregularities (Al-Karawi et al., 2024).

The implementation of computer-aided diagnosis (CAD) systems is capable of substantially lessening diagnostic mistakes, providing radiologists with support, and enhancing the efficiency of image analysis (Al-Karawi et al., 2024). AI models grounded on neural networks, such as convolutional neural networks (CNNs), exhibit high accuracy in mammogram interpretation, thereby improving cancer detection and lowering false-positive rates (Al-Karawi et al., 2024). Breast cancer detection is currently the most advanced and rapidly evolving sector of AI applications in breast imaging (Al-Karawi et al., 2024). The standardization of mammography and its widespread use as a screening tool present an opportunity to integrate AI and improve clinical outcomes. A recent study by Al-Karawi et al., (2024) demonstrated that the algorithms underwent the validation phase successfully, thereby verifying their capacity to detect cancerous lesions at a high level of performance accurately. There are currently more than 20 artificial intelligence (AI)-based applications for breast imaging that have been approved by the FDA. However, their use and introduction into daily medical practice are uneven and generally limited.

Breast imaging is distinctive in its specificity, which brings both opportunities and challenges for the development and implementation of AI technologies. Globally, breast cancer screening initiatives heavily depend on mammography to lower the incidence of morbidity and death linked to this disease (Taylor et al., 2023). For this reason, many of the most promising studies and available AI applications focus on detecting cancer based on mammography results. However, AI has the potential to offer much more - it can support medical decision-making, assess risk, analyze breast density, improve workflow, support the triage process, assess test quality, monitor response to neoadjuvant chemotherapy, and enhance the quality of images. In this paper, we look at the current status of these technologies, their availability, and the prospects and challenges facing their more widespread use (Taylor et al., 2023). In the US, outside of skin cancer, breast cancer is the most frequently diagnosed cancer in women, responsible for roughly one-third of all new female cancer cases each year. Population-based screening programs result in a huge number of mammograms each year, with nearly 40 million performed annually in the US alone (Taylor et al., 2023).

The EQUIP program, initiated in 2017, aims to improve the quality of assessments by introducing more efficient methods for screening examinations (Taylor et al., 2023). The widespread use of screening mammography as a public health strategy, coupled with its ability to decrease breast cancer mortality rates, has drawn the interest of medical researchers and imaging specialists. It's not a novel concept to use computer technology to enhance mammography performance. As far back as 1998, the FDA sanctioned the initial computer-aided lesion detection (CAD) tools. In 2002, technology was reimbursed by the Center for Medicare and Medicaid Services, leading to its rapid introduction into clinical practice. By 2008, up to 74% of mammograms were performed using CAD systems (Taylor et al., 2023). Although CAD technology contributed to an increase in the number of cases requiring further diagnosis (through higher recall rates), it did not significantly improve detection sensitivity or the detection of more advanced cancer cases (e.g., in terms of tumor size or lymph node status). Despite these limitations, CAD has become the standard for screening mammography. In 2016, it was used in 92% of all screening examinations in the US by integrating the cost of this technology with the price of standard mammography (Taylor et al., 2023).

AI Models - AI in breast imaging encompasses machine learning (ML) and deep learning (DL) (Bahl 2020):

- Machine Learning (ML) – enables computers to analyze and classify images based on data-driven patterns.
- Deep Learning (DL) – a subset of ML that utilizes neural networks to extract high-level features from raw image data (Bahl, 2020).

Recent advancements in AI-based technology have led to substantial enhancements in breast cancer detection systems, resulting in a decrease in both false positive and false negative rates. DL algorithms can identify anomalies in diagnostic images with an accuracy comparable to—or even exceeding—that of experienced radiologists. However, widespread adoption remains hindered by the lack of standardized datasets, potential biases in training data, and complex regulatory approval processes (Díaz et al., 2024). Further AI integration into diagnostic processes still requires additional investigation and medical verification, as suggested by promising developments. AI has the potential to transform breast cancer diagnostics by boosting detection accuracy and decreasing radiologists' workload. Deep learning-based systems can reduce inconsistencies between different readers and shorten the time needed for interpretation, as found. To integrate AI as a smooth part of breast imaging procedures, it is essential to have ongoing technological improvement, guaranteed transparency, and internationally agreed-upon regulatory guidelines (Díaz et al., 2024).

Decision support

Artificial intelligence can also assist radiologists in forming diagnostic conclusions, particularly in intricate scenarios. These algorithms help in decreasing the number of biopsies of non-cancerous growth and lower the likelihood of missing cancerous lesions that are hard to detect. Studies have shown that AI-based decision support improves both sensitivity and diagnostic specificity, especially for less experienced radiologists (Taylor et al., 2023).

Artificial Intelligence (AI) in the Context of Breast Cancer Detection and Diagnosis

Breast imaging is undergoing a significant transformation due to advancements in artificial intelligence, particularly in three major areas:

- Cancer detection abilities are enhanced by artificial intelligence technology, leading to improved sensitivity and specificity, which in turn decreases the number of false alarms and undetected cases (Bahl, 2020).
- Radiologists see a decrease in workload due to AI automating image analysis, which enhances workflow efficiency. Workflow efficiency – AI automates image analysis, decreasing the workload for radiologists (Bahl, 2020).
- Risk stratification – AI aids in individualized breast cancer risk assessment, facilitating personalized screening protocols (Bahl, 2020).

One example demonstrated that AI-based deep learning models achieved detection accuracy comparable to or surpassing that of experienced radiologists. AI also helps predict the effectiveness of pre-treatment chemotherapy and the likelihood of cancer spreading to lymph nodes (Bahl, 2020).

Evaluating the Effectiveness of Deployed AI Systems

The performance of an artificial intelligence algorithm in healthcare environments can deteriorate over time due to changes in the patient demographics, improvements in technology, or modifications in medical protocols.

Challenges Related to AI Transparency and Validation

Model evaluation requires both internal and external validation (Bahl, 2020):

- Internal validation – testing AI on data from the same source as its training set.
- External validation – assessing AI on entirely new datasets to confirm clinical applicability.

Performance assessment techniques include confusion matrices, receiver operating characteristic (ROC) curves, and heat maps, which visualize areas of diagnostic importance (Bahl, 2020). Despite growing use, one of the biggest challenges in the development of radiological AI algorithms is the lack of full transparency in their evaluation and validation. There is a need to publish detailed data on the efficacy of AI products, such as information on sample size, patient demographic characteristics, and equipment used for imaging. In addition, only a few studies offer data on the diagnostic efficacy of AI in populations underrepresented in studies. To enhance the implementation of AI in clinical practices, stricter validation standards and open access to public datasets are required, which could increase transparency and accelerate the process. (Rajpurkar and Lungren 2023).

Early detection of breast cancer is often achieved through the widespread use of screening mammography. In Europe, the double-reading system, where two independent radiologists review each scan, is the standard approach. However, due to the increasing shortage of breast radiologists and the growing volume of screenings, there is growing interest in using artificial intelligence (AI) as a potential replacement for one of the two readers (Dembrower et al., 2023). This study examines how different approaches to setting the abnormality threshold of AI systems affect cancer detection rates and diagnostic workload. The standalone-reader matching approach calibrates AI to match the sensitivity of a single radiologist, while the combined-reader matching approach adjusts AI to maintain the combined sensitivity of two human readers (Dembrower et al., 2023).

The study was conducted on 6,708 screening mammograms performed in Stockholm between 2012 and 2015. The dataset comprised 1,684 mammograms of women who were diagnosed with breast cancer within 23 months following their screening, alongside 5,024 mammograms of women without breast cancer. Studies show that customizing AI to mimic the assessments of a single radiologist significantly increases workload, resulting in the need for closer examination of a greater number of medical cases. For the adoption of the clinic, the combined-reader matching strategy appears more effective, as it reduces radiologists' workload while maintaining high cancer detection rates. Future studies should explore hybrid models, where AI calibration varies depending on breast tissue density (Dembrower et al., 2023).

AI can effectively support breast cancer screening, but its calibration significantly impacts diagnostic efficiency. Standalone-reader matching increases workload, training radiologists. Combined-reader matching optimizes workload management, maintaining high diagnostic accuracy. Future research should focus on personalized AI threshold adjustments, considering patient-specific factors such as breast density (Dembrower et al., 2023).

Evaluation of Effectiveness and Safety AI Systems

Comprehensive testing in a clinical environment and ongoing monitoring of their performance are essential to guarantee they meet safety standards. The FDA has approved the AI algorithms listed in Table 1 for use in breast imaging. Successful treatment and improved breast cancer outcomes rely heavily on early detection, which is a significant public health concern. Integrating AI into the current breast cancer screening procedure can yield quicker and more accessible outcomes for patients and may also decrease the workload of healthcare practitioners. Challenges persist and must be overcome, including the need to improve the generalizability of AI systems and to address ethical considerations.

Table 1. The role of AI in academic collaboration and investment

Importance and Partnership	
Role in Oncology:	AI is crucial in both academic and community oncology (McDonnell, 2023).
Partnership:	Effective integration of AI requires collaboration between academic institutions and community professionals (McDonnell, 2023).
Investment:	Necessitates investment in technology and education of healthcare workers (McDonnell, 2023).

The assessment of breast density

The proportion of fibroglandular to fatty tissue in the breast is a crucial indicator of breast density, which is a substantial risk factor for breast cancer and can impact the efficacy of mammography screening (Rajpurkar and Lungren 2023). The evaluation of breast density is significantly simplified and made more standardized through the use of AI, resulting in reduced disparities in outcomes among radiologists. Advanced deep learning-based algorithms can precisely categorize breast density, thereby facilitating tailored diagnostic methods and the determination of cancer risk. FDA-approved automated breast density assessment systems help reduce variability between radiologists and identify patients who may require additional imaging, such as ultrasound, contrast mammography, or MRI. Breast cancer risk is often heightened in dense breast tissue, making it more challenging to identify tumors (Rajpurkar and Lungren, 2023).

Evaluating the risk of cancer development

Breast cancer risk predictions can be made more accurate by integrating various data types, including mammography, clinical history, and genetics, into artificial intelligence models. Compared to traditional risk assessment models, this approach has shown better performance in recognizing women who require closer monitoring or preventive measures (Taylor et al., 2023).

Workflow optimization

Artificial intelligence can assist radiologists by streamlining their workflow, enabling them to prioritize examinations and promptly identify cases necessitating urgent intervention. Studies indicate that AI implementation in mammography triage can significantly decrease workload while enhancing diagnostic precision (Taylor et al., 2023).

Evaluation of image quality

A significant challenge in mammography is acquiring clear images and correctly positioning the breast. Artificial intelligence can automatically analyze mammograms to identify potential technical errors and offer recommendations for correction. As a result, they can enhance the efficiency and consistency of examinations (Taylor et al., 2023).

The application of artificial intelligence in breast imaging assessments

Research suggests that AI can have a substantial impact in several key areas, including increased diagnostic accuracy, reduced workload, and improved overall patient care quality (Dave and Patel 2023). The successful implementation of AI hinges on careful consideration of factors like local adaptation, integrating with existing workflows, and collaborative work among specialists. Radiology is an ideal area for integrating with AI due to the advancements in digital imaging and standardized data storage. Artificial intelligence algorithms can efficiently support workflow by automating tasks like the analysis of X-ray, CT or MRI images (Rajpurkar and Lungren 2023).

Challenges and limitations

Implementing AI in breast cancer screening and diagnosis offers numerous advantages but also introduces complexities and constraints that need to be taken into account. One of the significant challenges is guaranteeing the applicability of AI systems across multiple contexts. Training AI models on specific patient groups can lead to performance discrepancies when they are used with more diverse populations. Concerns have also been raised about the ethics of using artificial intelligence in healthcare, including problems related to patient confidentiality, secure data handling, and openness in medical decision-making processes (tables 2 and 3).

Table 2. The crucial challenges facing AI

Challenges in AI Implementation	
Data Quality:	Concerns about the quality of data input.

Table 3. Benefits of AI in detection of breast cancer

Benefits of AI in Breast Cancer Detection	
Early Detection:	AI applications can significantly enhance early detection and patient outcomes in breast cancer prevention.
Deep Learning:	Capable of analyzing genetic data and histopathological images to identify potential breast cancer markers.
Screening Process:	Simplifies obtaining results and encourages regular screening.

Ethical and Regulatory Challenges

The application of artificial intelligence in medical imaging has sparked a number of ethical and legal issues, which were highlighted in a study by Hickman et al., (2021).

- Inadequate diversity in training datasets can lead to disparities in diagnostic precision between different patient populations, largely due to algorithmic prejudice.
- Ensuring clinicians comprehend the reasoning behind AI decisions necessitates the development of explainable AI (XAI).
- Lack of clear regulations hampers the adoption of AI in clinical settings due to the uncertainty surrounding liability for AI-related misdiagnosis (Hickman et al., 2021).

Application of AI in radiology practice (mammography, CT, MRI).

Breast cancer screening relies on mammography, but AI can enhance lesion detection by identifying suspicious regions of interest (ROIs). AI has shown promise in reducing false positives and false negatives, thereby improving diagnostic confidence. AI-based mammography can also assist in breast density evaluation, a critical factor in breast cancer risk assessment (Palomba et al., 2024). AI algorithms in radiology perform a number of specialized functions that support radiologists in their daily work. AI is used to analyze images from various diagnostic techniques such as radiography, computed tomography (CT), ultrasound, or magnetic resonance imaging (MRI) (Rajpurkar and Lungren, 2023). As part of these functions, algorithms can perform quantification, workflow triage, and image quality enhancement, which significantly improves diagnostic accuracy (Rajpurkar and Lungren, 2023). For example, AI can be used to segment and measure anatomical structures, such as identifying lung nodules, analyzing breast tissue density or assessing blood flow in the brain. In addition, AI in radiology can help identify potentially dangerous lesions such as hemorrhages, vascular obstructions or pulmonary embolisms more quickly (Rajpurkar and Lungren, 2023).

Breast cancer screening programs rely on mammography to reduce both the morbidity and mortality associated with this cancer. As such, most research to date and existing artificial intelligence (AI) applications focus on cancer detection in screening mammography.

However, the potential applications of AI in breast imaging go far beyond just cancer detection. They can be grouped into two types: those requiring interpretation, like providing decision support or assessing responses to neoadjuvant chemotherapy, and those not needing interpretation, such as streamlining workflows, measuring breast density, or enhancing image quality (Taylor et al., 2023). Research indicates that AI models have the potential to extend interpretive capabilities beyond human abilities, especially in cases of complex diagnoses such as traumatic brain injury or cancer. AI algorithms can also predict clinical outcomes based on imaging data, such as computed tomography (CT) results or imaging of anatomical structures. In addition, artificial intelligence is facilitating the creation of novel imaging biomarkers, which enable the quicker and more impartial evaluation of pathological conditions, including bone mineral density and visceral fat levels (Rajpurkar and Lungren, 2023).

Benefits to patients include more tailored diagnostics, and they can also avoid radiation exposure. A new generation of general medical artificial intelligence (AI) models that will be able to analyze radiology images comprehensively is becoming increasingly feasible (Rajpurkar and Lungren, 2023). Using advanced technology, these models can produce comprehensive radiology reports and integrate image data with clinical information as well as past imaging findings. This approach will allow a deeper and more accurate interpretation of the results, considering the degree of uncertainty and the specificity of the data. Initial research on these models has shown that they can effectively detect different diseases in expert-level medical images, performing tasks without the need for further annotation, so-called 'learning from scratch' (Rajpurkar and Lungren, 2023).

This study aimed to compare the stand-alone performance of an AI system with that of 101 radiologists in detecting breast cancer on digital mammography (DM). Data from nine previous multi-reader studies were used, encompassing mammograms from different countries and imaging systems (Rodríguez-Ruiz et al., 2018). The study analyzed 2,652 mammograms, including 653 confirmed breast cancers, evaluated both by radiologists and an AI system (Transpara 1.4.0, Screen Point Medical BV, Nijmegen, Netherlands) (Rodríguez-Ruiz et al., 2018). The mammograms were obtained from multiple manufacturers and retrospectively assessed in previous multi-reader, multi-case studies. Radiologists assigned BI-RADS (1–5) or probability of malignancy scores (1–100) to each image, while the AI system provided a risk score (1–10), with 10 indicating the highest suspicion of cancer. Diagnostic performance was compared using the area under the receiver operating characteristic curve (AUC). A noninferiority threshold of 0.05 was used to determine clinical significance (Rodríguez-Ruiz et al., 2018).

The AI system demonstrated diagnostic performance comparable to radiologists (Rodríguez-Ruiz et al., 2018):

- AI AUC = 0.840 (95% CI: 0.820–0.860)
- Mean AUC of radiologists = 0.814 (95% CI: 0.787–0.841)

The difference between AI and radiologists was 0.026 (95% CI: -0.003 to 0.055), confirming that AI was not inferior to the average radiologist. Additionally, AI achieved a higher AUC than 61.4% of all radiologists and higher sensitivity than 57.9% of radiologists, although no AI model outperformed the best-performing radiologist in any dataset. The disparities between AI and radiologists were negligible across diverse datasets, implying that AI can be effectively utilized in multiple clinical environments (Rodríguez-Ruiz et al., 2018). According to Rodríguez-Ruiz et al., (2018), the study demonstrates that contemporary AI algorithms can attain diagnostic accuracy comparable to that of experienced radiologists. The actual effect in real-world situations hinges on data accuracy and the tactics used for clinical implementation.

Key points extracted are:

- Artificial intelligence can work independently or as a supplementary resource, especially in areas facing a shortage of breast imaging specialists.
- Further research is needed to assess AI's influence on clinical decision-making and workflow efficiency.
- AI-assisted mammography could reduce both missed cancers and false positives, improving screening program effectiveness.

The AI system demonstrated noninferior diagnostic performance compared to the average radiologist, confirming its potential as a valuable tool in breast cancer screening. While AI will not replace radiologists, it can significantly enhance diagnostic accuracy and optimize healthcare resources, ultimately improving breast cancer detection and patient care (Rodríguez-Ruiz et al., 2018).

The evaluation of the implementation of artificial intelligence (AI) in a nationwide breast cancer screening program in Germany

This is a multicenter, observational implementation study that compared AI-supported double reading of mammograms with traditional double reading without AI (Eisemann et al., 2025). The study was conducted at 12 screening centers, and 119 radiologists reviewed the data for 463,094 women aged 50–69 years. Key findings show that AI increased breast cancer detection rates by 17.6% (6.7 cases per 1,000 screenings in the AI group vs 5.7 in the control group), with a similar recall rate.

Furthermore, AI enhanced the positive predictive value (PPV) for both recall assessments and biopsies, i.e., increased cancer detection was not accompanied by increased false positives. Research suggests that integrating AI into breast cancer screening processes could not only increase the accuracy of cancer identification but also benefit radiologists by improving their working environment and minimizing the requirement for unnecessary medical treatments (Eisemann et al., 2025). Studies indicate that incorporating artificial intelligence into breast cancer screening protocols could enhance the precision of cancer diagnoses and create a more hospitable work environment for radiologists, in addition to decreasing the need for medically unnecessary procedures. The long-term effects of AI deployment are still uncertain, encompassing potential outcomes such as reduced interval cancers and fewer non-essential diagnostic tests (Eisemann et al., 2025).

CAD software in the practice of mammography – Power Look Density Assessment

iCAD's Power Look Density Assessment is a highly advanced software that streamlines and standardizes breast density assessment by utilizing mammographic images, thus automating the evaluation process (https://www.icadmed.com/breast-health/ai-breast-density-assessment). Power Look Density Assessment is a system that demonstrates the automation of breast density evaluation in the context of artificial intelligence applications in medical imaging, thereby eliminating the subjectivity found in traditional radiologist assessments. The system utilizes deep learning algorithms to examine mammographic images, categorizing breast tissue according to the BI-RADS standards that have been established.

Aidoc

Aidoc offers innovative AI-based solutions for the field of radiology that can analyze medical images and interpret them, suggest possible findings, and suggest actions to the care team. They offer products that fit into the current healthcare IT systems to support the implementation of AI in healthcare facilities. Aidoc boasts the most significant number of FDA-approved algorithms, enabling radiologists to make swift and precise decisions (https://www.aidoc.com/eu/).

In the field of radiology, the integration of artificial intelligence (AI) is a significant improvement in diagnosis and workflow. For example, Aidoc's platform is an automatic analysis of the medical images that can notify the radiologists of the need for urgent attention and sort the reports to be reviewed in the first place. Early intervention is achieved, leading to prompt treatment of severe patient conditions and consequently, more effective treatment outcomes.

Transpara

Transpara is an AI-based product developed by Screen Point Medical to assist radiologists in analyzing 2D and 3D mammography images. This system provides a second opinion that can aid in identifying breast cancer in its initial stages, thereby reducing the number of callbacks to the clinic. Pros of using Transpara in practice have been verified during clinical trials: the use of the system can improve the rate of cancer detection by 29%, while the workload of radiologists can be reduced by 44% without affecting the false positive rate. Likewise, Transpara – the product is developed by Screen Point Medical, assists radiologists in the analysis of mammograms, and offers them more information that can help in the diagnosis (ScreenPoint Medical, https://screenpoint-medical.com/choosing-transpara/#choosing).

Research has revealed that the use of this system boosts the rate of breast cancer detection by 29% and decreases the working time of radiologists by 44% without necessarily increasing the false positive rate. These cases illustrate how AI can support healthcare workers, thus enhancing the accuracy of diagnosis and the performance of healthcare institutions. The article published in The Lancet Digital Health is a piece of research that assessed the effectiveness of artificial intelligence in breast cancer screening in the Mammography Screening with Artificial Intelligence (MASAI) trial (Hernström et al., 2025). This randomized controlled trial compared double reading of traditional mammograms with a screening process assisted by AI. More than 105,000 women were involved in the study, and they were allocated to one of two groups:

- AI Group – Mammograms were analyzed by AI (Transpara v1.7.0) which used cancer risk to classify cases and suspect findings to refer.
- Control Group – The usual double reading by radiologists. Key Findings: It found that, AI increased breast cancer detection rate by 29% (6.4 per 1000 screenings in the AI group compared with 5.0 in the control group, p-value = 0.0021). More invasive cancers were

diagnosed (270 vs. 217, proportion ratio 1.24) along with in situ cancers (68 vs. 45, proportion ratio 1.51). It also enhanced the detection of small, node-negative tumours (58 more T1 cases and 46 more N0 cases). Without a significant rise in the false positive rate (1.5% for AI and 1.4% for the control group). The positive predictive value (PPV) of recall was higher in the AI group (30.5% vs. 25.5%, p value = 0.012) (Hernström et al., 2025).

The screen reading workload was reduced by 44%, which consequently eased the burden on radiologists. Thus, the use of AI improves the cancer detection rate and lightens the working load of the radiologists, which makes it a valuable tool in large screening programs. However, AI helped in the early identification of clinically significant cancers (e.g. triple negative and HER2 positive subtypes), which may lead to better patient outcomes (Hernström et al., 2025).

AI-assisted systems - computer-aided detection (CADe), diagnosis (CADx) and triaging (CADt) technology

AI-assisted systems such as computer-aided detection (CADe), diagnosis (CADx) and triaging (CADt) have been developed and implemented in clinical practice for decades. In recent years, developments in computing power and modern algorithms have significantly accelerated this process. Such systems analyze large amounts of quantitative data from images and support radiologists at various stages of their work, acting as a concurrent, Secondary or semi-autonomous reader (Le et al., 2019). This article analyses the current limitations and opportunities for the development of computer-aided detection (CAD) and artificial intelligence (AI) systems in breast imaging. The technologies discussed aim to improve breast cancer diagnosis, but at the same time face challenges in terms of implementation and effectiveness. The development of deep learning technologies has resulted in start-ups such as Therapixel and Kheiron Medical Technologies, which are using AI to improve screening mammography.

The advancement of digital breast tomosynthesis has led to the development of sophisticated AI-CAD systems, such as iCAD's Power Look Tomo Detection and Screen Point Medical's Transpara. In addition, AI-powered computer-aided diagnostic technologies are being created for other diagnostic methods, including ultrasound (USG) and magnetic resonance imaging (MRI), as mentioned in research by Le et al, (2019). For AI-CAD systems to be used in clinical settings, they must be evaluated in real-world scenarios. This requires:

- The use of large, representative datasets for testing. Assessing the interaction of radiologists with the systems.
- Assessing the interaction of radiologists with the systems.
- Cost-effectiveness analysis and feasibility studies to minimize the risk of unintended consequences (Le et al., 2019).

AI-CAD systems should be designed according to the principles of explainable artificial intelligence, which is particularly important in the context of the European Data Protection Regulation (RODO). This enables users to better understand the operation of the systems, which increases their acceptance in the clinical environment (Le et al., 2019). The development of AI-CAD tools faces numerous barriers, such as the lack of large, representative, high-quality datasets. Current datasets often come from single institutions, making it difficult to generalize results. In addition, differences in algorithm testing methodologies make comparison difficult (Le et al., 2019).

Advances CADe and CADx systems: in imaging and the development of artificial intelligence

Advances in imaging technology and advances in computers have contributed to a significant increase in the potential for artificial intelligence (AI) applications in breast cancer diagnosis. Artificial intelligence is used in risk evaluation, identification, diagnosis, forecasting outcomes, and tracking the response to treatment. Computer-aided detection and diagnosis systems, including CADe and CADx, have been developed over the decades and are now a standard part of routine clinical practice, particularly in mammography screening procedures (Bi et al., 2019). Computer-aided detection (CADe) and computer-aided diagnosis (CADx) systems are utilized in the screening process. CADe systems aid radiologists by identifying potential lesions on images and allowing human interpretation for classification. However, their effectiveness is limited by factors such as structural noise, radiologist fatigue or the subtlety of lesions. Deep learning algorithms are now being employed in CADe systems to analyze three-dimensional images obtained from three-dimensional ultrasound, MRI, and breast tomosynthesis, particularly benefiting women with dense breast tissue (Bi et al., 2019). Use of computer-aided diagnosis technology for distinguishing between cancerous and non-cancerous tissue growths. CADx systems employ a combination of pre-defined characteristics and those identified through deep learning techniques. These algorithms enable detailed numerical descriptions of lesions, including their size, shape, and texture. Dynamic contrast uptake analysis in breast MRI enables the evaluation of tumor heterogeneity, which can indicate tumor angiogenesis and susceptibility to treatment (Bi et al., 2019).

In addition to CADe and CADx, artificial intelligence facilitates the evaluation of breast cancer molecular subtypes, prognosis, and response to treatment. Investigations into predictive biomarkers employ data from clinical, molecular, and genomic images. AI also has applications in predicting patient response to specific therapies. Semi-automated MRI assessments of functional tumor volume have been pinpointed as predictors of recurrence-free survival in clinical trials. Automating these methods has the potential to accelerate the diagnostic process and enhance prognostic accuracy. Advances in breast cancer imaging technology, combined with advanced artificial intelligence (AI) algorithms, are opening new possibilities in diagnosis, risk assessment and personalization of therapy. Although AI brings many benefits, its effectiveness in clinical practice requires further validation and standardization to meet the challenges of data heterogeneity and the needs of patients and clinicians (Bi et al., 2019).

The function and constraints of routine breast cancer screenings via mammography - Widespread adoption of mammography in clinical settings has resulted in a substantial decrease in breast cancer mortality, most notably following the initiation of organized screening programs. Studies have shown that regular mammography check-ups can reduce mortality rates by up to 30% (Nicosia et al., 2023). Advances in artificial intelligence for mammography have led to considerable improvements in breast cancer diagnosis, yielding more precise cancer detection and refined diagnostic protocols (Lamb et al., 2022). This research delivers a thorough assessment of AI algorithms used for interpreting mammography images, examining how well they compare to radiologists' performance.

The research was undertaken as part of the DM DREAM Challenge, which included more than 1100 participants working on and evaluating AI algorithms designed to enhance breast cancer detection (Schaffter et al., 2020). This study retrospectively analyzed the diagnostic accuracy of AI algorithms compared to radiologists. Two large mammography datasets were used from (Schaffter et al., 2020):

- Kaiser Permanente Washington (KPW) in the U.S.
- Karolinska Institute (KI) in Sweden.
- Participants were divided into two subchallenges:
- Subchallenge 1 – AI models analyzed mammographic images without additional clinical data.
- Subchallenge 2 – AI models integrated imaging with prior mammograms, clinical history, and demographic risk factors.

Primary performance metrics included (Schaffter et al., 2020):

- The area under the receiver operating characteristic curve, measured as AUC.
- Specificity of AI algorithms at radiologists' fixed sensitivity (85.9% for KPW and 83.9% for KI).

Studies suggest that artificial intelligence should not replace radiologists but rather serve as a valuable tool to complement their work in the diagnostic process. Artificial intelligence can decrease the occurrence of false positives, thereby reducing the necessity for unnecessary biopsies and easing patient anxiety.

- Additional investigations are required to address the transparency of algorithms, ethical issues, and regulatory standards.
- Further research is needed on algorithm transparency, ethical concerns, and regulatory frameworks.
- AI integration should focus on enhancing radiologists' capabilities rather than replacing human expertise.

This study provides strong evidence that integrating AI into radiologist-led mammography interpretation improves accuracy. Although AI surpassed the performance of radiologists alone, its use as a tool to support them can optimize resource usage, lower the number of diagnostic mistakes, and improve breast cancer detection in screening programs (Schaffter et al., 2020). Breast cancer continues to be the most common form of cancer among women worldwide and a major reason for cancer-related deaths. Studies have shown that mammographic screening programs can significantly lower breast cancer death rates, but they also demand considerable radiologic resources. Over 99% of screening mammograms are negative, and the subjective nature of interpretation leads to 20–30% of cancers being missed during initial screenings (Larsen et al., 2024).

Artificial intelligence may help reduce the workload of diagnostics by either replacing one of the two radiologists involved in the screening process, or by prioritizing exams based on their associated cancer risk levels. This study, conducted within Breast Screen Norway, assessed the performance of a commercially available AI system in detecting breast cancer and its potential impact on radiologist workload (Larsen et al., 2024).

This retrospective study analyzed 661,695 digital mammograms from 242,629 women screened in Breast Screen Norway between 2004 and 2018. A total of 3807 screen-detected and 1110 interval breast cancers were included (Larsen et al., 2024). All images were analyzed using the INSIGHT MMG (Lunit, version 1.1.7.2). AI system, which assigned a continuous risk score (0–100) to each examination, with higher scores indicating a greater likelihood of malignancy. AI performance was measured using the area under the receiver operating characteristic curve (AUC) and cancer detection rates at different AI risk thresholds (Larsen et al., 2024). The AI system demonstrated high performance in detecting breast cancer within two years of screening, with an AUC of 0.93 (95% CI: 0.92–0.93) for all cancers and AUC of 0.97 (95% CI: 0.97–0.97) for screen-detected cancers (Larsen et al., 2024).

- At a 10% highest-risk threshold, AI correctly identified 92.0% of screen-detected cancers and 44.6% of interval cancers.
- At a 50% highest-risk threshold, AI detected 99.3% of screen-detected cancers and 85.2% of interval cancers, while also reducing false-positive results by 17.0%.

AI showed strong potential for reducing false-positive screenings, which could lead to fewer unnecessary patient recalls and biopsies (Larsen et al., 2024). Findings suggest that AI can significantly reduce radiologists' workload by automatically classifying low-risk cases and focusing human resources on high-risk findings. Key takeaways include (Larsen et al., 2024):

- AI should not replace radiologists but rather serve as a decision-support tool that enhances diagnostic efficiency.
- AI can improve standardization in mammography assessments, particularly in dense breast tissue, where cancer detection is more challenging.
- Further prospective studies are required to evaluate the real-world impact of AI on radiologist decision-making and diagnostic accuracy.

This study provides strong evidence that AI can improve breast cancer detection rates and reduce false positives, leading to a more efficient use of radiologic resources in screening programs. AI does not replace radiologists, but integrating it as a supplementary resource may lead to better diagnostic results and increased efficiency in breast cancer screening processes (Schaffter et al., 2020).

Assessment of Dense Breasts Utilizing Artificial Intelligence

Breast cancer is the most common type of cancer among women and a significant reason for cancer-related deaths. Timely identification is essential for successful treatment and enhanced patient outcomes (Mansour et al., 2022). Mammograms of women with high levels of glandular tissue are more difficult to read accurately due to the risk of obscuring cancerous growths, resulting in decreased sensitivity in diagnosis. The integration of artificial intelligence in mammogram analysis offers a chance to enhance the detection of breast cancer in women with dense breast tissue. This article explores the benefits and drawbacks of using AI to analyze mammograms from women with dense breasts (Mansour et al., 2022).

In this study, 6600 mammograms of patients with breast density classified as ACR "c" and "d" using full-field digital mammography and breast ultrasound. Mammographic images were evaluated using AI-based software (Lunit INSIGHT MMG) (Mansour et al., 2022). The final diagnosis was confirmed either by core needle biopsy by at least one year of imaging follow-up for stable findings. Mammographic analysis assisted by artificial intelligence in cases of dense breasts showed a sensitivity of 88.29% and a specificity of 96.34%, outperforming traditional mammography coupled with ultrasound (Mansour et al., (2022).

AI technology minimized both false-positive and false-negative outcomes, leading to an increase in overall diagnostic accuracy to 94.5%. The use of AI as a clinical decision-support tool significantly improved the identification of malignancies that might have gone undetected otherwise (Mansour et al., 2022).

Breast cancer diagnostics in women with dense breasts using AI have yielded promising results, yet numerous challenges persist. Further refinement of algorithms is required to reduce false-negative outcomes, especially when identifying small, low-contrast lesions (Mansour et al., 2022). Furthermore, the clarity and understandability of AI-produced outcomes need to be enhanced to facilitate smooth incorporation into clinical practice. Artificial intelligence is poised to transform breast cancer diagnosis in women with dense breast tissue by enhancing detection accuracy and decreasing the workload of radiologists. Moreover, AI could potentially become a standard resource that supports radiologists in making diagnostic choices in breast imaging by the time of a future study (Mansour et al., 2022).

CAD systems in traditional digital mammography (FFDM)

The first CAD systems in mammography were based on a rule-based approach, where diagnostic features were manually created and then classical machine learning techniques were used to classify them (Le et al., 2019). Conventional CAD systems relied on algorithms that were pre-programmed to detect cancerous lesions by identifying specific image characteristics. Nevertheless, clinical trials showed that these systems frequently resulted in more incorrect positive results and did not substantially boost cancer diagnosis rates. The initial excitement surrounding CAD had to be reassessed in light of its limitations when implemented in real-world clinical settings (Sechopoulos and Mann, 2020). The first commercial CAD system, Image Checker M1000, used computer vision techniques for pattern recognition.

In the late 1990s, the introduction of CAD systems was made with the aim of increasing the accuracy of breast cancer detection (Retson and Eghtedari, 2023). The first FDA-approved system, ImageChecker M1000, was designed to examine mammographic images for signs such as microcalcifications and irregular masses. Radiologists initially thought CAD would help identify potentially problematic growth, but it turned out these systems often generated a high volume of false alarms, leading to unnecessary biopsies and increased patient anxiety (Retson and Eghtedari 2023).

Research indicates that conventional CAD systems fail to enhance breast cancer diagnostic accuracy substantially, and numerous radiologists have disregarded the proposed annotations due to their lack of reliability (Retson and Eghtedari 2023). Furthermore, these systems lacked explainability mechanisms, which limited their clinical usefulness. However, studies have shown that CAD implementation could negatively impact the performance of some radiologists and lead to increased recall rates. Additionally, a cost-effectiveness analysis should be conducted, and large-scale feasibility studies should evaluate potential unintended consequences of AI implementation (Le et al., 2019). Furthermore, AI-CAD tools must comply with the European Union's General Data Protection Regulation (GDPR) and integrate explainable AI, ensuring greater transparency and trust in algorithmic decision-making. The first commercial CAD system was the ImageChecker M1000, approved by the FDA in 1998. This system was intended to support radiologists by providing additional opinions to improve diagnostic accurClassic computer vision methods were employed for pattern recognition, but this approach did not enable the system to operate independently as a diagnostic tool (Le et al., 2019).

AI algorithms have been found to exhibit high precision in identifying microcalcifications and heterogeneous masses, thereby facilitating the earlier detection of cancerous transformations (Al-Karawi et al., 2024). CNN-based models such as YOLO and Faster R-CNN achieve high accuracy in the automatic classification of mammographic images (Al-Karawi et al., 2024). The Digital Mammography DREAM Challenge brought together a multidisciplinary team of experts and provided 640,000 mammography images to develop methods to reduce false-positive screening results. The winning teams used deep learning (DL) techniques, including convolutional neural networks, to improve diagnostic performance (Le et al., 2019). The DM DREAM challenge ran from November 2016 to May 2017, gathering over 640,000 mammography images to enhance the diagnostic precision of breast cancer. Interdisciplinary collaboration and cutting-edge methods like deep learning enabled the development of solutions that substantially enhance the work of radiologists (Le et al., 2019).

Breast density, defined as the ratio of fibroglandular tissue to adipose tissue, is a significant risk factor for breast cancer. In full-field digital mammography (FFDM), breast density and parenchymal patterns are analyzed as potential biomarkers. Assessment of the spatial distribution of dense tissue and characterization of parenchymal textures through computer vision techniques enables the identification of women at heightened risk of breast cancer, specifically those with BRCA1/BRCA2 gene mutations. The role of artificial intelligence in breast cancer diagnostics is escalating, particularly in the context of screening mammography, where it improves cancer detection and simplifies image analysis. Presently, more than 15 AI algorithms have been cleared by the FDA for use in clinical settings, encompassing lesion detection and classification, breast density evaluation, risk assessment, and image quality control. Further research is necessary to validate the effectiveness and safety of these algorithms in clinical practice, even with the advancements in technology (Bi et al., 2019).

The gap of technology: contrast-enhanced spectral mammography

Artificial intelligence (AI) is rapidly advancing from pilot research to clinical implementation in breast radiology. This progress is fueled by enhanced computational algorithms, increasing availability of large datasets, and improved computing power. CAD systems introduced in the 1990s typically based their detection on pre-defined image characteristics such as density and shape. Current autonomous AI-based methods can automatically identify medically significant patterns that may remain undetected by the human eye (Bahl, 2020). Unfortunately, there is currently a shortage of suitable AI-powered tools for contrast-enhanced spectral mammography available for purchase. Further research and development of these solutions are now possible, potentially leading to increased diagnostic accuracy (Le et al., 2019).

Digital breast tomosynthesis (DBT) – challenges of AI in breast imaging

Digital breast tomosynthesis (DBT) is a 3D imaging technique that reduces the tissue overlap seen in 2D mammography. This improves the detection of cancerous lesions and reduces false positives. Combined with AI, DBT allows an even more effective diagnosis of breast cancer (Le et al., 2019). Despite its many opportunities, breast imaging also poses many challenges for AI. One of these developments is the swift adoption of new technologies like digital breast tomosynthesis (DBT). DBT produces significantly greater and more intricate image data than traditional digital mammography (FFDM). A single DBT scan can comprise multiple images, usually exceeding 1 gigabyte in file size, which presents difficulties in storing, transmitting, and processing the data within a clinical setting (Taylor et al., 2023).

DBT significantly increases the volume of image data radiologists need to examine, making it a prime candidate for AI-assisted support. Interpreting breast imaging is a multifaceted task, largely dependent on a number of factors, including the radiologist's level of experience, the patient's medical history, and the cancer's distinct features. The variation in DBT image appearance presents a significant challenge due to differences in both hardware manufacturer and software version. The complexity of the situation is exacerbated by the growing adoption of synthetic mammography images, which are now taking the place of conventional FFDM images. The challenge of AI systems is posed by the ability of manufacturers to decrease radiation doses for patients, as this is affected by variations between different companies and software upgrades, potentially impairing their functionality across a range of technological settings (Taylor et al., 2023).

Application of AI in ultrasonography

Breast ultrasound complements mammography, especially in women with dense breast tissue. Automated breast ultrasound systems reduce variability in operator technique, generating up to 2,000 images per examination, which in turn improves the speed of detecting initial tumorous growths. Furthermore, ultrasound offers a superior ability to distinguish between cystic and solid tumors compared to mammography. Algorithms used in AI systems enhance the understanding of ultrasound images by automatically identifying and categorizing cancerous growths (Le et al., 2019).

Ultrasound scans are an essential diagnostic tool, especially for women who have dense breast tissue. Mammography interpretation tends to be less subjective and less reliant on the individual operator compared to US image interpretation. Using artificial intelligence can improve the accuracy of diagnoses by utilizing uniform image analysis and reducing misinterpretations. Automated breast ultrasound systems utilizing AI facilitate a more objective evaluation by capturing full-breast images, thereby reducing the influence of operator-dependent image selection. Studies have shown that AI in ABUS achieves diagnostic performance comparable to experienced radiologists while reducing the time required for image analysis (Retson and Eghtedari, 2023).

Koios DC Breast

Koios DS™ Breast is a Smart Ultrasound program created to assist in the early and precise diagnosis of breast cancer. Utilizing intelligence algorithms, the system examines a few ultrasound images and evaluates numerous characteristics within each image. The program is designed to be easily used with PACS workstations, simplifying the process of evaluating the risk of malignancy. Users select a specific area to examine the malignancy risk more straightforwardly. Users choose an area to examine. Receive a prompt analysis from Koios DS, which rapidly categorizes all nodule characteristics in accordance with BI-RADS or ATA standards for real-time rating calculations (https://koiosmedical.com/products/koios-ds-breast/).

The findings can then be published in the American Journal of Roentgenology, indicating that employing AI-driven decision support enhances the accuracy of breast ultrasound lesion assessments and reduces discrepancies in interpretation among observers, yielding improvements in diagnostic precision. There were enhancements in the precision of diagnoses. This led to the discovery of 6 cancer cases per 100 evaluations. It could lower the rate of unnecessary biopsies by 31%. The Koios DS™ Breast represents a cutting-edge tool that combines machine learning techniques with ultrasound image interpretation to support healthcare decisions effectively.

Applications of AI in magnetic resonance imaging (MRI) and PET

MRI provides a detailed view of soft tissue structures, and deep learning algorithms are used for precise segmentation and assessment of cancerous lesion progression. Image enhancement in breast imaging can be improved by AI algorithms, such as sharpening diagnostic details. AI can also simulate MRI images with lower contrast dose, reducing the risks associated with its use (Taylor et al., 2023). MRI and PET imaging benefit from AI-driven radiomics and radio genomics, which allow for molecular-level tumor assessment without the need for invasive biopsies (Zheng et al., 2023).

The supplemental MRI in population-based breast cancer screening (ScreenTrustMRI trial)

The ScreenTrustMRI trial was a randomized clinical study evaluating the use of artificial intelligence (AI) to select individuals for supplemental MRI. The AI tool analyzed mammograms and assigned risk scores, with the top 6.9% of patients being offered MRI screening. Participants were then randomly assigned to receive MRI or no additional imaging (Salim et al., 2024). The study's primary endpoint was the detection of advanced breast cancers, while preliminary results focused on the detection of additional cancers using MRI. The study included 59,354 women whose mammograms were assessed using the AISmartDensity AI model (Salim et al., 2024). A total of 4,103 women had an AI-determined "very high" risk score and were eligible for participation. Ultimately, 1,315 participants consented to the study, with 663 undergoing MRI screening. MRI scans were interpreted by experienced radiologists using the BI-RADS classification system, guiding further diagnostic decisions (biopsy, observation) (Salim et al., 2024).

- AI-based selection was nearly four times more effective than traditional breast density-based methods in detecting cancers (64 cancers per 1,000 MRIs vs. 16.5 per 1,000 MRIs in the DENSE trial).
- 36 breast cancers were detected, most of which were invasive and multifocal.
- Positive predictive value (PPV) for individuals classified as BI-RADS 3–5 was 37.9%, indicating high selection efficiency.
- Detected cancers were smaller on average (13 mm) compared to standard mammography-detected cancers (15.8 mm) and interval cancers (19.6 mm), suggesting earlier detection through AI-assisted MRI screening.

While AI significantly improves patient selection for MRI, several challenges remain (Salim et al., 2024):

- Algorithm standardization – AI models require extensive validation before widespread clinical use.
- Physicians require AI models that provide transparent and understandable results to comprehend the underlying diagnostic logic.
- The high cost of MRI scans restricts their broader use in population screening programs.

Results from the ScreenTrustMRI study show that AI-driven selection of high-risk patients for additional MRI scans can improve early cancer diagnosis. The approach outperforms traditional breast density-based selection methods and could be more cost-effective. Additional clinical trials and regulatory clearances are needed before AI can become a standard part of breast cancer screening programs (Salim et al., 2024).

The combination of positron emission tomography (PET) and magnetic resonance imaging (MRI)

Integrating positron emission tomography (PET) and magnetic resonance imaging (MRI) into a single examination facilitates a comprehensive assessment of breast tumors by incorporating anatomical, perfusion, and molecular data. The integration of artificial intelligence in image analysis improves the detection of tumors, evaluates the risk of recurrence, and forecasts the response to treatment (Romeo et al., 2023). The latest applications of radiomics, machine learning, and deep learning for breast cancer image analysis are evaluated. Special attention is given to AI's applications in tumor molecular profiling, lymph node status assessment, and response prediction to systemic therapy (Romeo et al., 2023).

Research has shown that AI greatly enhances breast cancer identification and classification. Machine learning algorithms are capable of analyzing intricate imaging patterns that are beyond the scope of human perception. The combination of PET and MRI imaging with artificial intelligence has resulted in (Romeo et al., 2023):

- Performing non-invasive tests to analyze tumor molecules minimizes the requirement for surgical biopsy procedures.
- More accurate lymph node involvement prediction, leading to improved disease staging,
- Breast cancer recurrence risk stratification, allowing for personalized treatment planning,

Advanced AI analytics improve diagnostic precision and support informed clinical decisions, which may lead to better patient outcomes. Advanced AI analytics enhance diagnostic accuracy and facilitate informed clinical choices, potentially yielding improved patient outcomes. Moreover, further clinical trials, regulatory endorsements, and technical refinement are required before AI can become a widely accepted tool in breast cancer diagnostics (Romeo et al., 2023). In addition, techniques such as contrast-enhanced mammography and magnetic resonance imaging offer improved diagnostic precision. The introduction of new imaging methods, like digital mammography, tomosynthesis, and artificial intelligence, presents new possibilities for the identification of breast cancer (Nicosia et al., 2023). Further research is required to improve the integration of these advanced technologies (PET/MRI), with the ultimate goal being the development of the most precise and user-friendly diagnostic techniques (Nicosia et al., 2023; Romeo et al., 2023).

Applications of AI in Clinical Practice

Radiological artificial intelligence models are gaining global interest, with companies in more than 20 countries commercializing them. More and more hospitals and healthcare centers are beginning to adopt AI products, and larger facilities are embracing these technologies more frequently. Radiologists who have implemented AI in their work tend to give positive feedback, appreciating the technological support that artificial intelligence offers. Despite this, worries persist about inadequate understanding, diminished credibility, and the evolving responsibilities of radiologists. Providing adequate training and support will be crucial in enabling radiologists to effectively leverage AI as a complementary diagnostic and workflow improvement tool, similar to a co-pilot (Rajpurkar and Lungren, 2023). This technology has the potential to simplify clinical procedures and support well-informed decision-making processes. Artificial intelligence's ability to identify complex patterns, which can be difficult to spot without magnification, enables a more objective and fact-based examination of images. Furthermore, AI technology can analyze large quantities of data from various sources, like radiographic imaging, genomics, pathology, or medical records, facilitating intricate examinations and forecasts (Le et al., 2019).

The Evolution and Projected Development of Artificial Intelligence Models in the Medical Field

The rapid development of artificial intelligence models, such as self-monitoring and multimodal models, will undoubtedly lead to advancements in the field of radiology. Particular attention is being paid to large language models that can combine textual and image data (Rajpurkar and Lungren, 2023). Large language models such as GPT-4 have already demonstrated the ability to produce expert-level medical notes and answer clinical questions. In the future, it is anticipated that artificial intelligence will be able to process images, speech, and text, generating responses in the form of textual explanations, voice recommendations, and image annotations. These types of surgeons and GPs provide personalized recommendations and natural language interactions (Rajpurkar and Lungren, 2023).

Validation and Transparency Challenges

Despite its great potential, the application of generic artificial intelligence models in medicine comes with some challenges, especially in terms of validation and transparency. One of the main problems is the lack of sufficient data on the effectiveness of these models, especially in the context of the diversity of patient populations, imaging technologies and clinical practices. Although large language models can be trained on huge datasets, their ability to generalize to new, as yet unexplored patient groups and diverse geographical and technological contexts remains uncertain. Additionally, validating these models within real-world medical settings necessitates further research and the establishment of stringent standards to measure their performance (Rajpurkar and Lungren, 2023).

An AI system serves as an educational tool for patients to comprehend possible treatment strategies for breast cancer as examined in the CINDERELLA trial

Patients can now choose from various local treatments for breast cancer, yielding similar results in cancer care, yet varying in their cosmetic impact. The decision-making process is highly significant, and patients' high expectations for visually appealing outcomes greatly affect their overall satisfaction and quality of life (Kaidar-Person et al., 2023). The CINDERELLA Trial is a multicenter, randomized clinical study aimed at evaluating the efficacy of an AI-driven cloud-based system in aiding patient decision-making against traditional educational methods. This study involves the prospective randomization of breast cancer patients undergoing local therapy into two groups (Kaidar-Person et al., 2023):

- Control group – patients receive conventional information about available treatment options
- Intervention group – patients have access to the CINDERELLA platform, which provides personalized visual simulations of potential aesthetic outcomes for different surgical and radiotherapy procedures.

A computer system driven by artificial intelligence generates customized predictive images, allowing patients to acquire a more detailed comprehension of the potential consequences linked to a specific course of treatment. The central management of the randomization process reduces the impact of confounding variables like patient age, the type of surgery (breast-conserving versus mastectomy), and the use of radiotherapy (Kaidar-Person et al., 2023). The main goals of the trial comprise:

- Evaluating the match between the results and patients' expectations from a treatment and the actual beauty outcomes they experienced afterwards.
- Evaluating the agreement between AI-based pre-treatment predictions and patients' Self-assessments post-therapy.

Secondary objectives include:

- Measuring the impact of AI on body image satisfaction post-surgery,
- Assessing healthcare resource utilization (hospital visits, treatment duration, additional care requirements),
- Evaluating patient satisfaction with their professional and sexual life,
- Examining overall health-related quality of life.

The objective of the study is to recruit more than 1000 participants, with 515 individuals in each group, and to perform statistical assessments, which encompass multivariate regression models and evaluative assessments of aesthetic outcomes utilizing the BCCT.core scale (Kaidar-Person et al., 2023). The incorporation of artificial intelligence in decisions about breast cancer treatment is poised to revolutionize patient education, resulting in more accurate expectations, improved patient satisfaction, and a decreased need for additional corrective surgeries (Kaidar-Person et al., 2023).

- Providing clear explanations for AI-driven predictions so patients can comprehend their basis.
- Diverse data representation, to prevent biases in algorithmic recommendations
- User accessibility, ensuring the platform is intuitive and easily navigable, regardless of digital literacy.

The CINDERELLA Trial explores the potential of an AI-driven platform as a decision-support tool for breast cancer patients considering local therapy (Palomba et al., 2024). AI integration is expected to enhance patient satisfaction, optimize treatment choices and reduce unnecessary secondary procedures. Long-term, this platform may establish a new standard for shared decision-making in breast oncology, bridging the gap between medical expertise and patient expectations (Kaidar-Person et al., 2023).

AI support in oncogenetic diagnostics - Tempus NExT platform

Tempus, a technology company focused on precision medicine, has entered a partnership with Stemline Therapeutics, an affiliate of the Menarini Group, to adopt the Tempus NExT platform. This AI enabled care pathway intelligence platform is expected to help patients with metastatic breast cancer (mBC). Approximately 50% of patients with ER-positive and HER2-negative metastatic breast cancer are estimated to develop ESR1 mutations due to prior endocrine therapy in the metastatic setting. These mutations are important to recognize in order to make the right treatment decisions (https://tiny.pl/b2c25m1g).

The NExT platform reviews clinical data from mBC patients at selected centers and tells the clinician where to consider ESR1 testing when the disease has progressed. The Tempus NExT platform serves as a model for addressing unique challenges in the medical care of metastatic breast cancer patients through artificial intelligence applications. The system operates by examining current clinical data in real time and is able to determine whether specific diagnostic tests have been performed or not; for example, whether a patient has been tested for the ESR1 mutation or not, as it can impact treatment; utilizing such a tool may lead to a more targeted therapy, thereby improving treatment outcomes and the patient's quality of life.

Treatment with chemotherapy before surgery

Artificial intelligence has been used to forecast how patients will react to neoadjuvant chemotherapy, allowing for a more tailored treatment plan. AI systems can examine images from mammograms, MRIs, or ultrasound scans, predicting the response to treatment even before it commences (Taylor et al., 2023).

The Future of Generic AI Models in Healthcare

The potential of generic AI models in medicine, particularly in the interpretation of radiological images, has the potential to revolutionize not only radiology itself but the healthcare sector as a whole (Rajpurkar and Lungren, 2023). As technological advancements proceed, medical professionals can anticipate AI becoming an indispensable aid in their everyday work, enhancing the precision of diagnoses and expediting treatment procedures. However, in order to fully realize this potential, it will be necessary to overcome existing validation difficulties and ensure transparency and safety in the use of AI in clinical practice (Rajpurkar and Lungren, 2023).

Integrating AI with Clinical Data

Radiologists do not examine imaging data in isolation. Instead, they consider a patient's medical background, potential health risks, and clinical indicators. Additionally, AI can improve this process by combining imaging data with clinical information, such as a patient's family history and levels of tumour markers. Current data fusion models have demonstrated greater accuracy than conventional methods in assessing the risk of breast cancer, resulting in more precise diagnostic predictions (Retson and Eghtedari, 2023).

AI-CAD tools: implementation in clinical practice

In order to implement AI-CAD systems in clinical practice, it is necessary to test them in advance under realistic conditions. This requires:

- Retrospective evaluation of the effectiveness of the algorithms.
- The datasets are substantial and encompass a broad demographic of patients.

Including both sequential and interval cancer cases in trials. This approach will be sufficient to enable the algorithms to be properly prepared for use in screening (Le et al., 2019).

Directions of the future

The applications of AI in breast imaging have shown significant advancement, yet numerous obstacles persist, including algorithm validation across various clinical environments, result generalization, and patient and clinician education. Future research should concentrate on developing trust in these technologies while implementing AI systems into clinical practice to achieve maximum patient advantages

As AI progresses, its potential to revolutionize breast cancer diagnosis may lead to a substantial enhancement of healthcare quality and outcomes (Taylor et al., 2023). Multimodal machine learning aims to integrate and analyze information from different sources or imaging techniques. In the context of breast cancer research, data can come from different modalities such as mammography, ultrasound, magnetic resonance imaging (MRI), or pathology images.

This enables a more thorough understanding, ranging from a broad view of tissue organization to minute details at the cellular level. It is also possible to generate multimodal data from a single imaging technique, such as by using mammograms in various projections or multi-sequence MRI studies. In breast imaging, multimodal learning methods primarily aim to integrate these data in a unified manner. Included among the most commonly used approaches (Lo Gullo et al., 2024):

- Data from multiple sources are combined at the initial stage of processing.
- Joint fusion, which involves combining features extracted from different modalities.
- Late fusion, where decisions based on data from different modalities are combined in the final stage of analysis.

These approaches enable more effective use of information from different imaging techniques, which can lead to more precise diagnoses and a better understanding of disease processes. AI-assisted MRI may have applications in Primary systemic therapy (PST) as a treatment for breast cancer (Lo Gullo et al., 2024).

Primary systemic therapy (PST) is the standard treatment for patients with locally advanced breast cancer. It is also increasingly being used for the early stages of this disease. This therapy, particularly in the form of neoadjuvant chemotherapy (NAC), is as effective as adjuvant chemotherapy, while offering benefits such as a reduction in tumor size, which may allow for less invasive surgical procedures, including avoiding mastectomy or excision of axillary lymph nodes. This approach minimizes the risk of long-term complications such as lymphoedema (Lo Gullo et al., 2024).

In recent years, PST has also been used in patients with smaller tumours that require chemotherapy, particularly for triple-negative breast cancer (TNBC) or HER2-positive breast cancer. Neoadjuvant treatment of breast cancer includes various strategies such as chemotherapy, hormone therapy and targeted therapies. Traditional methods of assessing PST response using magnetic resonance imaging (MRI) are often subjective and depend on the experience of the radiologist (Lo Gullo et al., 2024).

Artificial intelligence, encompassing classical machine learning methods and deep learning, is becoming increasingly instrumental in MRI analysis, thereby facilitating more precise response prediction at both the pre-treatment stage and in the early stages of PST (Lo Gullo et al., 2024).

The potential of AI is substantial, yet considerable obstacles persist, according to Bahl (2020).

- The lack of clarity in many AI models, referred to as "black boxes," hampers their interpretability.
- Data standardization – large, diverse datasets are essential for AI accuracy.
- Clinician acceptance – radiologists require AI training for effective adoption.
- Legal and ethical concerns – accountability for AI-driven diagnostic errors must be clearly defined.

Future AI advancements will likely integrate electronic health records and function as "second readers", prioritizing cases that require human review. AI is poised to revolutionize breast imaging, yet its optimal integration requires continued research, validation, and regulatory oversight.

Radiomics and Radiogenomics – The Future of Breast Cancer Diagnostics

Using advanced radiomics techniques allows for the quantitative examination of various imaging characteristics, including texture, shape, and intensity, which can help forecast the severity of breast cancer. Radiomics combined with patient genetic data, specifically radiogenomics, could enable more tailored treatment approaches and enhance the accuracy of recurrence risk predictions (Retson and Eghtedari, 2023). Implementing artificial intelligence poses several difficulties. The implementation of AI in clinical practice to analyze PST responses is hindered by several challenges.

- The need for standardization of data and algorithms.
- Limited availability of large, representative datasets to train AI models.
- The need to evaluate the effectiveness of these systems in everyday clinical settings (Lo Gullo et al., 2024).

This paper explores the development of the "AI Silecosystem", a term describing the integration of hardware, software, and data that drive AI in both academic and community oncology. Special emphasis is placed on the implementation of AI in non-academic oncology practices, using the City of Hope Comprehensive Cancer Center as a case study. It provides a historical overview of AI in oncology and its gradual adoption in community-based settings (Mcdonnell, 2023). The Kuhnian paradigm framework is applied to describe the evolution of AI in oncology in three stages: (Mcdonnell, 2023)

- Inception – conceptual introduction and initial implementations.
- Intermission – stagnation phases in the 1970s and 1990s due to technological and funding limitations.
- Invigoration – rapid advancement fueled by innovations in hardware, algorithms, data accessibility.

A case study of AI deployment at City of Hope illustrates the collaborative role of academic and community oncology in adapting AI (Mcdonnell, 2023).

AI Transformation in Oncology

- Growing use of AI in diagnostics and therapy – AI is widely applied in cancer diagnostics, radiology, digital pathology, and precision oncology.
- Impact on community oncology – AI adoption is emerging in community practices but faces implementation barriers.
- Case study at City of Hope – AI-driven patient data analysis and treatment optimization showcase its practical benefits.

Technological Innovations Driving AI Development

It is discussed the key innovations that have enabled the AI Silecosystem (Mcdonnell, 2023):

- Quantum computing – accelerates AI-driven cancer research.
- Cloud computing – facilitates data accessibility and AI model deployment
- Machine learning algorithms – enhance predictive capabilities for cancer risk assessment and treatment selection.
- Despite the significant advantages AI offers in community oncology, challenges remain
- Integration into community practices – data standardization and clinician training are essential
- AI systems require transparency in their algorithms to ensure they can be understood and comply with patient confidentiality laws.

Deploying AI in smaller medical practices demands investments in infrastructure (McDonnell, 2023). Artificial intelligence is increasingly playing a vital role in both academic and community oncology. A close collaboration between educational establishments and community specialists is crucial for the successful integration of artificial intelligence, which also necessitates investments in technological advancements and training for healthcare professionals (Mcdonnell, 2023).

The potential of free AI applications to enhance early detection and patient outcomes in breast cancer prevention is substantial. Deep learning methods have proven capable of analyzing genetic data and histopathological images to pinpoint potential markers of breast cancer, thereby facilitating earlier treatment intervention. Integrating AI-based tools into the screening process can simplify the process of obtaining results and increase convenience, which may motivate a greater number of people to undergo regular screening.

The ongoing challenges in implementing AI in breast cancer screening should not overshadow the significance of advancing and incorporating these technologies, considering the widespread occurrence of the disease. Despite its advantages, the clinical implementation of AI presents numerous challenges. Key issues include the quality of data input, the need for model validation across diverse patient populations, and compliance with data protection regulations. There is also a need for transparent AI decision-making mechanisms that allow physicians to understand how algorithms reach their conclusions (Bitencourt et al., 2021).

Critical areas of focus include the integration of AI with other diagnostic technologies and the ethical considerations involved in this process (Bitencourt et al., 2021). Despite AI showing promising results in breast cancer imaging, its adoption in clinical settings is hindered by substantial obstacles. Algorithm optimization is necessary to reduce false negatives, and AI models must be more interpretable to facilitate radiologists' decision-making. Furthermore, large-scale clinical validation is required to confirm the real-world effectiveness of AI in breast cancer diagnostics (Zheng et al., 2023).

Artificial intelligence is expanding possibilities for breast imaging, providing tools that facilitate diagnosis, enhance the efficiency of radiologists, and elevate the standard of medical care offered (Rajpurkar and Lungren, 2023). Studies indicate that AI significantly enhances breast cancer detection than traditional methods. Advanced deep learning-based systems can analyze intricate imaging patterns, thereby lowering the incidence of incorrect positive and negative diagnoses (Bitencourt et al., 2021).

Additionally, AI has shown effectiveness in evaluating the structural features of cancerous growths and their potential to be aggressive. AI models can help radiologists make clinical decisions, shortening the time needed for image examination. Although there have been many successes, it is still vital to continue testing and refining these technologies for the clinical environment to guarantee their efficacy and safety across all patient populations (Bitencourt et al., 2021).

Artificial intelligence (AI) has tremendous potential to transform the field of radiology by assisting in diagnosis, enhancing the precision of image analysis, and ultimately leading to better patient results (Bitencourt et al., 2021). Further refinement of AI technology, along with transparent algorithm validation and post-implementation monitoring of its performance in clinical settings, is necessary for the technology to reach its full potential. As time passes, artificial intelligence will be integrated into radiologists' daily routines, helping them make precise and swift diagnostic choices (Rajpurkar and Lungren, 2023).

Breast cancer diagnosis is receiving improved quality due to advancements in AI and CAD technologies used in breast imaging (Rajpurkar and Lungren, 2023). However, successful implementation of these technologies requires further research, standardization of data, and ensuring that these systems are adapted to work in a variety of clinical settings (Le et al., 2019). Artificial intelligence could make a substantial difference in breast cancer diagnosis, leading to higher detection rates and greater efficiency for radiologists, as noted by Bitencourt et al., (2021).

Studies have shown its effectiveness, but further research and technological improvements are needed to fully incorporate it into diagnostic processes. Future clinical decision-making may become routine with the use of AI, but its effectiveness and safety need to be validated through extensive clinical trials (Bitencourt et al., 2021).

4. CONCLUSIONS

This review examines the current status of artificial intelligence in breast cancer detection and diagnosis, focusing on the advantages and difficulties associated with its adoption. Artificial intelligence (AI) in breast imaging is a rapidly growing field that is already playing a significant role in the diagnosis and management of women's health. Currently, many AI applications are focused on breast cancer detection, particularly in the context of screening mammography, which aims to reduce morbidity and mortality from this cancer. Existing technologies are achieving impressive results, supporting radiologists in identifying cancerous lesions, improving the accuracy of diagnoses and reducing false positives and negatives. However, the potential of AI in breast imaging goes far beyond cancer detection.

Applications are also being developed to support breast density assessment, cancer risk prediction, image quality improvement, and clinical workflow optimization. These tools aim not only to improve the work of radiologists, but also to make screening programs more accessible and effective. Moving forward, it is essential to refine and evaluate the algorithms in various clinical environments, taking into account the range of patient demographics and the unique characteristics of different imaging technologies, including tomosynthesis, ultrasound, and MRI. It will be crucial to guarantee that AI applications seamlessly interface with current healthcare systems in order to facilitate diagnostic and therapeutic decision-making processes.

Artificial intelligence has significant potential to transform breast imaging by improving diagnosis and patient care outcomes. To fully benefit from these new opportunities, additional research, collaborative work between engineers and clinicians, and the establishment of guidelines to guarantee the safety and effectiveness of the new technologies are necessary. Collaborating in this area has the potential to transform how we handle breast cancer diagnosis, leading to enhanced treatment results and a better quality of life for people affected globally.

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Anna Tokarska: Formal analysis, data curation, methodology, supervision
Katarzyna Gawrońska: Data curation, writing-rough preparation, investigation, visualization
Joanna Rybak: Formal analysis, writing-review and editing, methodology
Aleksandra Arnista: Writing-rough preparation, investigation,
Aleksandra Kołodziejczyk: Methodology, conceptualization, data curation, supervision
Agnieszka Waszczuk: Formal analysis, writing-review and editing,
Mateusz Świątko: Visualization, data curation, writing-rough
Paweł Sosnowski: Formal analysis, supervision, writing-review
Piotr Łapiński: Formal analysis, supervision, writing-review

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Conflict of interest

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Data and materials availability

All data sets collected during this study are available upon reasonable request from the corresponding author.

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