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Review on Present-day Breast Cancer Detection Techniques

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***Abstract* – Breast cancer remains a prevalent health complication among the female population. Early and reliable detection in an individual is necessary for effective treatment. Thus, R&D into techniques for detection of breast cancer continues to the present. Non-invasive techniques include tactile examinations, electromagnetic scanning and checks for chemical markers. Invasive techniques include biopsies that extract tissue and liquid samples. These techniques have limitations and setbacks that are being addressed with supplementary or complementary techniques. Like the pre-existing techniques, these techniques also rely on comparison of data between control samples and afflicted patients to measure their reliability. Therefore, R&D efforts towards detection of breast cancer have resulted in incremental improvements on established methodologies.**

Keywords— Breast Cancer, Cancer Detection, Non-invasive Methods, Invasive Methods, Mammography

I. INTRODUCTION

Breast cancer is a type of cancer that predominantly occurs in female populations and a comparatively small proportion in male populations [1]. In the present-day, mortality rates are estimated to be increasing at seven in million for every 5 years [2]. This is happening despite research and development (R&D) into methods of treatment.

Studies into breast cancer continue to show that early detection significantly improves the odds of successful treatment [3]. Therefore, there is also R&D of detection methods, with the goal of reliable confirmation of breast cancer or absence thereof. For the convenience of referring to these absences and presences, this article will henceforth refer to the confirmed absence of breast cancer as "true negative", and the confirmed presence as "true positive". This nomenclature has been practiced in other recent articles [4].

In the current era, there are digital tools that help in the detection of breast cancer among populations, such as AI assistance and big data. This article is not specifically about these digital tools and is instead about techniques that are applied on individual patients to determine the occurrence of breast cancer. However, these tools will be mentioned later, specifically in the matter of analyzing test results.

II. BACKGROUND & PROBLEM STATEMENT

The following passages provide a brief history of breast cancer awareness and methods for its detection.

A. Brief Statement on the Terminology of Breast Cancer

"Cancer" is a term that is based on what is understood by the community of experts that are researching cancer. The level of understanding changes when new methods are developed, leading to efforts to redefine which ailment is cancer and which is not [5]. This article is not about the definition of cancer, so it will defer to the general description of the occurrence of abnormal and malignant tissues in breasts [6].

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B. Awareness of Breast Cancer

Breast cancer has been identified as a category of cancers. Subtypes of breast cancers continue to be identified to the present day [7]. Identification of the subtypes is necessary for efficient treatment. However, the identification must be performed by trained personnel, due to the need for sophisticated equipment.

Furthermore, these procedures are performed after the patient has discovered signs of breast cancer and subjected oneself to further testing. Unfortunately, the data on the reliability of the patient making this discovery is inconsistent across the world, with no clear correlation between affluency and rate of self-exams [8][9][10].

C. Breast Cancer Detection, in General

The main tissues within breasts are composed of epithelial, stromal, and adipose cells; in layman's terms, these cells become surface, connective and fat tissues respectively [11]. Any deviation from this composition is potentially a sign of the emergence of breast cancer [11].

Thus, the methods of detection focus on determining the presence of anything that is out of the norm among breast tissues [13]. There are methods that rely on tactile sensations, e.g. any resistance to physical exertions on breasts in breast self-exams [14], and methods that rely on the transparency of the breast tissues to radiation [15], to cite some examples.

In the present-day, there is R&D into novel methods, such as the application of algorithms on breast mass and volume measurements [16], or revisiting previous methods like ultrasound [17]. These methods still follow the same principle of comparing the results from control samples, i.e. healthy breast tissues, with the results from samples by suspect cases.

To improve reliability of these detection methods and for thorough documentation of the results, a series of procedures that include these methods can be established. An example is the Reporting Items for Practice Guidelines in Healthcare (RIGHT) checklist, which is developed through international collaboration [18].

D. Breast Cancer Typification through Detection

In addition to detecting the presence of abnormalities in the breast, breast cancer detection methods also attempt to classify the abnormalities as either benign or malignant [12]. This is necessary for informing the treatments that would come after, because the methods for benign and malign cancers differ significantly [12].

Therefore, the detection methods must be able to differentiate between these broad categories of abnormalities; this is a significant challenge. For example, imaging methods require visual information on the distribution and spatial dimensions of abnormal cells, which are among the set of traits that are used to measure the probabilities of the cells being cancerous [12].

E. Breast Cancer Treatment, in General

Firstly, this article is not about the treatments for breast cancer. The topical matter of this review article is breast cancer detection methods. However, the method of cancer detection can contribute to the planning and execution of treatment procedures if treatment is possible [13]. For example, screening methods yield visual cross sections of breasts that can help the planning of surgeries.

After treatment, the same detection methods are applied again, with the goal of determining any changes due to the treatment. This is especially so if the treatment method is classified as clinical, i.e. having measurable results [19].

III. Detection Approaches

As implied earlier, the methods of detection must be able to determine the presence of breast cancer. The method must also reveal the cause and/or circumstances of the cancer so that appropriate treatment can be applied. The approaches that will be described hereafter adhere to these two goals, despite their differences in technique.

A. Non-Invasive Approaches

Non-invasive approaches are meant to avoid injuries of any severity to the patient. There are some overlaps with invasive approaches, however, due to inherent risks in some of the methods that will be described later.

Foremost among these approaches are methods that the patients use themselves, namely breast self-exams [8][9][10]. These are the methods by which patients discover concerns about their own bodies, which may compel them to seek clinical examination and thus other methods of breast cancer detection. However, uptake and practice of these methods vary significantly across the world [8][9][10].

Clinical non-invasive approaches generally resort to screening techniques. Screening typically involves subjecting the patient to radiation emissions of specific spectra, such X-ray and magnetic resonance, and/or non-radioactive transmissions, such as ultrasound [20]. This is generally the next step after a patient has raised concerns after a BSE [18].

For ease of reference, such methods will be henceforth referred to as “screening”. This is to differentiate these methods from those that do not subject the patient to emissions and transmissions. Incidentally, the results of screening methods are visually displayable on screens.

B. Invasive Approaches

Invasive approaches inflict injury on the patient, albeit in controlled ways. Notable examples of these approaches are core needle biopsies, in which tissue samples across the breasts are extracted using coring needles [21]. Therefore, invasive approaches are pursued usually after non-invasive approaches yield positive signs of breast cancer, or inconclusive results that require further measures to yield any useful information.

In practice, both approaches are used together because they search for different signs in ways that may be mutually exclusive. For example, when mammography reveals an abnormal lump in a breast, a biopsy is performed at the location of the lump to extract samples for pathological examination [3].

Different techniques of the same approach are also used together because of the same reason of mutually exclusive methodology. For example, a BSE may reveal the presence of lumps if they are dense enough for a tactile response, but a mammography or MRI can reveal the presence of abnormalities that cannot be revealed through self-exams [22].

IV. Non-Invasive Methods Available in Current Era

In addition to BSE, technological progress has enabled scanning-oriented methods. These methods focus on how cancerous tissue obstructs or otherwise distorts emissions or transmissions that pass through it if they pass through at all.

The following passages in this section describe the most notable methods that are used in the current era, together with their advantages and disadvantages as have been determined in the present day.

Although these approaches have been described as non-invasive, they are not without risks and issues of reliability. These will be described in the following passages.

A. Breast Self-Exam

Although there have been technological advances in screening technology, breast self-exam (BSE) remains the most readily available and economical [8][9][10]. Although its reliability greatly depends on the diligence of the individuals performing BSE, it is the foremost of early warnings.

Other than the diligence of the individual, the effectiveness of BSE at detecting abnormalities also depends on the characteristics of the individual's breasts. For example, breast sizes pose complications in the ease of performing BSE [23].

The most notable limitation of BSE is that it alone cannot confirm the presence of breast cancer. There must be follow-up procedures for clinical confirmation.

B. X-Ray Screening A.k.a. Mammography

"Mammography" is the term that is used for X-ray scanning of breasts, as acknowledged by communities of medical practice [24]. For clearer contrast against other screening methods in the text of this article, it will be referred to as "X-ray screening".

X-ray screening has been implemented in breast cancer screening for decades. Its reliability and risks have been debated over the years, but its ability to detect abnormalities in the distribution of tissue density means that it remains in use [25]. It is the proverbial "gold standard" which other methods are compared against [26]. For example, it is the standard procedure for breast cancer detection in Malaysia, with frequent attempts at making it economical through measures such as subsidies [27].

The main setback of X-ray screening is the radiation dosage that is applied to the patient. There are concerns about the risk of increasing the chance of cancer occurrence in the patient [28]. Thus, there must be a balance between the magnitude of the dosage and the amount of screening data that can be acquired.

C. Ultrasound

As mentioned earlier, the presence of cancerous tissue will produce screening results that are different from those of healthy tissue. This concept also applies to ultrasound. In the case of this method, cancerous tissue is displayed as anomalies in the ultrasound imaging, e.g. a void cluster among striations of breast tissue [29].

The main advantage of ultrasound is that it does not subject the patient to electromagnetic radiation. Thus, it can be applied continuously, which in turn allows for collection of real-time data such as the flow of bodily fluids through blood vessels [29]. In the case of this example, cancerous tissue might include blood vessels where there should be none in a healthy patient [29].

C. Novel Approaches

R&D into novel methods for breast cancer detection still follow the same concept of identifying deviations in the results from suspect cases, compared to the results from healthy patients, i.e. control samples. Specifically, these methods focus on symptoms that may arise from the occurrence of breast cancer.

For example, there is the theory that health issues cause imbalances in proteins within the body, which in turn lead to deposition of proteins on the fingertips; these proteins can be biomarkers [30]. Considering symptoms and/or causes of breast cancer can include protein imbalances, a detection method based on peptide tests on fingermarks is possible [31].

Another similar example is testing for biomarkers in saliva [32]. However, like the fingermark method, this method requires preparation to remove any contaminant that might skew the results of peptide testing [32].

Incidentally, approaches that make use of chemical tests, e.g. examination of biomarkers and other proteins, have the potential of differentiating between malignant and benign cases [33].

D. General Problems

The limitation that is common to all non-invasive approaches is that they do not yield any information that can be gained with examination of biological samples, such as the type of cancer cells or the location of cancerous regions [34]. Consequently, they do not yield any conclusive evidence of cancer. Moreover, supposedly positive results from these methods can be due to other health complications, or the physiological condition of an otherwise healthy patient, e.g. an asymptomatic individual [35].

Except for ultrasound, screening-based approaches subject the patient to electromagnetic waves of different spectra. As mentioned earlier, this raises concerns about inducing cancer or other problems in the patient [28]. These screening approaches are also economically more expensive than other methods due to investment costs in the machines that can perform them [35].

The approaches that are not based on screening do not produce data that indicate the physical presence and location of anomalous tissue. For example, the fingermark test can potentially yield results that indicate the type of cancerous tissue, depending on the proteins that are released or metabolized by the tissue [31]. However, the test does not reveal the location of the tissue within the patient's body.

Novel approaches for breast cancer detection have potential, but they require further study so that false and true positives and negatives can be catalogued. This is a concern for established approaches such as mammography [36], so it is expected to be a concern for these novel approaches too.

E. Upcoming Solutions for General Problems

Although there have been technological advances in screening methods, they still require devices that are not readily portable. However, there has been R&D in minimizing the size and number of components such that portable devices can be developed for use without having the patient be inserted into a machine or lying down on an examination bed; an example has been achieved for ultrasound methods [37].

In the case of screening methods that subject the patient to electromagnetic waves (including radiation dosages), R&D in these methods are oriented around the minimization of dosage while increasing the amount of information that can be gleaned from screening results through data and image processing. For example, X-ray scans can produce both 2D and 3D images, so there is R&D into using both sets of data for the detection of breast cancer [25].

Artificial intelligence (AI) has been used for statistical hypothesis testing of the results from screening-based methods [38]. Thus, there is the expectation that AI can be used to catalogue and analyze the results of non-screening methods; the earliest implementation of this that can be expected is a form of quality control with emphasis on identifying misdiagnoses, as demonstrated by Wen et al. [39].

V. Invasive Methods Available in Current Era

Invasive methods generally involve surgery, which is a long-time field of medical science. Thus, the invasive methods of today still follow the same mode of operation as methods of yesteryears, which is the extraction of samples for further examination, otherwise known as biopsy.

The following passages will mention the established techniques of invasive methods for detection of breast cancer. This is then followed by the mention of improvements that build on the basics of these techniques, or otherwise complement them.

A. Methods of Extraction

The tissue samples that are needed for confirmation of breast cancer must be extracted from regions of the body that are significantly below the skin. Thus, surgical biopsy is generally needed. Since breasts contain a considerable number of blood vessels, complications involving bleeding are significant risks [40]. These risks are stacked onto the complexity of varying breast sizes, shapes, and tissue composition. For example, there is the risk of seeding cancer cells elsewhere through contamination of the surgical tools and then physical contact of the tools with other regions of the body [41].

Thus, there are R&D efforts to determine other regions of the body that may be more consistently reliable for biopsy; examples of these will be described later. The intentions to carry biopsies in these other regions are ease of surgical entry, ease of recovery and minimization of risks of propagating cancer during surgery [41].

Percutaneous surgery involves the use of needles to extract a cylindrical core of tissue. In comparison, open surgery requires incision to expose the flesh to further and deeper procedures. In the present day, both percutaneous surgery and open surgery remain in use for invasive methods of breast cancer detection, depending on the complications that are posed by the patients' circumstances [42]. Percutaneous surgery is increasingly favored over open surgery due to fewer concerns about patient recovery after surgery [42].

R&D efforts into methods of extracting samples for examination include expansions of the search for types of tissues, or even effluvia, that may yield biomarkers of breast cancer; examples of these will be described later in section D.

B. Locations of Extraction

Understandably, extraction of breast tissue samples requires surgical entry into the patient's breasts. Recent studies still suggest that breast cancer originates within breast tissue, e.g. the lobules, tubes, and connective tissue [43]. Therefore, tissue samples from the breast would give affirmative results when examined.

However, as mentioned already, surgery of the breasts has complications both during and after [40][41][42][43]. Current R&D efforts into breast cancer biopsies include identification of tissues that can be affected by breast cancer, away from the breasts; the idea behind this alternative is that these other regions of the body may be easier to operate on.

For example, the axillary lymph nodes, which are located in between the armpit and shoulder blade, process the blood that circulates the breast; therefore, tissue samples extracted from these nodes may contain the biomarkers of breast cancer [44]. The reason for extracting these instead of tissues from the breast is that these tissues occur in regions of the human body that are more anatomically consistent across individuals, and are thus simpler to apply or adapt standardized surgery procedures for their removal [44][45].

C. Methods of Examining Samples

After extraction, tissue samples are examined to determine the presence of any anomalies; this is the basis of histopathology. This has been and remains performable on samples that are suspected of being directly affected by breast cancer [46].

Histopathology, as practiced in the examination of breast tissue samples, has been demonstrated to be applicable to other tissue samples such as those from the prostate [47]. Therefore, it may be possible to perform the same examination on tissue samples extracted from elsewhere, specifically a region of the body that is affected by the development of the breast or otherwise biologically associated with the breast.

For example, histopathology can be performed on samples of extracted ancillary lymph node tissues, both before and after treatment of breast cancer to check for changes [48]. Tests on ancillary lymph node samples suggest that changes due to treatment that are detected in breast tissue samples also occur in samples of ancillary lymph nodes, albeit at different magnitudes [48].

That said, the main issue with utilizing tissue samples from other regions of the body is the accuracy at which they suggest that breast cancer has occurred within the breasts of the patient. Tests of these other samples may suggest that the cancer has spread to other regions of the body instead, i.e. the various carcinoma that are associated with breast cancer, without affirmative information on the origin point [49]. Furthermore, without corroborating results from exams of tissue samples directly extracted from breasts or regions close to the breasts, the occurrence of breast cancer could not be reliably confirmed [49].

C. Existing Problems

The main issues of invasive methods are complications in the extraction of tissue from the patient and the recovery of the patient.

To elaborate, for direct confirmation of breast cancer, the tissue samples must be extracted from suspected regions of the patient's breast(s), or regions that are physiologically associated with the breasts. However, the variation of shapes, sizes and tissue compositions can lead to complications, such as post-surgery bleeding, from applying standardized procedures to non-standard surgery sites [52]. If biopsies of the breast are not directly possible, tissue samples would have to be sourced from elsewhere, thus raising the concern of not having reliable confirmation [49].

Other issues include the concern about private medical data of the patient being gleaned from the extracted samples. Sample extraction requires consent from the patients, and studies suggest that full disclosure of the results is best at encouraging the providing of consent [53][54].

D. Upcoming Innovations and Solutions

Tissue extraction for breast cancer detection requires biopsy on the patient's breasts. As mentioned already, the patient's circumstances, such as variation in breast shapes, sizes, and tissue composition, can pose complications during surgery. These problems are inherent [52].

Thus, the solutions to these problems are alternatives to tissues extracted from the breast. Liquid biopsy is the examination of the proteins in samples of bodily fluids for genetic markers; this is an alternative that is being currently explored for detection of various types of cancer, including breast cancer [55].

In the case of breast cancer, the proposed fluids are blood and breast milk. Blood tests have been in medical practices for a long time, with chemical tests performed to identify the presence of biomarkers; blood tests that specifically focus on biomarkers of breast cancer have been performed and studied [56]. Tests with breast milk is understandably limited to patients that are lactating, but studies with breast milk samples suggest that breast milk carry substantial proteins that can be checked for cancer biomarkers [57]. However, these methods are intended to be for early-detection [55]. They will not replace screening methods because they do not reveal the exact location of tumors for the purpose of excision [55]. On the other hand, the molecular make-up of the cancer cells as revealed by spectroscopy can help in designing chemotherapy and/or radiotherapy treatments [55].

As with data from non-invasive methods, there is the suggestion that machine learning, i.e. AI assistance, can be applied to analyze the data from biopsies, specifically to improve the rate of correct diagnoses [49]. For example, convolutional neural network has been demonstrated to be reliable at classifying breast cancer [50]. To complement these efforts at identification via computer science, there is the automated management of databases of breast cancer patients, for the purpose of cross-referencing information for more detailed risk assessment of suspected cases of breast cancer [51].

VI. Conclusion

Table 1 provides a summary of non-invasive breast cancer detection methods. The methods are broadly categorized to BSE, screening, and non-screening, which have been defined earlier in section IV of this article. Table 2 provides the summary for invasive methods. The methods are broadly categorized to breast tissue biopsies, non-breast tissue biopsies and liquid biopsies.

TABLE 1. Non-invasive methods of breast cancer detection.

Method Category	Practical Characteristics of Approach	
	Advantages	***Disadvantages***
BSE	Readily applicable	• Requires training and practice on the part of the patient. • Insufficient on its own for confirmation of breast cancer.
Screening	Provides visual imaging of suspected locations for later biopsies	• Depending on the technology that is used, this might expose the patient to radiation or otherwise affect the patient's health. • Immobility of utilized machines require patients to travel.
Non-screening	More portable, or otherwise requires samples from bodily surface of patients.	• Does not provide visual data for later biopsies. • Requires cross-referencing with data from other methods for corroborated confirmation.

TABLE 2. Invasive methods of breast cancer detection

Method Category	Practical Characteristics of Approach	
	Advantages	***Disadvantages***
Breast biopsies	Results are the most directly affirmative of the occurrence of breast cancer.	Anatomical differences across different individuals, e.g. different breast shapes, sizes, and tissue composition, can complicate surgery and post-surgery procedures.
Non-breast biopsies	Utilize regions of the body that are more anatomically consistent across individuals.	The results have differences from those of breast biopsies, depending on how physiologically related these other regions are to the breasts.
Liquid Biopsies	Use bodily fluids that are relatively easier to extract than tissue samples.	The results only reveal the presence of cancer, but not the origin point or the exact locations of tumors.

All non-invasive methods share the same limitation of not being able to provide directly affirmative occurrence of breast cancer, i.e. pathological information from tissue samples, but otherwise do not require intrusive examination of the patients. This is the converse for invasive methods, which typically require samples extracted from the patients' bodies.

VII. Recommendations

For both major types of methods, machine learning and AI are applicable for cross-referencing test results, improvement of correct diagnoses or affirmation for further examinations [39][49]. The use of computer science will be necessary because the types of breast cancer detection methods are expected to expand, and consequently the types of data from the results will also become more complicated and voluminous [58].

Furthermore, as more methods (novel, revisited or otherwise) are developed, more technical criteria for classifying breast cancer would be introduced; in the case of revisited methods, existing criteria must be revised to account for updates in methodology. Therefore, existing breast cancer databases must be revised, and new ones must be designed so that they can accommodate changes to these criteria or otherwise new information. For example, Jin et al. had been performing R&D on databases on clinical data related to breast cancer, with algorithms that are intended to cross-reference unstructured data with established information [59].

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References

[1] R. Hong, and B. Xu, "Breast cancer: an up-to-date review and future perspectives," *Cancer Communications,* vol. 42, no. 10, pp. 913-936, 2022. DOI: 10.1002/cac2.12358

[2] N. Azamjah, Y. Soltan-Zadeh and F. Zayeri, "Global Trend of Breast Cancer Mortality Rate: A 25-Year Study," *Asian Pacific Journal of Cancer Prevention*, vol. 20, no. 7, pp. 2015-2020, 2019. DOI: 10.31557/APJCP.2019.20.7.2015

[3] O. Ginsburg, C.H. Yip, A. Brooks, A. Cabanes, M. Caleffi, J. Dunstan Y., B. Gyawali, V. McCormack, M.M.L. de Anderson, R. Mehrotra, A. Mohar, R. Murillo, L. E. Pace, E. D. Paskett, A. Romanoff, A. F. Rositch, J. Scheel, M. Schneidman, K. Unger-Saldana, V. Vanderpuye, T.Y. Wu, S. Yuma, A. Dvaladze, C. Duggan, and B. O. Anderson, "Breast cancer early detection: a phased approach to implementation," *Cancer*, vol. 126, no. 10, pp. 2379-2393, 2021. DOI: 10.1002/cncr.32887

[4] T. Amir, M.P. Hogan, S. Jacobs, V. Sevilimedu, J. Sung and M.S. Jochelson, "Comparison of False-Positive Versus True-Positive Findings on Contrast-Enhanced Digital Mammography," *American Journal of Roentgenology*, vol. 218, no. 5, pp. 797-809, 2022. DOI: 10.2214/AJR.21.26847

[5] J.S. Brown, S.R. Amend, R.H. Austin, R. A. Gatenby, E.U. Hammarlund and K.J. Pienta, "Updating the Definition of

Cancer," *Molecular Cancer Research*, vol. 21, no. 11, pp. 1142-1147, 2023. DOI: 10.1158/1541-7786.MCR-23-0411

[6] L. Tabar, P.B. Dean, F.L. Tucker, A.M.F. Yen, S.L. Chen, G.H.H. Jen, J. W. Wang, R.A. Smith, S.W. Duffy, and T.H. Chen, "A new approach to breast cancer terminology based on the anatomic site of tumour origin: The importance of radiologic imaging biomarkers," *European Journal of Radiology*, vol. 149, no. 110189, pp. 1-21, 2022. DOI: 10.1016/j.ejrad.2022.110189

[7] M. Zubair, S. Wang and N. Ali, "Advanced Approaches to Breast Cancer Classification and Diagnosis," *Frontiers in Pharmacology*, vol. 11, no. 632079, 2021. DOI: 10.3389/fphar.2020.632079

[8] M.M. Pippin and T. Boyd, "Breast Self-Examination," *StatPearls* [Online]. StatPearls Publishing, 2023. PMID: 33351405

[9] R.H. Udoh, M. Ansu-Mensah, M. Tahiru, V. Bawontuo and D. Kuupiel, "Mapping evidence on women's knowledge and practice of breast self-examination in sub-Saharan Africa: a scoping review protocol," *Systematic Reviews*, vol. 9, no. 2, 2020. DOI: 10.1186/s13643-019-1254-7

[10] Y. Yang, J. Yu, A. Liu, J. Tian, L. Guo, D. Huo, P. Zhao, W. Ji, and B. Luo, "Self-detection remains a primary means of breast cancer detection in Beijing, China," *Translational Breast Cancer Research*, vol. 4, no. 27, 2023. DOI: 10.21037/tbcr-22-2

[11] M. Abubakar, S. Fan, E. A. Bowles, L. Widemann, M. A. Duggan, R.M. Pfeiffer, R.T. Falk, S. Lawrence, K. Richert-Boe, A.G. Glass, T.M. Kimes, J.D. Figueroa, T.E. Rohan, and G.L. Gierach, "Relation of Quantitative Histologic and Radiologic Breast Tissue Composition Metrics with Invasive Breast Cancer Risk," *JNCI Cancer Spectrum*, vol. 5, no. 3, 2021. DOI: 10.1093/jncics/pkab015

[12] M.S. Al Reshan, S. Amin, M.A. Zeb, A. Sulaiman, H. Alshahrani, A.T. Azar, and A. Shaikh, "Enhancing Breast Cancer Detection and Classification Using Advanced Multi-Model Features and Ensemble Machine Learning Techniques," vol. 13, no. 10, pp. 2093, 2023. DOI: 10.3390/life13102093

[13] S. Lukasiewicz, M. Czeczelewski, A. Forma, J. Baj, R. Sitarz and A. Stanislawek, "Breast Cancer—Epidemiology, Risk Factors, Classification, Prognostic Markers, and Current Treatment Strategies—An Updated Review," *Cancers (Basel)*, vol. 13, no. 17, pp. 4287, 2021. DOI: 10.3390/cancers13174287

[14] S. Idrees, S. Mayilvaganan, S. Mishra, G. Chand, A. Mishra, and G. Agarwal, "What makes women receptive to breast self-examination, animation, or simulation? – a comparative study," *Annals of Medicine & Surgery*, vol. 85, no. 9, pp. 4228-4233, 2023. DOI: 10.1097/MS9.0000000000000917

[15] S. Hooshmand, W.M. Reed, M.E. Suleiman, and P.C. Brennan, "A review of screening mammography: The benefits and radiation risks put into perspective," *Journal of Medical Imaging and Radiation Sciences*, vol. 53, no. 1, pp. 147-158, 2022. DOI: 10.1016/j.jmir.2021.12.002

[16] M. Cai, "A Novel Method for Diagnosis of Breast Cancer Tumors Based on Random Forest," *Journal of Biosciences and Medicines*, vol. 11, pp. 252-259, 2023. DOI: 10.4236/jbm.2023.114018

[17] A. Raza, N. Ullah, J.A. Khan, M. Assam, A. Guzzo and H. Aljuaid, "A Novel Deep Learning Model for Breast Cancer Detection Using Ultrasound Images," *Applied Sciences*, vol. 13, no. 4, pp. 2082, 2023. DOI: 10.3390/app13042082

[18] H. Zhou, H. Chen, C. Cheng, X. Wu, Y. Ma, J. Han, D. Li, G.H. Lim, W.M. Rozen, N. Ishii, P.G. Roy, and Q. Wang, "A quality evaluation of the clinical practice guidelines on breast cancer using the RIGHT checklist," *Annals of Translational Medicine*, vol. 9, no. 14, pp. 1174, 2021. DOI: 10.21037/atm-21-2884

[19] A. Bhushan, A. Gonsalves and J.U. Menon, "Current State of Breast Cancer Diagnosis, Treatment, and Theranostics," *Pharmaceutics*, vol. 13, no. 5, pp. 723, 2021. DOI: 10.3390/pharmaceutics13050723

[20] A.A.A. Halim, A.M. Andrew, M.N.M. Yasin, M.A.A. Rahman, M. Jusoh, V. Veeraperumal, H.A. Rahim, U. Illahi, M.K.A, Karim, and E. Scavino, "Existing and Emerging Breast Cancer Detection Technologies and Its Challenges: A Review," *Applied Sciences*, vol. 11, no. 22, pp. 10753, 2021. DOI: 10.3390/app112210753

[21] K. Cho, S. Tyldesley, C. Speers, B.P. Lane, K.A. Gelmon and C. Wilson, "The utilization and impact of core needle biopsy diagnosis on breast cancer outcomes in British Columbia," *British Columbia Medical Journal*, vol. 56, no. 4, pp. 183-190, 2014.

[22] N. Huang, L. Chen, J. He and Q.D. Nguyen, "The Efficacy of Clinical Breast Exams and Breast Self-Exams in Detecting Malignancy or Positive Ultrasound Findings," *Cureus*, vol. 14, no. 2, e22464, 2022. DOI: 10.7759/cureus.22464

[23] C.R. Baxter, T.A. Crittenden & N.R. Dean, "Self-reported breast size, exercise habits and BREAST-Q data – an international cross-sectional study of community runners," *JPRAS Open*, vol. 37, pp. 92-101, 2023. DOI: 10.1016/j.jpra.2023.06.013

[24] L. Nicosia, G. Gnocchi, I. Gorini, M. Venturini, F. Fontana, F. Pesapane, I. Abiuso, A.C. Bozzini, M. Pizzamiglio, A. Latronico, F. Abbate, L. Meneghetti, O. Battaglia, G. Pellegrino, and E. Cassano, "History of Mammography: Analysis of Breast Imaging Diagnostic Achievements over the Last Century," *Healthcare (Basel)*, vol. 11, no. 11, pp. 1596, 2023. DOI: 10.3390/healthcare11111596

[25] S.D. Maria, S. Vedantham & P. Vaz, "X-ray dosimetry in breast cancer screening: 2D and 3D mammography," *European Journal of Radiology*, vol. 151, no. 110278, 2023. DOI: 10.1016/j.ejrad.2022.110278

[26] L. Choridah, A.V. Icanervilia, A.A. Rengganis, J. At Thobari, M.J. Postma, and A.D.I. van Asselt, "Comparing the performance of three modalities of breast cancer screening within a combined programme targeting at-risk women in Indonesia: An implementation study," vol. 18, no. 1, 2023. DOI: 10.1080/17441692.2023.2284370

[27] M. Nu Nu Htay, M. Donnelly, D. Schliemann, S.Y. Loh, M. Dahlui, S. Somasundaram, N.S. Binti Ibrahim Tamin, and T.T. Su, "Breast Cancer Screening in Malaysia: A Policy Review," *Asian Pacific Journal of Cancer Prevention*, vol. 22, no. 6, pp. 1685–1693, 2021. DOI: 10.31557/APJCP.2021.22.6.1685

[28] E.K.J. Pauwels, N. Foray & M.H. Bourguignon, "Breast Cancer Induced by X-Ray Mammography Screening? A Review Based on Recent Understanding of Low-Dose Radiobiology," *Medical Principles and Practice*, vol. 25, no. 2, pp. 101-109, 2016. DOI: 10.1159/000442442

[29] O. Catalano, R. Fusco, F.D. Muzio, I. Simonetti, P. Palumbo, F. Bruno, A. Borgheresi, A. Agostini, M. Gabelloni, C. Varelli, A. Barile, A. Giovagnoni, N. Gandolfo, V. Miele & V. Granata, "Recent Advances in Ultrasound Breast Imaging: From Industry to Clinical Practice," *Diagnostics (Basel)*, vol. 13, no. 5, pp. 980, 2023. DOI: 10.3390/diagnostics13050980

[30] E. Patel, M.R. Clench, A. West, P.S. Marshall, N. Marshall, and S. Francese, "Alternative Surfactants for Improved Efficiency of In Situ Tryptic Proteolysis of Fingermarks," *Journal of the American Society for Mass Spectrometry*, vol. 26, no. 6, pp. 862-872, 2015. DOI: 10.1007/s13361-015-1140-z

[31] C. Russo, L. Wyld, M.D.C. Aubreu, C.S. Bury, C. Heaton, L.M. Cole, and S. Francese, "Non-invasive screening of breast cancer from fingertip smears - a proof of concept study," *Scientific Reports*, vol. 13, no. 1868, 2023. DOI: 10.1038/s41598-023-29036-7

[32] M. Koopaie, S. Kolahdooz, M. Fatahzadeh and S. Manifar, "Salivary biomarkers in breast cancer diagnosis: A systematic review and diagnostic meta-analysis," *Cancer Medicine*, vol. 11, no. 13, pp. 2644-2661, 2022. DOI: 10.1002/cam4.4640

[33] V.K. Sarhadi, and G. Armengol, "Molecular Biomarkers in Cancer," *Biomolecules*, vol. 12, no. 8, pp. 1021, 2022. DOI: 10.3390/biom12081021

[34] Z. He, Z. Chen, M. Tan, S. Elingarami, Y. Liu, T. Li, Y. Deng, N. He, S. Li, J. Fu & W. Li, "A review on methods for diagnosis of breast cancer cells and tissues," *Cell Proliferation*, vol. 53, no. 7, e12822. DOI: 10.1111/cpr.12822

[35] C.H. Barrios, "Global challenges in breast cancer detection and treatment," *The Breast*, vol. 62, no. 1, pp. S3-S6, 2022. DOI: 10.1016/j.breast.2022.02.003

[36] H.D. Nelson, E.S. O'Meara, and K. Kerlikowske, "Factors Associated with Rates of False-Positive and False-Negative Results from Digital Mammography Screening: An Analysis of

Registry Data," *Annals of Internal Medicine*, vol. 164, no. 4, pp. 226-235. DOI: 10.7326/M15-0971

[37] C.K.S. Park, T. Trumpour, A. Aziz, J.S. Bax, D. Tessier, L. Gardi & A. Fenster, "Cost-effective, portable, patient-dedicated three-dimensional automated breast ultrasound for point-of-care breast cancer screening," *Scientific Reports*, vol. 13, no. 14390, 2023. DOI: 10.1038/s41598-023-41424-7

[38] Y. Shen, F.E. Shamout, J.R. Oliver, J. Witowski, K. Kannan, J. Park, N. Wu, C. Huddleston, S. Wolfson, A. Millet, R. Ehrenpreis, D. Awal, C. Tyma, N. Samreen, Y. Gao, C. Chhor, S. Gandhi, C. Lee, S. Kumari-Subaiya, C. Leonard, R. Mohammed, C. Moczulski, J. Altabet, J. Babb, A. Lewin, B. Reig, L. Moy, L. Heacock and K.J. Geras, "Artificial intelligence system reduces false-positive findings in the interpretation of breast ultrasound exams," *Nature Communications*, vol. 12, no. 5645, 2021. DOI: 10.1038/s41467-021-26023-2

[39] Y. Wen, X. Li, F. Zeng, J. Lei, and S. Chen, "Application of Medical Record Quality Control System Based on Artificial Intelligence," *Journal of Sichuan University (Medical Sciences)*, vol. 54, no. 6, pp. 1263-1268, 2023. DOI: 10.12182/20231160206

[40] J.D. Lewis, A. Groszkiewicz, L. Hefelfinger, A. Doherty, A. Foringer, E. Shaughnessy, A. Heelan and A.L. Brown, "Clinically significant bleeding complications of percutaneous breast biopsy: 10-year analysis and a proposed management algorithm," *Clinical Imaging*, vol. 104, no. 110017, 2023. DOI: 10.1016/j.clinimag.2023.110017

[41] Y.C. Kong, N. Bhoo-Pathy, M. O'Rorke, S. Subramaniam, N. Bhoo-Pathy, T. Nanthini, M.H. See, S. Jamaris, K.H. Teoh, A. Bustam, L.M. Looi, N.A. Taib, and C.H. Yip, "The association between methods of biopsy and survival following breast cancer: A hospital registry-based cohort study," *Medicine*, vol. 99, no. 6, pp. e19093, 2020. DOI: 10.1097/MD.0000000000019093

[42] I. Teberian, T. Kaufman, J. Shames, V.M. Rao, L. Liao, and D.C. Levin, "Trends in the Use of Percutaneous Versus Open Surgical Breast Biopsy: An Update," *Journal of the American College of Radiology*, vol. 17, no. 8, pp. 1004-1010, 2020. DOI: 10.1016/j.jacr.2020.02.015

[43] M. Park, D. Kim, S. Ko, A. Kim, K. Mo, and H. Yoon, "Breast Cancer Metastasis: Mechanisms and Therapeutic Implications," *International Journal of Molecular Sciences*, vol. 23, no. 12, pp. 6806, 2022. DOI: 10.3390/ijms23126806

[44] J.M. Chang, J.W.T. Leung, L. Moy, S.M. Ha, and W.K. Moon, "Axillary Nodal Evaluation in Breast Cancer: State of the Art," *Radiology*, vol. 295, no. 3, pp. 500-515, 2020. DOI: 10.1148/radiol.2020192534

[45] H. Isozaki, Y. Yamamoto, S. Murakami, S. Matsumoto, and T. Takama, "Impact of the surgical modality for axillary lymph node dissection on postoperative drainage and seroma formation after total mastectomy," *Patient Safety in Surgery*, vol. 13, no. 20, pp. 1-9, 2019. DOI: 10.1186/s13037-019-0199-z

[46] F. Parvin and M. Al Mehedi Hasan, "A Comparative Study of Different Types of Convolutional Neural Networks for Breast Cancer Histopathological Image Classification," *2020 IEEE Region 10 Symposium,* TENSYMP 2020, pp. 945–948, Jun. 2020. DOI: 10.1109/TENSYMP50017.2020.9230787.

[47] N. M. a/l Loorutu, H. Yazid and K.S. Abdul Rahman, "Prostate Cancer Classification Based on Histopathological Images," *International Journal on Robotics, Automation and Sciences*, vol. 5, no. 2, pp. 43-53, 2023. DOI: 10.33093/ijoras.2023.5.2.5

[48] E.R.M. van Haaren, I.G.M. Poodt, M.A.S. van Weezelenburg, J. van Bastelaar, A. Janssen, B. de Vries, M.B.I. Lobbes, L.H. Bouwman, and Y.L.J. Vissers, "Impact of analysis of the sentinel lymph node by one-step nucleic acid amplification (OSNA) compared to conventional histopathology on axillary and systemic treatment: data from the Dutch nationwide cohort of breast cancer patients," *Breast Cancer Research and Treatment*, vol. 202, pp. 245-255, 2023.

[49] A. Khalid, A. Mehmood, A. Alabrah, B.F. Alkhamees, F. Amin, H. Al-Salman, and G.S. Choi, "Breast Cancer Detection and Prevention Using Machine Learning," *Diagnostics*, vol. 13, no. 19, 2023. DOI: 10.3390/diagnostics13193113

[50] F.F. Ting, Y.J. Tan, and K.S. Sim, "Convolutional neural network improvement for breast cancer classification," *Expert Systems with Applications*, vol. 120, pp. 103-115, 2019. DOI: 10.1016/j.eswa.2018.11.008

[51] K.S. Sim, S.S. Chong, C.P. Tso, M.E. Nia, A.K. Chong, and S.F. Abbas, "Computerized database management system for breast cancer patients," *Springerplus*, vol. 3, no. 268, 2014. DOI: 10.1186/2193-1801-3-268

[52] S. Goudreau, L.J. Grimm, A. Srinivasan, J. Net, R. Yang, V. Dialani, and K. Dodelzon, "Bleeding Complications After Breast Core-needle Biopsy—An Approach to Managing Patients on Antithrombotic Therapy," *Journal of Breast Imaging*, vol. 4, no. 3, pp. 241-252, 2022. DOI: 10.1093/jbi/wbac020

[53] J. Pollard, H. Rose, R. Mullen, and N. Abbott, "Breast Core Biopsy Information and Consent: Do we Prepare or do we Scare?," *Journal of Patient Experience*, vol. 8, 2021. DOI: 10.1177/23743735211049658

[54] D.S. Seah, J.P. Leone, T.H. Openshaw, S.M. Scott, N. Tayob, J. Hu, R.I. Lederman, E.S. Frank, J.J. Sohl, Z.K. Stadler, T.K. Erick, S.G. Silverman, J.M. Peppercorn, E.P. Winer, S.E. Come, and N.U. Lin, "Perceptions of patients with early stage breast cancer toward research biopsies," *Cancer*, vol. 127, no. 8, pp. 1208-1219, 2021. DOI: 10.1002/cncr.33371

[55] A. Bayle, F. Peyraud, L. Belcaid, M. Brunet, M. Aldea, R. Clodion, P. Dubos, D. Vasseur, C. Nicotra, A. Geraud, M. Sakkal, L. Cerbone, F. Blanc-Durand, F. Mosele, P. Martin Romano, M. Ngo Camus, I. Soubeyran, E. Khalifa, M. Alame, L. Blouin, D. Dinart, C. Bellera, A. Hollebecque, S. Ponce, Y. Loriot, B. Besse, L. Lacroix, E. Rouleau, F. Barlesi, F. Andre, and A. Italiano, "Liquid versus tissue biopsy for detecting actionable alterations according to the ESMO Scale for Clinical Actionability of molecular Targets in patients with advanced cancer: a study from the French National Center for Precision Medicine (PRISM)," *Annals of Oncology*, vol. 33, no. 12, pp. 1328-1331, 2022. DOI: 10.1016/j.annonc.2022.08.089

[56] S. Park, S. Ahn, J.Y. Kim, J. Kim, H.J. Han, D. Hwang, J. Park, H.S. Park, S. Park, G.M. Kim, J. Sohn, J. Jeong, Y.U. Song, H. Lee, and S.I. Kim, "Blood Test for Breast Cancer Screening through the Detection of Tumor-Associated Circulating Transcripts," *International Journal of Molecular Sciences*, vol. 23, no. 16, pp. 9140, 2022. DOI: 10.3390/ijms23169140

[57] P. Bhat-Nakshatri, B. Kumar, E. Simpson, K.K. Ludwig, M.L. Cox, H. Gao, Y. Liu, and H. Nakshatri, "Breast cancer cell detection and characterization from breast milk-derived cells," *Cancer Research*, vol. 80, no. 21, pp. 4828-4839, 2020. DOI: 10.1158/0008-5472.CAN-20-1030

[58] M.A. Naji, S. El Filali, K. Aarika, E.H. Benlahmar, R. Ait Abdelouhahid, and O. Debauche, "Machine Learning Algorithms for Breast Cancer Prediction and Diagnosis," vol. 191, pp. 487-492, 2021. DOI: 10.1016/j.procs.2021.07.062

[59] Y. Jin, W. Junren, J. Jingwen, S. Yajing, C. Xi, and Q. Ke, "Research on the Construction and Application of Breast Cancer-Specific Database System Based on Full Data Lifecycle," *Frontiers in Public Health*, vol. 9, no. 712827, 2021. DOI: 10.3389/fpubh.2021.712827