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Review Article

The Importance of MRI Imaging to Detect Breast Cancer: A Review

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ABSTRACT

Breast cancer is considered a lethal condition if it's not detected and treated early enough. MRI needs to be one of the ways of detecting breast cancer at its earliest stages. This study aims to investigate the value of radiography in the detection of breast cancer. This makes MRI an excellent choice as it can detect cellular changes and differentiate between benign and malignant tumors. With the further evolution of the field of breast imaging, MRI is sure to take the front seat not only in screening capacity but also as a diagnostic modality. Further refinement of the MRI techniques and improvement in accessibility and cost will only serve to solidify its position as an integral component of a comprehensive breast cancer detection and management strategy over the next decade. Already, diffusion-weighted imaging is part of routine protocols for breast MRI in many institutions worldwide, and the indications of breast DWI are numerous, stretching from lesion detection and differential diagnosis between malignant and benign tumors to the evaluation of prognostic biomarkers of breast cancer and assessment of treatment response. In a screening without contrast method, DWI might be appropriate for its usage. Beyond apparent diffusion coefficient mapping, which represents one of the quantitative DWI measures for clinical routine, advanced DWI models such as IVIM, non-Gaussian diffusion MRI, and DTI are being more broadly exploited in defining further parameters portraying tissue perfusion and architecture and are able to improve diagnostic accuracy without the use of contrast agents. Therefore, in the present review, the diagnostic accuracy of MRI was assessed and compared with the effectiveness of diverse imaging modalities in diagnosing breast cancer.

Keywords: MRI, breast cancer, imaging detection, MRI principles imaging.

INTRODUCTION

MRI plays an important role in the identification and staging of primary breast cancer (Woitek and Brindle, 2023). Breast cancer, the most prevalent tumor diagnosed in women, is a global health concern with rising rates of incidence and mortality (Ali *et al*., 2020; De Silva and Alcorn, 2022). According to the most recent international statistics, breast cancer continues to be a major health problem around the world. Approximately 2.3 million new cases were reported in 2020 with 685,000 deaths and it is the most common cancer among women globally. The incidence rate varies greatly by region, with a high of around 95.5 per 100,000 being recorded in Australia/ New Zealand and a low of about 26.2 per 100,000 in South-Central Asia (Sedeta *et al*., 2023). In western countries specifically, age-specific patterns show that breast cancer rates keep increasing until about the age of seventy while many Asian ones have their peak in the fifth or early sixth decade. There are more premenopausal cases than postmenopausal cases in Asia whereas Western countries have higher probabilities of having postmenopausal cases (Toi *et al*., 2023). Thus, the disease is growing among young individuals in Africa and Asia but is stable or declining among Northern America (Liang *et al*., 2023; DeSantis *et al*., 2023). Henceforth, different regions for instance age groups can be targeted to prevent the changing nature of breast cancer incidences all over the world, It affects around one woman out of every 12 women during their lives, and the rate increases to one woman out of every 8 women in some societies (Al-Rassam *et al*., 2023). Patients' survival rates drop as the disease progresses, as the recovery rate is very high, reaching nearly 98% if the disease is found in the early stages and decreasing to approximately 16% if it is detected in the late stages. As a result, early disease identification is critical for effective treatment (Ajaj and Mikael, 2024). However, as a screening method, mammography has its limitations when it comes to dense breast parenchyma or high risk of cancer hence necessitating the need for more reliable diagnostic tools such as magnetic resonance imaging (MRI) especially dynamic contrast enhanced (DCE-) MRI at 1.5 tesla strength. Research that compared full versus abridged protocols showed similar diagnostic accuracy which means that shortening the protocol can be useful in reducing examination time and costs without compromising on quality (Drinković *et al*., 2022). It is highly sensitive, especially in identifying lesions that may be missed by other imaging modalities (Xiaochen and Shaokai, 2023). MRI can be used to distinguish between benign and malignant tumors with great accuracy, thereby making it the most preferred technique for early and precise diagnosis of breast cancer (Sakakibara *et al*. 2023). Moreover, the usage of hyperpolarized [1-13C] pyruvate in MRI imaging holds hope for evaluating tumor metabolism that will serve in improving the clinical assessment of breast cancer (William and Konstantia, 2023). Additionally, fusion imaging techniques involving ultrasound and MRI have further improved the detection of difficult lesions enabling more accurate preoperative diagnoses and guiding safer biopsy procedures (Kataoka, 2023). However, despite limitations such as scanning time and cost, advances such as abbreviated MRI protocols are coming up to improve the feasibility as well as the efficacy of breast MRI screening.

Progress, in screening methods, with the use of learning and convolutional neural networks (CNNs) (Kode and Barkana, 2023; Bobowicz *et al*., 2023; Gengtian *et al*., 2023) has greatly improved the identification of breast cancer. Imaging with magnetic resonance (MRI) is favored for its accuracy, precision, and safety when assessing soft tissue tumors (Li *et al*., 2023). When combined with dynamic contrast enhanced MRI (DCE-MRI) and diffusion weighted Imaging (DWI), MRI techniques like DCE-MRI exhibit promising results in lesion detection (Boudouh and Bouakkaz, 2023). Preprocessing, segmentation, feature extraction, and classification are vital in lesion detection, where deep learning techniques, especially CNNs, excel in learning distinctive features effectively. Utilizing CNNs for building classifiers post-data augmentation emerges as the optimal choice for accurate lesion detection in breast cancer diagnosis, demonstrating how deep learning may be used to increase the efficiency and accuracy of diagnosis in medical contexts.

Biomarker research, including non-coding RNAs and therapeutic targets, offers promising avenues for improving breast cancer prognosis and treatment outcomes (Afzal *et al*., 2022). Understanding the molecular subtypes of breast cancer and utilizing advanced staging systems can guide personalized treatment strategies for better patient management and outcomes (Łukasiewicz *et al*., 2021). It is essential to learn and use the principles of MRI for the diagnosis of breast cancer. The review aims to discuss the importance of MRI, and its contribution not only as a diagnostic and screening tool but also as a measurement tool. Despite the growing number of users of MRI. With this review, we hope to point out its importance. We believe that the roles of breast MRI are multifaceted throughout the patients' journey pre-and post-operatively. First, it defines the extent of the disease at the time of diagnosis; second, it predicts the success of the conservative therapy of the breast by assessing the volume of the breast and that of the tumor, and third, it offers the best method to evaluate the success of primary treatment by detecting pathological complete responses that other imaging modalities may detect.

Fundamentals of MRI imaging

MRI is an imaging technique that does not require any surgery and uses powerful magnets and radio waves to form detailed images of internal structures of the body by manipulating the magnetic property of hydrogen protons (Baeez *et al*., 2019; Selvaganesan *et al*., 2023). The response signals from these protons are then detected and made into high-resolution pictures. With advents in MRI such as stronger magnets and better pulse sequences, it has become possible to do more with this imaging modality (Azhar and Chong, 2022). It is worth mentioning that novel functional biomaterials based on MRIs combined with nanotechnology can increase the sensitivity of detection, allow for targeting specific biomolecules and facilitate thera gnostic applications through using imaging probes also serving as drug carriers for diagnostic imaging purposes (Alzola-Aldamizetxebarria *et al*., 2022). This progression has extended the prospects in diagnostics and therapeutics using MRI particularly in nanomedicine providing information about a range of pathological states including cancer both in terms of anatomy along with function/metabolism (Bruno *et al*., 2022).

Magnetic-resonance imaging (MRI)

Improvements in MRI technology in the recent past have considerably expanded its role in the diagnosis and management of breast malignancy. MRI sensitivity in breast cancer detection has been realized, specifically in high-risk groups and in cases where conventional imaging modalities fail to bring clarity. It is vital in pre-operative evaluations, as it may identify co-existing pathology and help in staging, which aids in choosing appropriate treatment, more so in those patients who have neoadjuvant chemotherapy (Washington *et al*., 2024; Thompson *et al*., 2021). In the evaluation of ductal carcinoma in situ, MRI had good results with increased sensitivity in the detection of clinically significant lesions (Greenwood *et al*., 2020). The technology allows tracing responses to different treatments; it facilitates assessment of the integrity of breast silicone implants (Washington *et al*., 2024; Attenberger *et al*., 2020). However, there is still debate about the routine use of pre-operative MRI, with concerns voiced regarding possible overtreatment in subsets of patients (Thompson *et al*., 2021). In aggregate, changing competencies of MRI have made this modality a very important tool in the management of breast cancer practice. The use of preoperative MRI is increasing in early-stage breast cancer, particularly for the identification of multifocal or multicentric disease. However, the clinical benefits of this practice remain controversial. A meta-analysis indicates that although MRI is employed very often for different reasons, strong evidence linking it to improved surgical or oncologic outcomes is lacking (Karakatsanis *et al*., 2024). The utilization of MRI has recently increased from 48% to 60% for women who are not elderly between 2008 to 2020, and the use was influenced by the age, race, and location of the patient (Pan *et al*., 2023). The BREAST-MRI study reported an increased follow-up rate of 8% concerning patients receiving mastectomy with no differences in the indications of local relapse-free survival and overall survival (Mota *et al*., 2023). In addition, with the increasing application of MRI in neoadjuvant settings, its diagnostic accuracy is better than conventional methods, but its real necessity under such conditions has yet to be justified (Panico *et al*., 2022). Therefore, even though MRI is being used increasingly day by day, its impacts on patient outcomes remain uncertain; this warrants further research.

Role of imaging in breast cancer detection

Breast imaging plays a critical role in better health outcomes by being integral to the identification, diagnosis, and management of breast cancer. Imaging modalities applied in the identification of breast cancer include MRI, mammography, ultrasound, and microwave imaging (Qi J Guo *et al*., 2023; You *et al*., 2023; Singh *et al*., 2022). These modalities aid in the detection of abnormalities of the breast tissue and guide procedures, including the planning of treatments. Advances in imaging technologies have immensely enhanced the accuracy and sensitivity of breast cancer detection, thereby reducing rates of illness and death (Thakur *et al*., 2023). Figs. (1-3) show that MRI can detect tumor foci in addition to index cancer, which is not possible with conventional imaging (Berg *et al*., 2004).

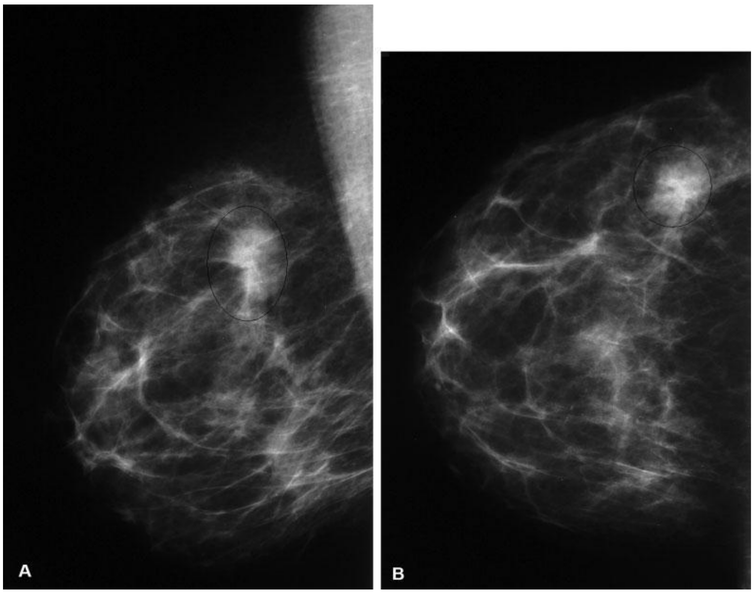

Fig. 1: (A, B) Female mammograms have a 43-years-old who had nodular density on mammography examination showing a mass approximately 2 cm in size from the left breast in the upper outer quadrant (Berg *et al*., 2004).

Fig. 2: This lesion was detected as a solid mass with characteristic malignant signs by ultrasound from the same 43-year-old woman who had a nodular density on screening mammography. The diagnosis of lobular carcinoma in situ (LCIS), a histological indicator of elevated breast cancer risk, was made possible by ultrasound-guided core-needle biopsy, which distinguished between invasive lobular carcinoma (ILC) and LCIS (Berg *et al*., 2004).

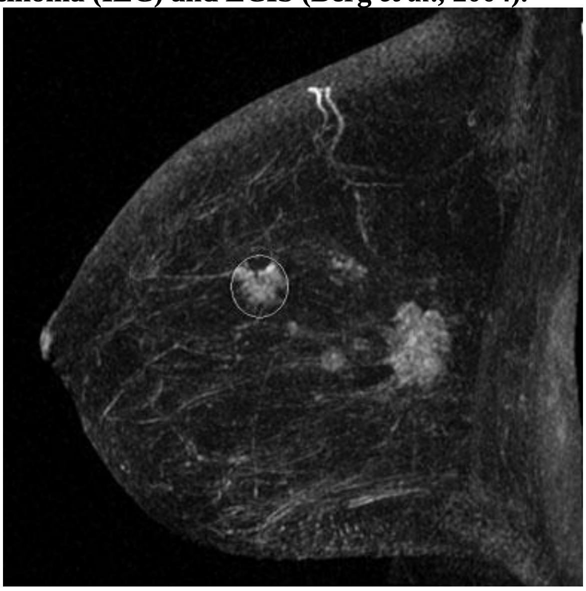

Fig. 3: Contrast-enhanced MRI of the same patient, a 43-year-old female with a nodular density on screening mammography and ultrasound, revealed the confirmed index cancer, which was larger on MRI than other imaging, along with a second, smaller mass (circled), situated approximately 5 cm further anteriorly and laterally than the index malignancy. A mastectomy was performed on this patient (Berg *et al*., 2004).

Besides, contrast agents like nanoprobes have increased the potential of MRI, fluorescence, and radionuclide imaging in detecting the early stages of breast cancer (Qi J Guo *et al*., 2023). The choice of imaging modality relies on factors such as the health condition, age, and breast density of a patient. Hybrid imaging techniques are emerging as a way to improve breast cancer detection (Iranmakani *et al*., 2020).

MRI is currently accepted as a technique for breast cancer surveillance in patients with genetic BRCA1 and BRCA2 gene mutations, or having previously undergone chest radiation, by recommendations of the american cancer society. Actually, studies showed that MRI had a greater sensitivity than mammography and ultrasound, detecting 14.7 new cancer cases per 1000 subjects when used as an additional method. While single, MRI considerably enhances the sensitivity of mammography in the detection of breast cancer, more so in high-risk patients (Mohammed *et al*., 2022). Though still associated with problems, such as expenses and patient discomfort, it is an underappreciated imaging modality for diagnosing breast cancer. Newer techniques, including dynamic contrast-enhanced MRI and magnetic resonance spectroscopy, further enhance the diagnostic potential of MRI in this application (Rahmat *et al*., 2022; Naranamangalam, 2022). Indeed, some techniques of MRI, magnetic resonance spectroscopy, diffusion-weighted imaging, and perfusion-weighted imaging, are very vital in the characterization of breast lesions and increasing diagnostic accuracy (Naranamangalam, 2022).

Moreover, MRI is also required to evaluate several molecular subtypes of breast cancer and to plan individual treatment methods. Again, MRI excels in preoperative staging, where it demonstrates a better estimation of tumor size and identifies additional tumor foci in breasts, improving surgical planning and subsequent outcomes. Finally, by virtue of its multiparametric assessment-with T1-weighted contrast-enhanced imaging and diffusion-weighted MRI-imaging improves the discrimination between malignant and benign breast lesions, most especially against mammography (Ritse *et al*., 2019).

With further evolution of the field of breast imaging, MRI is sure to take the front seat in not only a screening capacity but also as a diagnostic modality. Further refinement of the MRI techniques and improvement in accessibility and cost will only serve to solidify its position as an integral component of a comprehensive breast cancer detection and management strategy over the next decade.

MRI protocols for breast imaging

Breast imaging MRI protocols have made strides incorporating techniques like contrast-enhanced MRI and diffusion-weighted imaging (DWI) to improve diagnostic ability. Contrast-enhanced MRI with the use of gadolinium-based contrast agents helps in emphasizing areas of increased blood flow and perfusion, thus helping in the identification of a tumor (Park *et al*., 2023). However, DWI such as b value 2500s/mm^2 provides valuable information about how water molecules diffuse within breast tissue making it possible to differentiate between benign and malignant masses with high accuracy rates (Saccenti *et al*., 2023). Furthermore, DWI maximum-intensity projection (MIP) has been shown to be a cost-effective and reliable alternative to contrast-enhanced MRI that improves the detection of lesions especially in young patients who exhibit prominent background parenchymal enhancement (Park *et al*., 2023). Such developments concerning MRI protocols more so through the inclusion of DWI techniques are essential in the accurate characterization and diagnosis of breast abnormalities which eventually save patients. A good MRI protocol for early breast cancer detection combines high-resolution imaging with specific functional criteria. Early research suggests that a quality-assured, first-pass high-resolution MRI protocol is highly effective, especially in women with dense breasts, and has achieved over 95% detection rates of breast carcinomas and enhanced survival of more than 95% due to early detection of invasive cancers (Fischer, 2023). Furthermore, incorporation of ultrafast sequences as well as diffusion-weighted-imaging (DWI) improves diagnostic accuracy leading to better categorization between benign and malignant lesions respectively (Milon *et al*., 2023). They have comparable levels of sensitivity and specificity to standard protocols implying they are accessible and cost-effective but still maintain their diagnostic integrity like abbreviated protocols including those having T1-weighted sequence. Fig. (4) shows a series of images taken of a 43-year-old female with breast cancer using a 1.5 T MRI (MRI) machine with an 8-channel coil modified for breast examination. It works by placing the woman in the prone position with the breasts asymmetrically positioned in the coil. The contrast agent is gadolinium 0.2 mL/kg + (Gadovist Bayer Pharma AG, Berlin, Germany). The format consists of an original image and four sequential post-contrast images through dynamic breast evaluation for T1-weighted volume imaging (VIBRANT), and maximum projection lasting between 6 and 9 minutes for 3D density (Drinković *et al*., 2022). In summary, these advances in MRI protocols help not only in the early diagnosis but also improve overall survival outcomes of BC patients (Fischer, 2023).

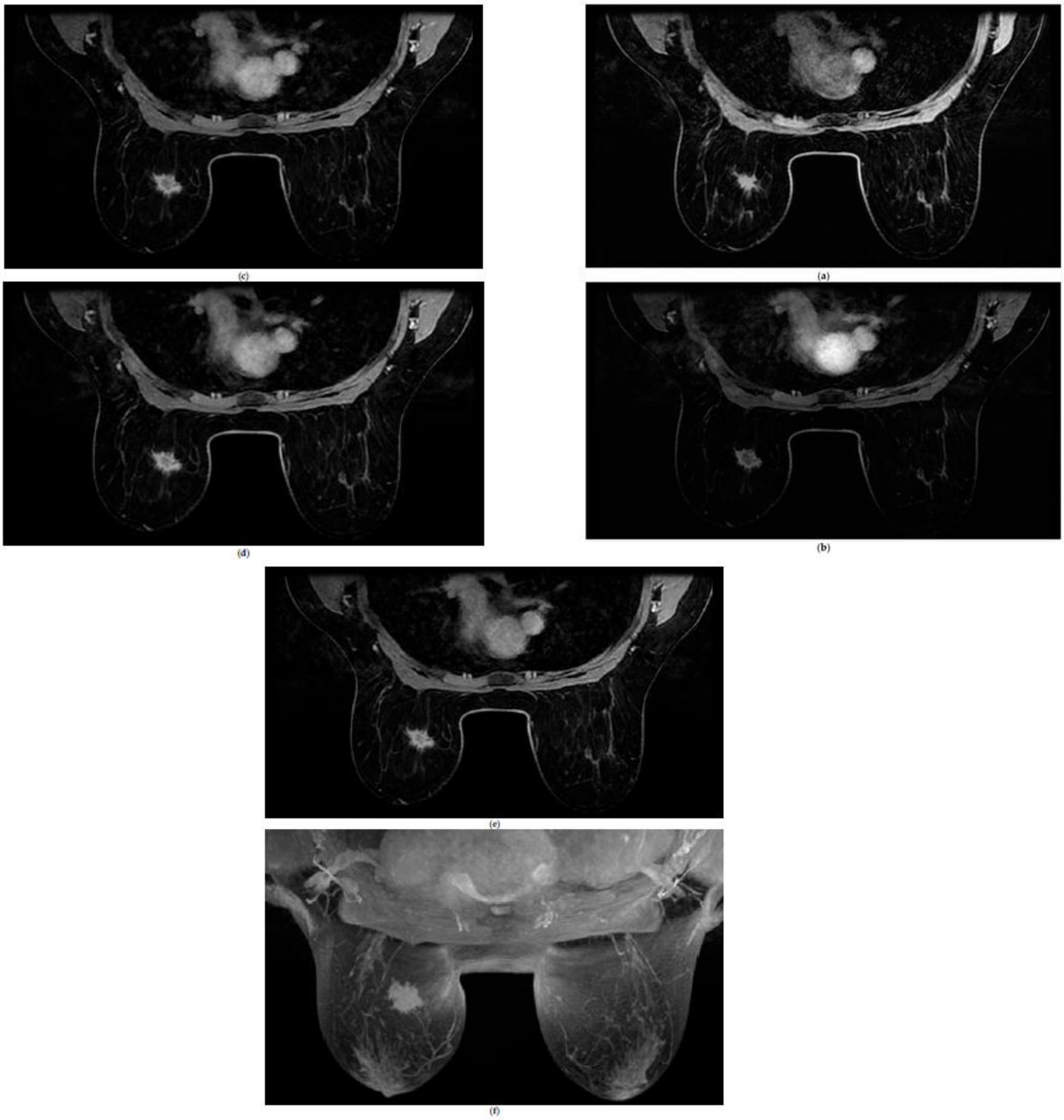

Fig. 4: A 43-year-old female Image with a new 2 cm of mass left breast (invasive ductal carcinoma-IDC). (a) Indigenous. (b) The initial postcontrast sequence. (c) A second post-contrast sequence. (d) The third post-contrast series. (e) Fourth post−variance sequence. (f) projection of the maximum intensity (Drinković *et al*., 2022).

CONCLUSIONS

MRI has emerged as a very good modality for the detection and management of breast cancer, having several advantages over classical imaging modalities. While understanding the principles of MRI and its applications is an evolving process, it can be expected to continue playing an increasingly crucial role in the early detection and effective treatment of this devastating disease. The future of MRI in breast cancer detection and treatment is very bright, with a focus on technological development and integration with AI. Particular emphasis is given in this current study to the research underway on the role of multiparametric and ultrafast MRI protocols in increasing diagnostic accuracy-more specifically, in high-risk populations and assessment of treatment responses. Besides, deep learning techniques that were included raised diagnostic performance quite a lot, providing high accuracy rates of differentiating malignant from benign conditions. Moreover, studies of novel imaging biomarkers like MRI-measured cell size in assessing therapeutic responses more effectively may provide information about the treatment effectiveness beyond the traditional volume-based metrics. Radiomics applied to image data with AI analysis could further add diagnostic capabilities in identifying subtle features that human observers may miss. Altogether, these trends point toward a future in which MRI improves early detection and provides patient-tailored treatment of breast cancer care. diffusion-weighted-imaging (DWI) is becoming an integral part of the breast MRI protocols run in most clinical settings around the world; hence its potential and relevance are gaining strength in clinical practice. DWI has versatile applications such as lesion, DWI is considered a moderate tool in detecting breast lesions. It helps to characterize between benign and malignant tumors. DWI can assess prognostic biomarkers of breast cancer that may help in treatment planning Prediction of response by the treatment. It can predict response to treatment by patients' non-contrast screening potential, it is a potential non-contrast MR imaging screening. This will be of value in patients who have contra-indications for the use of contrast agents advanced.

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أهمية التصوير بالرنين المغناطيسي للكشف عن سرطان الثدي: المراجعة

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الملخص

يعتبر سرطان الثدي حالة مميتة إذا لم يتم اكتشافه وعلاجه في وقت مبكر بما فيه الكفاية. يجب أن يكون التصوير بالرنين المغناطيسي إحدى طرق الكشف عن سرطان الثدي في مراحله الأولى. تهدف هذه الدراسة إلى معرفة مدى أهمية التصوير الشعاعي في الكشف عن سرطان الثدي. وهذا يجعل التصوير بالرنين المغناطيسي خيارًا ممتازًا لأنه يمكنه اكتشاف التغيرات الخلوية والتمييز بين الأورام الحميدة والخبيثة. مع التطور الإضافي في مجال تصوير الثدي، من المؤكد أن التصوير بالرنين المغناطيسي سيأخذ المقعد الأمامي ليس فقط في قدرة الفحص ولكن أيضًا كطريقة تشخيصية. إن تحسين تقنيات التصوير بالرنين المغناطيسي وتحسين إمكانية الوصول والتكلفة لن يؤدي إلا إلى ترسيخ مكانته كعنصر أساسي في استراتيجية شاملة للكشف عن سرطان الثدي وإدارته على مدى العقد المقبل. بالفعل، يعد التصوير الموزون بالانتشار جزءًا من البروتوكولات الروتينية للتصوير بالرنين المغناطيسي للثدي في العديد من المؤسسات في جميع أنحاء العالم، ومؤشرات الثدي DWI عديدة، وتمتد من اكتشاف الآفة والتشخيص التفريقي بين الأورام الخبيثة والحميدة إلى تقييم المؤشرات الحيوية النذير لسرطان الثدي وسرطان الثدي. تقييم الاستجابة للعلاج. في الفحص بدون طريقة التباين، قد يكون DWI مناسبًا لاستخدامه. إلى جانب رسم خرائط معامل الانتشار الواضح، والذي يمثل أحد مقاييس DWI الكمية للروتين السريري، يتم استغلال نماذج DWI المتقدمة مثل IVIM، والتصوير بالرنين المغناطيسي للانتشار غير الغوسي، وDTI على نطاق أوسع في تحديد المزيد من المعلمات التي تصور نضح الأنسجة والهندسة المعمارية وهي قادرة على لتحسين دقة التشخيص دون استخدام عوامل التباين. لذلك، في المراجعة الحالية، تم تقييم دقة تشخيص التصوير بالرنين المغناطيسي ومقارنتها بفعالية طرق التصوير المتنوعة في تشخيص سرطان الثدي.

الكلمات الدالة: التصوير بالرنين المغناطيسي، سرطان الثدي، الكشف عن التصوير، مبادئ التصوير بالرنين المغناطيسي.