REVIEW ARTICLE
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Advances in breast imaging: a review on where we are and where we are going

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ABSTRACT

Breast radiology has undergone significant advances in recent years, and, naturally, several possibilities open up for attending physicians. Concomitantly, it increases the responsibility to keep up to date and provide the best care for each patient. Aware of the complex implications that the implementation of some of the technological advances may bring, such as increased costs, limited availability of equipment, and a potential increase in examination time, the objective of this study is to carry out a narrative review and provide a collection of advances that, in our opinion, are already gaining ground and should be consolidated in clinical practice. We will discuss new breast imaging methods that can be used both for screening and for the diagnostic investigation of breast lesions and we will summarize the most relevant aspects of each of them, addressing the technique, applicability, positive aspects, and limitations of each modality in a standardized way.

KEYWORDS: breast; breast neoplasms; early cancer detection; breast ultrasonography; mammography; magnetic resonance imaging.

INTRODUCTION

The first uses of X-ray images for the diagnosis of breast cancer were made in 1927 and formed the basis for clinical trials that associated mammography with the reduction of breast cancer mortality[1]. In this historical context, it is worth highlighting the first randomized clinical trial, the 1961 Health Insurance Plan of Greater New York (HIP study), which showed a 22% reduction in breast cancer mortality, and also the "Breast Cancer Detection Demonstration Project," between 1973 and 1981, in which 39% of cancers were identified only on mammography, but not on clinical examination[2].

The era of breast radiology was then inaugurated. These first results boosted significant advances that allowed the dissemination of methods, such as ultrasound and magnetic resonance imaging (MRI), while others have emerged and continue to develop at a pace that challenges even great scholars to keep up to date.

In a dichotomous way, the speed of these advances is impressive, but at the same time, it raises questions about the viability of their applicability in clinical practice. Is there room for so much novelties? Will the promises of artificial intelligence (AI) ever be fulfilled?

Despite the impossibility of exhausting the topic, in the present article we aim to carry out a narrative review of the state of the art of breast imaging with an emphasis on the advances of different imaging methods that are gaining ground in clinical practice and should be progressively consolidated in the coming years.

METHODS

Data collection was based on bibliographic research in the PubMed, Scielo and LILACS databases between 2010 and 2023, including in the search the following terms: "breast imaging," "breast radiology," "contrast-enhanced mammography," "breast tomosynthesis," "automated whole-breast ultrasound," "abbreviated breast MRI," and "artificial intelligence breast imaging."

In view of the breadth resulting from the search for multiple subitems involved in this study, a narrative review of the literature was conducted, and the selection of studies was based on publications whose topics are most recurrent and with greater relevance in clinical practice. The vast topic of breast imaging was summarized with an emphasis on innovation in each of the techniques addressed. Historical data, properties of the method, sensitivity, specificity, advantages, and limitations were collected for each of the imaging techniques evaluated in this study. The main advances in breast imaging were summarized and presented in a standard way in the results section.

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RESULTS

Contrast-enhanced mammography

The only screening test proven to be associated with reduced breast cancer mortality in the population at regular risk is mammography, with a reduction of about 13–17% according to recent meta-analyses[2,3]. Since its inception, mammography has undergone significant advances, such as the conversion from analog to digital, in addition to the development of other imaging methods derived from mammography such as tomosynthesis (which will be discussed next) and contrast-enhanced mammography (CEM). Some highlights are worth making about the latter.

Contrast-enhanced mammography is an emerging technique consisting of obtaining dual-energy images after the administration of iodinated contrast, that is, a low-energy image, equivalent to the usual mammogram, and a high-energy image, which provides the recombination of the images and allows the identification of contrast enhancement. Since 2011, this technique has already had commercial application, and in 2022, a supplementary attachment to BI-RADS® was published, released by the American College of Radiology, with descriptions for CEM.

The rationale behind its creation is inspired by the success of MRI, the most sensitive imaging method for detecting breast cancer and whose performance is the result of an interpretation of anatomical and physiological findings. This is also the case with CEM. The physiopathological basis of this phenomenon is the greater vascular permeability of the blood vessels resulting from neoangiogenesis, which allows the extravasation of the contrasted material, which diffuses into the tumor tissue, culminating in the highlighted image[4]. This results in rapid local highlighting and allows the detection of neoplasms even in patients with dense breasts[4]. Simultaneously, arteriovenous shunts are formed, which also allow a rapid elimination of contrast.

The CEM can be used both as a diagnostic test, after an abnormal finding on a screening mammogram, and in the screening setting of high-risk women (lifetime risk for breast cancer >20%), especially those who cannot undergo MRI[4,5].

Advantages

The CEM has the advantage of demonstrating both anatomical changes and changes in breast perfusion, which, although not pathognomonic, may presumably result from neoplasms. This technique shows promising results in the first studies. Compared to conventional mammography, the CEM presents a significant gain in sensitivity, which can range from 48% in the case of dense breasts to 96%, while the specificity can range from 42% to 87%[6]. Studies have also demonstrated a better relationship between tumor size in CEM and histological size, making it a reliable test for preoperative planning[6].

When compared to MRI, CEM is an alternative in some situations because of the shorter execution time, around ten minutes, and reduced cost[7,8]. It is especially beneficial for patients who cannot perform MRI, such as claustrophobic patients, those using pacemakers and/or metal devices. Finally, the contrast-enhanced mammography also allows the detection of microcalcifications, and is therefore more sensitive than MRI in the diagnosis of ductal carcinoma *in situ*[6].

Disadvantages

Among the negative aspects of this new technique, we can first list the use of iodinated contrast, which brings with it the possibility of adverse effects. However, it should be noted that low osmolality contrast is used, which presents a lower risk of reaction when compared to conventional iodinated contrast.

The second negative aspect worth noting is the still limited availability of this examination. Due to the need for specific software, it cannot be performed on any mammography device.

Another consideration to be made is the increase in the radiation dose to which the patient is submitted, since a dual-energy mammogram is performed, with two mammogram purchases at the same compression, even though, of course, the radiation dose remains within safe limits.

With regard to sensitivity, even though it has a functional character, this technique is still based on morphological aspects and, therefore, it is affected by breast density. Lastly, it is worth considering that, when compared to conventional mammography, there is an increase in examination time, as images are obtained between 2 and 7 minutes after the intravenous administration of contrast[4,6].

Tomosynthesis

Digital breast tomosynthesis is an imaging method that is gaining ground in clinical practice and can be used both in breast cancer screening and in the diagnostic setting[9,10]. Resulting from the evolution of digital mammography, it is often mistakenly referred to as "3D mammography." In fact, the only technique that actually acquires three-dimensional X-ray images of the breast is computed tomography, which is not commonly used in breast radiology because it requires the acquisition of axial thoracic images, which would result in unnecessary radiation, especially to the intrathoracic organs. The tomosynthesis device acquires multiple two-dimensional images of the breast based on the rotation of the X-ray tube in an arc trajectory. The scanning amplitude comprises a limited range of angles, which can vary between 15º and 60º[9], obtaining images with a low radiation dose that are used for reconstruction and whose quality depends on the angle spectrum and the radiation dose used.

Advantages

The main objective of the tomosynthesis is to reduce the effect of tissue overlap, considering that a reconstruction of the breast is performed from multiple two-dimensional images from different angles[11]. This provides one of the great benefits of tomosynthesis: the reduction of false positive results caused by the effect of overlap. Therefore, tomosynthesis allows for a better identification and characterization of the nodal margins and the reduction of the unnecessary recall rate for the screening of patients with dense breasts by about 16%[12,13].

Another significant advantage is the increase in the breast cancer detection rate of 29% when tomosynthesis was added to digital mammography screening[9]. At this point, it should be noted that the long-term benefit is still uncertain. The question arises because the increased detection rate is, for the most part, due to the detection of low-grade tumors. If, on the one hand, this detection allows, in theory, for a less aggressive treatment, on the other hand, there is no robust evidence about the impact on survival[9]. To assess the survival benefits of breast cancer, prospective, randomized studies with long-term follow-up are necessary.

The Verona study[14] demonstrated that, among the invasive neoplasms detected by tomosynthesis, there was a large proportion with histological characteristics associated with a good prognosis. Supporting this line of reasoning, the Oslo study[15] showed that cancers detected exclusively by tomosynthesis tend to have lower Ki-67 rates.

Thus, despite the higher detection rate of breast cancer in tomosynthesis, considering that a significant proportion is comprised of tumors with a tendency to better prognosis, it is not clear whether these lesions could not be identified in subsequent digital mammography examinations, and long-term follow-up studies are necessary to elucidate the impact on overall survival[9].

Disadvantages

It should be noted that tomosynthesis is still an exclusively anatomical method, and it is, therefore, affected by breast density, with limitations remaining in cases of extremely dense breasts. In addition, the tomosynthesis is associated with an increase in image acquisition time, as well as interpretation time, although it should be noted here that interpretation time tends to decrease with the increase in the physician's experience with the examination[9].

Another noteworthy aspect is the concern about the increase in the radiation dose promoted by tomosynthesis, especially when the examination is performed in conjunction with digital mammography. This fear motivated the development of synthesized mammography, in which two-dimensional images are reconstructed from tomosynthesis data, in order to eliminate the need for simultaneous digital mammography.

Finally, it is worth noting that, despite being a promising method, tomosynthesis is still a method with limited availability in Brazil, both in the Brazilian Unified Health System (SUS) and in the private system, as it has a high cost (about four times the price of digital mammography) and it does not yet have universal coverage by health insurance plans.

Automated whole-breast ultrasound

The use of ultrasound as a complementary method to mammography, especially in patients with dense breasts, is already well-established in clinical practice[16]. In order to save time and standardize the images to allow interobserver comparisons and the comparison with previous examinations, a technique was developed that uses ultrasound and is performed in an automated manner. Thus, the automated whole-breast ultrasound (ABUS) emerged. ABUS can be used as a supplementary screening, combined with mammography in patients with extremely and heterogeneously dense breasts[17], and its use has been approved by the Food and Drug Administration since 2012.

Advantages

The great advantage of the ABUS is that it allows the image to be acquired by a technical professional, while the reading can be performed remotely by the doctor, allowing the optimization of time and focus on detecting the lesion. In addition, it is possible to simultaneously visualize in a single image the entire volume of the breast, from the skin to the chest wall, producing images similar to those of conventional manual ultrasound[18]. Furthermore, the image can be stored in order to allow temporal comparisons with previous and future studies, an essential characteristic when considering a screening exam[19].

According to a German study conducted by Wojcinski et al.[20], the accuracy, sensitivity, and specificity of the ABUS for the diagnosis of breast cancer was, respectively, 79.0%, 83.3%, and 78.1%.

Disadvantages

The greatest limitation of this technique is the noninclusion of the armpit in the ABUS field of view, so that conventional manual ultrasound is necessary for the evaluation of axillary lymph nodes[17]. Moreover, the benefit of reading in real time, which allows better detailing of a given finding, is lost at the expense of the standardization of the technique and the absence of a doctor during the examination.

Other negative aspects are the impossibility of the ABUS to guide biopsies and the unavailability of the use of Doppler[17]. Finally, when used in addition to mammography to screen patients at regular risk, it presents a low positive predictive value (5.4%) of biopsies performed on lesions identified exclusively by the ABUS[17].

In short, ABUS is an incipient imaging method, which aims to combine the desirable priorities of ultrasound with standardization and interobserver agreement. Although promising, the indications for the systematic application of this test in clinical practice are not yet consolidated in the literature. Besides, the price of the device and the cost of examinations for large-scale screening are not yet determined. It is known, however, that it is considerably more expensive than a high-quality conventional ultrasound device[21] and is intended exclusively for breast examination. Its large-scale employability in Brazil still remains a question.

Abbreviated breast MRI

MRI is, without a doubt, the most sensitive imaging method for the diagnosis of invasive breast cancer, and has a very well-established application in the screening of high-risk patients (lifetime risk for breast cancer >20%)[22]. In this scenario, MRI increases cancer diagnosis rates at earlier stages and reduces the rate of interval tumors[23]. However, this test is not accessible to a large number of high-risk patients. Considering the importance of MRI in this population, and in order to increase the availability of the method, a shorter protocol for screening was developed.

The abbreviated protocol was initially introduced and demonstrated its viability by Dr. Christiane Kuhl in 2014, consisting of a pre-contrast sequence and a post-contrast sequence, in addition to post-processing images[24]. In this study, Kuhl et al. demonstrated a very impactful reduction in image acquisition time, from 17 to 3 minutes[24], as well as in exam reading time, while maintaining diagnostic accuracy equivalent to the full protocol[24]. The time taken to acquire images, however, has a variable duration between different institutions. A review published in 2019 in the *Journal of the American College of Radiology*[25] evaluated the acquisition time of 70 abbreviated protocols and 736 complete protocols and found an average imaging time, respectively, of 17.5 minutes and 28.8 minutes. These data still demonstrate a significant reduction in the time taken to obtain the images, but to a lesser extent than the original study by Kuhl et al.[24]

Currently, the most used application of abbreviated MRI is in the scenario of screening high-risk patients[26]. A systematic review published in 2021 in the *European Journal of Radiology*, however, reported recent studies that also used abbreviated MRI in the diagnostic setting, aimed at studying the recurrence, staging, and assessment of the extent of the disease[27].

Advantages

The objective of shortening the MRI protocol is to make the method simpler, faster, and to increase its availability, in addition, of course, to improve its tolerability by patients[28,29]. In Brazil, abbreviated protocols are already validated and in operation, and there are others that are undergoing validation processes for use in the screening of high-risk women.

It is worth highlighting that there is heterogeneity of protocols between different institutions. In our service, for example, there is currently an abbreviated protocol in the process of being validated.

The SUS can also greatly benefit from this innovation, which makes a great contribution to the optimization of resources such as time and cost. Currently, the MRI examination is not included in the SUS table of procedures, medications and orthoses, prostheses, and special materials (SIGTAP). The code authorizing the examination to evaluate breast implant complications was revoked in December 2016. The dissemination of the abbreviated protocol offers prospects for the inclusion of MRI in the SUS procedure table, considering that it allows the optimization of machine time and reading time by the examiner, reducing costs and allowing the filling of the vast gap in the suppressed demand for breast MRI that currently exists in the Brazilian public system.

Disadvantages

As aforementioned, breast magnetic resonance imaging has a high cost and low availability, factors that limit its use on a population scale in Brazil. Furthermore, another negative aspect is the discomfort of performing it, as it requires a high degree of collaboration on the part of the patient, who must remain immobile throughout the examination period, which lasts an average of approximately 29 minutes[25]. Claustrophobic patients have great difficulty performing the examination.

Artificial intelligence in breast imaging

AI applied to breast imaging brings with it two recurring and intertwined concepts: machine learning, which corresponds to the way in which computers can learn and build models based on multiple statistical data[30]; and deep learning, which also consists of a learning methodology in which a complex multilayer network is developed to learn data representations automatically[31]. It is, therefore, an automated way of optimizing learning that allows the analysis of millions of cases, which not even the most experienced professionals would be able to study and memorize throughout their lives. AI, therefore, can be very robust as long as there is enough broad and diverse data for its training[31]. In fact, several retrospective studies have demonstrated AI models that perform better than experienced radiologists[32-35].

In the current clinical practice, AI resources are already available. The computer-aided detection and the computer-aided diagnosis help doctors in interpreting the tests, pointing out alarm signals and directing the evaluation. In addition, some more recent AI systems, when used in screening mammograms, demonstrated performance comparable to or even better than that of radiologists in the autonomous diagnosis of breast cancer, achieving a sensitivity of 56.2% to 81.9%, with a specificity of 84.3% to 96.6%[32,35]. AI, however, requires great standardization of examinations so that the data can be used. There is no doubt, therefore, that this topic is complex and that there are some steps that must be followed by professionals, national agencies, and health systems before AI becomes widely incorporated into clinical practice.

DISCUSSION

Breast radiology has undergone significant advances in recent years. Naturally, several possibilities open up for attending physicians. This study was developed to assist the attending physician in updating new topics in breast imaging, and during its execution, the main limitation we found was the wide breadth of the subject, as each of the advances discussed may be the focus of an individualized systematic review. Aware of the impossibility of investigating in depth each of the imaging methods discussed, our proposal in the present review was to highlight the new features that are already gaining ground in clinical practice and to provide a collection of advances that should be progressively consolidated in the coming years, both in the screening and diagnosis of lesions.

The contrast-enhanced mammography, which has been used commercially for just over a decade, stands out for achieving high sensitivity and specificity even in dense breasts. Despite the aforementioned limitations, because it is a functional method, it has the prospect of gaining space, especially in those contexts in which MRI cannot be used. Therefore, we can state that it is a method that has been adopted as an alternative to the use of resonance and as a complement to digital mammography in selected cases.

Another method derived from mammography, tomosynthesis, is already gaining ground in Brazil in the context of screening, especially in the private system. Despite the increase in radiation dose and the cost about four times higher than that of digital mammography, patients with dense breasts benefit from this method due to the higher breast cancer detection rate and lower false positive rate. Long-term follow-up studies may elucidate the impact on overall survival of this new method.

The ABUS is, among the four methods discussed, the least used in clinical practice. The idea of documenting large breast volumes simultaneously to allow temporal comparisons and between different observers requires a standardization of images that deprives the real-time assessment of lesions, a great advantage of conventional ultrasound. Furthermore, the lack of inclusion of the armpit in the field of view is another important limitation and requires the use of conventional manual ultrasound for the evaluation of axillary lymph nodes. Hence, there is still no consensus in the literature regarding its indications, and its use remains restricted.

Abbreviated MRI, in turn, is a version of the method that is already widely known, with the adaptation of its protocol aimed at saving examination time, leading to reduced costs and greater tolerability on the part of patients. It is an advance that presents greater prospects of use for patients at high risk for breast cancer than for patients at usual risk.

Finally, the topic of AI, although not limited to a specific imaging exam, was included in this study because of its development potential and the large number of recent publications. This phenomenon is a reflection of the great speed with which advances are being made in the field of AI in different imaging methods and the emergence of algorithms that can exceed human performance, increasing diagnostic accuracy and potentially reducing costs. This topic requires great technical knowledge, and its thorough investigation may be the topic of new targeted review studies.

CONCLUSIONS

In this study we presented a narrative review of the state of the art of breast imaging with an emphasis on the advances that are already employed in clinical practice and that tend to be consolidated in the near future. This is especially important for professionals working in a country such as Brazil, where, as technologies emerge, new challenges are simultaneously presented to attending physicians, firstly to keep up to date, and secondly to seek information about the availability of these new advances in each situation.

Brazil is already facing difficulties resulting from the dissociation between demand and supply of diagnostic procedures, especially in the public system, and not all technological advances will prove to be cost-effective in the long term. As new technologies tend to incorporate expenditures, the debate must focus on the rational use of resources, which requires studies with more robust follow-ups for most of the novelties discussed in this article.

We, as mastologists, understand that discoveries must be inserted into the reality of each patient, from a perspective that meets the trend in current medicine according to which the conducts must become increasingly individualized. The exponential number of recent publications on advances in breast imaging is an invitation to deepen the studies, and it is the responsibility of the attending physician, taking into account technical rigor, to filter information. Research such as the present review can assist in determining the best applicability in each case and in decision-making.

AUTHORS' CONTRIBUTION

FMOC: Conceptualization, Data curation, Investigation, Methodology, Project administration, Visualization, Writing – original draft. MFSVG: Data curation, Investigation, Writing – review & editing. KPCL: Data curation, Investigation, Writing – review & editing. RCSF: Investigation, Validation, Visualization, Writing – review & editing. JTCA: Conceptualization, Data curation, Formal analysis, Methodology, Project administration, Supervision, Validation, Writing – review & editing.

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