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FULL RESEARCH ARTICLE

Breast MRI acquisition and analysis protocol: a pictorial essay

I. Miranda Sanchez-Carenzo-Velez[1,2#], Yesika J. Davila-Zablah[1#], Elena Maria Sanchez-Siller[1#], Mané M. Ayala-Duran[1#], Ilany B. Lopez-Valdivia[2], Maria Guerra-Ayala[2], Jessica A. Perdomo-Galviz[2], Karla I. Soto-Valdez[2], Sofia Hurtado-Arellano[3], and Margarita L. Garza-Montemayor[1#]*

[1]*Diagnostic Breast Imaging Department, Hospital Zambrano Hellion Tec Salud;* [2]*Department of Radiology and Imaging, Tec Salud;* [3]*School of Medicine and Health Sciences, Tecnológico de Monterrey. Monterrey, Nuevo Leon, Mexico*

[#]*These authors contributed equally*

ABSTRACT

Breast cancer is a worldwide malignant disease that is heterogeneous in its macroscopic morphology and at the molecular level. Although mammography is the standard examination for diagnosis, breast magnetic resonance imaging (MRI) has the highest sensitivity for breast cancer detection. The indications for a breast MRI are diverse, with cancer staging being the most important. This pictorial essay presents a breast MRI acquisition and analysis protocol, supported by drawings of the morphologic features of mass and non-mass lesions based on the American College of Radiology Breast Imaging Reporting and Data System (BI-RADS) 5th Edition lexicon and the Kaiser score. Our institution includes the following sequences in the breast MRI protocol: T1-weighted spin-echo (SE), T2 fat-suppressed (FS), diffusion-weighted images (DWI), the apparent diffusion coefficient (ADC), T1 gradient echo (GE) with fat sat (FS), T1 dynamic contrast-enhanced (DCE) with gadolinium (Gd), time-signal intensity curve (kinetic curve), positive enhancement integral (PEI) values, maximum intensity projection (MIP) and the coronal T2 fast spin-echo (FSE). Experienced radiologists should interpret breast MRI in correlation with other imaging studies, such as a recent mammography and/or a breast ultrasound. This pictorial essay is published for educational purposes for radiologists and residents.

Keywords: *Breast magnetic resonance imaging. Kaiser score. Breast cancer. MRI lexicon.*

INTRODUCTION

The global incidence of breast cancer is increasing at a rate of 3.1% annually[1]. This reflects the importance of screening examinations such as mammography and ultrasound and other tools such as breast magnetic resonance imaging (MRI) with contrast medium. Breast MRI has a high sensitivity of 94-100% for detecting breast cancer[1,2]. The main indications for breast MRI are patients with a recent diagnosis of breast cancer for staging and treatment planning; the follow-up of women with a personal history of breast cancer to detect recurrence or a new tumor; women with an intermediate or high risk (15-20%) of breast cancer, and a positive gene test or a positive family history. This pictorial essay presents a breast MRI acquisition and analysis protocol, supported by drawings of the morphologic features of

Corresponding author:
I. Miranda Sanchez-Carenzo-Velez
E-mail: iamiranda7720@gmail.com

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mass and non-mass lesions based on the American College of Radiology Breast Imaging Reporting and Data System (BI-RADS) 5th Edition lexicon and the Kaiser score.

BREAST MRI ACQUISITION PROTOCOL

A 1.5T or higher MRI resonator is required to obtain images with higher spatial and temporal resolution. A dedicated breast coil is also essential to obtain images of adequate quality. Breast coils usually have between 4 and 16 channels[3,4].

Acquisition protocols may vary from institution to institution, but essential sequences such as T1-weighted spin echo (SE), T2 fat-suppressed (FS), diffusion-weighted images (DWI), T1 dynamic contrast-enhanced (DCE) with gadolinium (Gd), and kinetic curve must be performed[3,5,6]. Some additional sequences are performed in some centers, such as Ultrafast and T2 turbo inversion recovery magnitude (TIRM)[5,6].

Our institution includes the following sequences in the breast MRI protocol: T1-weighted SE, T2 FS, DWI, apparent diffusion coefficient (ADC), T1 gradient echo (GE) with FS, T1 DCE with Gd, T1 DCE with Gd and subtraction, maximum intensity projection (MIP), positive enhancement integral (PEI) values, coronal T2 fast-spin echo (FSE) and kinetic curve.

BREAST MRI ANALYSIS

After adequate and complete sequence acquisition, an image visualization and interpretation protocol is performed[6]. Interpretation should be performed by radiologists with experience in breast imaging[3]. Breast MRI should be interpreted in correlation with other imaging studies such as a recent mammography and/or breast ultrasound[7]. Image visualization should be performed on medical-grade monitors.

We recommend the following sequence screen arrangement with 8 simultaneous images in two rows: an upper row with 4 images and a lower row with 4 images. The sequences in the upper row, from left to right, are T1 weighted SE, T2 FS, DWI, and ADC. The sequences in the bottom row are T1 DCE with Gd, T1 DCE with Gd and subtraction, PEI, and coronal T2 FSE, from left to right. The images should be linked so they can be displayed simultaneously and dynamically. This sequence visualization protocol allows for accurate and efficient breast MRI interpretation. Breast MRI analysis should emphasize the advantages and benefits of each sequence.

The T1-weighted SE sequence is useful to assess normal breast anatomy (Figure 1). Fatty tissue appears hyperintense (bright), while lesions with fluid content, such as cysts or ectatic ducts, appear hypointense (dark). In the T2 FS sequence, fluids appear hyperintense, which allows the identification of cysts, edema, or inflammatory processes (mastitis).

DWI measures water molecule movement through tissues and helps differentiate benign and malignant lesions. Cancer cells generally have a higher cell content and, therefore, restrict the movement of water molecules, which leads to a more intense DWI sequence signal. The ADC map is derived from the DWI sequence and represents the degree of diffusion of water molecules within tissues. A low ADC indicates a high cell density, which suggests a malignant breast lesion. Conversely, a high ADC value suggests a benign breast lesion[2,4].

The T1 DCE with Gd highlights the areas where contrast is administered. This helps identify and characterize breast tissue lesions based on their vascularity. It is particularly useful for detecting malignant tumors, as these usually have higher blood flow and more contrast uptake than benign lesions.

The PEI sequence graphically represents a numerical value that measures the tissue perfusion of a contrast medium to highlight differences between normal and abnormal tissue. It can facilitate lesion detection and help differentiate between benign and malignant tumors. Kinetic curves characterize breast lesions by showing specific contrast uptake patterns and clearance. The coronal T2 FSE assesses the axillary lymph nodes in their three levels and the internal mammary chains.

BREAST MRI DESCRIPTION WITH THE ACR BI-RADS LEXICON

The general description of the composition based on the ACR BI-RADS 5th Edition[8] includes the amount of fibroglandular tissue and background parenchymal enhancement. On the other hand, the description of abnormal findings includes focus, mass, non-mass lesion, intramammary lymph nodes, skin lesions, associated features (non-enhancing findings, fat-containing lesions), the location, size, abnormal enhancement descriptors, and the kinetic curve[8].

Suspected malignant lesions are difficult to describe. To facilitate and not forget the features to be identified and described on the breast MRI, we developed the chart in figure 2. The chart includes the descriptors of mass and non-mass lesions, the distribution patterns

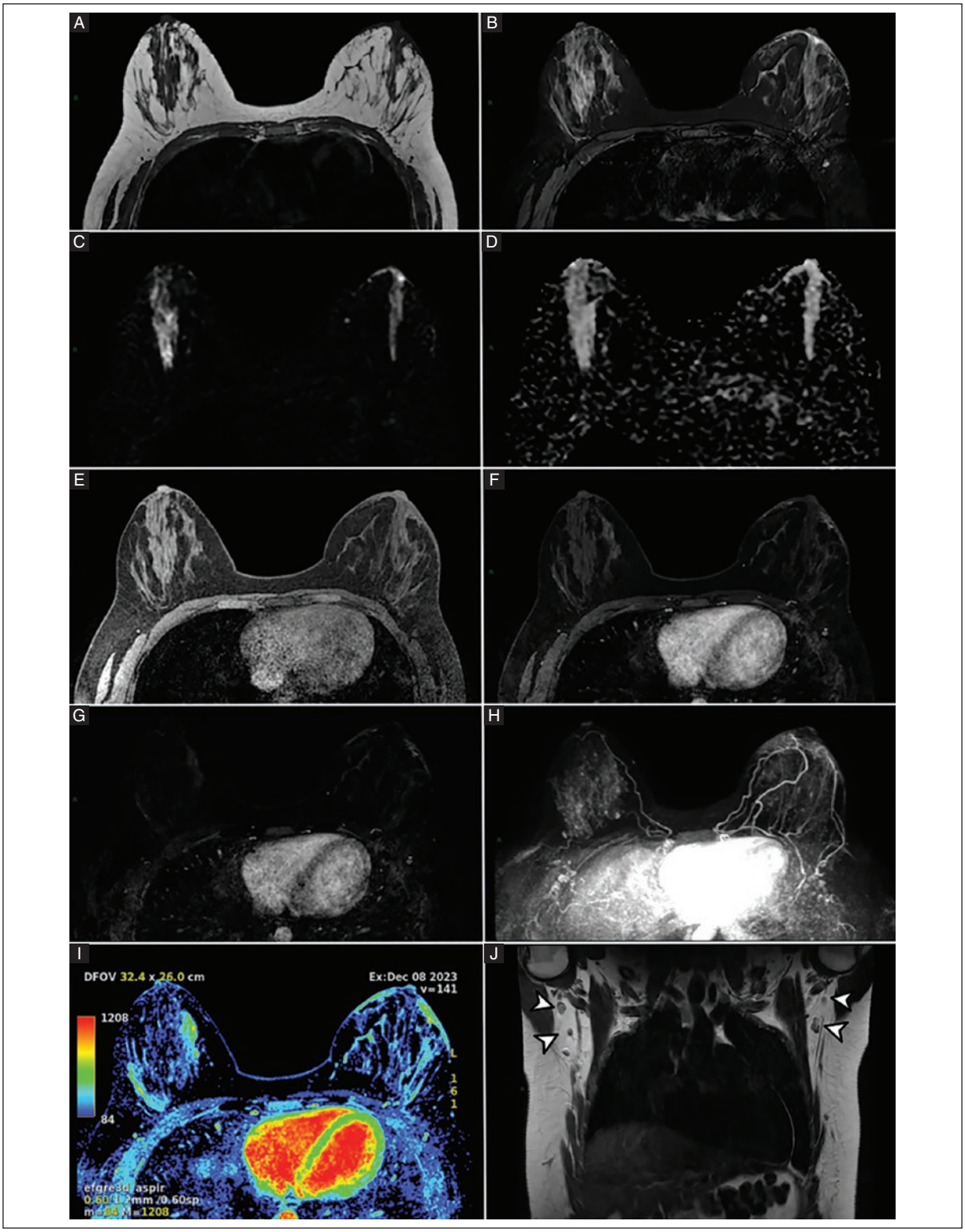

Figure 1. Normal breast MRI findings. **A:** T1 weighted SE with heterogeneous fibroglandular tissue. **B:** T2 FS without hyperintense findings. **C:** DWI sequence and **D:** ADC with no restrictive lesion. **E:** T1 GE with FS shows normal breast tissue and no suspicious findings. **F:** T1 DCE with Gd and physiologic enhancement. **G:** T1 DCE with Gd and subtraction. No abnormal lesions are present. **H:** MIP with normal fibroglandular tissue and vascular enhancement. **I:** PEI without correlation of time-signal intensity curves and no suspicious findings. **J**: coronal T2 FSE with normal axillary lymph nodes (arrowheads).

ADC: apparent diffusion coefficient; DCE: dynamic contrast-enhanced; DWI: diffusion-weighted images; FS: fat suppressed; FSE: fast spin echo; Gd: gadolinium; GE: gradient echo; MRI: magnetic resonance imaging; MIP: maximum intensity projection; PEI: positive enhancement integral; SE: spin echo.

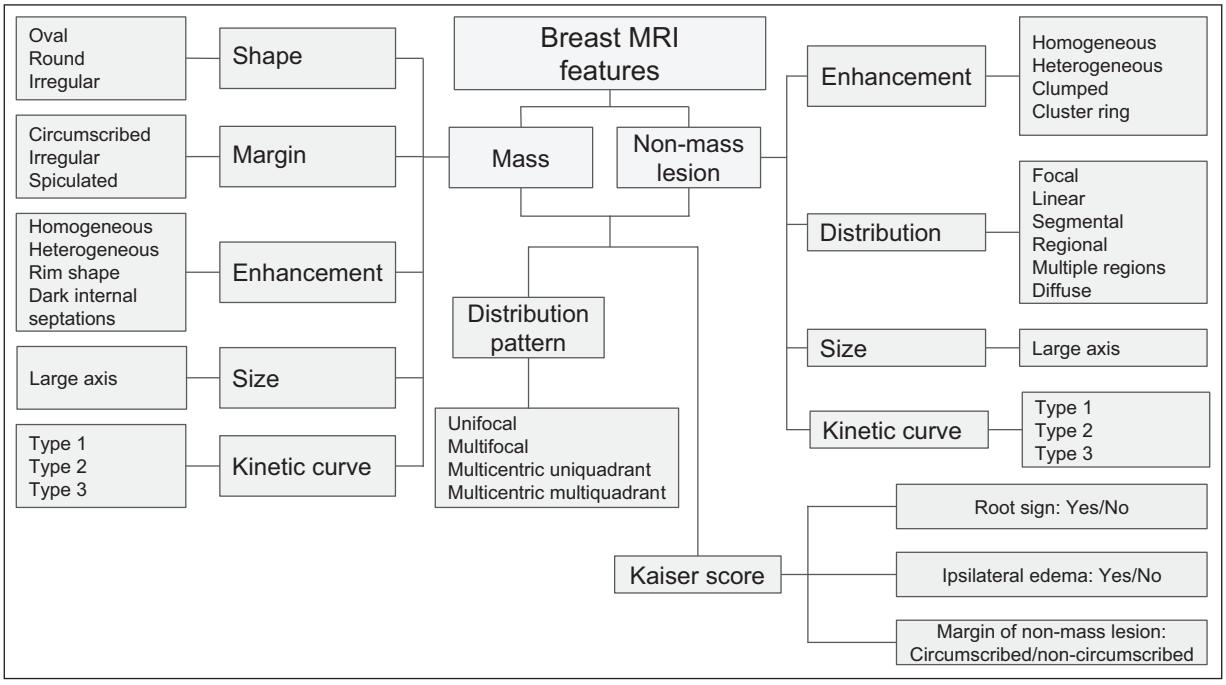

Figure 2. Diagram showing the features of lesions examined by breast MRI according to BI-RADS lexicon. The characteristics described include those of a mass, namely the shape (oval, round and irregular), followed by the margin (circumscribed, irregular and spiculated), mass enhancement (homogeneous, heterogeneous, rim shape, dark internal septations), the size which must be measured in the long axis and expressed in millimeters or centimeters, and the kinetic curve type (1, 2, 3). For non-mass lesions, the descriptors are enhancement (homogeneous, heterogeneous, clumped and cluster ring), distribution (focal, linear, segmental, regional, multiple regions and diffuse), size, which must be measured in its longitudinal axis and reported in millimeters or centimeters and the kinetic curve type (1, 2, 3). The distribution pattern of the malignant lesion should be described (unifocal, multifocal, multicentric uniquadrant, or multicentric multiquadrant). As an additional tool, the Kaiser score of the lesions should be determined, considering some characteristics not mentioned in the BI-RADS, such as root sign (yes/no), ipsilateral edema (yes/no), and non-mass lesion margin (circumscribed and non-circumscribed).

BI-RADS: Breast Imaging Reporting and Data System; MRI: magnetic resonance imaging.

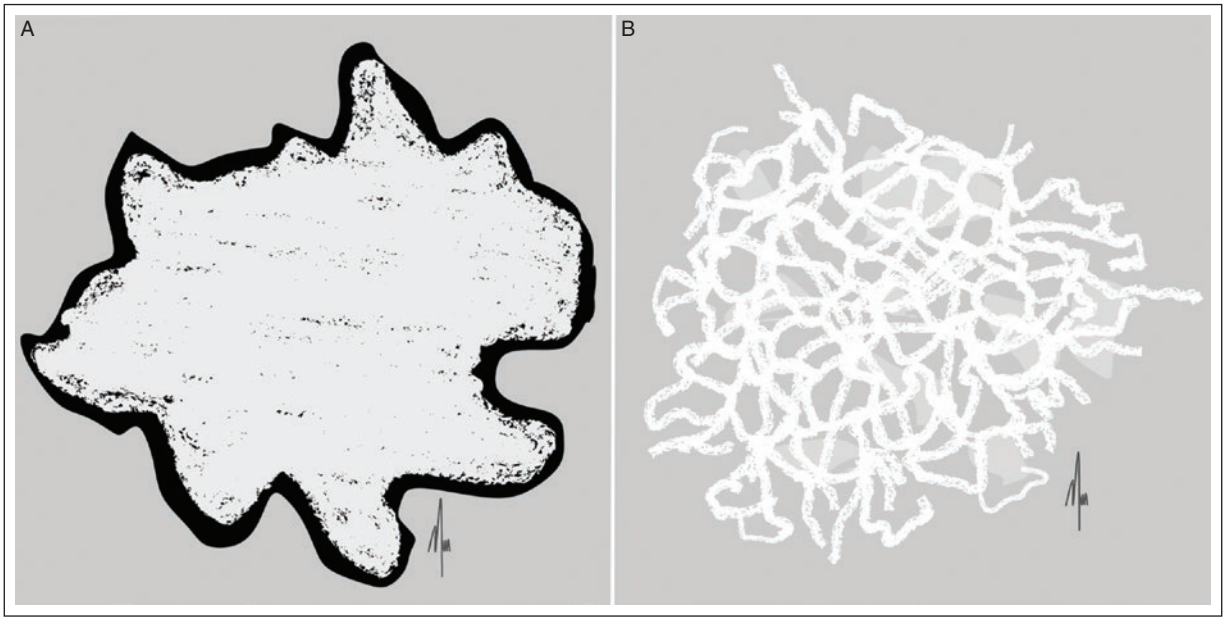

Figure 3. Drawings showing the difference between breast lesions. **A:** the mass is a three-dimensional, space-occupying lesion in the breasts. **B:** a non-mass lesion is an area of enhancement that does not meet the criteria for a mass, with a non-convex margin, interspersed fat, or fibroglandular tissue between the enhancement components.

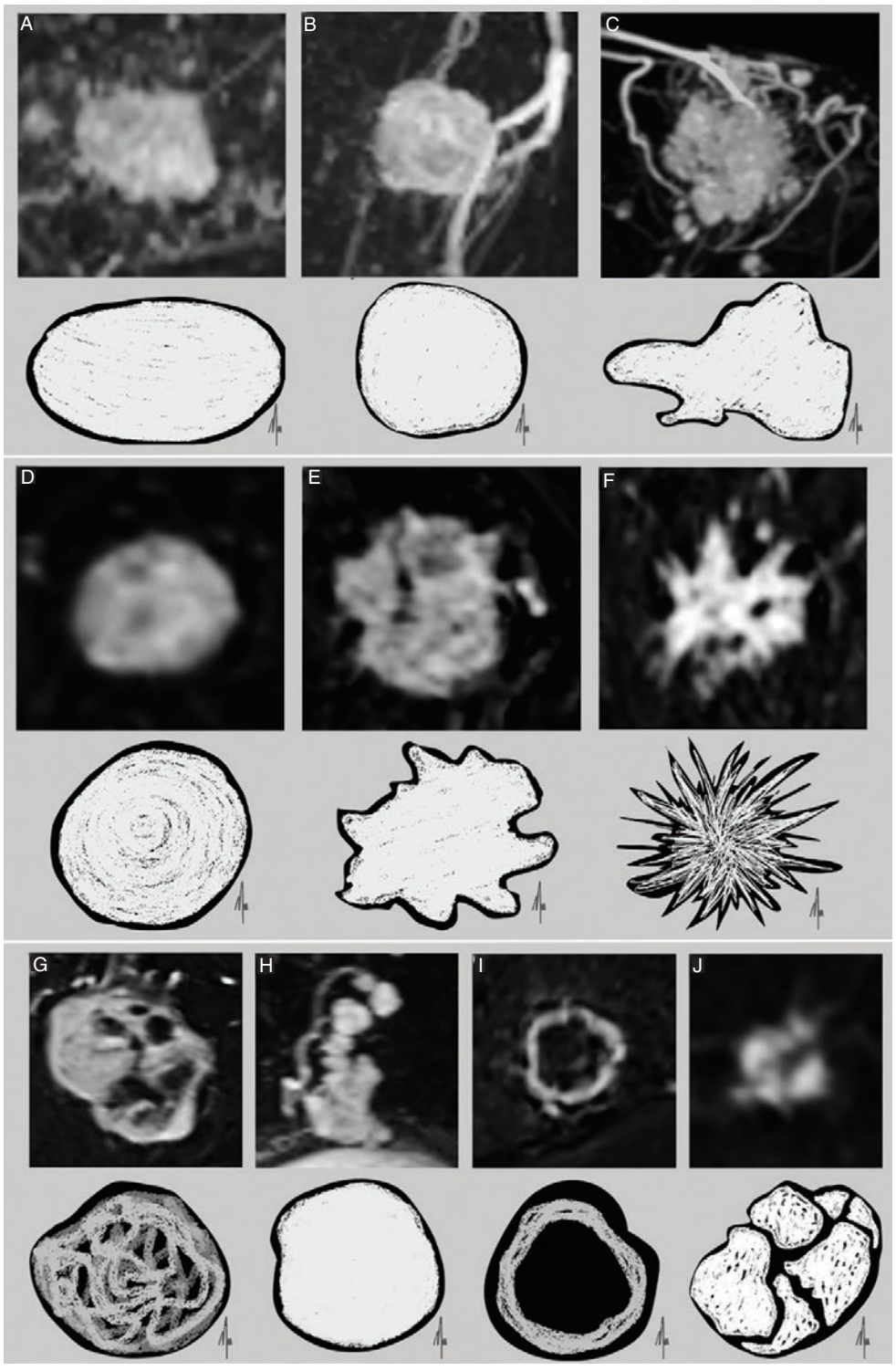

Figure 4. T1 DCE with Gd and drawings showing the three types of mass lesion morphology, the three types of margins, and the classification of mass lesion enhancement. **Morphology. A:** oval, elliptical, or ovoid shape with two or three undulations. **B:** round: spherical, circular, or globular. **C:** irregular, neither round nor oval, usually represents a suspicious malignant finding. **Margin. D:** circumscribed with a clear delimitation; an abrupt transition between the lesion and surrounding tissue is recognizable. The entire margin must be well-defined. **E:** irregular is pointed but not spiculated. **F:** spiculated with lines that radiate from the center to the periphery. This is a suspicious malignant lesion. **Enhancement. G:** heterogeneous with non-uniform enhancement but showing areas of varying signal intensity. **H:** homogeneous with uniform and confluent enhancement. **I:** rim shape is most pronounced at the periphery of the mass. **J:** dark internal septations with dark hypointense internal septa with non-enhancing lines located within a mass.

DCE: dynamic contrast-enhanced; Gd: gadolinium.

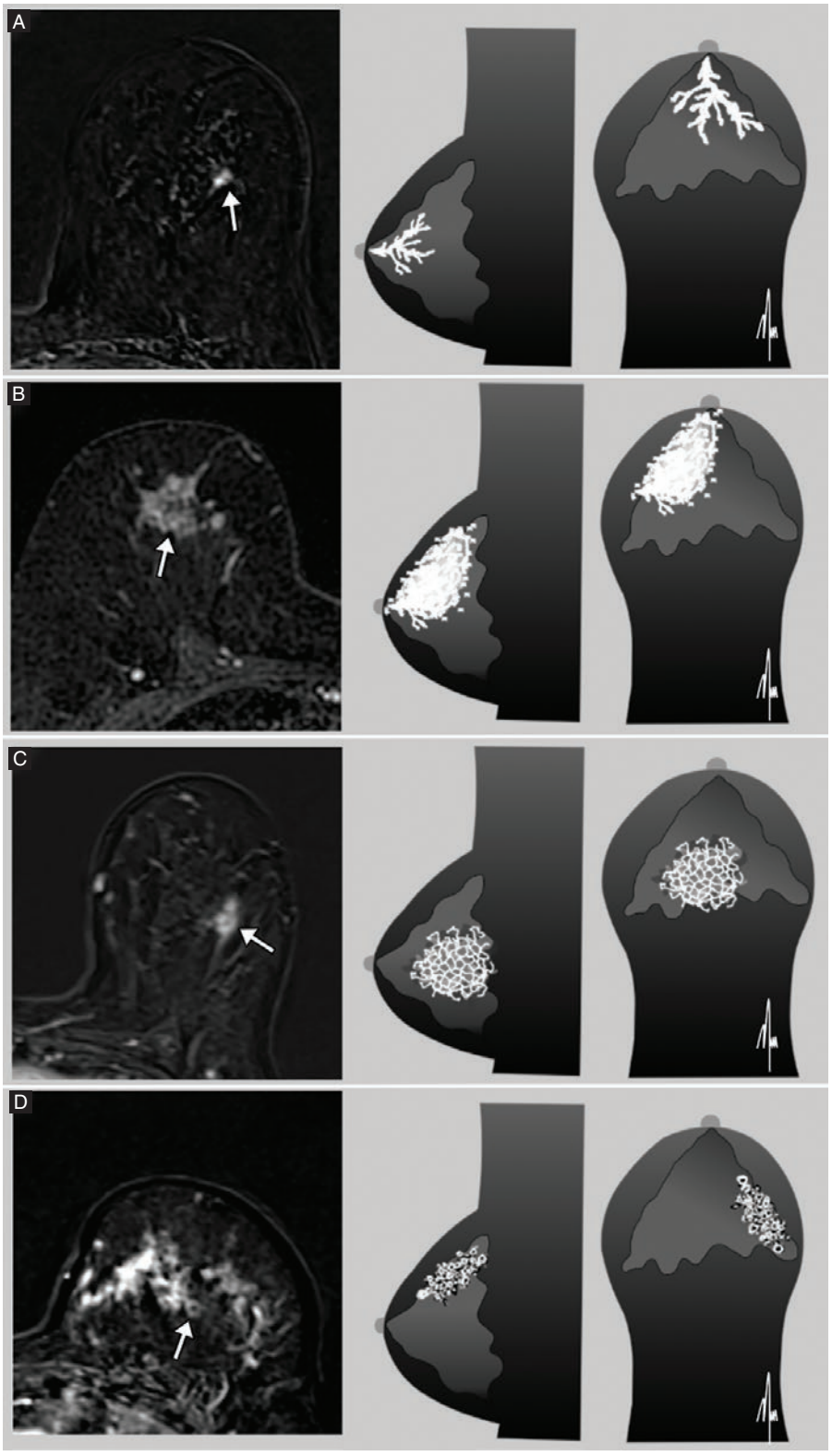

Figure 5. T1 DCE with Gd and drawings of the different types of non-mass lesion enhancement. **A:** homogeneous is confluent and uniform (arrow). **B:** heterogeneous is not uniform. It has a random distribution separated by areas of normal or fatty breast parenchyma (arrow). **C:** clumped with enhancement in lumps of different shapes and sizes and some confluent areas. It is suspicious of a malignant lesion (arrow). **D:** cluster ring with thin enhancement rings grouped around the ducts. It is suspicious of a malignant lesion (arrow).

DCE: dynamic contrast-enhanced; Gd: gadolinium.

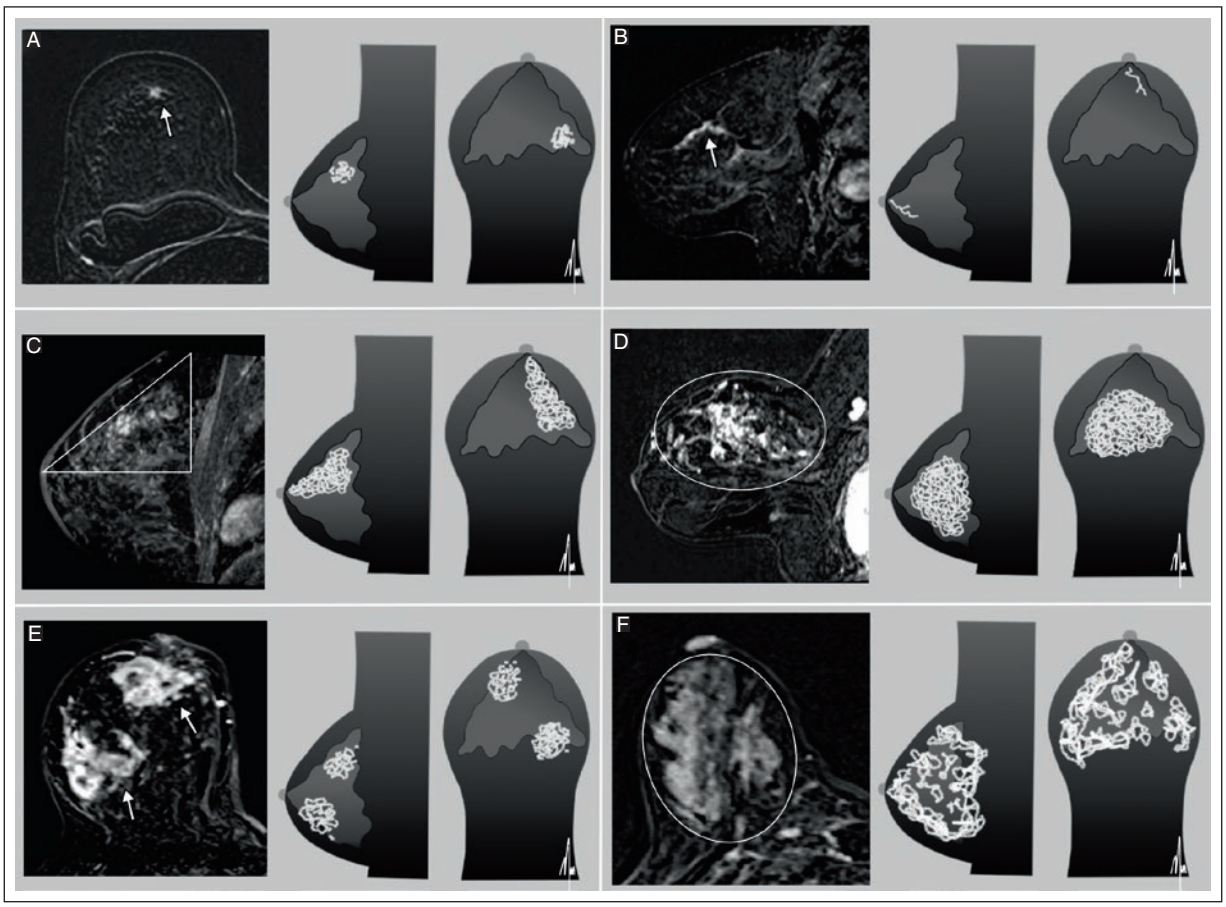

Figure 6. T1 DCE with Gd and drawings of the distribution of non-mass lesions: **A:** focal is limited to a sector with internal enhancement that is not considered nodular (arrow). **B:** linear with appearance of a straight line or a line those branches (arrow). **C:** segmentary is triangular or conical with the apex towards the nipple (triangle). **D:** regional, comprising more than one duct system, occupies at least one quadrant) (circle). **E:** multiple regions with several regions of enhancement in two large sectors separated from normal tissue (arrows). **F:** diffuse is randomly distributed over the entire breast (circle).

DCE: dynamic contrast-enhanced; Gd: gadolinium.

of malignant breast lesions[8,9], the Kaiser score, and its unique descriptors[10-12].

According to the chart, the first step is to differentiate between a mass and non-mass lesion, keeping in mind that a mass is a three-dimensional, space-occupying lesion in the breast and a non-mass lesion is an area of enhancement that does not meet the criteria for a mass or focus, such as a non-convex margin or interspersed fat or fibroglandular tissue between the enhancement components[8] (Figure 3).

The features of the mass described are shape, margin, enhancement, size, and kinetic curve. The unique and distinctive characteristics of the mass are its shape, margin, and enhancement. The shape may be oval (lobulated, elliptical, or ovoid, without or with two or three undulations), round (spherical, circular, or globular), or irregular, neither round nor oval, and is usually a suspicious, malignant finding (Figure 4). The margin may be circumscribed if there is a clear delimitation, with an abrupt transition between the lesion and surrounding tissue, and the entire margin must be well defined; irregular if they are pointed but not spiculated; and spiculated on this type of lesion shows lines radiating from the center to the periphery and is a suspicious finding. Enhancement may indicate the likelihood of a malignant lesion. Homogeneous and dark internal septations are usually benign, non-suspicious lesions, in contrast to heterogeneous margin enhancement, which is a suspicious finding for malignancy[8].

Enhancement, distribution, size, and kinetic curve are descriptive features that distinguish non-mass lesions. Enhancement can be homogeneous if it is confluent

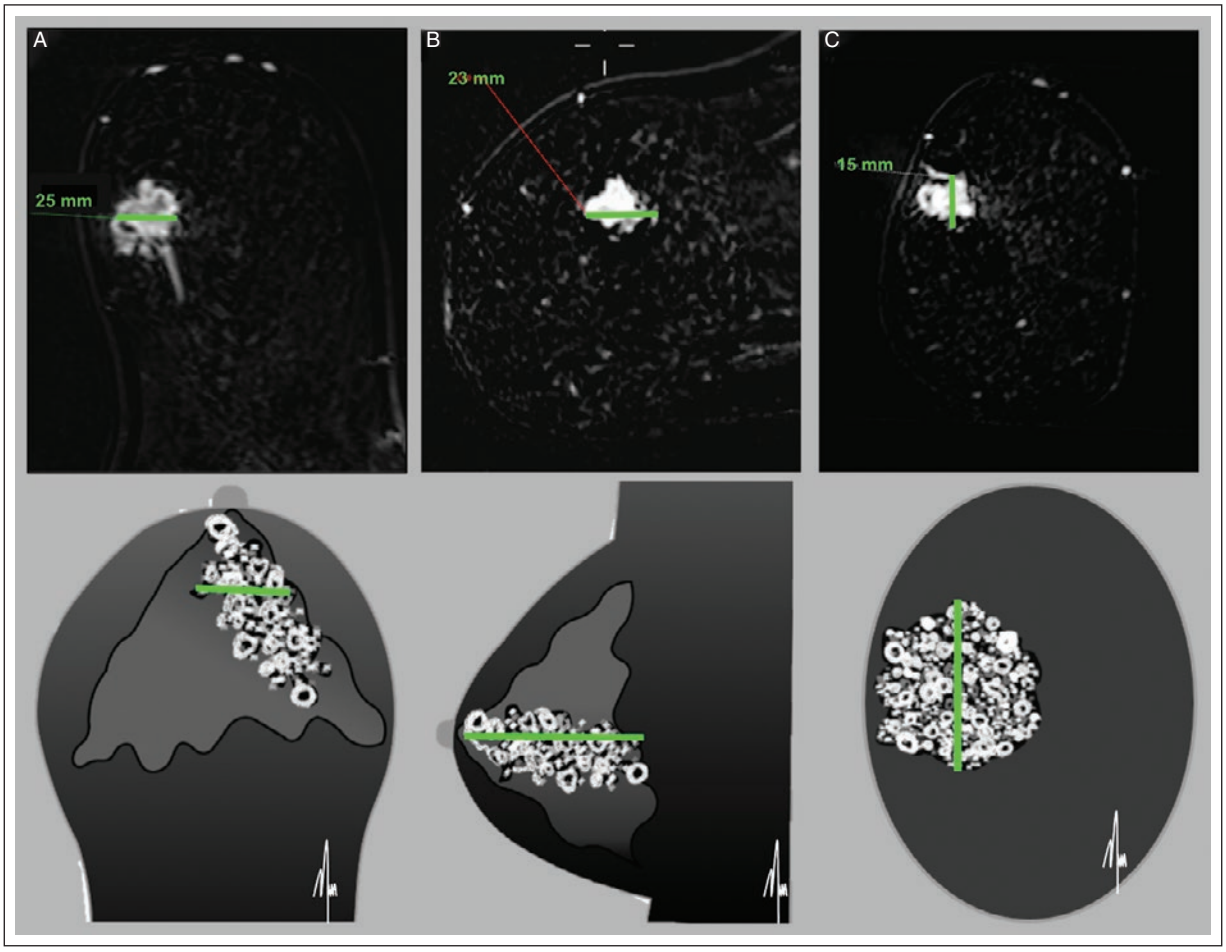

Figure 7. Drawing and T1 DCE with Gd show how the lesion's diameter is measured in the three planes. **A:** transverse diameter in the axial plane (green line). **B:** anteroposterior diameter in the sagittal plane (green line). **C:** cephalocaudal diameter in the coronal plane (green line). DCE: dynamic contrast-enhanced; Gd: gadolinium.

and uniform and heterogeneous if it is not uniform, has a random distribution, and is separated by areas of normal or fatty breast parenchyma. Clumped enhancement, a suspicious malignant finding, occurs in clumps of different shapes and sizes and some confluent areas develop. Clustered ring enhancement occurs when thin rings of enhancement are grouped around the ducts, it is a suspicious malignant finding (Figure 5).

The distribution can be focal, linear, segmental, in multiples regions, or diffuse. The term focal means it is confined to one sector of internal enhancement and is not considered nodular. By definition, it occupies less than one breast quadrant[8] (Figure 6). Linear if the appearance is a straight or branching line; segmental, if it is triangular or conical with the tip pointing towards the nipple; regional if it involves more than one ductal system and occupies at least one quadrant; multiple regions if several regions of enhancement are separated from normal tissue in two large sectors; diffuse if it is randomly distributed throughout the breast.

Features that are similar between mass and non-mass lesions and evaluated similarly are size and the kinetic curve. Size must be measured in the three axes where the largest diameter is determined and expressed in millimeters or centimeters (Figure 7).

The kinetic curves are those in which DCE MRI uses a temporal signal intensity curve obtained from repeated MRI scans after the injection of a contrast agent. They are useful for detecting breast cancer due to their high sensitivity[3]. The behavior of the initial phase (slow, medium, or fast) and the late phase (persistent, plateau, or washout) is analyzed. The kinetic curve can be presented in three types (Figure 8). The persistent curve (type 1) shows a progressive increase in the

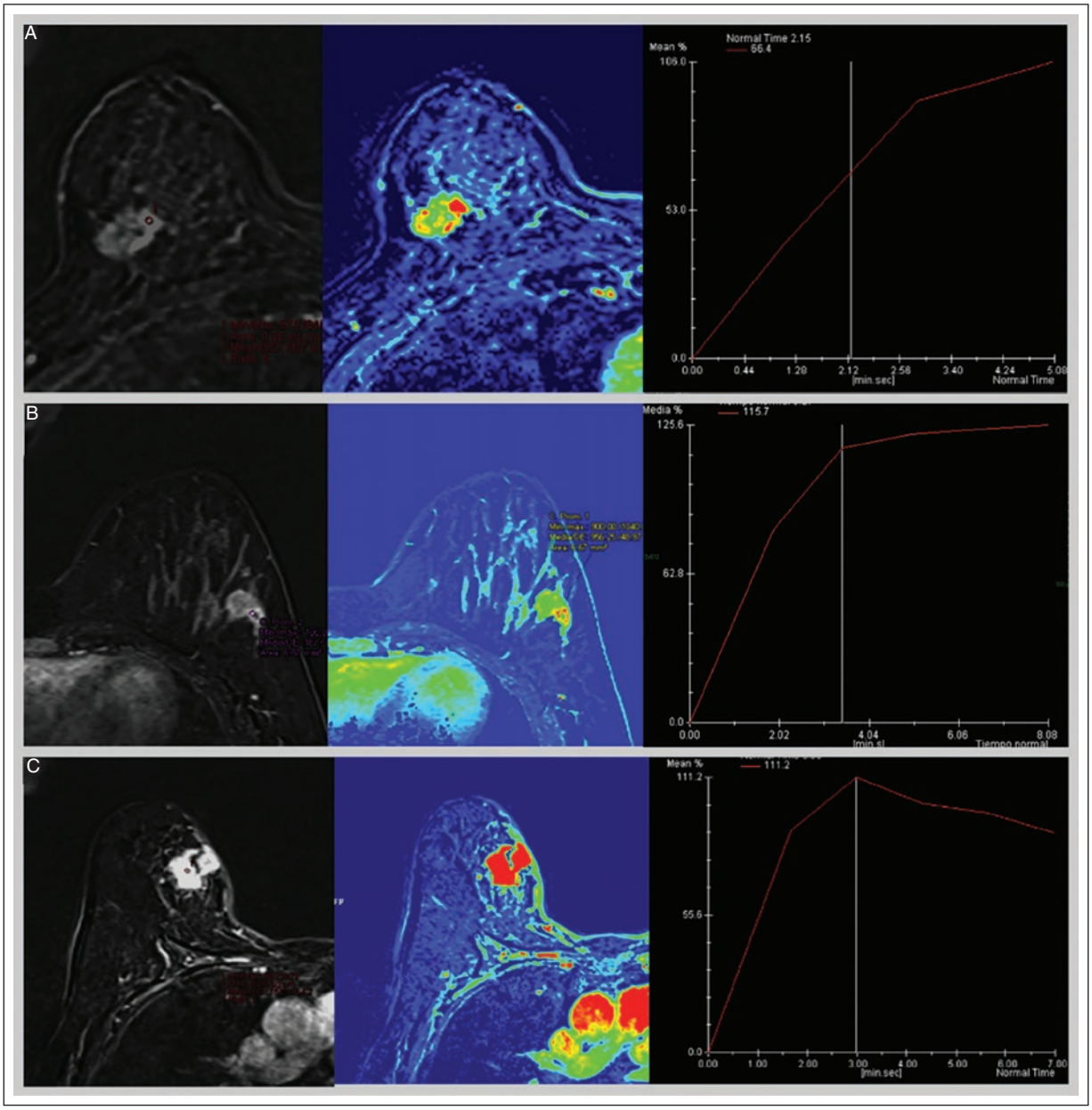

Figure 8. Examples of the different types of kinetic curves with their respective T1 DCE with Gd and PEI values. **A:** type 1, persistent curve, Kaiser score of 6, BI-RADS category 4. **B:** type 2, plateau curve, Kaise score of 7, BI-RADS category 4. **C:** type 3, washout curve, Kaiser score of 11, BI-RADS category 5.

BI-RADS: Breast Imaging Reporting and Data System; DCE: dynamic contrast-enhanced; Gd: gadolinium; PEI: positive enhancement integral.

enhancement curve in the early and delayed T1-weighted SE. It is not considered suspicious of breast malignancy. The plateau curve (type 2), if there is no further increase in signal intensity on T1-weighted SE images in the delayed phase after the early signal increase, is considered doubtful for malignancy, and the washout curve (type 3) if the signal intensity on delayed images decreases after the early signal increase. It is considered suspicious for malignancy[12].

DISTRIBUTION PATTERNS OF MALIGNANT BREAST LESIONS

Four distribution patterns of malignant breast lesions have been described[9]: a unifocal pattern (UF): a single lesion in a single breast regardless of its location; a multifocal pattern (MF): ≥ 2 lesions in a single breast in a single quadrant with a distance < 5 cm; a multicentric uniquadrant pattern (MCUQ): ≥ 2 lesions in a single

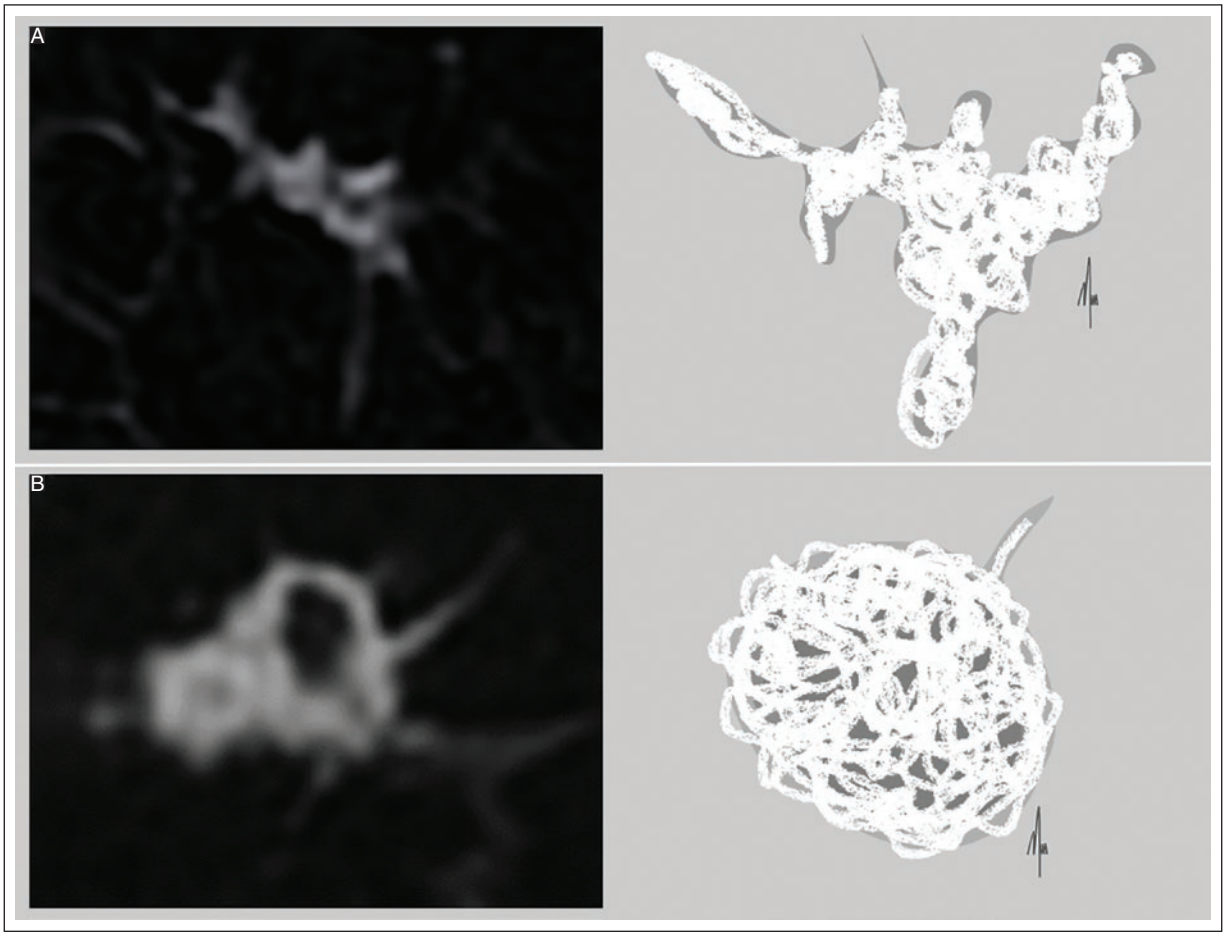

Figure 9. The root sign is an additional tool described in the Kaiser score. It is a spiculated extension of the lesion margin, even if the rest is smooth. It can help differentiate malignant from benign lesions. The presence of the root sign increases the probability of malignancy. **A:** T1 DCE with Gd showing a non-mass focal lesion with a root sign. **B:** T1 DCE with Gd with an irregular mass with a root sign.

DCE: dynamic contrast-enhanced; Gd: gadolinium.

breast in a single quadrant with a distance > 5 cm; and a multicentric multiquadrant pattern (MCMQ): ≥ 2 lesions in a single breast in ≥ 2 quadrants regardless of their distance.

DESCRIPTION OF THE KAISER SCORE

The Kaiser score includes some morphologic and kinetic characteristics of the BI-RADS lexicon to rate breast MRI lesions, such as enhancement (present or not), margin in masses (circumscribed, irregular, or spiculated), and the kinetic curve (type 1, 2, or 3). The Kaiser score also includes the root sign, edema, and the margin of a non-mass lesion (circumscribed or non-circumscribed)[10,11,13,14].

The root sign, a spiculated extension from the margin of the lesion, even if the rest of the margin is smooth, can vary from a single spike to multiple spiculations. This finding increases the likelihood of breast malignancy[12-14] (Figure 9).

Another feature that the Kaiser score considers is ipsilateral edema (present or not), which is seen as a high signal intensity on T2 FS images; only if it is ipsilateral or not is it considered (Figure 10). It is important to know if it is focal, which can indicate greater tumor invasiveness. There are three types of focal edema: peritumoral, prepectoral, and subcutaneous. Benign and malignant etiologies can cause diffuse edema.

The Kaiser score is determined with a virtual calculator available at https://school-of-radiology.com/kaiser-score/[15]. This calculator follows a flowchart practically and functionally as a step-by-step guide that asks key questions about the described breast characteristics. The questionnaire first asks if the lesion enhances or not.

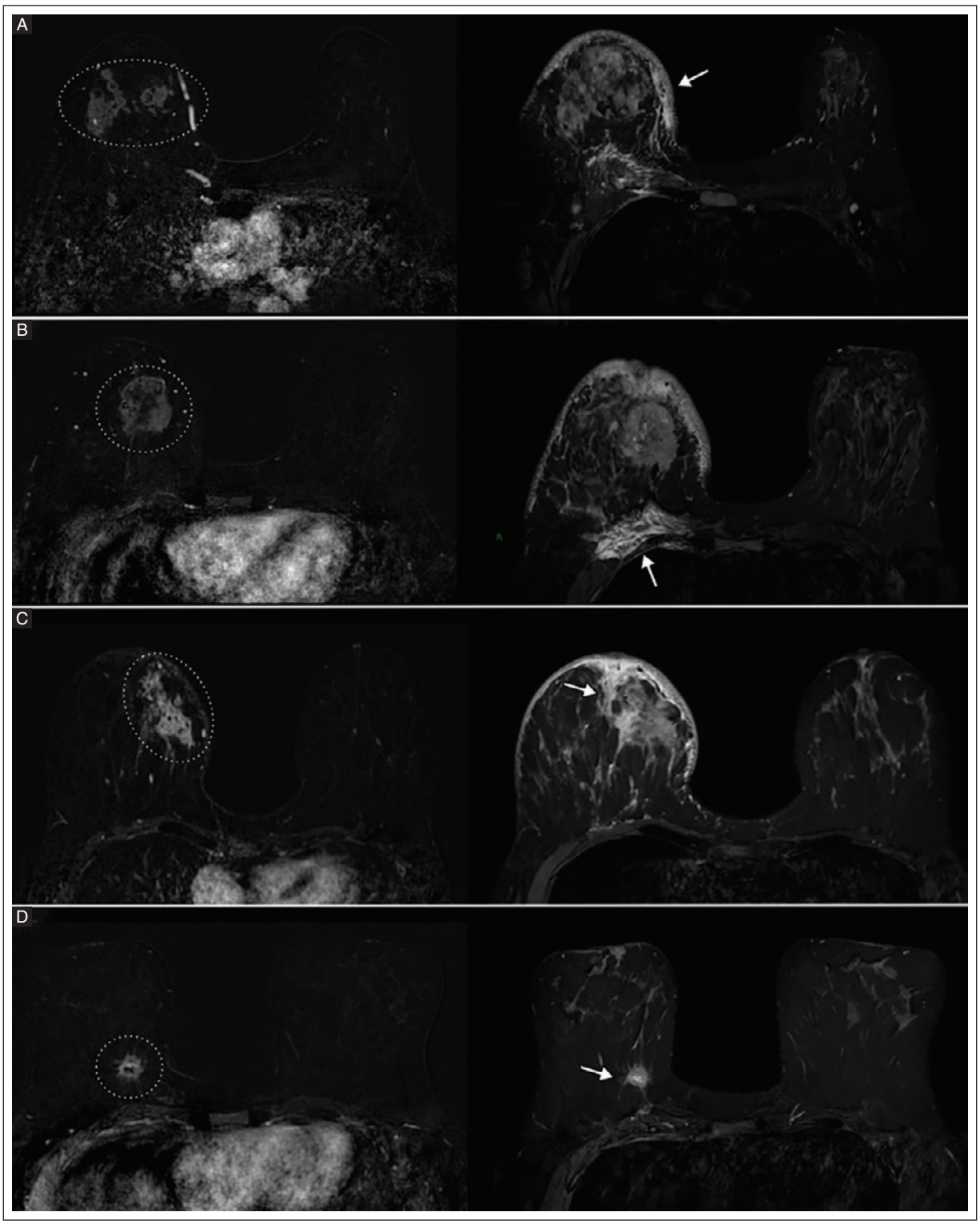

Figure 10. T1 DCE with Gd (left column) and T2 FS (right column) examples of the types of enhancement and edema. **A:** multiple irregular, oval masses in the right breast with rim shape enhancement (dotted circle). There is associated subcutaneous edema (white arrow). **B:** an irregular, oval mass in the right breast with heterogeneous enhancement (dotted circle). Prepectoral edema is associated (white arrow). **C:** irregular mass lesion in the right breast with heterogeneous enhancement (dotted circle). There is associated peritumoral edema (white arrow). **D:** irregular and spiculated mass in the right breast with rim shape enhancement. There is no edema (white arrow).

DCE: dynamic contrast-enhanced; FS: fat suppressed; Gd: gadolinium.

If not, the Kaiser score is not applicable and will be ended. If the answer is yes, it proceeds to the second question in which a distinction is made between mass and non-mass lesions[15]. If the lesion is a mass, it will ask if it has spiculations, referring to the root sign. The next question will be the type of kinetic curve (1, 2, or 3). If you select 1, the questionnaire will end. If you select curves 2 or 3, you will proceed to the last question, which defines if there is ipsilateral edema. This is the end of the questionnaire[15].

When the answer is a non-mass lesion, the next question will be if it has spiculations, referring again to the root sign. The next question is the type of kinetic curve (1, 2, or 3). If you select 1 or 2, it will ask you one last question about whether the margins are circumscribed. After this, it will finish and give you a result; however, if the answer is curve 3, the next and last question will change to confirm if there is homogeneous centrifugal or non-homogeneous centripetal enhancement. The questionnaire ends at this point[15].

Each of these findings has a score, and the combination of these criteria sums up to a Kaiser score of 1 to 11, which can be related to the probability of malignancy. It is translated into a BI-RADS categories: Kaiser score of 1-4 = BI-RADS category 2 or 3; Kaiser score of 5-7 = BI-RADS category 4; and Kaiser score of 8-11 = BI-RADS category 5.

CONCLUSION

This pictorial essay presents a breast MRI acquisition and analysis protocol, supported by drawings of the morphologic features of mass and non-mass lesions based on the updated ACR BI-RADS 5th Edition lexicon and Kaiser scoring. This pictorial essay is published for educational purposes for radiologists and residents.

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Conflicts of interest

The authors declare that they have no conflicts of interest.

Ethical considerations

Protection of humans and animals. The authors declare that the procedures followed complied with the ethical standards of the responsible human experimentation committee and adhered to the World Medical Association and the Declaration of Helsinki. The procedures were approved by the institutional Ethics Committee.

Confidentiality, informed consent, and ethical approval. The authors have followed their institution's confidentiality protocols, obtained informed consent from patients, and received approval from the Ethics Committee.

Declaration on the use of artificial intelligence. The authors declare that no generative artificial intelligence was used in the writing of this manuscript.

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