Observational Study

Medicine

OPEN

Magnetic resonance imaging evaluation of single axillary lymph node metastasis in breast cancer

Emphasis on the location of lymph nodes

Haejung Kim, MD[a], Boo-Kyung Han, MD, PhD[a,*], Eun Young Ko, MD, PhD[a], Eun Sook Ko, MD, PhD[a], Ji Soo Choi, MD, PhD[a]

Abstract

To evaluate the frequency and location of abnormal lymph nodes (LNs) in breast cancer patients with a single axillary lymph node (ALN) metastasis on breast magnetic resonance imaging (MRI). We retrospectively reviewed the MRI findings of 219 consecutive patients with breast cancer with single ALN metastasis who were surgically confirmed at our institution between January 2018 and December 2018. The morphological features and locations of the abnormal LN on MRI were analyzed. Pathology reports were reviewed to evaluate the size of the metastases and whether they were sentinel LNs (SLNs). Of the 219 patients with a single ALN metastasis, 56 (25.6%) showed abnormal MRI findings. Of these, 54 (96.4%) had either the lowest or second-lowest LN in the level I axilla. In 184 (91.5%) of 201 patients who underwent SLN biopsy, the metastatic LN were SLN. Macrometastases were found more frequently in cases with abnormal LNs than in those with normal-looking LNs ($P = .004$). The most frequent morphological feature of metastatic ALNs was a diffuse cortical thickening of 3 to 5 mm (37.5%). Although MRI findings of single ALN metastasis in breast cancer patients are none or minimal, abnormalities are observed in the lowest or second-lowest LN in the lower axilla when present, suggesting the location of the SLNs.

Abbreviations: ALN = axillary lymph node, LN = lymph node, MRI = magnetic resonance imaging, SLN = sentinel lymph node, SLNB = sentinel lymph node biopsy, US = ultrasound.

Keywords: axilla, breast cancer, metastasis, MRI, sentinel lymph node

1. Introduction

Axillary lymph node (ALN) metastasis in breast cancer is an important prognostic factor related to patient outcome and survival.[1] Since the introduction of the results of the American College of Surgeons Oncology Group (ACOSOG) Z0011 trial, axillary management has changed substantially, and the role of sentinel lymph node biopsy (SLNB) has become more critical.[2] Recently, several ongoing trials have abandoned SLNB in early breast cancer with clinically negative axilla when the ultrasound (US) findings of the axilla are negative.[3–7] This reflects a shift in the trend from pathology-based N0 to imaging-based N0 to obtain prognostic information through the prediction of nodal status; thus, radiologic staging tends to become more important.[8]

Preoperative breast magnetic resonance imaging (MRI) is a useful noninvasive imaging modality for evaluating ALN status in patients with breast cancer patients.[9–12] MRI is often included in the routine diagnostic workup for breast cancer to evaluate the extent of the tumor. It is also usually performed after neoadjuvant chemotherapy for treatment response assessment; at that time, the axilla is included in the field of view.[13] Although US is the primary imaging modality for evaluating ALN, being oriented in the axilla could be difficult with US.[9,14] Moreover, ambiguous axillary US findings may lead to unnecessary or negative percutaneous biopsies, making axillary US clinically irrelevant or detrimental.[9,15] MRI has multiple advantages over US: it allows visualization of deep or low-lying lymph nodes (LNs), provides a global view of both axillae, facilitates the comparison between the ipsilateral and contralateral axilla regardless of body habitus, and has less intra- and inter-observer variation.[12,13]

Many studies have reported the role of MRI in evaluating high axillary tumor burden.[16–21] However, only a few studies have focused on the value of MRI for evaluating low axillary tumor burden.[22] As sentinel lymph node (SLN) is defined as the first LN that drains lymphatics from the breast, efforts to search for SLNs on imaging are crucial for cases with low tumor burden. It would be helpful to know the location of the SLN in cross-sectional imaging because it makes imaging-based nodal evaluation more accurate and helps correctly identify the SLN, which would be targeted for US-guided biopsy. Britton et al

The authors have no funding and conflicts of interest to disclose.

The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

[a] Department of Radiology and Center for Imaging Science, Samsung Medical Center, Sungkyunkwan University School of Medicine, Seoul, Korea.

** Correspondence: Boo-Kyung Han, Department of Radiology and Center for Imaging Science, Samsung Medical Center, Sungkyunkwan University School of Medicine, 81, Irwon-ro, Gangnam-gu, Seoul 06351, Korea (e-mail: bkhan@skku.edu).*

How to cite this article: Kim H, Han B-K, Ko EY, Ko ES, Choi JS. Magnetic resonance imaging evaluation of single axillary lymph node metastasis in breast cancer: Emphasis on the location of lymph nodes. Medicine 2022;101:50(e31836).

Received: 5 August 2022 / Received in final form: 26 October 2022 / Accepted: 26 October 2022

http://dx.doi.org/10.1097/MD.0000000000031836

previously reported that the lowest 1 or 2 lymph nodes are SLN on US.[23] However, the study did not evaluate the location of SLNs based on cross-sectional imaging, such as MRI, which is a reliable imaging modality for evaluating axillary status in breast cancer patients.

This study aimed to evaluate the MRI findings of a single ALN metastasis of breast cancer, focusing on the frequency and location of abnormal LNs on MRI to reinforce the role of MRI by offering objective geometric information on the most likely location of SLN.

2. Materials and methods

2.1. Patients

This retrospective study was approved by the Institutional Review Board of the Samsung Medical Center, which waived the requirement for informed consent (IRB No. 2020-06-121). Between January 2018 and December 2018, 309 breast cancer patients with a single ALN metastasis were pathologically confirmed after surgery at our institution. Patients; Who were treated with neoadjuvant chemotherapy (n = 71); With MRI images recorded outside our institution (n = 14); with ALNs that showed severe post-biopsy changes on breast MRI images (n = 2); with unavailable MRI images (n = 2), and; with severe artifacts in MRI images (n = 1) were excluded. In total, 219 patients were included in this study. All patients underwent breast MRI and US before breast cancer surgery to determine the extent of the disease and nodal stage. Of the 219 patients, 18 did not undergo SLNB and instead underwent upfront ALN dissection.

2.2. Breast MRI protocol

Breast MRI was performed using a 3.0-*T* Achieva scanner (Philips Medical Systems) or 1.5-*T* Achieva scanner (Philips Medical Systems) with a dedicated bilateral phased-array breast coil. The patients underwent MRI in the prone position. Standard imaging sequences included axial *T*2-weighted images with fat suppression, *T*1-weighted images without fat suppression, and 3-dimensional dynamic contrast-enhanced (DCE) MRI obtained in the pre-contrast and post-contrast (60, 120, 180, 240, 300, and 360 s after contrast administration) phases for bilateral breasts. Intravenous administration of a bolus of 0.1 mmol/kg gadobutrol (Gadovist, Bayer Healthcare) was followed by a 20-mL saline flush. To evaluate nodal status, an axial fat-suppressed *T*1-weighted contrast-enhanced sequence was performed immediately after DCE imaging and added as an axillary imaging sequence using a breast coil that covered the bilateral axillae. For the 3-*T* scanner, the following parameters were used: repetition time (TR)/echo time (TE) of 450 to 650/10 ms, 60 sections of 3 mm thickness with no gap, flip angle of 90°, matrix size of 320 × 315, and FOV of 32 cm × 32 cm. For the 1.5-*T* scanner, the following parameters were used: TR/TE of 450 to 650/10 ms, 60 sections of 3 mm thickness with no gap, flip angle of 90°, matrix size of 424 × 379, and FOV of 38 cm × 38 cm. The FOV was optimized to include the bilateral axillae, and an area spanning 1 cm above and 17 cm below the axillary vein was scanned.

2.3. Data analysis

Breast MRI scans were retrospectively reviewed by 2 breast radiologists (XXX and XXX with 25 and 2 years of experience in interpreting breast imaging, respectively), who reached a consensus on cases of discrepancies through discussion. Nodal evaluation was performed using an axial fat-suppressed *T*1-weighted contrast-enhanced axillary imaging sequence, and an axial nonfat-suppressed non-enhanced *T*1-weighted sequence was used to identify the fatty hilum.

They focused on the location and morphological appearance of the clearly identified nodes in the axilla. We defined morphological criteria for suggesting ALN metastasis on MR images. The major criteria were as follows: Cortical thickness > 5 mm; complete loss of fatty hilum and/or round shape; Irregular shape and indistinct margin; and Markedly enlarged and morphologically abnormal LNs. The minor criteria were: Diffuse cortical thickening of 3 to 5 mm; focal cortical bulging and/or partial loss of fatty hilum, and; heterogeneous enhancement (Table 1).[9,14,24–27] The morphological features of the ALNs were analyzed. LNs with at least 1 major or 2 minor criteria were defined as suspicious and LNs with 1 minor criterion were defined as doubtful. The most representative criterion was recorded for cases with more than 1 major criterion. Both suspicious and doubtful ALNs were considered abnormal. We measured cortical thickness at the straight portion of the LN, excluding the curved portion.

We only included ALNs around the lateral thoracic vessels, excluding LNs along the thoracodorsal vessels, which predominantly drain the scapular region and posterior chest wall[9,28,29] (Fig. 1). To count the order of LNs from the bottom of the axilla, we found the point in the axilla from where the nipple line was located, no more LNs were identified, and the first LN identified from that point was denoted as the lowest LN. If more than 1 were identified in 2 consecutive sections (cross-sectional thickness of 3 mm), they were classified as LNs at the same level. On MR images, the frequency and morphological features of abnormal LNs and their relative locations in the craniocaudal axis were analyzed. Surgical pathology reports were reviewed to evaluate the size of metastases (macrometastasis, > 2 mm; micrometastasis, > 0.2 to ≤ 2 mm) and whether it was an SLN.

Categorical and continuous variables were analyzed using the $\chi 2$ test and Student's *t*-test, respectively. A P value < 0.05 was set as statistically significant, and all statistical analyses were performed using SPSS (version 20.0; IBM Corp.).

3. Results

The clinical and pathological characteristics of the patients are shown in Table 2. A total of 219 patients (mean age, 50.6 ± 11.1 years (range, 22–85 years) were included. Of the 219 patients, 102 (46.6%) had *T*1 stage, 106 (48.4%) had *T*2 stage, and 11 (5.0%) had *T*3 stage. The subtypes were as follows: 183 (83.6%) cases were hormone receptor-positive and human epidermal growth factor receptor 2 (HER2)-negative, 25 (11.4%) were HER2 positive, and 11 (5.0%) were triple-negative.

Table 1

Morphological criteria to detect metastatic axillary lymph node using MRI.

Majora	Minor
Cortical thickening of > 5 mm	Diffuse cortical thickening of 3–5 mm
Complete loss of fatty hilum and/or round shape	Focal cortical bulging and/or partial loss of fatty hilum
Irregular shape and indistinct margin	Heterogeneous enhancement
Markedly enlarged and morphologically abnormal	
Suspicious LNs: LNs with > 1 major criterion or > 2 minor criteria	
Doubtful LNs: LNs with 1 minor criterion	

LN = lymph node, MRI = magnetic resonance imaging.

[a] When multiple features defined as major criteria were found in one LN, the most representative one was recorded.

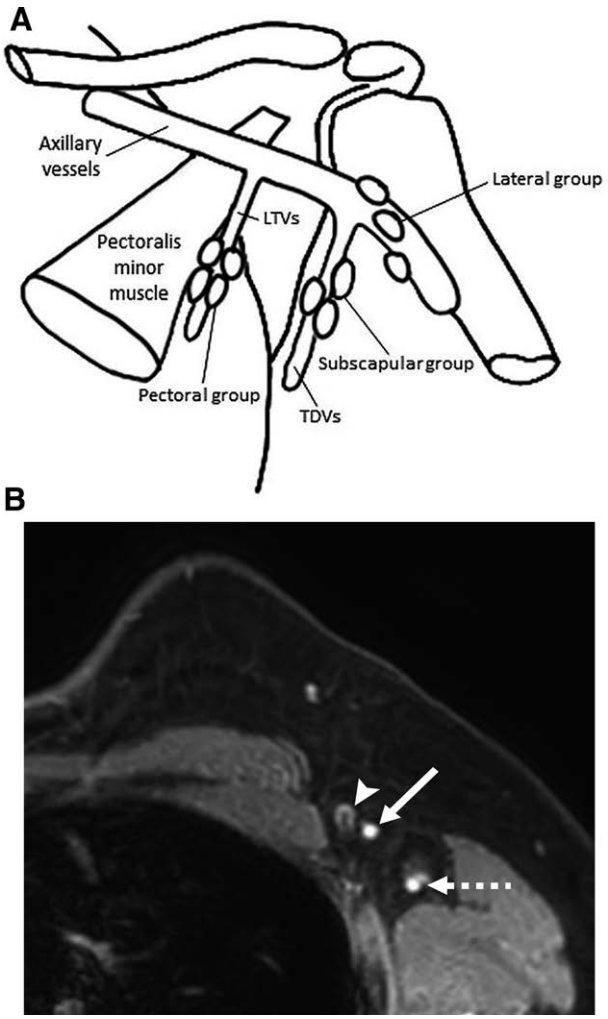

Figure 1. (A) Schematic diagram illustrates the locations of 3 groups of lymph nodes (LNs) in the level I axilla. The pectoral group LNs, which are located along the lateral thoracic vessels (LTVs) and centrally in the axillary fat, predominantly drain the breast. The lateral group LNs, which are often observed near the axillary vessels, predominantly drain the upper extremity. The subscapular group LNs are located posteriorly along the course of thoracodorsal vessels (TDVs) and predominantly drain the scapular region and the posterior chest wall. (B) Axial fat-suppressed *T*1-weighted contrast-enhanced magnetic resonance image of the left axilla in a 29-year-old woman with invasive ductal cancer in the left breast shows the LTVs (solid arrow) and TDVs (dotted arrow). Although only normal-looking LN was observed in the left axilla on the image (arrowhead), single axillary LN metastasis was reported pathologically. LN = lymph node,LTVs = lateral thoracic vessels, TDVs = thoracodorsal vessels.

The imaging and pathological characteristics of metastatic ALNs are shown in Table 3. Based on our criteria, MRI revealed abnormal LNs in 56 cases (25.6%), suspicious LNs in 28 (12.8%), and doubtful LNs in 28 (12.8%). Of the 28 suspicious LNs, the most common major findings were cortical thickening of > 5 mm in 13 cases and complete loss of fatty hilum and/or round shape in 9 cases. Of the 28 doubtful LNs, the most common minor finding was diffuse cortical thickening of 3 to 5 mm in 21 cases, and focal cortical bulging and/or partial loss of fatty hilum or heterogeneous enhancement was observed in 4 and 3 cases, respectively. Regarding location, 54 of the 56 abnormal LNs (96.4%) were either the lowest or the second-lowest LNs in the level I axilla, the lowest in 39 (69.6%), and the second-lowest in 15 (26.8%).

Eighteen patients with positive US-guided fine-needle aspiration (FNA) results for ALN-skipped SLNB. Among 201 patients who underwent SLNB, metastasis was found in the SLN in 184 (91.5%). Among them, 35 showed abnormal MRI findings (Fig. 2), and all were either the lowest (n = 27) or the second-lowest (n = 8). The 17 patients who had a single metastasis to non-SLN did not show MRI abnormalities, except for 3 patients. One of these 3 patients showed MRI abnormalities in the lowest LN and was confirmed to have a 20 mm macrometastasis in the non-SLN. The other 2 showed abnormalities in the third lowest or above LN on MRI.

In this study, the mean metastasis size was 3.66 ± 3.96 mm (range, 0.21 to 23 mm). Of the 219 patients, 137 had macrometastasis (> 2 mm) and 82 had micrometastasis (> 0.2 to ≤ 2 mm). The MRI abnormality rates were 32.1% (44/137) and 14.6% (12/82) in patients with macrometastases (Figs. 3 and 4) and micrometastases, respectively. The cases with abnormal LN on MRI showed more macrometastasis than those without (P = .004), and the mean metastasis size was significantly different between the cases with abnormal and normal MRI findings (6.45 mm vs 3.10 mm, P < .001).

4. Discussion

In our study, 74.4% of patients with single metastatic ALN showed no abnormal MRI findings even retrospectively, and 96.4% of LNs with abnormal MRI findings were either the lowest or the second-lowest LN in the level I axilla, suggesting the possible location of the SLN on MRI. Pathologically, 91.5% of the cases in which SLNB was performed were proven to have metastatic SLN.

In the post-ACOSOG Z0011 trial era, the trend has evolved toward less extensive axillary surgery for breast cancer, and identifying low versus high axillary tumor burden has become crucial.[2] Following the interest of clinicians in omitting SLNB in early breast cancer with clinically negative axilla makes a radiologic assessment of axillary nodal status more important.[3–8,14] In this context, radiologists should understand the strengths and weaknesses of the various imaging modalities for axillary nodal staging, and efforts should be made to identify clinically negative axillae by imaging correctly. US has intrinsic limitations in terms of significant operator dependency and the possibility of false-negative results without proper training and experience.[14] MRI may be a complementary imaging modality as it can evaluate lower-lying, deeply located suspicious ALN regardless of the patient's body habitus.[13] However, our study presented the limitation of MRI for the evaluation of single ALN metastasis; 74.4% of the cases might be categorized as clinically negative axilla, irrespective of its clinical significance. This is because both radiologists and clinicians need to know how to select appropriate axillary treatment options and prevent under-treatment.

Radiologists should be familiar with the imaging spectrum of the morphology and location of LN metastasis to accurately determine staging and perform FNA in appropriate cases.[14] In our study, the most frequent abnormal MRI finding, indicating a single metastatic LN, was cortical thickening. This finding suggests that morphologic changes in the cortex could be the most common finding in cases with low tumor burden because metastatic cells are initially deposited in the periphery of a node and arrested by cells in the cortex and paracortex, causing enlargement of the cortex.[9,14,26]

Although this might not be surprising, few studies have described the possible location of the SLN on MRI. Yuen et al previously reported CT-based SLN identification in their study.[28] However, they only considered the size of the LN and not the detailed morphology, as in our study. Theoretically, the ideal method to determine whether a specific LN on MRI is an SLN is to perform MRI after marking the LN with reference to radioisotope scintigraphy, which indicates the SLN.[30] Because such a procedure is impractical, we believe that the

Table 2

Clinical-pathologic characteristics of included patients with single ALN metastasis from breast cancer.

Characteristics	All patients (n = 219)
Age (yr)	50.6 ± 11.1
Pathologic diagnosis	
Invasive ductal carcinoma	199 (90.9)
Invasive lobular carcinoma	17 (7.8)
Mucinous carcinoma	2 (0.9)
Invasive papillary carcinoma	1 (0.5)
T stage	
T1	102 (46.6)
T2	106 (48.4)
T3	11 (5.0)
ER status	
Negative	16 (7.3)
Positive	203 (92.7)
PR status	
Negative	31 (14.2)
Positive	188 (85.8)
HER2 status	
Negative	194 (88.6)
Positive	25 (11.4)
Subtype	
HR positive and HER2 negative	183 (83.6)
HER2 positive	25 (11.4)
Triple negative	11 (5.0)
Surgery type	
Mastectomy	78 (35.6)
Breast conserving surgery	141 (64.4)

Unless otherwise specified, data are numbers of women, with percentages in parentheses.
ALN = axillary lymph node, ER = estrogen receptor, HER2 = human epidermal growth factor receptor 2, HR = hormone receptor, PR = progesterone receptor.

specific location of an abnormal LN observed in cases with a single metastasis might be the SLN location on MRI. The results of our study indicated that the lowest or second-lowest LNs were SLNs, suggesting where to look for. In actual clinical applications, 1 can find the lowest LN by searching for the point where the LN is no longer observed below, and sometimes 1 has to go down to the nipple level. This method can be applied when handheld US is performed, even though the skill to determine normal LNs within abundant axillary fat tissue differs according to the physician's experience. We suggest that location-based research is more advantageous for analysis than random research, especially in cases with low tumor burden. So, whether it is MRI or US, this is a part that can significantly increase diagnostic performance if we only know that we need to see the lower area of the axilla. Many beginner radiologists do not accurately recognize this fact and focus only on morphology when interpreting MRI and not on location. Moreover, FNA has proven it to be a metastatic LN. In that case, it can reduce the complex decision cases that need to be determined whether secondary axillary dissection should be conducted after SLN biopsy, and the orderly evaluation of LN at the higher axillary level would be carried out more easily.

One patient with a metastasis size of 20 mm showed abnormal MRI findings in the lowest LN, but was proven to have non-SLN metastasis. This case was attributed to the blockage of lymphatic flow to the SLN caused by cancer cells and the opening of an alternative pathway draining the blue dye or radioisotope to another uninvolved node.[9,31,32] This indicates that macrometastasis actually developed in the SLN; however, it was not detected by SLN localization techniques owing to lymphatic blockage and was classified as non-SLN. On MRI, the ALN was observed as a markedly enlarged LN with complete loss of the fatty hilum, round shape, and heterogeneous enhancement.

This study had several limitations. The major limitation is the difficulty in evaluating the exact node-to-node correlation due to the absence of a localization method in this retrospective study. Moreover, as 18 patients underwent upfront ALN dissection, it was impossible to evaluate whether the metastatic LN were SLN

Table 3

Imaging-pathologic characteristics of ALNs in breast cancer patients with single nodal metastasis.

Characteristics	No. (%) of patients
MRI finding	
Normal	163 (74.4)
Abnormal	56 (25.6)
Suspicious	28 (12.8)
One major criterion	
Cortical thickening of > 5 mm	13 (5.9)
Complete loss of fatty hilum and/or round shape	9 (4.1)
Irregular shape and indistinct margin	1 (0.5)
Markedly enlarged and morphologically abnormal	2 (0.9)
Two minor criteria	
Focal cortical bulging and/or partial loss of fatty hilum + heterogeneous enhancement	3 (1.4)
Doubtful	28 (12.8)
Diffuse cortical thickening of 3-5 mm	21 (9.6)
Focal cortical bulging and/or partial loss of fatty hilum	4 (1.8)
Heterogeneous enhancement	3 (1.4)
Location of abnormal ALN on MRI (n = 56)	
Lowest	39 (69.6)
2nd lowest	15 (26.8)
3rd lowest or above	2 (3.6)
Result of SLNB (n = 201)	
Metastasis to SLN	184 (84.0)
Metastasis to non-SLN	17 (7.8)
Unknown	18 (8.2)
Metastasis size	
Micrometastasis (> 0.2 to ≤ 2 mm)	82 (37.4)
Macrometastasis (> 2mm)	137 (62.6)

Unless otherwise noted, data are numbers of patients with percentages in parentheses.
ALN = axillary lymph node, MRI = magnetic resonance imaging, SLN = sentinel lymph node, SLNB = sentinel lymph node biopsy.

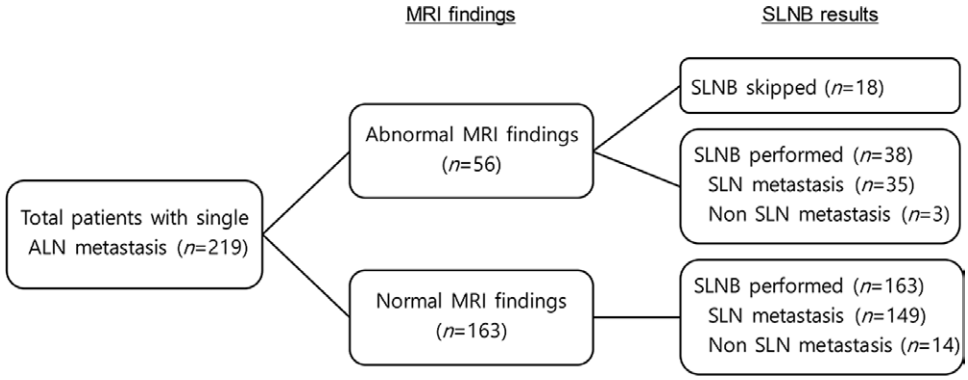

Figure 2. Schematic presentation of the MRI findings and SLNB results. ALN = axillary lymph node, MRI = magnetic resonance imaging, SLN = sentinel lymph node, SLNB = sentinel lymph node biopsy.

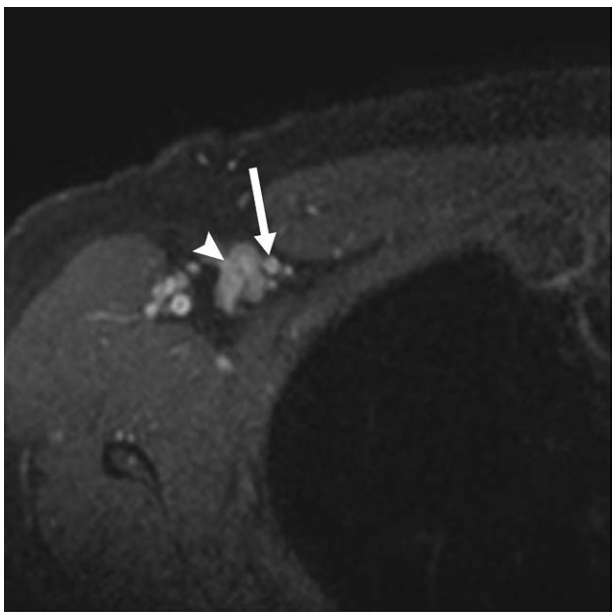

Figure 3. Axial fat-suppressed *T*1-weighted contrast-enhanced magnetic resonance image in a 50-year-old woman with invasive ductal cancer in the right breast shows a suspicious lymph node (LN) with cortical thickening of > 5 mm in the right axilla (arrowhead), located alongside the right lateral thoracic vessels (arrow). It was the lowest LN in the right level I axilla, and no more LN was observed below it. The suspicious LN was pathologically confirmed to be metastasis confined to a single sentinel LN, and the metastasis size was 7 mm. LN = lymph node.

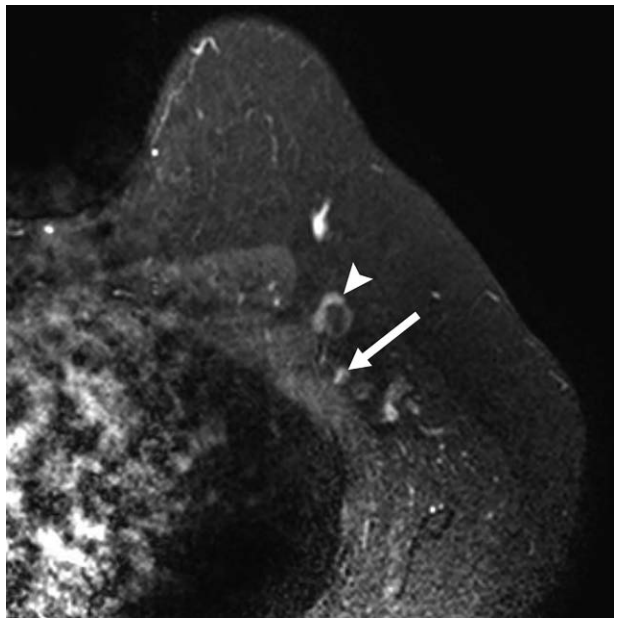

Figure 4. Axial fat-suppressed *T*1-weighted contrast-enhanced magnetic resonance image in a 68-year-old woman with invasive lobular cancer in the left breast shows a normal-looking lymph node (LN) with a cortical thickness of 2.5 mm in the left level I axilla (arrowhead), located medially to the left lateral thoracic vessels (arrow). It was the lowest LN in the left level I axilla, and no more LN was observed below it. This normal-looking LN (arrowhead) was pathologically confirmed to be metastasis confined to a single sentinel LN, and the metastasis size was 10 mm. LN = lymph node.

in these patients. Second, because we retrospectively collected patients with a single LN metastasis, inevitable selection bias might have affected the results. As the reviewers were aware of the nodal status, they might have classified an equivocal finding as a positive finding, thereby increasing the detection rate of abnormal LN. Finally, we referred to the axial fat-suppressed *T*1-weighted contrast-enhanced axillary imaging sequence, which was acquired using a breast coil covering the axilla. The slice thickness of the axillary sequence was 3 mm, which might have underestimated the cortical thickening. However, we did not use a dedicated axillary sequence that required a narrower slice thickness because our study was conducted while maintaining a routine protocol to avoid lengthening the overall study time. The results may vary depending on the sequence or the protocol used.

In conclusion, although MRI shows abnormal LN infrequently when axillary metastasis is confined to a single LN, most abnormal LNs were either the lowest or the second-lowest LNs, suggesting the location of the SLNs on MRI. We recommend that radiologists concentrate on the features of the lowest ALNs when evaluating clinically negative axillary or low axillary tumor burden on MRI.

Author contributions

Conceptualization: Boo-Kyung Han.
Data curation: Haejung Kim, Boo-Kyung Han.
Formal analysis: Haejung Kim, Eun Young Ko, Eun Sook Ko.
Investigation: Haejung Kim, Eun Young Ko, Eun Sook Ko, Ji Soo Choi.
Methodology: Haejung Kim, Boo-Kyung Han, Eun Young Ko, Ji Soo Choi.
Project administration: Boo-Kyung Han, Ji Soo Choi.
Resources: Eun Young Ko, Eun Sook Ko.
Supervision: Boo-Kyung Han.
Validation: Boo-Kyung Han, Eun Sook Ko, Ji Soo Choi.

Visualization: Haejung Kim.
Writing – original draft: Haejung Kim.
Writing – review & editing: Boo-Kyung Han.

References

[1] Carter CL, Allen C, Henson DE. Relation of tumor size, lymph node status, and survival in 24,740 breast cancer cases. Cancer. 1989;63:181–7.
[2] Giuliano AE, Ballman KV, McCall L, et al. Effect of axillary dissection vs no axillary dissection on 10-year overall survival among women with invasive breast cancer and sentinel node metastasis: the ACOSOG Z0011 (Alliance) randomized clinical trial. JAMA. 2017;318:918–26.
[3] Clinicaltrials.gov. Omitting Sentinel Node Procedure in Breast Cancer Patients Undergoing Breast Conserving Therapy. Available at: https://clinicaltrials.gov/ct2/show/NCT02271828.
[4] Clinicaltrials.gov. Comparison of Axillary Sentinel Lymph Node Biopsy Versus no Axillary Surgery (INSEMA). Available at: https://clinicaltrials.gov/ct2/show/NCT02466737.
[5] Clinicaltrials.gov. No Axillary Surgical Treatment in Clinically Lymph Node Negative Patients After Ultrasonography. Available at: https://clinicaltrials.gov/ct2/show/NCT04303715.
[6] Clinicaltrials.gov. Sentinel Node Biopsy vs Observation After Axillary PET. Available at: https://clinicaltrials.gov/ct2/show/NCT04072653.
[7] Clinicaltrials.gov. Sentinel Node vs Observation After Axillary UltrasouND (SOUND). Available at: https://clinicaltrials.gov/ct2/show/NCT02167490.
[8] Gentilini O, Veronesi U. Staging the axilla in early breast cancer: will imaging replace surgery?. JAMA Oncol. 2015;1:1031–2.
[9] Ecanow JS, Abe H, Newstead GM, et al. Axillary staging of breast cancer: what the radiologist should know. Radiographics. 2013;33:1589–612.
[10] Kuijs VJ, Moossdorff M, Schipper RJ, et al. The role of MRI in axillary lymph node imaging in breast cancer patients: a systematic review. Insights Imag. 2015;6:203–15.
[11] van Nijnatten TJA, Ploumen EH, Schipper RJ, et al. Routine use of standard breast MRI compared to axillary ultrasound for differentiating between no, limited and advanced axillary nodal disease in newly diagnosed breast cancer patients. Eur J Radiol. 2016;85:2288–94.
[12] Baltzer PA, Dietzel M, Burmeister HP, et al. Application of MR mammography beyond local staging: is there a potential to accurately assess axillary lymph nodes? evaluation of an extended protocol in an initial prospective study. AJR Am J Roentgenol. 2011;196:W641–7.
[13] Chang JM, Leung JWT, Moy L, et al. Axillary nodal evaluation in breast cancer: state of the art. Radiology. 2020;295:500–15.
[14] Chung HL, Le-Petross HT, Leung JWT. Imaging updates to breast cancer lymph node management. Radiographics. 2021;41:1283–99.
[15] Jozsa F, Ahmed M, Baker R, et al. Is sentinel node biopsy necessary in the radiologically negative axilla in breast cancer?. Breast Cancer Res Treat. 2019;177:1–4.
[16] Ha SM, Chang JM, Kim SY, et al. Prediction of axillary nodal burden in patients with invasive lobular carcinoma using MRI. Breast Cancer Res Treat. 2021;186:463–73.
[17] Byon JH, Park YV, Yoon JH, et al. Added value of MRI for invasive breast cancer including the entire axilla for evaluation of high-level or advanced axillary lymph node metastasis in the Post-ACOSOG Z0011 trial era. Radiology. 2021;300:46–54.
[18] Kim WH, Kim HJ, Lee SM, et al. Prediction of high nodal burden with ultrasound and magnetic resonance imaging in clinically node-negative breast cancer patients. Cancer Imag. 2019;19:4.
[19] Kim WH, Kim HJ, Park CS, et al. Axillary nodal burden assessed with pretreatment breast MRI is associated with failed sentinel lymph node identification after neoadjuvant chemotherapy for breast cancer. Radiology. 2020;295:275–82.
[20] Kim WH, Lee S-W, Kim HJ, et al. Prediction of advanced axillary lymph node metastases (ypN2-3) using breast MR imaging and PET/CT after neoadjuvant chemotherapy in invasive ductal carcinoma patients. J Sci Rep. 2018;8:1–9.
[21] Hyun SJ, Kim EK, Moon HJ, et al. Preoperative axillary lymph node evaluation in breast cancer patients by breast magnetic resonance imaging (MRI): Can breast MRI exclude advanced nodal disease? Eur Radiol. 2016;26:3865–73.
[22] Samiei S, van Nijnatten TJA, van Beek HC, et al. Diagnostic performance of axillary ultrasound and standard breast MRI for differentiation between limited and advanced axillary nodal disease in clinically node-positive breast cancer patients. Sci Rep. 2019;9:17476.
[23] Britton P, Moyle P, Benson JR, et al. Ultrasound of the axilla: where to look for the sentinel lymph node. Clin Radiol. 2010;65:373–6.
[24] Korteweg MA, Zwanenburg JJ, Hoogduin JM, et al. Dissected sentinel lymph nodes of breast cancer patients: characterization with high-spatial-resolution 7-T MR imaging. Radiology. 2011;261:127–35.
[25] Cho N, Moon WK, Han W, et al. Preoperative sonographic classification of axillary lymph nodes in patients with breast cancer: node-to-node correlation with surgical histology and sentinel node biopsy results. AJR Am J Roentgenol. 2009;193:1731–7.
[26] Bedi DG, Krishnamurthy R, Krishnamurthy S, et al. Cortical morphologic features of axillary lymph nodes as a predictor of metastasis in breast cancer: in vitro sonographic study. AJR Am J Roentgenol. 2008;191:646–52.
[27] Alvarez S, Anorbe E, Alcorta P, et al. Role of sonography in the diagnosis of axillary lymph node metastases in breast cancer: a systematic review. AJR Am J Roentgenol. 2006;186:1342–8.
[28] Yuen S, Sawai K, Ushijima Y, et al. Evaluation of axillary status in breast cancer. CT-based determination of sentinel lymph node size. Acta Radiol. 2002;43:579–86.
[29] Coroneos CJ, Woodward WA, Wong FC, et al. Anatomy and physiology of the sentinel lymph nodes of the upper extremity: implications for axillary reverse mapping in breast cancer. J Surg Oncol. 2021;123:846–53.
[30] Kimura K, Tanigawa N, Matsuki M, et al. High-resolution MR lymphography using ultrasmall superparamagnetic iron oxide (USPIO) in the evaluation of axillary lymph nodes in patients with early stage breast cancer: preliminary results. Breast Cancer. 2010;17:241–6.
[31] Kataria K, Srivastava A, Qaiser D. What is a false negative sentinel node biopsy: definition, reasons and ways to minimize it?. Ind J Surg. 2016;78:396–401.
[32] Nathanson SD, Burke M, Slater R, et al. Preoperative identification of the sentinel lymph node in breast cancer. Ann Surg Oncol. 2007;14:3102–10.