



## Breast imaging

## MRI predictors of tumor-positive margins after breast-conserving surgery

Manisha Bahl<sup>a,\*</sup>, Jay A. Baker<sup>a</sup>, Emily N. Kinsey<sup>b</sup>, Sujata V. Ghate<sup>a</sup><sup>a</sup> Duke University Medical Center, Department of Radiology, DUMC Box 3808, Durham, NC 27710, United States of America<sup>b</sup> Duke University Medical Center, Department of Medicine, DUMC Box 3913, Durham, NC 27710, United States of America

## ARTICLE INFO

## Keywords:

Breast cancer  
Breast-conserving surgery  
Ductal carcinoma in situ  
Magnetic resonance imaging  
Surgical margins

## ABSTRACT

**Purpose:** The purpose of this study is to identify predictors of tumor-positive surgical margins after breast-conserving surgery on dynamic contrast-enhanced (DCE) MRI.

**Materials and methods:** We conducted a retrospective study of consecutive women who underwent DCE MRI before breast-conserving surgery from 2005 to 2014. Patient demographics, indication for surgery, MRI findings, biopsy pathology results, and surgical outcomes were reviewed. The unpaired *t*-test and *chi*-square test were used to compare the positive and negative margins groups.

**Results:** 554 women (mean age, 56; range, 26–90) underwent DCE MRI before 575 breast-conserving surgeries for invasive carcinoma ( $n = 473$ ) or ductal carcinoma in situ (DCIS) ( $n = 102$ ). Positive margins requiring re-excision occurred in 19.7% (93/473) of surgeries for invasive carcinoma and 31.4% (32/102) of surgeries for DCIS. For invasive carcinoma surgeries, positive margins were more common when MRI demonstrated the finding of non-mass enhancement (NME) rather than the finding of enhancing mass (33.8% [22/65] versus 16.9% [61/360],  $p < 0.01$ ). Tumor size on MRI was significantly larger in the positive margins group (2.5 cm versus 1.9 cm,  $p < 0.001$ ). Positive margins were more common with invasive lobular rather than invasive ductal histology at core biopsy (38.3% [18/47] versus 16.0% [56/350],  $p < 0.001$ ). For DCIS surgeries, there were no significant differences in positive margin rates related to MRI features.

**Conclusion:** For invasive carcinoma surgeries, positive margins are associated with NME on MRI, larger tumor size on MRI, and lobular histology at core biopsy. These findings may be used to predict which patients are at risk for positive margins after breast-conserving surgery.

## 1. Introduction

Large trials have demonstrated similar survival between women with breast cancer who undergo breast-conserving therapy (lumpectomy with adjuvant radiation) versus mastectomy [1–3]. When lumpectomy is performed, tumor-negative surgical margins are necessary to reduce the risk of recurrence [4,5]. If negative margins are not achieved at the time of the initial operation, then a re-excision is performed [5–8]. Re-excision after lumpectomy can result in increased health care costs, delays in adjuvant treatment, and poorer cosmetic outcomes [9].

It would be useful to be able to predict which women are at increased risk of tumor-positive surgical margins [10,11]. First, the recognition of imaging features associated with an increased risk of positive margins could aid in pre-operative planning and surgical

decision-making. Second, surgeons and other clinicians would be able to inform patients about the risk of positive margins and thus the likelihood of needing more extensive surgery.

Breast dynamic contrast-enhanced (DCE) MRI is being increasingly utilized in the pre-operative setting to define extent of disease, to assess for multifocal and/or multicentric disease, and to screen the contralateral breast [12,13]; but, to our knowledge, there are limited published data on specific DCE MRI findings that could be used to predict the likelihood of positive margins after breast-conserving surgery [14,15]. The purpose of our study was to identify predictors of tumor-positive surgical margins on preoperative DCE MRI.

**Abbreviations:** BPE, background parenchymal enhancement; DCIS, ductal carcinoma in situ; DCE, dynamic contrast-enhanced; NME, non-mass enhancement

\* Corresponding author at: Massachusetts General Hospital, Department of Radiology, 55 Fruit Street, WAC 240, Boston, MA 02114, United States of America.

**E-mail addresses:** [mbahl1@mgm.harvard.edu](mailto:mbahl1@mgm.harvard.edu) (M. Bahl), [jay.baker@duke.edu](mailto:jay.baker@duke.edu) (J.A. Baker), [emily.kinsey@duke.edu](mailto:emily.kinsey@duke.edu) (E.N. Kinsey), [sujata.ghate@duke.edu](mailto:sujata.ghate@duke.edu) (S.V. Ghate).

<sup>1</sup> Present Affiliation: Massachusetts General Hospital, Department of Radiology, 55 Fruit Street, WAC 240, Boston, Massachusetts 02114.

<https://doi.org/10.1016/j.clinimag.2019.05.006>

Received 15 January 2019; Received in revised form 19 April 2019; Accepted 14 May 2019

0899-7071/© 2019 Elsevier Inc. All rights reserved.

## 2. Materials and methods

### 2.1. Study subjects

This study was approved by the institutional review board with a waiver for the need to obtain informed consent and was compliant with the Health Insurance Portability and Accountability Act (HIPAA). We performed a retrospective review of consecutive female patients who underwent DCE MRI before breast-conserving surgery from January 1, 2005, to December 31, 2014. The hospital's electronic medical record was searched for breast MRI reports and patients who underwent breast-conserving surgery during the same time period. Patients who received neoadjuvant therapy prior to breast-conserving surgery were excluded.

### 2.2. Imaging technique and interpretation

MRI examinations were obtained at the discretion of the patient's breast surgeon, medical oncologist, or radiation oncologist. All examinations were performed with a 1.5 T system (SignaHDx and SignaHDxt, GE Healthcare, Little Chalfont, United Kingdom; Magnetom Avanto, Siemens, Munich, Germany) or a 3 T system (SignaHDx and Signa Excite, GE Healthcare; Magnetom Trio, Siemens) with a dedicated seven-channel breast coil (Invivo, Orlando, FL). Each study included a noncontrast nonfat-saturated T1-weighted sequence, a noncontrast fat-saturated T2-weighted sequence, a noncontrast fat-saturated gradient-echo T1-weighted sequence, and three or four dynamic postcontrast T1-weighted gradient-echo series images with fat suppression after intravenous administration of a gadolinium-based agent. All MRI examinations were interpreted by fellowship-trained breast imaging radiologists.

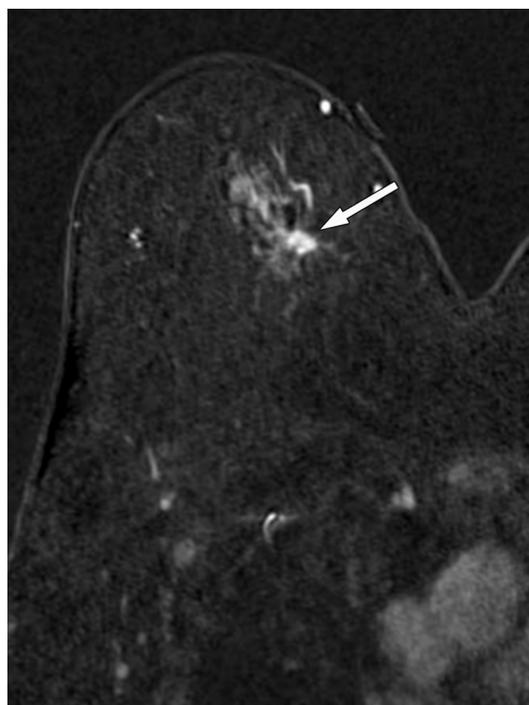
### 2.3. Data collection and statistical analysis

MRI reports were reviewed for findings (non-mass enhancement [NME] versus enhancing mass), size of tumor, and background parenchymal enhancement (BPE) assessment. Medical records were also reviewed for patient age, breast density on mammography, histological subtype on core biopsy pathology, tumor grade on core biopsy pathology, and margin status on surgical pathology.

All data were analyzed with a spreadsheet software program (Microsoft Excel, 2013 version, Redmond, Washington). For purposes of the analysis, margins reported as “negative” or “close” (historically defined as carcinoma < 2 mm from the surgical margin) were considered “negative” margins. During the study period, the pathologists at our institution shifted from the use of “negative,” “close,” or “positive” to only “negative” or “positive” (with reporting of the distance of the carcinoma from the surgical margin). For cases of invasive carcinoma, surgical margins with ductal carcinoma in situ (DCIS), invasive carcinoma, or both at the inked surface of the specimen were considered “positive.” Also, for purposes of the analysis, the final surgical margin status at the time of initial operation was used; that is, if the margins were reported to be “positive” but additional margins were taken at the time of the initial operation and the final surgical margin status was technically negative, the case was considered to be “negative.” The unpaired *t*-test (for continuous variables) and *chi*-square test (for categorical variables) were used to compare the positive and negative margins groups. *P*-values < 0.05 were considered statistically significant.

## 3. Results

Over a ten-year period, 795 female patients underwent breast MRI before breast-conserving surgery for invasive carcinoma or DCIS. 241 patients who received neoadjuvant chemotherapy were excluded. The study cohort was thus comprised of 554 patients (mean age, 56 years



**Fig. 1.** 64-year-old female with biopsy-proven grade 2 invasive lobular carcinoma in the upper inner quadrant of the right breast at middle depth. The subtracted axial MR image demonstrates an irregular enhancing mass with surrounding non-mass enhancement. The anterior and posterior margins of the surgical specimen were positive for invasive carcinoma.

old; age range, 26–90 years old) who underwent 575 breast-conserving surgeries (21 had bilateral carcinomas) for invasive carcinoma ( $n = 473$ ) or DCIS ( $n = 102$ ). Of the 473 surgeries for invasive carcinoma, 39 (8.2%) were upgraded from benign or high-risk pathologies at core biopsy ( $n = 10$ ) or DCIS at core biopsy ( $n = 29$ ) to invasive carcinoma at surgery. Of the 102 surgeries for DCIS, 12 (11.8%) were upgraded from benign or high-risk pathologies at core biopsy to DCIS at surgery.

Tumor-positive surgical margins occurred in 19.7% (93/473) of surgeries with invasive carcinoma (Figs. 1–3). Of the 93 cases with positive margins, 72 underwent re-excision to achieve negative margins, 20 ultimately underwent mastectomies, and one patient transferred her care to another institution. Positive margins were more common when the MRI demonstrated the finding of NME rather than the finding of enhancing mass (33.8% [22/65] versus 16.9% [61/360],  $p < 0.01$ ) (Table 1). There was also a statistically significant difference in tumor size on MRI with positive versus negative margins (2.5 cm versus 1.9 cm,  $p < 0.001$ ). There were no statistically significant differences in positive margin rates related to BPE on MRI. Positive margins were more commonly seen with lobular rather than ductal histology on core biopsy pathology (38.3% [18/47] versus 16.0% [56/350],  $p < 0.001$ ). Positive margins were also more commonly observed with grade 2 rather than grade 3 invasive carcinoma (24.9% [51/205] versus 9.5% [9/95],  $p < 0.01$ ). There were no statistically significant differences related to surgeon (among those who performed at least 50 operations over the study period), patient age, or breast density on mammography.

Tumor-positive surgical margins occurred in 31.4% (32/102) of surgeries with DCIS. Of the 32 cases with positive margins, 22 underwent re-excision to achieve negative margins and ten ultimately underwent mastectomies. There was a trend toward positive margins being more common when the MRI demonstrated moderate or marked BPE rather than minimal or mild BPE, but this relationship was not statistically significant (45.5% [10/22] versus 27.5% [14/51],



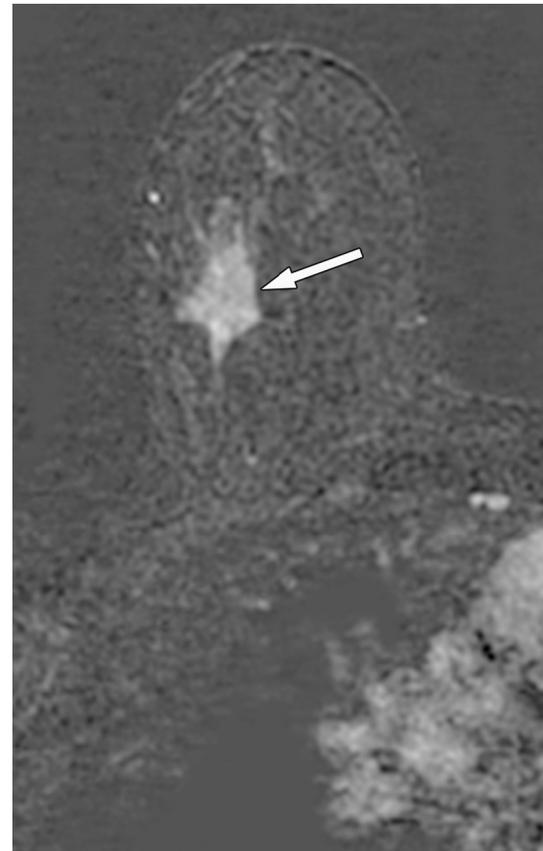
**Fig. 2.** 40-year-old female with biopsy-proven grade 2 invasive ductal carcinoma in the lower central aspect of the left breast at posterior depth. Axial maximum intensity projection (MIP) image from the pre-operative MRI demonstrates an irregular enhancing mass (arrow). The anterolateral margin of the surgical specimen was positive for invasive carcinoma.

$p = 0.13$ ) (Table 2). There were no statistically significant differences in positive margin rates related to finding on MRI (NME versus enhancing mass) or size on MRI. There were no statistically significant differences in positive margin rates related to surgeon (among those who performed at least 30 operations over the study period), patient age, breast density on mammography, or tumor grade on core biopsy pathology.

#### 4. Discussion

Our study finds that, for patients with invasive carcinoma, tumor-positive surgical margins requiring re-excision were associated with NME (rather than enhancing masses) on DCE MRI, larger tumor size on DCE MRI, and lobular (rather than ductal) histological subtype at core needle biopsy. This information may be used to aid in surgical planning and to counsel patients regarding the likelihood of needing further surgery. We did not identify any predictive MRI features for patients with DCIS.

The rates of positive margins in our study (19.7% for invasive carcinoma and 31.4% for DCIS) are in keeping with reported rates in the literature, which range from 15% to 37% for invasive carcinoma with even higher rates for DCIS [16–19]. At our institution, DCE MRI is not routinely performed in all patients with biopsy-proven carcinoma prior to surgery; instead, MRI examinations are obtained at the discretion of the patient's breast surgeon, medical oncologist, or radiation oncologist based on such factors as patient age, breast density, histologic subtype (ductal versus lobular), and tumor size. Given this selection bias, it is likely that the positive margin rate in this selective group of patients is higher than the rate for all patients who undergo breast-conserving surgery. The wide range of positive margin rates reported in the literature may be due to differences in patient populations, inconsistent definitions of “positive” and “negative” margins, and variations in



**Fig. 3.** 53-year-old female with biopsy-proven grade 2 invasive ductal carcinoma in the upper outer quadrant of the right breast at middle depth. The subtracted axial MR image demonstrates a focal area of non-mass enhancement. The margins of the surgical specimen were negative for invasive carcinoma.

intraoperative pathologic assessment of margins [19]. In 2014, the Society of Surgical Oncology and American Society for Radiology Oncology issued consensus guidelines, concluding that the use of no ink on tumor is the standard for an adequate margin in invasive carcinoma and is associated with low rates of recurrence in the ipsilateral breast [5].

For invasive carcinoma, we found that the presence of NME, large tumor size, lobular histology, and tumor grade of 2 were associated with increased likelihood of positive margins, similar to other studies [4,7,10,19–22]. Apart from large tumor size on MRI, the only other feature on MRI found to be predictive of positive margins was the finding of NME (rather than an enhancing mass). Two other studies have also demonstrated that NME on MRI is associated with a higher rate of re-excision [15,23]. NME on MRI can be seen in the setting of DCIS, invasive lobular carcinoma, estrogen receptor-negative invasive ductal carcinoma, focal adenosis, and fibrocystic changes [24].

For DCIS, previous studies have identified size on mammography and histological grade as factors associated with increased likelihood of positive margins [18,25,26]. Although we found no statistically significant associations between size on MRI or histological grade on core biopsy pathology with positive margins, there was a trend toward positive margins being more common when the MRI demonstrates moderate or marked BPE rather than minimal or mild BPE. Moderate or marked BPE can limit evaluation of tumor extent, as has been reported in prior studies, and underestimation of disease on MRI could lead to inadequate surgical resection [27,28]. There is limited published data on the association of BPE and surgical outcomes, such as surgical margin status. The one prior study on this topic, which was a retrospective series of 91 patients who underwent MRI before breast-conserving surgery, found no significant correlation between BPE and surgical margin status [14].

**Table 1**

Comparison of patient, imaging, and biopsy pathology features between breast-conserving surgeries for invasive carcinoma with positive vs negative margins.

	Positive margins	Negative margins	p-value
Age	57 (34–80)	56 (26–90)	0.99
Breast density on mammography			
Almost entirely fatty breasts or scattered areas of fibroglandular density	34/188 (18.1%)	154/188 (81.9%)	0.67
Heterogeneously or extremely dense breasts	52/264 (19.7%)	212/264 (80.3%)	
MRI findings <sup>a</sup>			
Non-mass enhancement	22/65 (33.8%)	43/65 (66.2%)	< 0.01
Enhancing mass	61/360 (16.9%)	299/360 (83.1%)	
Size (cm)	2.5 (0.6–8.5)	1.9 (0.5–8.2)	< 0.001
Background parenchymal enhancement on MRI			
Minimal or mild background parenchymal enhancement	53/285 (18.6%)	232/285 (81.4%)	0.66
Moderate or marked background parenchymal enhancement	20/97 (20.6%)	77/97 (79.4%)	
Histology on core biopsy pathology <sup>b</sup>			
Invasive ductal carcinoma	56/350 (16.0%)	294/350 (84.0%)	< 0.001
Invasive lobular carcinoma	18/47 (38.3%)	29/47 (61.7%)	
Tumor grade on core biopsy pathology			
Grade 1	21/130 (16.2%)	109/130 (83.8%)	< 0.01
Grade 2	51/205 (24.9%)	154/205 (75.1%)	
Grade 3	9/95 (9.5%)	86/95 (90.5%)	

<sup>a</sup> Thirty-three cases that were reported as enhancing mass and non-mass enhancement were not included in the analysis.<sup>b</sup> Forty-two cases of invasive carcinoma with mixed features (ductal and lobular) were not included in the analysis.**Table 2**

Comparison of patient, imaging, and biopsy pathology features between breast-conserving surgeries for ductal carcinoma in situ (DCIS) with positive vs negative margins.

	Positive margins	Negative margins	p-value
Age	52 (39–69)	53 (31–77)	0.53
Breast density on mammography			
Almost entirely fatty breasts or scattered areas of fibroglandular density	9/33 (27.3%)	24/33 (72.7%)	0.72
Heterogeneously or extremely dense breasts	20/65 (30.8%)	45/65 (69.2%)	
MRI findings			
Non-mass enhancement	21/64 (32.8%)	43/64 (67.2%)	0.21
Enhancing mass	2/13 (15.4%)	11/13 (84.6%)	
Size (cm)	2.9 (0.6–9.0)	2.8 (0.6–11.4)	0.96
Background parenchymal enhancement on MRI			
Minimal or mild background parenchymal enhancement	14/51 (27.5%)	37/51 (72.5%)	0.13
Moderate or marked background parenchymal enhancement	10/22 (45.5%)	12/22 (54.5%)	
Tumor grade on core biopsy pathology			
Grade 1	1/9 (11.1%)	8/9 (88.9%)	0.22
Grade 2	8/34 (23.5%)	26/34 (76.5%)	
Grade 3	13/35 (37.1%)	22/35 (62.9%)	

Our study cohort does not include patients who received neoadjuvant therapy prior to breast-conserving surgery, since MRI findings may not be used to guide surgical treatment in this population. In particular, a complete imaging response does not obviate the need for surgery [29]. According to the American College of Radiology (ACR), MRI can be used before, during, and/or after chemotherapy to evaluate treatment response and to evaluate the extent of residual disease [30]. MRI findings are a stronger predictor of pathologic response to neoadjuvant chemotherapy than is clinical assessment [31]; however, studies have demonstrated that MRI can overestimate or underestimate residual disease [32]. Factors that can affect the accuracy of MRI for evaluating treatment response include tumor molecular subtype, type of chemotherapy, and pattern of tumor response [29].

This study has several limitations. First, it was conducted at an academic institution with dedicated breast imaging radiologists, and thus the results may not be generalizable to other practices. Second, at our institution, breast MRI is not routinely performed in all patients with biopsy-proven carcinoma prior to surgery; instead, MRI examinations are obtained at the discretion of the patient's breast surgeon, medical oncologist, or radiation oncologist. Given this selection bias, the results of this study may not be generalizable to other institutions that routinely perform MRI in all patients with biopsy-proven carcinoma or refer patients for MRI based on different criteria than used by our referring providers. Third, although our study cohort

includes > 550 patients, some of the subgroup populations (particularly for DCIS) are relatively small, which limits statistical power.

## 5. Conclusions

Our findings suggest an additional use of breast MRI in the pre-operative setting: to predict which patients are at risk for tumor-positive surgical margins. We identified findings on MRI that are associated with increased likelihood of positive margins after breast-conserving surgeries for invasive carcinoma: NME (rather than an enhancing mass) and large tumor size. This information may be used to identify those patients who are at increased risk for tumor-positive surgical margins and may thus have implications for clinical pre-operative decision-making.

## Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

## Declaration of Competing Interest

There are no declarations that are relevant to this work. Dr. Sujata Ghate was paid for a reader study by QT Ultrasound in 2017 but has no

ongoing relationship.

Dr. Ghate also has a research grant from Bracco.

## References

- [1] van Dongen JA, Voogd AC, Fentiman IS, Legrand C, Sylvester RJ, Tong D, et al. Long-term results of a randomized trial comparing breast-conserving therapy with mastectomy: European Organization for Research and Treatment of Cancer 10801 trial. *J Natl Cancer Inst* 2000;92:1143–50.
- [2] Fisher B, Anderson S, Bryant J, Margolese RG, Deutsch M, Fisher ER, et al. Twenty-year follow-up of a randomized trial comparing total mastectomy, lumpectomy, and lumpectomy plus irradiation for the treatment of invasive breast cancer. *N Engl J Med* 2002;347:1233–41 <https://www.nejm.org/doi/full/10.1056/NEJMoa022152>.
- [3] Early Breast Cancer Trialists' Collaborative Group (EBCTCG), Darby S, McGale P, Correa C, Taylor C, Arriagada R, et al. Effect of radiotherapy after breast-conserving surgery on 10-year recurrence and 15-year breast cancer death: meta-analysis of individual patient data for 10,801 women in 17 randomised trials. *Lancet* 2011;378:1707–16 [https://www.thelancet.com/journals/lancet/article/PIIS0140-6736\(11\)61629-2/fulltext](https://www.thelancet.com/journals/lancet/article/PIIS0140-6736(11)61629-2/fulltext).
- [4] Keskek M, Kothari M, Ardehali B, Betambeau N, Nasiri N, Gui GP. Factors predisposing to cavity margin positivity following conservation surgery for breast cancer. *Eur J Surg Oncol* 2004;30:1058–64 [https://www.ejso.com/article/S0748-7983\(04\)00207-0/fulltext](https://www.ejso.com/article/S0748-7983(04)00207-0/fulltext).
- [5] Moran MS, Schnitt SJ, Giuliano AE, Harris JR, Khan SA, Horton J, et al. Society of Surgical Oncology-American Society for Radiation Oncology consensus guideline on margins for breast-conserving surgery with whole-breast irradiation in stages I and II invasive breast cancer. *J Clin Oncol* 2014;32:1507–15 <http://ascopubs.org/doi/10.1200/JCO.2013.53.3935>.
- [6] Ananthakrishnan P, Balci FL, Crowe JP. Optimizing surgical margins in breast conservation. *Int J Surg Oncol* 2012;2012:585670 <https://doi.org/10.1155/2012/585670>.
- [7] Barentsz MW, Postma EL, van Dalen T, van den Bosch MA, Miao H, Gobardhan PD, et al. Prediction of positive resection margins in patients with non-palpable breast cancer. *Eur J Surg Oncol* 2015;41:1106–12 <https://linkinghub.elsevier.com/retrieve/pii/S0748798314010567>.
- [8] Escriba JM, Esteban L, Galvez J, Pla MJ, Melia A, Gil-Gil M, et al. Reoperations after primary breast conserving surgery in women with invasive breast cancer in Catalonia, Spain: a retrospective study. *Clin Transl Oncol* 2017;19:448–56. <https://doi.org/10.1007/s12094-016-1546-5>.
- [9] Jeevan R, Cromwell DA, Trivella M, Lawrence G, Kearins O, Pereira J, et al. Reoperation rates after breast conserving surgery for breast cancer among women in England: retrospective study of hospital episode statistics. *BMJ* 2012;345:e4505. <https://doi.org/10.1136/bmj.e4505>.
- [10] Kurniawan ED, Wong MH, Windle I, Rose A, Mou A, Buchanan M, et al. Predictors of surgical margin status in breast-conserving surgery within a breast screening program. *Ann Surg Oncol* 2008;15:2542–9. <https://doi.org/10.1245/s10434-008-0054-4>.
- [11] Agostinho JL, Zhao X, Sun W, Laronga C, Kiluk JV, Chen DT, et al. Prediction of positive margins following breast conserving surgery. *Breast* 2015;24:46–50 <https://linkinghub.elsevier.com/retrieve/pii/S09660977614001908>.
- [12] Lehman CD, DeMartini W, Anderson BO, Edge SB. Indications for breast MRI in the patient with newly diagnosed breast cancer. *J Natl Compr Canc Netw* 2009;7:193–201.
- [13] Gutierrez RL, DeMartini WB, Silbergeld JJ, Eby PR, Peacock S, Javid SH, et al. High cancer yield and positive predictive value: outcomes at a center routinely using preoperative breast MRI for staging. *AJR Am J Roentgenol* 2011;196:W93–9. <https://doi.org/10.2214/AJR.10.4804>.
- [14] Kohara S, Ishigaki S, Satake H, Kawamura A, Kawai H, Kikumori T, et al. Background parenchymal enhancement in preoperative breast MRI. *Nagoya J Med Sci* 2015;77:373–82.
- [15] Kim OH, Kim SJ, Lee JS. Enhancing patterns of breast cancer on preoperative dynamic contrast-enhanced magnetic resonance imaging and resection margin in breast conserving therapy. *Breast Dis* 2016;36:27–35. <https://doi.org/10.3233/BD-150195>.
- [16] Mokbel K, Choy C, Leris C, Akbar M, Vinnicombe S, Kessar P, et al. Predictors of positive margins after local excision of ductal carcinoma in situ. *Am J Surg* 2001;181:91–5.
- [17] Gajdos C, Tartter PI, Bleiweiss LJ, Hermann G, de Csepe J, Estabrook A, et al. Mammographic appearance of nonpalpable breast cancer reflects pathologic characteristics. *Ann Surg* 2002;235:246–51.
- [18] de Roos MA, Grooten AD, Pijnappel RM, Post WJ, de Vries J, Baas PC. Small size ductal carcinoma in situ of the breast: predictors of positive margins after local excision. *Int Surg* 2006;91:100–6.
- [19] Lovrics PJ, Cornacchi SD, Farrokhyar F, Garnett A, Chen V, Franic S, et al. The relationship between surgical factors and margin status after breast-conservation surgery for early stage breast cancer. *Am J Surg* 2009;197:740–6 <https://linkinghub.elsevier.com/retrieve/pii/S0002961008005308>.
- [20] Chagpar AB, Martin 2nd RC, Hagendoorn LJ, Chao C, McMasters KM. Lumpectomy margins are affected by tumor size and histologic subtype but not by biopsy technique. *Am J Surg* 2004;188:399–402. <https://doi.org/10.1016/j.amjsurg.2004.06.020>.
- [21] Smitt MC, Horst K. Association of clinical and pathologic variables with lumpectomy surgical margin status after preoperative diagnosis or excisional biopsy of invasive breast cancer. *Ann Surg Oncol* 2007;14:1040–4. <https://doi.org/10.1245/s10434-006-9308-1>.
- [22] Clough KB, Gouveia PF, Benyahia D, Massey EJ, Russ E, Sarfati I, et al. Positive margins after oncoplastic surgery for breast cancer. *Ann Surg Oncol* 2015;22:4247–53 <https://link.springer.com/article/10.1245%2Fs10434-015-4514-3>.
- [23] Jung W, Kang E, Kim SM, Kim D, Hwang Y, Sun Y, et al. Factors associated with re-excision after breast-conserving surgery for early-stage breast cancer. *J Breast Cancer* 2012;15:412–9. <https://doi.org/10.4048/jbc.2012.15.4.412>.
- [24] Agrawal G, Su MY, Nalcioglu O, Feig SA, Chen JH. Significance of breast lesion descriptors in the ACR BI-RADS MRI lexicon. *Cancer* 2009;115:1363–80. <https://doi.org/10.1002/cncr.24156>.
- [25] Mai KT, Yazdi HM, Ford JC, Matzinger FR. Predictive value of extent and grade of ductal carcinoma in situ in radiologically guided core biopsy for the status of margins in lumpectomy specimens. *Eur J Surg Oncol* 2000;26:646–51. <https://doi.org/10.1053/ejso.2000.0975>.
- [26] Hassan RA, Maesaka JY, Ricci MD, Soares JM, Doria MT, Baracat EC, et al. Predictive factors for positive surgical margins in the treatment of breast ductal carcinoma in situ. *J Cancer Res Ther* 2016;12:995–8 <http://www.cancerjournal.net/article.asp?issn=0973-1482;year=2016;volume=12;issue=2;page=995;epage=998;aulast=Hassan>.
- [27] Uematsu T, Kasami M, Watanabe J. Does the degree of background enhancement in breast MRI affect the detection and staging of breast cancer? *Eur Radiol* 2011;21:2261–7 <https://link.springer.com/article/10.1007%2Fs00330-011-2175-6>.
- [28] Bignotti B, Signori A, Valdora F, Rossi F, Calabrese M, Durando M, et al. Evaluation of background parenchymal enhancement on breast MRI: a systematic review. *Br J Radiol* 2017;90:20160542 <https://doi.org/10.1259/bjr.20160542>.
- [29] Fowler AM, Mankoff DA, Joe BN. Imaging neoadjuvant therapy response in breast cancer. *Radiology* 2017;285:358–75. <https://doi.org/10.1148/radiol.2017170180>.
- [30] ACR practice parameter for the performance of contrast-enhanced magnetic resonance imaging (MRI) of the breast. American College of Radiology. <https://www.acr.org/-/media/ACR/Files/Practice-Parameters/mr-contrast-breast.pdf>. Published 2018. Accessed April 15, 2019.
- [31] Hylton NM, Blume JD, Bernreuter WK, Pisano ED, Rosen MA, Morris EA, et al. Locally advanced breast cancer: MR imaging for prediction of response to neoadjuvant chemotherapy—results from ACRIN 6657/I-SPY TRIAL. *Radiology* 2012;263:663–72. <https://doi.org/10.1148/radiol.12110748>.
- [32] Lobbes MB, Prevost R, Smidt M, Tjan-Heijnen VC, van Goethem M, Schipper R, et al. The role of magnetic resonance imaging in assessing residual disease and pathologic complete response in breast cancer patients receiving neoadjuvant chemotherapy: a systematic review. *Insights Imaging* 2013;4:163–75 <https://link.springer.com/article/10.1007%2Fs13244-013-0219-y>.