Am J Transl Res 2025;17(2):1039-1048
www.ajtr.org /ISSN:1943-8141/AJTR0161893

Original Article

Quantitative dynamic contrast-enhanced MRI parameters effectively predict treatment efficacy of neoadjuvant chemotherapy in breast cancer

Ling Xu*, Fangfang Zhou*, Lianzi Su, Longsheng Wang

Radiology Department, The Second Affiliated Hospital of Anhui Medical University, Hefei 230601, Anhui, China.
**Equal contributors and co-first authors.*

Received November 10, 2024; Accepted January 9, 2025; Epub February 15, 2025; Published February 28, 2025

Abstract: Purpose: To investigate the predictive value of quantitative DCE-MRI parameters for estimating the treatment efficacy of neoadjuvant chemotherapy (NACT) in breast carcinoma (BC). Methods: A retrospective analysis was conducted on 178 pathologically confirmed cases of BC, diagnosed via puncture biopsy, at The Second Affiliated Hospital of Anhui Medical University between January 2019 and June 2023. All patients received preoperative NACT. Based on postoperative pathological inspection results, 53 patients with grade IV-V pathological responses were included in the major histological response (MHR) group, and the remaining 125 with grade I-III pathological responses were assigned to the non-major histological response (NMHR) group. The pre- and post-chemotherapy early-phase enhancement rate (E_1), peak enhancement rate (E_{max}), and time to peak (T_{max}) on DCE-MRI were compared between the two patient cohorts. Quantitative parameters such as volume transfer constant (K^{trans}), rate constant (K_{ep}) and extravascular extracellular volume fraction (V_e) were obtained, and the post-NACT maximum tumor diameter (D-max) reduction rate and tumor volume reduction rate (TVRR) were calculated. Furthermore, the predictive efficacy of pre- and post-NACT quantitative DCE-MRI parameters for treatment responses was evaluated using receiver operating characteristic (ROC) curves. Results: The MHR group showed statistically higher post-NACT D-max reduction rate and TVRR than the NMHR group. The two patient cohorts were similar in pre-chemotherapy K_{ep}, but the pre-chemotherapy K^{trans} and V_e were lower in MHR; the post-chemotherapy K^{trans}, K_{ep} and V_e were all statistically different between groups ($P < 0.05$). The MHR group presented markedly lower E_1 and E_{max} values and statistically longer T_{max} compared to the NMHR group after NACT (all $P < 0.05$). The pre-NACT quantitative DCE-MRI parameters demonstrated limited prediction performance, with V_e showing the highest efficacy (AUC = 0.612); in contrast, post-NACT quantitative DCE-MRI parameters exhibited improved predictive accuracy, with K^{trans} demonstrating the best predictive performance (AUC = 0.801). Conclusions: The pre-NACT quantitative DCE-MRI parameters are not effective in predicting the therapeutic outcome of NACT. However, the post-NACT DCE-MRI parameters provide accurate and reliable predictions of pathological responses, with K^{trans} showing the highest predictive value and considerable clinical applicability.

Keywords: Dynamic contrast-enhanced magnetic resonance imaging, quantitative parameters, breast carcinoma, neoadjuvant chemotherapy, predicted value

Introduction

Breast carcinoma (BC) is the leading cause of morbidity and mortality among women, with an increasing incidence in younger age groups. This common malignant tumor significantly impacts women's physical and mental health and poses a serious threat to their lives [1]. In China, BC is among the malignancies with the fastest-growing fatality rate [2]. Early prevention and treatment are crucial for improving patient outcomes, with the current standard of care relying on a combination of surgical intervention, radiotherapy and chemotherapy, targeted therapy, endocrine therapy, and immunotherapy [3-6]. However, many patients are diagnosed at intermediate or advanced stages, resulting in poor prognoses due to the lack of specific symptoms in early-stage BC.

The advent of neoadjuvant chemotherapy (NACT) has revolutionized the treatment for

https://doi.org/10.62347/GTIX2261

locally advanced BC [7]. Preoperative NACT can effectively reduce tumor size and downgrade the tumor stage, increasing the possibility of breast-conserving surgery and the likelihood of achieving a postoperative pathological complete response (pCR) [8]. NACT has demonstrated high clinical response rate (80%), with pCR observed in 6-25% of BC patients [9, 10]. A 2014 meta-analysis of 11,955 cases published in *The Lancet* highlighted that patients achieving pCR after NACT experienced improved event-free and overall survival, with pCR being strongly associated with long-term survival benefits [11]. Thus, accurate and timely evaluation of the pathological response to NACT is crucial for guiding treatment decisions. Histopathological examination remains the "gold standard" evaluating tumor response [12], offering high diagnostic accuracy. However, it can only be performed post-surgery, which may result in missing the optimal window for adjusting treatment plans. Thus, the ability to dynamically assess tumor responses to NACT in vivo is vital, enabling timely adjustments for both responders and non-responders.

Various imaging modalities, including ultrasound, mammography, and breast magnetic resonance imaging (MRI), have been applied to evaluate the pathological response of BC patients to NACT [13-15]. While numerous studies have sought to determine the optimal diagnostic model for evaluating NACT efficacy, no consensus has been reached [16-18]. Dynamic contrast-enhanced magnetic resonance imaging (DCE-MRI) is a minimally invasive and widely applied imaging technique [19], enabling quantitative evaluation of the hemodynamic changes in tumors. It reflects the biological response of the tumor during treatment and provides a more accurate and earlier assessment of the tumor's response compared to purely morphological evaluations. This technique can assist clinical evaluations and predict the efficacy of chemotherapeutic drugs. Meanwhile, DCE-MRI has significant advantages, as it not only reflects changes in microvessel density and tumor hemodynamics during chemotherapy, but also offers detailed information on tumor's angiogenic status. By directly introducing contrast agents or using pharmacokinetic models for perfusion analysis, three parameters, namely volume transfer constant (K^{trans}), rate constant (K_{ep}) and extravascular extracellular volume fraction (V_e), can be calculated to provide insights into tumor blood perfusion and microvascular permeability [20]. K^{trans} reflects local blood volume, blood flow, and vascular permeability; K_{ep} correlates with local blood flow and vascular permeability; and V_e is associated with cell density and microvessel density. It has been reported that K^{trans} and V_e are closely related to microvessel density [21]. Previous studies have generally indicated that quantitative DCE-MRI parameters after two cycles of chemotherapy can predict patient outcomes [22-24]. However, controversies still exist regarding the effectiveness of DCE-MRI in predicting NACT efficacy for BC. In this study, DCE-MRI was performed on BC patients before and after NACT to assess the predictive value of its parameters and their correlation with post-NACT pathological responses.

Materials and methods

Study population

This retrospective study included 178 BC patients, all of whom were pathologically confirmed by core needle biopsy at The Second Affiliated Hospital of Anhui Medical University and received preoperative NACT. Inclusion criteria: (1) Diagnosis of breast cancer by core needle biopsy before NACT, and confirmed by pathology biopsy after surgery; (2) No prior BC surgery or systemic chemotherapy before the first MRI examination; (3) Clinical staging of IIA-IIIC, with distant metastasis excluded by imaging; (4) No previous history of cancer; (5) Receipt of three or more cycles of NAC after diagnosis, followed by curative-intent surgery, such as breast-conserving surgery or modified radical mastectomy; (6) Completion of both pre- and post-NACT DCE-MRI of the breasts; (7) Availability of complete medical records. Exclusion criteria: (1) Imaging artifacts severe enough to affect evaluation; (2) Previous cancer history; (3) Chemotherapy intolerance or switch to an alternative chemotherapy regimen during treatment; (4) Absence of postoperative pathological examination results due to lack of post-chemotherapy surgical treatment; (5) Incomplete medical records.

The NACT scheme primarily consisted of anthracyclines or taxanes, including the TEC regimen (paclitaxel, epirubicin, and cyclophosphamide),

the PC regimen (paclitaxel and carboplatin), and the FAC scheme (5-fluorouracil, anthracycline, and cyclophosphamide). The choice of NACT regimen for patients was based on tumor characteristics, patient's physical condition, allergic history, and the physician's experience with the medications. This study was approved by the Ethics Committee of The Second Affiliated Hospital of Anhui Medical University.

Inspection methods

All patients underwent DCE-MRI both before and after NACT. Prior to the examination, patients were instructed to fast for 6 hours, and were advised against physical exercise or coughing during the procedure. The examination was performed using Siemens 3.0T MRI scanner equipped with an 8-channel phased array breast coil. During the scan, patients were positioned in the prone position with the breasts hanging naturally within the surface coil; intravenous access was established using a 12G needle for the hyperbaric injector before the examination. The scanning procedures were as follows. Plain Scan: T1-weighted imaging (T1WI), adipose-suppressed T2WI in the axial plane, diffusion weighted imaging (DWI) (b = 0, b = 800 s/mm^2). Dynamic Contrast-Enhanced Imaging: 3D fast spoiled gradient echo sequence (FLASH-3D) and T1WI fat-suppressed axial imaging, parameters: TR/TE 4.56 ms/1.5 ms, flip angel = 12°, field of view (FOV) = 360 mm, matrix = 384×288, slice thickness = 1 mm. A total of 5 phases were scanned continuously, with each phase collected over 90 seconds, for a total duration of 7 minutes and 30 seconds. The procedure included an initial "mask" scan, followed by contrast injection with gadopentetate dimeglumine (0.2 mL/kg), and a saline flush of 20 mL at a flow rate of 2 mL/s. An immediate dynamic enhancement scan was performed following the injection.

Image analysis

All data were analyzed using Siemens Mean Cure software and Siemens Vida syngo MR XA20 post-processing software. Rhe acquired images were imported into the workstation, and the region of interest (ROI) was selected from the area showing the most significant enhancement and the largest lesion size during continuous contrast-enhanced scanning. To ensure consistency, the same ROI was used before and after chemotherapy. Care was taken to avoid necrotic and vascular areas during ROI selection. The software automatically calculated the following parameters: early-phase enhancement rate (E_1), peak enhancement rate (E_{max}), time to peak (T_{max}), volume transfer constant (K^{trans}, mmol/min), rate constant (K_{ep}, mmol/min; rate constant of inter-tissue contrast agents returning to the blood vessels), and extravascular extracellular volume fraction (V_e; the volume fraction of the extravascular extracellular space). For each lesion ROI, the software automatically generated quantitative parameter values. Measurements were repeated three times, and the average values were recorded. Care was taken to avoid cystic and necrotic areas. Additionally, the maximum tumor diameter (D-max) and tumor volume were determined, and the D-max reduction rate and tumor volume reduction rate (TVRR) post-NACT were calculated as follows: D-max or TVRR = (Pre-chemotherapy value - Post-chemotherapy value)/Pre-chemotherapy value × 100%.

Pathological evaluation

A pathologist with over 10 years of experience was tasked with reviewing the tissue specimens in a blinded manner. Pathological results from the surgical sections of all patients were graded according to the Miller & Payne grading system. The pathological responses were classified into either non-major histological response (NMHR) or major histological response (MHR). NMHR: grade I - No change in the number of tumor cells before and after NACT; grade II - Tumor cell density decreased by ≤ 30% after NACT; grade III - Tumor cell density decreased by 30%-90% after NACT. MHR: grade IV - Tumor cell density decreased by ≥ 90% after NACT; grade V - Complete disappearance of tumor cells, with no residual invasive carcinoma.

Statistical methods

The primary quantitative parameters for analysis were DCE-MRI parameters, while the secondary parameters were the histological response grades. SPSS 22.0 software and Graphpad Prism 8 were used for statistical analyses. The categorical data were represented by counts (%) and analyzed using the χ^2

Table 1. General information of selected patients

Clinicopathological features	Number of cases (n = 178)
Age (years old)	46.9±6.2
Maximum lesion diameter (cm)	3.7±1.1
Lesion distribution	
Left breast	87
Right breast	91
Clinical staging	
IIA	17
IIB	73
IIIA	62
IIIB	19
IIIC	7
Neoadjuvant chemotherapy regimen	
TEC regimen	53
PC regimen	48
FAC regimen	77
Pathological evaluation of chemotherapy	
Non-major histological response	125
Major histological response	53

Note: TEC regimen (paclitaxel, epirubicin, and cyclophosphamide); PC regimen (paclitaxel and carboplatin); FAC regimen (5-fluorouracil, anthracycline, and cyclophosphamide).

test. The measurement data were expressed as mean ± standard deviation. Normality of |the data was assessed first; if the data followed a normal distribution, comparisons were made using the t-test. If the data were not normally distributed, non-parametric tests were used. The prediction performance was assessed using receiver operating characteristic (ROC) curves and the area under the curve (AUC), which was further compared using DeLong test. The difference was considered statistically significant at *p*-value < 0.05.

Results

General information of the included patients

A total of 178 BC patients included in this study underwent postoperative pathological evaluation, with 17, 73, 62, 19, and 7 cases of stages IIA, IIB, IIIA, IIIB, and IIIC, respectively. Of these, 53 patients were treated with TEC regimen, 48 patients with PC regimen, and 77 patients with FAC regimen. There were 53 patients in MHR group and 125 patients in NMHR group, as shown in **Table 1**.

Comparison of D-max reduction rate and TVRR between the two groups

As shown in **Figure 1**, MHR patients exhibited notably higher post-NACT D-max reduction rate and TVRR than the NMHR patients (both $P < 0.05$).

Pre- and post-NACT quantitative DCE-MRI parameters in the two groups

The comparison of pre- and post-NACT quantitative parameters of DCE-MRI is shown in **Table 2**. Before chemotherapy, the MHR group showed similar K_{ep} values ($P > 0.05$) but lower K^{trans} and V_e values ($P < 0.05$) compared to the NMHR group. After chemotherapy, all three indices, K^{trans}, K_{ep} and V_e, were significantly lower in the MHR group compared to those in the NMHR group (all $P < 0.001$). In the MHR group, K^{trans}, K_{ep} and V_e values were significantly lower post-chemotherapy compared to their pre-chemotherapy values (all $P < 0.05$), while in the NMHR group, the V_e values remained unchanged before and after chemotherapy ($P > 0.05$).

Pre- and post-NACT DCE-MRI signal parameters of patients in the two groups

Before NACT, the MHR group exhibited significantly higher E_1 and E_{max} values and shorter T_{max} compared to the NMHR patients (all $P < 0.05$). After NACT, the MHR group showed marked reductions in E_1 and E_{max}, but statistically prolonged T_{max}, compared to their pre-NACT levels (all $P < 0.05$). In contrast, the NMHR group demonstrated significant increases in E_1 and E_{max} but notably shorter T_{max} compared to their pre-NACT levels (all $P < 0.05$). In addition, the inter-group comparison revealed lower E_1 and E_{max} while longer T_{max} in MHR group as compared to NMHR group (all $P < 0.001$), as shown in **Table 2**.

A typical case is illustrated in **Figure 2**. A 48-year-old female patient was diagnosed with right breast cancer after a 3-year history of a right breast mass. MRI showed a mass-like soft tissue signal in the upper quadrant of the right breast, characterized by low signal in the T1WI sequence, slightly high signal in the T2WI sequence, and longer T2 sig-

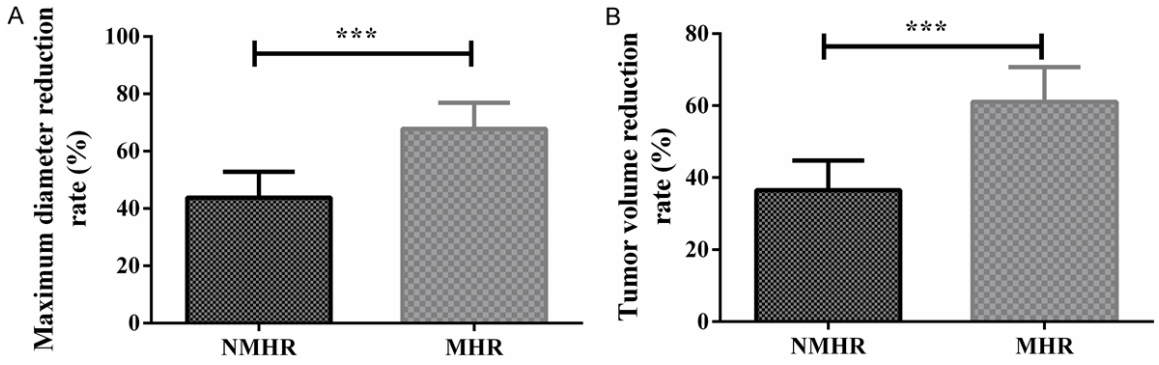

Figure 1. Comparison of maximum tumor diameter reduction rate and tumor volume reduction rate. A: Maximum tumor diameter reduction rates; B: Tumor volume reduction rates. MHR, Major histological response; NMHR, Non-major histological response; ***P < 0.001.

Table 2. Comparison of pre- and post-NACT quantitative DCE-MRI parameters

	Parameters	NMHR group (n = 125)	MHR group (n = 53)	t/Z	P
Before chemotherapy	K^{trans} (min^{-1})	0.322±0.112	0.280±0.119	2.247	0.026
	K_{ep} (min^{-1})	0.938±0.256	0.860 (0.683, 1.116)	1.368	0.173
	V_e	0.462±0.101	0.412±0.115	2.913	0.004
	E_1 (%)	87.8±13.0	102.2±15.9	6.311	< 0.001
	E_{max} (%)	138.7±23.6	158.7±23.3	5.189	< 0.001
	T_{max} (s)	151.3±17.1	64.5±9.7	34.631	< 0.001
After chemotherapy	K^{trans} (min^{-1})	0.252±0.091*	0.166±0.051*	6.514	< 0.001
	K_{ep} (min^{-1})	0.633±0.155*	0.510±0.098*	5.320	< 0.001
	V_e	0.439±0.103	0.375±0.086*	3.985	< 0.001
	E_1 (%)	101.6±14.5*	62.8±6.9*	18.586	< 0.001
	E_{max} (%)	165.9±20.5*	138.7±18.9*	8.280	< 0.001
	T_{max} (s)	131.8±10.0*	152.7±15.5*	10.721	< 0.001

Note: NACT, Neoadjuvant chemotherapy; DCE-MRI, Dynamic contrast-enhanced magnetic resonance imaging; MHR, Major histological response; NMHR, Non-major histological response; K^{trans}, Volume transfer constant; K_{ep}, Rate constant; V_e, Extravascular extracellular volume fraction; E_1, Early-phase enhancement rate; E_{max}, Peak enhancement rate; T_{max}, Time to peak; *P < 0.05, versus before chemotherapy within the group.

nal in the inner part of the breast. The DWI sequence showed a high signal, and the ADC map showed a low signal, with irregular morphology, lobular shape, poorly defined borders, and an area of about 3.9×5.4×5.2 cm. The mass was adjacent to thickened skin of the right breast, which exhibited uneven enhancement after contrast injection, with a rich blood supply and multiple tortuous thickened blood vessels visible on maximal intensity projection (MIP). After 4 months of neoadjuvant chemotherapy, the lesion significantly reduced in size, and the T1WI, T2WI, and DWI sequences were not clear. Post-chemotherapy enhancement showed flaky enhancement foci.

Predictive efficacy of pre- and post-NACT quantitative DCE-MRI parameters

The predictive efficacy of pre-NACT quantitative DCE-MRI parameters in predicting NACT efficacy is shown in **Figure 3** and **Table 3**. The pre-NACT parameters demonstrated poor prediction efficiency, with V_e being the most effective (AUC = 0.612), showing a sensitivity of 56.6% and a specificity of 63.2%. Post-NACT quantitative DCE-MRI parameters showed improved predictive performance, with K^{trans} providing the greatest predictive efficiency (AUC = 0.801, sensitivity of 83.0%, and specificity of 72.0%). The prediction performance of K_{ep} was moder-

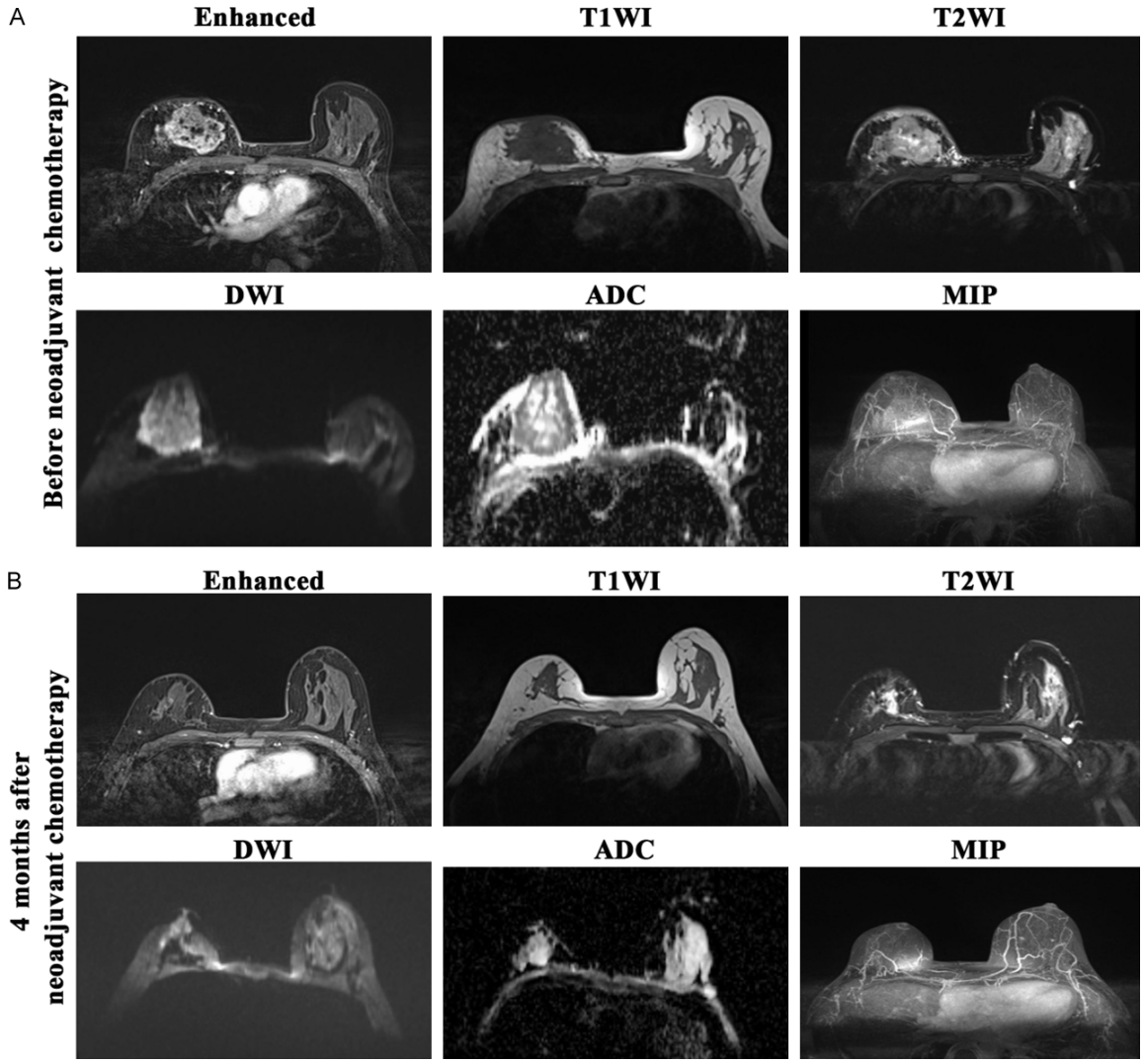

Figure 2. MRI images of a 48-year-old female case before and after neoadjuvant chemotherapy. A: Before neoadjuvant chemotherapy; B: 4 months after neoadjuvant chemotherapy. DWI, Diffusion weighted imaging; ADC, Apparent dispersion coefficient; MIP, Maximal intensity projection.

ate, with an AUC of 0.738, while that of V_e value was the least, with an AUC of 0.689.

Discussion

NACT has become the standard treatment for locally advanced BC. As a systemic cytotoxic therapy administered before operation, NACT aims to downstage both the primary tumor and lymph nodes [25], thus increasing the possibility for breast-conserving surgery. A proper evaluation of NACT efficacy not only helps guide the treatment plans but also provides insights into tumor responses to chemotherapy, offering a reliable theoretical basis for postoperative treatment decisions. Dynamic contrast-enhanced magnetic resonance imaging (DCE-MRI) can provide valuable information about tumor intercellular space, cell composition, blood supply, and vascular permeability, all of which can reflect pathological responses and predict survival outcomes to some extent.

DCE-MRI has been widely used in numerous studies to evaluate and predict the response of breast tumors to NACT [26-28]. Early research primarily focused on semi-quantitative analyses, using enhanced MRI to measure changes in tumor volume [29, 30]. Cheung et al. [31] analyzed differences in pre- and post-treatment tumor sizes after a chemotherapy cycle, as well as final tumor size remissions in 33 patients.

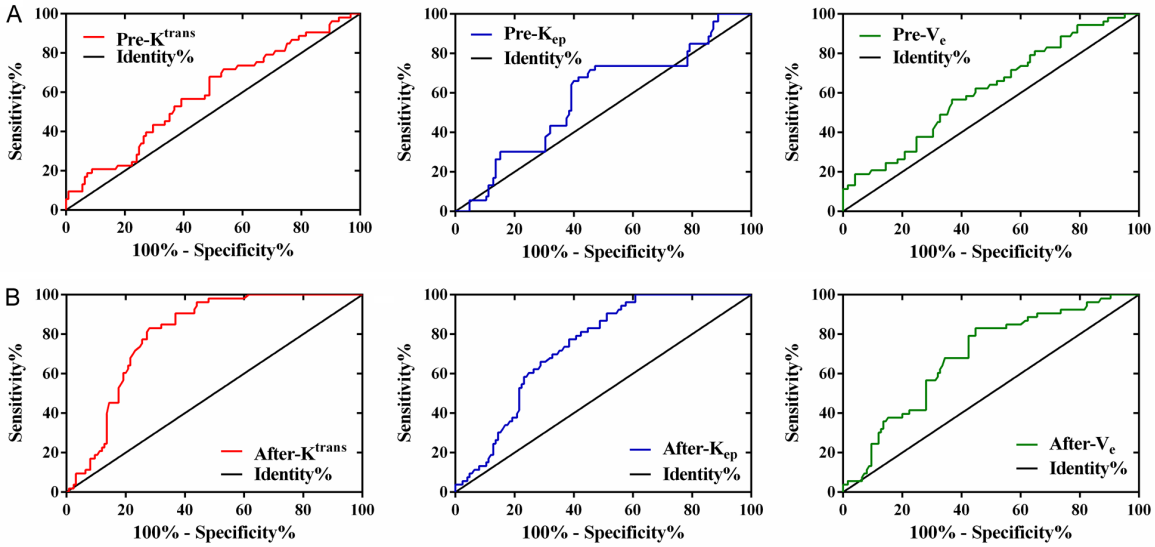

Figure 3. ROC curves for pre- and post-NACT DCE-MRI parameters in predicting major histological responses to NACT. A: Pre-NACT DCE-MRI parameters in predicting major histological responses; B: Post-NACT DCE-MRI parameters in predicting major histological responses. NACT, Neoadjuvant chemotherapy; DCE-MRI, Dynamic contrast-enhanced magnetic resonance imaging; ROC, Receiver operating characteristic.

Table 3. Predictive efficiency of quantitative DCE-MRI parameters before and after neoadjuvant chemotherapy

	Parameters	AUC	Cut-off	Maximum Youden index	Sensitivity (%)	Specificity (%)	P
Before chemotherapy	K^{trans} (min^{-1})	0.591	0.326	0.191	51.2	67.9	0.056
	K_{ep} (min^{-1})	0.583	0.911	0.264	52.8	73.6	0.110
	V_e	0.612	0.441	0.198	56.6	63.2	0.018
After chemotherapy	K^{trans} (min^{-1})	0.801	0.204	0.550	72.0	83.0	< 0.001
	K_{ep} (min^{-1})	0.738	0.643	0.394	48.8	90.6	< 0.001
	V_e	0.689	0.432	0.328	55.2	83.0	< 0.001
Delong test	Before chemotherapy	After chemotherapy	Difference in AUC	SE	95% CI	Z	P
	K^{trans} (min^{-1})	K^{trans} (min^{-1})	0.210	0.059	0.094-0.327	3.540	< 0.001
	K_{ep} (min^{-1})	K_{ep} (min^{-1})	0.155	0.059	0.038-0.273	2.597	< 0.001
	V_e	V_e	0.077	0.058	-0.036-0.190	1.338	0.181

Note: DCE-MRI, Dynamic contrast-enhanced magnetic resonance imaging; K^{trans}, Volume transfer constant; K_{ep}, Rate constant; V_e, Extravascular extracellular volume fraction; AUC, Area under curve; SE, Standard error.

Their findings revealed that all complete responders experienced a tumor size reduction of more than 45% following one treatment cycle. In this study, 53 patients were classified as MHR and 125 as NMHR. Comparing the tumor shrinkage between the two cohorts revealed that both the D-max reduction rate and TVRR were notably higher in MHR group compared to the NMHR group. The evaluation of treatment efficacy is primarily based on changes in D-max, which is easy to measure, reproducible, and highly accurate. It correlates well with pathological outcomes and is therefore an effective indicator of treatment response and pathological changes in patients undergoing NACT. While these results are promising for BC treatment, morphological changes, such as tumor size and qualitative enhancement patterns, are temporal consequences of underlying physiological alterations. Consequently, changes in tumor perfusion parameters may serve as early surrogate biomarkers for treatment response. Thus, alongside tumor size evaluation, researchers have increasingly focused on the quantitative physiological parameters provided by DCE-MRI [26].

Tumor tissue typically contains a large number of neovascular vessels that are immature and lack endothelial cells or smooth muscle cells,

resulting in high vascular permeability. BC patients with better NACT response generally have fewer blood vessels in the tumor and lower permeability, significantly compromising tumor's blood supply and perfusion [32]. It has been shown that the growth and metastasis of breast cancer depend on a rich blood supply, and that local blood supply and capillary permeability play a crucial role in the absorption of chemotherapeutic drugs [33, 34]. Changes in K^{trans} and k_{ep} can therefore reflect the tumor's response to treatment efficacy.

Quantitative parameters such as K^{trans}, K_{ep}, and V_e were compared in this study, and the post-NACT reductions of K^{trans}, K_{ep}, and V_e were more prominent in MHR patients compared to NMHR patients. During chemotherapy, tumor cell necrosis can reduce vascular endothelial growth factor production, leading to apoptosis of immature vascular endothelial cells and reduced neovascularization, which results in a significant decrease in K^{trans} and K_{ep} [35]. Interestingly, we found no statistical difference between pre- and post-chemotherapy V_e in the NMHR group. This may be due to the instability of V_e measurement, as the surrounding edema of the lesion has a strong influence. Thus, the use of V_e in efficacy evaluation remains controversial [36]. Besides, while pre-chemotherapy K_{ep} was similar between the two cohorts, K^{trans} and V_e were lower in the MHR group as compared to the NMHR group, which may be related to measurement errors in K^{trans}, as factors affecting blood perfusion, like hypertension, can affect K^{trans} value, leading to inaccuracies [37]. As there is a relationship between V_e and K^{trans} and K_{ep} ($V_e = K^{trans}/K_{ep}$), any errors in K^{trans} measurement can propagate to V_e calculations.

Furthermore, the pre-NACT E_1 and E_{max} in MHR patients were noticeably higher compared with NMHR patients, while the pre-NACT T_{max} was markedly shorter. After NACT, MHR patients showed statistically lower E_1 and E_{max}, along with a longer T_{max} than NMHR patients. In patients with effective NACT, changes in tumor microvessels and permeability often result in residual tumor lesions being largely unenhanced, causing hemodynamic parameters to resemble those of normal tissue. This leads to a significant reduction in E_1 and E_{max}, as well as an extension of T_{max}. Moreover, ROC curve analysis revealed that the predictive efficiency of pre-NACT quantitative DCE-MRI parameters was poor, with V_e being the most effective (AUC = 0.612). However, post-NACT, the predictive performance of these parameters improved, with K^{trans} showing the best predictive efficacy (AUC = 0.801). The discrepancies observed in existing studies may be attributed to differences in scanning machines, temporal resolutions, scanning protocols, chemotherapy regimens, and experimental grouping criteria.

Still, there are some limitations that need to be addressed. First, this study is a single-center retrospective analysis, with a small sample size and relatively narrow pathological scope, which limits its generalizability. Second, some patients had non-mass-like lesions, making it difficult to depict ROI in multi-phase axial dynamic enhanced images. Although the values of all parameters were averaged, there are still potential deviations from the actual values of lesions. Furthermore, the number of MHR cases was smaller than the number of NMHR cases, which could influence the analysis of group differences. Despite these limitations, this study provides valuable information for the clinical assessment of the prognosis of neoadjuvant chemotherapy in BC patients. Moreover, given that DCE-MRI is a noninvasive test, its application holds higher potential for clinical convenience and value. Conclusively, quantitative DCE-MRI parameters are effective in predicting pathological responses following NACT for BC, providing valuable prognostic information for BC patients undergoing NACT.

Acknowledgements

This study was supported by the Clinical application of cone-beam breast spectral CT in early screening and diagnosis of breast cancer, Anhui Provincial Health Research Project, No.: YX2024-038(F1).

Disclosure of conflict of interest

None.

Address correspondence to: Longsheng Wang, Radiology Department, The Second Affiliated Hospital of Anhui Medical University, Hefei 230601, Anhui, China. Tel: +86-0551-63869470; E-mail: Bg303418@126.com

References

[1] Waks AG and Winer EP. Breast cancer treatment: a review. JAMA 2019; 321: 288-300.

[2] Wang X, Wang C, Guan J, Chen B, Xu L and Chen C. Progress of breast cancer basic research in China. Int J Biol Sci 2021; 17: 2069-2079.

[3] Heil J, Kuerer HM, Pfob A, Rauch G, Sinn HP, Golatta M, Liefers GJ and Vrancken Peeters MJ. Eliminating the breast cancer surgery paradigm after neoadjuvant systemic therapy: current evidence and future challenges. Ann Oncol 2020; 31: 61-71.

[4] Korde LA, Somerfield MR, Carey LA, Crews JR, Denduluri N, Hwang ES, Khan SA, Loibl S, Morris EA, Perez A, Regan MM, Spears PA, Sudheendra PK, Symmans WF, Yung RL, Harvey BE and Hershman DL. Neoadjuvant chemotherapy, endocrine therapy, and targeted therapy for breast cancer: ASCO guideline. J Clin Oncol 2021; 39: 1485-1505.

[5] Sun M, Duan Y, Ma Y and Zhang Q. Cancer cell-erythrocyte hybrid membrane coated gold nanocages for near infrared light-activated photothermal/radio/chemotherapy of breast cancer. Int J Nanomedicine 2020; 15: 6749-6760.

[6] Bahreyni A, Mohamud Y and Luo H. Emerging nanomedicines for effective breast cancer immunotherapy. J Nanobiotechnology 2020; 18: 180.

[7] Asaoka M, Gandhi S, Ishikawa T and Takabe K. Neoadjuvant chemotherapy for breast cancer: past, present, and future. Breast Cancer (Auckl) 2020; 14: 1178223420980377.

[8] Liu Y, Wu M, Tan W, Gong J and Ma J. Efficacy evaluation of neoadjuvant chemotherapy in breast cancer by MRI. Contrast Media Mol Imaging 2022; 2022: 4542288.

[9] Kaufmann M, von Minckwitz G, Mamounas EP, Cameron D, Carey LA, Cristofanilli M, Denkert C, Eiermann W, Gnant M, Harris JR, Karn T, Liedtke C, Mauri D, Rouzier R, Ruckhaeberle E, Semiglazov V, Symmans WF, Tutt A and Pusztai L. Recommendations from an international consensus conference on the current status and future of neoadjuvant systemic therapy in primary breast cancer. Ann Surg Oncol 2012; 19: 1508-1516.

[10] Bear HD, Anderson S, Smith RE, Geyer CE Jr, Mamounas EP, Fisher B, Brown AM, Robidoux A, Margolese R, Kahlenberg MS, Paik S, Soran A, Wickerham DL and Wolmark N. Sequential preoperative or postoperative docetaxel added to preoperative doxorubicin plus cyclophosphamide for operable breast cancer: National Surgical Adjuvant Breast and Bowel Project Protocol B-27. J Clin Oncol 2006; 24: 2019-2027.

[11] von Minckwitz G, Untch M, Blohmer JU, Costa SD, Eidtmann H, Fasching PA, Gerber B, Eiermann W, Hilfrich J, Huober J, Jackisch C, Kaufmann M, Konecny GE, Denkert C, Nekljudova V, Mehta K and Loibl S. Definition and impact of pathologic complete response on prognosis after neoadjuvant chemotherapy in various intrinsic breast cancer subtypes. J Clin Oncol 2012; 30: 1796-1804.

[12] Nigam M and Nigam B. Triple assessment of breast-gold standard in mass screening for breast cancer diagnosis. Iosr-Jdms 2013; 7: 1-7.

[13] Wang J, Chu Y, Wang B and Jiang T. A narrative review of ultrasound technologies for the prediction of neoadjuvant chemotherapy response in breast cancer. Cancer Manag Res 2021; 13: 7885-7895.

[14] Wang Z, Lin F, Ma H, Shi Y, Dong J, Yang P, Zhang K, Guo N, Zhang R, Cui J, Duan S, Mao N and Xie H. Contrast-enhanced spectral mammography-based radiomics nomogram for the prediction of neoadjuvant chemotherapy-insensitive breast cancers. Front Oncol 2021; 11: 605230.

[15] Janssen LM, den Dekker BM, Gilhuijs KGA, van Diest PJ, van der Wall E and Elias SG. MRI to assess response after neoadjuvant chemotherapy in breast cancer subtypes: a systematic review and meta-analysis. NPJ Breast Cancer 2022; 8: 107.

[16] Li H, Yao L, Jin P, Hu L, Li X, Guo T and Yang K. MRI and PET/CT for evaluation of the pathological response to neoadjuvant chemotherapy in breast cancer: a systematic review and meta-analysis. Breast 2018; 40: 106-115.

[17] Gu YL, Pan SM, Ren J, Yang ZX and Jiang GQ. Role of magnetic resonance imaging in detection of pathologic complete remission in breast cancer patients treated with neoadjuvant chemotherapy: a meta-analysis. Clin Breast Cancer 2017; 17: 245-255.

[18] Dialani V, Chadashvili T and Slanetz PJ. Role of imaging in neoadjuvant therapy for breast cancer. Ann Surg Oncol 2015; 22: 1416-1424.

[19] Khalifa F, Soliman A, El-Baz A, Abou El-Ghar M, El-Diasty T, Gimel'farb G, Ouseph R and Dwyer AC. Models and methods for analyzing DCE-MRI: a review. Med Phys 2014; 41: 124301.

[20] O'Connor JP, Jackson A, Parker GJ and Jayson GC. DCE-MRI biomarkers in the clinical evaluation of antiangiogenic and vascular disrupting agents. Br J Cancer 2007; 96: 189-195.

[21] Kim SH, Lee HS, Kang BJ, Song BJ, Kim HB, Lee H, Jin MS and Lee A. Dynamic contrast-enhanced MRI perfusion parameters as imag-

ing biomarkers of angiogenesis. PLoS One 2016; 11: e0168632.
[22] Yu Y, Jiang Q, Miao Y, Li J, Bao S, Wang H, Wu C, Wang X, Zhu J, Zhong Y, Haacke EM and Hu J. Quantitative analysis of clinical dynamic contrast-enhanced MR imaging for evaluating treatment response in human breast cancer. Radiology 2010; 257: 47-55.
[23] Kim Y, Kim SH, Song BJ, Kang BJ, Yim KI, Lee A and Nam Y. Early prediction of response to neoadjuvant chemotherapy using dynamic contrast-enhanced MRI and ultrasound in breast cancer. Korean J Radiol 2018; 19: 682-691.
[24] Sharma A, Sharma S, Sood S, Seam RK, Sharma M and Fotedar V. DCE-MRI and parametric imaging in monitoring response to neoadjuvant chemotherapy in breast carcinoma: a preliminary report. Pol J Radiol 2018; 83: e220-e228.
[25] Schott AF and Hayes DF. Defining the benefits of neoadjuvant chemotherapy for breast cancer. J Clin Oncol 2012; 30: 1747-1749.
[26] Li X, Arlinghaus LR, Ayers GD, Chakravarthy AB, Abramson RG, Abramson VG, Atuegwu N, Farley J, Mayer IA, Kelley MC, Meszoely IM, Means-Powell J, Grau AM, Sanders M, Bhave SR and Yankeelov TE. DCE-MRI analysis methods for predicting the response of breast cancer to neoadjuvant chemotherapy: pilot study findings. Magn Reson Med 2014; 71: 1592-1602.
[27] Fan M, Wu G, Cheng H, Zhang J, Shao G and Li L. Radiomic analysis of DCE-MRI for prediction of response to neoadjuvant chemotherapy in breast cancer patients. Eur J Radiol 2017; 94: 140-147.
[28] Tudorica A, Oh KY, Chui SY, Roy N, Troxell ML, Naik A, Kemmer KA, Chen Y, Holtorf ML, Afzal A, Springer CS Jr, Li X and Huang W. Early prediction and evaluation of breast cancer response to neoadjuvant chemotherapy using quantitative DCE-MRI. Transl Oncol 2016; 9: 8-17.
[29] Chou CP, Wu MT, Chang HT, Lo YS, Pan HB, Degani H and Furman-Haran E. Monitoring breast cancer response to neoadjuvant systemic chemotherapy using parametric contrast-enhanced MRI: a pilot study. Acad Radiol 2007; 14: 561-573.
[30] Martincich L, Montemurro F, De Rosa G, Marra V, Ponzone R, Cirillo S, Gatti M, Biglia N, Sarotto I, Sismondi P, Regge D and Aglietta M. Monitoring response to primary chemotherapy in breast cancer using dynamic contrast-enhanced magnetic resonance imaging. Breast Cancer Res Treat 2004; 83: 67-76.
[31] Cheung YC, Chen SC, Su MY, See LC, Hsueh S, Chang HK, Lin YC and Tsai CS. Monitoring the size and response of locally advanced breast cancers to neoadjuvant chemotherapy (weekly paclitaxel and epirubicin) with serial enhanced MRI. Breast Cancer Res Treat 2003; 78: 51-58.
[32] An YY, Kim SH, Kang BJ and Lee AW. Treatment response evaluation of breast cancer after neoadjuvant chemotherapy and usefulness of the imaging parameters of MRI and PET/CT. J Korean Med Sci 2015; 30: 808-815.
[33] Jeh SK, Kim SH and Kang BJ. Comparison of the diagnostic performance of response evaluation criteria in solid tumor 1.0 with response evaluation criteria in solid tumor 1.1 on MRI in advanced breast cancer response evaluation to neoadjuvant chemotherapy. Korean J Radiol 2013; 14: 13-20.
[34] Marinovich ML, Sardanelli F, Ciatto S, Mamounas E, Brennan M, Macaskill P, Irwig L, von Minckwitz G and Houssami N. Early prediction of pathologic response to neoadjuvant therapy in breast cancer: systematic review of the accuracy of MRI. Breast 2012; 21: 669-677.
[35] Pickles MD, Lowry M, Manton DJ, Gibbs P and Turnbull LW. Role of dynamic contrast enhanced MRI in monitoring early response of locally advanced breast cancer to neoadjuvant chemotherapy. Breast Cancer Res Treat 2005; 91: 1-10.
[36] Fukuda T, Horii R, Gomi N, Miyagi Y, Takahashi S, Ito Y, Akiyama F, Ohno S and Iwase T. Accuracy of magnetic resonance imaging for predicting pathological complete response of breast cancer after neoadjuvant chemotherapy: association with breast cancer subtype. Springerplus 2016; 5: 152.
[37] Li SP, Taylor NJ, Makris A, Ah-See ML, Beresford MJ, Stirling JJ, d'Arcy JA, Collins DJ and Padhani AR. Primary human breast adenocarcinoma: imaging and histologic correlates of intrinsic susceptibility-weighted MR imaging before and during chemotherapy. Radiology 2010; 257: 643-652.