Thieme

Breast MRI at Very Short TE (minTE): Image Analysis of minTE Sequences on Non-Fat-Saturated, Subtracted T1-Weighted Images

Brust MRT mit sehr kurzer TE Zeit (minTE): Bildanalyse der minTE Sequenzen auf nicht fettunterdrückten, subtrahierten T1 gewichteten Bildern

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ZUSAMMENFASSUNG

Einleitung Das Ziel war es in der Brustmagnetresonanztomografie einen Vergleich zwischen zwei Sequenzen mit einer minimalen TE-Zeit (minTE) und mit einer Standard TE Zeit (nTE) bei Patienten mit Brustläsionen anzustellen.

Methoden 144 Frauen wurden mit einem 1,5-Tesla-MRT untersucht. Zusätzlich zu den Standard-Gradienten-Echo-Sequenzen mit normaler TE (4,8 ms) wurde eine Variante mit minimaler TE (1,2 ms) verwendet was zu einer besseren zeitlichen Auflösung führt und die Scanzeit um ca. 50 % reduzieren sollte. Die Läsionsgrößen wurden gemessen und das Signal-Rausch-Verhältnis (SNR) sowie das Kontrast-Rausch-Verhältnis (CNR) wurden berechnet. Die subjektive Diagnosesicherheit wurde mit Hilfe einer 3-Punkte-Skala (1 = sehr sicher, dass ich eine Läsion identifizieren und klassifizieren kann, 2 = ziemlich sicher, dass ich eine Läsion identifizieren und klassifizieren kann, 3 = auf jeden Fall benötigt man eine nTE Sequenz zur abschließenden Bewertung) und die subjektive Bildqualität aller Untersuchungen wurde unter Verwendung einer vierstufigen Skala (1 = scharf, 2 = leichte Unschärfe, 3 = mäßige Unschärfe und 4 = starke Unschärfe / nicht auswertbar) sowohl für die Läsion als auch die Schärfe der Haut evaluiert. Ebenso wurden die Herdbeschaffenheit und die KM-Aufnahme evaluiert.

Ergebnisse Mit minTE Sequenzen wurde keine Läsion mit „auf jeden Fall benötigt man eine nTE Sequenz zur abschließenden Bewertung“ bewertet. Der Längs- und Querdurchmessers unterschied sich nicht signifikant ($p > 0,05$). Mit minTE Sequenzen wurden Läsionen und Haut deutlich verschwommener bewertet ($p < 0,01$ für Läsionen und $p < 0,05$ für Haut). Es gab keinen signifikanten Unterschied zwischen den beiden Sequenzen in SNR, CNR, Herdbeschaffenheit, KM-Aufnahme und in der Erkennung von Multifokalität.

Zusammenfassung Ein dynamisches Brust-MRT ist mit minTE Sequenzen ohne größeren Informationsverlust durchführbar (SNR, CNR, Herdbeschaffenheit, KM-Aufnahme und Läsionsgröße) und die zeitliche Auflösung kann durch minTE Sequenzen um einen Faktor 2 erhöht werden.

Kernaussagen
- Erhöhung der zeitlichen Auflösung für eine bessere KM-Anflutungskurve.
- Dynamische Brust-MRT mit einer kurzen TE Zeit ist ohne relevanten Informationsverlust möglich.
- Mögliche Reduktion der gesamten Scandauer.

ABSTRACT

Purpose The aim was to evaluate a minimum echo time (minTE) protocol for breast magnetic resonance imaging (MRI) in patients with breast lesions compared to a standard TE (nTE) time protocol.

Methods Breasts of 144 women were examined with a 1.5 Tesla MRI scanner. Additionally to the standard gradient-echo sequence with nTE (4.8 ms), a variant with minimum TE (1.2 ms) was used in an interleaved fashion which leads to a better temporal resolution and should reduce the scan time by approximately 50 %. Lesion sizes were measured and the signal-to-noise ratio (SNR) as well as the contrast-to-noise ratio (CNR) were calculated. Subjective confidence was evaluated using a 3-point scale before looking at the nTE sequences (1 = very sure that I can identify a lesion and classify it, 2 = quite sure that I can identify a lesion and classify it, 3 = definitely want to see nTE for final assessment) and the subjective image quality of all examinations was evaluated using a four-grade scale (1 = sharp, 2 = slight blur, 3 = moderate blur and 4 = severe blur/not evaluable) for lesion and skin sharpness. Lesion morphology and contrast enhancement were also evaluated.

Results With minTE sequences, no lesion was rated with “definitely want to see nTE sequences for final assessment”. The difference of the longitudinal and transverse diameter did not differ significantly

(p > 0.05). With minTE, lesions and skin were rated to be significantly more blurry (p < 0.01 for lesions and p < 0.05 for skin). There was no difference between both sequences with respect to SNR, CNR, lesion morphology, contrast enhancement and detection of multifocal disease.

Conclusion Dynamic breast MRI with a minTE protocol is feasible without a major loss of information (SNR, CNR, lesion morphology, contrast enhancement and lesion sizes) and the temporal resolution can be increased by a factor of 2 using minTE sequences.

Key points

- Increase of temporal resolution for a better in-flow curve.
- Dynamic breast MRI with a shorter TE time is possible without relevant loss of information.
- Possible decrease of the overall scan time.

Citation Format

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Introduction

Magnetic resonance imaging (MRI) has become an accepted method in breast imaging, joining mammography and ultrasound. Several indications are widely accepted for its use, like screening women with a high risk of breast cancer, occult primary breast cancer or searching for recurrent disease in inconclusive mammography and ultrasound [1 – 9]. The role of MRI in the preoperative staging of tumor extent is still under debate [10, 11]. MRI image analysis is based on lesion enhancement patterns in dynamic breast MRI and on morphologic changes [12 – 19]. With these criteria, breast MRI has a sensitivity of about 85 % to 99 % in detecting malignant breast lesions, as has been shown in several studies [1, 2, 16 – 24]. Recently, the implementation of MRI exams in regular screening settings has been discussed as well [19, 25, 26]. If MRI of the breast is to be used under screening conditions, the shortening of protocols would be preferable. In non-fat-suppressed dynamic breast imaging, it is a well-accepted recommendation to acquire data at or close to echo times that fulfill the in-phase condition for fat and water, such as 4.8 ms at 1.5 Tesla, in order to avoid chemical shift artifacts that lead to signal cancellation at fat/water interfaces. This effect was described and analyzed, e. g., by Bedrosian et al.[1] and Fischer et al. [1, 4, 27] with the recommendation of using either in-phase echo time (TE) or "TE less than 1.2 ms" resulting in a phase difference of below 90° [28]. With otherwise comparable parameter settings, this would result in a decrease of 50 % of the acquisition time due to the resulting shorter repetition time (TR) of approximately 8 ms vs. 4 ms. Meanwhile, with current gradient systems and fast imaging sequences (now rapid changes of the magnetic gradient due to a better scanner geometry and improved materials are possible and better coils lead to an improved signal) [28 – 30] as well as better software-based post-processing, it has become possible to achieve such short echo times without compromising the matrix size or the bandwidth. In this study, we have set up an interleaved protocol approach to achieve a direct comparison of a minimum TE (minTE) vs. standard TE (nTE) acquisition within a clinical standard protocol. The purpose of our study was to evaluate the image quality on non-fat-saturated, subtracted T1-weighted images of the minTE acquisition compared to conventional standard TE protocols (nTE) in patients with breast lesions. To our knowledge, this is the first study in which the feasibility of minTE breast MRI has been evaluated in a prospective manner.

Methods

Patients

The study was approved by the local institutional review board and all patients gave written consent to the study and the MRI exam. The study complies with the Declaration of Helsinki. The parameters of the study sequence ranged within the limits of breast MRI performance guidelines [31, 32].

From January 2014 to July 2014, 231 women underwent breast MRI at our institution for various indications. A total of 144 women were randomly scheduled for the scanner with the additional minTE sequences dependent on scanner slot availability. MRI indications for these women were: to exclude preoperatively multifocal disease (n = 11) of histologically verified breast cancer, positive family history for breast cancer (n = 40), to exclude recurrent breast cancer (n = 39), monitoring neo-adjuvant chemotherapy (n = 2), unclear findings in mammography (BI-RADS 0), ultrasound or clinical breast complaints (n = 47), and cancer of unknown primary (n = 5).

MRI protocol

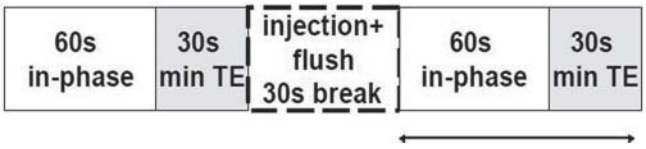
Data were acquired on a 1.5 Tesla MRI scanner (MAGNETOM Avanto, Siemens, Erlangen, Germany) using a bilateral dedicated phased-array breast coil (4-channel breast array coil, Siemens, Erlangen, Germany). Besides the dynamic T1 protocol, an axial 2 D T2-weighted turbo spin echo (TSE) pulse sequence (TR/TE, 5250/113 ms, FOV 380 × 380 mm, matrix 512 × 358, slice thickness 3 mm, in-plane resolution 0.4 × 0.4 mm) and one pre- and one post-dynamic contrast sagittal 3 D T1-weighted spoiled gradient echo pulse sequence (TR/TE, 21/4.8 ms, FOV 380 × 380 mm, matrix 512 × 512, slice thickness 2 to 2.5 mm, in-plane resolution 0.4 × 0.4 mm) for morphologic details were used. The dynamic sequence was a bilateral, axial 3 D spoiled gradient echo pulse sequence (TR/TE, 7.3/4.8 ms, FOV 340 × 340 mm, matrix 512 × 430, slice thickness 2 mm, in-plane resolution 0.8 × 0.8 mm) and consisted of one pre- and four post-contrast repetitions of the whole volume of both breasts. Contrast agent (Gadobutrol, Bayer, Leverkusen, Germany, 0.1 mmol per kilogram body weight) was applied after the first dynamic acquisition with an MR-compatible power injector (Spectris; Medrad, Pittsburgh, PA, USA) with a flow of 1 ml/sec followed by a 20 ml saline flush.

In addition to the "normal" standard TE of 4.8 ms (nTE), a sequence with a "minimal" TE of 1.2 ms (minTE) was used (▶ **Table 1**). The very short TE of 1.2 ms was achieved by a gradient-echo sequence (VIBE) that allows asymmetric readout win-

▶ **Table 1** Comparison of the technical specifications of nTE sequences and minTE sequences.

▶ **Tab. 1** Vergleich der technischen Spezifikationen der nTE und der minTE Sequenzen.

technical specifications	nTE (4.8 ms)	minTE (1.2 ms)
TR/TE	7.3/4.8 ms	3.6/1.2 ms
FOV	340 × 340	340 × 340
matrix	512 × 430	512 × 430
slice thickness	2 mm	2 mm
in-plane resolution	0.8 × 0.8 mm	0.8 × 0.8 mm
spatial resolution	0.8 × 0.8 × 2 mm^3	0.8 × 0.8 × 2 mm^3
flip angle	25	15
bandwidth	445 Hz	445 Hz



▶ **Fig. 1** Scan protocol of the dynamic gradient echo sequences with the interleaved dynamic minTE sequences. After an unenhanced sequence with conventional sequence parameters (TE 4.8 ms) and one with a minimal TE (1.2 ms), we injected contrast media and performed four post-contrast conventional sequences. Each of these sequences was followed by a sequence with a minimal TE, so both nTE and minTE sequences were measured alternately during the whole dynamic scan.

▶ **Abb. 1** Scan-Protokoll der dynamischen Gradientenechosequenzen mit den zusätzlichen dynamischen minTE-Sequenzen. Nach einer nativen Sequenz mit herkömmlichen Sequenzparameter (TE 4.8 ms) und einer mit einem minimalen TE (1,2 ms) injizierten wir Kontrastmittel. Vier konventionelle post-KM Sequenzen wurden aquiriert. Jeder dieser Sequenzen folgte eine Sequenz mit einer minimalen TE, beide Sequenzen (nTE und minTE) wurden abwechselnd während der Kontrastmittelphase gemessen.

dows. Thus, only an adjustable percentage of the gradient echo is sampled. The clinical reference protocol with nTE was set up in a way that all scan parameters were identical with the minTE protocol, except for the echo asymmetry and the flip angle, which were adapted to the TR. The spatial resolution was 0.8 × 0.8 × 2 mm^3 with a bandwidth of 445 Hz; parallel imaging was used (GRAPPA acceleration factor of 2). This resulted in an acquisition time of 60 s for the nTE scans and 30 s for the minTE scans, thus the resulting temporal resolution for both techniques was 90 s. ▶ **Fig. 1** shows the interleaved scan protocol, which allows a direct comparison and ▶ **Fig. 2** shows an example of the complete protocol.

Post-processing included subtractions of the second post-enhanced sequence from the sequence without contrast medium using the scanner software.

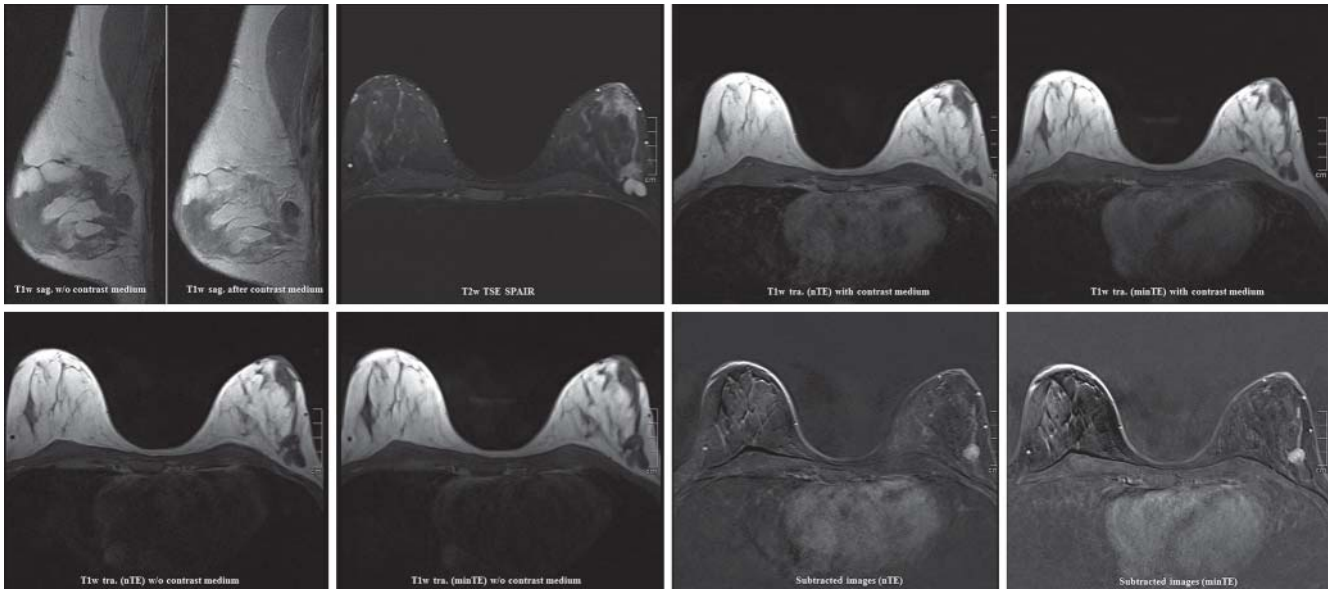
Image analysis

The breast MRI images were evaluated in consensus by one senior breast radiologist with more than 10 years of experience in breast MRI and one radiologist with 2 years of experience in breast and MR imaging. For the comparison of the standard TE sequence (nTE) and the minimum TE sequence (minTE), only examinations with identifiable enhancing lesions in the contrast-enhanced sequences were chosen. The study evaluation was performed on the second post-enhanced sequence. Dignity of the lesions was either confirmed by core or excisional biopsy or on the basis of the clinical examination, ultrasound, mammography and MR findings.

- Image quality was assessed on standard PACS workstations on images in the axial plane. For each examination the regions of interest (ROI) were placed in the enhancing lesion, in the pectoral muscle and in the air between the right and left breast. The mean signal intensity and the standard deviation were obtained for each measurement. Standard deviation of the air was considered as image noise. Signal-to-noise ratio (SNR = mean density/standard deviation of image noise) and contrast-to-noise ratio (CNR = (mean density of the lesion – mean density of the pectoral muscle)/standard deviation of image noise) were calculated for the ROIs of the enhancing lesions and the pectoral muscle in the native and in the second post-contrast sequence of both the nTE and minTE dynamic series.
- The lesion size (longitudinal and transverse diameter) was measured in millimeters.
- The subjective confidence of the minTE sequences was evaluated on a subjective 3-point scale before looking at the nTE sequences (1 = very sure that I can identify a lesion and classify it, 2 = quite sure that I can identify a lesion and classify it, 3 = definitely want to see nTE for final assessment).
- The subjective image quality of all examinations (nTE and minTE sequences) was evaluated using a subjective four-grade scale (1 = sharp, 2 = slight blur, 3 = moderate blur and 4 = severe blur/not evaluable) for lesion (= lesion surrounding) and skin sharpness (= skin evaluation).
- Multifocal disease was detected on both sequences (more than one suspicious lesion: yes or no).
- To describe single lesions, we used the ACR BI-RADS® Atlas (fifth edition 2013). Initially we distinguished the lesions between focus (less than 5 mm in diameter) and mass/non-mass enhancement. In masses, the shape (oval, round, irregular), the margins (circumscribed, not circumscribed (irregular/spiculated)) and the internal enhancement patterns (homogeneous, heterogeneous, rim enhancement, dark internal septations) were evaluated. In non-mass enhancement we checked for the distribution (focal, linear, segmental, regional, multiple regions, diffuse) and for the internal enhancement patterns (homogeneous, heterogeneous, clumped, clustered ring). Histologically proven multifocality was evaluated for both the nTE and the minTE sequences.

Statistical analysis

Statistics were calculated using Excel 2007 (Microsoft, USA) and Graph-Pad Prism 4.03, 2005 (Graph-Pad Software, San Diego, CA). The difference in lesion surroundings and skin evaluation



▶ **Fig. 2** MRI protocol with different sequences as well as the subtracted and non-subtracted images of a 43-year-old woman with a 1.2 cm enhancing mass in the left breast. Histology after breast-conserving surgery revealed a 1.2 cm invasive ductal carcinoma. nTE: mass with round shape, circumscribed margins, homogeneous enhancement; minTE: mass with round shape, circumscribed margins, homogeneous enhancement.

▶ **Abb. 2** MRT Protokoll mit den unterschiedlichen Sequenzen und den subtrahierten und nicht subtrahierten Bildern einer 43 Jahre alten Frau mit einer 1,2 cm großen Raumforderung in der linken Brust. Histologisch ergab sich nach brusterhaltender Operation ein 1,2 cm invasives duktales Karzinom. nTE: glatt begrenzter, runder Knoten, homogene KM-Aufnahme; minTE: glatt begrenzter, runder Knoten, homogene KM-Aufnahme.

was evaluated with the Wilcoxon signed rank test and the signal intensity in both nTE and minTE sequences was evaluated with the paired t-test. A p-value < 0.05 was considered as significant, and a p-value < 0.01 was considered as highly significant.

Results

Patients

A total of 144 MRI exams with minTE sequences were performed. 121 patients did not require histological interventions (78 patients with BI-RADS 1, 43 patients with BI-RADS 2). A total of 46 lesions were identified in the MRI examinations in 23 patients in 26 breasts.

MRI indications for these 23 patients were multifocal breast cancer (n = 11); family history of breast cancer (n = 4); unclear findings in mammography (BI-RADS 0), ultrasound or clinical breast complaints (n = 6); and exclusion of local recurrence (n = 2). Histology revealed 32 malignant and 14 benign lesions (▶ **Table 2**).

Comparison of patient images is presented in ▶ **Fig. 3 – 6**.

The median age of all patients included in the study was 47.6 years (range: 22 to 72 years).

ROI measurements

The mean SNR of the lesions before contrast medium was 22.5 ± 9.1 in minTE and 23.3 ± 7.6 in nTE sequences (p = 0.6) and after contrast medium 42.5 ± 13.1 in minTE and 41.4 ± 14.4 in nTE sequences (p = 0.45). The mean CNR of the lesions was 42.8 ± 23.6 in minTE and 47.6 ± 21.8 in nTE sequences (p = 0.17) (▶ **Fig. 7**).

Lesion size

The mean longitudinal diameter was 1.8 cm (range: 0.3 to 8.6 cm) and the transverse diameter was 1.4 cm (range: 0.3 to 6.8 cm) in the nTE (4.8 ms) sequences. In the minTE (1.2 ms) sequences, the mean longitudinal diameter was 1.8 cm (range: 0.3 to 8.4 cm) and the transverse diameter was 1.4 cm (range: 0.3 to 6.9 cm). The difference was not significant using the paired t-test (p = 0.96 for longitudinal diameter and p = 0.99 for transverse diameter).

Subjective confidence

With the minTE sequence, 26 lesions were rated with 1 = very sure that I can identify a lesion and classify it and 20 lesions with 2 = quite sure. No lesion was rated with 3 = definitely want to see nTE sequences for final assessment.

Subjective image quality (lesion surroundings, skin evaluation) and multifocality

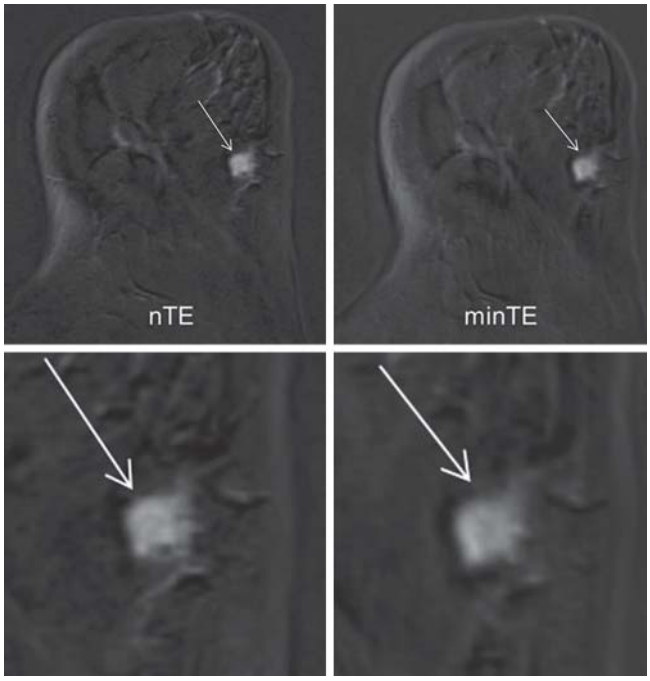
In minTE sequences, lesions and the skin were rated to be significantly more blurry than in the normal TE sequences with a p-value of 0.0003 (lesions) and 0.047 (skin); see ▶ **Table 3, 4**. Nevertheless, neither the skin nor the lesion was rated as having severe blurring in nTE or in minTE sequences. There was no difference between the nTE and the minTE sequences in the detection of histologically confirmed multifocal disease.

▶ **Table 2** Histology of the 46 lesions. 10 women had two or more suspicious lesions.

▶ **Tab. 2** Histologie der 46 Herdbefunde. Zehn Frauen hatten zwei oder mehr Läsionen.

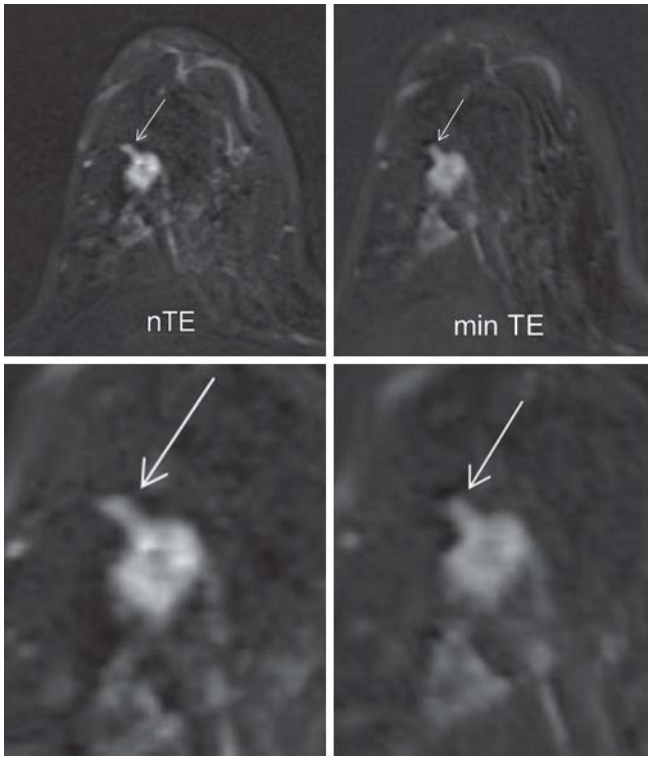
Histology	IDC	ILC	DCIS	(fibrocy. dis.)	FA	atyp. prol.	Pap.	infl. cyst
Number of patients	22	4	6	7	4	1	1	1
13 women had a single lesion (4 IDC; 3 ILC, 1 DCIS; 3 fibrocystic disease, 1 papillomatosis and 1 fibroadenoma)								
2 patients had 2 lesions (patient a: 2x IDC; patient b: ILC + fibrocystic disease)								
5 patients had 3 lesions (patient a: IDC + DCIS + fibroadenoma, patient b-d: 3 × IDC and patient e: 2 × IDC + fibrocystic disease)								
1 patient had 4 lesions (4 × IDC)								
2 patients had 5 lesions (patient a: 2 × fibroadenoma, 1 × atypical epithelial proliferation, 1 × fibrocystic disease, 1 × inflammatory cyst; patient b: 4 × DCIS + fibrocystic disease)								

invasive ductal carcinoma (IDC), invasive lobular carcinoma (ILC), ductal carcinoma in-situ (DCIS), fibrocystic disease (fibrocy. dis.), fibroadenoma (FA), atypical epithelial proliferation (atyp. prol.), papillomatosis (pap.), inflammatory cyst (infl. cyst).



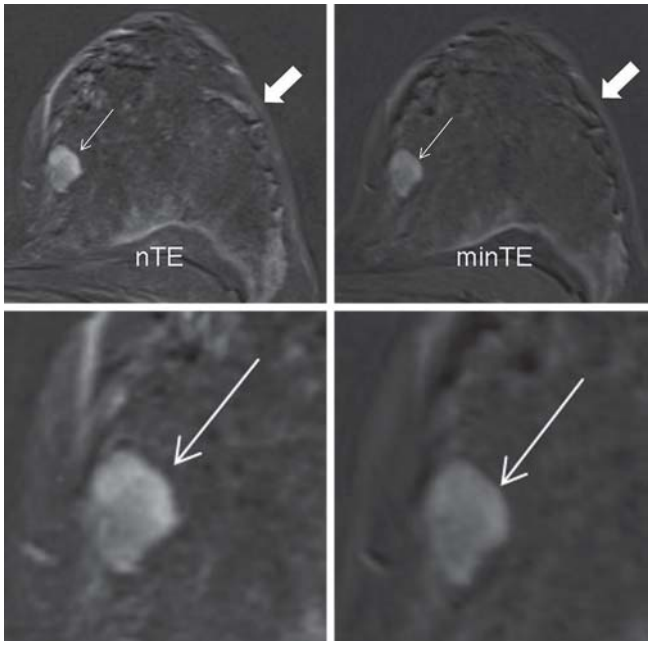
▶ **Fig. 3** Second post-contrast axial subtraction series of a 67-year-old woman with a 1.2 cm enhancing mass lesion in the left breast. The lesion in the normal TE (4.8 ms) sequence appears slightly sharper (thin arrow). Histology after breast-conserving surgery revealed a 1.2 cm invasive ductal carcinoma. nTE: mass with irregular shape, not circumscribed margins, heterogeneous enhancement, no adjacent vessel; minTE: mass with irregular shape, not circumscribed margins, heterogeneous enhancement, no adjacent vessel.

▶ **Abb. 3** Axiales Subtraktionsbild einer 67-jährigen Frau mit einer 1,2 cm großen, KM-aufnehmenden Raumforderung in der linken Brust. Die Läsion erscheint in der normalen TE (4.8 ms) Sequenz etwas schärfer (dünner Pfeil). Die Histologie nach brusterhaltender Operation ergab ein 1,2 cm invasives duktales Karzinom. nTE: irregulär begrenzter Knoten, nicht glatt begrenzt, heterogene KM-Aufnahme, kein zuführendes Gefäß; minTE: irregulär begrenzter Knoten, nicht glatt begrenzt, heterogene KM-Aufnahme, kein zuführendes Gefäß



▶ **Fig. 4** Second post-contrast axial subtraction series of a 34-year-old woman with a 1.1 cm invasive ductal carcinoma in the right breast. The tumor-feeding vessel (thin arrow) can be adequately delineated in the nTE and minTE sequence. nTE: mass with oval/irregular shape, circumscribed margins, heterogeneous enhancement, adjacent vessel; minTE: mass with oval/irregular shape, circumscribed margins, heterogeneous enhancement, adjacent vessel.

▶ **Abb. 4** Axiales Subtraktionsbild einer 34-jährigen Frau mit einem 1,1 cm invasiven duktalen Karzinom in der rechten Brust. Ein kräftiges, den Tumor versorgendes Gefäß (dünner Pfeil) kann in der nTE und in der minTe Sequenz ausreichend abgegrenzt werden. nTE: irregulär/ovalär begrenzter, umschriebener Knoten, heterogene KM-Aufnahme, zuführendes Gefäß; minTE: irregulär/ovalär begrenzter, umschriebener Knoten, heterogene KM-Aufnahme, zuführendes Gefäß.



▶ **Fig. 5** Second post-contrast subtraction series in axial orientation of a 24-year-old woman with a strong family history for breast cancer. The 1.5 cm histologically verified fibroadenoma in the left breast can be delineated equally in both sequences. The skin appears a bit unsharp in the minTE sequence. nTE: mass with round shape, circumscribed margins, homogeneous enhancement, no adjacent vessel; minTE: mass with round shape, circumscribed margins, homogeneous enhancement, no adjacent vessel.

▶ **Abb. 5** Axiales Subtraktionsbild einer 24-jährigen Frau mit einer positiven Familienanamnese für Brustkrebs. Das 1,5 cm große, histologisch nachgewiesene Fibroadenom in der linken Brust kann gleichermaßen in beiden Sequenzen abgegrenzt werden. In der minTE Sequenz wirkt die Haut ein wenig unschärfer. nTE: glatt begrenzter, runder Knoten, homogene KM-Aufnahme, kein zuführendes Gefäß; minTE: glatt begrenzter, runder Knoten, homogene KM-Aufnahme, kein zuführendes Gefäß.

Lesion characterization

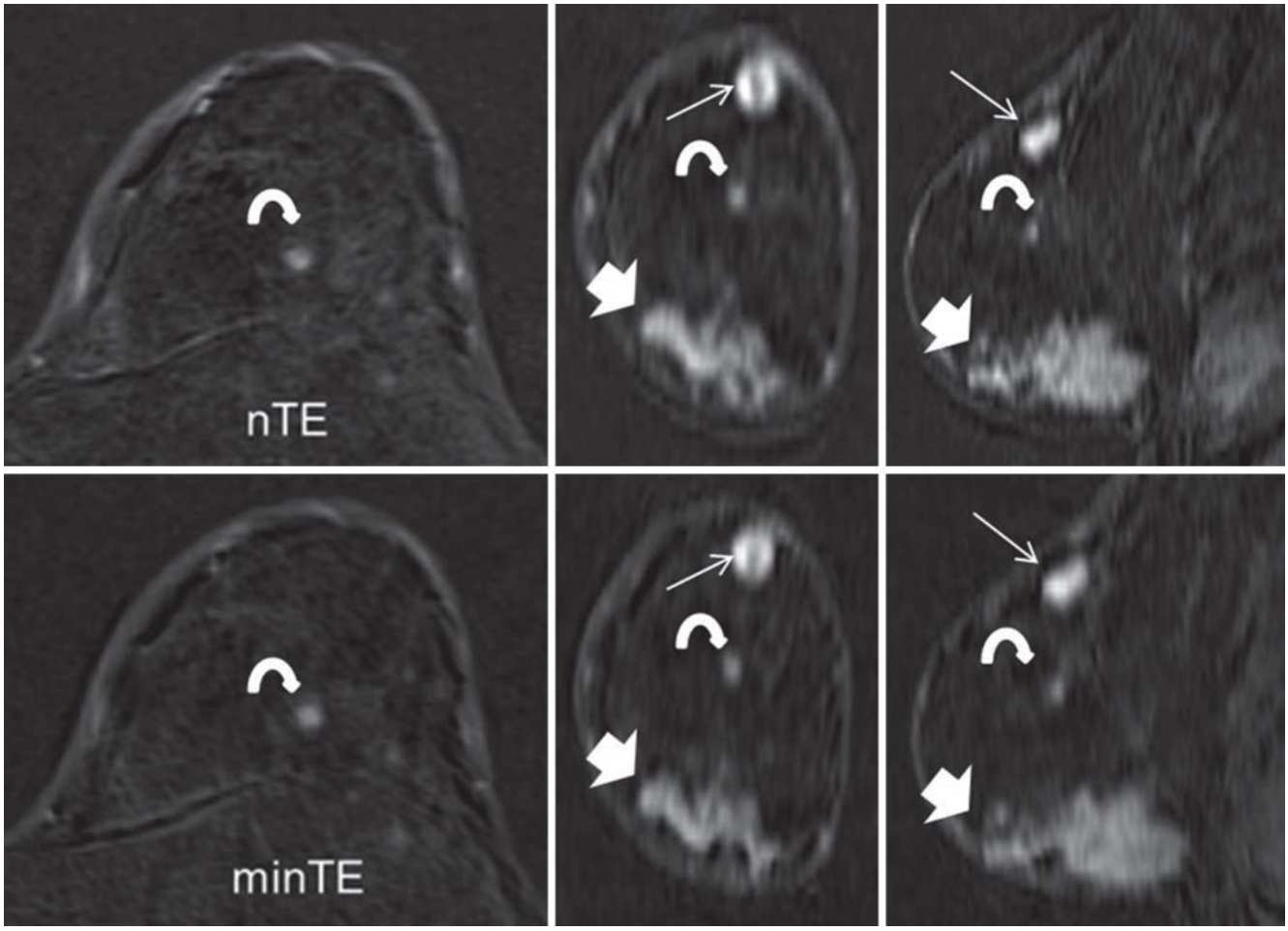
7 lesions were rated as a focus in nTE and in minTE sequences. No non-mass enhancement was seen in both sequences. Therefore, 39 lesions were evaluated as mass enhancement. In both sequences the shape of this mass enhancement was rated as round in 10 lesions, as oval in 6 lesions and as irregular in 23 lesions. There was also no difference in the evaluation of the margins (12 × circumscribed, 13 × not circumscribed (irregular), 14 × not circumscribed (spiculated)) and the internal enhancement (11 × homogenous, 25 × heterogeneous, 1 × rim enhancement, 2 × dark internal septations). Overall no difference in lesion characterization was detected between nTE and minTE sequences.

Discussion and conclusion

In our study we compared the subtracted images of two different TE sequences without fat saturation, a minTE sequence (TE 1.2 ms) and a normal TE sequence (TE 4.8 ms), for the enhancement kinetics. The study suggests that visualizing breast disease and its extent is feasible with a minTE MRI sequence. Compared to the classic approach, there was no significant difference in the detection, morphology and size determination of breast lesions. In our approach we used a TE of 1.2 ms, which reduced the scan time per time point by about 50 % with no significant SNR or CNR changes of the lesions. This short TE did not lead to false-negative or false-positive findings. As there was no significant difference in the longitudinal and transverse lesion diameter, the minTE sequence should not lead to a clinically important under- or overestimation of the lesion size. The drawback of the minTE measurement is an increase in skin and lesion blurring, which can be explained by the asymmetric readout that does not detect the full echo signal. Therefore, there could be a loss of signal information. Opposed phase cancellation might also play a role in small lesions [28, 33]. Also in the literature ultrashort TE sequences acquire an echo signal from the central to the outer parts of k-space with ramp sampling and therefore are very sensitive to small k-space trajectory errors [34]. There was no significant difference in the detection of multifocal disease in minTE and nTE. We were also able to detect tumor vessels in both sequences which is important because the adjacent vessel sign was significantly associated with malignancy [35, 36].

To our knowledge, no breast MRI study has dealt with short TE sequences before. There were some studies that showed the feasibility of ultrashort TE sequences for the clinical routine but, unlike our study, the TE time ranged between 0.07 ms and 0.14 ms. For example, Robson et al. showed that contrast enhancement can be identified in tissues using ultrashort TE pulse sequences (TE of 0.08 ms) [37] or the periosteum can be visualized with ultrashort echo time pulse sequences in health and disease [38]. In addition, ultrashort TE pulse sequences provided anatomical detail not apparent with conventional sequences and showed patterns of both increased and decreased enhancement in tendinopathy [39]. However, in contrast to our study, they did not use a dynamic protocol. Yamashita et al. demonstrated that with a 3.0 Tesla MRI scanner the middle ear ossicles could be clearly visualized on short TE images, while they were not visible in long TE images [40]. In contrast to this study, we used a 1.5 Tesla MRI scanner and were not able to find a difference in lesion detection in breast imaging.

Recently, it was reported that the maximum curve slope in an ultrafast protocol performed even better in the differentiation of benign and malignant lesions compared to BI-RADS curve types [25]. This study reported that the initial phase of the enhancement curve was more important compared to late-phase characteristics. Typically, such ultrafast protocols are realized using view-sharing protocols that lead to temporal blurring, while in this study, all time points are acquired separately. The minTE technique allows acquisition of more time points in dynamic scans because minTE last 30 s and nTE last 60 s (therefore two minTE sequences are acquired in the time it takes to acquire one nTE sequence). Therefore, this could lead to more detailed dynamic curves and/or to a shortened protocol so that one option for minTE application could be a short-scan protocol with few minTE dynamic time points for lesion detection and to perform the dynamic early curve-phase evaluation. This is a possible scenario for a screening population in which detection is more important than

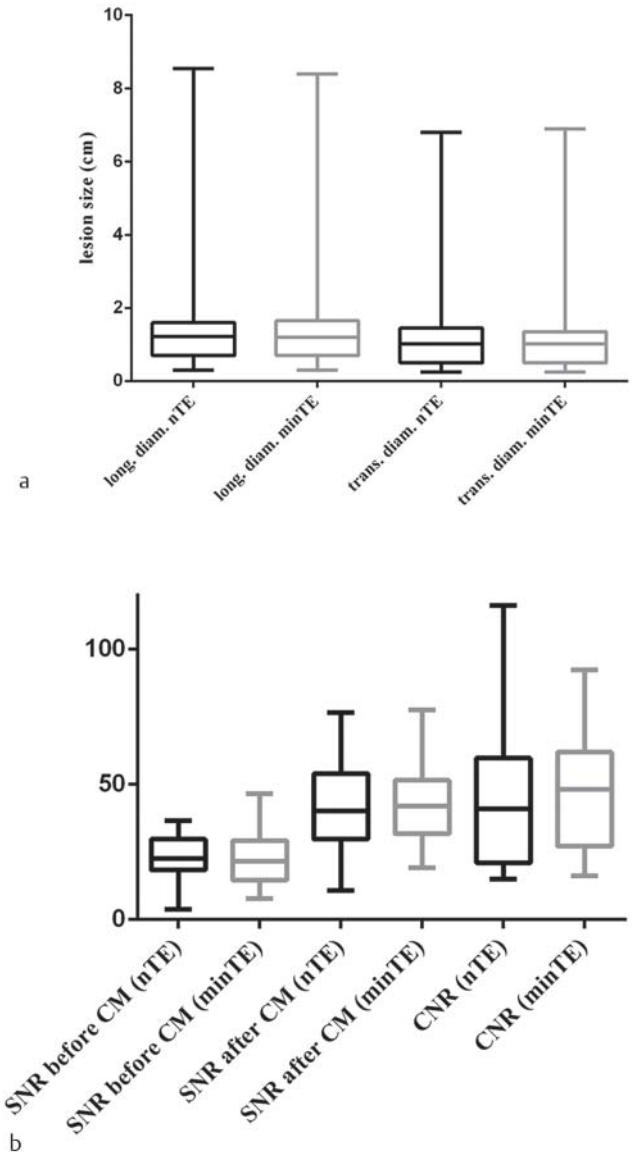


▶ **Fig. 6** Second post-contrast subtraction series of a 32-year-old woman with multifocal breast cancer – multiplanar reconstructions in axial, coronal and sagittal orientation. There is an obvious lesion in the upper quadrants (invasive ductal carcinoma, thin arrow) and another one in the lower quadrants (invasive ductal carcinoma, thick arrow). Between these pathologies a third lesion with a size of 4 mm can be identified in the nTE and minTE sequence (curved arrow).

▶ **Abb. 6** Axiales Subtraktionsbild einer 32-jährigen Frau mit multifokalen Brustkrebs – multiplanare Rekonstruktionen in axialer, koronaler und sagittaler Ausrichtung. Es gibt eine Läsion im oberen Quadranten (invasives duktales Karzinom, dünner Pfeil) und eine weitere im unteren Quadranten (invasives duktales Karzinom, dicker Pfeil). Zwischen diesen Pathologien kann eine dritte Läsion mit 4 mm in der nTE und in der minTE-Sequenz (gebogener Pfeil) identifiziert werden.

detailed morphologic lesion characterization [26]. For more detailed morphologic information, a high-resolution non-dynamic sequence could be added to the scan protocol. Mango et al. showed that an abbreviated breast MRI protocol allows detection of breast carcinoma with only one pre- and post-contrast T1-weighted sequence [41]. Whether a shortening of the examination time with minTE also shows this effect needs to be clarified in a further study.

There are some limitations to our study. The number of individuals undergoing breast MRI and showing a suspicious lesion was small. We only evaluated the subtracted images and not the kinetic curves because the different TE sequences were acquired consecutively and therefore would result in slightly different kinetic curves. The impact of more measurements on the kinetic curve has to be evaluated in the future in a separate study. Lesion detection, classification and time curves are not only dependent on sequence parameters but also on the contrast medium used [42]. We used just one type of contrast medium because the comparison of different contrast mediums was not part of the study. The diagnoses of suspicious lesions smaller than 5 mm were all made in breasts with another obvious pathological lesion. Opposed-phase lesion cancellation might play a role in affecting curve shape in small lesions, but this was not part of the study. Malignant lesions sometimes show central necrosis and the rim of the lesion may be too thin for correct ROI placement. In our study we evaluated one rim-enhancing cyst where it was impossible to settle a correct ROI, but the enhancing cyst could be detected in both sequences, and it was rated as suspicious in both sequences. Interestingly there was no non-mass enhancement in our study despite some findings as DCIS usually shows non-mass enhancement. We can only speculate about this finding. Maybe the number of patients was too small in this study. Nevertheless no non-mass enhancement was seen in both sequences and so there was no difference between these two sequences. We fo-



▶ **Fig. 7** **a** shows boxplots of the longitudinal and the transverse lesion size according to nTE and minTE. In **b** boxplots of the SNR (before and after contrast medium) and the CNR are shown.

▶ **Abb. 7** **a** zeigt Boxplots des Längs- und Querdurchmessers der unterschiedlichen Sequenzen (nTE vs. minTE) und **b** zeigt Boxplots der SNR (vor und nach Kontrastmittel) und der CNR.

cused our study on the image quality of subtracted images. Therefore, there could be a bias in the evaluation of the skin and lesion surroundings due to motion artifacts. Nevertheless, motion artifacts were in both sequences, and therefore should not be statistically relevant. Another limitation was that a subjective scale was used for image analysis, but images were evaluated in consensus by two breast radiologist.

In conclusion, dynamic breast MRI with a shorter TE time than the in-phase condition (nTE) is possible. Shorter TE times increase the temporal resolution, which leads to a better in-flow curve and might decrease the overall scan time.

▶ **Table 3** Evaluation of the lesion borders.

▶ **Tab. 3** Beurteilung der Läsionsbegrenzung.

Lesion border	nTE (4.8 ms)	minTE (1.2 ms)
Sharp	26 [0.57]	12 [0.26]
Slight blur	19 [0.41]	24 [0.52]
Moderate blur	1 [0.02]	10 [0.22]
Severe blur	0 [0]	0 [0]
Number of lesions (n)	46	46

Using the Wilcoxon signed rank test, there was a significant difference between the two types of sequences ($p < 0.01$). Relative frequency is shown in brackets [..].
Mit Hilfe des Wilcoxon Rangsummentest konnte ein signifikanter Unterschied festgestellt werden ($p < 0.01$). Die relative Häufigkeit wird in den eckigen Klammern angegeben [..].

▶ **Table 4** Evaluation of the skin.

▶ **Tab. 4** Beurteilung der Hautschärfe.

Skin	nTE (4.8 ms)	minTE (1.2 ms)
Sharp	22 [0.96]	13 [0.57]
Slight blur	1 [0.04]	10 [0.43]
Moderate blur	0 [0]	0 [0]
Severe blur	0 [0]	0 [0]
Number of patients (n)	23	23

Using the Wilcoxon signed rank test, there was a significant difference between the two types of sequences ($p < 0.05$). Relative frequency is shown in brackets [..].
Mit Hilfe des Wilcoxon Rangsummentest konnte ein signifikanter Unterschied festgestellt werden ($p < 0.05$). Die relative Häufigkeit wird in den eckigen Klammern angegeben [..].

CLINICAL RELEVANCE

- Increase of the temporal resolution for a better in-flow curve
- Dynamic breast MRI with a shorter TE time than the in-phase condition is possible
- Possible decrease of the overall scan time

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