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Detection of brain metastases by 3D-MR imaging at 3T: comparison between T1-VISTA and 3D-T1-FLAIR imaging

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Abstract

Objective: To compare the diagnostic performance in detection of brain metastases between contrast-enhanced T1-weighted-Volume ISotropic Turbo-spin-echo Acquisition (T1-VISTA) and 3-dimensional T1-weighted fluid-attenuated inversion recovery (3D-T1-FLAIR) imaging at 3T.

Methods: Two neuroradiologists selected 129 true (metastases) and 70 false (vessels and artifacts) lesions on the contrast-enhanced T1-VISTA and 3D-T1-FLAIR images of 14 cancer patients with hyperintense brain lesions. Four blinded neuroradiologists distinguished between the true and false lesions, using a five-point confidence rating scale. The receiver operating characteristic analysis was performed to compare the diagnostic performance. Contrast-to-noise ratio (CNR) of the true lesions was also compared between the two sequences by using paired t-tests.

Results: For lesions < 3 mm, the area under curve and sensitivity achieved by T1-VISTA imaging were significantly greater than 3D-T1-FLAIR imaging. The CNR was also significantly greater with T1-VISTA imaging.

Conclusion: The contrast-enhanced T1-VISTA imaging is better suited than 3D-T1-FLAIR imaging, for detection of small metastases.

Keywords

Brain

Metastases

Magnetic resonance imaging

Volume isotropic turbo-spin-echo acquisition

Fluid-attenuated inversion recovery

Introduction

In cancer patients, accurate detection of brain metastases is important, as the presence or absence of brain metastases as well as their number greatly influences the management and prognosis (1). As an example, brain metastases which are undetected may be left untreated, or be subjected to suboptimal therapy (2). In addition, while patients with single brain metastasis may be eligible for surgery and stereotactic radiation, patients with multiple metastases would need to undergo whole brain radiation therapy and/ or chemotherapy — the adverse effects of which are reported as worse than those of the former techniques (1, 3, 4). Patients with multiple brain metastases are also reported to have earlier rate of disease progression and poorer prognosis, than those with smaller number of metastases (1, 5).

Magnetic resonance (MR) imaging is the imaging modality of choice for detection of brain metastases (6-11). For several years, substantial efforts have been made to improve accuracy in detection of brain metastases by MR imaging (6-11). These efforts have led to the development of several modified MR imaging sequences and contrast media dose regimes. A few examples of these modifications include application of magnetization transfer imaging for improved contrast-to-noise ratio (CNR) of the metastatic lesions (12, 13), the combined use of two or more contrast-enhanced imaging sequences for improved accuracy (6), and the use of double or triple dose of contrast media for accentuation of lesion enhancement (9, 14). Among these modifications, the use of increased dose of contrast media poses the risk of developing nephrogenic systemic fibrosis, especially in patients with impaired renal function (15, 16).

Nowadays, 3T imagers have become widely available for clinical use. The major advantage of imaging at 3T is the possible acquisition of high-quality isotropic 3D imaging in short scan time — due to high signal-to-noise ratio (SNR) (17, 18). Another advantage is improved CNR between the enhancing lesions and background brain parenchyma on the contrast-enhanced T1-weighted images — due to suppression of signal from the normal brain parenchyma associated with prolonged T1 relaxation time and magnetization transfer effect (19, 20). Superiority of 3T over 1.5T in detection of brain tumors including metastases has been reported (10). Although specific absorption rate (SAR) issues had limited 3D imaging at 3T to the gradient-recalled echo (GRE) imaging sequences until the past several years, recent improvements in parallel imaging techniques, k-space trajectory, and variable flip angle techniques have allowed acquisition of 3-dimensional fast spin echo (3D-FSE) imaging (11). Studies have suggested improved diagnostic performance with 3D-FSE sequence compared to 3D-GRE sequence in detection of brain metastases — thought to be attributed to the improved CNR, magnetization transfer effect, and suppression of the signal from blood vessels (11, 18).

Although the contrast-enhanced T1-weighted 3D-FSE images improve detection of brain metastases at 3T, these images have poorer gray-white matter contrast than the 3D-GRE images (17-20). To alleviate this issue, some vendors have introduced T1-weighted fluid-attenuated inversion recovery (T1-FLAIR) imaging (19). The T1-FLAIR imaging is an inversion recovery sequence which generates T1-weighted images by employing intermediate inversion time (TI) (21-26). The T1-FLAIR images have improved tissue contrast, improved suppression of signals from blood vessels, and less susceptibility

artifacts (21). Some studies using 1.5T imagers have demonstrated that the contrast-enhanced T1-FLAIR imaging is more sensitive in detection of the enhancing lesions than the conventional spin echo (SE) sequences (21-24), although there have been some controversies (25, 26). To our knowledge, there have been no reports on the diagnostic performance of 3D-T1-FLAIR imaging in detection of brain metastases at 3T.

The purpose of this study was to compare the diagnostic performance in detection of brain metastases between the contrast-enhanced T1-weighted 3D-FSE {T1-weighted Volume isotropic turbo-spin-echo acquisition (T1-VISTA)} and 3D-T1-FLAIR imaging sequences, using 3T MR imaging.

Methods

This study was approved by the institutional review board of our hospital. Written informed consent for contrast-enhanced MR imaging was obtained from all patients.

MR imaging

From August, 2009 through August, 2010, the routine MR imaging protocol for screening of brain metastases at 3T (Achieva TX, Philips Medical Systems, Best, the Netherlands) included contrast-enhanced T1-VISTA {repetition time (TR) = 400 msec, echo time (TE) = 13 msec, field of view (FOV) = 175 x 215 x 250 mm, voxel size = 0.8 x 0.96 x 0.98 mm, echo train length (ETL) = 14, refocusing flip angle = 60°, reduction factor = 2 (x-direction) and 2.3 (y-direction), number of excitation (NEX) = 1, acquisition time (TA) = 5 min 19 sec}, contrast-enhanced 3D-T1-FLAIR {TR = 2000 msec, TE = 89 msec,

TI = 800 msec, FOV = 179 x 250 x 250 mm, voxel size = 0.56 x 1.04 x 1.04 mm, ETL = 100, reduction factor = 1 (x-direction) and 2.6 (y-direction), NEX = 2, TA = 5 min 2 sec }, and contrast-enhanced 3D-T2-FLAIR {TR = 6000 msec, TE = 156 msec, TI = 2000 msec, FOV = 168 x 235x 260 mm, voxel size = 0.6 x 0.9 x 0.9 mm, ETL = 94, reduction factor = 3 (x-direction) and 2 (y-direction), NEX = 1, TA = 5 min 42 sec} imaging sequences. The TA in 3D-T1-FLAIR imaging was set to resemble that of T1-VISTA imaging. An 8-channel array head coil was used. In all patients, MR imaging was performed in the order of T1-VISTA, 3D-T2-FLAIR, and 3D-T1-FLAIR imaging. The images were acquired in sagittal sections, and 1-mm thick axial and coronal images were reconstructed. The dose of contrast media was 0.1 mmol/kg, and the contrast media used was one of the followings: gadopentetate dimeglumine (Magnevist, Bayer Schering Pharma, Berlin, Germany), gadoteridol (ProHance, Bracco Diagnostics, Inc., Milan, Italy), and gadodiamide (Omniscan, Nycomed-Amersham, Oslo, Norway). Imaging started within 5 min after intravenous injection of the contrast media.

Participants and selection of images

An author reviewed the MR imaging reports of the brains of those patients who had primary cancer and were screened for brain metastases at 3T during the above mentioned period, for inclusion in the study. The inclusion criterion was the presence of one or more hyperintense lesions in the brain reported as metastases or suspicious of metastases. The exclusion criteria were those patients who failed to undergo one of the three sequences and those whose images were severely affected by gross artifacts. Of 54 consecutive patients

who underwent MR imaging for screening of brain metastases at 3T, 14 patients (10 men and 4 women; mean age = 60.8 ± 13.8 years, range = 23-79 years) who had hyperintense lesions in the brain were eligible for the study. The primary tumors were 12 lung cancers and 2 breast cancers. Eleven patients had distant metastases in other organs of the body, such as lymph node, adrenal gland, liver, and bone.

Two neuroradiologists (24 and 11 years of experience in neuroimaging) then reviewed the MR images of these 14 patients; and determined the hyperintense areas as metastases, normal structures (enhanced blood vessels), signal inhomogeneity, and artifacts, by mutual consensus. Determination as metastases was based on the appearance of the lesions {e.g., ring enhancing lesions, lesions with peritumoral edema, and lesions which were hyperintense without continuity as vascular structure on all three sequences or one sequence of interest (i.e., T1-VISTA or 3D-T1-FLAIR) and 3D-T2-FLAIR imaging sequence} and the presence of growth or regression on the follow-up MR images (available in seven patients). The 3D-T2-FLAIR imaging sequence was included in distinguishing between the true and false lesions as it has been reported that the addition of this sequence to the T1-SE imaging sequences improves the diagnostic performance in detection of brain metastases, through improved visualization of peritumoral edema, improved suppression of signal from blood vessels, and decrease in phase-shift artifacts (6). The number of hyperintense areas determined as metastases (true lesions) was 129. To perform visual analysis, 70 false lesions (blood vessels, signal inhomogeneity, and phase-shift artifacts which were hyperintense on T1-VISTA or 3D-T1-FLAIR images) were also selected. The lesions were then numbered and highlighted by square boxes on the coronal sections of T1-

VISTA and 3D-T1-FLAIR images (Fig. 1).

Qualitative analysis

Four neuroradiologists (4 to 10 years of experience in neuroimaging), who were blinded to the selection of the lesions, were asked to distinguish between the true and false lesions — which were numbered and highlighted by square boxes — on the T1-VISTA and 3D-T1-FLAIR imaging sequences, using a five-point confidence rating scale (grade 1 = definitely not metastasis; grade 2 = probably not metastasis; grade 3 = indeterminate; grade 4 = probably metastasis; grade 5 = definitely metastasis). They viewed the images on a 21.3-inch (54-cm) color monitor (CCL 252i2, Totoku Electric Co., Tokyo, Japan) with display of 1600 x 1200 lines. They were allowed to adjust the window level and width, and change the magnification of the images independently. All three imaging planes (axial, coronal, and sagittal) were provided. The observers were allowed to freely increment the sections by using a mouse with a wheel. The visual analysis was conducted in two sessions. Each session included all 14 cases. Each case contained either T1-VISTA or 3D-T1-FLAIR imaging sequence. The order of cases was randomized, and more than a two-week interval was kept between the sessions. The receiver operating characteristic (ROC) analysis was performed to compare accuracy in detection of metastases; and the area under curve (AUC) was calculated by using the computer program LABMRMC (http://www-radiology.uchicago.edu/krl/KRL_ROC/software_index6.htm) (27). LABMRMC uses the Dorfman-Berbaum-Metz algorithm to compare multiple treatments (e.g., imagining modalities) by using data from multiple readers and cases. The analysis was performed by

including (i) all lesions, and (ii) lesions < 3 mm in the largest dimension (The objective of evaluating lesions < 3 mm was to compare the diagnostic performance in detection of small brain metastases). The statistically significant difference in the AUC values between the two sequences was estimated by using jackknife methods (27). For each sequence, sensitivity, specificity, and accuracy were also calculated.

Measurement of the lesion size and CNR

An author measured the lesion size, and calculated the CNRs between the true lesions and adjacent normal brain parenchyma and between the normal-appearing gray and white matter. The measurement was done at a workstation (Dr.View/LINUX R2.5.0, AJS, Tokyo, Japan). The coronal images were used.

The lesion size was measured by the diameter. For oblong lesions, the greater dimension was used.

Circular ROIs were used to calculate the CNR. The ROI size of lesion was adjusted so as to contain many voxels of the lesion while avoiding inclusion of the adjacent structures. The diameter of ROI of the adjacent brain parenchyma was 2.93 mm. For calculation of the CNR between the normal-appearing gray and white matter, the circular ROIs each measuring 2.93 mm in diameter were used. A total of 10 ROIs each for gray and white matter were used. The CNR was calculated by using the following formula (28):

$$\text{CNR} = (S_A - S_B) / \{0.5(SD_A + SD_B)\} \dots \dots \dots \quad (1)$$

In calculation of CNR between the true lesions and normal adjacent brain parenchyma, S_A and S_B represent the mean signal intensities of the hyperintense lesion and adjacent white

matter, and SD_A and SD_B represent the standard deviations of S_A and S_B , respectively. In calculation of CNR between the normal-appearing gray and white matter, S_A and S_B represent the mean signal intensities of the normal-appearing gray and white matter, and SD_A and SD_B represent the standard deviations of S_A and S_B , respectively.

The lesion size and CNR were compared between the two sequences, using paired t-tests. The statistical significance was determined at $P < 0.05$.

Comparison of the degree of suppression of signal from blood vessels between the T1-VISTA and 3D-T1-FLAIR imaging sequences

To compare the ability of each sequence to suppress the signal from blood vessels, the blood vessels which were hyperintense were visually counted by the two neuroradiologists who determined the hyperintense areas as metastases or not, by consensus. Blood vessel counting was performed on a single axial section, at the level of foramen of Monro. All 14 cases were included. Paired t-test was used to determine statistical significance, and $P < 0.05$ was considered as significant.

Test of the influence of imaging timing to CNR

To test the influence of imaging timing to CNR, MR imaging was performed to another ten patients with 30 brain metastases, in the following order: the contrast-enhanced T1-VISTA, 3D-T2-FLAIR, followed by a repeated acquisition of T1-VISTA imaging. The CNR was calculated using Equation (1), and compared between the first and second T1-VISTA acquisitions. Paired t-test was used to determine statistical significance, and $P <$

0.05 was considered as significant.

Results

Qualitative analysis

Fig. 2 shows the results of ROC analysis for all lesions (Fig. 2a) and lesions < 3 mm (Fig. 2b). When all lesions were included in the analysis, the AUC value achieved by the T1-VISTA imaging (0.99) tended to be larger than that achieved by the 3D-T1-FLAIR imaging (0.97). However, statistical significance was not reached ($P = 0.07$). Evaluation of < 3 mm lesions revealed that the diagnostic performance was significantly improved with T1-VISTA imaging (0.99), compared to 3D-T1-FLAIR imaging (0.93) ($P = 0.03$). On comparison of sensitivity, specificity, and accuracy between the two sequences, it was observed that the sensitivity in detection of lesions < 3 mm was significantly greater with T1-VISTA imaging (0.97) than with 3D-T1-FLAIR imaging (0.75) ($P = 0.02$) (Table 1). The specificity and accuracy did not vary significantly. The total number of false positive findings did not vary greatly between the two sequences (Table 2).

Lesion size and CNR

Lesion size

The mean lesion size on the T1-VISTA imaging was 6.09 ± 5.50 mm (range = 1.09 - 34.07 mm), whereas that on the 3D-T1-FLAIR imaging was 6.30 ± 5.67 mm (0.00 - 34.39 mm). Three true white matter lesions were not identifiable on the 3D-T1-FLAIR images (Figs. 3 and 4). The size of these lesions was recorded as 0.00 mm. There was no

statistically significant difference in lesion size between the two sequences ($P = 0.15$).

CNR

For all 129 lesions considered as metastases, the mean CNR between the true lesions and adjacent brain parenchyma achieved by the T1-VISTA imaging was 5.20 ± 3.60 (range = 0.17 - 18.18), and that by the 3D-T1-FLAIR imaging was 2.99 ± 3.25 (range = -8.86 - 15.04). For 40 lesions which were < 3 mm in the greatest dimension, the mean CNR achieved by the T1-VISTA imaging was 2.47 ± 1.93 (0.17 - 8.01), and that by the 3D-T1-FLAIR imaging was 0.58 ± 2.30 (-8.86 - 5.06). The CNR achieved by the T1-VISTA imaging was significantly greater than the 3D-T1-FLAIR imaging, for (i) all lesions, and (ii) lesions <3 mm ($P < 0.001$).

The mean CNR between the normal gray and white matter achieved by the T1-VISTA imaging was 8.86 ± 4.22 (range = 0.20 - 22.40), and that by the 3D-T1-FLAIR imaging was 9.46 ± 4.66 (range = 0.40 - 25.00). The CNR achieved by the T1-VISTA imaging tended to be poorer than that achieved by the 3D-T1-FLAIR imaging, but statistical significance was not reached ($P = 0.07$).

Comparison of the degree of suppression of signal from blood vessels between the T1-VISTA and 3D-T1-FLAIR imaging sequences

The total number of blood vessels which were hyperintense on the T1-VISTA imaging was 278 (mean = 19.86 ± 6.43), and that on the 3D-T1-FLAIR imaging was 58 (mean = 4.14 ± 1.96). The number of blood vessels which were hyperintense was

significantly less on the 3D-T1-FLAIR imaging than the T1-VISTA imaging ($P < 0.001$).

Test of influence of imaging timing to CNR

There was no significant difference in CNR between the first (mean = 9.25 ± 8.32 , range = 0.79 - 37.21) and second T1-VISTA (mean = 11.07 ± 13.92 , range = 0.15 - 56.44) imaging ($P = 0.21$).

Discussion

This study compared the diagnostic performance in detection of brain metastases between the contrast-enhanced T1-VISTA and 3D-T1-FLAIR imaging at 3T, for determination of the optimal imaging sequence. It was observed that the AUC and sensitivity achieved by the T1-VISTA imaging were greater than the 3D-T1-FLAIR imaging, which reached statistical significance for lesions < 3 mm. Quantitative analysis revealed improved CNR of metastases with the T1-VISTA imaging. It is considered that the improved AUC and sensitivity with the T1-VISTA imaging were due to improved CNR between the true lesions and adjacent normal brain parenchyma. The improved CNR with T1-VISTA imaging is thought to be attributed to suppression of signal from normal brain parenchyma (11, 18, 19). The suppression of signal from blood vessels was poorer with the T1-VISTA imaging, and there were some residual hyperintensities within blood vessels on the T1-VISTA images (Figs. 3 and 4). Previous studies have reported increases in false positive findings with T1-weighted 3D-FSE imaging, due to the residual signal from the blood vessels (11, 28). In this study, six enhanced vessels were rated as probable or definite

metastases. Considering the average number of enhanced blood vessels per a 1-mm-thick axial T1-VISTA images (i.e., 19.86 per patient), it is thought that the number of enhanced vessels which were misinterpreted as metastases (i.e., 6 in 14 patients) is small. This may be due to the fact that the readers were able to correctly identify the enhanced vessels by their tubular structures — an advantage of viewing consecutive sections.

In this study, MR imaging was performed in the order of T1-VISTA, 3D-T2-FLAIR, and 3D-T1-FLAIR imaging. One might think that the difference in CNR between the T1-VISTA and 3D-T1-FLAIR imaging was due to the difference in elapsed time between injection of contrast media and imaging, between the two sequences. To exclude this possibility, T1-VISTA imaging was repeated at the timing of 3D-T1-FLAIR imaging in ten patients (30 brain metastases); and the CNR was compared between the two T1-VISTA acquisitions. The CNR did not vary significantly between the two acquisitions (Some might interpret as there was tendency toward slight improvement in CNR with the T1-VISTA imaging acquired at the timing of 3D-T1-FLAIR imaging.). It is thus considered that the difference in elapsed time between the two sequences did not account for the poorer CNR with the 3D-T1-FLAIR images. The finding of lack of significant difference in CNR between the two T1-VISTA acquisitions is consistent with that reported by Akeson et al (29). According to Akeson et al, the peak enhancement occurs around 3.5 min after injection of contrast media, and the intensity of enhancement does not change for the next 25 min. In another study which evaluated time-dependent changes in image contrast in brain tumors after gadolinium administration, Schörner et al reported that the optimal imaging time for contrast enhancement is between 8.5 and 38.5 min after contrast

administration (30). In this study, the MR imaging started within 5 min after contrast administration, and the total scan time inclusive of scout scans was about 18 min. The scan finished within the proposed time interval for optimal contrast by Akeson et al and Schörner et al (29, 30). The poorer CNR and failure to identify three true white matter lesions with the 3D-T1-FLAIR imaging are thought to be due to the bright signal of normal white matter on the 3D-T1-FLAIR imaging. Although three different types of contrast media were used to evaluate contrast enhancement in this study, it is not considered as a potential confounder because only one contrast agent was used in each patient.

With recent improvements in MR imaging technology, 3D-FSE imaging can be coupled with MSDE preparation — a technique for black-blood imaging. This technique employs the motion-sensitizing gradients to selectively suppress the signals from flowing blood (31). It is expected that the contrast-enhanced T1-VISTA imaging coupled with MSDE preparation improves suppression of the signal from blood vessels, and facilitates image reading or interpretation. However, depending on the velocity encoding (VENC) setting, suppression of signal from the blood vessels of the brain surface may not be complete. Some vessels with very slow flow may remain partially hyperintense at the lowest possible VENC setting (28). Partial hyperintensity of the blood vessels can mimic brain metastases, especially when continuity is lost and the normal tubular appearance cannot be identified — which may lead to increase in false positive findings.

Some studies suggest the application of two or more sequences for improved accuracy in detection of the brain metastases. According to Nagao et al, the contrast-enhanced T1-FSE sequence in combination with the contrast-enhanced T1-GRE sequence

provide improved accuracy than either sequence alone (28). In this study, altogether three MR imaging sequences — T1-VISTA, 3D-T2-FLAIR, and 3D-T1-FLAIR imaging — were acquired. Although all three sequences were used to distinguish between the true and false lesions in preparation for image analysis, the analysis included only two sequences of interest (T1-VISTA and 3D-T1-FLAIR). This study did not evaluate the accuracy in detection of brain metastases when two or more sequences are used. It is possible that the combination of these sequences provides better results. However, the application of many sequences is time-consuming, which may not be appropriate for ill patients. An option for those patients who can withstand long scan time is the combined use of contrast-enhanced T1-VISTA and 3D-T2-FLAIR imaging. The contrast-enhanced 3D-T2-FLAIR imaging offers different contrast characteristics to the contrast-enhanced T1-VISTA imaging. As mentioned previously, the addition of the contrast-enhanced T2-FLAIR imaging to the T1-SE imaging sequences could improve diagnostic performance in detection of brain metastases through improved visualization of peritumoral edema, improved suppression of signal from blood vessels, and decrease in phase-shift artifacts (6).

This study has a few limitations. First, histological confirmation of brain metastases was not obtained as the patients with multiple metastases do not generally undergo surgery. Lack of histological confirmation might have led to errors in determining between the true and false lesions. However, it is believed that the chance of wrongly determining the true lesions as false and vice versa is very small, as the lesions were carefully selected by two experienced neuroradiologists based on the MR imaging characteristics of each lesion and with the aid of other MR imaging sequences (i.e., the contrast-enhanced 3D-T2-FLAIR

imaging sequence and follow-up MR imaging sequences) (6). Second, in qualitative analysis, the observers were asked to evaluate those lesions which were numbered and highlighted by square boxes — a situation different from a real clinical setting. One might wonder if similar results would be obtained in a real clinical setting. In our study which involved selection of true lesions by the observers themselves (“picking up” the true lesions which is closer to a real clinical setting), superiority of the T1-VISTA imaging over 3D-T1-FLAIR imaging was also achieved (Data not shown). Third, MR imaging was performed after injection of contrast media. The pre-contrast-enhanced T1-weighted imaging was not performed so that it is not known if all hyperintense lesions are truly enhancing lesions.

In conclusion, this study compared the diagnostic performance in detection of brain metastases between the contrast-enhanced T1-VISTA and 3D-T1-FLAIR imaging at 3T. The results revealed improved diagnostic performance in detection of small brain metastases (< 3 mm in the largest dimension) with the contrast-enhanced T1-VISTA imaging, due to improved CNR between metastases and normal brain parenchyma. The contrast-enhanced T1-VISTA imaging is considered as a suitable MR imaging sequence for detection of small brain metastases. It is expected that the improved diagnostic performance in detection of brain metastases by the contrast-enhanced T1-VISTA imaging would benefit the patients in selection of optimal treatment regime and estimation of prognosis. Further efforts for optimization of the MR imaging sequences such as the combined use of two or more contrast-enhanced MR imaging sequences might prove better results.

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Figure legends

Fig. 1. An example of the hyperintense lesions for qualitative analysis of the contrast-enhanced T1-VISTA images is shown. The hyperintense lesions are numbered and highlighted by square boxes on the coronal sections of the contrast-enhanced T1-VISTA and 3D-T1-FLAIR images. The observers evaluated the lesions by scrolling the images in axial, coronal, and sagittal planes.

Fig. 2. The results of ROC analysis, for all lesions (a), and for lesions < 3 mm (b). The AUC value achieved by the contrast-enhanced T1-VISTA imaging ($AUC_{T1\text{-}VISTA}$; 0.99) is significantly larger than that of the 3D-T1-FLAIR imaging ($AUC_{3D\text{-}T1\text{-}FLAIR}$; 0.93), for lesions < 3 mm ($P=0.03$).

Fig. 3. An example showing improved detection of suspicious metastasis on the contrast-enhanced T1-VISTA image (a). The lesion (white arrow) is difficult to identify on the contrast-enhanced 3D-T1-FLAIR image (b). Compared to the 3D-T1-FLAIR imaging, suppression of signal from the blood vessels is poorer with the T1-VISTA imaging. Residual hyperintensity within the blood vessels is observed on the T1-VISTA image (white arrowhead).

Fig. 4. Another example showing improved detection of suspicious metastasis on the contrast-enhanced T1-VISTA image (a). The lesion (white arrow) is difficult to identify on the contrast-enhanced 3D-T1-FLAIR image (b). Compared to the 3D-T1-FLAIR imaging,

suppression of signal from the blood vessels is poorer with the T1-VISTA imaging. Residual hyperintensity within blood vessels is observed on the T1-VISTA image (white arrowhead).

Tables

Table 1. The sensitivity, specificity, and accuracy in detection of metastases, achieved by the contrast-enhanced T1-VISTA and 3D-T1-FLAIR imaging sequences.

	T1-VISTA	3D-T1-FLAIR
Sensitivity	0.906 *	0.747*
Specificity	0.946	0.950
Accuracy	0.926	0.877

* $P = 0.02$

Table 2. Summary of the false-positive findings.

Findings	T1-VISTA	3D-T1-FLAIR
Vessels	6	1
Venous angioma	0	1
Signal inhomogeneity	1	3
Phase shift artifact	0	1
Total	7	6

Note: The sum of false positive findings in four readers is given.













