A Comparison of Post-Contrast 3D T1 SPACE, 3D SPACE FLAIR, and 3D T1 MPRAGE Sequences in Various Brain Parenchymal and Meningeal Pathologies at 3T MRI

S. Babu Peter, MD DNB MNAMS FICR

Barnard Institute of Radiology, Madras Medical College, Rajiv Gandhi General Hospital, Chennai, India

Introduction

Contrast-enhanced magnetic resonance imaging (MRI) is well-suited for diagnosing meningeal and brain parenchymal abnormalities at an early stage, and this increases the survival rate of patients [1].

Intravenous magnetic resonance contrast agents are used to detect and characterize central nervous system disorders. The commonly used MR contrast agent gadolinium shortens both the T1 and T2 relaxation times of the tissues in which it has accumulated.

Mechanisms of contrast enhancement vary depending on the site of the lesion: With intra-axial brain lesions, disruption of the blood–brain barrier causes gadolinium to enter the extracellular space; with extra-axial lesions, enhancement occurs due to the relatively high vascularity; and in leptomeningeal regions, contrast leaks from the vessels into the cerebrospinal fluid (CSF).

While in the past, 2D imaging was common practice and protocols have been highly optimized for contrast-enhanced imaging. Nowadays, 3D imaging is becoming more and more popular, multiple 3D sequences are available, and protocols vary between institutions. The choice of 3D sequence can be tailored according to individual needs.

It is possible to acquire high-spatial-resolution 3D T1-weighted data of the brain in a convenient time with spin-echo contrast rather than gradient echo contrast. Variable flip angle refocusing pulses in SPACE reduce the specific absorption rate. In some studies, 3D T1 SPACE images identified a high number of discrete enhancing small lesions, which the MPRAGE sequence missed [3].

Many clinical studies have shown that the post-contrast 3D SPACE FLAIR sequence offers more information than a post-contrast 3D T1 SPACE sequence alone. Thanks to suppression of the CSF signal, no or minimal enhancement of blood vessels, reduction of phase shift artifacts derived from enhanced blood vessels or dural sinuses, and better detection of peritumoral edema, lesions are more conspicuous in 3D SPACE FLAIR sequences [4–6].

However, in post-contrast 3D SPACE FLAIR imaging alone, the observed hyperintense lesion may be less conspicuous due to either T2 lengthening or T1 shortening. This limits the usefulness of the FLAIR sequences, which should therefore be performed with both pre-contrast and post-contrast scans.

Objectives

We compare post-contrast 3D T1 SPACE, 3D SPACE FLAIR, and 3D MPRAGE sequences in various brain parenchymal and meningeal pathologies.

Specifically, we

- evaluate different meningeal enhancement patterns such as pachymeningeal enhancement, leptomeningeal enhancement, gyral enhancement, folial enhancement, and cisternal enhancement
- identify which MRI sequence is best for detecting conglomerate ring-enhancing lesions, scolices, and multiple lesions

Literature review

Post-contrast 3D T1 SPACE sequences
3D T1 SPACE (Sampling Perfection with Application optimized Contrast using different flip-angle Evolutions) sequence is a single-slab 3D TSE sequence with a slab-selective, variable excitation pulse. Enhancing vessels may mimic meningeal enhancement in MPRAGE sequences, which makes differentiation difficult. T1 SPACE is a 3D fast spin echo sequence in which refocusing of the transverse magnetization is done by radiofrequency pulse. It is the least affected by magnetic field inhomogeneities and shows the absence of flow-related signal from vessels [9, 10]. The magnetization effect produced by the pulses provides better delineation of lesions by suppressing white matter signal intensity [11, 12].

Post-contrast 3D SPACE FLAIR sequences
FLAIR MRI techniques were first described by Hajnal et al. [13]. Long T2 relaxation times improve conspicuity of brain lesions on FLAIR images [14–16]. The usefulness of gadolinium-enhanced FLAIR MRI in revealing enhancement of brain lesions has recently been investigated.

Post-contrast 3D SPACE FLAIR imaging adds significantly more information than post-contrast MPRAGE imaging: The study by Fukuoka et al. [17] showed that 3D SPACE FLAIR was more sensitive to low gadolinium concentrations and less sensitive to high gadolinium concentrations than MPRAGE.

The abnormal enhancement also depends on the amount of contrast given. An intravenous injection of gadolinium at a dose of 0.1 mmol kg^{-1} can detect brain lesions effectively. The maximum concentration of gadolinium in the blood after 10 to 60 seconds of intravenous injection of gadolinium at 0.1 mmol kg^{-1} of body weight is 2.0 ± 1.2 mmol L^{-1} for the aorta and 0.6 ± 0.3 mmol L^{-1} for the inferior vena cava. Therefore, administration of contrast at a dose of 0.1 mmol kg^{-1} is ideal [18].

Since many cases showed abnormalities on both pre-contrast and post-contrast 3D SPACE FLAIR images, only those that showed up on subtraction images were taken as evidence of abnormal post-contrast FLAIR enhancement.

Materials and methods

In the period from January to December 2019, a total of 82 patients with high suspicion of brain parenchymal and meningeal abnormalities (excluding cerebrovascular accident and trauma) were evaluated. The study was carried out in Rajiv Gandhi Government General Hospital, Madras Medical College, Chennai, Tamil Nadu, India. Approval was obtained from the institute's ethics committee. Prior informed consent was obtained from the patients who underwent MRI. 60 patients fulfilled the inclusion criteria and underwent pre-contrast and post-contrast 3D T1 SPACE, 3D SPACE FLAIR, and 3D T1 MPRAGE imaging. The images from the three different contrast sequences were evaluated in parallel and a final decision was reached on which sequence showed which lesions most conspicuously.

Inclusion criteria

All patients with high clinical suspicion of new-onset neurological symptoms and either criteria (a) or (b):

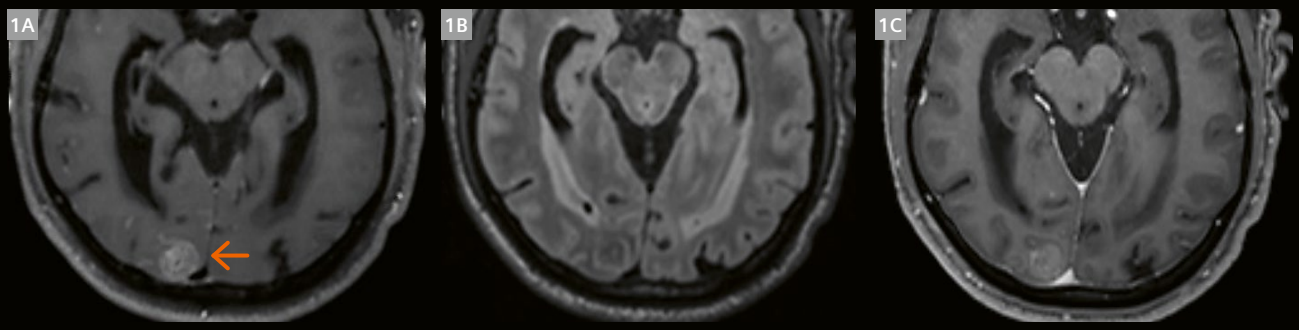
a) Multiple parenchymal lesions with abnormal CSF findings or known history of primary tumor
b) Suspicious meningeal abnormalities with abnormal CSF findings or known history of primary tumor

Exclusion criteria

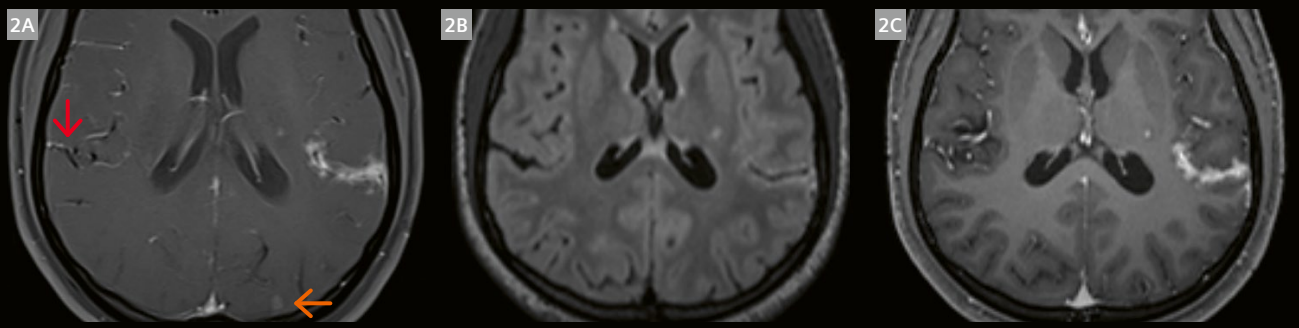
1. All patients with a previous history of neurological disease
2. Patients with a previous history of brain surgery
3. Patients with diffusion abnormalities corresponding to vascular territory

Imaging technique

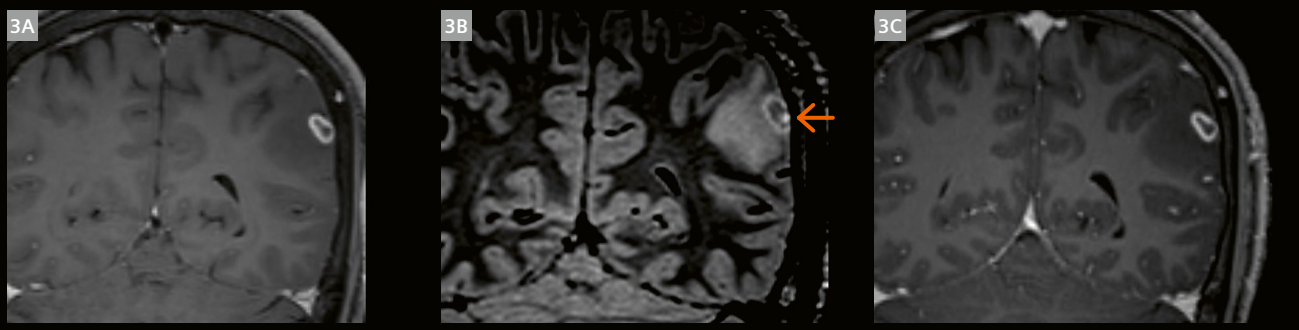
All studies were performed using a 3T MRI system (MAGNETOM Skyra, Siemens Healthcare, Erlangen, Germany). Gadolinium was administered intravenously at a dose of 0.1 mmol/kg. The MR studies were started about 60–120 seconds after contrast injection. The post-contrast 3D T1 MPRAGE sequence was performed first, followed by the post-contrast 3D T1 SPACE and the 3D SPACE FLAIR.



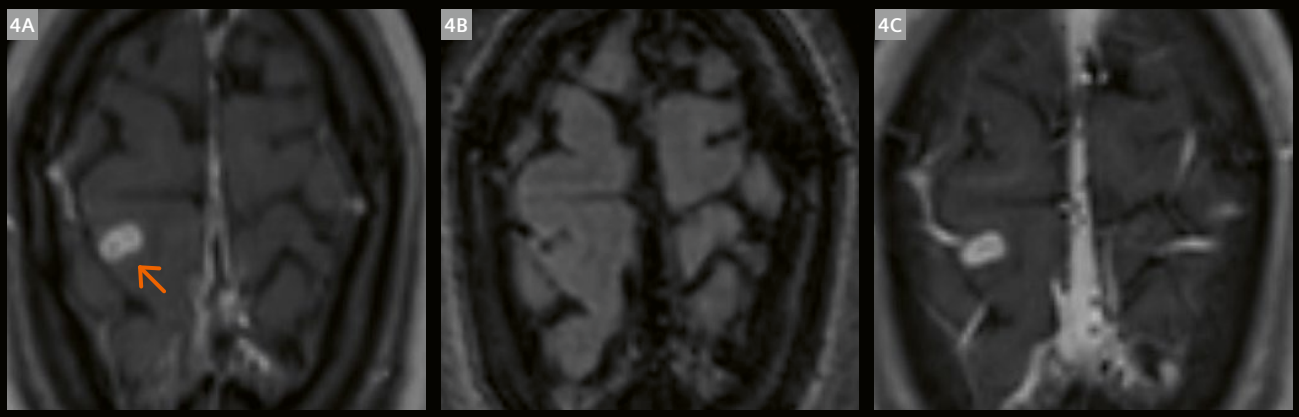
1 **Nodular enhancing discrete lesion**
(1A) Post-contrast 3D T1 SPACE image showing a heterogeneously enhancing nodule (arrow) in the right occipital lobe; lesions are less conspicuous in the **(1B)** post-contrast 3D SPACE FLAIR image and **(1C)** post-contrast 3D T1 MPRAGE image.



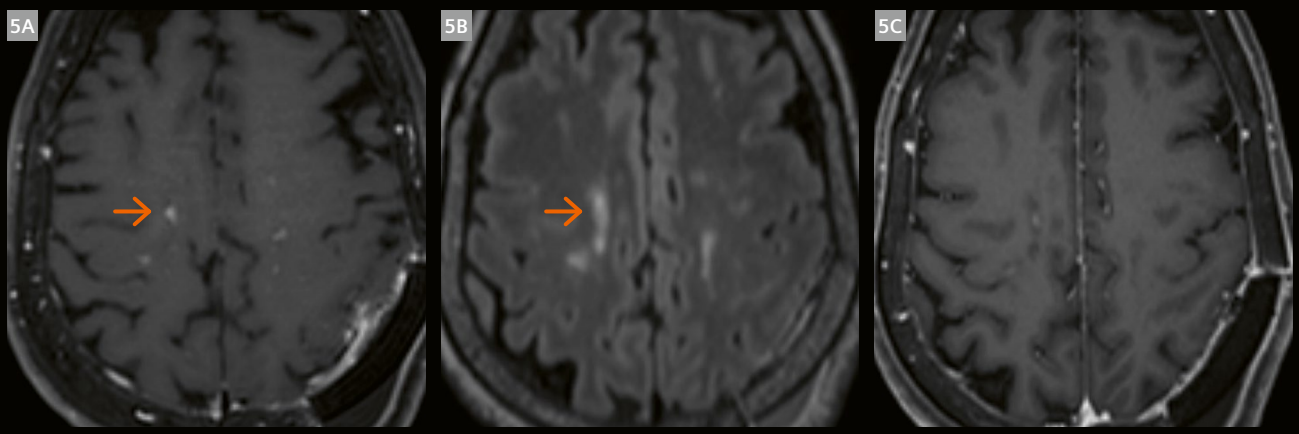
2 **TB meningitis**
(2A) Post-contrast 3D T1 SPACE; **(2B)** post-contrast 3D SPACE FLAIR and **(2C)** post-contrast 3D T1 MPRAGE; vessel enhancement particularly in the perisylvian region can be mistaken for meningeal enhancement in MPRAGE, but the 3D T1 SPACE image shows flow voids (red arrow). A nodular enhancing lesion (orange arrow) is visible in the left occipital lobe on 3D T1 SPACE, but not on the other sequences.



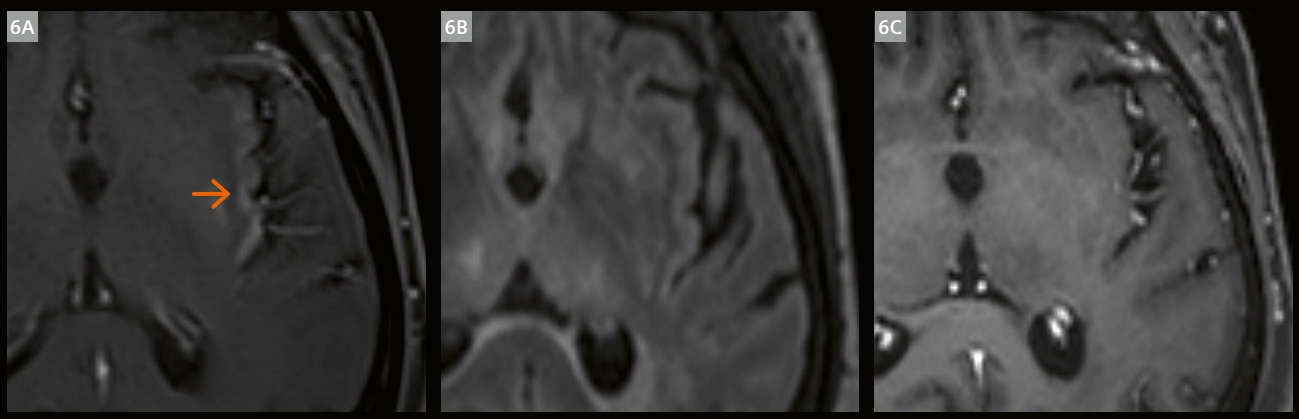
3 **Neurocysticercosis**
(3A) Post-contrast 3D T1 SPACE; **(3B)** post-contrast 3D SPACE FLAIR and **(3C)** post-contrast 3D T1 MPRAGE; the eccentric scolex is better seen on the 3D SPACE FLAIR image (orange arrow).



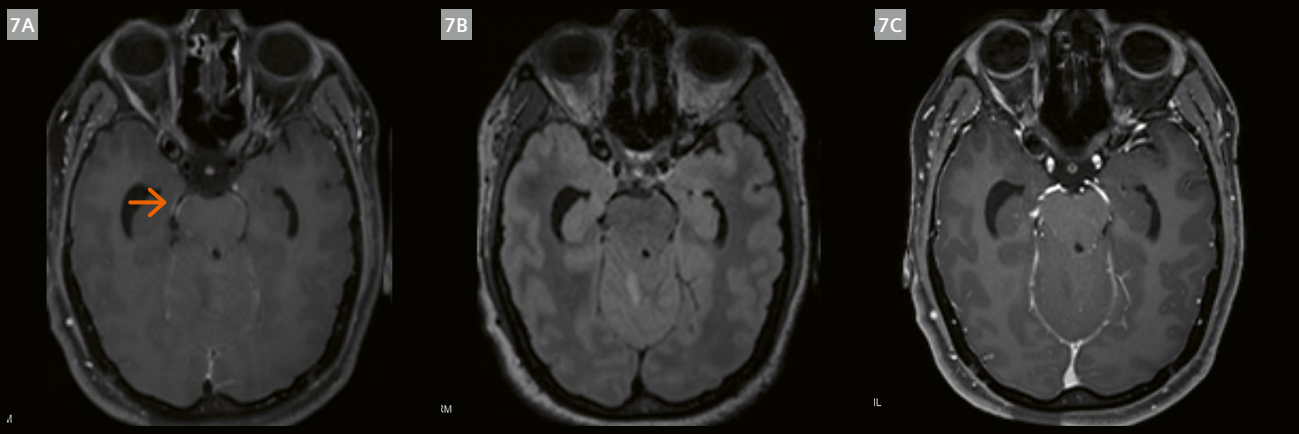
4 Tuberculoma
(4A) Post-contrast 3D T1 SPACE; **(4B)** post-contrast 3D SPACE FLAIR and **(4C)** post-contrast 3D T1 MPRAGE; tandem lesions better seen on the 3D T1 SPACE image (orange arrow).



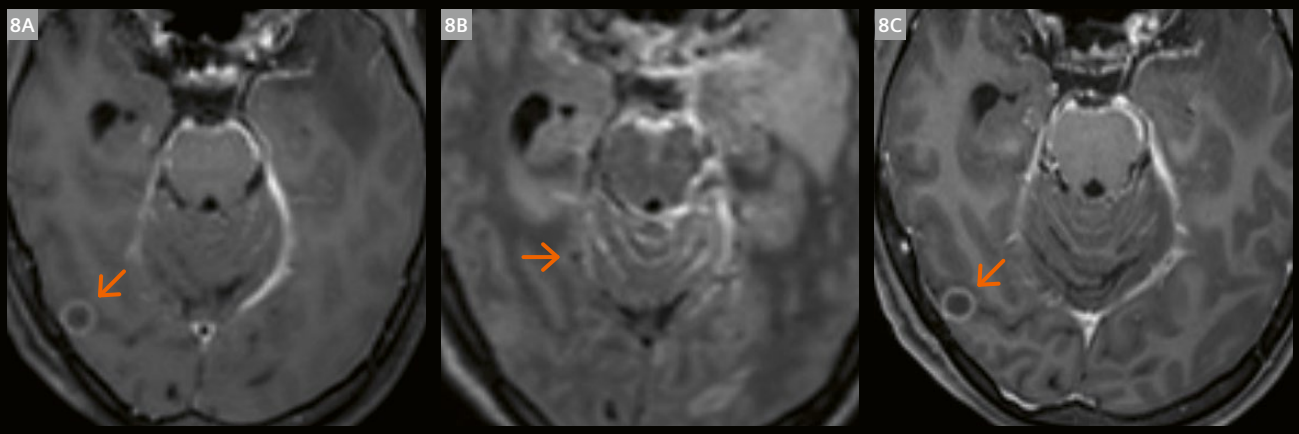
5 Demyelination
(5A) Post-contrast 3D T1 SPACE; **(5B)** post-contrast 3D SPACE FLAIR and **(5C)** post-contrast 3D T1 MPRAGE; enhancing lesions better seen on the 3D T1 SPACE and 3D SPACE FLAIR images (orange arrows).



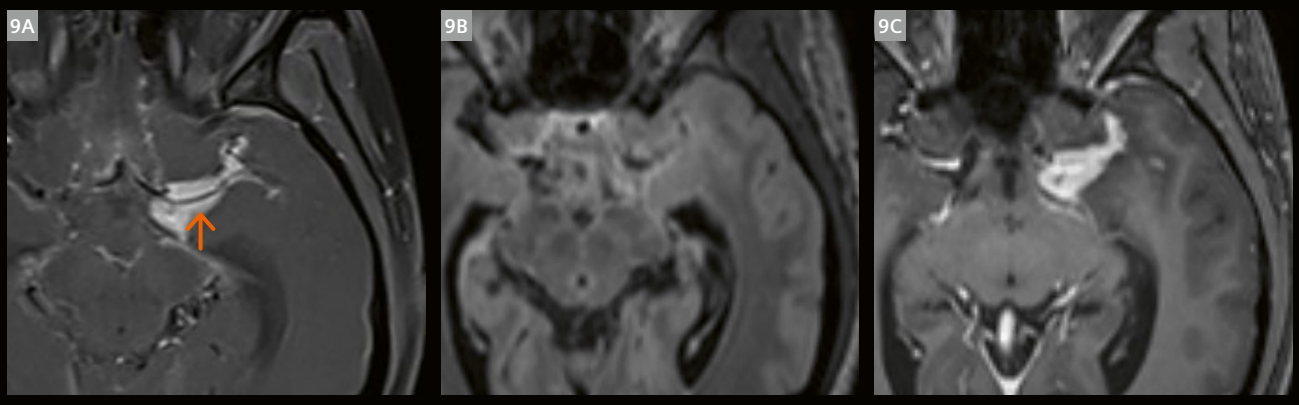
6 Herpes encephalitis
(6A) Post-contrast 3D T1 SPACE; **(6B)** post-contrast 3D SPACE FLAIR and **(6C)** post-contrast 3D T1 MPRAGE; gyriform enhancement in the left sylvian fissure better seen on the 3D T1 SPACE image (orange arrow).



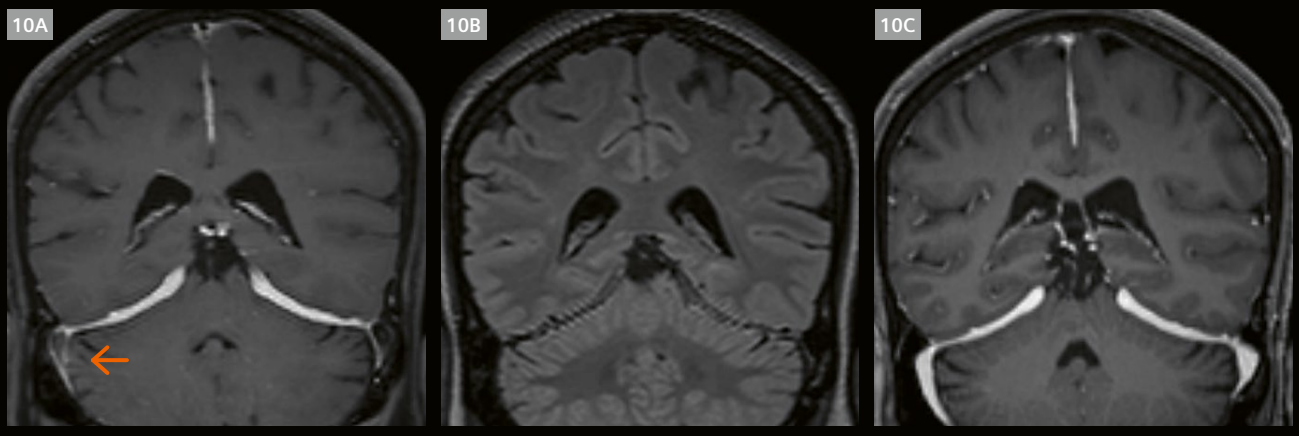
7 Bacterial meningitis
(7A) Post-contrast 3D T1 SPACE; **(7B)** post-contrast 3D SPACE FLAIR and **(7C)** post-contrast 3D T1 MPRAGE; basal cistern meningeal enhancement better seen on the 3D T1 SPACE image (orange arrow).



8 Tuberculoma with meningoencephalitis
(8A) Post-contrast 3D T1 SPACE; **(8B)** post-contrast 3D SPACE FLAIR and **(8C)** post-contrast 3D T1 MPRAGE; superior cerebellar folia enhancement better seen on the 3D SPACE FLAIR image, while ring-enhancing lesions are better seen with 3D T1 SPACE and 3D SPACE FLAIR (orange arrows).



9 TB meningitis
(9A) Post-contrast 3D T1 SPACE; **(9B)** post-contrast 3D SPACE FLAIR and **(9C)** post-contrast 3D T1 MPRAGE; thickening with enhancement of meninges in the left medial temporal region adjacent to the left middle cerebral artery is well seen on both, the 3D T1 SPACE and the 3D MPRAGE images; with MPRAGE the vessels could not be separately delineated, but with SPACE the vessels are seen as signal voids.



10 Hypertrophic pachymeningitis
(10A) Post-contrast 3D T1 SPACE; **(10B)** post-contrast 3D SPACE FLAIR and **(10C)** post-contrast 3D T1 MPRAGE. Meningeal enhancement is seen in both SPACE and MPRAGE images, but the right sigmoid sinus could be separately delineated with 3D T1 SPACE.

Standard MRI protocols used on the 3T MAGNETOM Skyra at Barnard Institute of Radiology (BIR) and at Rajiv Gandhi General Hospital (RGGH)

Parameters	3D T1 SPACE	3D SPACE FLAIR	3D T1 MPRAGE
Repetition time (TR)	700 ms	5000 ms	1800 ms
Effective echo time (TE eff)	11.0 ms	388 ms	2.32 ms
Inversion time		2000 ms	900 ms
Imaging time	5:07 min	4:47 min	3:34 min
Field of view	250 x 250 mm	250 x 250 mm	240 x 240 mm
Thickness	0.9 mm thick sections	0.9 mm thick sections	0.9 mm thick sections

The images were evaluated by two senior radiologists, who looked for brain parenchymal lesions and meningeal enhancement, and characterized lesions.

Results

The ideal sequences for the different brain and meningeal pathologies are given in tables 1–4.

Parenchymal abnormalities

	3D T1 SPACE		3D SPACE FLAIR		3D T1 MPRAGE	
	Rad 1	Rad 2	Rad 1	Rad 2	Rad 1	Rad 2
< 1 cm	29	28	18	15	20	19
1–3 cm	84	83	65	63	78	76
> 3 cm	35	35	35	35	35	34

Table 1: Number of discrete lesions identified.

For detecting discrete lesions, the overall sensitivity of 3D T1 SPACE was highest (99.3%), followed by 3D T1 MPRAGE (88.5%), and 3D SPACE FLAIR (78%). 3D T1 SPACE performed well even for lesions < 1 cm (sensitivity: 98.3%), whereas the sensitivity was less for 3D SPACE FLAIR (56.9%) and 3D T1 MPRAGE (70.7%). All three sequences showed sensitivity above 98% for lesions > 3 cm.

3D T1 SPACE		3D SPACE FLAIR		3D T1 MPRAGE	
Rad 1	Rad 2	Rad 1	Rad 2	Rad 1	Rad 2
20	18	36	34	21	19

Table 2: Number of lesions with scolex.

For detecting lesions with scolex, the sensitivity of 3D SPACE FLAIR was higher (97.2%) than both 3D T1 MPRAGE (55.5%) and 3D T1 SPACE (52.8%).

	3D T1 SPACE		3D SPACE FLAIR		3D T1 MPRAGE	
	Rad 1	Rad 2	Rad 1	Rad 2	Rad 1	Rad 2
< 1 cm	23	24	15	14	18	18
1–3 cm	16	15	13	14	14	13
> 3 cm	6	6	6	6	6	6

Table 3: Number of conglomerate ring-enhancing lesions.

For detecting conglomerate ring-enhancing lesions, the overall sensitivity of 3D T1 SPACE was highest (98.5 %), followed by 3D T1 MPRAGE (83.3%) and 3D SPACE FLAIR (79.7%). 3D T1 SPACE performed well even for lesions < 1 cm (sensitivity 97.9%), while the sensitivity was less for 3D SPACE FLAIR (60.4%) and 3D T1 MPRAGE (75%). All three sequences showed 100% sensitivity for lesions > 3 cm.

	3D T1 SPACE		3D SPACE FLAIR		3D T1 MPRAGE	
	Rad 1	Rad 2	Rad 1	Rad 2	Rad 1	Rad 2
Supratentorial						
Pachymeningeal enhancement	12	12	10	9	6	7
Leptomeningeal enhancement	25	24	22	23	18	15
Gyral enhancement	6	6	6	5	3	3
Infratentorial						
Folial enhancement	9	9	8	9	4	5
Cisternal enhancement	25	26	23	22	17	15

Table 4: Number of cases with meningeal abnormalities.

For detecting meningeal abnormalities, the sensitivity of 3D T1 SPACE was highest (98.7%), followed by 3D SPACE FLAIR (87.8%) and 3D T1 MPRAGE (59.6%).

Distribution of abnormalities:

Tuberculosis	25%	Viral meningitis	10%
Metastases	13.33%	Demyelination	6.66%
Neurocysticercosis	10%	Neurosarcoidosis	3.33%
Bacterial meningitis	23.33%	Brain abscess	8.33%

Discussion

The results of our study show that both 3D T1 SPACE and 3D SPACE FLAIR provide significantly more information than a routine post-contrast 3D T1 MPRAGE sequence alone. 3D T1 SPACE (black blood) offers several benefits. In brain tumors, it can differentiate vessel from tumor enhancement after contrast perfusion imaging, and can therefore better differentiate true from spurious enhancement. 3D T1 SPACE is also preferable in cases of meningitis, as are neuronavigation protocols for the same reason. 3D SPACE FLAIR is better able to demonstrate scolices.

Conglomerate lesions, typically seen in tuberculosis, were better delineated by 3D T1 SPACE than by 3D SPACE FLAIR and MPRAGE. Pachymeningeal enhancement is seen in, for instance, transient postoperative changes, spontaneous intracranial hypotension, granulomatous disease, and neoplasms such as meningiomas, metastatic disease, and secondary CNS lymphoma. In our study, we found that post-contrast 3D T1 SPACE is much better for demonstrating pachymeningeal involvement than 3D SPACE FLAIR and 3D T1 MPRAGE.

Conclusion

Multiple 3D sequences are available and protocols vary between institutions. The choice of a particular 3D sequence can be tailored according to individual needs. We found that 3D T1 SPACE (black blood) was more robust and offered several benefits compared to 3D T1 MPRAGE and in many cases also compared to 3D SPACE FLAIR.

Acknowledgments

The author would like to acknowledge the contributions of Dr. A. Mohideen Asraf, M.D., Assistant Professor at BIR and RGGH; Dr. Swarnalakshmi, M.D., of RGGH; and Dr. S. Harishpriya, DMRD, junior resident at BIR.

References

1 Chang KH, Han MH, Roh JK, Kim I0, Han MC, Kim CW. Gd-DTPA-enhanced MR imaging of the brain in patients with meningitis: comparison with CT. AJNR Am J Neuroradiol. 1990;11(1):69–76.
2 Melhem ER, Bert RJ, Walker RE. Usefulness of optimized gadolinium-enhanced fast fluid-attenuated inversion recovery MR imaging in revealing lesions of the brain. AJR AM J Roentgenol. 1998;171(3): 803–7.
3 Komada T, Naganawa S, Ogawa H, Matsushima M, Kubota S, Kawai H, et al. Contrast-enhanced MR imaging of metastatic brain tumor at 3 tesla: utility of T(1)-weighted SPACE compared with 2D spin echo and 3D gradient echo sequence. Magn Reson Med Sci. 2008;7(1):13–21.
4 Essig M, Knopp MV, Schoenberg SO, Hawighorst H, Wenz F, Debus J, et al. Cerebral gliomas and metastases: assessment with contrast-enhanced fast fluid-attenuated inversion-recovery MR imaging. Radiology. 1999;210(2):551–7.
5 Mathews VP, Caldemeyer KS, Lowe MJ. Brain: gadolinium-enhanced fast fluid-attenuated inversion-recovery MR imaging. Radiology. 1999;211(1):257–63.
6 Tsuchiya K, Katase S, Yoshino A, Hachiya J. FLAIR MR imaging for diagnosing intracranial meningeal carcinomatosis. AJR Am J Roentgenol. 2001;176(6):1585–8.
7 Lee EK, Lee EJ, Kim S, Lee YS. Importance of Contrast-Enhanced Fluid-Attenuated Inversion Recovery Magnetic Resonance Imaging in Various Intracranial Pathologic Conditions. Korean J Radiol. 2016;17(1):127–41.
8 Singh SK, Agris JM, Leeds NE, Ginsberg LE. Intracranial leptomeningeal metastases: comparison of depiction at FLAIR and contrast-enhanced MR imaging. Radiology. 2000;217(1):50–3.
9 Chang C, Stuckey S, Alatakis S, Low K. Contrast Enhanced 3D T1-weighted SPACE: Pictorial Essay of Appearances, Advantages and Disadvantages Compared with Conventional Contrast Enhanced 3D T1-weighted Imaging (MPRAGE). Poster presented at: RANZCR-AOCR 2012. August 30 – September 2; Sydney, Australia. Available from: http://www.ranzcr.edu.au. [Last accessed on 2018 Apr 09].
10 Kumar S, Kumar S, Surya M, Mahajan A, Sharma S. To Compare Diagnostic Ability of Contrast-Enhanced Three-Dimensional T1-SPACE with Three-Dimensional Fluid-Attenuated Inversion Recovery and Three-Dimensional T1-Magnetization Prepared Rapid Gradient Echo Magnetic Resonance Sequences in Patients of Meningitis. J Neurosci Rural Pract. 2019;10(1):48–53.
11 Kato Y, Higano S, Tamura H. Usefulness of contrast-enhanced T1-weighted sampling perfection with application-optimized contrasts by using different flip angle evolutions in detection of small brain metastasis at 3T MR imaging: comparison with magnetization-prepared rapid acquisition of gradient echo imaging. AJNR Am J Neuroradiol. 2009;30(5):923–9.
12 Okada T, Kanagaki M, Yamamoto A, Sakamoto R, Kasahara S, Morimoto E, et al. Which to Choose for Volumetry: MPRAGE or SPACE? Proceedings of the ISMRM 19th Annual Meeting & Exhibition; 2011 May 7–13; Montreal, Quebec, Canada.
13 Hajnal JV, Bryant DJ, Kasuboski L, Pattany PM, De Coene B, Lewis PD, et al. Use of fluid attenuated inversion recovery (FLAIR) pulse sequences in MRI of the brain. J Comput Assist Tomogr. 1992:16(6):841–4.
14 De Coene B, Hajnal JV, Gatehouse P, Longmore DB, White SJ, Oatridge A, et al. MR of the brain using fluid-attenuated inversion recovery (FLAIR) pulse sequences AJNR Am J Neuroradiol. 1992;13(6):1555-64.
15 Rydberg JN, Hammond CA, Grimm RC, et al. Initial clinical experience in MR imaging of the brain with a fast fluid-attenuated inversion-recovery pulse sequence. Radiology 1994;193(1):173–80.
16 Thurnher MM, Thurnher SA, Fleischmann D, Steuer A, Rieger A, Helbich T, et al. Comparison of T2-weighted and fluid-attenuated inversion-recovery fast spin-echo MR sequences in intracerebral AIDS-associated disease. AJNR Am J Neuroradiol. 1997 Oct;18(9):1601–9.
17 Fukuoka H, Hirai T, Okuda T, Shigematsu Y, Sasao A, Kimura E, et al. Comparison of the added value of contrast-enhanced 3D fluid-attenuated inversion recovery and magnetization-prepared rapid acquisition of gradient echo sequences in relation to conventional postcontrast T1-weighted images for the evaluation of leptomeningeal diseases at 3T. AJNR Am J Neuroradiol. 2010;31(5):868-73.
18 Griffiths PD, Coley SC, Romanowski CA, Hodgson T, Wilkinson ID. Contrast-enhanced fluid-attenuated inversion recovery imaging for leptomeningeal disease in children. AJNR Am J Neuroradiol. 2003;24(4):719–23.
19 Jeevanandham B, Kalyanpur T, Gupta P, Cherian M. Comparison of post-contrast 3D-T1-MPRAGE, 3D-T1-SPACE and 3D-T2-FLAIR MR images in evaluation of meningeal abnormalities at 3-T MRI. Br J Radiol. 2017;90(1074):20160834.

Contact

Professor S. Babu Peter, MD DNB MNAMS FICR
Barnard Institute of Radiology
Madras Medical College
Rajiv Gandhi General Hospital
Opposite to Chennai Central Railway Station
Chennai, Tamil Nadu, India
drbabupeter@gmail.com