A desirable advancement but not without concern for black blood sequences: vessel wall imaging may not be blindly done

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Abstract

Time of flight (TOF) gradient echo magnetic resonance angiography (MRA) is a bright lumen method that is supposed to be simpler but is not free of challenges. Post-treatment, tricky geometry, Gd build up and high fields pose challenges and practice variation making some special applications of even the well-developed bright blood method questionable in treated AVMs as discussed in a prior editorial (Sarkar Eur Rad, 2023). In this editorial another, perhaps more important (pseudo-steady state for black blood angiography) is discussed. It has been agreed upon that assessment of vessel wall integrity, particularly plaques and other arterial wall diseases is best done with dark arterial lumen and bright wall visualization. To meet that goal 3D FSE T_1-based imaging is possible within clinically tolerable scan times by generating long lasting echoes (pseudo steady state) with sub-millimeter resolution. The 3D FSE T_1 approach is relatively recent, more complex than 3D FSE T_2 and is less understood. There are many variants also, and the best ones apply excessive demands on hardware and software and drain SNR and CNR of the target pathologies. The lengthening of relaxation times was shown by author (Appl Spectrosc, 1991 and Radiology, 2011) as well as by Alsop (MRM, 1997) and a few others that essentially have built the basis of pseudo-steady state MRI getting popular today. In this editorial caution is advised since variability continues in such assessments of carotid plaques and similar vessel wall applications. Hence a blind trust in 3D FSE T_1-MRI to achieve black blood angiography with bright wall pathologies could prove to be a pre-matured victory lap.

Before discussing the work of Zhang et al [1] on black blood vessel wall imaging that is complex, it is useful to start with the bright blood with contrast, Time of flight (TOF) gradient echo magnetic resonance angiography (MRA) is a bright lumen method that is supposed to be simpler but is not free of challenges, and some of its high field contrast-enhanced applications may yield back to lower fields or non-contrast arterial spin labeling vessel MRA. Post-treatment, tricky geometry, Gd build up and high fields pose challenges and practice variation making some special applications of even the well-developed bright blood method questionable in treated AVMs [2]. Spin echo applications with dark lumen can extend the 3D MRA diagnostics like the one we are discussing here [1] by reducing susceptibility and treatment induced variation at high fields if we develop a mechanistic understanding of the long echo train 3D fast spin echo (FSE) sequences first as suggested below.

It has been agreed upon that assessment of vessel wall integrity and associated diseases is best done with dark lumen and bright wall visualization. To meet that goal 3D FSE T_1-based imaging is possible within clinically tolerable scan times by generating long lasting echoes (pseudo steady state) allowing high resolution. But there is a trade-off between the two, not emphasized by vessel wall works. There is a tendency to develop and trust 3D FSE T_1-based imaging today following the footsteps of modestly successful 2D and 3D pseudo steady state FSE T_2 sequences [3-5]. Both of these T_1 and T_2-weighted tools try to maintain spin steady states respectively in the transverse (XY plane for FSE T_2) or in the longitudinal (XZ or YZ planes for FSE T_1) without mixing T_1 and T_2 processes and without favoring one tissue over the other. The 3D FSE T_1 approach is relatively recent, more complex than 3D FSE T_2 and is less understood. There are many variants [6-8], and the best ones apply excessive demands on hardware and software and drain SNR and CNR that can be beneficial to suppress some tissues or not so if the pathologies happen to lose SNR and CNR, meaning suppression of select native tissues without

control or knowledge could be problematic [8]. All of these issues are the basis of concern in this commentary against generalization claimed by Zhang et al [1].

Low radiofrequency flip angle spin echo methods (low RF), used by Zhang et al, exploit an accidental spin echo phenomenon that involves modifying T_2 and T_1 relaxation times and keep the imageable spins at steady state except spins for flowing tissue, cerebrospinal fluid (CSF) or fat or unfortunately, as the science may logically support, sometimes Gd infused pathology or blood products! This allows use of very long echo trains to cover a 3D tissue region undergo spin echo imaging with modest or very low levels of tissue heating (low SAR) when an important imaging requirement is met. The requirement is to successfully "prepare" and maintain a steady supply of magnetized spins in the volume of interest for several seconds.

The lengthening of relaxation times was suspected during 1970s after solid-echo experiments in Nuclear Magnetic Resonance spectroscopy (NMR) and a very bold imaging formalism was put forward for modified spin echoes in 1997 [3] and in 2004 [4]. Demonstration of residual magnetization lasting longer than expected was also shown by 3D gradient echoes applied to porous media without mechanistic models or underlying theory in 1991 [9]. The formalism put forward in 1997 and 2004 was extended toward safer clinical spin echo imaging in 2011 [5] and such modified spin echoes or pseudo spin echoes provided the much-needed speed, quality and safety at higher fields and is the basis for 3D fast spin echoes practiced today.

This "accidental" opportunity to observe MR signal that modifies T_2 and T_1 decay needed several hardware advancements including high field magnets, multi-element radiofrequency (RF) coils or multi-coil receiver matrix arrays and seemed to be suitable for imaging relatively motion free, low susceptibility tissue systems that allowed prediction and manipulation of spin dynamics in different planes to evolve and maintain a steady state of spin echoes with minimal signal decay from pulsatility, bony interfaces or regions with high susceptibility. Also needed was successful use of parallel imaging with acceleration in phase encoding and slice sectioning directions that alleviates some of the increased susceptibility at high fields and cuts the 3D imaging times with an acceptable increase in hardware or tissue induced noise. So, a smart and tricky balance is created between SNR, CNR, resolution and scan time in these methods. The goal is to slow down the T_2 and T_1 relaxations of normal tissue to allow long echo trains and still call it a T_1 tool allowing high spatial resolution while maintain the relative relaxations of competing pathologies to truly image the acute versus sub-acute versus the old. This editorial questions the ability to achieve the second goal by indiscriminate use of multiple 3D FSE T_1 products that vendors have made available, particularly for black blood imaging, with little translational research.

Lindenholz et al [6] have compared 7 variants of 3D FSE VISTA T_1 (Volume Isotropic Turbo Spin Echo Acquisition) from Philips but did not clarify strengths and weaknesses or the mechanistic differences among those. However due to potential misreads, Lindenholz et al [7] also have recommended cautious interpretation of vessel wall imaging and have listed some steps how to do it. Cho et al [8] have compared on healthy volunteers 4 versions of 3D FSE T_1 from various vendors demonstrating significant SNR and CNR penalty not only in the lumen but also in the wall matrix when any black blood preparation is used (by delay alternating with nutation for tailored excitation [DANTE] i.e. modified RF pulse to disqualify some tissues, or improved motion-sensitized driven equilibrium [iMSDE] i.e. use of multiple crusher or signal scrambling gradients to remove select tissue signals). Zhang et al [1] have arbitrarily chosen one of these 4 variants to image diffuse wall thickening pathologies (DWT). Their results seem to have value and they have accidentally benefitted by using a sequence version better than most of the other variants available [6, 8]. They achieved reasonable wall resolution in clinically feasible scan times and their dedicated carotid surface RF coil that couple well with neck tissue may be the best choice for now in spite of uneven steady state generation due to non-uniform RF profiles in surface coils at different carotid depths, e.g. potentially in different size neck in the patient pools. Use of large volume coils or different acquisition planes are common elsewhere as we already see among the reported vessel imaging works and are prone to variability in spin steady states as well as lower SNR than surface coils.

Based on this “accidental” opportunity with 3D sequences, particularly with 3D pseudo spin-echoes, one may develop the next generation of “low-SAR” 3D methods and apply to brain tissue even with high susceptibility interfaces [10] or flowing tissue (dark blood). However, without further development of underlying mathematics of spin states and by applying the old physics and chemistry of enhanced tissue we may be heading toward formidable mistakes in wall characterization when there is no gold standard available to compare the vessel wall pathologies. The current commentary agrees that the DWT work of Zhang et al [1] is a valuable application as well as notes the interpretation guidelines from Lindenholz et al [8] as helpful. Additionally, this commentary maintains that 3D FSE T_1, due to the significant demands on and variability of hardware and pulse sequences, can produce quite variable results and should be carefully verified by additional MR sequences in vessel wall imaging in the absence of histopathology. Zhang et al [1] have used whatever sequence was available and it seems they were accidentally lucky at this time due to a version with moderately short echo trains and short echo times, shorter TR and faster acquisitions with quite appropriate hardware and Gd usage. One may believe their pseudo steady states are indeed 3D FSE T_1 type with desirable efforts from black blood and T_1 signal manipulation. However, many other workers will not be that lucky and variable results may persist in

assessments of DWT and similar vessel wall applications. Hence this commentary cautions placing a blind trust in such black blood advancements without further research and standardization among 3D FSE T_1 products.

References

1. *Zhang J, Chen X, Tian J et al (2023) Associations between atherosclerotic luminal stenosis in the distal internal carotid artery and diffuse wall thickening in its upstream segment. Eur Radiol.*
2. *Sarkar S (2023) Brain arteriovenous malformations: the long way ahead in physics, chemistry, and MR angiography practice before fully replacing digital subtraction angiography. Eur Radiol 33:7136-7138*
3. *Alsop DC (1997) The sensitivity of low flip angle RARE imaging. Magn Reson Med 37: 176 – 184*
4. *Hennig J, Weigel M, Scheffler K (2004) Calculation of flip angles for echo trains with predefined amplitudes with the extended phase graph (EPG)-algorithm: principles and applications to hyperecho and TRAPS sequences. Magn Reson Med 51:68 –80*
5. *Sarkar SN, Alsop DA, Madhuranthakam AJ et al (2011) Brain MRI at ultra-low SAR: a potential protocol for imaging of patients with contraindicating implants. Radiology 259:550–557*
6. *Lindenholz A, Harteveld AA, Zwanenburg JJM et al (2018) Comparison of 3T Intracranial Vessel Wall MRI Sequences. AJNR Am J Neuroradiol 39:1112-1120*
7. *Lindenholz A, van der Kolk AG, Zwanenburg JJM et al (2018) The Use and Pitfalls of Intracranial Vessel Wall Imaging: How We Do It. Radiology 286:12-28*
8. *Cho SJ, Jung SC, Suh CH et al (2019) High-resolution magnetic resonance imaging of intracranial vessel walls: Comparison of 3D T1-weighted turbo spin echo with or without DANTE or iMSDE. PLoS ONE 14(8): e0220603*
9. *Sarkar SN, Wooten EW, Komoroski RA (1991) NMR Imaging of Water in Model Porous Materials. Appl Spectrosc 45:619-625*
10. *Sarkar SN, Sarkar PR, Papavassiliou E, Rojas RR (2014) Utilizing fast spin echo MRI to reduce image artifacts and improve implant/tissue interface detection in refractory Parkinson's patients with deep brain stimulators. Parkinsons Dis 2014:508576*