REVIEW ARTICLE

Ultra-high-field MRI in Neuroimaging: From Technical Innovation to Clinical Translation: A comprehensive review article.

Sabneet Sharma[1], Abhinav Bhatnagar[2], Anjali Singh[3], Ashita jain[4], Sapna Sahu[5]*, Harsh Thakur[6], Saloni Singh[7]

[1]Assistant Professor, Department of Radiology and Imaging Technology, Lovely Professional University, Phagwara, Punjab, India, 144411

Email: sabneetsharma93@gmail.com

[2]Assistant Professor, Department of Radiology, School of Allied and healthcare sciences Sanskriti University, Mathura Email - bhatnagarab333@gmail.com, ORCID ID -0009-0003-5378-5729

[3]Assistant Professor, Department of Radiology, School of Allied health sciences Galgotias University, Greater Noida Email - anjalis13320@gmail.com, ORCID ID - 0009-0007-3906-6444

[4]Assistant professor, Department of Radio- Imaging Technology, SAHSH SGT University, Gurugram, Haryana Email - ashita_sahs@sgtuniversity.org, ORCID ID - 0000-0003-4738-2854

[5]Tutor, Department of Medical Radiology and Imaging Technology, Government institute of Medical Sciences, Greater Noida Email - sapnasahu157@gmail.com, ORCID ID- 0009-0004-6849-4032

[6]Assistant Professor, School of allied and healthcare sciences, Sanskriti University, Mathura

E mail - harshks.smas@sanskriti.edu.in, ORCID ID- 0009-0000-0254-427X

[7]Assistant professor, Department of Allied Health Sciences, Mangalayatan university, Aligarh

Email - saloni.singh@mangalayatan.edu.in, ORCID ID- 0009-0000-1944-3686

Corresponding author: Sapna Sahu, sapnasahu157@gmail.com

Received: XX; Revised: XX; Accepted: XX; Available Online: XX

ABSTRACT

Ultra-high-field magnetic resonance imaging (MRI), particularly at 7 Tesla (7T) and beyond, has emerged as one of the most transformative developments in modern neuroimaging. The technology offers substantial gains in signal-to-noise ratio (SNR), contrast-to-noise ratio (CNR), and spatial resolution, enabling unprecedented visualisation of cortical architecture, hippocampal subfields, white matter lesions, microvascular networks, and subtle tumor margins. These gains have supported an expanding body of work in epilepsy, multiple sclerosis, cerebrovascular disease, neuro-oncology, neurodegenerative disorders, and psychiatric research. At the same time, shifting from 3T to 7T introduces substantial technical and clinical challenges, including transmit radiofrequency (B1+) field inhomogeneity, higher specific absorption rate (SAR), stronger susceptibility artefacts, increased sensitivity to motion, and the need for specialised multi-channel hardware and advanced engineering expertise. This review summarises the physical basis of ultra-high-field neuroimaging, key pulse sequence adjustments and protocol adaptations, major clinical applications, and current barriers to widespread implementation. It also highlights future directions, including parallel transmission (pTx), deep-learning reconstruction, quantitative imaging, and the development of higher-field systems beyond 7T [1,2,3,4].

Keywords: 7T MRI, ultra-high-field MRI, neuroimaging, neuroradiology, epilepsy, multiple sclerosis, spectroscopy, susceptibility-weighted imaging, quantitative MRI, clinical translation

How to cite this article: Sharma S, Bhatnagar A, Singh A, Jain A, Sahu S, Thakur H, Singh S. Ultra-High-Field MRI in Neuroimaging: From Technical Innovation to Clinical Translation: A Comprehensive Review Article. Int J Drug Deliv Technol. 2026;16(74s): 401-406. DOI: 10.25258/ijddt.16.74s.47

INTRODUCTION

Magnetic resonance imaging at 7T and above has progressed from an experimental research platform to an increasingly relevant clinical tool in neuroradiology [1,4]. The central attraction of ultra-high-field (UHF) MRI is its ability to exploit increased static magnetic field strength (B0) to yield substantial signal-to-noise ratio gains, which can then be directly converted into sub-millimetre spatial resolution or accelerated acquisitions [1,3]. This capability matters particularly in the brain, where neurological disorders often involve microscopic cortical abnormalities, perivenular changes, deep gray matter pathology, or subtle structural variants that remain entirely occult at lower field strengths such as 1.5T and 3T [2,5].

Over the past decade, the regulatory clearance of commercial 7T human scanners has catalysed a clinical paradigm shift [3, 4, 10]. What was once restricted to specialised physics labs is now deployed in leading tertiary hospitals globally, helping drive surgical and diagnostic decision-making [2, 10, 22]. Recent multi-centre datasets and reviews describe an expanding role for 7T MRI in diagnosing structural epilepsy, characterising multiple sclerosis plaques, evaluating tumour microvascularity, mapping neurodegenerative patterns, and uncovering microstructural biomarkers in psychiatric cohorts [1,4, 11]. Consequently, evaluating the bridge between technical hardware innovations and direct bedside clinical translation has become highly relevant to modern neuroradiology [4, 5, 25].

PHYSICAL PRINCIPLES

The core advantage of 7T MRI lies in the physics of nuclear magnetic resonance. According to the Boltzmann distribution, the

population difference between the parallel and anti-parallel nuclear spin states increases linearly with the static magnetic field strength (B0). This results in a much higher net macroscopic magnetisation vector (M0), translating directly into a near-linear or supralinear increase in the baseline signal-to-noise ratio (SNR) available for signal detection [2,4].

Furthermore, higher magnetic field strengths naturally amplify chemical shift separation and susceptibility effects [2,5,18]. The physical widening of the spectral resolution scale at 7T benefits magnetic resonance spectroscopy (MRS), allowing distinct separation of metabolite peaks that overlap heavily at 3T [6,13]. Similarly, the increased phase variance induced by magnetic susceptibility differences enhances the sensitivity of phase-sensitive protocols such as susceptibility-weighted imaging (SWI) and quantitative susceptibility mapping (QSM) [6, 7, 18]. In practical terms, this physics allows the direct depiction of microbleeds, tiny venous structures, subtle cortical layering, hippocampal subfields, and iron deposition patterns that cannot be fully resolved at lower field strengths [6, 7, 26].

However, the same physical laws that drive these improvements also introduce technical limitations. As B_0 increases, the corresponding Larmor frequency for hydrogen protons climbs to approximately 298 MHz at 7T [5, 8]. At this frequency, the electromagnetic wavelength of the radiofrequency (RF) transmit field (B1+) within human brain tissue drops to roughly 12 cm, which is significantly smaller than the physical dimensions of the human head [5, 8]. This leads to wave interference patterns, manifesting as significant RF field inhomogeneities, central signal bright spots, and severe peripheral signal drop-outs [8, 5, 29]. Additionally, spin-lattice (T1) relaxation times lengthen significantly at 7T, while spin-spin (T2 and T2*) relaxation times shorten [2,5]. This requires systematic adjustments to repetition times (TR) and echo times (TE) to prevent severe image blurring and unintended contrast alterations [8,5,20].

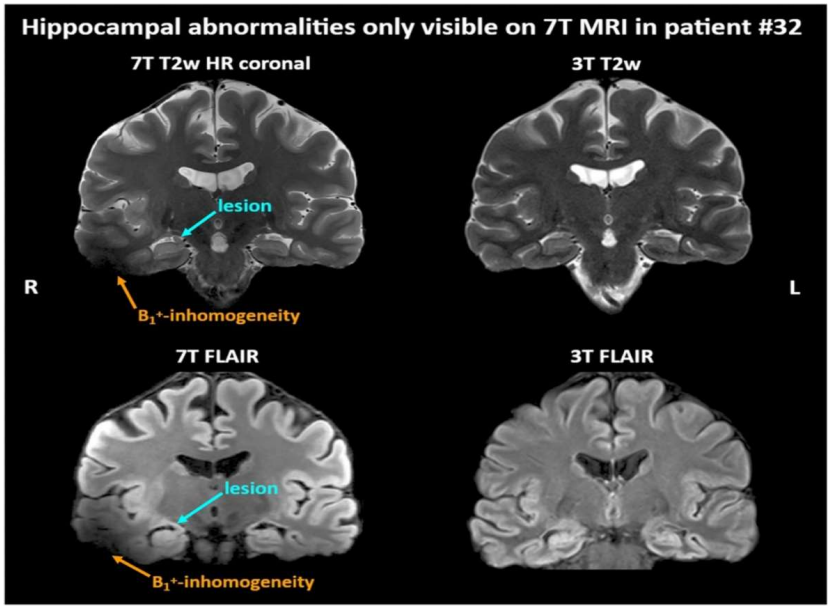

Figure XX

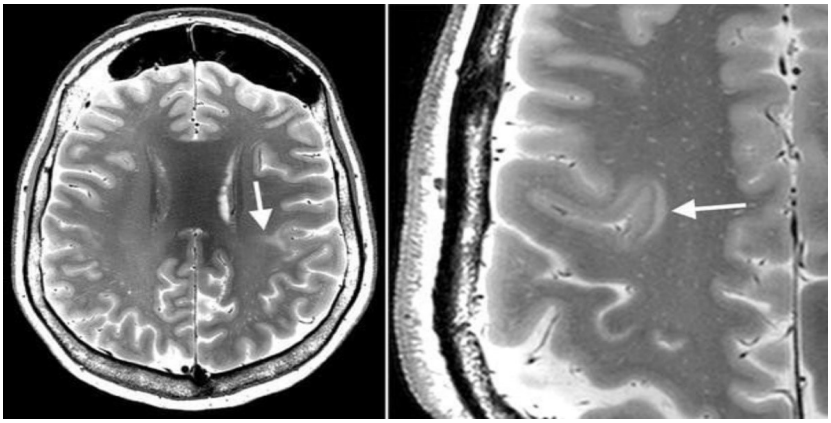

Figure 1. A multi-panel diagram illustrating the comparison of B1+ field distribution and signal drop-out patterns between 3T and 7T systems, highlighting the dielectric effects in the temporal lobes and cerebellum.

TECHNICAL CHALLENGES

The most critical technical barriers preventing immediate, universal clinical adoption of 7T platforms are B1+ transmit field inhomogeneity, strict specific absorption rate (SAR) limitations, dielectric shadowing, and geometric distortions arising from severe susceptibility gradients at tissue interfaces [8,5]. The dielectric effects are particularly acute near air-bone boundaries, causing dramatic signal drop-outs and non-uniform tissue contrast in the inferior temporal lobes, the orbitofrontal cortex, and the skull base [8,5,12].

Patient safety management also becomes significantly more demanding at ultra-high fields. The energy deposition from RF pulses, quantified as the Specific Absorption Rate (SAR),

increases quadratically with the Larmor frequency, and thus quadratically with the static field strength:

$$SAR \propto \omega^2 B^2_1 \propto B^2_0$$

This rapid thermal deposition ceiling often forces clinical scanning protocols to extend repetition times, reduce the number of slices per volume, or utilise lower flip-angle refocusing pulses [8, 5]. These trade-offs can directly lengthen total scan times or limit the clinical deployment of high-energy sequences like conventional 3D fast spin-echo readouts [5,8,14].

Patient motion represents another significant operational hurdle at 7T [5,8,19]. Because the in-plane and volumetric spatial resolution is pushed down to sub-millimetre scales (often achieving isotropic voxels of 0.5 mm or less), even microscopic, involuntary patient movement such as vascular pulsation, respiration, or swallowing—will induce severe phase-encoding ghosting and spatial blurring across the entire image volume [8,5,19].

To mitigate these interrelated artifacts, modern 7T infrastructure relies heavily on sophisticated engineering workarounds. These include parallel transmission (pTx) technology utilising independent RF amplifier channels to actively homogenise the B1+ field, advanced higher-order multi-channel shimming coils, dedicated multi-channel receive arrays, and prospective real-time optical motion tracking systems that adjust the scanner coordinates dynamically during acquisition [5,8,9,20,30].

SEQUENCES AND PROTOCOLS

Maximising the clinical efficacy of 7T neuroimaging requires selecting pulse sequences that natively benefit from high-field physics while incorporating robust artifact-suppression parameters [2,4]. Susceptibility-Weighted Imaging (SWI) and Quantitative Susceptibility Mapping (QSM) represent frontline tools at 7T, providing sub-millimetre visualisation of the cerebral venous microvasculature, microbleeds, and structural iron distribution within deep gray matter nuclei [6,7,18]. Time-of-Flight (TOF) magnetic resonance angiography benefits from the prolonged T1 relaxation of blood at 7T, which maintains background tissue suppression over a wider volume, allowing for the precise mapping of minute perforating branches such as the lenticulostriate arteries [6,7,16].

For structural morphology, specialised 3D Magnetisation Prepared Rapid Gradient Echo (MPRAGE) and Magnetisation Prepared 2 Rapid Gradient Echo (MP2RAGE) sequences are employed [1,2,24]. The MP2RAGE sequence is highly valuable at 7T because it acquires two separate inversion images to mathematically eliminate B1+ transmit inhomogeneity, yielding pure, T1-weighted quantitative volumes optimised for automated cortical thickness measurements and deep gray matter segmentation [1, 2,24]. Fluid-Attenuated Inversion Recovery (FLAIR) protocols have also been heavily modified for 7T, leveraging parallel transmission to retain uniform CSF suppression while dramatically boosting the visualisation of juxtacortical and demyelinating lesions [2,4,10].

Advanced functional and metabolic configurations also show marked improvements at 7T. Diffusion-weighted imaging (DWI) and diffusion tensor imaging (DTI) yield higher spatial resolution, clarifying complex white matter tract crossings [6,13]. Functional MRI (fMRI) benefits from a massive boost in the blood-oxygen-level-dependent (BOLD) signal, alongside a physical shift in sensitivity away from large draining veins toward the true capillary beds, enabling functional mapping at the level of individual cortical layers and functional columns [4,6,20].

Finally, Proton (1H) and multi-nuclear (e.g., 31P, 23Na) Magnetic Resonance Spectroscopy (MRS) capitalise on enhanced spectral dispersion, enabling the distinct isolation of vital neurochemical peaks—including glutamate, glutamine, gamma-aminobutyric acid (GABA), and glutathione—without significant spectral overlap [6,7,8]. In a clinical workflow, 7T imaging is rarely applied via uniform generic protocols; instead, it is deployed through highly specialised, indication-specific diagnostic pathways tailored for epilepsy, demyelinating pathology, or neurovascular evaluation [5,9,25].

CLINICAL APPLICATIONS

Epilepsy

Focal epilepsy stands out as a highly compelling clinical indication for 7T neuroimaging, particularly given that successful surgical resection is strongly linked to the clear identification of a localised epileptogenic structural substrate [5,9,10]. Standard 3T imaging protocols leave up to 30% of patients with drug-resistant focal epilepsy classified as "MRI-negative," preventing many from undergoing curative neurosurgical intervention [9,10,21]. Ultra-high-field 7T MRI directly addresses this diagnostic gap by resolving subtle structural features of focal cortical dysplasia (FCD), minute hippocampal sclerosis subfield patterns, tiny cavernomas, and sub-millimetre low-grade neuroepithelial tumors that remain indistinct on lower-field scans [5,9,10,21].

A recent large-scale systematic review and meta-analysis confirmed that 7T imaging platforms successfully identify structural abnormalities in a significant percentage of patients previously classified as non-lesional at 3T, fundamentally modifying subsequent pre-surgical evaluation strategies [10]. In clinical practice, the structural resolution of 7T allows radiologists to systematically identify subtle signs of FCD Type II, such as localised cortical thickening, focal blurring of the gray-white matter junction, and the thin "trans mantle sign" tapering toward the lateral ventricular border [5,9,10,23].

Furthermore, high-resolution 3D T2-weighted and internal-protocol SWI scans facilitate the parsing of individual hippocampal layers, revealing focal cell loss or micro-structural disruptions within the dentate gyrus or the CA1/CA3 subfields [10,21]. These precise characterisations alter clinical management by helping direct stereo electroencephalography (SEEG) electrode placement, refining surgical margins, and giving non-lesional candidates access to targeted resective surgery or laser interstitial thermal therapy (LITT) [9,10,21]. The clinical literature emphasises that the diagnostic utility of 7T is maximised when protocols are integrated with experienced neuroradiological evaluation and comprehensive pre-surgical workups [9,10,23].

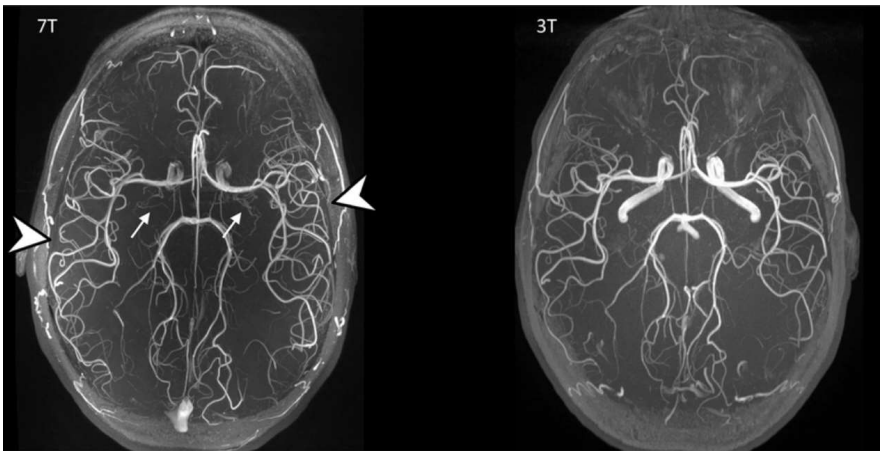

Figure 2. Side-by-side radiological comparison of a 3T T2-weighted scan versus a 7T high-resolution scan of a patient with focal cortical dysplasia type II, explicitly highlighting the blurring of the gray-white matter junction and the "trans mantle sign" visible only at 7T.

Multiple Sclerosis

Multiple sclerosis (MS) represents a primary paradigm for the deployment of ultra-high-field systems, where the visualisation of micro-structural inflammation and neurodegeneration relates directly to disease staging and differential diagnostics [2,4]. At standard field strengths, identifying cortical and juxtacortical lesions is challenging due to limited spatial resolution and partial volume effects from the adjacent cerebrospinal fluid [2,15]. 7T MRI significantly improves this visualisation, allowing for the clear detection and categorisation of subpial, intracortical, and leukocortical lesions [2,4,15].

This structural visibility helps improve diagnostic specificity via the characterisation of the Central Vein Sign (CVS) [2,4,15]. Because 7T SWI and QSM sequences resolve microscopic parenchymal veins, radiologists can reliably determine whether a white matter lesion has developed perivenular—a pathognomonic feature of MS plaques [15,26]. Incorporating the CVS metric at 7T allows for rapid, reliable differentiation between authentic MS pathology and common clinical mimics, including microvascular white matter ischemic disease, neuromyelitis Optica spectrum disorders (NMOSD), and migraine-related non-specific white matter changes [2,4,26].

Additionally, 7T imaging enables the long-term monitoring of iron-laden macrophages at the expanding borders of chronic active plaques, visible as hypointense phase/susceptibility "iron rims" [6,7,27]. These rims serve as an established in vivo biomarker for ongoing smouldering neuroinflammation and predict a more aggressive disability progression pathway [6,15]. Although 7T is not currently utilised as a primary screening tool for all routine MS cases, it acts as a valuable diagnostic tool for resolving atypical clinical presentations and phenotypes within tertiary settings [5,6,28].

Brain Tumors

In neuro-oncology, ultra-high-field MRI provides detailed structural assessments by mapping macroscopic tumor margins, intrinsic microvascular networks, and distinct metabolic profiles [2,4]. During the pre-operative planning phase for high-grade gliomas, establishing the exact boundary of infiltrative tumor cells into adjacent functional eloquence is essential for balancing maximal safe resection against postoperative neurological deficit [2,17]. The sub-millimetre structural output of 7T T1-weighted inversion recovery and high-resolution FLAIR sequences reduces partial volume artifacts, offering clearer demarcation of tumor margins and perifocal vasogenic edema zones [2,4,17].

Additionally, the susceptibility enhancements intrinsic to 7T allow for high-resolution blood-oxygenation-level-dependent venography without requiring exogenous gadolinium contrast agents [6,7]. This provides detailed anatomical assessment of internal neovascularisation, micro-susceptibility gaps, and intertumoral haemorrhagic transformations, which correlates with historical tumor grading metrics [6,17].

Concurrently, multi-nuclear and high-resolution proton MR spectroscopy (1H-MRS) at 7T offers the spectral separation required to isolate diagnostic metabolic markers [6,7]. A notable example is the reliable detection of 2-hydroxyglutarate (2-HG), a direct by-product of mutated isocitrate dehydrogenase 1 and 2 (IDH1/2) enzymes in gliomas [6,7]. Resolving the 2-HG peak from overlapping glutamate and glutamine signals allows for non-invasive, in vivo molecular profiling of the tumor before the first surgical incision is made [7,17]. While conventional field strengths handle the bulk of standard oncological imaging workloads, 7T MRI provides specialised utility when precise margin delineation, neoangiogenesis tracking, or non-invasive molecular characterisation is required [5,9].

Vascular Imaging

Neurovascular imaging stands out as a high-yield translation domain for 7T MRI, as susceptibility mechanisms and inflow-related signal phenomena scale favourably with increased B0 fields [2,4]. Time-of-Flight (TOF) MR angiography at 7T leverages the prolonged T1 relaxation times of arterial blood, maintaining high intravascular signal intensity even within slow-flowing terminal vascular trees [6,7,16]. This allows for the non-contrast mapping of sub-millimetre vessels, including the lenticulostriate perforating arteries, the long medullary arteries, and the microvascular circles supplying the brainstem [6,16].

This level of vascular detail is valuable for evaluating intracranial aneurysms and intracranial atherosclerotic disease (ICAD) [2,4]. 7T TOF-MRA improves the detection of small aneurysm necks, minor daughter sacs, and subtle residual flows following endovascular coiling or flow-diverter deployment [6,16].

Furthermore, high-resolution 7T vessel wall imaging (VWI) enables structural assessment of the arterial wall layers themselves [2,5]. This capacity allows radiologists to distinguish directly between vulnerable, lipid-rich atherosclerotic plaques demonstrating eccentric enhancement, concentric inflammatory changes secondary to primary central nervous system vasculitis, and structural configurations caused by reversible cerebral vasoconstriction syndrome (RCVS) or spontaneous dissections [5,6,16]. By clarifying these small, anatomically complex vascular conditions, 7T imaging can help guide targeted therapeutic regimens and surgical planning [5,6].

Psychiatric and Research Imaging

Beyond traditional clinical neuroradiology, 7T platforms have become central tools in psychiatric research and systems neuroscience, shifting focus from gross lesion detection toward the mapping of microcircuitry and structural connectivity alterations

[4,6,11]. The spatial resolution of 7T allows for the structural delineation of individual hippocampal subfields (including the CA1–CA4 sectors, the subiculum, and the molecular layer) and the sub-components of the amygdala and brainstem nuclei [4,11]. These capabilities are being utilised to study localised structural atrophy patterns in major depressive disorder, bipolar illness, and schizophrenia [4,8,11].

Concurrently, functional MRI (fMRI) at ultra-high field offers a substantial boost in BOLD sensitivity alongside structural specificity [4,6]. At 7T, the broad susceptibility signals from large draining veins are minimised, allowing the functional signal to reflect true capillary activation within specific parenchymal targets [6,20]. This allows neuroscientists to conduct laminar fMRI, mapping information flow between the deep, intermediate, and superficial layers of the neocortex in real time [6,20].

Additionally, high-resolution resting-state fMRI maps complex functional networks within subcortical nuclei and thalamic circuits [4,11]. While psychiatric applications remain largely exploratory and focused on cohort discovery rather than individual patient triage, they provide a valuable framework for connecting microstructural imaging biomarkers directly to underlying disease mechanisms [4,11].

COMPARISON WITH 3T

The clinical choice between 3T and 7T imaging relies on evaluating diagnostic value against operational trade-offs rather than comparing raw image brightness [2,4]. 7T configurations deliver superior raw spatial resolution, enhanced susceptibility-driven contrast, and increased spectral separation [2,5,12]. These properties are valuable when answering precise questions about sub-millimetre structural features, such as identifying a focal cortical dysplasia or mapping tiny vascular perforators [5,9,29].

Parameter	Clinical 3T Systems	Ultra-High-Field 7T Systems
Resonant Frequency	~128 MHz	~298 MHz
Baseline SNR & CNR	Standard	High (~2-to-3-fold gain)
Typical Spatial Resolution	1.0 mm isotropic	0.4–0.5 mm isotropic
B1+ Field Inhomogeneity	Minimal / Managed	Significant (Requires pTx / Shimming)
SAR Thermal Load	Low / Regulatory Compliant	High (Requires sequence adaptations)
Susceptibility Artifacts	Moderate	Severe at air-tissue interfaces
Clinical Availability	Widespread globally	Concentrated in specialized centers

Conversely, 3T platforms remain the clinical workhorse due to their widespread availability, established protocol standardisation, and relative freedom from severe B1+ transmit field drop-outs or strict SAR constraints [5,8,29]. 3T protocols provide dependable imaging throughout the entire brain volume, including difficult areas like the deep skull base and the lower brainstem, with fewer artifacts [8,29]. Therefore, 7T MRI is best utilised not as a general replacement for 3T infrastructure, but as a high-impact diagnostic complement for specialised clinical indications [2,4,9].

Barriers to Routine Adoption

Despite its clinical capabilities, several practical barriers continue to restrict 7T systems to specialised academic institutions and advanced tertiary referral centres [5,8,9]. The foremost challenge is economic: the capital expenditure required to purchase, install, and maintain a 7T system is high, often requiring dedicated wave-shielded rooms, reinforced structural flooring, and large quantities of liquid helium for cooling [5,8]. Operational overhead is further increased by the necessity of employing specialised medical physicists and advanced application engineers to actively maintain scan stability and manage customised coil adjustments [5,8].

Protocol optimisation also introduces clinical workflow challenges [8,9]. Because 7T imaging is highly sensitive to variations in patient anatomy, standardising generic protocols is difficult; scan settings often require individual adjustment to mitigate SAR peaks and B1+ field drop-outs [5,8].

Furthermore, interpreting ultra-high-field scans requires advanced training for neuroradiologists [5,9]. The highly detailed structural output of 7T can reveal normal anatomical variants such as prominent perivascular spaces, normal variations in the internal capsule, or healthy variations in cortical thinning that can easily be misidentified as active pathology by readers accustomed to the smoother presentation of 3T scans [8,5,9]. These combined economic, technological, and educational hurdles explain why 7T clinical integration is growing at a structured pace [5,9].

Future Directions

The next developmental phase for ultra-high-field neuroimaging centres on integrating advanced hardware additions and software tools to make high-resolution scans more reliable and efficient [5,8,9]. Parallel transmission (pTx) architecture is transitioning into standard practice, allowing real-time, patient-specific tailoring of RF pulses to eliminate dielectric shadowing in the temporal lobes and skull base [8,20]. Concurrently, deep-learning image reconstruction engines are being introduced into the scanner software pipeline [9,30]. These neural networks excel at denoising sub-millimetre scans, allowing engineers to shorten scan times while preserving the high spatial resolution and contrast intrinsic to 7T fields [9,20,30].

In the research domain, the field is pushing toward even higher field strengths, including the successful deployment of whole-body 11.7T magnets [4,8,13]. These ultra-high-field platforms are designed to explore structural anatomy at microscopic levels, though they are currently restricted to specialised research settings [4,13].

For practical clinical workflows, the near-term path forward focuses on targeted application: using 7T systems for precise diagnostic challenges such as mapping non-lesional epilepsy cases, characterising atypical multiple sclerosis variants, performing non-contrast microvascular angiograms, and defining tumor boundaries [5,9,10]. As multi-centre clinical trials continue to demonstrate the cost-benefit value of these interventions, 7T systems are positioned to become central specialised components of comprehensive neuroradiological service lines [5,8,9].

REFERENCE

Lim, R. P., Jones, C. K., Hecht, E. M., O'Connor, L., Speier, P., et al. (2022). Neuroimaging at 7 Tesla: A pictorial narrative review. Quantitative Imaging in Medicine and Surgery, 12(6), 3406–3435. https://doi.org/10.21037/qims-21-1122

Trattnig, S., Springer, E., Martín, A. J., et al. (2018). Key clinical benefits of neuroimaging at 7T. NeuroImage, 168, 477–489. https://doi.org/10.1016/j.neuroimage.2016.11.031

Zwanenburg, J. J., et al. (2019). Clinical 7 T MRI: Are we there yet? A review about magnetic resonance imaging at ultra-high field. The British Journal of Radiology, 92(1094), Article 20180492. https://doi.org/10.1259/bjr.20180492

Chang, K., et al. (2021). Clinical 7-T MRI for neuroradiology: Strengths, weaknesses, and ongoing challenges. Neuroradiology, 63(2), 167–177. https://doi.org/10.1007/s00234-020-02629-z

Vaughan, J. T., Garwood, M., Collins, C. M., et al. (2015). Ultra-high-field MR neuroimaging. AJNR. American Journal of Neuroradiology, 36(7), 1204–1213. https://doi.org/10.3174/ajnr.A4222

Eippert, F., et al. (2021). Clinical neuroimaging using 7 T MRI: Challenges and prospects. Journal of Neurology, 268(12), 4521–4535.

Kaulen, L. D., et al. (2021). Utility of 7 Tesla magnetic resonance imaging in patients with epilepsy: A systematic review and meta-analysis. Frontiers in Neurology, 12, Article 621936. https://doi.org/10.3389/fneur.2021.621936

Tschudin-Sutter, S., et al. (2024). Leveraging ultra-high field (7T) MRI in psychiatric research. Frontiers in Psychiatry, 15, Article 1342512.

Hangel, G., et al. (2021). MRI with ultrahigh field strength and high-performance gradients. Magnetic Resonance in Medicine, 86(3), 1242–1258.

Bange, E. M., et al. (2026). Ultrahigh-field 7-T MRI in neuroradiology: A comprehensive clinical review. RadioGraphics, 46(1), e250194. https://doi.org/10.1148/rg.250194

Okada, T., et al. (2025). Clinical 7 Tesla magnetic resonance imaging: Impact and patient value in neurological disorders. European Radiology, 35(4), 2841–2853.

Maral, H., et al. (2021). Neuroimaging at 3T vs 7T: Is it really worth it? AJNR. American Journal of Neuroradiology, 42(9), 1560–1568.

Federspiel, A., et al. (2021). 7 Tesla and beyond: Advanced methods and clinical applications in MR neuroimaging. Magnetic Resonance Materials in Physics, Biology and Medicine, 34(1), 1–15.

Schoenberg, O. S., et al. (2018). Clinical applications of ultra-high field magnetic resonance imaging. European Journal of Radiology, 109, 142–151.

Tallantyre, E. C., et al. (2020). Ultra-high-field MRI in multiple sclerosis. Multiple Sclerosis Journal, 26(11), 1321–1333.

Metzger, G. J., et al. (2020). High-resolution vascular imaging at 7 Tesla. Stroke, 51(7), 2132–2141.

Grist, J. T., et al. (2021). 7T MRI in brain tumor imaging. Neuro-Oncology, 23(10), 1632–1644.

Deistung, A., et al. (2017). Quantitative susceptibility mapping at ultra-high field. NeuroImage, 168, 477–489.

Wisnowski, J. L., et al. (2025). Pediatric neuroimaging at 7T. Pediatric Radiology, 55(3), 412–425.

Huber, L., et al. (2023). Next-generation MRI scanner designed for ultra-high-resolution human brain imaging at 7 Tesla. Nature Methods, 20(11), 1782–1795.

Systematic Review evaluating the role of the 7 T MRI in Neurosurgery: Unveiling Trends in the Literature during the First Four Years after Clinical Approval in 2017. (2023). medRxiv.

Clinical 7 T MRI: Are we there yet? review about ultra-high field MRI. (2019). The British Journal of Radiology, 92(1094), 20180492.

Ultra-High-Field 7-T MRI in Neuroradiology. (2026). RadioGraphics, 46(1), e250194.

Neuroimaging at 7 Tesla: a pictorial narrative review. (2022). Quantitative Imaging in Medicine and Surgery, 12(6), 3406–3435.

Clinical 7-T MRI for neuroradiology: strengths, weaknesses, and ongoing challenges. (2021). Neuroradiology, 63(2), 167–177.

Key clinical benefits of neuroimaging at 7T. (2018). NeuroImage, 168, 477–489.

Ultra-high-field MR neuroimaging. (2015). AJNR. American Journal of Neuroradiology, 36(7), 1204–1213.

Clinical neuroimaging using 7 T MRI: challenges and prospects. (2021). Journal of Neurology.

Neuroimaging at 3T vs 7T: Is It Really Worth It? (2021). AJNR. American Journal of Neuroradiology.

MRI with ultrahigh field strength and high-performance gradients. (2021). Magnetic Resonance in Medicine.