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Potential applications of 7 Tesla magnetic resonance imaging in paediatric neuroimaging: Feasibility and challenges

Arachchige AS *et al*. 7 T MRI in paediatric neuroimaging
Abstract

The integration of 7 Tesla magnetic resonance imaging (7 T MRI) in adult patients has marked a revolutionary stride in radiology. In this article we explore the feasibility of 7 T MRI in paediatric practice, emphasizing its feasibility, applications, challenges, and safety considerations. The heightened resolution and tissue contrast of 7 T MRI offer unprecedented diagnostic accuracy, particularly in neuroimaging. Applications range from neuro-oncology to neonatal brain imaging, showcasing its efficacy in detecting subtle structural abnormalities and providing enhanced insights into neurological conditions. Despite the promise, challenges such as high cost, discomfort, and safety concerns necessitate careful consideration. Research suggests that, with precautions, 7 T MRI is feasible in paediatrics, yet ongoing studies and safety assessments are imperative.

Key Words: 7 Tesla magnetic resonance imaging; Pediatric imaging; Feasibility; Challenges


Core Tip: 7 Tesla magnetic resonance imaging has the potential to revolutionize paediatric neuroimaging, offering unparalleled clarity and precision given that the necessary safety precautions and challenges are addressed. Its heightened sensitivity reveals subtle structural abnormalities, aids in epilepsy diagnosis, and provides deeper insights into conditions like neuro-oncology. Harnessing the power of ultra-high-field imaging may provide access to a new era of diagnostic accuracy and therapeutic planning for paediatric patients.

INTRODUCTION
In the ever-evolving landscape of medical imaging, the integration of cutting-edge technologies holds immense promise for advancing diagnostic precision and patient care. One such groundbreaking innovation is the 7 Tesla magnetic resonance imaging (7 T MRI) which received United States Food and Drug Administration (FDA) and European Medicines Agency approval for clinical use in 2017[3]. In particular, the FDA has approved 7T MRI in infants of 1 month and older. The limit of the main static field in neonates is 4T MRI while the specific absorption rate limits are the same for both adults and neonates[11]. Traditionally reserved for research settings due to its unprecedented image resolution, the feasibility of employing 7 T MRI in routine clinical practice for paediatric cases could present a transformative prospect. According to a team of experts at King’s College London, the current emphasis is on scanning infants at a high risk of brain injuries that may go unnoticed by other scanners, such as those born prematurely or with congenital heart conditions[16].

However, the transition to 7 T MRI in infants is not without its intricacies and hurdles. This article delves into the current state of the art in 7 T MRI for paediatric patients, exploring both its feasibility as a diagnostic tool and the unique challenges encountered in its application. By navigating the nuances of this technological frontier, we aim to provide a brief overview that contributes to the ongoing discourse surrounding this technical innovation in paediatric radiology.

APPLICATION
Most of the applications of 7 T MRI in the paediatric population so far have been focused on neuroimaging and holds substantial promise in this realm, presenting a spectrum of opportunities and challenges. 7 T MRI offers superior signal-to-noise and contrast-to-noise ratios, elevated spatial resolution, and enhanced tissue contrast, making it an appealing tool for in-depth examination of the paediatric brain and spinal cord, see Figure 1.

In the last years, there have been several ultra-high-field MRI studies demonstrating diagnostic benefits in neuroimaging. The high spatial and contrast resolution enable the
detection of subtle structural abnormalities, particularly relevant in epilepsy cases where imaging at conventional field strengths may yield negative results\[19\]. Studies on adult and paediatric population with epilepsy have demonstrated that the higher spatial resolution, signal-to-noise ratio and altered contrast behaviour of 7 T MRI can increase detection sensitivity and delineation of potential epileptogenic lesions as well as the detection of epileptogenic focal cortical dysplasia (FCD) not clearly visible at conventional field strengths. In a prospective study, 7 T MRI revealed distinct lesions in some patients previously considered MRI-negative. For example, 7 T MRI helped diagnose FCD in paediatric patients who underwent surgical resection\[9\]. Also, FCD is very common among paediatric patients and can make epileptogenic lesions seen in focal epilepsy radiologically subtle. A pilot study by Vecchiato et al suggested that among paediatric patients, those who are 3 T MRI-negative, but positron emission tomography-positive in particular could benefit from MRI at 7 T\[9\]. Similarly, at 7 T imaging could reveal more anatomic details of polymicrogyria compared with 3 T conventional sequences.

Furthermore, 7 T MRI has been shown to enhance MR angiography, offering improved image quality and the ability to detect smaller vessels. This capability, together with the increased contrast is especially pertinent in neurovascular assessments, for example allowing better identification of subtle vascular malformations due to increased susceptibility-weighted imaging (SWI) contrast, as well as delineation of cavernomas\[12-14\].

Structural and functional connectivity studies, facilitated by 7 T MRI, empower presurgical planning for deep brain stimulation surgery and hold promise for unravelling alterations in neuronal networks associated with various neuropsychiatric disorders. Neuro-oncology applications also benefit significantly from the fine structural detail attainable at 7 T. To provide an example of the level of detail achievable at 7 T, a recent study investigated childhood maltreatment (CM) related changes using 7 T MRI. The study suggested that experiencing emotional abuse or neglect in childhood affects morphology of brain regions involved in cognition,
emotional processing, and memory. Further investigations of CM related morphological brain changes with 7 T MRI and greater sample size will be needed to confirm these findings and to be conducive to better understanding of the neurological effects of emotional events[3].

Another area of immense promise is magnetic resonance spectroscopy (MRS) at 7 T. Due to the increased signal-to-noise ration and increased spectral resolution, this advanced technique could take advantage from the increased magnetic field strength allowing for the quantification of numerous neurometabolites with higher precision, presenting diagnostic and prognostic opportunities for conditions involving disrupted neurotransmitter balances, such as mood disorders, autism spectrum disorder, and epilepsy. Additionally, MRS can serve as a valuable tool for monitoring therapeutic responses, aiding in the personalized treatment of neurological conditions. The advantages of 7 T MRI extend beyond MRS. For example, chemical exchange saturation transfer imaging at 7 T provides opportunities to probe tissue chemistry in unprecedented detail, potentially unveiling insights into conditions like stroke, tumors, and neurodegeneration by monitoring pH and metabolite levels. Even spinal cord imaging, historically challenging at high field strengths, shows promise at 7 T, enabling research into conditions like multiple sclerosis[2].

In addition, the neonatal period is a critical phase of rapid brain development, making it an opportune time to study brain anatomy and potential injuries. However, conventional MRI systems at 1.5 T and 3 T have limitations in terms of tissue contrast and resolution. In contrast, 7 T MRI offers enhanced signal-to-noise ratio and tissue contrast, potentially improving sensitivity to both anatomical and pathological features in neonatal brain imaging. In a study by De La Fuente et al involving 17 neonatal scans with a median corrected age of 40 + 3 wk, all conducted with ethical approval, revealed that 7 T MRI provided additional anatomical and pathological details compared to 3 T MRI in the same neonates. These improvements were confirmed through neuroradiology reviews and included enhanced visualization of structures like the hippocampus, cerebellar vermis, and occipital cortical folding. Moreover, 7 T imaging
offered better insights into conditions like periventricular leukomalacia, providing clearer visualization of cystic septi and the hemorrhagic origin of cystic lesions in preterm infants. Furthermore, 7 T MRI has demonstrated diagnostic value in various neurological conditions, including polymicrogyria, moyamoya disease, hippocampal sclerosis, brain tumors, stroke, and multiple sclerosis. Likewise, outside applications in the nervous system, a study by Kolb et al. evaluated the clinical feasibility of ultrahigh field 7-T SWI to visualize vessels and assessed their density in the immature epiphysial cartilage of human knee joints. The study concluded that the use of SWI in conjunction with 7-T MRI makes the in vivo visualization of vessels in the growing cartilage of humans feasible, providing insights into the role of the vessel network in acquired disturbances. While there exist only few studies discussing the applications of the 7T MRI outside the CNS in paediatric patients, we can speculate that its use will expand to other areas in the near future.

As also demonstrated through feasibility studies, the enhanced quality of both SWI and single-shot T2-WI (T2WI) at 7 T is ascribed to a shorter T2-relaxation time, superior spatial resolution, and heightened susceptibility, potentially facilitating microstructural assessments. In contrast, T1WI quality at 7 T in infants has been observed to be inferior to that at 3 T, attributed to prolonged T1-relaxation time and the elevated water content in neonatal brains. However, the extended T1-relaxation time holds promise for future improvements in angiography quality.

CHALLENGES AND SAFETY CONSIDERATIONS

While studies at 7 T on adults are numerous, the literature about application and safety in paediatric population is scarce. It is imperative to highlight the certain considerations before conducting ultra-high field MRI studies in paediatric patients. Challenges associated with 7 T MRI include high cost, susceptibility artifacts, image inhomogeneity, and patient comfort and safety concerns including tissue heating, consideration with protocol to reduce specific absorption rate, implants heating, etc.
Increased radiofrequency power deposition, dizziness, nausea, vertigo, visual disturbances, and metallic taste are potential discomforts associated with 7 T MRI\textsuperscript{[5]}.

In the context of exploring the feasibility of employing 7 T MRI in paediatric settings, Chou \textit{et al}\textsuperscript{[7]} have shed crucial light on the comfort and practicality of this high-field imaging technique for children. Notably, the prevalence of noisiness as a source of discomfort across all age groups underscored the importance of addressing the sensory experiences of paediatric patients undergoing 7 T MRI scans. Additionally, the age-related differences in discomfort levels, with younger children reporting higher discomfort, highlighted the need for age-appropriate approaches to ensure the feasibility of 7 T MRI in paediatrics. While general discomfort was more frequent in adults during 7 T scans, the majority of adult respondents believed that children aged 12-17 years would tolerate 7 T scans well. These perceptions emphasize the potential psychological factors influencing pediatric patients’ experiences. In light of these findings, cautious enrolment of younger children in 7 T MRI studies is recommended, prioritizing their comfort and well-being, and underscoring the necessity for further research and strategies to enhance the feasibility and acceptance of 7 T MRI in paediatric populations. Nonetheless, the study concluded that the tolerability of 7 T MRI in children, particularly those above 8 years of age, appears to be comparable to lower field strengths, suggesting its potential viability for use in this demographic\textsuperscript{[7]}.

In addition, specific considerations are needed when using 7 T MRI in paediatric patients due to differences in size and development. Thus, optimizing the system and ensuring safety, particularly with regards to the magnetic susceptibility effect, relaxation times, and participant comfort\textsuperscript{[8]}. Fuente \textit{et al}\textsuperscript{[4]} performed a paediatric 7 T imaging study and to ensure the safety and comfort of the neonates during the 7 T scans, various precautions were taken, including modifying the scanner software to address potential temperature instability, swaddling the infants using vacuum-evacuated bags, providing hearing protection, and continuously monitoring vital signs such as heart rate and temperature using 7 T-compatible equipment. A range of MRI sequences were acquired, including high-resolution T2WI in multiple planes,
susceptibility-weighted images, T1 and T2 quantitative maps, functional MRI, and spectroscopy. The results of this study demonstrated the feasibility of conducting 7 T MRI scans on neonates, with all infants tolerating the procedure well. Vital sign monitoring remained stable throughout the scans, which lasted for an average of 52 min.

Furthermore, despite the advantages, there are limited reports of the clinical application of paediatric 7 T MRI. Thus, further research and experience are needed to determine the full potential of 7 T MRI in this context and therefore, rigorous safety screening and assessment are imperative before any paediatric patient enters the magnetic resonance scanner[9,10].

Incorporating the findings from Annink et al[10] into our discussion on preparations and safety measures for infant 7 T MRI enhances our understanding of specific considerations for this vulnerable population. According to Annink et al[10], positioning the infant precisely in the isocenter of the coil is paramount for Specific Absorption Rate (SAR) safety. This emphasizes the importance of meticulous patient positioning to optimize safety profiles. Additionally, they highlighted the significance of acoustic noise protection during 7 T MRI examinations. The study reported that the background noise in the sound booth was 28 dB, and the 7 T hood attenuated this noise by 8.5 dB. Using hearing protection devices such as the Alpine Muffy Baby and Natus Minimuffs further reduced the acoustic noise levels, ensuring a safer and more comfortable environment for infants. Importantly, the study found that global and peak SAR levels in the infant model did not exceed those in the adult model when positioned correctly, reaffirming the feasibility of 7 T MRI in infants when appropriate safety measures are implemented. Integrating these findings, it is evident that specific preparations, including precise positioning and acoustic noise protection, are essential for ensuring the safety and efficacy of 7 T MRI in infants, aligning with the overarching goal of minimizing risks while maximizing the potential benefits of this advanced imaging modality[10].
Moreover, recently, a patient has been scanned for the first time in the world under general anaesthesia in the highly powerful MAGNETOM Terra 7 T MRI scanner from Siemens Healthineers. This was performed at King’s College London’s Advanced MRI Centre, located St Thomas’ Hospital, London. This innovative anesthetic approach aims to enable patients, particularly young children who struggle to remain still in the 7 T MRI scanner, to access the technology. The procedure has the potential to benefit children dealing with conditions like epilepsy, tumors, and movement disorders, including dystonia-induced muscle spasms. Additionally, it could contribute to advancing innovative research projects[15].

CONCLUSION
In conclusion, as the investigation into the feasibility of implementing 7 T MRI in paediatric settings continues, the undeniable allure lies in its potential advantages concerning diagnostic precision, treatment monitoring, and research capabilities. The heightened image quality achieved through enhanced resolution and tissue contrast holds promise for elevating diagnostic sensitivity, shedding new light on the pathophysiological intricacies of conditions, especially those impacting neonates, such as neurodevelopmental disorders[17-19]. Nevertheless, the realization of these benefits necessitates a delicate balance with safety considerations and optimization efforts. The distinct challenges posed by high magnetic fields, particularly in the paediatric population, underscore the importance of ongoing research and expert oversight to ensure the judicious application of this advanced imaging technology.
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