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An Ultra-low-field Brain MRI Scanner that is Low-cost and does Not Require Shielding

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Commentary

Magnetic resonance imaging is an important diagnostic tool in modern healthcare, but the high installation, maintenance, and operation costs of the technology might make it prohibitively expensive. There are around seven scanners per million people, with over 90% concentrated in high-income countries. We describe an ultra-low-field brain MRI scanner that uses a conventional AC power source and is inexpensive to construct. It does not require magnetic or RF shielding cages since it uses a permanent 0.055 Tesla Samarium-cobalt magnet and deep learning to negate electromagnetic interference. During scanning, the scanner is small, portable, and acoustically quiet. We demonstrate preliminary capability in diagnosing brain tumour and stroke using four conventional clinical neuroimaging protocols (T1- and T2-weighted, fluid-attenuated inversion recovery like, and diffusion-weighted imaging) using our system. This type of technology has the ability to satisfy clinical needs at the point of care or in poor and middle-income countries.

Magnetic Resonance Imaging (MRI) is largely regarded as the most significant medical imaging technology advancement in modern medicine. Because it is non-invasive, non-ionizing, essentially quantitative, and multi-parametric, MRI is intrinsically superior to other imaging modalities. Because the human body is 70% water, there is an abundance of protons that can be activated, controlled, and observed by MRI. This allows doctors to see different types of tissues and assess their structural and physiological integrity. Every year, almost 150 million MRI investigations are performed worldwide. Examples of routine clinical MRI applications include disease diagnosis and prognosis (e.g., tumours, ischemic stroke, and haemorrhage) and bodily system damage (e.g., nervous, hepatobiliary, pancreatic, and musculoskeletal systems). The success of MRI use has been driven by the collaborative efforts of clinicians, physicists, and engineers around the world in their quest of quality and imaging capabilities. Notable technological advances include the development of powerful gradient and RF electronics to exploit the increased signal-to-noise ratio (SNR) at high field for speed and new contrasts; parallel signal receiving for fast imaging; and ultra-high-field MRI (7 T and higher) for scientific exploration and clinical applications. MRI accessibility, on the other hand, is limited and very inhomogeneous over the world.

According to the 2020 Organization for Economic Cooperation and Development (OECD) estimates, there are around 65,000 MRI scanner installations globally (7 per million inhabitants), compared to 200,000 CT scanners and 1,500,000 ultrasound scanners. The distribution of MRI scanners is primarily concentrated in high-income countries, with limited availability in low- and middle-income countries. As a result, 70% of the world's population has little or no access to MRI. This gap emphasises the prohibitively expensive nature of high-field superconducting MRI scanners (1.5 T and 3 T). For starters, these scanners rely on complex superconducting electromagnet/cryogenics designs and ever-increasingly powerful electronics (including gradient and radiofrequency power systems) for fast imaging and/or advanced imaging features such as brain functional MRI and diffusion tractography, despite the fact that routine clinical uses only necessitate a subset of these imaging protocols. Second, because to infrastructural requirements, they necessitate costly installation (e.g., site preparation to host the large magnets that typically weigh 3000-4500 kg, magnetic shielding and radiofrequency shielding, emergency helium exhaust conduit, electricity to drive power-consuming electronics, and water requirement for gradient cooling). Third, they necessitate a significant maintenance expense for helium refill/re-liquification (a scarce and diminishing non-renewable resource) and routine cold-head services. Finally, these sophisticated scanners necessitate substantial operating costs for trained radiography experts. As a result, the vast majority of clinical MRI scanners are housed on the ground floors of hospitals and clinics, in highly specialised radiology departments, big centralised imaging centres, or on the bottom floors of hospitals and clinics. This fact precludes neurology clinics, trauma centres, surgical suites, neonatal/pediatric hospitals, and community clinics from having simple access.

Finally, these considerations offer a significant barrier to MRI accessibility in healthcare. There has recently been a push to create low-cost MRI technologies with ultra-low-field (ULF) strengths, such as 0.1 T, for true point-of-care applications. They include resistive electromagnets capable of producing a homogeneous field (0.0065 T and 0.023 T), rotating Halbach permanent magnet array capable of producing an inhomogeneous field (0.077 T), Halbach single-sided permanent magnet array capable of producing an inhomogeneous field at 0.064 T, and magnet-free earth-field MRI imaging. These designs, however, have not exhibited sufficient picture quality or adaptability for clinical purposes. Despite its limitations, we and others believe that ULF has the potential to provide a new class of low-cost MRI technologies for accessible healthcare, with scanners that are simple to onboard, maintain, and operate. In this paper, we describe the design and preliminary clinical testing of a permanent magnet-based, low-cost, low-power, shielding-free brain ULF MRI scanner. Specifically, we built our system on a homogenous 0.055 T permanent double-pole magnet with linear imaging gradients. This setup enables us to create images with a variety of globally accepted contrasts and adjustable orientations for clinical brain imaging, such as Fluid-attenuated Inversion Recovery (FLAIR) and Diffusion-weighted Imaging (DWI). It also allows for a great degree of flexibility in constructing future ULF MRI protocols by drawing on the approaches developed for high-field MRI scanners over the last three decades. Second, we created a deep learning-driven EMI cancellation technique that can model, forecast, and robustly remove external and internal EMI signals from MRI signals, thereby eliminating the need for a standard RF shielding cage. Third, we were successful in integrating the four basic protocols for clinical brain MRI on our low-cost prototype scanner, namely T1-weighted (T1W), T2-weighted (T2W), FLAIR-like, and DWI with isotropic diffusion weighting. Finally, we established the early viability of using 3 T clinical MRI results to diagnose tumour and stroke cases [1-5].

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