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Final Version

From ultrahigh to extreme field magnetic resonance: where physics, biology and medicine meet

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The development of ultrahigh-field magnetic resonance (UHF-MR) is moving forward at an amazing speed that is breaking through technical barriers almost as fast as they appear. UHF-MR has become an engine for innovation in experimental and clinical research [1–11]. With more than 35,000 MR examinations already performed at 7.0 Tesla, the reasons for moving UHF-MR into clinical applications are more compelling than ever. The value of high-field MR has already proven itself many times over at lower field strengths; now 7.0 T has opened a window on tissues, organs and (patho)physiological processes that have been largely inaccessible in the past. Images from these instruments have revealed new aspects of the anatomy, functions and physio-metabolic characteristics of the brain, heart, joints, kidneys, liver, eye and other organs/tissues, at an unparalleled quality. The number 35,000 sounds large, but in fact we have barely cracked open the door and have yet to truly assess what lies on the other side.

That makes this a perfect moment for a highly topi- cal special issue of MAGMA: those of us who work in UHF-MR can see a clear route forward for resolving tech- nological issues and can outline some of the new opportunities that will accompany even higher field strengths. The issue provides an overview of the state of the art and discusses the clinical relevance of what we have already observed and can clearly foresee. Articles are devoted to development of novel methodology [12–16], safety topics [17–19] early multicenter trials [20], frontier human stud- ies [21–28], breakthrough clinical applications [29–36] and future directions of UHF-MR [37, 38]. At the moment some of these new concepts and clinical applications are merely of proof-of-principle nature and visions, but they are compelling enough to drive the field forward. We hope to engage the interest of clinicians, basic scientists, engineers, translational researchers and applied scientists from many areas, and particularly to attract young scientists and new entrants into the field. In doing

so, we hope to con- vince the MR imaging and spectroscopy communities to throw their weight into the task of solving technical prob- lems and conceiving new clinical applications. UHF MR has a staggering number of potential uses in neuroscience, neurology, radiology, cardiology, internal medicine, oncol- ogy, nephrology, ophthalmology and other related clinical fields. As they are developed, we will push the boundaries of MR physics, biomedical engineering and biomedical sci- ences in many other ways.

Another reason this special issue is timely is because physicists, engineers and pioneers from related disciplines have already taken an even further step into the future, in their minds, with something they are calling Extreme Field MR (EF-MR). This envisions human MR at 20 T [37, 38], and it is an important leap of the imagination because it aims to fill a crucial "resolution gap" in our understand- ing of human biology [39, 40]. While discoveries are pour- ing in on the molecular and cellular level every day, it is extremely difficult to integrate these findings into a coher- ent picture of the functions of tissues and pathological pro- cesses at a mesoscopic level above that of the cell. There is a wide gap between the view of biologists and clinicians that is begging to be filled. Extreme field MR is probably an ideal technology that will reach between these levels in vivo by bridging a crucial gap in resolution in space and time.

Achieving this goal will certainly require extra resources—and the will to go there. While the first 20 T class MR instruments will likely be devoted to discovery and to proof of principle, the findings will be crucial guides to making the best use of lower-resolution imaging tech- niques. The only thing that could keep the dream of human MR at 20 T from becoming reality would be a failure to fol- low the path and see what develops. Will the clinic even- tually be able to follow us to even higher fields? It always does, if a whole community of experts devotes their crea- tive efforts to the task. Currently we have only the roughest sense of what we will find. But even that glimpse has made some of us believers. We hope that this issue will convey the seeds of this vision and inspire you—as it has us—to become pioneers in these amazingly promising new areas of biomedical research: ultrahigh field and extreme field MR.

Compliance with ethical standards

Conflict of interest

The authors declare that they do not have a con- flict of interest with the exception that Thoralf Niendorf is CEO and founder of MRI.TOOLS GmbH, Berlin, Germany.

Ethical standards This editorial does not contain any studies with human participants or animal performed by any of the authors with the exception of references to previously published work included in this editorial.

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