Protocols and Methodologies in Basic Science and Clinical Cardiac MRI

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Foreword

Cardiovascular imaging is dynamic … not just in the literal sense as one follows cardiac contraction, but in a more global sense as this book highlights its continuing evolution. Cardiac imaging continues to undergo dramatic technical advances that spur new applications. The cycle of innovation, application, and innovation is seen repeatedly in this text. This book does a superb job of capturing the state of the art.

While there are many cardiac imaging methods, magnetic resonance provides by far the most comprehensive and diverse approach to understanding cardiovascular physiology and disease. The contributors to this book describe methods that cover the scale from molecular to macro. At the molecular level, hyperpolarized MRI (Chap. 4) and in vivo spectroscopy (Chaps. 5 and 6) probe cardiac metabolites in both endogenous and enhanced molecular species. At the cellular level, molecular-specific contrast agents yield insight into atherosclerosis (Chap. 8) through longitudinal studies that follow the evolution of plaques. At the cytoarchitectural scale, diffusion MRI and tractography (Chap. 3) illuminate details of the functional building units of the heart. At the meso- and macroscale, dynamic imaging methods (Chaps. 1, 2, and 9) simultaneously yield structure and function.

This book is comprehensive in a second important sense in that it covers cardiovascular disease in a truly interdisciplinary fashion. The fundamental physics of NMR is discussed in a comprehensible and relevant fashion. Engineering details of pulse sequences and novel strategies for measuring stress and strain are made clear. The chemistry underlying the metabolic pathways is accessible. Methods for quantitative measure of cardiovascular physiology and mechanics are included. Throughout, the many interdisciplinary threads are woven into the fabric of clinical cardiovascular disease. This book will find ready use by both basic scientists and clinicians seeking to use NMR/MRI to further understand cardiovascular disease.

Durham, NC, USA G. Allan Johnson

Preface

Magnetic resonance imaging has been a short-lived, yet an exciting and a fast-progressing scientific field. Its early era spans the early technical development years through ground-breaking work at Aberdeen ('spin-warp' fundamentals) in the late 1970s, the introduction of the concept of the gradients by Paul Lauterbur, the subsequent parallel efforts and the early prototype tests at Nottingham (Sir Peter Mansfield, Raymond Andrew, Waldo Hinshaw, Neil Holland) in the late 1970s, and the first clinical work at Hammersmith in London in the early 1980s. Collective efforts of chemists, physicists, engineers, and mathematicians led to the clinical product that found its way into widespread use in the clinic, engaging radiologists, cardiologists, neuroscientists, and radiographers, in a truly multidisciplinary effort. Original scientific efforts in Europe were complemented, and were often rivalled, by parallel (or competitive) efforts across the Atlantic. International conferences were held as early as 1976 in Nottingham, followed by the well-known conference in Winston-Salem in North Carolina in 1981 (inspired by the Wright brothers who used to travel through the American mid-west states (Ohio to North Carolina) during summer breaks to run tests on their plane prototypes, marking the onset of the modern aviation era). Despite their limited attendance, both conferences were organized by leading scientific figures in NMR/MRI (Professors Hoult, Johnson, Mansfield, Edelstein, Bottomley, Lauterbur, etc.) later to become some of the scientific pillars that supported and led the MRI field. The International Society of Magnetic Resonance Imaging was formed soon thereafter (1982) that supports and steers this niche scientific area to this date.

While early imaging efforts focussed on brain imaging, there are documented cardiac NMR attempts that date back to the 1950s. Some of the first high-resolution cardiac imaging works are attributed to Professor G. Pohost and dates back to the early 1980s. Early strides targeted studies on T_1 and T_2 relaxation, and perfusion and metabolism in myocardial, while independent attempts in New York were steered towards novel, direct, multinuclear (^{23}Na, ^{31}P) MRI (Professors Hilal, Cannon). Professors Zerhouni and Axel introduced (independently) the fundamental ideas behind myocardial tagging in the late 1980s, in an era that marked the onset of major, concerted efforts towards cardiac imaging, and the desire to establish cardiac MRI as a 'one-stop-shop' in the clinic.

Tremendous scientific progress was documented in the 1990s, including perfusion imaging (Professor N. Wilke), breathhold imaging (Professors McVeigh, Atalar), fast non-rectilinear imaging (Professor Glover), phase contrast imaging (Professor Pelc), cardiac functional imaging (Professors Higgins, Pettegrew, Raichek), and late gadolinium imaging (Professors Judd, Kim).

Strategic scientific planning in the early 2000s, concomitant with genomic mapping, opened new avenues in this area by introducing high-field, rodent cardiac imaging in the community. In association with major US funding program calls in nanomedicine, the introduction of stem cells to the scientific community during the same time period led to the emergence of the new subfield of molecular imaging, engaging molecular biology scientists, synthetic chemists, and geneticists (among others), marking the era of modern, personalized medicine.

This book focuses on the practical issues of the implementation of the state-of-the-art cardiac acquisition methodologies and protocols for both basic science and clinical practice. The motivation and philosophy behind its introduction is to serve as a practical guidebook for both beginners and advanced users for easy and practical implementation of acquisition protocols. It is relevant for a wide audience that ranges from students, residents, fellows, basic scientists, physicists, engineers, and medical practitioners.

The usefulness of this book relates to its intended practical use and focus on state-of-the-art cardiac MRI techniques that span both the clinical and basic science fields. In comparison and contrast to other similar, existing books, it is expected to distinguish itself for its practical usefulness and conciseness. Correspondingly, it may be used as a handbook (quick reference) for new starters, or people who would like to establish state-of-the-art cardiac MRI techniques at their institutions.

Given the historical evolution of the technical developments in MRI, the clinical and basic science topics are described separately. However, in instances where basic science development complements (or is envisaged to complement) clinical development, every effort has been made to ensure a comprehensive review, and associations of the clinical/basic science subfields.

Thirteen excellent contributions, which comprise this book, overview the current state of the art and describe relevant protocols and methodologies for implementation of basic science and clinical cardiac MRI techniques. Professor Young's opening chapter provides a superb overview of the role of MRI in preclinical and clinical functional quantification and modelling, while Professor Yu summarizes the current cardiac MRI techniques (tagging, DENSE, HARP, and SENC) for quantification of regional myocardial mechanics in the preclinical setting. Dr. Teh presents a comprehensive overview of ex- and in vivo diffusion MRI and tractography spanning the scales of the human to the animal hearts. On the forefront of metabolic and direct multinuclear imaging, Dr. Miller provides an excellent overview of the exciting new advances in ^{13}C hyperpolarized MRI and their role in the study of cardiac energetics (Kreb's cycle, CK pathways). Complementary is the following chapter by Dr. Maguire who introduces the fundamentals of preclinical cardiac, in vivo spectroscopy, and recent efforts to accelerate imaging using chemical shift imaging. Dr. Constantinides completes this chapter trilogy with a discussion on direct, cardiac multinuclear imaging, emphasizing direct ^{23}Na, ^{31}P, and ^{39}K MRI.

The final three chapters in the first part of this book introduce novel and exciting new approaches in MRI, including cardiac elastography by Professor Kolipaka, molecular imaging of atherosclerosis by Dr. Plaza, and compressed sensing and fast imaging by Dr. Wech and Professor Schneider.

The second part overviews the current state of the art in clinical MRI, with excellent contributions by Dr. Francois on MR flow and quantification, myocardial viability in ischemic heart disease by Drs. Alkhalil and Dall'Armellina, congenital heart disease in paediatric cases by Dr. Muthurangu, and an excellent overview of cardiac MR angiography by Dr. Prieto.

I am honoured to have had the opportunity to edit these superb contributions from some of the most progressive MR scientists nowadays, a truly international effort. I am indebted to the support provided by the local Oxford environment, and Springer publications (Mr. Weston, Mr. Tournois), who have been extremely supportive of this effort since its early start.

I wish and foresee that this book will be welcomed by the International Society of Magnetic Resonance Imaging and the scientists in the field of MRI as a useful resource in addition to the plethora of other existing books currently used for teaching or other educational purposes.

With a sense of indebtedness, I sincerely thank Professor G. Allan Johnson who has graciously accepted to write the foreword of this book, a true gentleman, and one of the pillars of this field since its early inception. It has been a unique experience to have met and worked with him, and I am truly obliged by his genuine support over the years.

Oxford, UK Christakis Constantinides

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Editor's Bio Information

Dr. Christakis Constantinides completed his undergraduate studies at the Imperial College of Science, Technology and Medicine (Bachelors with First Class Honors in Electrical and Electronic Engineering, 1992) and his graduate (CASP/USIA scholar) and postgraduate (Whitaker Foundation scholar) studies at the Johns Hopkins University Whiting School of Engineering (M.S.E, 1994) and the Johns Hopkins University School of Medicine (Ph.D., 2000), in Biomedical Engineering. He held an appointment as a Visiting Research Fellow (Fogarty International Fellow) at the National Institutes of Health (2001–2003). He became an Assistant Professor in the Mechanical Engineering Department at the University of Cyprus (2005–2013). He was subsequently trained at the EU Institutions (DG-EAC) in Brussels (October 2013–February 2014). He is currently a Marie-Sklodowska Curie Research Fellow in the Department of Cardiovascular Medicine at University of Oxford (2015–2017). His specific research interests focus on the study of cardiac mechanical function, computational and tissue structural modeling and characterization, hardware design, and functional and cellular tracking methods using magnetic resonance imaging.

He has published over 80 papers in international peer-reviewed journals and conferences. He is the author of one book, four book chapters, and the editor of three books. He is a member of the American Physiological Society (APS), the International Society of Magnetic Resonance in Medicine (ISMRM), and serves as a reviewer (among others) for the journals of *JCMR*, *PLoS One*, *Magnetic Resonance in Medicine*, *Journal of Magnetic Resonance Imaging*, *Journal of Magnetic Resonance*, *NMR in Biomedicine*, and *Journal of Applied Physiology*. He is also a reviewer for ISMRM, IEEE-SBI, EMBS, and EU's COST-Action program.

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Part I
Preclinical Cardiac Imaging