

Angelo Auricchio
Jagmeet Singh
Frank E. Rademakers *Editors*

Cardiac Imaging in Electrophysiology

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To my family for their support, love and patience.

Angelo Auricchio

To Noopur, Ashan and Ahaana for always being there.

Jagmeet Singh

To my wife and children for their love, support and understanding.

Frank Rademakers

Foreword

Cardiovascular imaging has become a subspecialty in cardiology on its own merit. It is central to every diagnostic pathway from detection to treatment of patients with all sorts of cardiac conditions. The advances and sophistication of all imaging modalities we have in our possession have progressed so much that close collaboration between imaging experts and clinicians is more essential than ever. Such is the level of sophistication of each individual imaging modality that it has become virtually impossible for any imager alone to be expert in all modalities so that individual expertise is required. At the same time, the cost of the technology has increased and a rational approach is required in order to avoid duplication of information. A careful balance between the diagnostic yield with the cost and potential safety concerns (radiation and contrast) is important. The real value of imaging in relation to improved outcomes however remains subjective, which explains, at least in part, the inconsistent utilisation of those technologies around the world.

Imaging has also become essential for the diagnosis and treatment of electrical disorders and the wealth of imaging options for the practicing electrophysiologist has exploded over the last decade, led perhaps by the ability to effectively ablate patients with atrial fibrillation and device implantation for treating heart failure patients. This book, by experts in electrophysiology and cardiovascular imaging, offers an essential guide to advanced imaging in patients with electrical disorders from a critical appraisal of technology through ablation and device therapies and the latest advances in magnetic and robotic navigation. It is ultimately, however, in the hands of the clinician to make the best use of the available technology for the patient's best benefit and avoid duplication and overlap, and this book offers exactly that.

London, UK

Petros Nihoyannopoulos

Preface

Major technological, basic, and clinical research breakthroughs have led to impressive changes in both diagnostic and therapeutic capabilities for the management of cardiac rhythm disorders. Over the last three decades, the diagnostic part has been enriched by sophisticated ECG recording systems and automatic analysis techniques, by the development of 3-dimensional (3D) electroanatomical mapping systems and advances in novel implantable devices capable of recording electrical signals as well as intracardiac and intravascular pressures. On the other hand, the most striking progress in the therapeutic arena has been in catheter-based ablation of different rhythm disorders, fast-paced progress in device therapy inclusive of implantable cardioverter-defibrillators, and cardiac resynchronization therapy.

Consequently, the role of the electrophysiologist in the field of cardiology has significantly expanded and the role of cardiac imaging has become a crucial and integral part of diagnostic and therapeutic electrophysiological procedures. This book attempts to cover the increased role of cardiac imaging in diagnosis and electrophysiological procedures. Various cardiac imaging modalities are now available to guide the electrophysiologist, from the first encounter with the patient and subsequently throughout the procedural and postprocedural care. These modalities have come to play an important role in appropriately selecting patients, guiding therapy, thereby reducing complications, and enabling us to closely monitor the effects of device therapy or catheter ablation procedures.

The advances in imaging modalities have been immense, and their use is no longer confined to the domain of the noninvasive cardiologist, but has expanded into the realm of image-guided interventions. This trend is clearly appreciated in transcatheter-based treatment of atrial and ventricular arrhythmias as well as in device implantation and management. Some of the potential advantages of imaging during invasive diagnostic and curative procedures include easier navigation, greater precision in targeting the region of interest, better catheter stability, minimizing collateral damage, and a reduction in radiation exposure to both patient and physician.

It is probably true that the diagnosis and treatment of atrial arrhythmias represent the best example of cardiac rhythm disorders in which imaging-assisted therapy delivery has played a major role. In particular, the demands created by the complexity of treating atrial fibrillation by catheter ablation has forced the paradigm shift from a pure electrophysiological based approach, in which intracardiac signal recording and fluoroscopy had originally founded the basis of therapy delivery, to the more contemporary approach involving 3D electroanatomical mapping integrated with either rotational angiography, cardiac tomography (CT), or magnetic resonance imaging (MRI). Image-guided atrial fibrillation ablation has facilitated the accuracy in localizing the anatomical target, enhanced safety while significantly reducing the procedure, and fluoroscopy time. At present, catheter ablation for AF is considered a reasonable option when antiarrhythmic drugs have failed. The cornerstone for most AF ablation procedures is the electrical isolation of pulmonary veins. The role of imaging in catheter ablation for AF encompasses (1) segmentation and integration of left atrium (LA) 3D anatomy into navigation systems, (2) intraprocedural visualization of the pulmonary veins, (3) delineating macro-reentrant circuits via activation maps, (4) mapping complex fractionated electrograms, and (5) most importantly manual as well as robotic-guidance of the ablation catheter to the specific area of interest.

More recently, the need to better define the substrate and more precisely define the anatomical characteristics of the chamber wall has come to be considered important for individualizing the ablative approach. A large number of imaging modalities have become potentially available for visualization of the LA wall, its thickness, and related tissue characterization. Rather than the conventional nomenclature of paroxysmal or persistent atrial fibrillation dictating the approach and extent of the ablation, it has become clear that more attention needs to be paid to structural characteristics such as atrial fibrosis. It is noteworthy that fibrosis may result from different disease processes that either directly alter the atrial wall 3D architecture and anatomical characteristics, or as a consequence of thermal damage occurring during isolation of the AF circuits. By analyzing fibrosis with delayed enhancement MRI, one may be able to better describe predictors of success and also help plan the ablation approach. Interestingly, recent work has shown that patients who had recurrent AF showed delayed enhancement in all portions of the LA, whereas patients free of AF-recurrence showed delayed enhancement confined to the posterior wall and septum. Image-guided ablation of these areas of contention appears to be related to improved ablation outcomes. Targeted and individualized approaches will help limit the extent of the ablation while enhancing success. Imminently, the future approaches will consist of real-time 3D imaging, thereby eliminating the errors and limitations of integration techniques.

Similar to catheter ablation of atrial arrhythmias, there is growing evidence that cardiac imaging can now better define the anatomic substrate and ablation targets for ventricular tachycardia (VT). CT and MRI strategies have become effective in complementing the conventional electroanatomical voltage map, providing an anatomic correlate to the underlying electrophysiological data during substrate ablation of scar-related VT. Novel multi-array mapping catheters specifically designed for VT ablation together with innovative postprocessing algorithms capable of high spatial resolution of scar tissue identified by MRI will continue to increase the accuracy to specifically localize the reentry isthmus and potentially improving the effectiveness of ablative therapy. Whether functional and metabolic information, derived either by nuclear medicine techniques or by MRI, will further help in defining the area of abnormal tissue activity is an area of intense investigation.

A novel concept within the constantly evolving imaging world involves interventional MRI, where the electrophysiologist in conjunction with 3D electroanatomical mapping performs real-time MR tracking of a deflectable MR compatible catheter. At present, this method involves real-time MRI positioning of an electrophysiologic catheter, which is overlaid onto high-resolution, time-resolved images. This technique provides real-time visualization of the anatomical substrate identical to the exposure of tissues obtained during surgery. Future development faces challenges such as catheter device improvement and acoustic noise reduction. Despite these challenges, MRI could revolutionize image-guided ablations above and beyond what can be currently provided by conventional imaging approaches. Another innovative technology, still in its preliminary stages, involves the use of real-time intracardiac 3D and transesophageal 4D ultrasound imaging probes to guide catheter ablation. The advantage of intracardiac or transesophageal ultrasound imaging is intrinsically related to the widespread utilization of the technique, the easy accessibility of the technology compared to MRI, the limited amount of human and finance resource utilization required for running it, as well as the modest initial investment.

A significant problem in the use of cardiac imaging for both device and ablation procedures by electrophysiologists is the limited training that most fellows in electrophysiology usually receive. Imaging techniques such as standard echocardiography or nuclear imaging are usually learned during cardiology training whereas more sophisticated techniques such as CT, MRI, or 3D/4D echocardiography are usually neglected. On the other hand, most imaging cardiologists or cardiac radiologists have little exposure to electrophysiological procedures or device implantation; therefore, for the purpose of guiding complex electrophysiological procedures, acquired images may be of suboptimal quality or image resolution and consequently integration into 3D electroanatomical systems may be inadequate. This gap between the community

of electrophysiologists and cardiac imagers should be bridged by more extensive common educational programs offered by scientific societies or dedicated training and educational programs.

Still questionable is whether the procedural efficiency will grow, and if the learning curve will get shortened. Evidently, the future of imaging modalities for treating arrhythmias and implementing device therapy will be determined by the overall clinical utility and cost-effectiveness of their use. At present, the appropriateness criterion for cardiac CT and cardiac MRI allows electrophysiologists to be formally guided for the use of imaging modalities pre- and post-procedurally. There are however limited data about the value of intra-procedural cardiac imaging in most electrophysiological procedures, inclusive of device implantation. The complexity in quantifying the real value of cardiac imaging is intertwined with the need for a corresponding advancement in the efficacy of the delivery of electrophysiologic therapy. Also of concern is that the imaging-enhanced guidance of electrophysiological procedures may have a significant impact on workflow and increase the absolute procedural costs.

In conclusion, the benefit of noninvasive and invasive imaging methods during electrophysiology procedures is as important as the benefits obtained pre- and post-procedurally. Identification of anatomical landmarks and prediction of possible postprocedural complications is crucial to deliver appropriate and safe therapy. The choice of imaging methods varies between institutions and is reflected not only by patient population, but also by the experience, expertise, and technological availability at each institution. The patient's age, patient's comorbidities, biological risk of exposure to radiation, and economics of each method should be weighed when evaluating patients. In order to improve cost-effectiveness, future studies should be focused on decreasing the percentage of nonresponders to therapies, reduction of failure rate and recurrence rate, while measuring success in terms of patient-centered end-points. The future of imaging in electrophysiology not only depends on the physician's skill and clinical knowledge, but also on a willingness to explore new frontiers. Ultimately, this will improve the efficiency, better individualize our treatment strategies while enhancing the safety profile of these procedures.

Angelo Auricchio
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Part I

Technology Evaluation