applied sciences

MDPI

Editorial

Applied Sciences—Special Issue on Emerging Techniques in Imaging, Modelling and Visualization for Cardiovascular Diagnosis and Therapy

Cristian A. Linte [1,*] and Mihaela Pop [2,*]

[1] Biomedical Engineering and Imaging Science, Rochester Institute of Technology, Rochester, NY 14623, USA
[2] Schulich Heart Research Program, Sunnybrook Research Institute, Toronto, ON 4MN 3M5, Canada
* Correspondence: calbme@rit.edu (C.A.L.); mihaela.pop@utoronto.ca (M.P.)

check for updates

Citation: Linte, C.A.; Pop, M. Applied Sciences—Special Issue on Emerging Techniques in Imaging, Modelling and Visualization for Cardiovascular Diagnosis and Therapy. *Appl. Sci.* **2023**, *13*, 984. https://doi.org/10.3390/app13020984

Received: 9 January 2023
Accepted: 9 January 2023
Published: 11 January 2023

Editors' Foreword

Ongoing developments in computing and data acquisition, along with continuous advances in medical imaging technology, computational modelling, robotics and visualization have revolutionized many medical specialties and, in particular, diagnostic and interventional cardiology. As a result, the diagnosis and treatment of many cardiac conditions that previously relied on invasive tests or procedures have been reshaped by breakthroughs in medical imaging and visualization. A concrete example is cardiac surgery, which, for many decades, was only conducted via a highly invasive sternotomy (i.e., open chest), with the patient connected to a heart–lung machine. By slowly complementing and eventually substituting the need for a direct view of the surgical field with medical imaging, open chest access was later replaced by a smaller incision (i.e., mini-thoracotomy) between the ribs for some procedures, or, for others, by access ports through which laparoscopic or robotic instruments were introduced, enabling the surgeon to operate on the heart under real-time visualization provided by a laparoscopic video camera. Ultimately, the navigation of catheters via percutaneous access through the peripheral vasculature and into the heart became the least invasive means to deliver cardiac therapy, yet it relies solely on medical imaging for guidance, as clinicians have no direct visual access to the sites or tissues they manipulate during therapy.

Hence, effective minimally invasive approaches to diagnose, plan therapy or treat cardiac conditions rely heavily or almost entirely on medical imaging and, therefore, require the development of reliable, accurate and robust tools and techniques at the interface of medical image computing, modelling and visualization. These research contributions are often the result of multi-disciplinary collaborations among scientists and professionals, spanning basic and translational research, clinical practice, medical (bio)physics, engineering, mathematics and computer science.

Several examples include, but are not limited to, the development of the following: advanced techniques in cardiovascular imaging to investigate structure-function interaction and identify pathology; image analysis algorithms and artificial intelligence (AI)-based classification methods to better characterize tissue and physiological signals; computational modelling platforms that enable the characterization and visualization of normal or pathologic anatomy, geometry, morphology and mechanical properties of the heart and coronary vessels, including applications relevant to 3D printing; the personalized, non-invasive in silico modelling-based assessment of cardiovascular function and simulation-based planning and optimization of treatments; novel pre-clinical experimental models and clinical approaches employed in electro-anatomical mapping for image-aided cardiac ablation, electroporation or resynchronization therapy; and, last but not least, innovative image-guided interventional procedures for cardiovascular applications.

The goal of this Special Issue was to disseminate emerging techniques and innovative solutions that comprehensively address unmet needs in cardiovascular disease and have the potential to be translated into the clinical arena to help improve the timeliness and accuracy of disease diagnosis, as well as the precision and efficacy of therapy delivery, toward achieving optimal patient outcomes. This Issue consists of thirteen scientific contributions: ten research articles, two review articles and one technical note, spanning several topics, from novel algorithms and platforms for medical image computing to biomechanical and hemodynamic modelling and to functional assessment in response to drug therapy, as briefly highlighted below.

Magnetic resonance imaging (MRI) provides unrivaled images of cardiac anatomy and function, thanks to its exquisite capability of capturing soft tissue contrast. As a result, a vast body of work has focused on the development of optimal image segmentation algorithms designed to extract various cardiac structures and key features of interest for better diagnosis or superior therapy planning. The review article by Galati et al. [1] provides a comprehensive overview of deep learning-based image segmentation algorithms designed to operate on cardiac MRI images and focuses specifically on the critical importance of the accuracy, reliability and robustness of cardiac image segmentation tools prior to their deployment in clinical practice. In the cardiac image segmentation arena, Guo et al. [2] also propose a deep learning model for left ventricle myocardium and blood pool segmentation from cine cardiac MR images and the subsequent functional evaluation based on clinical indices, such as stroke volume and ejection fraction. Moreover, Hasan et al. [3] describe a novel semi-supervised approach for learning the deep representations of cardiac structures that enables the highly accurate segmentation of 4D cine cardiac MRI images using as little as 1% annotated data.

To facilitate the integration of multi-modality cardiac imaging data with measured electrical activity toward enabling more accurate predictive modelling, Merle et al. [4] introduce a novel and robust software platform, created as part of a newly established consortium with international hospitals, which is dedicated to cardiovascular diagnosis and therapy guidance and features a plethora of AI/deep learning-based methods for cardiac image computing, modelling and visualization. This integrative platform has great utility in routine clinical procedures, especially in the catheter electrophysiology lab.

The interesting studies by Wang et al. [5] and Albors et al. [6] provide a deeper dive into the cardiac modelling and simulation fields for two different applications—cardiac ablation and resynchronization therapy. The former study [5] describes a cardiac ablation simulator that consists of an X-ray compatible 3D-printed, bi-atrial model contained in a custom-made enclosure for RFA simulation using a new soft tissue-mimicking polymer. The group used this phantom to perform a full simulation of a radiofrequency ablation procedure in the cardiac catheterization laboratory and demonstrated the effective delivery and visualization of radiofrequency ablation lesions. The latter study [6] describes a first attempt at the development of a meshless in silico model of cardiac electrophysiology designed to predict patient response to cardiac resynchronization therapy (CRT), as a means to optimize electrode placement during CRT procedures. Such virtual simulation-based approaches will continue to receive considerable attention, as they provide non-invasive methods to improve therapy outcome.

The contributions by Joseph et al. [7] and Hunter et al. [8] focus on different aspects of cardiovascular modelling. Specifically, using mathematical models, these authors explore vascular hemodynamics, whose understanding is critical when making decisions with respect to the spectrum of therapies. For instance, the treatment of coronary stenosis is decided based on the fractional flow reserve diagnostic index, whose estimation requires high-risk surgery. As such, the work by Joseph et al. [7] proposes an extensive mathematical description of the coronary vasculature that provides non-invasive estimates of coronary fractional flow reserve, which could be used to predict a patient eligibility for subsequent therapy. The study by Hunter et al. [8], on the other hand, is founded on the premise that cardiac arrhythmia may reduce cerebral blood perfusion and describes a novel cardio-cerebral lumped parameter hemodynamic model to investigate the role of the circle of Willis variants on cerebral blood flow dynamics under atrial fibrillation conditions.

Another venture into the vast field of cardiac biomechanical modelling is the exhaustive contribution by Bracamonte et al. [9], which provides a comprehensive review of the field of patient-specific inverse modelling of cardiovascular mechanics based on image-derived kinematic data.

Furthermore, the use of imaging as a biomarker for quantifying cardiac disease has become a popular topic in computer-integrated diagnosis. Driven by the goal to non-invasively characterize cardiac tissue that may have undergone chronic myocardial infarction, the pre-clinical work by Rahman et al. [10] describes the utility of cardiac diffusion tensor MR imaging to identify the microstructural-based biomarkers of myocardial infarction by evaluating the diffusion tensor invariants, eigenvalues and radial diffusivity in different myocardial areas (i.e., scar, border zone and healthy myocardium) of several porcine subjects. In their clinical study, Mihuta et al. [11] employed the ultrasound imaging of the carotid artery to quantify the carotid intima-media thickness as a potential biomarker indicative of atherosclerotic progression in children and young adults, with the overall goal to provide a more complete evaluation of their cardiometabolic risk. Lastly, the work by Lin et al. [12] also illustrates the development of a novel assessment protocol tested on several porcine subjects which integrates MR imaging and electrophysiology measurements to assess the effect of chemotherapy on cardiac function by quantifying several imaging-based biomarkers and assessing the presence of drug-induced tissue fibrosis or electrical remodelling.

Finally, to further attest to the popularity gained by ultrasound imaging for cardiovascular applications and, specifically, for therapy planning and guidance, the work by Carnahan et al. [13] describes the development of a novel method to register multi-view 3D transesophageal echocardiography images to enable volume compounding as a means to generate extended field-of-view images that can be used to plan mitral valve procedures.

In sum, while we acknowledge that the contributions disseminated in this Special Issue barely scratch the surface and only briefly address a very few niches of the vast field of cardiac image computing, modelling and visualization, we hope our readers find these pieces sufficiently intriguing to foster their curiosity and to dig deeper and seek additional literature on the topics of their interest.

Author Contributions: C.A.L. and M.P. both contributed to the preparation, writing and editing of this editorial. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Acknowledgments: This Issue would not be possible without the contributions of various talented authors, committed reviewers and the dedicated editorial team at Applied Sciences. We thank all authors for publishing their high-quality research results in this Special Issue. We would also like to express our sincere thanks to all reviewers and editors for their feedback, comments and suggestions that helped the authors improve their manuscripts. Finally, we would like to take the opportunity to acknowledge the outstanding support provided by the editorial team at Applied Sciences.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Galati, F.; Ourselin, S.; Zuluaga, M.A. From Accuracy to Reliability and Robustness in Cardiac Magnetic Resonance Image Segmentation: A Review. *Appl. Sci.* **2022**, *12*, 3936. [CrossRef]
2. Hasan, S.M.K.; Linte, C.A. Learning Deep Representations of Cardiac Structures for 4D Cine MRI Image Segmentation through Semi-Supervised Learning. *Appl. Sci.* **2022**, *12*, 12163. [CrossRef]
3. Guo, F.; Ng, M.; Roifman, I.; Wright, G. Cardiac Magnetic Resonance Left Ventricle Segmentation and Function Evaluation Using a Trained Deep-Learning Model. *Appl. Sci.* **2022**, *12*, 2627. [CrossRef]
4. Merle, M.; Collot, F.; Castleneau, J.; Migerditichan, P.; Juhoor, M.; Ly, B.; Ozenne, V.; Quesson, B.; Zemsemi, N.; Coudiere, Y.; et al. MUSIC: Cardiac Imaging, Modelling and Visualisation Software for Diagnosis and Therapy. *Appl. Sci.* **2022**, *12*, 6145. [CrossRef]
5. Wang, S.; Saija, C.; Choo, J.; Ou, Z.; Birsoan, M.; Germanos, S.; Rothwell, J.; Vakili, B.; Kotadia, I.; Xu, Z.; et al. Cardiac Radiofrequency Ablation Simulation Using a 3D-Printed Bi-Atrial Thermochromic Model. *Appl. Sci.* **2022**, *12*, 6553. [CrossRef]

6. Albors, C.; Lluch, E.; Gomes, J.F.; Cedilnik, N.; Mountris, K.A.; Mansi, T.; Khamzin, S.; Dokuchaev, A.; Solovyova, O.; Pueyo, E.; et al. Meshless Electrophysiological Modeling of Cardiac Resynchronization Therapy—Benchmark Analysis with Finite-Element Methods in Experimental Data. *Appl. Sci.* **2022**, *12*, 6438. [CrossRef]
7. Joseph, J.; Sun, C.; Lee, T.Y.; Goldman, D.; Kharche, S.R.; McIntyre, C.W. Structure (Epicardial Stenosis) and Function (Microvascular Dysfunction) That Influence Coronary Fractional Flow Reserve Estimation. *Appl. Sci.* **2022**, *12*, 4281. [CrossRef]
8. Hunter, T.J.; Joseph, J.J.; Anazodo, U.; Kharche, S.R.; McIntyre, C.W.; Goldman, D. Atrial Fibrillation and Anterior Cerebral Artery Absence Reduce Cerebral Perfusion: A De Novo Hemodynamic Model. *Appl. Sci.* **2022**, *13*, 1750. [CrossRef]
9. Bracamonte, J.H.; Saunders, S.K.; Wilson, J.S.; Truong, U.T.; Soares, J.S. Patient-Specific Inverse Modeling of In Vivo Cardiovascular Mechanics with Medical Image-Derived Kinematics as Input Data: Concepts, Methods, and Applications. *Appl. Sci.* **2022**, *12*, 3954. [CrossRef]
10. Rahman, T.; Moulin, K.; Perotti, L.E. Cardiac Diffusion Tensor Biomarkers of Chronic Infarction Based on In Vivo Data. *Appl. Sci.* **2022**, *12*, 3512. [CrossRef] [PubMed]
11. Mihuta, M.S.; Paul, C.; Ciulpan, A.; Dacca, F.; Velea, I.P.; Mozos, I.; Stoian, D. Sub-clinical Atherosclerosis Progression in Obese Children with Relevant Cardiometabolic Risk Factors Can Be Assessed through Carotid Intima Media Thickness. *Appl. Sci.* **2022**, *11*, 10721. [CrossRef]
12. Lin, P.; Escartin, T.; Larsen, M.; Ng, M.; Li, M.; Barry, J.; Roifman, I.; Pop, M. MR Imaging and Electrophysiological Features of Doxorubicin-Induced Fibrosis: Protocol Development in a Small Preclinical Pig Study with Histological Validation. *Appl. Sci.* **2022**, *12*, 11620. [CrossRef]
13. Carnahan, P.; Moore, J.; Bainbridge, D.; Chen, E.C.S.; Peters, T.M. Multi-View 3D Transesophageal Echocardiography Registration and Volume Compounding for Mitral Valve Procedure Planning. *Appl. Sci.* **2022**, *12*, 4562. [CrossRef]