Index

Agradecimientos 5

List of Figures 13

Acronyms 21

Abstract 23

Resumen 25

Resum 27

Chapter 1 29

1.1. Introduction and motivation 29
1.2. Objectives 31
1.3. Structure of the thesis 32

Chapter 2 35

State of the art 35

2.1. Introduction to the heart 35
2.1.1. Cardiac Action Potential 37
2.1.2. Cardiac Electrophysiology 38
2.1.3. Atrial Fibrillation 38
2.2. The electrocardiogram 46
2.3. Body Surface Potential Mapping 47
2.3.1. Body Surface Potential Mapping in atrial fibrillation 48
2.4. Electrocardiographic Imaging 49
2.4.1. Forward Problem of electrocardiography 50
2.4.2. Inverse Problem of electrocardiography 51
2.4.3. ECGI for atrial fibrillation 53
2.5. Cardiac Modelling 56
2.5.1. Cellular level modelling 56
2.5.2. Atrial cell mathematical models 57
2.5.3. Tissue level modelling 58
2.5.4. Geometrical models 60

Compendium of articles 63

Chapter 3 65

Effects of Torso Mesh Density and Electrode Distribution on the Accuracy of Electrocardiographic Imaging During Atrial Fibrillation 65

Abstract 65

3.1. Introduction 66
3.2. Materials and methods 67
3.2.1. Study population - Data acquisition 67
3.2.2. Data processing 68
3.2.3. Quality of mesh evaluation metrics 71
3.2.4. Frequency metrics 71
3.3. Results 71
3.3.1. Impact of mesh density on ECGI reconstruction 71
3.3.2. Impact of electrode relocation in low-density torso meshes on ECGI reconstruction 74
3.4. Discussion 77
3.4.1. Limitations 79
3.5. Conclusion 80
3.6. Ackowledgements 80
References 81

Chapter 4 85

Robustness of Imageless Electrocardiographic Imaging Against Uncertainty in Atrial Morphology and Location 85

Abstract 85

4.1. Introduction 86
4.2. Material and Methods 87
4.3. Results 89
4.4. Discussion 91
4.5. Conclusion 92
4.6. Acknowledgments 92
References 92

Chapter 5 95

Improving Electrocardiographic Imaging Solutions: A Comprehensive Study on Regularization Parameter Selection in L-curve Optimization 95

Abstract 95

5.1. Introduction 96
5.2. Material and methods 97
5.2.1. Cardiac simulations 97
5.2.2. Patient data 98
5.2.3. Modelling the influence of noise 99
5.2.4. Inverse problem calculation 100
5.3. Results 102
5.3.1. Effect of noise in the inverse problem using atrial simulations 102
5.3.2. Patient examples 108
5.4. Discussion 112
5.4.1. Effects of Noise in the L-curve 112
5.4.2. Effects of noise in the extracted ECGI maps 113
5.4.3. Limitations 114
5.5. Conclusion 114
Ackowledgements 114
References 115

Chapter 6 119

Filtering Strategies of Electrocardiographic Imaging Signals for Stratification of Atrial Fibrillation Patients 119

Abstract 119

6.1. Introduction 120
6.2. Methods 121
6.2.1. Patient signal and geometry acquisition 121
6.2.2. ECGI post-processing 122
6.2.3. Reentrant activity detection 122
6.2.4. Reentrant activity evaluation and statistical analysis 123
6.3. Results 124
6.3.1. Reentrant activity analysis 124
6.3.2. Post-processing effects and PVI outcome 130

6.4. Discussion 131
6.4.1. ECGI-derived phase metrics and PVI outcome 132
6.4.2. Effects of filtering ECGI signals for rotor detection 133
6.4.3. Effects of time-space criteria for rotor detection 133
6.4.4. Clinical implications 134
6.4.5. Limitations and future work 135
6.5. Conclusion 135
Funding Sources 136
References 136
Chapter 7 139

Higher Reproducibility of Phase Derived Metrics from Electrocardiographic Imaging During Atrial Fibrillation in Patients Remaining in Sinus Rhythm after Pulmonary Vein Isolation 139

Abstract 139

7.1. Introduction 140
7.2. Methods 141
7.2.1. Study Population 141
7.2.2. Data acquisition 142
7.2.3. Data processing 142
7.2.4. Atrial fibrillation complexity quantification 143
7.2.5. Reproducibility measurements 143
7.2.6. Statistical analysis 143
7.2.7. Outcome prediction based on ECGI reproducibility 144
7.3. Results 144
7.3.1. Reproducibility of ECGI metrics vs. patient outcome 145
7.3.2. ECGI Reproducibility vs. AF type 148
7.3.3. Association of PVI success based on ECGI variability metrics 149
7.4. Discussion 150
7.4.1. Mechanism of AF and PVI outcome 150
7.4.2. Temporal reproducibility of ECGI derived metrics 151
7.4.3. Clinical implications 151
7.5. Limitations 151
7.6. Conclusions 152
Acknowledgments 152

Funding Sources 152
References 153
Chapter 8 157
Complexity and Recurrence of Body Surface Electrocardiograms Correlates with Estimated Reentrant Atrial Activity with Electrocardiographic Imaging in Atrial Fibrillation Patients 157
Abstract 157
8.1. Introduction 158
8.2. Methods 159
8.2.1. Data acquisition and processing 159
8.2.2. Assessment of AF substrate complexity and AF propagation recurrence on Body Surface Potential Mapping 160
8.2.3. Reentrant atrial activity analysis from ECGI signals 162
8.2.4. Statistical analysis 162
8.3. Results 163
8.3.1. BSPM-based versus ECGI-based AF substrate complexity and AF propagation recurrence 163
8.3.2. BSPM-based AF substrate complexity and AF propagation recurrence vs ECGI-based reentrant atrial activity 164
8.3.3. Assessment of left and right atrium differences 165
8.3.4. BSPM-based AF substrate complexity and AF propagation recurrence vs ECGI-based reentrant atrial Activity per atrium 167
8.4. Discussion 169
8.4.1. Relationship between reentrant activity and BSPM-based AF complexity and AF propagation recurrence 170
8.4.2. Left and right atrium assessment of AF substrate complexity 170
8.4.3. Limitations 171
8.5. Conclusion 171
Acknowledgments 172
Supplementary Table 172
References 173
Chapter 9 177
Discussion and conclusions 177
9.1. Main findings 177
9.2. Comparison with previous studies 179

9.3. Limitations 180
9.4. Conclusions 181
9.5. Guidelines for future works 184
Chapter 10 185
Contributions 185
10.1. Main contributions of this thesis 185
10.1.1. Journal Papers 185
10.1.2. International Conferences 186
10.2. Contributions related to this thesis 187
10.2.1. Journal Papers 187
10.2.2. International Conferences 187
10.2.3. National Conferences 188
10.3. Patents 188
10.4. Awards 188
10.5. Participation in scientific international committees 188
10.6. Diffusion of results 189
10.7. Industrial collaboration 189
10.8. Teaching 189
10.8.1. Supervision of bachelor thesis 189
10.8.2. Supervison of master thesis 190
10.9. Research stay 190
10.10. Research projects and funding 190
References 193