

# Contents

<b>Agradecimientos</b>	<b>iii</b>
<b>Acronyms</b>	<b>v</b>
<b>Sumari</b>	<b>xv</b>
<b>Sumario</b>	<b>xvii</b>
<b>Abstract</b>	<b>xix</b>
<b>1 Introduction</b>	<b>1</b>
1.1 Motivation . . . . .	2
1.2 Objectives . . . . .	3
1.3 Structure of the thesis . . . . .	4
<b>2 State of the art</b>	<b>7</b>
2.1 Introduction to Electrocardiography . . . . .	8
2.1.1 The heart . . . . .	8
2.1.2 The surface electrocardiogram . . . . .	9
2.1.3 The vectorcardiogram . . . . .	13
2.1.4 Body Surface Potential Mapping . . . . .	16
2.2 Atrial fibrillation . . . . .	18
2.2.1 Pathophysiology . . . . .	18
2.2.2 Epidemiology . . . . .	20
2.2.3 Treatment of atrial fibrillation . . . . .	20
2.3 Spatial characterization of ECG signals . . . . .	21
2.3.1 Derivation of orthogonal leads from the standard electrocardiogram . . . . .	21
2.3.2 Study of spatial characteristics of derived atrial loops during atrial fibrillation . . . . .	23
2.4 Optimization of electrocardiographic leads . . . . .	24
2.4.1 Determination of the number and location of optimum electrocardiographic leads . . . . .	24

2.4.2	Repositioning of electrocardiographic leads for the study of atrial fibrillation . . . . .	28
2.5	Organization degree of atrial fibrillation . . . . .	30
2.5.1	Quantification of the temporal organization of AF . . . . .	30
2.5.2	Quantification of the spatial organization of AF . . . . .	32
2.5.3	Understanding the mechanisms of atrial fibrillation . . . . .	33
2.5.4	Clinical implications . . . . .	35
<b>3</b>	<b>Materials</b>	<b>37</b>
3.1	PTB database . . . . .	37
3.2	BSPM recordings . . . . .	38
3.2.1	Acquisition system . . . . .	38
3.2.2	Study Population . . . . .	41
<b>4</b>	<b>Spatial characteristics from the ECG</b>	<b>47</b>
4.1	Introduction . . . . .	48
4.2	Materials and Methods . . . . .	50
4.2.1	Study Population . . . . .	50
4.2.2	Signal conditioning . . . . .	50
4.2.3	Preprocessing of P waves . . . . .	51
4.2.4	Preprocessing of AF waves . . . . .	52
4.2.5	Optimized transforms for P-wave and QRS complex derivation . . . . .	52
4.2.6	Stability of transform matrices . . . . .	53
4.2.7	Derivation of orthogonal leads from the ECG . . . . .	53
4.2.8	Performance on the P wave and QRS complex . . . . .	53
4.2.9	Performance on AF waves . . . . .	54
4.3	Results . . . . .	56
4.3.1	Transform matrices . . . . .	56
4.3.2	Stability of transform matrices . . . . .	56
4.3.3	Comparison of true vs. derived P waves . . . . .	56
4.3.4	Comparison of true vs. derived AF waves . . . . .	63
4.4	Discussion . . . . .	68
4.4.1	Main findings . . . . .	68
4.4.2	Transform matrix optimized for the P wave . . . . .	68
4.4.3	On the derivation of AF loops from the ECG . . . . .	69
4.4.4	Limitations of the study . . . . .	71
4.5	Conclusions . . . . .	71
<b>5</b>	<b>Optimization of ECG leads</b>	<b>73</b>
5.1	Introduction . . . . .	74
5.2	Evaluation of lead selection methods . . . . .	76
5.2.1	Materials and Methods . . . . .	76
5.2.2	Results . . . . .	79

5.2.3	Discussion . . . . .	84
5.3	Selection of ECG leads for AF . . . . .	88
5.3.1	Materials and Methods . . . . .	88
5.3.2	Results . . . . .	92
5.3.3	Discussion . . . . .	99
5.4	Conclusions . . . . .	104
<b>6</b>	<b>Non-invasive mapping of human AF</b>	<b>105</b>
6.1	Introduction . . . . .	106
6.2	Materials and Methods . . . . .	107
6.2.1	Study Population . . . . .	107
6.2.2	ECG Signal Processing . . . . .	107
6.2.3	Map display and wavefront propagation descriptors . . . . .	109
6.2.4	Assessment of short-term reproducibility . . . . .	111
6.3	Results . . . . .	111
6.3.1	Atrial fibrillatory signals on the body surface . . . . .	111
6.3.2	Surface activation patterns during AF . . . . .	113
6.3.3	Surface activation patterns during AF and similarity among AF signals on the body surface . . . . .	113
6.3.4	Short-term reproducibility of dominant activation patterns	115
6.4	Discussion . . . . .	117
6.4.1	Main findings . . . . .	117
6.4.2	Comparison with invasive mapping data . . . . .	117
6.4.3	Comparison with non-invasive studies . . . . .	118
6.4.4	Limitations . . . . .	118
6.5	Conclusions . . . . .	119
<b>7</b>	<b>Discussion and conclusion</b>	<b>121</b>
7.1	Discussion . . . . .	121
7.1.1	Main findings . . . . .	122
7.1.2	Comparison with previous studies . . . . .	123
7.1.3	Limitations . . . . .	125
7.2	Conclusion . . . . .	125
7.3	Guides for future work . . . . .	126
7.3.1	Spatiotemporal quantification of atrial organization . . . . .	126
7.3.2	Clinical applications . . . . .	127
7.3.3	Transfer of technology . . . . .	127
<b>8</b>	<b>Contributions</b>	<b>129</b>
8.1	Publications . . . . .	129
8.1.1	Main contributions of this thesis . . . . .	129
8.1.2	Contributions related to this thesis . . . . .	130
8.2	Framework of the Dissertation . . . . .	131
8.2.1	Research projects . . . . .	131

8.2.2	International research stays . . . . .	133
8.2.3	Collaborations . . . . .	133